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THE GEOLOGY

OF

NORTH CENTRAL WISCONSIN

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PREFACE.

In the present report are described the principal geological features of a large area in north central Wisconsin, an area, which, although investigated to some extent by earlier workers in the field of geology, has, nevertheless largely remained unknown land to students and investigators of earth history. The report is one of a series aimed to describe the geology of the State, and especially the northern part, which was but very briefly referred to in the reports of the former State Geological Survey.

The present report, however, does not present, by any means, the complete and final account of the geology of the area; it is only a contribution added to our knowledge of the region. To geologists it is superfluous to mention this, but to the ordinary reader it may be important to emphasize that this bulletin does not aim to set forth a complete and final account of the geology of the area. In spite of all the earnest study which has been given to it, there are still many questions to be answered; the knowledge which has been gained seems small in comparison with that which yet remains in the unknown.

The problems presented by the area are mainly those relating to the earliest rocks, namely, the pre-Cambrian, and those relating to the very latest, namely, the Pleistocene or glacial. The great gap between these widely separated formations is represented by the records of a vast amount of erosion which was wrought throughout a very long period of geological time.

The pre-Cambrian formations consist, to a relatively small extent, of metamorphosed sedimentaries, and to a very large extent of igneous intrusives. Besides presenting the usual complex geology of the pre-Cambrian periods, there are within the area igneous rocks which are highly interesting in character, considerable portions of them being apparently quite unusual in chemical and mineralogical composition. The problems of the igneous rocks are sketched only in outline; some new associations of minerals are described, and some new minerals have been discovered, but there are still many questions concerning the igneous rocks and their mineral contents, from a scientific point of view, which need further study. Enough has already been accomplished, however, to indicate that certain phases of the igneous formations, namely, the syenites and associated pegmatites of this region, furnish a rich and interesting field for the student of mineralogy and igneous geology.

The glacial deposits of the area furnish the records of four distinct ice invasions. The alluvial deposits in the valleys, and the characteristic features of the non-glaciated parts add additional interest to the geology of the Pleistocene. While the main features of the Pleistocene have probably been outlined, there still remains the question of the position and correlation of the several drift formations with the Pleistocene outside of this region. The correlation can probably be determined when the report on the geology of the northwestern part of the State is completed.

The account of the development of the topographic features of the area, the plains, the hills, and the valleys, and the various agencies by which, in the course of ages, these surface reliefs have been molded into their present form and condition constitutes a distinct part of the report.

It is hoped that this report will be of interest to various classes of readers. Citizens of the State, and especially those within the area described, will find a statement of the character of the rock formations upon which they live and the various agencies which have developed the superficial forms of the land. The chapter on physiography is designed to give a brief statement of the geography from the viewpoint of its origin, and should be of value to teachers of physical geography in the schools. One of the principal objects of the Survey reports is the educational value to the citizens and schools of the State, a feature probably much more important than the commercial or economic value.

In the preparation of this bulletin the author takes pleasure

in acknowledging the courtesies received from many citizens of the area. He is under obligation to Dr. E. A. Birge, Director of the Survey, for the many courtesies shown, to President C. R. Van Hise for assistance in the study of the pre-Cambrian geology, and to Professor T. C. Chamberlin for assistance in the study of the Pleistocene. Both the latter gentlemen visited the area at various times, and to their general guidance the author owes much. The author is also indebted to Professor W. W. Daniells and to Professor Victor Lenher for the chemical analyses of rocks and minerals, to Mr. W. D. Smith for assistance in field work in portions of the area, to Dr. J. C. Elsom for many of the photographic views of landscapes, and to Mr. E. B. Hall for the photographs of most of the rock sections.

THE GEOLOGY OF NORTH CENTRAL WISCONSIN.

CHAPTER I.

INTRODUCTION, GENERAL GEOLOGY, AND PREVIOUS EXPLORATION AND LITERATURE.

INTRODUCTION.

The area described in the present memoir is the north central portion of Wisconsin (see figure 1), and includes the whole of the counties of Marathon, Lincoln, Taylor, Clark, Wood and Portage, and parts of the adjoining counties of Langlade, Price and Rusk. It constitutes about one-eighth of the state and contains something over 7,200 square miles. There is no geologic or topographic feature which especially characterizes this area, and hence it is given a name descriptive of its geographic location in the state.

The topography resembles that of other portions of the Mississippi valley and of the plains of the Great Lakes region. The area slopes to the south. The elevation above sea level of the broad valley bottoms in the southern part is about 1,000 feet, and of the narrow valley bottoms in the northern part about 1,450 feet. The summits of the uplands, with a few exceptions, preserve a sloping crest line rising from the level of the broad valley plain of the southern part of the area to 200 to 300 feet above the level of the narrow valley bottoms in the northern part. The notable exceptions that rise above the even crested uplands are Rib Hill and the adjoining quartzite hills near Wausau, the former having an elevation of 1,942 feet above sea level, and about 800 feet above the adjoining valley. Powers Bluff is a prominent quartzite hill in central Wood county. In the southern part of the area the broad valley plain is dotted here and there with castellated rocks or buttes of sandstone.

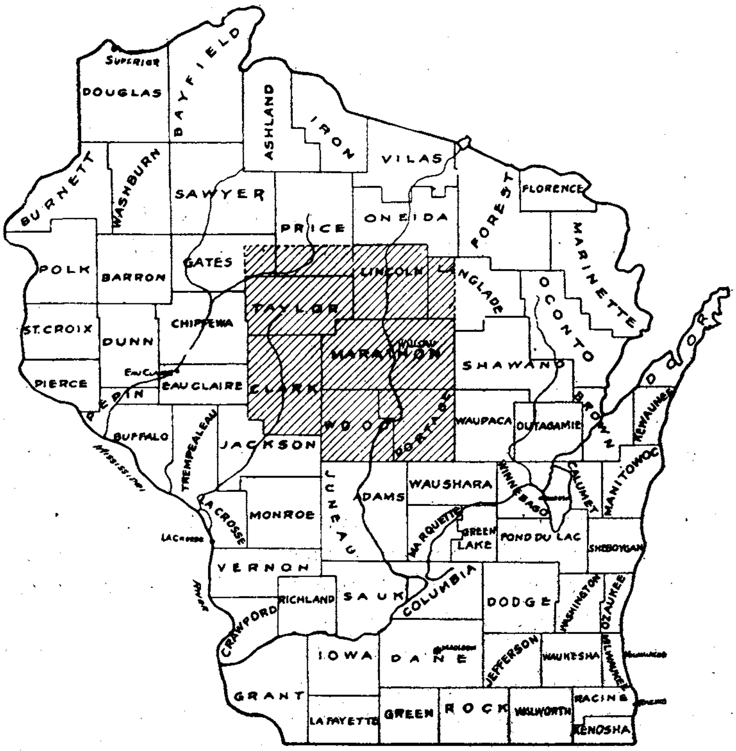

Fig. 1. Map showing location of the North Central Wisconsin district.

The area is principally drained by the Wisconsin and Black rivers flowing southward through the area. The northwestern part of the area is drained by tributaries of the Chippewa river, and the southeastern and northeastern portions by branches of the Wolf river flowing to Lake Michigan.

The population of the six whole counties of the area in 1900 was 148,267 and in 1905, 172,440. The leading cities, according to the census of 1905 are: Wausau, with a population of 14,458; Merrill, 9,197; Stevens Point, 9,022; Antigo, 6,663; Grand Rapids, 6,157; Marshfield, 6,035; Tomahawk, 2,626; Neillsville, 2,117; Medford, 1,923. The aggregate population of these cities with the smaller towns of the six whole counties approximates 60,000. The population of the farming community is about 112,000.

The principal industries of the area are agriculture and manufacturing. Formerly the region was rich in pine and hardwood. The numerous rapids of the Wisconsin and its tributaries furnish ready water power for the manufacture of lumber and other wood products. As fast as the lands were cleared of their timber, farms were developed and the area gradually passed from one of manufacturing and lumbering to one in which agriculture now greatly predominates. Mining plays an insignificant role in comparison with farming and manufacturing. The principal mineral resources are building and ornamental stone, clay and quartz.

It is very probable that with the coming years agriculture will increase at a greater rate than the other industries and will remain the chief occupation of the area. For this reason considerable time has been spent upon mapping the surface formations of the area which have produced the present excellent soil conditions and made the area one of promising agricultural possibilities.

The area is favored with fair railroad facilities. Being an agricultural district, good wagon roads afford easy access through the settled parts of the area. Large portions of the region, however, still remain covered with dense forests. The glacial and the residual soils, which have made the region one of rich agricultural resources, have obscured the relations and structure of the crystalline rocks and made the geology of the pre-Cambrian difficult to decipher. On the other hand, this obscurity of pre-Cambrian geology has been somewhat counterbalanced by the numerous artificial exposures of crystalline rocks made in the region, such as those furnished by the farm wells and the wagon roads in the settled portions of the district.

GENERAL GEOLOGY.

The rock formations at the surface in the northern part of the area are of pre-Cambrian age and consist of various igneous rocks and metamorphic sediments. The crystalline rocks of this area form the southern part of the large pre-Cambrian region of northern Wisconsin. The metamorphic sedimentaries are phases of shale, slate, quartzite and conglomerate. Among the igneous rocks may be mentioned varieties of gabbro, diabase, diorite, quartz-syenite, nepheline-syenite, granite and rhyolite. The southern and western portion of the area is largely covered by horizontal beds of upper Cambrian (Potsdam) sandstone. Above the pre-Cambrian and Cambrian rocks is a covering of glacial and alluvial deposits of variable thickness.

The rock formations of the area, beginning with the youngest, are shown in the following table:

Pleistocene ......
- Wisconsin Drift formation.
- Third Drift formation.
- Second Drift formation.
- First Drift formation.
- Alluvial deposits (contemporaneous with drift).

Unconformity.

Paleozoic—Potsdam (Upper Cambrian) Sandstone.

Unconformity.

Pre-Cambrian ...

Upper Sedimentary Series .... Middle Huronian? (*Stratigraphic relations unknown — presumably contemporaneous*).	North Mound Conglomerate & Quartzite. Arpin Conglomerate & Quartize. Mosinee Conglomerate. Marshall Hill Conglomerate. Marathon Conglomerate.
Unconformity.	
Intrusive Igneous Formations. (*In order of intrusion*).	3. Granite-Nepheline-Syenite Series. 2. Gabbro-Diorite Series. 1. Rhyolite Series.
Unconformity.	
Lower Sedimentary Series .... Lower Huronian? (*Stratigraphic relations unknown*).	Rib Hill Quartzite. Powers Bluff Quartzite. Hamburg Slate. Wausau Greywacke.
Unconformity.	
Basal Group .... Laurentian or Keewatin?	Gneiss and Schists.

Position of the formations of North Central Wisconsin in the General Geological Column.

In the following table for the purpose of comparison is shown the position of the formations of North Central Wisconsin in the general geological column of North America. It will be seen that only the oldest and youngest formations are present in this area the great middle portion of the geological column extending from the early Paleozoic to the Pleistocene being wholly unrepresented.

TABLE OF GEOLOGICAL FORMATIONS.

	North America	North Central Wisconsin
Caenozoic series	Present or Human Period Pleistocene or Glacial Pliocene Miocene Oligocene Eocene	Present or Human Period Pleistocene or Glacial.
Mesozoic series	Cretaceous Jurassic Triassic	
Paleozoic series.	Permian Pennsylvanian Mississippian Devonian Silurian Ordovician Cambrian	Upper Cambrian (Potsdam Sandstone)
Pre Cambrian series (Proterozoic and Archeazoic	Keweenawan Upper Huronian Middle Huronian Lower Huronian Kewaatin Laurentian	 Upper sedimentary series. Igneous intrusive series. Lower sedimentary series. Basal Group

PREVIOUS EXPLORATION AND LITERATURE.

The earliest geological reconnaissance into the central part of Wisconsin was made in 1847 under the direction of the United States Treasury Department. This general survey, which covered the territory of Wisconsin, Iowa and Minnesota, was made under the immediate supervision of Dr. D. D. Owen, whose final report[1] was published in 1852.

The pioneer geological explorer of this area was Dr. J. G. Norwood, a member of Dr. Owen's corps, who in 1847 made a reconnaissance from Lake Superior southward up the Montreal river over the Portage Lake Trail to the head waters of the Wisconsin river, thence down the Wisconsin to Winnebago, the present site of the city of Portage. Dr. Norwood's course, therefore, led him through the central part of the area here described, and he was occupied from Oct. 7th to Oct. 12th, 1847, in traversing the Wisconsin from a few miles above Grandfather Falls to Point Bas, the present site of Nekoosa. In his narrative,[2] which is in the form of an itinerary covering about five pages, there are brief references to the rocks at Grandfather Bull Falls, at the mouth of Copper river, "Beaulieux Rapids," —the present site of Merrill, at the rapids near the mouth of Pine river, and at the Trap Rapids. He also described briefly the red granite at the present site of Granite Heights, the syenitic granite at Big Bull Falls, the present site of Wausau, and the rocks at Little Bull Falls, the present site of Mosinee, and at Stevens Point. He noted the folded contorted rocks at Conants Rapids, which he truthfully describes as having been "compressed by lateral forces into almost every possible wave-like form." The numerous rock islands in the river above Grand Rapids are noted, and also the rocks at Whitney's Rapids and Point Bas.

A. Randall, another member of the corps of Dr. Owen's survey, passed through the northwestern part of this area about the year 1847. He explored the Black river from its mouth to the 4th Principal Meridian and thence to Lake Superior. His observations are embodied in two or three pages of Dr. Owen's

[1] Owen's Geological Survey of Wisconsin, Iowa and Minnesota, 1852.
[2] Ibid. p. 285–289.

report,[1] accompanied by colored cross-sections[2] showing the structure of the region explored.

He observed the granite and gneiss in the vicinity of the present site of Neillsville, and the sandstone hills 10 or 15 miles farther north. He passed over a generally flat region along the 4th Meridian, north of township 30, and noted no rock appearing at the surface, except boulders, for a distance of 60 miles.

The results of the explorations of Norwood and Randall are presented in the general geological map[3] of the area reconnoitered by Owen's survey. At that time, however, the U. S. Land Survey along the Wisconsin and the Black rivers had not been made, and the various ledges located by Norwood and Randall are with reference to the water courses.

In 1855 Dr. J. G. Percival, then state geologist, spent five months in making a general reconnaissance of the entire state, and in his course examined the rocks at Stevens Point and vicinit. The alternating layers of gneiss and granite are noted[4] and the overlying sandstone at the upper end of Conants Rapids on the east side of the river is referred to.

Following the brief work of Dr. Percival upon the rocks in the vicinity of Stevens Point, no further geological work in the central part of the state was done until 19 years later, in 1874. During 1874 and 1875 R. D. Irving covered a region of about 10,000 square miles in the south central portion of the state. Irving's area did not extend further north than Marathon county and included territory as far south as Dane county. This region contained thick Paleozoic sediments in its southern portion and the pre-Cambrian crystallines in its northern part. The area described in the present report is somewhat larger than the northern crystalline portion of Irving's area.

The results of Irving's[5] work in 1874 and 1875 was a general report upon the pre-Cambrian crystalline rocks, the Cambrian and Silurian sedimentaries, and the Pleistocene formations of

1 Ibid. p. 151–152.

2 Illustrations, Owen's Geological Survey, Section 2 R.

3 Illustrations, Owens Geological Survey.

4 Ann. Report Geological Survey of Wis., 1856, p. 107–108.

5 Wis. Geol. Survey, Vol. II, Part III, p. 408–636.

the area explored. This report, published in 1877, was supplemented[1] in 1881 by a petrographic description of the crystalline rocks of the upper Wisconsin valley, prepared by C. R. Van Hise. The rocks examined by Van Hise were those collected in 1879 by A. C. Clark in addition to those collected by Irving in 1874 and 1875.

The field studies of Irving, and the areas from which the collection of specimens by Clark was made, were almost entirely along the Wisconsin river and its main branches, along the Wisconsin Central railroad in the vicinity of Stevens Point, and along the Chicago, Milwaukee and St. Paul railroad from Grand Rapids to Merrill. Van Hise had not seen the specimens examined by him in their field relations, and Irving had time only to assist in the preparation of their general report. Irving was able, however, to apply the extensive knowledge and experience gained by him in his detailed microscopic study of similar crystalline rocks near Lake Superior. The petrographic descriptions and series of sketch maps prepared by Irving and Van Hise for the limited area they cover are in general accurate, and have been of much value in the prosecution of the present work. The general map and summary[2] of results of Irving, as stated by himself, "can be regarded as nothing more than an intelligent guess." His brief discussion of the broader structural and genetic relations of the crystalline rocks of this area has been of little value in the present work.

The work of T. C. Chamberlin within the present area has been principally with reference to the glacial and surface geology. But a short time was spent by him in the field study of this area, and his principal references to it are in his report[3] of the Superficial Geology of the Upper Wisconsin Valley, mainly based on the observations of A. C. Clark. References to this area may also be found in his general discussion[4] of the Quarternary Age.

W. W. Daniells in 1883 spent a few days in this area and his

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[1] Wis. Geol. Survey, Vol. IV, Part VII, p. 625–714.

[2] Wis. Geol. Survey, Vol. IV, Part VII, p. 711–714.

[3] Geol. of Wis., Vol. IV, Part VIII, pp. 717–723.

[4] Geol. of Wis., Vol. I, pp. 261–298.

observations were incorporated in the very general report of Irving's[1] on the Archean of the Northwestern States.

In 1888 C. W. Hall[2] made a few days' trip along the Wisconsin river from Rhinelander to Stevens Point and presented a petrographic description of the rocks collected during his reconnaissance.

C. R. Van Hise[3] in 1896 presented the evidence of an ancient base-leveled plain in the central Wisconsin region, which was based upon observations made during the prosecution of the present work.

Since the present survey of the area was begun, several papers by the writer,[4] dealing with certain phases of the geology of the area have been issued. The results of investigations described in these papers are incorporated in the present report.

The geological literature of this area is not of a voluminous nature. It is obvious that in the hurried excursions of the early explorers into the area, the variety of rock formations and their structural relations were necessarily only surmised. The first general geological report of the region which included the southern portion of this area is that of Irving in 1877 and 1881, who traversed only the princpal thoroughfares of the portion described. The present report may be considered the first attempt to present a detailed account of the area. It is a work never attempted before, and could hardly have been accomplished earlier. Other reports will undoubtedly follow it in the future which will add much new information to the results of investigations here presented. To all previous writers upon the geology of this area the writer is indebted; especially is this true of the work of Chamberlin and Irving, of the former State Geological Survey, not only concerning the geology of this particular area, but more especially to their work in adjoining parts of the state, and elsewhere.

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1 5th Ann. Rept., U. S. Geol. Survey, pp. 175–242, 1884.

2 Minn. Acad. Nat. Sci., Vol. III, No. 2, pp. 251–268.

3 Science Vol. 4, 1896, pp. 57–59.

4 The pre-Potsdam Peneplain of the pre-Cambrian of North Central Wisconsin; Jour. of Geol., Vol. XI, pp. 289–313, 1903.

Soils and Agricultural Conditions of North Central Wisconsin; Wisconsin Geol. & Nat. Hist. Survey, Bull. No. XI, 1903.

Widespread Occurrence of Fayalite in Certain Igneous Rocks of Central Wisconsin; Jour. of Geol., Vol. XII, pp. 551–561, 1904.

PART I.

HISTORICAL, OR STRATIGRAPHIC, GEOLOGY.

OUTLINE.

Under historical, or stratigraphic, geology is described the various rock formations in the area in the order of their appearance and succession, and the sequence of events of which they form the records is interpreted. The historical geology falls into three sections or parts, one section relating to the pre-Cambrian geology, one section relating to the Paleozoic geology, and one section relating to the Pleistocene or glacial geology.

The pre-Cambrian geology is described in three chapters:

Chapter II. The Basal Group.
Chapter III. The Lower Sedimentary series.
Chapter IV. The Igneous Intrusive formations.
Chapter V. The Upper Sedimentary series.
Chapter VI. The Correlation of the pre-Cambrian, and the Unconformity between the pre-Cambrian and Paleozoic.

The Paleozoic geology forms one chapter:

Chapter VII. The Potsdam Sandstone (Upper Cambrian)

The Pleistocene or glacial geology is described in four chapters:

Chapter VIII. The general character of glaciers and glacial drift.
Chapter IX. The Glacial formations.
Chapter X. The Alluvial formations.
Chapter XI. The Driftless area.

PRE-CAMBRIAN GEOLOGY.

CHAPTER II.

THE BASAL GROUP.

Along the Wisconsin river extending from the vicinity of Stevens Point as far south as Nekoosa, and along the Yellow river in the vicinity of Pittsville, and along the Black river in the vicinity of Neillsville, are abundant and often quite continuous exposures of foliated and banded gneisses closely associated with, and intruded by, several granite and diorite schist formations. These banded gneisses and schists are in marked contrast with the massive granite, gabbro, rhyolite and other igneous rocks intrusive in the metamorphic sedimentaries farther north about Wausau. The foliated and banded gneiss is the oldest of these formations. It is intruded in turn, by fine-grained diorite (greenstone) schists, by medium grained quartz-syenite schist, and by medium-grained mica-granite schist. Each later schist has intruded the older formations and through subsequent earth movements these have again and again been mashed together until the whole series has been made into a very complicated and complex mass.

This group of formations consisting of foliated gneiss and intrusive schists is believed to represent the oldest rocks of the area. While these rocks were nowhere found in actual contact with any of the Pre-Cambrian sedimentary formations, yet the gneiss and schists appear with probably little doubt to be the ancient rock floor upon which the oldest sedimentaries of the area were deposited. The belief that the complex mass of schistose and gneissic formations represents the oldest rocks in the area is based, first, upon the extreme metamorphism of the formations of this group as compared with the oldest sedimentary and associated intrusive igneous formations, and, secondly, upon the similarity in character of this group of rocks in most respects, if not all respects, with the rock floor of the abundant oldest sedimentary formations in the adjacent Lake Superior region to the north.

The gneiss and schists, here referred to as the Basal Group, are penetrated by widespread igneous intrusions, which also intrude the older series of sedimentary rocks about Wausau. Among these intrusives are included the rhyolite formations; the greenstone formation, which consists of aphanitic greenstone, olivine diabase and diorite; and the granite-syenite rocks, which include massive granite, quartz-syenite, nepheline-syenite and related rocks. The intrusion of these later igneous rocks followed the period of the deposition of the earliest sedimentaries of the area, and appears to have been contemporaneous with a prolonged period of orogenic and mountain-making movements effecting the region. These later intrusives are often extremely mashed and metamorphosed in places, like the formations of the basal group are as a whole. On this account, therefore, it is often difficult and sometimes impossible to separate in the field small exposures of the later intrusives from those belonging to the basal series; however, where the rock is exposed to any extent, the older and more metamorphosed gneisses and schists can usually be separated from the later more massive and less altered formations.

AREA OF THE BASAL GROUP.

The gneiss and schists are unusually abundant in a belt extending across the southern part of the district, as already stated, in the vicinity of Stevens Point, Pittsville, and Neillsville. This belt, as indicated by isolated rock exposures, is apparently from 5 to 20 miles wide, and trends in a general way nearly east and west. Its eastern end is located at Stevens Point, still further east of which it probably extends, but is covered by a great thickness of alluvium and glacial drift. Its western end is known to extend far beyond the western boundary of this area.

The gneiss and schists constitute the predominating rocks forming the rapids of the Wisconsin river from Stevens Point southward as far as Nekoosa. South of Nekoosa the Cambrian sandstone covers the Archean and becomes the surface formation. Huronian rocks underlie the sandstone within a few miles south of Nekoosa. The width of the belt along the Wisconsin river is at least 15 miles.

Along the Yellow river, in the vicinity of Pittsville, the belt has a known width of about 6 to 9 miles, being delimited on the north by the intrusive massive granite and greenstone, and covered on the south in the vicinity of Dexterville by the Cambrian sandstone and the Pleistocene alluvial deposits. About 6 miles southwest of Dexterville in the vicinity of the southeast corner of Sec. 6, T. 31, R. 3 W., is located North Mound, consisting of conglomerate and quartzite undoubtedly much younger than the gneiss and schists.

Along the Black river in the vicinity of Neillsville the gneisses and schists extend for a distance of about 20 miles, as shown on the map, being delimited on the north by massive intrusive rocks north of Neillsville and on the south by the Huronian quartzite and later igneous intrusives at Black River Falls.

The broad region lying between the Wisconsin, Yellow and Black rivers in southwestern Wood and southern Clark counties contains but few roads and therefore is difficult to traverse. The area is covered with alluvium, glacial drift, and Cambrian sandstone, and for these reasons but few igneous rock exposures were found, and much of the pre-Cambrian geology is obscure. However, because these rivers show continuous exposures of this basal group of rocks, the area between is believed to be of similar rock and for this reason the belt is mapped as continuous across.

There is also an area of isolated occurrences of schistose and gneissoid rocks north of the main belt in the southwestern part of Marathon county. The extremely metamorphosed rocks of these isolated areas are very often doubtfully placed, but where much foliated, banded, and variously intruded by one or more later formations they are placed with the oldest group. A considerable area of rocks, probably of this group occurs in the vicinity of Halder post office, about 10 miles west of Mosinee. Small areas of banded gneisses and schists have also been noted along the railroad about a mile north of the station at Fenwood, along the Big Eau Pleine river near Stratford, and in the vicinity north of Rozellville post office.

TOPOGRAPHY.

The foliated schists and gneisses are exposed quite continuously along the river beds, as above stated, where the known width of the belt is best determined. For long stretches along the water courses they constitute the rock of the bottom of the river beds, with the horizontal sandstone appearing in thin cappings above them on the banks. The surface of the land away from the river is a very gently sloping plain with isolated thin cappings of the sandstone interspersed with low ledges of crystalline rock, the whole generally covered with a variable thickness of alluvium and glacial drift.

KINDS OF ROCK.

The various rocks of the oldest group include (1) gneiss, (2) greenstone-schist, (3) quartz-syenite schist, (4) biotite granite schist. These will be described in the order of their relative ages.

GNEISS.

The gneiss has a structure due to the interlamination of different rock types or to the alternating occurrence of bands or lenticules especially rich in certain minerals, which give the rock a streaky, laminated or banded appearance. For these reasons it does not denote a rock of some definite composition, but, as a rule, is a combination of different rock types. It belongs with that class of rocks recently referred to by Harker as mixed rocks. Most of the gneiss here described has the composition of an intermediate igneous rock, for it is principally the product of the inter-injection of phases of granite by such rocks as diorite, diabase or gabbro.

General Occurrence.—The general distribution of the basal rocks, forming a belt extending east and west across the southern part of the area, has already been pointed out. The delimitation of this belt mainly coincides with the distribution of the gneiss formation here described, for it is the foliated, banded and contorted character of this gneiss which furnishes the most striking feature and distinguishing character of the older group of rocks as compared with the later and more massive formations. Hence, in general, this gneiss is found wherever the formations are mapped as belonging with the basal group.

Along the Wisconsin River.—The foliated gneiss occurs north of Stevens Point at Langenberg's brick yard. Unusually abundant exposures of the gneiss occur along Conants Rapids of the Wisconsin river opposite the upper paper mill. The foliated gneiss is also abundant along Rocky Run from Sec. 1, T. 23, R. 7 E., as far south as the Wisconsin river, and also along Mill creek in Sec. 15, T. 23, R. 7 E. Gneiss is also abundant along the Wisconsin river, and the southern part of Grand Rapids and also along the rapids immediately north of the Port Edwards pulp mill, between the mill and the dam, nearly a mile farther north.

On the Yellow River and Hemlock Creek.—The banded gneiss is also abundant along the Hemlock creek in the SE. 1/4 of Sec. 36, T. 23, R. 3 E., and for some distance farther north. Along the Yellow river for several miles both above and below Pittsville the foliated and contorted gneiss is abundant.

On the Black River.—In the vicinity of Neillsville, and along the Black river at the mouth of Cunningham creek the gneiss is abundantly exposed.

Isolated Occurrences.—Only isolated occurrences of very small extent of the gneiss or other crystalline rocks were found in the nearly level area in southwestern Wood and southern Clark counties. About a mile southwest of Granton, Clark county, in SW. 1/4 NE. 1/4 of Sec. 10, T. 24, R. 1 W., there are several railroad cuts in the gneiss formation.

Petrographic Character.

Macroscopic.—The gneiss throughout its various exposures varies from fine to medium grained, the former having bands varying in width from 1 mm. to 3 or 4 mm., the coarser varieties having correspondingly wider leaves. The various phases usually show the effects of mashing and granulation by the readiness with which they crumble in the hand on the freshly fractured surfaces. Sometimes the leaves and bands of the gneiss are but slightly folded and extend in fairly straight lines for some distance. More usually, however, the gneiss is intricately folded, crumpled, and faulted. It is also much veined and pegmatized. In the numerous exposures of the foliated gneiss examined along the Wisconsin, Yellow and Black rivers no evidence of bedding or sedimentation was noted. Some phases of the gneiss appear to have been developed by the extreme mashing of phases of granite accompanied by or followed later by the injection of mineral solutions from basic rocks. Other phases are apparently mashed aphanitic greenstones containing veins of feldspar and quartz. Very often the "augen structure" is developed in the gneiss while the rock was under great pressure by the linear arrangement of dark acicular minerals such as amphibole and biotite about the larger and more rigid crystals of feldspar or feldspar and quartz.

Microscopic.—The thin sections show the gneiss to consist, usually, if not always, of feldspar, quartz and amphibole with a varying and usually less amount of biotite. The feldspar is either orthoclase, microcline or the albite variety of plagioclase the latter generally predominating. The coarser grained phases show the crystals of feldspar and quartz in a more or less fractured and granulated condition. In the finer grained phases these minerals are of fairly uniform size and have the appearance of being developed through their breaking down by granulation from larger crystals. The amphibole is probably the common green hornblende having a bluish-green and yellowish-green pleochroism. The biotite is the common brown variety and is in part an alteration of the hornblende and in part secondarily developed with a parallel oriention in the interstices of the feldspar and quartz. Besides these common and abundant minerals there is usually a small amount of apatite and sometimes a few minute crystals of zircon present in many of the phases of gneiss. While evidence of fragmental character of the gneiss was searched for, no evidence of sedimentary origin was found by microscopic study.

On account of the foliated and fissile structure of the gneiss and the readiness with which water penetrates it, it is very often deeply weathered. The decomposition minerals of the feldspar and amphibole are usually sericite, chlorite, epidote, biotite, and calcite. In the basic phases of the gneiss magnetite is often present both as a secondary and an original constituent.

Greenstone Schist.

The greenstone schists are fine-grained schistose basic rocks, closely associated with the foliated and banded gneisses. This greenstone schist in many places clearly intrudes the gneiss above described and is in turn cut by later more acid or granitic schists of the basal complex. The rocks here described under greenstone schists are quite variable in the proportion of minerals contained. Phases of these schists are similar to such rocks elsewhere described as hornblende schist, amphibole schist, mica amphibole schist, etc.

Distribution.—Along Conants Rapids south of Stevens Point are several localities of the Archean containing lenses and dike-like masses of the fine-grained greenstone schist. Good exposures of this formation occur on the west side of the river opposite the upper paper mill near the center of Sec. 8, T. 23, R. 8 E. Other occurrences are in the rapids at Grand Rapids and farther south along the Wisconsin river at the Port Edwards pulp mill. Along the Yellow river at Pittsville and for several miles farther north there are mashed phases of greenstone closely associated with the foliated gneiss. Along the Black river a mile west of Neillsville are similar occurrences of the greenstone schists intrusive in the foliated gneiss.

Petrographic Character.

Macroscopic.—The prevailing character of the greenstone schists is uniform and is in all respects like that of the greenstone schists of other pre-Cambrian areas of the northwest. The greenstone schist is fine-grained and is mainly composed of feldspar, amphibole, mica, and quartz. The weathered surface of the rock is often greenish-black; the fresh surface is very generally black. On account of their fissility and the easy penetration of water into them the greenstone schists are often deeply weathered.

Microscopic.—Under the miscroscope the greenstone schists are seen to be quite uniform in the character of the minerals present but often differ considerably in the relative abundance of these minerals. Usually the most abundant minerals are the plagioclase feldspars and green hornblende. Next in abundance is biotite and quartz. Very often orthoclase feldspar is present in considerable quantity. The feldspars are generally much altered to sericite, chlorite, green amphibole, biotite, and quartz. Epidote, magnetite, and zoisite are also often present, quite generally as alteration products.

The schistose rocks here called greenstone schists bear no evidence of being of sedimentary origin, possessing, neither traces of fragmental origin under the microscope nor evidence of stratification in their field exposures. While having throughout well developed schistosity and cleavage, this structure was very probably mainly induced by such secondary processes as mashing of the rock as a whole, and recrystallization and orientation of the amphibole and mica while under pressure.

The greenstone schists were very probably originally phases of the finer grained diorites, diabases, gabbros and peridotites and other basic igneous rocks. No olivine or pyroxene was found in the greenstone schists here classed with the basal formations, although these minerals may occur in some of them. The olivine diabases found intrusive in the gneiss and schist at Grand Rapids and near Pittsville on account of their massive character are classed with the later intrusives.

Quartz Syenite Schist.

The quartz syenite schist is a fine-grained rock with well developed schistosity. It is intrusive in the foliated gneiss and shows much less metamorphism than the latter. It is, however, a thoroughly mashed rock and shows much more deformation than the abundant massive quartz-syenite in the area farther north about Wausau.

Distribution and Exposures.—This formation cannot, as a rule, be recognized and separated from the biotite granite schists associated with it. A clearly defined exposure of this formation is to be seen on the west side of the Wisconsin river opposite the upper paper mill at Conants Rapids, where it is clearly shown to be a distinct formation by having a composition differing markedly from the associated granite schists and in possessing a cleavage and jointing system also differing markedly from and not in conformity with the latter. It is believed, therefore, that there is a general distribution of quartz syenite schist throughout the basal formations.

Petrographic Character.

Macroscopic.—As already stated, the rock is a fine grained schist with marked cleavage and jointing. Feldspar and biotite appear to be the principal constituents seen in the hand specimens. In the locality above referred to, opposite the upper paper mill at Conants Rapids, this formation is cut by numerous veins of granite and also by numerous pegmatite veins, the larger veins generally trending northwest and being nearly parallel with the strike of the associated foliated gneiss. Some of the dikes of the granite schist also cut directly across the cleavage of this formation.

Microscopic.—In thin sections this rock is seen to consist of orthoclase, albite, quartz, biotite, and amphibole. Much the larger portion of the rock consists of the feldspars. The biotite and amphibole are in approximate parallel orientation. The amphibole is common green hornblende showing incipient alteration to biotite. Quartz is an important constituent but not so abundant as in granite. Apatite occurs in numerous needle crystals. A small amount of epidote, sericite, and chlorite is present.

BIOTITE GRANITE SCHIST.

This formation is a mashed, fine to medium grained granite containing a variable amount of biotite and other dark minerals.

Distribution.—The biotite granite schist has a widespread occurrence in the area of the basal group of rocks and appears to be about as abundant as the foliated and banded gneiss. It occurs abundantly along the Wisconsin river at Stevens Point, at Conants Rapids, Birons Mill, Grand Rapids and Nekoosa. On the west side of the river at the upper paper mill in Conants Rapids this granite schist is seen cutting directly across the strike of the foliated gneiss and it also penetrates in a complex manner the quartz-syenite schist above described. The granite schist is in turn penetrated by coarse pegmatite veins which lead out from the massive granite of the vicinity, the latter being a much younger formation and believed to belong with the massive granite which intrudes the sedimentaries about Wausau. Along the Yellow river north of Dexterville are several exposures of the granite schist and along the Black river in the vicinity of Neillsville there is an abundance of the granite schist containing large crystals of feldspar and having the general appearance of "augen gneiss."

Petrographic Character.

Macroscopic.—This formation is fine to coarse-grained and possesses quite generally well developed schistosity though not nearly so schistose as the other formations here classed with the basal group. The abundant minerals are feldspar, quartz and mica. In the field exposures all evidence pointed to this rock being merely a mashed phase of a medium to coarse grained granite. Along the Wisconsin river the granite schist is generally medium grained. On the Black river south of Neillsville a few miles, are numerous exposures of coarser phases of the granite schist containing an abundance of large crystals of feldspar and having the general appearance of "augen gneiss."

Microscopic.—In the thin sections the feldspar components of the schist are seen to be principally orthoclase and albite. The larger crystals of orthoclase usually show peripheral granulation with abundant flakes of biotite mingled with the granulated portions. The larger crystals of quartz are generally fractured and possess undulatory extinction. Various stages of the granulation of the feldspar and quartz can be detected in the different phases of the schist. The biotite crystals, the most common dark mineral, quite generally have their longer axes in a common direction and to this parallelism of the biotite is mainly due the schistosity of the rock. Other minerals noted in phases of the granite schist are small amounts of muscovite, hornblende, epidote, magnetite, chlorite, sericite and zircon.

THE INTRUSIVES IN THE BASAL GROUP.

The gneiss and various schists of the basal group are cut by numerous dikes and boss-like masses of acid and basic rocks such as (1) rhyolite, (2) diabase, (3) fine-grained diorite, and (4) granite, named in the order of their intrusion. These formations are intrusive in certain sedimentary rocks of the area and a much fuller description of them is found in succeeding pages of this report.

RHYOLITE.

Rhyolite occurs at several places in the gneiss and diabase along the Yellow river between Dexterville and Pittsville. In the northern part of Sec. 10, T. 22 N., R. 3 W., the rhyolite apparently forms dikes intrusive in the greenstone. About half a mile below the wagon bridge at Pittsville the rhyolite occurs in massive ledges in the near vicinity of the foliated gneiss. Near the center of Sec. 3, T. 22 N., R. 3 W., the rhyolite[1] occurs with the gneiss and apparently intrudes the latter in a very irregular manner.

The rhyolite is generally a massive rock having a greenish-gray aphanitic ground-mass containing numerous phenocrysts of quartz and feldspar. Under the microscope there is seen to be quite a variation in the texture of the ground-mass. Some phases of the rhyolite have a fine-grained ground-mass containing numerous small spherulites which show distinctly the usual cross under the nicols. Other phases have a coarse ground-mass approaching the texture of a fine granite. The phenocrysts of feldspar and quartz are well developed in all phases. The quartz phenocrystals are often deeply embayed and corroded and often reveal unusually well developed rhombohedral cleavage. The feldspar phenocrysts are apparently plagioclase, some phases of the rhyolite containing varieties rich in lime, as indicated by their decomposition, and replacement by calcite. The rhyolite contains numerous minerals due to weathering, the principal ones being sericite, chlorite and calcite, with less amounts of amphibole, epidote and biotite.

[1] Irving, Wis. Geol. Survey, Vol. II, p. 491.

Olivine Diabase.

In the river at Grand Rapids a short distance north of the wagon bridge is a dike of olivine diabase about 125 feet in width with numerous smaller dikes of the same formation in the near vicinity. The diabase cuts across numerous pegmatite veins and appears to be much later in origin than the foliated gneiss and the associated schistose rocks. This rock is fine grained, having a firm even texture and black to browninsh-black color, and is quite uniform in general appearance.

Under the microscope the rock is seen to consist of small lath-shaped feldspars having the extinction of labradorite or bytownite. Good sized crystals of a green, weakly pleochroic pyroxene having a large angle of extinction, indicating augite, and olivine, apatite, magnetite, hematite, biotite and serpentine, are the usual minerals of the diabase. As is usual in diabase, the augite and bytownite show a close relationship in development indicated by the large crystals of the augite enclosing numerous elongated crystals of the bytownite. The specimens examined were collected near the water's edge where the rock is now being eroded and is consequently quite fresh. The bytownite, however, shows slight alteration, mainly to kaolinite. The augite generally shows less alteration than the bytownite but in places it is changed to brown mica and green chlorite. The olivine occurs in small irregular grains and as usual shows more alteration than either the feldspar or pyroxene. The olivine is altered to serpentine, magnetite, hematite, and chlorite, and all stages of the alteration from the pure olivine to a complete change to an aggregate of alteration minerals are to be seen. The apatite occurs in numerous needle crystals enclosed within the feldspar and augite crystals.

Diorite.

At Grand Rapids and at Pittsville are intrusions of fine-grained diorite, or greenstone, which, like the olivine diabase, appear to be much later in origin than the foliated gneiss and schist.

Along the Yellow river north of Pittsville, near the south quarter post of Sec. 21, T. 23 N., R. 3 W., along the border of the foliated gneiss and the younger intrusives lying to the north, are numerous instances of diorite dikes (6292,[1] 6293) in the gneiss. The diorite is generally fine-grained and massive and to all appearances belongs to the large area of fine diorite occuring along Rocky Run immediately to the north. Under the microscope the diorite is seen to consist principally of green amphibole and plagioclase. The amphibole is somewhat altered in places to chlorite, epidote and magnetite. The plagioclase is finely striated and is either albite or oligoclase and is considerably altered to kaolinite, sericite, and zoisite and contains numerous inclusives of apatite in needle-like crystals.

GRANITE.

It is necessary to give but a brief description of the extensive granite intrusives found in the Basal series for in most cases these can readily be shown to belong to the great intrusive mass of granite belonging with the granite-syenite series intruding the lower sedimentaries of the region and fully described in following pages. As already stated, no sedimentaries have been found in contact with the series of formations here designated as the basal group. Everywhere along the northern border of the belt of foliated gneisses and schists the latter seem to be delimited by intrusive rocks, most of which appear to belong to this granite formation. Within the belt of older rocks also, wherever exposed in any considerable quantity, dikes of the massive granite may be found, sometimes very limited in width, at other times having the appearance of being great bosses in the gneisses and schists.

Clear cut examples of the massive granite dikes in the basal group of rocks are shown in the exposures along the Yellow river about a mile north of Pittsville, and along the Wisconsin river at Conants Rapids, Biron's Mill and Grand Rapids.

The granite is fine to medium grained, varying in color from reddish to grayish. It is schistose in places but is more generally massive and in marked contrast with the formations of gneiss and granite schist which it intrudes. The formation is very often jointed and contains veins of quartz, and segregation

[1] The numbers refer to specimens in the Wisconsin Survey Collection.

veins of coarse granite and pegmatite. The constituent minerals are those commonly found in granite, such as orthoclase, microcline, albite, quartz, biotite, muscovite, rarely amphibole, epidote, chlorite, sericite, magnetite, pyrite and zircon.

DESCRIPTION OF LOCALITIES.

The general distribution of the foliated gneisses and schists, here referred to the basal group, has already been outlined. It is purposed to present in the following pages a more detailed description of localities along the Wisconsin, the Yellow, and the Black rivers where these formations are well exposed.

Along the Wisconsin River.

Stevens Point.—In the rapids at Stevens Point none of the oldest foliated gneiss of the basal group was found. The prevailing rock appears to be schistose granite, the schistosity trending from N. 40° E. to N. 80° E. and generally dipping to the northwest. The schistose granite (6694) is rich in biotite and pink and white felspar and limpid quartz. It contains fragments of finer grained granite schist (6695), the latter being abundant in the vicinity of the dam.

Beneath the outcroppings of sandstone, which are quite abundant in the vicinity of Stevens Point, there may be found a variable thickness of residual clay and partially decomposed schist, which, as pointed out by Irving,[1] has been developed through the decomposition of the crystalline rocks. Good examples of the decomposed gneiss and schist are shown on both sides of the river just below the bridge of the Wisconsin Central railroad where there is a thickness of 5 to 10 feet of the decomposed schist which may readily be seen grading downward into the fresh crystalline rock at the water's edge, and covered over with a capping of the Potsdam sandstone. The clay bank of the Langenberg brick-yard, located about a mile north of the city, consists of gneiss and schist decomposed into clay to a depth of

[1] Geol. of Wis., Vol. II, pp. 464, 468.

FOLIATED GNEISS OF THE BASAL GROUP AT CONANTS RAPIDS.

10 to 20 feet. As pointed out more fully in a later chapter of this report, the relation of the decomposed crystallines and the sandstone undoubtedly points to the origin of the residual clay long before the deposition of the overlying Potsdam sandstone.

Southwest of Stevens Point is a small creek known as Rocky Run, occupying an old channel of the Wisconsin river. Through Sections 1 and 12, T. 23 N., R. 7 E., there are almost continuous exposures of the rock in the bottom of the deserted channel. The rock is mainly a mashed and extremely pegmatized phase of the schistose granite similar to that along the river in Stevens Point. Still farther southwest along Mill creek in the southern half of Sec. 15, T. 23 N., R. 7 E., there is a large number of low lying exposures of pegmatized and schistose granite where Wood's saw mill was formerly located. The rock here approaches somewhat the character of the foliated gneiss, but generally differs from the latter in containing no injected leaves of basic rock. The strike of the schistosity is quite variable, but is generally between N. 55° W., and N. 85° W. The rock contains numerous veins of quartz and pegmatite. The pegmatite veins consist of all proportions of feldspar and quartz, and vary in thickness from fine films to thick veins 4 to 6 feet in width which cut across the schistose structure of the rock in every direction.

Conants Rapids.—The rapids along the Wisconsin river in the vicinity of Stevens Point extend southward from Stevens Point to the central portion of Sec. 15, T. 23 N., R. 8 E., near the great bend of the river. That portion of the rapids extending from the center of Section 8 southward to the bend of the river is known as Conants Rapids. On the east bank of the river, at Conants Rapids, are located two large paper and pulp mills, generally referred to as the upper paper mill and the lower paper mill.

The upper mill is located near the center of the SE. ¼ of Sec. 8, T. 23 N., R. 8 E. On the west side of the river opposite the mill, at the end of the dam is a small area of rocks well exposed, which shows clearly the several formations of the basal group and their relations. There is perhaps no place along the Wisconsin river where the oldest rocks of the region can be studied to better advantage. The accompanying photograph, Plate III, is intended to convey an idea of the general structure and relations of these formations. The rocks are much more contorted and intermingled than is possible to show by any drawing or sketch. The general relations of the rocks at this place have already been referred to. (See page 19.) The oldest formation present is the foliated gneiss consisting of layers of gray granite alternating with layers of dark basic rock having a general trend of N. 75° W. and dip of about 60° to 75° SW. Dike-like masses of greenstone schist occur here and there in the gneiss. The next oldest formation is a mashed quartz syenite schist having a cleavage with a dip and strike nearly parallel to the banding of the gneiss. The quartz syenite schist is intrusive in the foliated gneiss and is in turn penetrated by a biotite granite somewhat schistose in character. Large dikes of the granite schist cut directly across the banded gneiss and parallel with these larger dikes are numerous narrow pegmatite veins and jointing planes. Systems of pegmatization, as shown by the distribution of some of the veins in all the formations, while certain others are limited to only one or two of them, appear to be connected in origin with the quartz syenite schist and the biotite granite schist and also with the later massive granite. A few hundred feet south of the upper paper mill, where the river turns to the east, there is an abundance of coarse massive granite having the character of the intrusive granite about Wausau, and believed to belong with the latter formation. This is believed to be a later formation than any of those occurring at the upper mill, and to have been the origin of the latest series of pegmatite veins occurring there.

At the lower paper mill exposures of the crystalline rock are less abundant. On the east side of the river where the Sherman saw mill was formerly located, on a mill race leading from the mouth of the Plover river, there is a good exposure of the foliated gneiss and schist in the bed of the abandoned race. The rock in the race is mostly granite-schist with marked fissility, having a nearly vertical dip and strike generally trending N. 30° to 35° E. Outside of the mill race in the yard of the paper mill and along the river bank there are exposures of the diorite schist and of the foliated and crumpled gneiss.

Biron's Mill.—From the lower paper mill at Conants Rapids to Biron's paper mill, but few large exposures are to be found. In the NW. ¼ of Sec. 35, T. 23 N., R. 6 E., is the northern limit of a long stretch of rock exposures in the river channel forming the Grand Rapids of the Wisconsin. The city of Grand Rapids is located near the lower end of the rapids and near the northern end is the Biron paper mill. Immediately below the dam at Biron's mill the rock is well exposed, showing the presence of at least three distinct formations, two of granite and one of diorite, and numerous aplite and pegmatite veins cutting these in various directions. The foliated gneiss was not noted at this place. The oldest formation appears to be a schistose diorite, or greenstone, the strike of its most prominent system of close joints and cleavage being generally N. 70° E. with a less prominent system trending N. 35° W. and thus running nearly at right angles to the close joints. The older granite is fine grained and somewhat schistose and shows much jointing and veining and other effects of extreme pressure. The cleavage structure of the schistose granite agrees closely with that of the greenstone, the two formations apparently having been mashed together. The massive and younger granite is medium to coarse grained and disintegrates readily. It clearly cuts across the cleavage structure of both the mashed finer granite and greenstone formations. The latter formations appear as large fragments in the former, and numerous pegmatite veins run out from the massive granite and permeate the schistose granite and greenstone formations.

Grand Rapids.—In the rapids at Grand Rapids the oldest rock is a gneiss, the main body of which consists of mashed granite into which has been injected basic material in leaves parallel to the schistosity. The gneiss is much crumpled and faulted, with an average strike between N. 50° E. to nearly E. W. The dip is variable, but is usually nearly vertical or to the SE.

The gneiss is especially abundant north of the wagon bridge. In this portion of the rapids there is some massive granite, the intruding masses of the latter being largely controlled in direction by the foliated character of the gneiss. In some places the gneiss forms thin leaflets between broad areas of the massive granite, while in other places the gneiss contains only a few films of the intrusive. The belts of intruding granite therefore vary in thickness from a score of feet across to paper-like leaflets. At various places in the rapids are shown all proportions of the two rocks.

FIG. 2. GENERALIZED SECTION OF PRE-CAMBRIAN AT GRAND RAPIDS.
A—Foliated gneiss, b—Greenstone schist, c—Granite schist, d—Olivine diabase, e—Granite.

The basic igneous rocks intrusive in the gneiss are of two kinds, olivine diabase and diorite, or greenstone schist. The greenstone schist is abundant in the lower portion of the rapids and the strike and dip of its schistosity is generally parallel to that of the foliated gneiss. The olivine diabase forms a large dike, twenty-five feet thick, with numerous small branches, immediately above the wagon bridge. The olivine diabase is massive and cuts across the schistosity of the gneiss.

In the southern part of the city schistose granite intrusive in the gneiss is quite abundant. The schistosity of the granite is nearly parallel with the average strike of the foliated and crumpled gneiss. Immediately north of the Chicago & Northwestern railroad bridge there is considerable foliated gneiss striking northeast and parallel to the river bank. In this vicinity there are greeenstone dikes in the gneiss, both seemingly having been mashed together.

At Grand Rapids, therefore, besides the foliated gneiss there are at least four distinct intrusive formations showing a similarity to the associated rocks at Conants Rapids. Pegmatite veins are abundant, a period of pegmatization apparently following each of the granite intrusions.

South Centralia.—In South Centralia is a paper mill and dam located in the SE. ¼ of SW. ¼ of Sec. 24, T. 22 N., R. 5 E. Here the rock is granite and greenstone, the granite predominating.

On the west bank of the river where the Wisconsin Central railroad crosses over the mill race to the island on which the mill is located, there is a railroad cut showing a thickness of 10 to 12 feet of decomposed schist. This clay bank, the decomposed product of gneiss and schist, is exposed for at least 100 feet back from the river bank.

Port Edwards.—Below the dam at the upper end of the island north of the Port Edwards paper mill the rock is mainly the much crumpled and foliated gneiss having a trend to the northeast. The gneiss (6771) is cut by dikes of massive granite, and about 100 yards south of the dam is a mass of intrusive greenstone (6772) like that at the south end of the island near the mill, and also like that forming a part of the foundation of the mill.

At the foot of the rapids at Port Edwards, on the west side of the river, is a rather coarse grained red granite schist, with a strike N. 45° E. and dip 50° northwest. Immediately north of this is an exposure of banded gneiss with a general strike parallel to the granite schist. Throughout the rapids along the west side of the river the prevailing rock appears to be the foliated gneiss with smaller portions of granite schist. The general strike is N. 45° E., and dip nearly vertical, sometimes dipping to the northwest and sometimes to the southeast. There is a joint system parallel to the schistosity and banding, and also a less perfect set normal to this direction. Quartz veins, pegmatitic veins, and granite dikes are also present.

Nekoosa.—At Whitney's Rapids at the village of Nekoosa occurs the southernmost exposure of the crystalline schists along the Wisconsin river. The crystalline rock forms the river bed with the Potsdam sandstone overlying it along the banks. The rock forming the rapids at the southern end of the small island is granite schist containing much biotite and chlorite. Ten paces up the river is an exposure of fine grained greenstone schist, the schistosity having a strike N. 50 E., and a nearly vertical dip. Immediately north of the island is a predominance of the granite schist. The rock in the vicinity of Nekoosa is mainly granite schist interspersed with some greenstone schist having a strike generally ranging from 35 E. to N. 45 E. and high dips. These are penetrated in numerous places by quartz and granite veins. Besides the jointing parallel to the schistosity there is a set of joints much less prominent, striking nearly normal to the schistosity. Lying between the hard crystalline schists and the sandstone is a variable thickness of clay and partially decomposed schists which has developed through the alteration and weathering of the crystalline rock.

Along the Yellow River.

The Yellow river, after flowing over numerous rapids in Wood county consisting of several phases of massive granite and greenstone, finally meets with the foliated and contorted gneiss at the mouth of Rocky Run, a small stream which enters the Yellow in the NE. ¼ of Sec. 21, T. 23 N., R. 3 E. From this point southward to the bridge of the Chicago, Milwaukee & St. Paul railroad at Dexterville where the most southerly outcrop of pre-Cambrian occurs, the prevailing rocks are the banded gneiss and associated intrusions. The gneiss along the Yellow river is in all respects like that along the Wisconsin river. The rocks associated with the gneiss are massive granite, generally massive syenite or diorite, massive and schistose greenstone and rhyolite. At various places along the river each of these are shown to be intrusive in the crumpled gneiss. A short distance south of the junction of Rocky Run with the Yellow river the massive granite intrudes the gneiss. The greenstone is intruded in the gneiss at the bend of the river near the south quarter post of Sec. 21, T. 23 N., R. 3 E. A short distance below Pittsville is an occurrence of quite massive rhyolite in the vicinity of ledges of the foliated gneiss. Near the center of Sec. 3, T. 22 N., R. 3 E., is a dike of greenstone 6 or 8 feet thick in the gneiss extending directly across the structure of the gneiss.

Near the center of the SE. ¼ of Sec. 5, T. 22 N., R. 4 E., along the Hemlock creek, there are exposures of the banded gneiss in contact with the intrusive granite and fine-grained diorite. South of the latter point, along the Hemlock creek to the sandstone district, the prevailing rock is the basal gneiss and schist, while north of it the Hemlock creek and some of the branches show almost continuous exposures of the massive granite and dioritic rocks.

The dip of the bands of gneiss is generally nearly vertical and the strike is in a northwest direction quite generally along the

Yellow river. At the Pittsville wagon bridge the strike is N. 50° W.; about a mile north of the bridge it is also N. 50° W.; in the vicinity immediately north of the south quarter post of Sec. 21 the strike is N. 75° W.; near center of Sec. 3, T. 22 N., R. 3 E., the strike of gneiss is N. 65° W.; near center of Sec. 10 the strike is N. 25° W.

Along the Black River.

Rocks of prevailing gneissic and schistose structure occur along the Black river from the vicinity of Neillsville southward beyond the borders of this area. North of Neillsville while some banded gneiss occurs, yet most of the rocks exposed appear to be massive phases of granite, gabbro, and diabase, which in many cases, if not in all cases, can be proven to be intrusive in the gneiss and schists farther south. For these reasons, therefore, the border of the basal group is provisionally placed just north of the city of Neillsville.

Vicinity of Neillsville.—Along the Black river from the SW. ¼ of Sec. 11, T. 24 N., R. 2 W., to Cunningham creek and up the O'Neill creek for several miles, are abundant exposures of the foliated and banded gneiss, generally, though not always, having a strike to the northwest. Exceptions to the northwest strike were noted in the SW. ¼ of Sec. 11, where strike is N. 80° E.; along wagon road near center of Sec. 15 where strike is N. 80° E.; and along Cunningham creek just east of wagon bridge near the west quarter post of Sec. 26 where the gneiss is much crumpled and the average strike is N. 80° E. This banded gneiss consists of alternating bands of acid and basic rock with parallel veins of quartz and pegmatite and is in all respects like that occurring along the Yellow and Wisconsin rivers. The gneiss (6802) occurring just north of the wagon bridge west of Neillsville may be considered an average type of this formation. The rock consists of alternating bands of granite and diorite rock. Under the microscope the diorite bands are seen to consist of common green amphibole and some biotite, and the granite bands mainly of quartz and feldspar.

Granite schist formed by the mashing of common granite occurs in the vicinity of Neillsville and is the prevailing rock exposed along the Black river from the junction of the O'Neill creek to the railroad bridge. This granite schist is fine grained. In the railroad cut the strike of the schistosity is northwest but at the bend of the Black river north of the railroad bridge the strike of the schistosity is N. 30° E. In the railroad cut ½ mile west of the Neillsville depot the granite schist is well exposed. This schist is a fine grained pinkish rock with good cleavage. Under the microscope it is seen to consist of large crystals of feldspar and quartz partly broken down through process of granulation to a mass of small grains of microcline and quartz. The small grains of microcline and quartz have much the appearance of these minerals in some metamorphic sedimentaries, but their association with large crystals of feldspar and quartz indicated their origin in the mashing and granulation of granite. Much of the feldspar is partially altered to chlorite. Biotite and muscovite are also present. For some distance south of the wagon bridge across the Black river in Sec. 15 the granite schist forms steep rocky walls along the east bank of the river. About two miles below the wagon bridge at the bend of the river in the NW. ¼ of Sec. 26, T. 24 N., R. 2 W., are numerous exposures on the north slope of a hill of coarse granite schist having the "eye structure" of the "Augen gneiss." This coarse granite schist (6800) also forms steep walls along the river bank immediately to the west. The eye structure of the schist is made by the parallel arrangement of biotite and other minerals about the feldspar cores of "eyes," the feldspar not having succumbed during the mashing to the granulation and breaking-down process like the rest of the rock. The feldspar cores now stand out as eyes around which the other minerals have assumed a flowage or parallel arrangement. Under the microscope besides the large crystals of feldspar are to be seen an abundance of small grains of quartz, feldspar and epidote and some muscovite and apatite.

Fine grained diorite occurs as an intrusive in the banded gneiss at the wagon bridge west of Neillsville. This rock is black, has a good cleavage and is rich in hornblende. Under the microscope it is seen to consist of about 60 per cent of bluish green amphibole, 25 per cent of plagioclase, 10 per cent of quartz, and the remainder chlorite, apatite, epidote and magnetite.

Massive granite, believed to be intrusive in the schistose granite and banded gneiss, occurs along the south bank in the bend of the river just north of the railroad crossing.

In the vicinity of Neillsville, therefore, there are at least four distinct formations of igenous rock exposed,—the banded gneiss, generally, though not always, striking to the northwest, granite schist of both coarse and fine phases, diorite schist, and massive granite.

South of Cunningham Creek.—The next abundant exposures of crystalline rock noted along the Black river are those in the vicinity of the mouth of Conlan creek in the SW. ¼ of Sec. 23, T. 24 N., R. 2 W. North of this, however, along the west river road in the NE. ¼ of the NE. ¼ of Sec. 33, a small ledge of gneiss was noted on the west side of the road in a field. This exposure consists of banded gneiss apparently made up of alternating bands and seams of granite and mashed diorite (6809). The diorite (6809) is fine grained, and under the microscope it is seen to be extremely fractured, the green amphibole, the quartz, and feldspar being broken into fragments.

Granite schist rich in mica was struck in bottom of a well on the east side of the road between the road and river a short distance north of Conlan creek.

Fine grained diorite was found on the river bank immediately north of Conlan creek.

At the wagon bridge crossing the river near the east quarter post of Sec. 5, T. 23 N., R. 2 W., are exposures of greenstone schist and granite on both sides of the river. On the west bank of the river opposite the south end of the island in SE. ¼ of Sec. 5 is a ledge of granite. Similar granite also occurs along the east river road about half a mile south of this.

Immediately south of the junction of Wedges creek and the Black river on the wagon road is a ledge of fresh-looking massive granite (6812) of medium grain. Under the miscroscope this granite (6812) is seen to consist of orthoclase, microcline, and quartz with some biotite and muscovite. The thin section shows the effects of some deformation of the massive granite, but very slight compared with the mashing of the schistose formations. This rock appears to be very similar to the intrusive massive granites of the area.

About a mile south of the mouth of Wedges creek in the southwest corner of Sec. 8, T. 23 N., R. 2 W., and just above the wagon bridge the river flows through a gorge with precipitous walls, the granite being the massive red variety, considerably seamed and jointed, but not schistose.

Along the wagon road in the SE. ¼ of Sec. 24, T. 23 N., R. 3 W., there are several exposures of granite and banded gneiss. In the NW. ¼ of Sec. 25, T. 23 N., R. 3 W., about a mile to a mile and a half north of the mouth of the east fork of the Black river, for a distance of about half a mile, are exposed numerous ledges of gray banded gneiss, and massive granite and diorite schists. Near the south end of these exposures on the west bank is a ledge about 150 feet long and 25 feet high of the fine to medium grained massive granite. At the north end near the old dam, where French's mill was formerly located, is similar massive gray granite (6814). Under the microscope this granite is seen to consist of orthoclase and quartz and some biotite and epidote. Most of the quartz shows mashed undulatory extinction and the orthoclase is somewhat altered to sericite, epidote, and biotite. The banded gneiss at the old dam strikes in general E. W. with an approximate vertical dip. The diorite schist (6815) which is closely associated with the banded gneiss is rich in green hornblende, most of which has a distinct parallel arrangement. Immediately west of the exposures in this vicinity on the west side of the wagon road is a ridge of sandstone 30 to 40 feet high trending north and south, which shows at several places the unconformable junction of the sandstone and the crystallines.

IRVING'S CONCEPTION OF THE GNEISSES AND SCHISTS OF CENTRAL WISCONSIN.

It was formerly believed by many geologists that the ordinary banded gneisses and most schists of various parts of the world were of sedimentary origin. Accepting this belief, Irving in 1875 and 1876 applied it to the gneisses and schists of central Wisconsin. Hence in the description of the schistose and banded rocks along the Wisconsin, Yellow and Black rivers in the former reports[1] of the Wisconsin Geological Survey, Irving[2] constantly speaks of their bedding, and throughout considered their lamination and schistosity as proof of their sedimentary origin. Even several years later, in 1881, after the microscope had been applied to the study of these rocks Irving[3] believed that only the granites and quartz porphyry of massive character and those formations appearing as dikes and clearly intrusives were of igneous origin. While at the present time rocks which are properly called granite and quartz porphyries are necessarily of igneous origin, Irving in a few instances applied these names as well as that of gneiss, greenstone schist, hornblende schist, etc., to formations which he believed to be of sedimentary origin.

These conceptions of Irving are pointed out here in order that the reader may understand his writings concerning these formations and how his description of the geology of these rocks in Vol. II, Geology of Wisconsin should be interpreted when compared with the description of the same rocks in the present report.

While the strikes and dips of the so-called bedding and laminations of the schists and gneisses, taken and recorded by Irving, are usually the strikes and dips of the same phenomena measured by the writer as secondary cleavage and banding, yet the structures in mind, in some cases at least, were not the same. In some instances Irving evidently discriminated between the system of close joints, or fissility, and veining, and measured, instead, alternating layers, or zones of coarse and fine rocks, which he believed to denote stratification, but which is obviously due to differences in the rate of cooling and crystallization of the igneous magmas.

1 Geol. of Wisconsin, Vol. II, pp. 461–501.

2 Ibid. p. 463.

3 Geol. of Wis., Vol. IV, pp. 712–714.

THE ORIENTATION OF THE SCHISTOSE AND BANDED STRUCTURES OF THE BASAL GROUP.

The general orientation of the cleavage and banded structure, while apparently the same within small areas, cannot be said to persist over large areas.

Along the Wisconsin river south of the great bend at the lower end of the Conants rapids, the general strike of the cleavage and banding seems to be more often towards the northeast than to the northwest and the dip is generally nearly vertical though apparently as often in one direction as in another. North of Conants Rapids the strike appears to be as often to the northwest as to the northeast and the dip variable. Along the Yellow river throughout the belt of gneiss there is a persistent strike of cleavage and banding to the northwest with variable dips to the northeast and southwest. Along the Black river also the strike is quite generally towards the northwest.

While there seems to be a common direction for the secondary structure to trend northwest along the Black and Yellow rivers, no such persistency in strike seems to prevail along the Wisconsin river. When it is considered that the strike and dip of the secondary structure was observed of only a very small portion of the area of the basal group as compared with the extent of the belt as a whole, it will be seen that a general conclusion concerning the orientation of the secondary cleavage and banding is hardly justifiable. From our general knowledge of the distribution of the rocks of the basal group in a belt extending east and west we would expect to find the strike of the lamination more often towards the east and west, that is, parallel to the greatest length of the area, than in any other direction. On the other hand, when it is considered that the basal group is penetrated throughout with later igneous rocks and especially with great masses of granite, and that all the older rocks are but great fragmentary masses in later intrusives, it should be expected that more or less secondary or subsequent shifting of the strikes and dips would take place, on account of the movement of the intrusive magmas.

ORIGIN OF THE BASAL GROUP.

The several formations constituting the basal group, described above as gneiss, diorite or greenstone schist, quartz-syenite schist, and granite schist, are clearly of igneous origin, and have assumed their present banded, laminated, and schistose character through the effects of pressure and igneous intrusions. It is possible, even probable, that sedimentary schists older than some of the members of the basal group may occur in the area mainly occupied by the gneisses and schists, but none were observed or recognized by the writer, although especially searched for.

RELATION TO OTHER FORMATIONS.

As stated at the beginning of this chapter, the gneisses and schists are believed to constitute a series older than the sedimentaries and massive igneous rocks lying to the north over the principal portion of the area. Since sedimentary rocks, however, were not found in contact with this belt it is not positively known that the group forms the floor upon which the lower sedimentary series of the area rests. It is known only that the igneous formations intrusive in the lower sedimentary series are likewise intrusive in this basal group, a relation which obviously proves only that the gneisses and schists as well as the lower sedimentary group antedated the intrusives.

The principal reasons for believing that the group of gneisses and schists are older than the lower sedimentary series are: *1st.* The gneisses and schists have been subjected to greater pressure and chemical or contact metamorphism than the sedimentaries. This extreme metamorphism appears to prevail over each small portion of the entire area of the gneisses and schists, producing throughout a fairly uniform mingling of the several members of the group. While the lower sedimentaries and later igneous intrusives constitute areas of considerable extent, two or more members of the gneiss and schist group usually if not always occur indiscriminately mixed together in such small areas as a fraction of an acre. *2d.* The group of gneiss and schists constitute the predominating rocks over a considerable belt and as such can be mapped and separated from other formations. This belt varies in width from 5 to 20 miles, and extends in a NW.-SE. direction across the area. North of the belt and also south of it occur the less metamorphosed igneous rocks and the sedimentaries, and hence the gneiss and schist appear to have the position of an older arch, or anticlinal fold with the corresponding syclinal troughs of younger rock both to the north and the south of it.

As previously stated, the position of this basal group of the area in the stratigraphy of the pre-Cambrian is not definitely known. It seems very probable, however, as shown later, that this group is older than the Lower Huronian and is near or at the base of the pre-Cambrian series of rocks.

CHAPTER III.

THE LOWER SEDIMENTARY SERIES.

The Lower Sedimentary Series consists of the following formations: The Rib Hill quartzite, the Wausau graywacke, the Hamburg slate, the Powers Bluff quartzite, the quartzite at Rudolph, and the Junction City quartzite. The stratigraphic succession of these several formations is not known. They occur in isolated areas separated and intruded by great masses of the later igneous formations of granite-syenite, the diorite-gabbro, and the rhyolite.

THE RIB HILL QUARTZITE.

The formation consists of coarse white quartzite and is given the name of "Rib Hill Quartzite" because it has its best development in the bold ridgy prominence of Rib Rill. It also forms the adjoining hills of Upper and Lower Mosinee Hills and Hardwood Hill, all located within 5 to 10 miles of Wausau.

GENERAL DISTRIBUTION.

The Rib Hill Quartzite formation does not form a continuous belt or area of great extent. The quartzite occurs in irregular areas partly or wholly separated from one another. The largest single exposure is that of Rib Hill, having an extent of four or five square miles and covering the whole or parts of Sections 7, 8, 9, 10, 15, 16, 17, and 18, T. 28 N., R. 7 E., and Section 12, T. 28 N., R. 6 E. The upper Mosinee Hill and lower Mosinee Hill, located one mile and two miles respectively south of the east end of Rib Hill in Sections 22 and 27, T. 28 N., R. 7 E., have an extent of one-fourth of a square mile each. The prominent rounded elevation, known as Hardwood Hill, located about three miles southwest of the west end of Rib Hill in the southwest part of Section 23, T. 28 N., R. 6 E., and adjacent parts of the adjoining sections, consists of similar quartzite and has an extent of about one-half of a square mile. The above four hills, Rib Hill, Upper and Lower Mosinee Hills, and Hardwood Hill, constitute the largest exposures of this formation in the vicinity of Wausau. A small ledge of the quartzite is located at the south end of Little Rib Hill in the northeast corner of Section 31, T. 29 N., R. 7 E. The quartzite also constitutes a considerable portion of the southern and eastern parts of the flat topped hill covering Sections 21, 22, 27 and 28, T. 29 N., R. 7 E. In these smaller exposures just mentioned the quartzite is often in contact with the quartz-syenite and is often permeated with an unusual amount of mineral from the intrusion of the latter rock. Several small areas of a pinkish quartzite, which may have been formed at the same time as the Rib Hill quartzite, are located in the area of coarse granite in T. 27 N., R. 6 E., as shown on the map, Plate I.

TOPOGRAPHY.

Because of the very resistant character of the coarse quartzite, its larger exposures have come to be the highest hills of the region. To the casual observer these hills of quartzite appear to have been pushed upward through the surrounding formations until they now rest far above the general level of the latter. In reality, the surrounding rock, principally a coarse syenite and granite, which is easily disintegrable, has been worn away more readily than the resistant coarse quartzite, and for this reason the quartzite areas now remain projecting above the surrounding less resistant formations.

Rib Hill is the largest of these prominences. It is an elongated hill or ridge, slightly curved like a rib, and is about five miles long and about two miles wide in its widest part. Its central and thickest portion reaches an elevation of 1942 feet above sea level, nearly 500 feet above the surrounding upland area and about 750 feet above the broad alluvial valleys of the Rib and Wisconsin rivers which are located at its base on its northern and eastern sides.

Although the summit of Rib Hill presumably reaches a lower elevation above sea level than numerous points farther north about the headwaters of the Wisconsin river, yet Rib Hill very probably extends to a higher elevation above its immediate surroundings than any other prominence within the northern part of the state and has the distinction of being one of the largest hills in Wisconsin. The lower portion of the hill is a gradual upward slope while the upper portion possesses numerous perpendicular walls, and steep talus slopes, the latter being covered by an accumulation of large rectangular blocks of the white quartzite.

The Upper and Lower Mosinee Hills together have the form of a dumb-bell. These hills, whose summits are about a mile apart, are connected by a continuous stretch of quartzite although separated from Rib Hill by a low area of granitic rock. Upper Mosinee is the larger of the two and reaches an elevation of 1596 feet above sea level and about 400 feet above the alluvial plain of the Wisconsin river. Lower Mosinee has an elevation of about 300 feet above the alluvial plain. Both these hills are gently sloping on their western flanks, whereon are located several farms, while their eastern sides adjacent to the river possess steeper slopes and near their upper parts are covered with talus of quartzite blocks.

Hardwood Hill is a dome-like hill whose summit reaches an elevation of 1566 feet above the sea and about 200 feet above the surface of the uplands of the vicinity and 400 feet above the valleys within a mile or so of the hill.

The general relation of these quartzite hills are monadnocks extending above the ancient crystalline peneplain, represented by the even summitted uplands of the region, is fully described in the general discussion of the physiographic features of the district in a following chapter of this report.

PETROGRAPHICAL CHARACTER.

Macroscopical. The Rib Hill quartzite formation in its various occurences, although variable in texture or size of grain, is remarkably pure, white, vitreous, and firmly cemented. It varies some from a white to a pale pink color, due to iron stain. While varying in texture within certain limits, it remains pure in composition throughout. It is very hard and brittle and breaks with a conchoidal fracture. The purer coarser phases are well adapted to the various abrasive purposes to which the crushed and powdered rock has been applied. (See page 652.)

The quartzite varies from medium grained to very coarse grained phases. The finest grained phases are usually as coarse as the coarsest phase of the average Huronian quartzite, while the coarse phases often approach vein quartz in their general character. There are all gradations between the very coarse and fine phases and they appear to give place to one another in a very irregular manner.

The coarse quartzite is quite abundant on Rib Hill and especially in the broadest and highest portion. Wherever there are low places on Rib Hill there the finer grained rocks appear to prevail. The earlier fractures in the quartzite are filled with vein quartz which often contains small amounts of white mica and geods of quartz crystals.

In one or two places the quartzite has disintegrated to some depth and is very friable, like soft sandstone. This friable quartzite, however, seems to have been formed entirely by the weathering of the ordinary firmly cemented rock. No phases of slate, greywacke, or feldspathic quartzite are known to be associated with the Rib Hill quartzite in any of its occurrences about Wausau. Nor has any conglomerate been found at the base of this formation or interstratified with it at any place.

A peculiar contact phase of the quartzite, which is mainly an intrusive breccia formed by the intrusion of one or more acid igneous rocks into the quartzite, is quite abundantly associated with the quartzite of Rib Hill and vicinity and will be only briefly referred to here and more fully described in connection with the intrusive syenite. This contact phase consists of numerous angular fragments of quartzite enclosed in a matrix of granite and quartz syenite. Associated with the quartzite fragments in places are abundant fragments of a black schist, and more rarely fragments of different phases of rhyolite. The fragments of quartzite in the contact rock are usually angular and vary in size up to a foot in diameter. The larger fragments are often broken and pulled apart normal to their longer axes. The quartzite in the fragments, and also the massive quartzite for a number of feet from the contact with the granite or syenite, is impregnated with more or less feldspar and also with a blue soda amphibole.

The intrusive breccia contact rock is well exposed on the west side of Upper Mosinee Hill. It is also shown in the vicinity of a mile or so south of Rib Hill, also on Little Rib Hill, and about the edge of the flat-topped hill immediately northwest of Wausau, and in small quantity at all contacts of the quartz syenite with the quartzite formation. The widespread occurrence of the intrusive breccia about the massive quartzite areas indicates that the quartzite must have had a wider distribution at an early date than it has at present.

Microscopical.—The Rib Hill quartizite formation is composed throughout of quartz crystals which generally vary from 3 to 8 and sometimes even 10 millimeters in diameter. The individuals of quartz are very irregular in form and their surfaces possess numerous angular projections and re-entrants which allow the quartz to dove-tail in a very complex manner. The general appearance of a thin section of the quartzite is presented in Plate VII which shows the angular grains interlocking firmly together, forming a compact, coherent mass after the manner of vein or granitic quartz.

The purity of the quartzite is noteworthy as compared with the general run of quartzite formations. It apparently generally contains about 99 per cent of silica. A chemical analysis made by Prof. W. W. Daniells for the Wausau Quartz Company yielded as follows:

Analysis of Rib Hill quartzite.

SiO_2	99.07
Al_2O_3	.52
Fe_2O_3	.17
CaO	None
MgO	None
H_2O	.06
	99.82

The sample analyzed was an average of the quartzite rock used by the above company in the manufacture of its crushed quartz product and is a fair representative of much the larger portion of the rock of Rib Hill. There is probably a small amount of potassa in the rock, not searched for in the analysis, in combination with the alumina to form the muscovite noted in small flakes in much of the quartzite.

Besides the small flakes of muscovite often present there is at times also some feldspar and magnetite. These are usually located at the junction of the angular quartz or along the fractures within them. There are also present numerous minute crystals entirely embedded within the quartz.

The minute crystals included within the quartz are mainly of two kinds, long hair-like minerals and short stout ones. The former appear as dark lines either straight or slightly curved with their longer axes many times greater than their shorter and are probably needles of rutile or apatite. The stout crystals are brownish-yellow in color and their length is about twice as great as their breadth. They appear to be slightly pleochroic and have nearly parallel extinction and appear to be a variety of pyroxene or amphibole.

Besides the crystal inclusions in the grains of quartz there are also numerous inclusions of gas and fluid. These minute gas and fluid inclusions are usually arranged in lines and along planes which sometimes appear to pass irregularly through the quartz, and sometimes are arranged in parallel planes which may be in accord with the crystallographic constants of the quartz. As seen in cross section the lines of the inclusions often appear to continue across from one crystal to another, while at other times they clearly stop abruptly at the contact of the grains. The inclusions are uniformly abundant throughout the quartz, and no difference in number of inclusions near the centers or at the boundaries could be noted.

The general appearance and distribution of these fluid and gas inclusions are similar in all respects to those occurring in quartz in granite. The shapes of the inclusions are very variable. Sometimes they have the form of perfect dihexahedral crystals, at other times a semi-crystal form, or are irregularly angular or bay-shaped. The composition of the included fluid and gas in the cavities in the quartz is not known, but as generally considered the fluid is usually water which carries in solution bubbles of vapor or various gases such as air, carbon dioxide, nitrogen, or a mixture of these gases. The mobility of the gas bubbles enclosed within many of the fluid inclusions may be readily noted under the highest power of the microscope. On the application of a heated needle point to the vicinity of the bubbles an increase in their movement was noted. The movement of the bubbles in the interior of the quartz reminds one very forcibly of such living organisms as amœba or diatoms moving in water.

Sometimes there are small angular grains of quartz between the larger crystals, apparently due to the peripheral shattering of the large quartzes, and there are also often numerous fractures along the incipient rhombohedral cleavage of the quartz. Undulatory extinction is also a common phenomena of the quartz. Yet these evidences of dynamic metamorphism are not a marked feature of the formation. It is usual that the ordinary phases of the pre-Cambrian quartzite are composed of rounded grains of quartz of somewhat uniform size, which show enlargements filling the entire interspaces between the original grains, so that the clastic grains of sand of the original deposit can readily be distinguished from the secondary interstitial quartz. But no such phenomena of original grains with enlargements can be detected in the Rib Hill quartzite in any of the numerous thin sections examined.

The granitic texture of the Rib Hill quartzite was previously noted by Van Hise[1] as shown in the following description of two specimens of this formation, as follows:

"Specimen 927. Microscopic: Massive, translucent, glassy quartz is the only mineral visible.

Microscopic: Almost pure quartz. Usually the grains are of very large size, some of them reaching 7½mm. in greatest breadth, and interlocking after the manner of the quartz of gneiss and granite. The only other minerals present are a little oxide of iron, mostly magnetite, and a few minute flakes of muscovite. As to cavities in this quartz, they are as common as in the quartz of granite, and from the position of the grains were evidently crystallized in place.

Specimen 936. Macroscopic: Like 927. Crystalline rock. The only minerals distinguishable are shining flakes of mica and grains of quartz.

Microscopic: As in all the preceding quartzites the grains of quartz fit perfectly along their irregular lines

[1] Geol. of Wis., Vol. IV, p. 685.

of junction. They are of about the same size as in 927 and freer from other minerals and inclusions than either of the preceding. Iron oxide appears to be the only impurity present. In none of these rocks is there any trace of a clastic origin."

It was undoubtedly this granitic texture of the quartzite which led Irving[1] to suggest its marked similiarity in internal and external structure to a large formation of vein quartz. The quartzite, however, shows cross stratification in places, and also well preserved ripple marks (Plates V and VI) and is clearly a metamorphosed sandstone. Although the microscopic texture of the quartzite is like that of an igneous rock or of vein quartz, the texture of the quartzite as seen in hand specimens is essentially different from vein quartz. While the quartzite always breaks with a conchoidal fracture, the rock throughout retains a distinct granular or saccharoidal texture not usual in vein quartz.

In respect, therefore, to the granitic crystalline texture of the quartzite and the entire absence of evidence of clastic origin in thin sections, this quartzite appears to be unique, and to differ, as a formation, from the usual quartzite formations of the Lake Superior region. This difference in crystalline texture is undoubtedly due, as above stated, to the extreme metamorphism to which the rock has been subjected, for there can be no doubt that the formation was originally a sandstone with from 25 to 35 per cent of pore space, and that these interspaces were filled, as in all quartzite, by the deposition of interstitial quartz.

The metamorphism of this sandstone, however, did not stop with the completion of the process of consolidation and cementation. A further process of metamorphism, that of the complete recrystallization of the original and the interstitial quartz, was brought about. This recrystallization process is similar to that necessary to the development of marble from ordinary limestone. The most favorable condition for the recrystallization of marble is by the intrusion of igneous rocks with the production of the necessary metamorphosing agents, heat and warm solutions. That recrystallization occurs under these conditions is known, not only from observations at numerous marble localities, but

[1] Geol. of Wis. Vol. IV, p. 669.

EXPLANATION OF PLATES

V, VI AND VII.

Plate V. Rib Hill Quartzite Showing Bedding Planes. Quarry of the Wausau Sandpaper Co., near the northeast end of Rib Hill. The joint planes dipping downward to the right very probably represent the bedding of the quartzite formation. Fracture planes extend in all directions throughout the formation.

Plate VI. Ripple Marks in the Rib Hill Quartzite. Natural size. Although the quartzite is wholly recrystallized by metamorphic processes yet the structure of the ridging of the sand by the waves of the pre-Cambrian sea is completely preserved.

Plate VII. Microsections of the Rib Hill Quartzite. Section 4302. With analyzer, x25. Figures 1 and 2 illustrate the same features, namely the close-fitting interlocking structure of the quartz grains without any interstitial material. The boundary lines of the rounded clastic grains of the original sandstone have been obliterated and by the addition of new quartz and by recrystallization a solid mass of interlocking quartz is formed like vein quartz. The recrystallization is due to metamorphism by igneous contact.

RIB HILL QUARTZITE SHOWING BEDDING PLANES.

RIPPLE MARKS IN RIB HILL QUARTZITE.

Fig. 1.

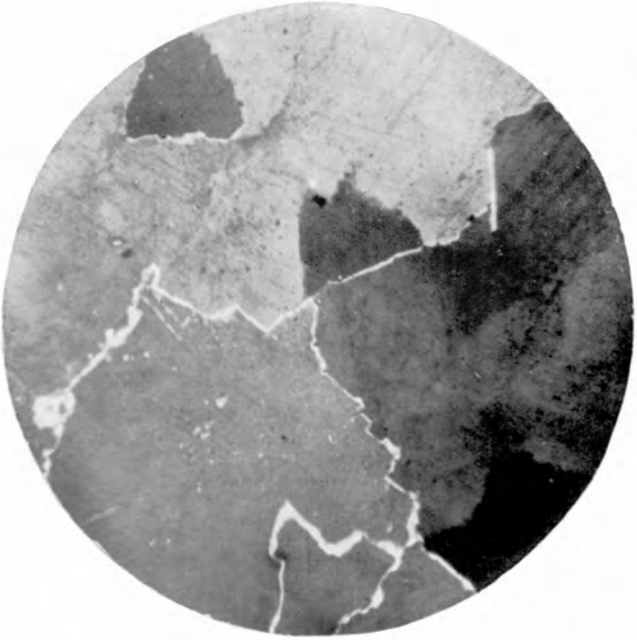


Fig. 2.

MICROSECTIONS OF RIB HILL QUARTZITE.

by the action of similar processes upon marble in the laboratory. The recrystallization of quartzite, however, probably requires much more work than that of marble. The reason for this belief is the fact that marble formations of considerable size are quite numerous, whereas formations of quartzite that have been wholly recrystallized are very rare.

The internal evidence of the recrystallization of the quartzite, such as the intricate interlocking association of the quartz crystals, like that of the quartz in granite or quartz veins, and the uniform distribution of the lines of fluid and gas inclusions throughout entire crystals, as well as extending from one crystal to another, is much strengthened by abundant external evidence of widespread igneous intrusions in the quartzite, which could produce the conditions for recrystallizing the quartzite. Similar lines of fluid inclusions in quartz grains have been described by Van Hise[1] in the quartzite of the Black Hills as due to occluded fluids induced by secondary crystallization. Wherever the massive and widespread granite and syenite formation comes in contact with the quartzite, numerous fragments of the latter rock are enclosed within it, forming considerable belts of brecciated quartzite about the large areas of quartzite. And not only has the granite-syenite formation intruded the quartzite, but also one or more earlier igneous formations have penetrated it in a complex manner, producing belts and areas of brecciated rock of even greater extent, in a few places, than the granite-syenite intrusion. There seems, therefore, to be sufficient evidence of intrusive phenomena connected with the quartzite to explain the unusual metamorphism and recrystallization of the latter.

The metamorphic effect of igneous intrusions upon sandstones and quartzites has been observed[2] in many other localities. The homogeneous quartzite resulting from the complete metamorphism of a pure quartose rock by igneous contact is not difficult to distinguish from a quartzite formed by the deposition of interstitial quartz through the ordinary processes of cementation and consolidation. As the intruded quartzite acquires the heat of the intruding igneous mass and the tempera-

[1] Bull. Geol. Soc. Am., Vol. I (1890), p. 218.

[2] Harker: Petrology for Students, p. 286, 1897.

ture becomes sufficiently high, the whole will be recrystallized into a quartz mosaic with a complete obliteration of all traces of the original clastic character. In such a metamorphosed quartzose rock, there is no distinction of original grains and cementing material, nor of secondary growths upon original nuclei, but each individual of the quartz mosaic is clear and homogeneous with penetrating boundaries fitting into the inequalities of those adjacent. But in such metamorphosed formations the recrystallization is usually only of local occurrence. The Rib Hill quartzite differs from these formations in being completely recrystallized throughout instead of only in part or locally.

STRUCTURE AND THICKNESS.

But very little can be said concerning the folding and the position of the bedding of the Rib Hill quartzite. The reason for this is obviously due to the extremely metamorphosed character of the formation and the movement of the surrounding masses of intrusive igneous rocks.

In a number of places on Rib Hill the cross-bedding of the quartzite can be made out in the finer grained phases of the rock, and in a few places beautiful ripple marks have been discovered (Plate VI). In one locality a distinct southwest dip of the bedding is to be noted (Plate V). These evidences of sedimentation, however, are the exception and nowhere is there evidence of continuous joints along bedding planes or the continuous alternation of coarse and finer grained sediment that would furnish means for the measurement of the dip and strike of the beds over any considerable area, as is usually the case with the ordinary phases of the finer grained pre-Cambrian quartzites.

A certain streaky character of the quartzite prevails throughout Rib Hill and the Mosinee Hills. This streaky character is due to lamination and lines of easy parting which have in general a nearly vertical dip and a strike parallel to the long axis of the quartzite areas. Upon Rib Hill, therefore, these lines extend east and west, while in the quartzite of the Mosinee Hills they run nearly north and south. The streaky character is very probably secondary and is due to the numerous planes of easy parting made by dynamic forces at the time of the general folding of the quartzite beds with the other rocks of the region. The folding of the Rib Hill quartzite in its various exposures therefore could not be made out, although it is believed that the original sandstone beds must have been subjected to various orogenic movements sufficient to fold the rock in a very complex manner. No persistent sets of jointing were noted in the quartzite of Rib Hill or the other areas. Numerous irregular jointings and fracturings, however, are everywhere present.

It is impossible to give any accurate estimate of the thickness of the Rib Hill quartzite because the position of the bedding could not be determined. Only an intelligent guess based upon the present distribution of the rock and its extent can be made. If a continuous line be drawn about the quartzite of Hardwood Hill, Rib Hill and the Mosinee Hills, it will be seen to enclose an area which may be compared to a crescent, convex towards the north. The thick portion of the crescent is the broadest part of Rib Hill and the two ends of the crescent are Hardwood Hill and the Mosinee Hills. If the quartzite was surrounded by the rock floor upon which it was deposited, then this crescentiform area might well represent a curving complex fold with its greatest breadth about one and one-half miles across at the broad part of Rib Hill. If the folding was simple, then the thickness of the formation would be at most not more than one-half the breadth of the thickest part of the crescent, namely 4,000 feet. Since rock formations which show as much metamorphism as this quartzite are quite usually folded in a complex manner and not into simple folds, it may readily be assumed that the original thickness of the formation was very much less than one-half its greatest superficial breadth or much less than 4,000 feet. Although the quartzite is not now in contact, so far as known, with its original rock floor, it may reasonably be assumed that it was complexly folded, as above indicated, before it was intruded by the various igneous rocks now surrounding it. The vast quantity of quartzite fragments in the intrusives indicates a greater original distribution of this formation than it now possesses. In view of the probable complex folding of the quartzite and the wide distribution of quartzite fragments in the surrounding intrusives, it is believed that a fair estimate of the thickness of the Rib Hill quartzite formation is somewhere between 1,000 and 4,000 feet.

RELATIONS TO ADJACENT FORMATIONS.

With the exception of a single locality of sedimentary rock, the quartzite appears to be entirely surrounded by igneous formations. The oldest of these igneous rocks is apparently the unusually metamorphosed syenite fully described on following pages of this report. This peculiar metamorphosed rock occurs in abundance on Little Rib Hill and in the flat topped hill northwest of Wausau. At these localities the metamorphic rock is readily shown to be of later origin than the quartzite, for numerous angular fragments of the latter are widely distributed through the former. These quartzite fragments vary in size from a fraction of an inch to several inches in diameter and are usually flattened parallel to the cleavage plane of the intruding rock, and are distributed for long distances from the ledges of massive quartzite.

The other members of the granite syenite series of rocks also intrude the quartzite. Especially is this true of the quartz-syenite which occupies all the low intervening land between the quartzite hills about Wausau. Examples of quartzite fragments in this quartz-syenite may be found at numerous places about Rib Hill and the Mosinee Hill. The quartz syenite is also an abundant intrusive in the older metamorphic syenite on Little Rib Hill which intruded this quartzite at a much earlier date. Massive granite is intrusive in the quartzite on the west side of Upper Mosinee Hill at the southeast end and on the northwest end of Rib Hill. Although the nepheline syenite was not found intruding the quartzite, yet the nepheline syenite undoubtedly intrudes the early syenite formations which contain numerous fragments of the quartzite. The amphibole granite formation, a member intermediate in composition between the granite and quartz syenite, surrounds and intrudes the quartzite of Hardwood Ridge.

A single ledge of diorite occurs on Rib Hill near the southeast corner of the NW. 1/4 SW. 1/4 of Sec. 15, T. 28 N., R. 7 E., which apparently represents a dike intruding the quartzite.

An occurrence of sedimentary rock is in contact with the quartzite on the east end of Rib Hill in the southeast 1/4 NW. 1/4 of Sec. 15, T. 29, R. 7 E., at the test pit made a few years ago by Mr. P. St. Austin. This sedimentary rock is mainly conglomerate and contains pebbles of quartzite and rounded grains of coarse quartz and microperthitic feldspar. It appears to be made up of the detritus from the syenite and the coarse quartzite formation and is therefore considered to be a formation of a much later date than this quartzite. It is probably contemporaneous with the Marshall Hill conglomerate a few miles north of Wausau.

WAUSAU GRAYWACKE.

Under this name is included the feldspathic quartzite and graywackes occurring in the vicinity of Wausau.

DISTRIBUTION AND EXPOSURES.

The rocks of this formation occur in isolated masses within a few miles northeast and northwest of Wausau. Exposures of this formation on the east side of the Wisconsin river occur in the western part of Sec. 19, T. 29, R. 8, and in the adjoining eastern part of Sec. 24, T. 29, R. 7. Four miles northwest of Wausau in the SW. ¼ of the SW. ¼ of Sec. 9, T. 29, R. 7, and vicinity, are several exposures of sedimentary rock placed with this formation. This rock formation is not an extensive one and is not an important one so far as area is concerned, but the discovered relations of this formation to the associated rocks are of much interest and importance, and hence it is here described in some detail.

TOPOGRAPHY.

There is nothing distinctive in the topographic features of the few exposures of rocks referred to this formation. The formation crops out on the sides and summits of the low hills on the east side of the river in Sec. 24, T. 29, R. 7. In the western part of Sec. 9, T. 29, R. 7, the formation forms a few low exposures along the creek of that vicinity

PETROGRAPHICAL CHARACTER.

This formation consists of a variety of fine grained to medium grained rocks, mainly belonging to phases of argillaceous quartzite or graywacke. The rocks of this formation in places have been much fractured and brecciated, and in other places the intrusion of masses of igneous rock have more or less obscured their original textures.

Macroscopical.—The rocks of this formation, as already stated, occur in small patches in two areas, the one being immediately adjacent and northeast of Wausau and the other area several miles northwest of Wausau.

In the area northeast of Wausau the fine grained graywacke is found in small out-crops protruding through an overlying, pre-Cambrian conglomerate formation, and also as fragments in the intrusive rhyolite of the vicinity. The various phases of the Wausau formation in this vicinity, therefore, are found mainly as fragamentary areas surrounded by the associated younger rocks, and the isolated small ledges of this formation distributed over a considerable area indicates the probable occurrence of this formation in considerable quantity in the region, and now hidden by the younger and overlying rocks.

Near the center of the NW. ¼ of Sec. 19, T. 29, R. 8 E., on the northwest slope of the upland, is a small exposure, about 10 or 12 feet square, of a fine grained greenish shale or graywacke having a dip about 80° NW. and strike N. 65° E. The rock at this place (6718) has prominent lines of stratification, and is somewhat fractured, and veined, but gives no evidence of the extreme metamorphism to be found prevailing throughout the Rib Hill quartzite of Rib Hill, or in the numerous fragments of the quartzite occurring in the quartz-syenite about two miles immediately west. The overlying conglomerate of the Upper Sedimentary series is exposed within a few feet of this small ledge and it contains numerous fragments of this formation.

The above small ledge is the only one found in this vicinity, and attention is now called to the various fragments of this formation found in the associated younger rocks, in both the conglomerate and the intrusive rhyolite of the vicinity.

In the various exposures of the conglomerate in the vicinity of the NW. ¼ of Sec. 19, T. 29, R. 8 E., the prevailing pebbles to be found are phases of a greenish fine quartz shale, or novaculite-like rock, and of phases of slatey rocks, also generally fine grained and showing clearly the lines of bedding. Fragments of fine grained white quartz rock were also noted which are in marked contrast with the coarse white quartzite of Rib Hill. In the rhyolite outcrops located in the SE. ¼ and in the NE. ¼ of Sec. 24, T. 29, R. 7 E., are numerous fragments of fine grained greenish quartzite or shale.

About five miles northwest of Wausau, in Sec. 9, T. 29, R. 7 E., as shown on the map (Pl. IV) are numerous low exposures of fine chert or graywacke. These rocks are generally very much fractured, and in such cases the bedding is generally obliterated. In places the stratification can be readily distinguished, the formation being composed of alternating coarse and fine sediment. The exposures of this rock on the east side of the creek near the center of Sec. 9 are very much fractured, the rock having an appearance similar to the finely fractured greenstone. Near the west quarter post of Sec. 9 the rocks of this formation consist of alternating coarse and fine sediment, the bedding being clearly much folded and crumpled. The medium grained beds contain numerous crystals of small feldspar, readily seen on the weathered surface of the rock, which vary in size up to two or three millimeters in diameter.

In the SE. ¼ of Sec. 8, numerous blocks of the country rock have been picked up and thrown into large heaps and used in the construction of stone fences. This loose rock shown in the stone fence along the road along a portion of the south side of the southeast quarter of Sec. 8 is mainly composed of a very fine grained grayish quartzite (6633), many fragments of which are rich in calcite or dolomite. No outcrops of this rock were found but since glacial drift is entirely wanting in this vicinity it is believed the prevailing rocks in these stone fences and rock heaps indicate the parent ledges immediately below the soil in this vicinity. In this vicinity also were noted two or three angular blocks of rock consisting of pinkish fine grained quartzite or chert (6631) containing seams of iron ore about one inch thick.

The various phases of rock classed with this formation which are found in situ and which occur as fragments in the associated younger, intrusive and conglomerate immediately adjoining the parent ledges, and as loose angular field rocks in the area of this formation, all indicate a once considerable distribution of this formation in the region northeast and northwest of Wausau. The most abundant rocks of the formaton appear to be fine grained graywacke, greenish quartz shale, grayish chert, and quartzite grading into calcareous chert. The original sediment, therefore, appears to have been mainly siliceous silts and mudstone.

Microscopical.—Since the various rocks of this formation occur in isolated patches in place or as fragments or pebbles in the associated younger rocks, it seems advisable to describe the microscopic appearance of the various phases of rock separately, though it should be understood that all gradations exist between such phases, a fact which could be readily shown if the exposures of this formation were sufficiently abundant.

Graywacke. The rocks rich in feldspar here referred to as graywacke occur in greatest abundance in Sec. 9, T. 29, R. 7 E. In this section these rocks are seen to be mainly composed of feldspar, quartz, chlorite and sericite, with sometimes a variable but small quantity of calcite and magnetite. In places this rock consists of coarse and fine layers, which layers are approximately an inch or so in thickness. The coarser layers of the rock consist of abundant crystals of feldspar from one to three millimeters in diameter in a cement, or matrix, of fine quartz, chlorite, and sericite; while the finer layers consist of the fine quartz, chlorite and sericite like the matrix in the coarser layers. The fractured phases of the fine grained graywacke in Sec. 9, like 6743, consist of angular quartz and altered feldspar, the secondary minerals being mainly chlorite. The fracturing noted in the hand specimens is clearly shown in the thin sections, though the seams and the ruptures are seen to be firmly cemented by the chlorite.

Fine quartz shale.—A phase of this formation which appears abundantly in fragments in the younger rocks in Sec. 19, T. 29, R. 8 E., is a very fine grained greenish siliceous rock, suggesting chert, but whose original form seems to have been a fine quartzose silt of fragmental origin like the graywackes with which it is associated. In thin sections these fine grained hard greenish rocks are seen to be mainly composed of very fine quartz with some feldspar and numerous fine flakes of chlorite and sericite.

Grayish quartzite. The prevailing rocks forming the numerous field rocks in the southeast quarter of Sec. 8, T. 29, R. 7 E., appear to be a phase of quartzite and calcaleous chert. The quartzite in thin sections is seen to consist of numerous grains of quartz of small and medium size, but mainly of small size, a considerable but subordinate amount of chlorite and sericite, some small scattered grains of magnetite, and very little if any feldspar. The quartz rock enclosed in the rhyolite in the southeast corner of the SW. ¼ of the SW. ¼ of Sec. 30, T. 29, R. 8 E., is seen under the microscope to consist almost wholly of granular quartz.

Chert.—With the above described quartzite are to be found phases of calcareous chert, which under the microscope are seen to consist of fine chalcedonic quartz and calcite or dolomite. This phase of rock is not abundant but its occurrence indicates that it is present, at least in small quantity, as a part of this formation, and as closely allied to the quartzite and quartz shale.

Slate.—No phases of slate with well developed slatey cleavage were found in situ in the area of this formation, but fragments of fine slates were noted in the overlying conglomerate of the vicinity. These slate fragments consist of fine quartz, feldspar, sericite and chlorite.

RELATIONS TO ADJACENT FORMATIONS.

The relation of the Wausau graywacke and quartzose shales to some of the adjacent formations has already been pointed out. It has also been pointed out that the principal reason for describing these various rocks under one formation is because clear cut relations are shown between these sediments and the associated rocks of the area. It is likely that this formation is conformable with and is a part of the Hamburg slate formation to the northwest and with the Rib Hill quartzite to the southwest.

In contact with some of the exposures of this formation, both in the vicinity of its occurrence northeast of Wausau in Sec. 19, T. 29, R. 8 E., and also northwest of Wausau in Sec. 9, T. 29, R. 7 E., is a conglomerate formation made up of pebbles and detritus of this formation. In the occurrence northeast of Wausau this conglomerate also contains numerous pebbles and fragments of the rhyolite, which, as already stated, encloses fragments of and intrudes the Wausau formation. It is evident, therefore, that the rhyolite first intruded the Wausau formation and at a later period the conglomerate made up of the detritus of these formations was deposited upon both of them.

It will be shown in a later chapter of this report that of the great masses of igneous rocks of the area, the rhyolite formation, the granite-syenite formation, and the various basic rocks included in the diorite-gabbro formation, the rhyolite is the oldest of the three, as shown by the contact relations wherever these rocks are exposed together. This being the case, it will at once be seen that the Wausau graywacke and shale formation is, therefore, older than the great masses of granite and syenite and of the greenstones of the area. Direct evidence upon this point is furnished by the exposures of various rocks on the west bank of the Wisconsin river opposite the water works pumping

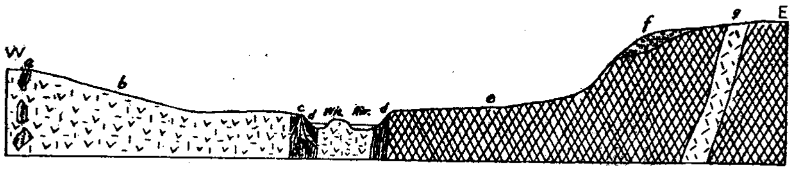


FIG 3. Section of the pre Cambrian at Wausau. a, Fragment of quartzite. b, Quartz-syenite. c, Greywacke. d, Greenstone schist. e, Rhyolite. f, Conglomerate. g, Diorite.

station in the northern part of Wausau. At this place the rocks form a nearly vertical wall extending for two or three hundred feet along the river. The prevailing rock is the rhyolite formation intrusive in a considerable mass of indistinctly stratified and much crumpled fine grained graywacke or shale occurring near the south end of the exposure. Cutting across both the rhyolite and the sedimentary formation is a vertical dike of schistose greenstone and cutting across all the above formations are several small dikes or veins of medium to coarse granite or pegmatite, apparently apophyses of the intrusive quartz-syenite abundanty exposed in the rapids at Wausau. (See Fig. 3.)

The grayish quartzite rock, occuring on the southeast slope of the hill along the road a short distance southwest of the Marathon county jail, is undoubtedly a large fragment caught up in the rhyolite magma.

Like the Rib Hill quartzite and the Hamburg slate formation, the Wausau formation, therefore, appears to be wholly surrounded by younger rocks, being overlaid by later conglomerate, and intruded by the various igneous rocks occurring abundantly in the area, and closely associated with it. This being the case, it will at once be apparent that this sedimentary formation is separated from the conglomerate overlying it by a very long period, a period long enough for the successive intrusions of vastly different varieties of rock, such as the rhyolite formation, the greenstone formation, and lastly the granite-syenite formation with its complex varieties. It is very evident also that during this long period, this formation with the later igneous intrusions were complexly folded and raised into mountainous areas and deeply eroded before the overlying conglomerate was deposited, for detritus of the deep seated plutonic igneous rocks, as well as of the surface volcanics, constitute the rock floor of the overlying conglomerate of the upper sedimentary series.

THICKNESS.

The thickness of this formation can only be roughly estimated. The rocks of this formation range from what was originally sandstone, mudstone, and silt, to apparent limestone phases of rock, and thus it would seem reasonable to believe that the formation may have been one of considerable thickness.

THE HAMBURG SLATE.

Under this name is included the slate formation having a considerable distribution in the townships of Berlin and Hamburg, Marathon county. The predominating rocks of the formation are slate and shale, although graywacke and its schistose phases are also quite abundant.

DISTRIBUTION.

The area of this formation constitutes an irregular belt extending from the vicinity of Merrill, in southern Lincoln county, southwestward to the vicinity of Athens in northwestern Marathon county. This formation does not form a continuous belt throughout the area named, but, as shown by the map, Pl. I is discontinuous, there being isolated small areas at each end of the main central portion, namely at Merrill and Athens. Beginning about 6 miles southwest of Merrill in Sec. 30, T. 31 N., R. 6 E., the belt is continuous as far west as the central portion of Township 30, R. 4 E., with the probable exception of a break by intrusive diorite in Secs. 20 and 21, T. 30 N., R. 6 E. The northeast end of the belt, north of this diorite has a width of one and a half to two miles. West of the diorite it rapidly spreads out to a width of 5 or 6 miles in the vicinity of the Big Rib river in the western part of the town of Hamburg. In this western broader portion are numerous exposures and small areas of igneous rocks such as granite and diorite, some of which, if not all, are of intrusive character. Outside of the portions of the belt mapped as continuous are some small areas of graywacke schist and slate at the bend of the Wisconsin river about a mile south of Merrill and also about a mile farther east at the south quarter post of Sec. 8, T. 31 N., R. 7 E. In the vicinity of Athens at the west end of the belt are several exposures of slate, as indicated upon the map, Plate VIII.

On account of the softness of the slate formation and the development of soil as well as the drift covering of the area, but few natural exposures were found even in the belt mapped as a continuous formation. Most of the exposures found were along the Rib river and the other streams of the area. While natural exposures are not very abundant, a great deal of slate formation was noted in artificial exposures. In fact, the principal data for outlining the area of the formation was the information gathered concerning the rocks in the farmers' wells, a few test pits, and the rock exposed in ditches along the highways.

TOPOGRAPHY.

The slate formation appears to furnish nothing distinctive to the topographical features of the area. In general the land occupied by the slate appears to be neither higher nor lower than that of the adjoining rock formations. This indifference of the topographic forms to the character of the rock formations is probably due to the comparative recency of the process of dissecting the ancient peneplain of the pre-Cambrian, which is fully described in a later chapter of this memoir. The stream valleys are yet in their youthful state and their history has also undoubtedly been greatly modified by factors due to the glaciation of the area. As time goes on and the topography changes from youth to maturity the softer rocks like the slates will undoubtedly form the lowest portions of the land. At the present time, however, the valleys appear to lie indiscriminately across the formations. Now and then there may be exceptions to this such as the development of small side valleys in the slate, but the larger streams like the Rib river have only narrow V-shaped valleys lying across the alternating formations of the area.

KINDS OF ROCK.

The slate formation as a whole consists of a variety of argillaceous rocks. The rocks vary from coarse grained graywacke through fine grained graywacke to very fine grained shales. Through mashing and other processes of metamorphism the graywackes have in places been changed to graywacke schists, certain phases being rich in mica, staurolite, cordierite, garnet and tourmaline. Through the mashing of the fine grained shales the fissile slates have been developed. There are also phases of ferruginous quartzite and of jaspilite. The shales and slates occur in greatest abundance. In describing these rocks the coarser grained are described first and then the shales and slates.

GRAYWACKE.

Macroscopic.—The graywacke is quite generally medium grained and massive. As its name implies, it is a gray rock, very often hard and brittle like quartzite, and is generally compact and coherent, like the latter. Typical graywacke (5855) was encountered in a well in the NW. ¼ NW. ¼ of Sec. 16, T. 30, R. 6 E., in a well (5442) in the southeast corner of Sec. 28, T. 30, R. 5 E., and in several wells (5444 and 5445) in the vicinity of the southeast corner of Sec. 21, T. 30, R. 5 E. Graywacke appears to be quite widely distributed throughout the area of the slate formation. It consists of rounded and angular grains of quartz and feldspar set in a fine grained matrix.

Sometimes rounded fragments of igneous rock and of vein quartz occur in the coarser phases of the graywacke. This rock was originally a sandstone or grit, and through processes of consolidation and cementation it has been changed to graywacke. The finer grained graywackes grade insensibly into shale. The graywacke, as noted in the field exposures, is often jointed and fractured. At places it is mashed into schistose rock. Usually, but not always, the bedding planes can readily be seen and in such cases much folding and crumpling of the strata is to be noted.

Microscopic.—The graywacke is composed largely of rounded and angular grains of quartz and feldspar, united by a cement or matrix consisting of finer grains of quartz and feldspar, flakey crystals of biotite, muscovite, sericite, kaolin, chlorite, and amphibole, and granular crystals of calcite and sometimes magnetite. The graywacke is quite variable in composition and texture and is similar in most respects to the Marshall Hill graywacke. Besides the larger clastic grains of quartz and feldspar in the matrix there may be present small fragments, more or less rounded, of igneous or other crystalline rock. As the proportion of rock fragments becomes larger, the rock approaches a fine or coarse conglomerate. As the proportion of the fine interstitial material increases and the number of larger fragmental grains decrease the rock approaches the character of shale. The proportion of the clastic quartz and feldspar is variable but in general the feldspar appears to predominate.

Much of the matrix material was deposited with the larger fragmental grains at the time of the original deposition of the sediment, and much of it also was deposited in the pore spaces, through the action of underground waters bearing mineral matter in solution, long after the original deposition of the rock as an arkose or grit. The minerals calcite and magnetite or hematite, which abound in the matrix are probably largely secondarily formed through deposition by underground waters. The flakey minerals such as the mica, chlorite and amphibole have a parallel orientation and were developed from material at hand, and from that brought in solution when the rock was heated and under pressure. In addition to these changes in the original matrix of the graywacke the spaces between the original grains also became filled by the deposition of siliceous and feldspathic growths in crystal continuity with the original quartz and feldspar, as enlargements of the original clastic grains. This phenomena of original clastic cores and secondary enlargements is well shown in many of the thin sections of the graywacke. The original clastic grains are generally rounded and in ordinary light a thin film of dark material is generally seen separating the original nucleus from the outgrowth. Between the cross nicols the rounded grains and the outgrowths extinguish simultaneously and prove their crystal continuity. By the deposition of secondary minerals in the interstices, and the enlargement of the large clastic grains, the original porous arkose becomes a typical coherent graywacke.

In many of the thin sections of the graywacke, especially of the schistose phases, the effects of great mechanical forces upon the rock is shown. A common effect of pressure upon the graywacke is the production of strain shadows or wavy extinction in the quartz. The clastic grains often show this phenomenon remarkably well and sometimes when the stresses are great even the smallest grains of quartz reveal strain shadows. The flakey minerals such as the mica and chlorite often show a bending of their crystals about the clastic grains of quartz and feldspar. When the pressure upon the rocks exceeds their crushing strength the larger clastic grains become fractured, and differential movements take place between the fractured parts and also between the smaller crystals of the matrix. The larger crystals of quartz and feldspar begin to granulate and fracture about their borders and finally become wholly crushed and recrystallized into a fine mosaic of new minerals. Aided by the heated waters bearing minerals in solution there develops from the quartz a simple aggregate of numerous secondary quartz crystals, while from the feldspar there develops a complex aggregate of secondary quartz, feldspar, mica, chlorite, and various other minerals. This process of internal fracture and crushing of the hard compact graywacke, which is accompanied by more or less recrystallization of the component minerals and the development of new ones, changes the massive graywacke into graywacke-schist.

GRAYWACKE-SCHIST.

Macroscopic.—The graywacke-schist is the mashed and schistose equivalent of the graywacke. Its most abundant constituents are granular quartz and mica. It also contains some feldspar. Phases of the graywacke schist occurring along the Rib River in Secs. 14 and 24, T. 30 N., R. 4 E., and at the bend of the Wisconsin River south of Merrill, in the SE. ¼ of Sec. 7 and the NE. ¼ of Sec. 18, T. 31, R. 7 E., contain abundant crystals of staurolite, cordierite, and garnet. The staurolite crystals are often over an inch in diameter and generally have angular crystal form. The cordierite has rounded forms, many of them also over an inch in diameter. On the weathered surface of the schist, the staurolite and the cordierite, on account of their greater resistance to weathering, stand out above the other minerals, having the appearance of angular and rounded fragments in the rock. The garnet occurs in smaller octahedral crystals which also roughen the surface of the weathered schist. Where lines of stratification were noted in the schist, the bedding planes were generally cut across at various angles by the secondary cleavage of the schists. The original beds of graywacke, or arkose, were thus very evidently folded and plicated during the mashing process of the graywacke-schist. (See Pl. X, Fig. 2.)

Microscopic.—The graywacke-schist is composed principally of quartz, feldspar, and biotite, with smaller amounts of muscovite, chlorite, amphibole and magnetite. Apatite and tourmaline are also often present, and in certain phases of the schist are abundant porphyritic crystals of staurolite, cordierite, and garnet. The phases of rock here described under graywacke schist are similar to rocks often described as mica-schists, amphibole-schists, staurolite-schists, cordierite-schists, garnet-schists, etc. They are here classed under graywacke-schists because they are mashed and metamorphosed graywackes, or grits. See Figures 2, 3 and 4 Pl. XI.

Quartz is the most abundant constituent of the schists and occurs as small fragments or pebbles of quartz rock, as good sized grains considerably fractured and granulated, and as small close fitting grains. The feldspar generally occurs in large grains more or less fractured and shattered, and is usually con-

EXPLANATION OF PLATES

X AND XI.

PLATE X. SPECIMENS OF THE HAMBURG SLATE FORMATION.

Fig. 1. Fine grained slate showing banding due to stratification. Specimen 5889, two-thirds natural size. The plane of easiest cleavage is diagonal to the bedding.

Fig. 2. Staurolite cordierite schist. Specimen 5895, three-fourths natural size. The round and subangular inclusions are large crystals of staurolite and cordierite.

PLATE XI. MICROSECTIONS OF THE HAMBURG SLATE FORMATION.

Fig. 1. Microsection of the ordinary slate. Section 5433. Without analyzer, x25. The light colored mineral is quartz and feldspar, the dark mineral is hematite.

Fig. 2. Microsection of biotite-quartz-slate. Section 5897. Without analyzer, x25. Section consists mainly of quartz and biotite. Also contains feldspar, magnetite, garnet, chlorite and tourmaline.

Fig. 3. Microsection of biotite-quartz slate. Section 5896. Without analyzer, x25. Section consists of much quartz, some feldspar, and much biotite in parallel position. Also some green hornblende, magnetite and tourmaline.

Fig. 4. Microsection of staurolite-cordierite-schist. Section 6228. Without analyzer, x25. Section contains cordierite, staurolite, quartz and biotite. Also some apatite, magnetite, and tourmaline.

Fig. 1. HAMBURG SLATE.

Fig. 2. STAUROLITE CORDIERTE SCHIST.

SPECIMENS OF THE HAMBURG SLATE FORMATION.

Fig. 1.

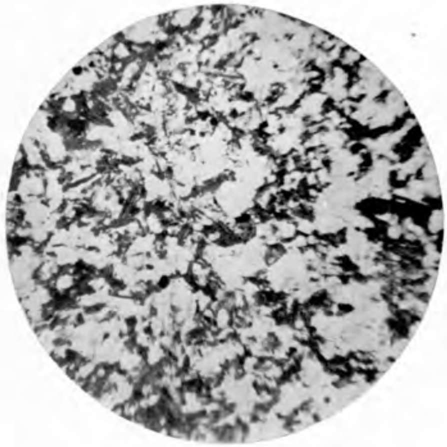


Fig. 2

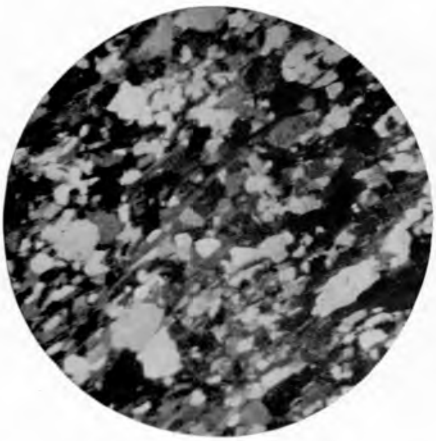


Fig. 3.

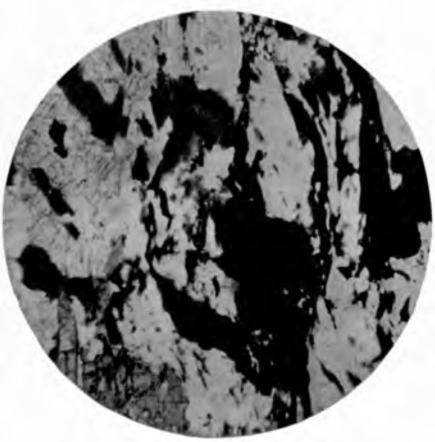


Fig. 4.

MICROSECTIONS OF HAMBURG SLATE AND STAUROLITE SCHIST.

siderably altered to smaller grains of feldspar and quartz and flakes of biotite, muscovite and chlorite.

The texture of the schist is that of a crystalline rock, and the internal arrangement of the constituents, as seen in thin sections, furnishes little or no evidence of its fragmental character. In the graywacke, enlargements of clastic grains of quartz and feldspar are abundant, but in the schists no such phenomenon of cores and rims was seen. The sedimentary origin of the schist is mainly verified by traces of the stratification of the rock, and the interlamination of thin beds of conglomerate material seen in exposures in the field.

Biotite or dark colored mica is much more abundant than muscovite and has a parallel orientation in the schist. The larger folia of biotite enclose numerous small grains of quartz. The general parallelism of the biotite crystals and their numerous inclusions of quartz grains indicate that they were developed about the quartz grains while under pressure. The flakes of mica and chlorite have their longer axes in a common direction in lines and planes which cut across the original bedding at various angles.

As is common in most crystalline schists the apatite occurs in grains with but slight indication of crystalline boundaries. They often occur in aggregates. A persistent mineral in the schist occurs in very minute needles in bundles and aggregates within the quartz grains. These can be detected only with the highest power of the microscope. These acicular crystals are colorless and appear to have the refraction of apatite. They may, however, be needles of sillimanite, since they have a habit of occurrence similar to the sillimanite in the metamorphic schists.

The tourmaline occurs sparingly but persistently throughout the schists, rich in mica, in the vicinity of Merrill, in short columnar crystals, most of which are but a small fraction of a millimeter in length. They are strongly pleochroic in bluish and greenish tones and apparently bear no traces of alteration.

A number of the crystals of biotite in the schist at Merrill are intergrown with a blue amphibole. This amphibole is developed at the ends and along the margins of the biotite, and has the appearance of being developed at the expense of the biotite. The amphibole is strongly pleochroic, having the blue and yellow-green color of glaucophane or riebeckite, the varieties rich in soda. This alteration of the biotite to the soda amphibole is best developed in the schist bearing staurolite and cordierite and may have been caused by contact metamorphism of adjacent granitic intrusives. Alkali amphibole, notably riebeckite, is well known to develop from alkaline solutions leading from granitic intrusives.

The phenomena of the peripheral shattering and granulation of the larger grains of quartz and feldspar, and the complete parallel arrangement of the biotite and muscovite are cataclastic structures which can only be brought about by extreme pressure accompanied by heated water solutions. The development of the mica schist from the ordinary graywacke or fine conglomerate through schistose graywackes has already been alluded to. Wherever the graywacke was subjected to fracture and mashing during the general folding of the rocks of the region, there would be a tendency to obliterate the internal clastic structure of the massive rock and to develop the cataclastic structure of the schist.

The Porhyritic Minerals of the Graywack Schist.

In the schists occurring at Merrill (Specimens 5102 to 5107 and 5895 to 5898) and along the Rib river in Sec. 14, T. 30 N., R. 4 E., (Specimens 6220, 6222 to 6229) there are numerous porphyritic crystals of staurolite, cordierite, and garnet. According to the prevailing minerals contained, these phases of the schist may properly be called staurolite-mica-schist, cordierite-mica-schist, and garnet-mica-schist. There are naturally all gradations between these phases and not infrequently all these porphyritic minerals are found in a single hand specimen or microscopic slide. Usually, however, but one of these minerals prevails within certain narrow limits. These minerals are silicates of alumina, the staurolite containing much iron, the cordierite much magnesia, and the garnet probably much lime.

Staurolite.—The staurolite has the usual character of this mineral. As seen under the microscope it has a high index of refraction and strong double refraction. The pleochroism is distinct in tones ranging from grayish to yellowish. The cleavage is variable and appears as short sharp cracks. The staurolite occurs in the schist usually in large porphyritic crystals and sometimes as small grains. The larger porphyritic crystals are often shattered and granulated and contain numerous inclusions principally of grains of quartz, and leaves of biotite, muscovite and chlorite, and elongated crystals of magnetite and tourmaline. The various minerals now included in the staurolite, however, do not all bear similar relations to the latter. Some of the included minerals are older, some are developed through alteration of the staurolite and some probably have a synchronous growth.

The included quartz grains are very numerous and are like those in the surrounding matrix. The quartz grains have no systematic arrangement in the staurolite and the latter evidently developed in the interstices between the quartz grains. In its development it had the capacity to absorb only the alumino-silicates such as the feldspar and the micas, and left the quartz grains as residual material. This selective process is readily understood when the low silica percentage of staurolite as compared with the alumina contained is called to our attention. The cordierite, richer in silica than staurolite, often occurring along side the staurolite as in section 6228 contains very few of the quartz grains very presumably because a much greater amount of silica is required for its development, Fig. 4, Pl. X.

The biotite, muscovite, and chlorite occur along the fractures or cleavage cracks of the staurolite. The first to develop in the fractures where movement has evidently taken place is generally the chlorite. Later the chlorite appears to develop into biotite and muscovite. The chlorite is probably corundophilite, the variety rich in alumina. These flakey minerals often occupy the same crystal forms and grade into one another. Some magnetite also occurs in the staurolite. As the staurolite becomes much fractured and is pulled apart the leaves of biotite and muscovite wind throughout the dismembered parts in general parallelism with the mica of the matrix.

The tourmaline enclosed within the staurolite is probably a synchronous crystallization as this mineral is well known to develop under conditions of extreme thermal metamorphism as is the case with staurolite. The tourmaline apparently bears no relation to the cleavage or fractures of the staurolite but appears as well developed small crystals in the body of the latter.

Cordierite.—The cordierite occurs as large porphyritic crystals in the schist with usually a zone of alteration minerals about their borders. For this reason they appear rounded like pebbles on the weathered surfaces of the rock instead of having angular crystal forms like the staurolite. The cordierite of this schist has the usual appearance of the colorless varieties of this mineral. The index of refraction and the double refraction are weak. It has a distinct cleavage parallel to the brachypinnacoid.

The cordierite is often fractured and granulated and contains inclusions of quartz, staurolite, magnetite, biotite, tourmaline, and muscovite.

The included quartz grains were present in the rock before the growth of the cordierite and the latter developed in the interspaces between and enclosing them. As above stated, the quartz grains are much less abundant in the cordierite than in the staurolite, which may be attributed to the fact that the cordierite required much more silica for its development than the staurolite.

The flakey minerals such as the micas are clearly alteration products of the cordierite as shown by their location along the cleavage cracks and fractures and about the boundaries of the crystals. As is usual with cordierite it is much more altered than the staurolite. There appears to be a greater abundance of green mica along the cleavage in the body of the cordierite than in the large fractures and about the boundaries where pressure was probably more effective. The alteration of the cordierite can be seen to begin along the minute fractures and cleavage at some distance from the large fractures. Along these openings the fresh cordierite is replaced by fibrous growths of colorless minerals some of them having a high double refraction which are probably muscovite and others with lower double refraction, probably serpentine. In the larger fractures where the alteration is more advanced the secondary minerals have attained a larger size. About the borders of the cordierite and forming a continuous zone about them, are the still larger folia of muscovite, and the colorless or grayish foliated mineral having the appearance of serpentine, probably the variety marmolite. Some chlorite is also developed with the muscovite, and the muscovite in the larger fractures often has the granular appearance of the variety pinite. Of the two principal end products in the alteration of the cordierite, the muscovite and serpentine, the former is apparently the more abundant. This would necessitate the partial removal of the magnesia and the introduction of potash from the alkaline solutions coming from the abundant granitic rocks of the vicinity, a process noted by Zirkel[1] and which may be contemporaneous with the alteration of the biotite to the soda amphibole as above described.

The inclusions of small crystals of tourmaline and small grains of staurolite are in the body of the cordierite and since they are often developed under conditions similar to cordierite they were probably formed just previous to the growth of the latter but belonging to the same metamorphic stage.

Garnet.—The garnet in the schists occurs in very much smaller crystals than either the cordierite or the staurolite. They generally range from one to four millimeters in diameter. In the hand specimens they have an amber-yellow or honey-yellow color but under the microscope they appear colorless. They have the usual high index of refraction of garnet and are generally isotropic. Some of the garnets possess good crystal form and in cross section are four, six, or eight-sided. Most of the crystals, however, are fractured and mashed like the staurolite and cordierite and thus indicate a common period of dynamic metamorphism for these porphyritic minerals. In many of the granulated garnets the optical anomaly of double refraction is well exhibited.

The inclusions in the garnet are principally the angular grains of quartz inclosed within the garnet in its growth. The garnet is sometimes intergrown with staurolite and where this is the case both are seen to be equally broken and mashed and while the garnet still remains fresh and unaltered the staurolite reveals the ever-present process of alteration to mica. The general appearance of the garnet and absence of decomposition would appear to indicate that it is one of the aluminous varieties.

The quartz grains in the graywacke schist do not possess the rounded forms of clastic grains or the rims and enlargements of secondary growths about quartz nuclei so common a phenomena of clastic quartz grains of ordinary consolidated and cemented graywacke or quartzite. All traces of the clastic char-

[1] Zirkel. Lehrb. d. Petr., Zw. Auf., Bd. I, p. 372.

acter of the quartz grains have been obliterated, the fragmental origin of the graywacke being determined by the traces of bedding in the formation.

It seems obvious, therefore, that the quartz grains of the original sedimentary deposit of sandstone, with the other original clastic grains which must have been deposited with the quartz, have all passed through a process of recrystallization produced by thermal metamorphism by igneous intrusions. In all of the localities of graywacke schist, intrusive rocks, either granite or diorite, occur, and hence furnish abundant field evidence of contact phenomena.

The graywacke schist, therefore, is like the Rib Hill quartzite in being a wholly recrystallized rock. The graywacke itself is a part of the slate formation, the ordinary phases of the slate on the whole not being extensively metamorphosed. It seems likely that the coarse-grained texture of the graywacke furnished more favorable conditions for process of contact metamorphism than the fine-grained shales and slate. The coarse-grained rock like graywacke would allow the permeation of highly heated solutions from the intruding magma much more readily than fine-grained rocks like the slate.

Staurolite, cordierite, garnet, tourmaline, and certain other alumino-silicates are highly characteristic of mica-schists and similar metamorphic rock, rich in alumina. In regions where such rocks are well exposed, these minerals are known to have a somewhat definite order of development as the degree of metamorphism increases, and hence their secondary growth, due to thermal metamorphism, can be verified. In many schists also the porphyritic minerals contain numerous inclusives of angular quartz grains like those of clastic origin outside the crystals, and hence show that they were developed about and enclosed these quartz crystals long after their original deposition as clastic grains in the rock. Because of the lack of continuous exposures and also because of the fracturing and granulation of the porphyritic crystals, it is only the last named evidence of their metamorphic origin that is apparent in these schists at Merrill and along the Rib river. The metamorphic stages through which the staurolite, cordierite, and garnet-bearing schists have passed appear to be about as follows:

Beginning with the ordinary graywacke or fine conglomerate, three subsequent stages of metamorphism may be detected. First, occurred the mashing of the graywacke by mechanical forces into graywacke schists accompanied by a variable amount of recrystallization and metasomatism. Second, static or thermal metamorphism followed the dynamic metamorphism, and along the planes of fissility and cleavage of the mica shists much heat and abundant mineral solutions were transmitted, and the development of the staurolite, cordierite, and garnet took place. Third, the stage of development of the porphyritic minerals was followed by a second stage of dynamic metamorphism and the staurolite, cordierite, and garnet were fractured and granulated and the earlier schistose structure was obliterated and a second schistosity and fissility was developed, many of the secondary porphyritic minerals being partially mashed and rotated parallel to the later cleavage planes of the schist. During this stage of dynamic metamorphism, heated alkaline solutions apparently leading from granitic rocks permeated the schist, the biotite being partially altered to the blue soda amphibole and the cordierite to muscovite.

SHALE.

Macroscopic.—The shale has a composition similar to the graywacke but it is much finer grained. It was originally a fine clayey sediment or mud. It is closely associated with and readily grades into its mashed equivalents, the fissile slates, throughout the area.

Microscopic. The shale consists of a fine textured base or background of flakes of mica and chlorite and minute granules of chalcedonic quartz in which are imbedded larger sub-angular grains of clastic quartz and feldspar. There is also present a variable amount of iron oxide, calcite, and other secondary minerals. Shale differs from graywacke in being finer grained and in containing a larger proportion of the argillaceous minerals. It differs from slate only in not possessing the distinctive slatey cleavage or fissility of the latter. The alternating fine and coarser layers of the shale are well shown in the thin sections. The finer layers consist of the chalcedonic quartz and scales of sericite and chlorite, the latter often having a parallel arrangement of the flakey constituents in planes diagonal to the planes of stratification. It is very probable that most, if not all, the fine grained argillaceous rocks, whether shales or slates, have a parallel arrangement and orientation of the mica and chlorite.

SLATE.

Macroscopic.—The slates are very fine grained rocks that readily split into thin laminae or leaves. As just noted, the slate is the dynamically metamorphosed equivalent of the shale and these two phases of argillaceous rock are closely intermingled and alternate with each other in accordance with the mashing and development of schistosity in them. The shales and slates are the most abundant rocks, as already stated, of this formation, and constitute the prevailing rocks of most of the out-crops. The slatey cleavage or fissility of the slate may be parallel to the bedding, but usually it cuts across it at various angles. This non-conformity in the original and secondary structures may be noted in many of the hand specimens, and clearly indicates that the slate is folded into numerous isoclinal folds. Calcareous and carbonaceous varieties of the slate occur in a few places. The fissile slates beside grading into the shales also grade into the fine grained graywacke-schist.

Microscopic.—The slate differs from the shale only in having a well developed fissility or slatey cleavage. Like the shale, the slate consists principally of a fine grained background or matrix of small flakes of mica and chlorite, and minute grains of quartz, feldspar, and iron oxide, in which are imbedded somewhat larger grains of rounded quartz and feldspar. Under the microscope the slate reveals evidence of much internal movement such as fracturing, crumpling of the laminae, and bending of the leaves of mica about the clastic grains of quartz and feldspar. While most of the shales have a parallel arrangement of the mica and chlorite it appears that it is only when the rocks have been subjected to stresses greater than their ultimate strength, and consequent mashing and differential internal movement have taken place, that fissility is developed. The slate is therefore the dynamically metamorphosed equivalent of the shale and there are all gradations between typical shale and typical slate as there are between the graywacke and the phases of graywacks schists.

Some of the phases of the shale (5345) and slate contain some carbonaceous material which appears as black specks under the microscope. Other phases contain a variable amount of calcite and hence may be called calcareous shale or slate. There is also present in the shale and slate a variable amount of iron oxide, principally magnetite, and where the latter becomes abundant as in 5433, the rock may be called a ferruginous slate. These carbonaceous and iron-bearing phases of the shale and slate have not been found in any quantity in the area. The ferruginous slates often appear to be closely associated with ferruginous quartz rocks.

While the fine grained slate is the predominating rock of this formation, from the mineralogical view it presents little of interest. It is fairly uniform in texture and general appearance over the entire area, and grades into the various phases of the formation above described. Originally it apparently consisted of somewhat gritty clays of dark color containing a fairly uniform though small amount of iron oxide and in a few places much carbonaceous material.

There are hard, brittle, reddish, fine grained quartz rocks which occur interbedded in several places with the fine grained slates in the vicinity of Ziegler. These rocks grade into banded jaspilite-like rocks and into ferruginous slate and do not appear to be abundant.

Ferruginous Chert and Quartzite.—These phases of the slate formation consist principally of quartz, the chert (like 5408) consisting of very fine granular quartz like chalcedony, and the quartzite (like 5435) consisting of larger close-fitting grains of quartz. The quartzose rocks associated with the slates are usually very dark or reddish in color on account of the iron contained. Usually these brittle quartzose rocks are much fractured, and the seams are impregnated with magnetite or hematite. These phases occur imbedded with the slates and shales near Ziegler.

Certain phases of the slate formation are quite similar to portions of the slate formations associated with the iron bearing rocks in the vicinity of Lake Superior and for this reason evidences of the presence of iron ores were searched for in the area. In only a few places were meager phases of cherty rocks and jaspilite-like rocks found and nothing that approaches an iron ore was noted anywhere. In Secs. 30, 31, and 32, T. 30, N., R. 6 E., several test pits from 50 to 100 feet deep were sunk in the slate formation about 15 years ago in prospecting for iron ore. The formation at these several test pits, however, was either ordinary slate or brittle quartzose slate, much fractured and veined. Many of the veins, usually an inch or less in thickness, consisted mainly of hematite, and it was probably this vein hematite which led to the exploration. No noteworthy magnetic attraction is known to occur in the area, though small boulders of magnetic slate have been found occurring in the thin glacial drift upon the adjoining rock formations. While iron ore may occur in the slate formation, it does not seem likely, because of the very meager occurrence of the characteristic rocks associated with the pre-Cambrian iron ores.

STRUCTURE OF HAMBURG SLATE.

Nothing definite can be said concerning the position of the beds of the slate and the folding of the formation. In a few places only could the strike and dip of the beds be determined because of the scarcity of natural rock exposures. Generally the cleavage planes of the slate are nearly vertical, with a general NE.-SW. strike. Wherever bedding could be detected over any considerable exposure, the original and secondary structures were seen to be generally unconformable and abundant evidence shows that the bedding has been plicated into numerous folds. With the statement that the formation has been subjected to compressive forces sufficient to develop much folding, and perhaps considerable faulting, and also widespread mashing of the original beds of shale and graywache into fissile slates and schists, perhaps nothing further can be said concerning the structure.

THICKNESS.

In view of the fact that nothing definite is known concerning the position of the beds of the slate and graywacke, or of the prevailing system of folding only an intelligent guess can be hazarded concerning the thickness of the formation. The present distribution of the formation as indicated by its isolated outcrops appears to extend over an area of 75 to 100 square miles.

This is an area of considerable extent as compared with the general run of pre-Cambrian sedimentaries for the Lake Superior region. The large area of the slate would seem to indicate that it has a considerable thickness. It should be considered also that this slate formation belongs well down in the pre-Cambrian series and that the original formation has undoubtedly been subjected to great erosion. Two periods, at least, of erosion are known, the one preceding the deposition of the conglomerate of the upper sedimentaries of the pre-Cambrian, and the long interval of erosion preceding the deposition of the Potsdam sandstone. On account of erosion, therefore, the present area of the slate must be considered as being only a portion of the original formation. When the great age and probable extensive erosion of the formation are considered it may well be believed that the formation originally possessed considerable thickness. It is believed that the original formation may well have been from 500 to 1,000 feet thick in the vicinity of the area where now exposed.

RELATIONS TO ADJACENT FORMATIONS.

Four formations were found in contact with this slate formation,—the rhyolite, the greenstone, the granite, and the conglomerate of the Upper Sedimentary series. Rhyolite was not found in actual contact with this formation, though within a few feet of it.. In the vicinity of Wausau, however, where the relations of the rhyolite formation is distinctly shown to the older and younger sedimentaries, the rhyolite is intrusive in the inferior sedimentary formation, which is correlated with this formation on account of showing similar relations to the granites and greenstones.

The diorites, diabases, etc., here classed in the greenstone formation show intrusive relations to this formation. The graywacke-schist and slate outcropping a few miles east of Merrill in the vicinity of the south quarter post of Sec. 8, T. 31 N., R. 7 E., are clearly intruded by the greenstone of that vicinity which is apparently a continuation of the belt of greenstone lying south of and adjacent to the large slate area of the towns of Berlin and Hamburg. In the vicinity of the northwest corner of Sec. 21, T. 30 N., R. 6 E., along the wagon road the slate and greenstone schist alternate with each other in such manner as to indicate the intrusion of the greenstone into the slate. About a mile east of Athens, near the north quarter post of Sec. 5, T. 29 N., R. 4 E., fine diorite is exposed within a few feet of fissile slate, the former having the appearance of being intruded across the schistosity of the latter. In all cases where the greenstone outcrops occurred in the near vicinity of slate outcrops, no difference in the coarseness of the slate was to be noted adjacent to the greenstone.

The granite occurring near the graywacke schist in Sec. 14, T. 30 N., R. 4 E., along the Rib river, is believed to be intrusive in the latter for there is present no conglomerate. The granite is massive and the original graywacke is mashed into a schist and such metamorphic minerals as staurolite, cordierite, and garnet have been developed in it, minerals which are likely to be developed under the influence of intrusive magmas. The relation of the massive granite and syenite to the Rib Hill quartzite, as already pointed out, is that of an intrusive and a similar relation holds for the Wausau shales and cherts in the vicinity of Wausau, and hence it is believed there is little doubt that the prevailing massive granite of the areas adjacent to the area of slate is much later in origin than the latter.

In the SE. 1/4 of Sec. 4, T. 30 N., R. 6 E., along the boundary of the massive granite formation and the slate formation are numerous exposures along a small stream bed of a coarse graywacke, or fine conglomerate, containing pebbles of slate and granite. Several blocks of coarser conglomerate were noted in the thin drift of this vicinity which was made up in great part of pebbles of the slate formation. In Secs. 7 and 8, T. 29 N., R. 5 E., adjacent to the Rib river, and perhaps separated from this slate area, though not far from it, is a small area of similar conglomerate and graywacke containing pebbles of the underlying granite and also of an older slate formation. In a following chapter the upper sedimentary rocks are described and abundant evidence shown for the existence of at least two sedimentary series in the area, the Hamburg slate formation with other sediments belonging with the older series and furnishing detrital material for the later conglomerate formations.

The various rock formations found associated with the slate formation are, therefore, all apparently younger than the slate, the igneous rocks being intrusive in it, and the conglomerate overlying it. This is the same relation, as already shown, which the Rib Hill quartzite formation bears to its surrounding rock formations. While it is not improbable that outcrops belonging to the rock floor upon which the slate was deposited occur in the area of the slate, or its near vicinity, yet all evidence points to the intrusive character at least of the great masses of the surrounding igneous formations. This belief is based not so much upon data concerning this slate formation as upon the intrusive relation of similar igneous rocks to similar fragmental rocks in the vicinity of Wausau, and to the Rib Hill quartzite.

INTERESTING LOCALITIES OF THE HAMBURG SLATE FORMATION.

Vicinity of Merrill.—As already noted, graywacke schist forms low exposures just south of Merrill on the east bank of the Wisconsin at the bend of the river in Sec. 18, T. 31 N., R. 7 E. Similar schist occurs immediately north of this on the north side of the wagon road in the southeast corner of Sec. 7. These schists consist for the most part of quartz and biotite and are especially interesting petrographically because they carry an abundance of cordierite, staurolite and garnet. The stratification of the schists could readily be detected and is unconformable with the secondary structure of cleavage and schistosity. The strata are much plicated and in the few exposures shown, nothing definite concerning the dip and strike of the beds could be determined. About a mile east of the bend of the river in the vicinity of the south quarter post of Sec. 8, in an old valley bottom now occupied by a small stream, there are numerous exposures of the slate formation. The bedding of the slate formation here is distinct and usually conforms with the secondary cleavage, which has an average strike of N. 35° E.; the dip is generally 75° NW., though in places the dip is only 20° to 30° NW. The slate here is closely associated with fine grained diorite intrusive in the slate.

Along Big Rib River.—Over the principal portion of the main belt of slate in the towns of Berlin and Hamburg, the outcrops of slate are small exposures along the streams, in ditches along the highways, or in the farm wells, and their occurrence presents nothing of special interest either from the topographic view point or the mineralogical. Along the Big Rib river in Sections 14 and 24 of T. 30, R. 4 E. occur interesting phases of graywacke schist containing an abundance of the porphyritic minerals staurolite, cordierite and garnet, similar to the schist occurring at Merrill. Good exposures of this schist occur on the river bank at the old mill site in the NE. 1/4 of Sec. 24, and about two miles farther up the river near the southeast corner of the NE. 1/4 of Sec. 14, T. 30, R. 4 E.

POWERS BLUFF QUARTZITE.

This formation consists of medium to very fine grained quartzite and is given the name of Powers Bluff quartzite because it forms the main portion of the broad-based hill known as Powers Bluff near Arpin in central Wood county.

GENERAL DISTRIBUTION.

The main portion of this quartzite formation is confined to Powers Bluff and immediate vicinity, and as shown on the general map, Pl. 1, and the detailed map, Pl. XII, it mainly occurs in Secs. 19, 29, 30, 31 and 32, of T. 24, R. 4 E., and in the adjoining sections of 24, 25 and 36, of T. 24, R. 3 E. Exposures of this formation, not connected with this main area, occur in very small outcrops, as shown on the map, in the southern part of Sec. 13, the southwest corner of Sec. 15, and the southwest corner of Sec. 16, in T. 23, R. 4 E. Isolated exposures of rock similar to the Powers Bluff quartzite occur in other parts of the area, which are described under the general heading of "Isolated exposures of sedimentary rocks."

TOPOGRAPHY.

On account of the resistent character of this rock it constitutes the highest prominence, Powers Bluff, in Wood county. Powers Bluff is a broad based dome-like ridge with its longest axis extending in a southeast-northwest direction. Its elevation is not known but its highest point is probably between 300

and 400 feet above the surrounding lower land of the immediate vicinity. The small exposures of this formation south of Powers Bluff form the cores of low ridges rising from 20 to 40 feet above the adjacent lower lands.

PETROGRAPHICAL CHARACTER.

Macroscopical.—The Powers Bluff formation appears to be mainly a very fine grained pinkish quartzite, the pervailing phase of which has much the appearance of the pinkish chert. In the vicinity of Woodlawn Academy and Bethel phases of the medium grained quartzite and the very fine grained chert-like quartzite occur together, showing every evidence of the one grading into the other. The quartzite forming the highest point of the bluff, located near the southeast corner of Sec. 30, T. 24, R. 4 E., is composed mainly of the fine grained phase of rock, which is very much fractured and jointed, the fractures apparently running in all directions, each small fracture of a square inch of the rock being permeated with them. The rock of this highest portion of the bluff has a streaky character, the lines or streaks trending along the main axis of the ridge and dipping vertically. This streaky character is probably due to metamorphism. The quartzite occuring in the isolated exposures south of Powers Bluff is quite generally coarser and whiter than that of the bluff.

Overlying this quartzite formation on the southeast side of Powers Bluff is a conglomerate formation grading upward into a medium to coarse grained quartzite. This conglomerate contains detritus of the Powers Bluff formation, such as pebbles of quartz rock like that above described, and also of other phases of sedimentary rock not found at present in place in this vicinity, and thus indicating the presence here of other phases of sedimentary rock probably belonging with the older quartzite formation.

Microscopic.—Under the microscope the prevailing fine grained phases of this rock have much the appearance of chert or chalcedony. The coarser phases of the formation are fine grained to medium grained quartzite. The chert-like phases of the rock grade into the granular phases of quartzite, as illustrated by specimen 6271*a*, thin sections of which show the rock to consist of very fine interlocking grains of quartz with which are mingled larger grains like those usually found in quartzite. These larger grains show the effect of pressure by their undulatory or wavy extinction under the cross nicols. The fine grained chert-like portions of the rock are reddish or pink in the hand specimens, due to the presence of numerous fine grains of iron oxide and perhaps some other dark mineral. The streaky distribution of the iron oxide gives it the appearance of having filtered into the quartzite. The Powers Bluff quartz rock seems to have been originally a medium grained quartzite, which, through process of mashing and granulation has been in large part granulated into a fine grained rock, the granulation being accompanied by the development of secondary chalcedonic quartz in the rock in such places where the pressure was sufficient to assist materially in the recrystallization of the rock, or where openings were made in which vein chert was deposited. The fine grained chert-like quartzite appears to be very similar to certain phases of the Mesnard quartzite formation in the Marquette district which Van Hise describes[1] as cherty quartzite. The evidence for such extreme mashing, granulation, recrystallization and vein filling is shown by the extensive brecciation of the chert-like quartzite seen everywhere in the rock exposures, the numerous vein-like streaks pervading the formation which are filled with what to all appearances is secondarily deposited magnetite or hematite, and to some extent with fine flakes of mica and amphibole. See Figures 1, 2, 3, Pl. XIII.

The isolated exposures of this formation occurring a few miles south of Powers Bluff consist of quartzite, thin sections of which closely resemble the medium grained Rib Hill quartzite.

THICKNESS.

The thickness of this quartzite formation, like the thickness of the other sedimentary formations of this district, can only be surmised. The formation is now much fractured and metamorphosed, so that all traces of stratification have been lost, and the dip and folding of the beds cannot be discerned. It seems reasonable to believe, however, that the formation as it now stands—

1 The Marquette Iron-bearing District. Mon. 28. U. S. Geol. Survey, p. 224.

EXPLANATION OF PLATE

XIII.

Plate XIII. Microsections of Powers Bluff Quartzite and Rudolph Ferruginous Quartzite.

Fig. 1. Microsection of Powers Bluff quartzite. Section 6563. With analyzer, x25. Section consists wholly of close-fitting quartz, without matrix, and shows the characteristic wavy extinction developed by pressure.

Fig. 2. Same as above. Section 6567. Shows a stage in the breaking down and granulation of the larger quartz grains into small grains.

Fig. 3. Same as above. Section 6565. The final stage in the granulation of the coarse quartzite.

Fig. 4. Microsection of the ferruginous quartzite occurring at Rudolph. Section 6328. Without analyzer, x25. The light mineral is quartz, the dark is hematite.

Fig. 1.

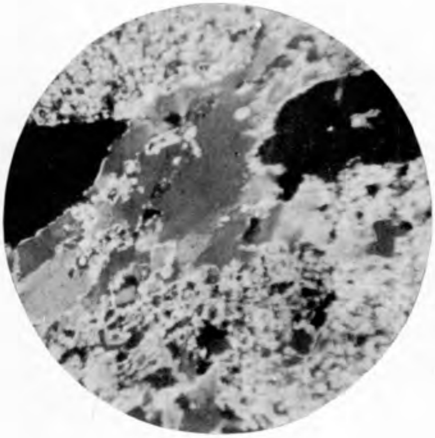


Fig. 2.

Fig. 3.

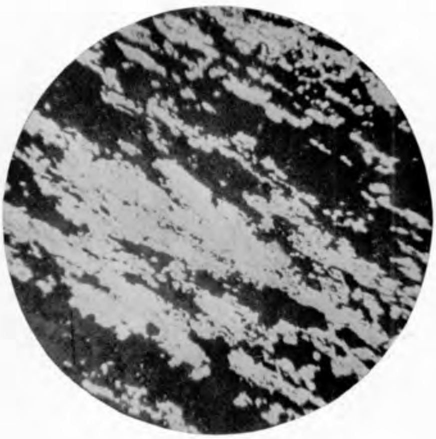


Fig. 4.

MICROSECTIONS OF POWERS BLUFF QUARTZITE AND FERRUGINOUS QUARTZITE.

as the remnant of a larger formation long since eroded, has a considerable thickness, perhaps a thousand feet. The areal distribution of the formation would seem to indicate that it was approximately as thick as the Rib Hill quartzite formation.

RELATIONS TO ADJACENT FORMATIONS.

The rock formations found in immediate contact with or immediately adjacent to this quartzite formation are granite, diorite, quartzite and quartzite conglomerate, and sandstone and sandstone conglomerate.

The granite is the massive reddish variety like that occurring about Wausau. This granite was not found in contact with the quartzite but it forms the prevailing rock formation surrounding the entire area of Powers Bluff (See Pl. XII). The nearest occurrence of the granite to the quartzite noted in the area is in the field, just east of the railroad, in the SW. ¼ of NE. ¼ of Sec. 2, T. 23, R. 4 E. At this place outcrops of the fine grained pink quartzite and the granite are within 25 to 30 paces of one another. Both formations are massive and while there is no positive proof that the granite is intrusive in the quartzite, it is believed that such is the relation existing between these formations, partly on account of the massive character of the two formations immediately adjacent to one another, and partly on account of the undoubted intrusive relations of similar granite to the similar quartzite formation near Wausau.

Fine grained diorite was noted apparently intruding the quartzite about one-fifth of a mile south of the north quarter post of Sec. 25, T. 24, R. 3 E. In drilling the well at the Woodlawn Academy I was told this diorite was struck in the quartzite. It would seem, therefore, that the diorite, like the granite, is intrusive in the Powers Bluff formation, thus bearing the same relation to the latter that the diorite and granite about Wausau bear to the Rib Hill quartzite.

On the low slopes of the southwest side of Powers Bluff is a grayish quartzite or feldspathic quartzite formation, containing beds of conglomerate made up of pebbles and fragments of the Powers Bluff cherty quartzite. The fragments and pebbles of the Powers Bluff formation in the conglomeratic quartzite point clearly to the later age of the latter. The Potsdam sandstone containing fragments of the quartzite is exposed at numerous places about the bluff.

It would appear, therefore, that so far as can be learned the Powers Bluff cherty quartzite formation, like the Rib Hill quartzite, is older than the prevailing rock formations immediately adjacent to it and that while the rock floor upon which this formation was deposited probably exists somewhere in the vicinity it was not definitely located.

QUARTZITE AT RUDOLPH.

Near the villiage of Rudolph in eastern Wood county are several isolated areas of quartzite that are believed to belong with the older series of sedimentaries. (See Plate XII.)

DISTRIBUTION AND TOPOGRAPHY.

The largest single area of quartzite in this vicinity is that occurring immediately east of the small village of Rudolph in Section 4, Township 23, Range 6, as indicated on the map. This quartzite forms a ridge-like elevation trending north and south in the southwest quarter of the southeast quarter of Section 4 and adjoining portion of Section 9. There are several small natural exposures in this vicinity, and also exposures along the ditch of the road between the school house and the railroad station. Similar quartzite also occurs about half a mile southwest of Rudolph, forming a low ledge in the northeast corner of the southeast quarter of Section 8. In the last mentioned vicinity are numerous angular field blocks of quartzite, indicating the presence of quartzite near the surface. About two and one-half miles to the north of Rudolph in the northwest quarter of the southwest quarter of Section 28, Township 23, Range 6, is a quartzite knob about 45 feet in height, covering an area of a fraction of an acre.

PETROGRAPHICAL CHARACTER.

Macroscopic.—The most common phase of quartzite (6326) of the immediate vicinity of Rudolph in Sections 4 and 8 is a grayish dark rock of medium to fine grained texture. The dark colored vitreous quartzite grades into, in many places, a quartzite (6328) rich in iron oxide, mainly hematite and limonite. Several years ago this quartzite was quite extensively prospected for iron ore, but the rock nowhere apparently becomes rich enough in iron to be considered an iron ore. This may be due to the fact that this formation is not associated with the characteristic jaspilite, or other formations quite generally found with the pre-Cambrian iron-ore deposits

The quartzite forming the knob about two and a half miles north of Rudolph, in Section 28, is a very fine grained reddish quartzite containing but a small amount of iron oxide. This quartzite is very much fractured, the fracture planes running in all directions. There, however, appears to be a pronounced system of jointing planes, which slopes to the north and northwest at angles of 20° to 30°.

Microscopic.—The thin sections of the prevailing phases of quartzite about Rudolph show a fine to medium grained rock made up almost entirely of close-fitting quartz grains without matrix. The original grains of clastic quartz are enlarged, filling entirely the interstitial spaces with quartz in optical continuity with the clastic grains. Rims of hematite and limonite indicate the original boundaries of the clastic grains. There appears to be about 10 per cent of hematite and limonite, and about 90 per cent of quartz in the normal phase of the quartzite.

Several thin sections of the quartzite unusually rich in hematite and limonite were examined and found to reveal much evidence of mashing and recrystallization, like the predominating phases of quartzite. The iron oxide occurs in streaks and lenses in the quartzite, about 50 per cent of the rock being made up of iron oxide and 50 per cent of quartz. The quartz grains are angular and close-fitting, and appear to be wholly recrystallized. The quartzite rich in iron oxide was very apparently originally a ferruginous sandstone. The iron oxide does not occupy the interstitial spaces in the sand rock but alternates in streaks, lenses and layers with the streaks and lenses wholly of quartz. This very ferruginous phase of the quartzite may have been developed by contact, metamorphism of the surrounding basic greenstone. The iron oxide may have been introduced when the clastic quartz grains were recrystallized. The ordinary quartzite and the ferruginous phases at Rudolph very much resemble the ferruginous quartzite and associated quartzite occurring at Black River Falls. See Figure 4, Pl. XIII.

The quartzite of the quartzite knobs in Section 28 consists of close-fitting minute grains of quartz very similar to the Powers Bluff quartzite. This quartzite contains but a fraction of one per cent of iron oxide.

In general the petrographic character of the quartzite about Rudolph both macroscopically and microscopically resembles much more closely the quartzite of the lower sedimentary series than the quartzite of the upper series of the area.

STRUCTURE AND THICKNESS.

Nothing definite concerning the bedding structure of the quartzite could be made out. The rock shows the effects of much differential movement in being much fractured and mashed, the recrystallization of the quartz grains undoubtedly having obliterated much of the evidence of differential movement. The thickness of the quartzite formation about Rudolph can only be conjectured, but it is believed to be at least 300 to 400 feet, this thickness, of course, representing only the remnant of a once more extensive formation now eroded away.

RELATIONS TO ADJACENT FORMATIONS.

The quartzite exposures are wholly within the area of the greenstone formation and occur only near outcrops of the latter. In the near vicinity of the quartzite east of Rudolph are outcrops of greenstone but no actual contacts between the two formations were found and hence the exact relations are not known. Because of the intrusion of the greenstone into similar quartzite in other parts of the area it is believed that similar relations exist here. The general character of the quartzite, with regard to extent of metamorphism and recrystallization, is very similar to that of the quartzite formations elsewhere intruded by the surrounding massive igneous formations.

JUNCTION CITY QUARTZITE.

In the vicinity of Junction City in northwestern Portage county are several separated areas of quartzite and quartzite schist which may be conveniently described together.

DISTRIBUTION AND TOPOGRAPHY.

The largest area of the quartzite lies southwest of Junction City and as shown on map, Pl. XII, it occurs in Sections 8, 9, 10, 16, 17 and 18 of Township 24, Range 6 East, apparently having an extent of three or four square miles. About a mile north of Junction City, in Section 34, Township 25, Range 6 East and adjoining sections, is a small area of quartzite, quartzite schist, and carbonaceous shale which has attracted some attention on account of the carbonaceous material it contains. Small exposures of quartzite also occur in the southwest quarter and the northwest quarter of Section 1, Township 24, Range 6 east, and in the northwest quarter of the northeast quarter of Section 6, Township 25, Range 7 East. The land surface of this vicinity is gently sloping and none of these quartzite areas furnish any characteristic topography.

PETROGRAPHIC CHARACTER.

Macroscopic.—The prevailing phase of quartzite about Junction City, at least that kind of quartzite which is to be seen at the surface, is a medium to fine grained rock, rich in quartz, showing various stages of schistosity. At the graphite mine in Section 34 a mile north of Junction City where several large open pits have been made in this formation, the kinds of rock found are medium grained quartzite, quartzite schist, and carbonaceous shale. The formation rapidly varies from quartzite to shale, the whole being much mashed, slickensided, and foliated. The strike of the schistosity, which probably does not correspond to bedding, is approximately N. 30° E., the dip being 75° NW. The quartzite schist and carbonaceous shale are much weathered at the surface to depths varying from a few feet to 20 or 25 feet, and perhaps to depths even greater than this. In the area southwest of Junction City the prevailing rock exposed at the surface is fine grained pink quartzite grading into ferruginous shale or slate. The quartzite in Section 1, about a mile east of Junction City, is white, and medium to coarse grained. The quartzite exposed along the road on the north side of the northwest quarter of Section 6, Township 24, Range 7, and that thrown out of several test pits a short distance south of the road is medium to fine grained, considerably mashed into schistose quartzite. Medium to fine grained pink quartzite forms low outcrops in the flat land in the southwest corner of the southeast quarter of Section 19, Township 25, Range 7 East, in the rear of the town hall.

Microscopic.—The quartzite is medium to fine grained, has no matrix but consists of close fitting grains that intricately dovetail with one another after the manner of vein quartz. The texture of the quartzite is in all respects like the Rib Hill or the Powers Bluff quartzite, which are believed to be wholly recrystallized quartzites. Associated with the vitreous quartzite are phases of argillaceous quartzite and shale which were undoubtedly originally clayey deposits or mudstones. These argillaceous rocks in the small area north of Junction City in Sections 34 and 35 contain a variable amount of carbon and iron oxide. A number of specimens were collected from the test pit at the "graphite mine" located in the northeast corner of the southeast quarter of Section 34, Township 25, Range 6 East. The specimens collected from this place are shown by microscopic examination to vary from quartzite-schist to carbonaceous shale. The quartzite-schist shows various stages of its development through mashing and granulation to wholly recrystallized quartzite. The thin section of the quartzite-schist consists of medium grained close fitting quartz grains without matrix, the quartz being on the average 0.25 mm. to 0.5 mm. in diameter. Alternating with the coarser grained quartz are streaks of granulated quartz, the larger grains being granulated and broken down into numerous smaller ones, averaging from 0.02 to 0.05 mm. in diameter. In the streaks of granulated quartzite iron oxide has filtered, giving the streaks a reddish color. In the granulated portions are also found needles of apatite, flakes of biotite, and small rounded specks of carbonaceous material. The carbonaceous shale in thin section appears as a dark, nearly opaque mass, made up of chlorite, sericite, fine quartz, carbonaceous material, and iron oxide. There are all gradations between the shale and the quartzite.

Composition of the Carbonaceous Shale.—Since the so-called graphite deposits at Junction City have attracted quite a little local attention and some exploratory work has been done and a mill erected for the purpose of putting a graphite product on the market, a description of the shale with regard to its carbon content seems advisable. A sample of the crushed shale used at the graphite mill, as analyzed by S. V. Peppel,[1] is as follows:

Analysis of carbonaceous shale.

SiO_2	34.29
Al_2O_3	13.35
Fe_2O_3	16.73
CaO	0.47
MgO	5.66
Na_2O	0.15
K_2O	1.32
TiO_2	1.12
MnO	1.97
C	13.87
H_2O	10.53
	99 63

This carbonaceous shale is closely related to the quartzite and quartzite schist of the vicinity, the carbonaceous material apparently occurring in patches finely disseminated through the sedimentary schists. The content of one of the richest of these patches is shown by the above analysis having 13.87 per cent of carbon. These carbonaceous patches in the shale occur in the form of lenses, all of small extent, so far as could be observed, varying from a fraction of an inch to 2 to 3 feet in thickness and from 5 to 20 feet in length. These lense-shaped carbonaceous beds rapidly alternate with one another in a few places in the area, and may occur throughout a large portion of the sedi-

[1] Bull. VII, Part I, Clays and Clay Industries of Wisconsin, by E. R. Buckley; p. 272.

mentary formation, but up to the present time, so far as known, no large deposit of the carbonaceous material has been found.

Since the carbonaceous material has been advertised and placed upon the market as graphite, it became of interest to the survey to investigate carefully the nature of these deposits. Graphite, like diamond, is a form of carbon, and it is necessary to apply physical tests to the carbonaceous shale in order to show whether it contains true graphite or merely amorphous carbon. In the trade two forms of graphite are recognized: "Amorphous graphite" and "crystalline graphite." These trade divisions are based upon purity of condition, the crystalline graphite being a nearly pure carbon, generally crystallized in a columnar or foliated form; while the amorphous carbon is finely granular and mixed with clay and quartz and various minerals.

The results of Prof. Lenher's investigation of samples of the product prepared for the market, as stated on subsequent pages, show this carbonaceous material to be amorphous carbon and not graphite.

The discussion of the commercial value of this shale is deferred to another portion of this report (see page 655–7).

The carbonaceous shale and quartzite schist, as already stated, are deeply weathered and decomposed forming a thick deposit of clay in certain portions of the area north of Junction City. It seems probable that this clay may have some commercial value for the manufacture of brick, and hence an analysis was made of it.

STRUCTURE AND THICKNESS.

But a few dips and strikes of this formation could be discovered on account of the scarcity of the outcropping rock, and hence the thickness of this formation about Junction City can only be conjectured. The formation is very probably close folded, as indicated by the prevailing schistose structure of the rocks. The general trend of the bedding is probably to the northeast and southwest, parallel to the belt southwest of Junction City, and to the prevailing schistose structure of the carbonaceous shale north of Junction City. It is probable that the beds are so folded as to bring to the surface the same beds several times, and hence the apparent thickness is not the real thickness. A fair approximation of the thickness may be from 200 to 500 feet, and possibly 1,000 feet.

RELATIONS TO ADJACENT FORMATIONS.

The quartizte here described shows definite relations to only two of the formations found in the vicinity of Junction City. The most abundant rock in the vicinity of the quartzite appears to be the greenstone formation. About a mile and a half northeast of Junction City where a small stream crosses the road in the southeast corner of Section 35, Township 25, Range 6 East, greenstone occurs, and in some of the greenstone blocks of this vicinity fragments of the quartzite were found. Thin sections of the agglomerate showed the latter to be an augite-andesite and the quartzite fragments similar in all respects to the prevailing vitreous phase of the quartzite in this vicinity.

The massive granite formation of this vicinity is not found in contact with the quartzite, though the latter occurs in several places not far from the granite with an entire absence of conglomerate in the quartzite. Furthermore, the granite is intruded into the greenstone at many places in this vicinity, and since the greenstone, as above pointed out, is intrusive in the quartzite, the granite must also have the relation of an intrusive to the quartzite. Not only are the relations of the quartzite to the surrounding formation similar to the relations of the Rib Hill quartzite and the Powers Bluff quartzite, but the general recrystallized character of the quartzite from these several places is the same. The various evidences for a similar stratigraphic position for these several areas of quartzite are discussed at the end of this chapter. To all appearances, therefore, the quartzite is surrounded, mainly at least, by younger rocks, and nowhere is recognized the floor upon which this formation was deposited. It is believed, however, that the few patches of foliated gneiss existing in the intrusive rocks of this area, which are clearly much older than the intruding massive granite and greenstone formations, probably represent a portion of the floor upon which the quartzite and shales were deposited.

RÉSUMÉ.

The various formations here placed in this, the lower sedimentary series,—the Rib Hill quartzite, the Powers Bluff quartzite, the Hamburg slate, and the Wausau graywacke, and the Junction City and Rudolph quartzite as already described, bear similar relations to the igneous formations with which they are in contact, and apparently without exception are intruded by the igneous formations associated with them. They are in turn overlain by sedimentary rocks, which also lie upon the igneous intrusive masses. These sedimentary formations are almost wholly of fragmental or clastic origin. A few rocks only may be cited of a non-fragmental origin, such as some small occurrences of calcareous cherts, ferruginous cherts and carbonaceous shales, all of which appear to be closely associated in origin with the finer grained clastic rocks.

Thus these formations not only bear similar relations to the associated igneous rocks, but are also of similar sedimentary character.

The Rib Hill quartzite and the Powers Bluff quartzite are fairly pure quartz rocks of equally extremely metamorphosed character. They may very well be stratigraphic equivalents, although in the absence of definite proof of their equivalency, it seems best to regard them as separate formations.

The Hamburg slate appears to be a formation of considerable thickness and extent, and the various isolated occurrences of slate throughout the area may be portions of this formation.

The graywacke and fine grained quartzite shales lying north of Wausau occur in small extent only and are chiefly of interest in showing their relations to the associated igneous rocks.

The quartzites in the vicinity of Junction City and Rudolph with their carbonaceous and ferruginous phases may represent the same formations, as carbonaceous and ferruginous deposits are quite generally closely associated. These quartzites are extremely metamorphosed and recrystallized and are similar in crystalline texture to the Rib Hill and Powers Bluff quartzites.

It is possible that the several formations here placed in one series may represent formations from two series separated from each other by an unconformity. This seems hardly probable, however, in view of the fact that there is a lack of great variety in the character of the sediments of these formations. If these formations belong to two unconformable series instead of a single series, then it would seem probable that the quartzites belong together in a series older than the slates and graywackes, because the quartzites appear to be wholly recrystallized masses, like marble, and more metamorphosed than the argillaceous sediments of slate and graywacke. In this connection it may be stated, however, that certain phases of the graywacke schists are also greatly metamorphosed with extensive secondary development of cordierite, staurolite and garnet.

On the whole, however, it seems most probable that the formations here described belong to a single conformable series which has been subjected to an unusual amount of metamorphism through intrusion of large igneous masses. The position of this series in the stratigraphy of the pre-Cambrian is discussed in subsequent pages (pp. 378–9).

CHAPTER IV.

THE IGNEOUS INTRUSIVE FORMATIONS.

INTRODUCTORY.

About 75 per cent of the area of North Central Wisconsin is occupied by intrusive igneous rocks, which appear to fall readily into three well defined formations, groups or series. These formations are intrusive in the Basal group of gneiss and schists, and also in the Lower Sedimentary series, and are in turn overlain by the Upper Sedimentary series of the area. Thus these widespread igneous formations occupy a well defined position in the stratigraphy of the area and as such can be conveniently described together.

In the order of their stratigraphic succession, or intrusion into older formations, these igneous masses are: 1st. The rhyolite formations, with phases of andesite; 2nd. The diorite-gabbro series; 3rd. The granite-syenite series. In following pages these groups are described separately. The rhyolite, and the diorite-gabbro series occur in isolated areas and hence each area can conveniently be described separately. The granite syenite rocks, on the other hand, are very abundant, and form the main body of the igneous rocks of the area, constituting a sort of background or matrix in which all other rocks occur, either as fragmentary areas entirely enclosed by it, or as small overlying areas resting upon it. The granite-syenite series, including the nepheline bearing syenites, are therefore described as a unit and not as separate areas.

It should, perhaps, be stated at the outset that none of the formations or series above named represent a single flow or intrusion of igneous magma, but that each represents a mass of complex flows and intrusions, the extrusion of which very probably occupied a relatively long period. The rhyolite and related andesite appear to be the most simple in character and geology. The diorites, gabbros, and peridotites, on the other hand, constitute a wide variety of rocks, and the same is true of the various rock phases of the granite-syenite series. The members of each composite series, however, appear to bear a similar relation to the members of the other, and hence with respect to their geological relations, each composite series stands as a unit, though a very complex one.

SECTION I. THE RHYOLITE SERIES.

The various areas and occurrences of rhyolite are described as follows: The Wausau area of rhyolite; the Big Sandy Creek area of rhyolite; the Eau Claire River area of rhyolite-schist; the Pine River area of rhyolite-schist; the rhyolite in the vicinity of Mosinee; the rhyolite at Edgerton's farm; rhyolite-andesite; isolated small areas of rhyolite.

THE WAUSAU AREA OF RHYOLITE.

EXTENT.

The largest area of rhyolite in the region extends from the eastern part of the city of Wausau, eastward for a distance of two miles, and northward four or five miles, along the Wisconsin river. This area, as outlined on the general map, lies in Secs. 5 and 6, T. 28, R. 8, and the two western tiers of sections in T. 29, R. 8, and a large part of the northeastern portion of T. 29, R. 7.

TOPOGRAPHY.

The occurrences of rhyolite furnish nothing distinctive to the topography of the district. In the near vicinity of Wausau, the rhyolite appears in low-lying ledges, and loose blocks, along the sides of the ravines and summits of the ridges that lead back from the Wisconsin river. There is a marked absence of sharply rugged topography, and only here and there appear the low lying ledges projecting above the gentle contours of the gently sloping uplands. Farther to the north, where it is overlain by the quartz-schist graywacke and conglomerate formation, the rhyolite often projects through its mantle of younger formations, but never rises far above this cover.

CHARACTER AND VARIETY OF RHYOLITE.

The rhyolite formation in the vicinity of Wausau is made up of several varieties, between which are numerous phases and gradations. These varieties are (1) rhyolite, (2) banded rhyolite, (3) rhyolite-breccia, and (4) rhyolite-granite.

1. Rhyolite.

This name designates the normal phase of the rhyolite or quartz-porphyry. This variety makes up from 80 to 90 per cent of the formation.

Macroscopic.—It is characterized by a variable abundance of feldspar and quartz phenocrysts, distributed nearly uniformly through a fine-grained ground mass. The phenocrysts vary in size from a very small fraction to one-fourth of an inch in diameter. The varying abundance of the porphyritic constituent is quite marked. In some places the phenocrysts are large and constitute about one-half the mass of the rhyolite; in other places they are quite small and make up a very small proportion. An uncommon phase is one in which phenocrysts are entirely absent, but this phase is very rare, and needs no special mention. The ground-mass is dense, and usually dark colored, depending upon the degree of weathering and alteration. See Pl. XVI, Fig. 2.

This rhyolite is usually pink in color. It consists of a fine grained groundmass containing albite and quartz phenocrysts,

EXPLANATION OF PLATES

XVI AND XVII.

Plate XVI. Phases of Rhyolite.

Fig. 1. Banded Rhyolite, from the vicinity of Wausau, three-fourths natural size. The rock consists of porphyritic crystals of feldspar and quartz in a fine grained groundmass. The porphyritic crystals are segregated into bands.

Fig. 2. Specimen of the normal Wausau Rhyolite No. 5653, three-fourths natural size. The porphyritic crystals are mainly feldspar.

Plate XVII. Microsections of Rhyolite and Rhyolite Schist.

Microsections of normal rhyolite. Section 3940. Without analyzer, x20. The section contains a large phenocryst of quartz in the fine grained groundmass.

Fig. 3. Microsection of the rhyolite schist from the Dells of the Eau Claire River. Section 5947. With analyzer, x20. The section shows the elongation of a small quartz phenocryst and the granulation of two larger phenocrysts. The biotite and other flaky minerals in the groundmass are arranged with their long directions parallel to the elongated phenocrysts. The rock represented in Fig. 2 was originally like that of Fig. 1 and by compression and recrystallization the schistose structure was developed in it.

Fig. 1. BANDED RHYOLITE.

Fig. 2. RHYOLITE.

PHASES OF RHYOLITE.

Fig. 1.

Fig. 2.

MICROSECTIONS OF RHYOLITE AND RHYOLITE SCHIST.

the former being the most abundant. The groundmass consists of fine grained feldspar and quartz with much muscovite, biotite and very probably considerable margarite and other members of the clintonite group containing a high content of alumina.

Chemical Composition.—The analysis of a phase of the porphyritic rhyolite by Prof. W. W. Daniells, considered to represent the average rock (3975), from the rhyolite ledges on the hill east of the Wausau High School, is as follows:

Analysis of Rhyolite of Wausau.

SiO_2	72.68
Al_2O_3	16.40
Fe_2O_3	0.99
FeO	1.53
MgO	0.48
CaO	1.56
Na_2O	3.85
K_2O	2.10
H_2O	0.37
Total	99 96

Microscopical.—With the microscope the rhyolite porphyry is seen to be made up of fine-grained ground mass, in which occur the phenocrysts of feldspar and quartz.

Feldspar Phenocrysts.—The porphyritic feldspar is usually, if not wholly, plagioclase, showing the usual habit of twinning. Measurements of the plane of extinction in the zone perpendicular to 010 showed the feldspar to be albite, with composition near the Ab molecule. The albite often shows the effects of pressure in having bent twinning lamellae, and in being fractured. The most usual kind of metamorphism, however, is that due to chemical change, by which the feldspar is altered to sericite, biotite, margarite, quartz, and epidote. The alteration of the albite varies from those nearly fresh and clear, to those almost, and even completely, changed. These alteration products are aggregated along and near fractures and cleavage planes, and along the composition faces of the twins. Many of those of advanced alteration, when seen in certain cross sections, show a general definite arrangement of the secondary products. Much of the albite of advanced alteration contains small grains of magnetite and calcite, which may be, in part, due to infiltration.

Quartz Phenocrysts.—The porphyritic quartz crystals possess a fairly good crystal outline. Many of them show the effects of pressure by undulatory extinction, and some of them are fractured. Very often they contain numerous rhombic areas of the ground mass. In some cases (5720) aureoles of feldspathic material have crystallized about them, encasing them in husks or shells. See Pl. XVII, Fig. 1.

The Groundmass.—The groundmass is cryptocrystalline and consists of fine feldspar and quartz, minute flakes of biotite, sericite, margarite, and chlorite, with less quantities of epidote, magnetite, calcite, green hornblende, sphene, ilmenite, and pyrite. Volcanic textures of the groundmass are marked. The arrangement of the constituents of the groundmass in streaks and winding lines, indicating a fluxion texture, is common to most of the thin sections. This texture is largely due to the small mica crystals being arranged with their longer axes in a parallel direction. How much of the parallel arrangement of these small minerals is due to primary causes, and how much to secondary crystallization, under pressure, is impossible to say. The micro-poikilitic texture occurs in a few of the sections examined, and some also show a spherulitic (5750) crystallization of the groundmass, with fibrous growths and enlargements extending from the phenocrysts of feldspar and quartz.

2. Banded Porphyritc Rhyolite.

Macroscopical.—This variety occurs in several places near Wausau, such as the NW. ¼ of NE. ¼ of Sec. 31, T. 29, R. 8, and the SW. ¼ of SW. ¼ of Sec. 19, T. 29, R. 8, and also near the center of SE. ¼ of Sec. 24, T. 29, R. 7, and in the SW. ¼ of NW. ¼ of Sec. 30, T. 29, R. 8.

The general banded appearance of this rock is shown in Pl. XVI. An examination of hand specimens shows this rock to be made up of alternating bands of rock material, which differ from one another by the abundance of phenocrysts they contain; or, in other words, the bands consist of material which has attained different degrees of crystallization. On the weathered surfaces this difference is distinctly brought out. The bands in which the phenocrysts are abundant show the most weathering, appearing as zones of depression of varying widths, in which the numerous porphyritic crystals of feldspar and quartz stand out in angular and rounded prominences. The bands, which contain a much less proportion of phenocrysts and a much larger proportion of groundmass, stand out on the weathered surface as ridges, the surfaces of which are weathered and worn nearly smooth.

Microscopical.—With the microscope this banded rock does not appear essentially different from the more homogeneous variety, the characteristics of which have already been pointed out. In the bands containing the unusually large number of phenocrysts, there seems to be a tendency for the phenocrysts, especially those of plagioclase, to assume a more complete crystal form. This is perhaps due to less corrosion by the magma. The feldspar phenocrysts are more altered in general where they are congregated in close proximity. The quartz phenocrysts do not appear different in either bands. In the phase of the banded rhyolite containing but few phenocrysts the enlargement rims upon quartz were noted. The porphyritic constituents of both kinds in general have assumed a position with their longer axes parallel to the bands.

There is also a phase of the banded rhyolite possessing laminae which are very thin, and which weather smoothly, and do not form ridges and grooves as is shown in Plate XVI. This rock is especially characterized by the small size and irregularity of the phenocrysts. It grades into a phase which contains no phenocrysts (a banded non-porphyritic rhyolite), but this extreme phase is of rare occurrence.

The Groundmass.—The groundmass differs somewhat from the homogeneous rhyolite groundmass in having a greater proportion of alteration products in the bands of phenocrysts. It also appears to be somewhat coarser where the phenocrysts are abundant.

Origin of the Banded Rhyolite.—As stated above, the bands differ from one another in the degree of crystallization. This fact is brought out in the process of weathering, by which the laminae appear as alternating hollows and ridges. These alternating bands usually vary from one-fourth of an inch to an inch in thickness, and are of variable length. Two or three bands sometimes merge into one, giving the rock much the appearance of the cross bedding of a sedimentary rock.

In some places, especially near the center of the SE. ¼ of Sec. 24, T. 29, R. 7, the bands are bent into folds, giving evidence of differential movement in the rhyolite that would not have been apparent in the more homogeneous unbanded phase. In the fresh surfaces there is an apparent gradation between these laminae, but on the weathered surfaces the boundaries between the ridges and hollows are, in general, fairly sharp. It is believed that this banding is due to differential movement which took place in the rhyolite magma some time before its extrusion, and at that time formed lenticular or spherulitic masses. This separation is not likely to have taken place at great depths below the surface, for under great pressure, and when possessing high temperature, the magma would likely be easily miscible. The fact that rhyolite magmas become viscous at high temperatures, and consequently their differentiation begins earlier than in basic lavas, is shown by the occurrence of the banded and laminated character common to rhyolite, while the basic lavas universally have a homogeneous texture.

The banded rhyolite in the vicinity of Wausau is massive, and appears to have been extruded under greater pressure than the more pumiceous laminated rock, like that occurring at Obsidian Cliff[1] in the Yellowstone National Park. However, the lamination of the more massive and deeper-seated phase of rhyolite very probably did not differ much in origin from those phases extruded at the surface under very little pressure. It is believed, that before the extrusion of the lava there was variation in the crystallization of the magma, and that irregular shaped portions of the magma separated out in the vent, because such portions had absorbed different amounts of mineralizing vapors or solutions. During the process of the out-flowing of the lava these masses of different consistency and crystallization were drawn out and pressed into laminae by the force of gravity, thus developing the flowage bands.

3. Rhyolite Breccia.

This rock is composed of angular fragments of fine-grained rhyolite embedded in the normal porphyritic rock. The angular fragments vary in size, and usually are not more than an inch

[1] 7th Ann. Rept. U. S. Geol. Survey. p. 286–7.

in diameter. This phase is usually, if not always, formed by the mashing and fracturing of the banded rhyolite. It is associated with the folded banded rhyolite in irregular elongated areas which generally have their longer axes parallel to the banding of the rhyolite. The enclosed fragments also usually have their longer axes parallel to the bands.

The brecciated phase of the rhyolite is developed to a small extent in the southeast corner of the NW. ¼ of SE. ¼ of Sec. 24, T. 29, R. 7, where the crumpled bands strike N. 55 E., and dip nearly vertical. It also occurs in the SE. ¼ of SW. ¼ of Sec. 18, T. 29, R. 8, where it is associated with the overlying conglomerate. The distribution of the conglomerate overlying the rhyolite formation, which contains an abundance of rhyolite pebbles and fragments, and the frequent close association of the conglomerate with this rhyolite breccia, sometimes makes it very difficult to discriminate between the two formations.

Microscopical.—This breccia does not differ very much under the microscope from the normal phase of rhyolite. The quartz phenocrysts are fractured considerably, and possess undulatory extinction. The porphyritic feldspar crystals are also much fractured, and the fractures are filled with quartz, sericite and often calcite. In much fractured parts of the feldspars alteration is much advanced, and in such places of deformation occur quartz, muscovite, and some epidote. The groundmass, besides containing much sericite, is especially characterized by the presence of secondary quartz in angular shaped areas and in irregular reticulating veins.

4. Rhyolite-Granite.

This variety of the rhyolite formation does not appear to be abundant. Outcrops showing the gradation of the normal rhyolite into a fine-grained granite occur in the NE. ¼ of SW. ¼ of Sec. 30, T. 29, R. 8. It also occurs quite extensively developed in zones or narrow belts, alternating with rather coarse rhyolite, in the southeast part of Wausau, especially along Franklin street, between La Salle and Hoefflinger streets.

Macroscopical.—In the hand specimen the rhyolite-granite is with difficulty distinguished from the granitic rock, on the one hand, and the porphyritic rock, on the other. The rhyolite associated with the rhyolite-granite possesses numerous phenocrysts of both quartz and feldspar. While the rhyolite-granite is characterized by good sized feldspar phenocrysts, there is an apparent absence of the porphyritic texture, even where a marked difference between phenocryst and groundmass can be detected under the microscope. In the field, therefore, masses of the rhyolite-granite were called fine-grained granite, rather than rhyolite-granite or rhyolite.

Microscopical.—Some of the rock (Specimen 5716) occurring on E. Washington St. between Montana and Farnham streets, is a fair example of the rhyolite-granite. Under the microscope this rock reveals a micropegmatitic texture. It is quite apparent that there are two generations of the feldspar and quartz in the rhyolite-granite, one generation being the larger crystals, which approach idiomorphism, and the other generation being the pegmatitic, or granophyric phase, occurring as a filling between the large well outlined crystals. This rock, therefore, appears to be a phase between granite and rhyolite. It grades into the usual rhyolite, and no sharp contacts were noted anywhere between them.

In the NE. ¼ of the SW. ¼ of Sec. 30, T. 29, R. 8 E., are a number of ledges of the rhyolite showing gradation to granite, as shown in specimen 5656. This rock, as shown in thin section, does not have a distinct granophyric texture of the groundmass, although the feldspar is clearly of two generations. The first generation consists of fairly well outlined crystals of feldspar and quartz, which do not differ in any way from the usual porphyritic crystals common to rhyolite. The quartz and feldspar of the second generation are much smaller than the quartz and feldspar of the first generation. This rock very clearly stands as a phase between rhyolite and granite. Within a few feet it grades into rhyolite, in which the groundmass is fine-grained, although not cryptocrystalline. A granite phase of this rock was not observed at this place, although it no doubt occurs in some small quantity associated with the other granitic phase of the rhyolite. Similar gradations of rhyolite[1] into granite have been noted elesewhere.

[1]J. P. Iddings. Mon. 20. U. S. Geol. Survey.

Origin.—Two methods of origin may be suggested for the rhyolite-granite. It may be a coarsely crystallized phase of the rhyolite of primary origin; or it may be a recrystallized phase of the rhyolite produced by thermal metamorphism through the intrusion of the quartz-syenite and associated granite of the vicinity. That the intrusive granite and syenite could produce the recrystallization of the rhyolite along the contact of the two formations in the vicinity of Wausau is amply illustrated elsewhere in the district where the intruding magma of granite-syenite comes in contact with the Rib Hill quartzite, and graywacke, and also older igneous formations.

ASSOCIATED ROCKS.

About two-thirds of the surface outcrops within the boundaries of this area consist of the rhyolite formation. The other rock formations appearing are fine-grained diorite, granite, graywacke, and conglomerate. The area is almost entirely surrounded by the granite-syenite mass, the granite on the north and east sides, and the quartz-syenite phase on the southwest. The northeast portion of the area, in Secs. 5 and 9, T. 29, R. 7, comes in contact with the fine-grained diorite and the nepheline-syenite formations.

RELATIONS TO ASSOCIATED ROCKS.

The rhyolite is intrusive in the Wausau graywacke formation, as shown by the occurrence of numerous fragments of the graywacke in the rhyolite. The rhyolite is in turn intruded by the fine-grained diorite and granite formations, as shown in the rock exposures on the west side of the Wisconsin river in the northern part of Wausau (See page 60). The Marshall Hill conglomerate formation overlies the rhyolite and associated igneous rocks, the pebbles of this overlying conglomerate largely consisting of the rhyolite debris. The rhyolite therefore is older than all the formations it comes in contact with, except the Wausau graywacke, which it intrudes (See Fig. 3.)

THE BIG SANDY CREEK AREA OF RHYOLITE.

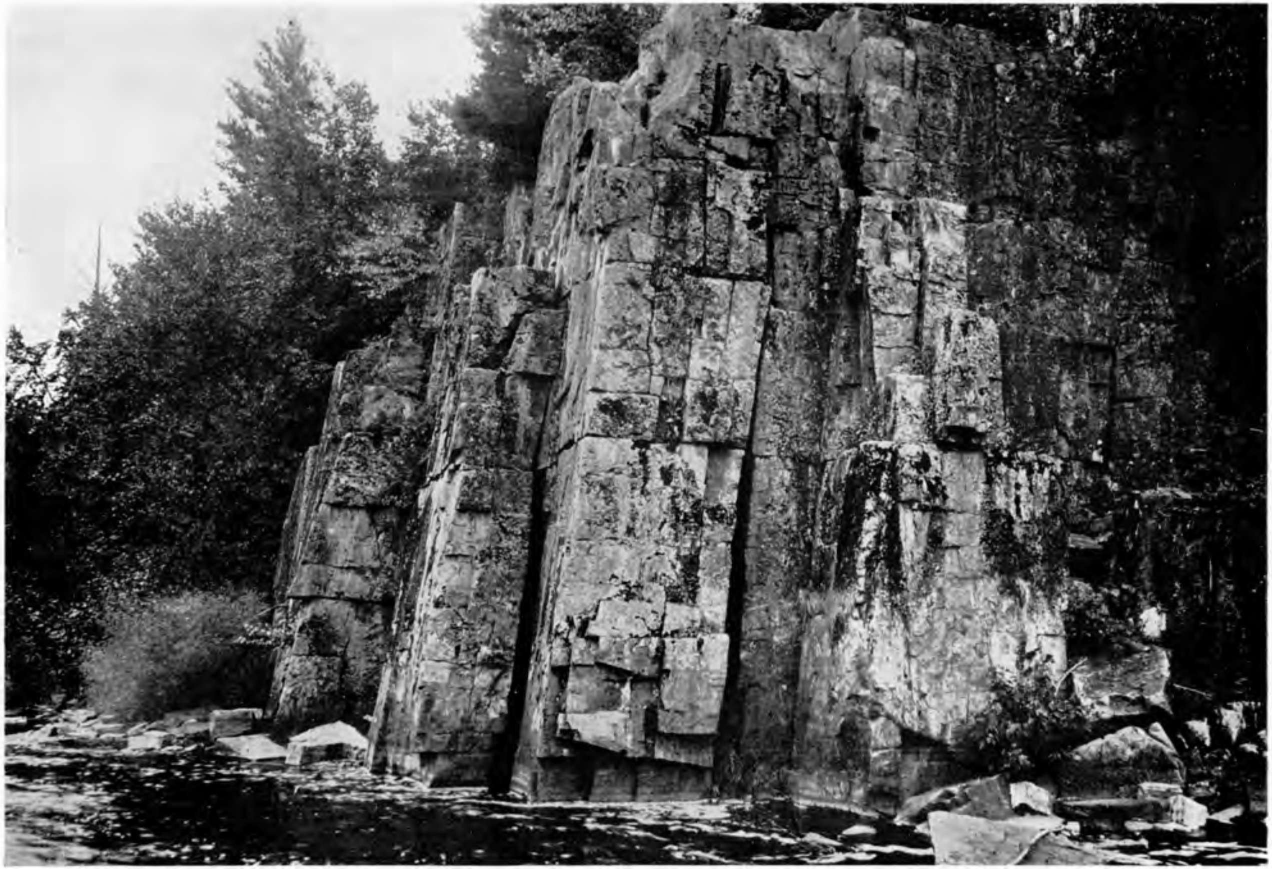
LOCATION AND EXTENT.

There are a number of exposures of rhyolite occurring along and adjacent to the Big Sandy Creek. These outcrops are found at various places along this stream from the SE. ¼ of Sec. 31, T. 30, R. 9 E., to the SW. ¼ of Sec. 25, T. 29, R. 8 E., within the area indicated upon the map. The probable extent of the rhyolite along this stream is six or seven square miles. See Pl. IV.

CHARACTER AND VARIETY OF ROCK.

This rock occurs in porphyritic and non-porphyritic varieties, which are schistose, and massive. In the specimens collected from this area there seem to be more phenocrysts of feldspar than of quartz. Specimen 5169 from NE. ¼ of SW. ¼ of Sec. 25, T. 29, R. 8 E., is a greenish gray rock, which is very fine-grained, and contains a few small crystals of quartz. The rock breaks with a conchoidal fracture, and is not schistose. Specimen 5171 from Lot 20, Sec. 19, T. 29, R. 9 E., differs from 5169 in having numerous white feldspar phenocrysts occurring in the dark ground mass. Specimen 5113 from Lot 5, Sec. 19, T. 29, R. 9 E., is much like 5171, and contains numerous phenocrysts of feldspar, and a few of quartz. Specimen 5804 from Lot 4, Sec. 18, T. 29, R. 9 E., is like 5171 in all respects. Specimens 5116 and 5117, occurring in the vicinity of 5804, are mashed phases of the same kind of rock as 5804. Specimen 5805 is very fine-grained rhyolite, and is similar to 5169. Specimen 5152 occurs in the NW. corner of the NE. ¼ of Sec. 6, T. 29, R. 9 E., and is a mashed fine-grained rhyolite.

Thin sections of these rocks examined under the microscope show them to have a very fine-grained ground mass, in which occur a variable number of phenocrysts. Feldspar phenocrysts are more numerous than those of quartz. These phenocrysts vary in size from a small fraction of an inch to ⅜ of an inch in diameter. Quite a few of the specimens have only small



CHARACTERISTIC WEATHERING OF THE RHYOLITE SCHIST, DELLS OF THE EAU CLAIRE RIVER.

phenocrysts. The ground mass is made up of fine quartz and feldspar, with a variable quantity of sericite, calcite, biotite and hornblende.

Taken as a whole, the rhyolite along the Big Sandy Creek does not possess much evidence of mashing and dynamic metamorphism. In some places, the rock is mashed, however, and has much the appearance of the rhyolite schist of the Eau Claire river farther east. This rock differs from that in the vicinity of Wausau in having fewer phenocrysts of quartz. The relation of the Big Sandy Creek rhyolite to the Wausau rhyolite and Eau Claire River rhyolite will be referred to again.

RELATION OF ASSOCIATED ROCKS.

The rocks occurring in the vicinity of the rhyolite are granite and diorite. The granite is usually rich in quartz, and evidently intrusive in the rhyolite, as abundantly shown elsewhere in this district. The diorite is found intrusive in the rhyolite.

THE EAU CLAIRE RIVER AREA OF RHYOLITE SCHIST.

LOCATION AND EXTENT.

The rhyolite schist which occurs along the Eau Claire River in northeastern Marathon county has an extent of twenty-five to thirty square miles. It occurs in scattered exposures along the Eau Claire river from the SE. ¼ of Sec. 7, T. 29, R. 10 E., to the center of Sec. 33, T. 29, R. 8 E. It also occurs in Sec. 18, T. 28, R. 9 E. and through the valley in SW. ¼ of the SW. ¼ of Sec. 10, T. 28, R. 8 E. It is also found at various places adjacent to the river, as indicated upon the map. It thus occurs in a belt of varying width along the Eau Claire, about fifteen miles long and from two to six wide, extending from the NW. corner of T. 29, R. 10 E., nearly to the junction of the Eau Claire with the Wisconsin river.

STRUCTURE AND TOPOGRAPHY.

This formation in this area has a definite schistose structure and cleavage. The strike of this cleavage system is about N. 35° E. and the dip nearly vertical. The pronounced cleavage of the rock allows it to split readily along the cleavage planes, and its readiness to split and more readily erode along this plane probably governs to some extent at least the course of the Eau Claire river across this formation. This is well exemplified in the dells of the river, in the south half of Sec. 7, T. 29, R. 10 E. Here the river forms rapids or cascades where it is cutting across the cleavage (See Plate LXXIII), and runs smoothly where the river course is parallel to the cleavage. The jointing of this formation is well defined and prominent, as exemplified in the illustration, Plate XVIII. In the latter illustration the front surface represents the plane of the cleavage. The jointing (or fracture cleavage) is in three sets, two approximately vertical, and one approximately horizontal. One of the vertical sets is in a plane parallel to the principal cleavage, the other normal to it, and the horizontal set is also normal to the plane of principal cleavage. There are other joints, as seen in the photograph, but the above are the principal ones, and the tendency for the rock therefore is to crumble into paralleopipedons.

The most prominent topographical feature of this formation is the narrow valley of the Eau Claire, known as the dells of the river, located in the south half of Sec. 7, T. 29, R. 10 E., portions of which are illustrated in the above views.

CHARACTER OF RHYOLITE SCHIST.

The most pronounced feature of this rock is its well developed cleavage and schistosity. It appears as a mashed rock wherever found along the Eau Claire river. In color it is usually grey or pink. It is very hard, and breaks and splits readily along the cleavage planes. For convenience in describing the formation, it may be divided into three kinds, between which are all gradations. These kinds are,—porphyritic, non-porphyritic, and garnetiferous phases of the rhyolite-schist.

The porphyritic constituents are quartz, feldspar and garnet. These constituents vary in abundance from less than one per cent of the rock to 20 or 25 per cent. Quartz seems to be the most abundant porphyritic constituent throughout the formation, although there are some phases in which the phenocrysts are almost wholly of feldspar. Garnet, which is a porphyritic constituent only, furnishes but a small percentage of the rock in those phases of the rock in which it occurs.

The non-porphyritic phases are very fine-grained, and their cleavage laminae are thin and straight. In the porphyritic phase, the laminae bend about the phenocrysts, the latter being greatly lengthened out in the plane of the cleavage.

The Porphyritic Phase.—The phase of the formation probably makes up from 80 to 90 per cent of the rhyolite schist. It is made up of phenocrysts of quartz and feldspar in varying abundance imbedded in a fine-grained groundmass. The size of the phenocrysts range from those a small fraction of an inch in diameter to 3/8 inch in diameter. The quartz seems to be more abundant, and larger than the feldspar. The groundmass is granular and fine-grained, and consists of quartz, feldspar, mica, sericite and amphibole.

Quartz Phenocrysts.—The phenocrysts of quartz generally stand out prominently in the ground mass. They usually approach idiomorphism unless mashing has obliterated their crystal form. The quartz reveals various stages of deformation, all having undulatory extinction. Some are flattened in the plane of cleavage without showing any granulation, while others are granulated to such an extent as to completely lose their individuality. It is clear that the larger crystals withstand deformation much better than the smaller ones. for many of the small ones are completely granulated while the larger ones are only fractured. In those crystals which have been mashed to such an extent as to lose their individuality, there is associated with the broken parts some biotite, and very often also a small quantity of calcite and magnetite. All of the phenocrysts of quartz have their longer axes in the plane of schistosity, although there seems to be no symmetry in the optical orientation. See Fig. 2 Pl. XVII.

Feldspar Phenocrysts.—The feldspar is polysynthetically twinned, and is somewhat altered. The phenocrysts of feldspar are usually smaller than those of quartz. They reveal the effect of pressure in having bent twinning lamellae and in being granulated. Many of them are very much altered, which alteration has probably been very much accelerated by the process of mashing and granulation of the rock. Very few of the altered crystals have retained their crystal form. Most of them have their edges irregular and jagged, due to the process of granulation. The feldspar is altered to, or impregnated with, biotite, quartz, chlorite, and a small quantity of hornblende, calcite and magnetite. Where the process of alteration is complete, the change produces a mineral mass similar in composition and texture to the granular groundmass. The schist occurring at the wagon bridge at the upper end of the dells appears to contain few phenocrysts other than feldspar, and porphyritic feldspar in this rock also does not appear to have a parallel arrangement. There are other phases in which there is about an equal abundance of quartz and feldspar, and also other phases which contain only quartz phenocrysts, as already stated.

The Groundmass.—The groundmass consists of quartz, feldspar, biotite, muscovite, sericite, green amphibole, blue amphibole, some calcite, and a little magnetite. The groundmass does not possess any of those textures common to fresh volcanic rocks. The evidence of the extreme mashing of this rock is shown by the marked cleavage and schistosity of the rock in the field, and in the fracturing and granulation of the porphyritic quartz and feldspar.

The textures or association of minerals of the ground mass are of two kinds. The quartz and feldspar possess the granular texture "Gleichmässig-Körnige Structur" of Zirkel, while the mica and amphibole have a parallel orientation texture, "Schieferige Structur."

The quartz and feldspar occur in about equal proportions, and constitute about 70 per cent of the groundmass. Crystals of the above are about equal in size, and the grains are approximately equi-dimensional. The three axes of the crystals being nearly equal, they do not interlock in any intricate fashion, as they do in the groundmass of rhyolites that have not been dynamically metamorphosed. The size of the crystals varies much. There are often present numerous streaks of large crystals of quartz with a small quantity of feldspar, which may be due to infiltration and impregnation, or to the mashing and granulation of phenocrysts of quartz and feldspar. The mica and amphibole constituents form 20 to 25 per cent of the groundmass. They occur in about equal abundance, although individual sections very often show a preponderance of one over the other. The mica and amphibole are arranged in nearly parallel orientation, and have their longer axes (c axes), in the plane of cleavage of the rock. The parallel orientation is only general. In some places these constituents form streaks and lines which bend about the phenocrysts of quartz and feldspar.

The mica occurs in two varieties,—biotite and muscovite, the latter occurring in somewhat larger crystals than the biotite. The biotite and muscovite occur mingled with granules of quartz and feldspar of the granulated and fractured phenocrysts.

There are also two varieties of amphibole present in the groundmass. One variety is common green hornblende with the following absorption:

a—yellow green, *b*—dark green, *c*—bluish green.

The other variety is blue amphibole, with an absorption as follows:

a—greenish yellow, *b*—light blue, *c*—deep blue.

This latter variety does not appear to be so abundant as the green hornblende.

Calcite or dolomite is present in most of the thin sections. Magnetite also occurs to a variable extent, throughout the ground mass.

Non-porphyritic Phase.—As already stated there are all gradations between the porphyritic and non-porphyritic phases of the rhyolite schist. The rock bearing no phenocrysts is not so abundant as that containing a few or many porphyritic crystals. The texture of this phase is exactly similar to the texture of the ground mass of the porphyritic rock, and the description applied to the groundmass of the latter can be given to the general texture and composition of this phase of the rhyolite. Quartz and feldspar form a granular aggregate, and the mica and amphibole are usually of nearly parallel orientation.

Much the greater part of this phase probably contained no phenocrysts at the first cooling and crystallizing of the rock. However, the mashing process to which the rock has been subjected, might have granulated and obliterated the phenocrysts in some cases at least, and in this way, produced a non-porphyritic phase.

The Garnetic Phase.—This phase of the formation is probably not very abundant. Two specimens out of sixteen examined under the microscope contained garnet. It occurs in good sized porphyritic crystals, and the manner in which the mica and amphibole bend about them evidences their development before the mashing of the rock with the original phenocrysts of quartz and feldspar. The garnet has the usual habit and appearance of this mineral. It is somewhat fractured, and sometimes is drawn out in the plane of cleavage. The garnet occurs where quartz phenocrysts also occur. In one instance phenocrysts of garnet and quartz about equal in size were adjacent to each other, and both were equally fractured, and the laminae of biotite and amphibole extended about them in a similar way, indicating that both had been subjected to the same process of deformation.

ORIGIN OF THE RHYOLITE SCHIST.

As implied in the foregoing discussion of this rock, the texture of the schist is believed to have been formed by mashing of the ordinary rhyolite. Another alternative explanation of its origin is that it might be a metamorphosed clastic rock, and originally a graywacke. It is believed to be an altered rhyolite, instead of an altered clastic rock, for three reasons.

1st. No unquestionable evidence of stratification or bedding of this formation is found in the numerous exposures along the Eau Claire river, although such evidence was especially searched for.

2nd. The porphyritic crystals of quartz and feldspar possess good crystal forms except where broken and granulated by the mashing process. None of them have the rounded character common to clastic quartz and feldspar.

3rd. The granular association of the quartz and feldspar and the parallel structure of the mica and amphibole in the non-porphyritic phase of the gneiss are exactly similar to the texture and character of these minerals in the ground mass of the porphyritic phase. It is the granular and schistose texture of the constituents which give the rock so much the appearance of being a clastic. It is very apparent, however, that the textures in both the porphyritic and non-porphyritic phases have developed in the same manner, as there are all gradations between phases that bear abundant phenocrysts and those which bear but few or no phenocrysts. Both phases are intermingled and have been subjected to the same kind of metamorphism, as indicated by the character of the individual minerals and their association. And since the porphyritic schist is clearly a mashed porphyritic rhyolite, as shown by the character and form of the porphyritic crystals, it is also believed that the non-porphyritic schist, in a similar way, is but the mashed phase of the non-porphyritic rhyolite.

ASSOCIATED ROCKS.

The formation associating with the rhyolite schist are granite, diorite and norite. The granite bounds the rhyolite schist on all sides. Fine grained diorite is interlaminated with the schist along the Eau Claire river, and also occurs in large areas in sections 3, 4. 9, 10, 15, 16, in T. 28, R. 9 E. The norite occurs in sections 13 and 24 of T. 28, R. 8 E. The massive rhyolite probably comes in contact with the rhyolite schist in Sec. 19, T. 29, R. 9 E.

RELATIONS TO ASSOCIATED ROCKS.

The granite formation is intrusive in the rhyolite schist, as evidenced by the extreme crumpling of the schist at the contact at the upper end of the dells of the Eau Claire river. The garnet and blue amphibole in the rhyolite may have originated by contact metamorphism of the granite. The diorite is also intrusive in the schist, at least this is true of a fine-grained diorite interlaminated with the rhyolite schist along the Eau Claire. The rhyolite along the Big Sandy creek is very likely an unmashed phase of the rhyolite schist.

PINE RIVER AREA OF RHYOLITE SCHIST.

LOCATION AND EXTENT.

The area of the rhyolite along the Pine river has an extent of six or seven square miles, and forms a strip about one and one-half miles wide, and four miles long, through which the Pine river flows near its junction with the Wisconsin. This area, as outlined on the map, lies in Sections 13, 14, 15, 21, 22, 23, 24, 26, 27, 28 and 32, of T. 21, R. 7 E. in Lincoln county.

STRUCTURE AND TOPOGRAPHY.

Most of the Pine river rhyolite is a mashed rock, and possesses a very good cleavage. The strike of this cleavage is generally from 25° to 30° E. of N.; the dip 60° to 70° NW. The pronounced schistosity of the rhyolite allows it to split very readily along its cleavage planes, and this feature makes the rock easily distinguishable throughout the area. Besides this cleavage structure, there are present numerous minute faults and fractures in the rock.

The most pronounced topographic feature within the area is the narrow valley with steep slopes, which is occupied by the Pine river. The river has cut its way to a considerable depth along the cleavage planes through the area, forming a gorge over a mile long about a mile from its junction with the Wisconsin river, (Pl. LXXIV) known as the Dells of the Pine river, which in its deepest part has a depth of 160 feet below the surrounding table-land. In places there are narrow gorges from twenty feet to forty feet deep, and ten to forty feet wide, where the side streams have cut across the cleavage to join the Pine.

CHARACTER AND VARIETY OF THE RHYOLITE.

The rhyolite, as already stated, is a mashed rock, with marked schistose and cleavage structure. It consists mainly of the fine-grained ground mass, in which occur the phenocrysts of plagioclase. Neither quartz phenocrysts nor phenocrysts of amphibole or pyroxene were noted in the hand specimen or thin sections of this formation.

The rhyolite varies much in the abundance of plagioclase phenocrysts. In some places they are rare, and in other places they are very abundant. Where these two varieties occur together, as at the old mill site in the NE. 1/4 SE. 1/4 of Sec. 28, T. 31, R. 7 E., the rock, with abundant phenocrysts, appears to be less mashed than the finer grained rock. There is a less perfect cleavage in the coarser rock, but when these two varieties are studied under the microscope, it appears that there is as much deformation and mashing in one as in the other, and that the more schistose varieties are usually made from the finer grained rocks, because such rocks are more readily mashed than those with the abundant phenocrysts.

Some phases of the fine-grained rhyolite resemble basic rock very much, and could with difficulty be distinguished from the fine-grained diabase and diorite formation of the vicinity.

Faulting and fractures are quite prevalent throughout the rhyolite formation: Deformation of this sort, is well shown in numerous places along the Pine river, and especially at the old mill site in NE. 1/4 SE. 1/4 of Sec. 28, T. 30, R. 7 E. At this place the fractures are very numerous, and run diagonally across the cleavage, some of the fractures apparently having a genetic relation to the cleavage, while other fractures appear to have no such relation. Some of these fractures are short and broad, while others are very long and narrow. Calcite is the most abundant vein material present in these fractures.

Chemical Composition.—The analysis of the predominating phase of this rock (5088) from the dells of the Pine, by Prof. W. W. Daniells, is as follows:

Analysis of Rhyolite of Pine River.

SiO_2	74.60
Al_2O_3	13.04
Fe_2O_3	0.76
FeO	3.34
MgO	0.61
CaO	....
Na_2O	5.40
K_2O	0.82
H_2O	1.06
Total	99.63

This analysis was made for the purpose of comparison with the massive rhyolite about Wausau. This analysis is of interest in showing a high content of sodium oxide in comparison with the content of potassium oxide. By comparing this analysis with that of the Wausau rhyolite it will be noted that both contain much more soda than potassa. The analysis of the Wausau rhyolite contains 1.56 per cent of CaO while the analysis of the Pine river rhyolite shows no CaO.

Microscopic.—The miscroscope shows the rhyolite to be made up of very fine-grained or crypto-crystalline ground mass, in which are distributed mainly phenocrysts of plagioclase.

The Plagioclase Phenocrysts.—The porphyritic crystals of feldspar are small and vary from a small fraction of an inch to an eighth of an inch in diameter. They also vary in abundance, as already stated, and range in quantity from mking up less than 5 per cent of the rock to making up 25 or 35 per cent of the rock.

The rhyolite which contains a relatively small amount of porphyritic feldspar is much more mashed than the porphyritic phases, thus developing a more perfect schistosity. In this phase the phenocrysts of plagioclase are not only fractured, but the fractured parts are often separated and pulled apart from one another. By this process of mashing and fracturing they are extended several times their original length in the plane of cleavage. There seems to be no common orientation of the optic axes, and more often than otherwise the plagioclase is granulated and fractured to such an extent as to lose its individuality. In the pulled-out and lengthened crystals, the intervening spaces between the dismembered parts are usually filled with calcite, with some green hornblende, and sericite. The sericite and hornblende are probably due in part to the alteration of the plagioclase. The alteration of the plagioclase has gone on in some cases to a complete change to these minerals.

In that phase of the rock, in which the phenocrysts are numerous, the phenocrysts are likewise fractured and have bent twinning lamellae; however, they do not show the amount of deformation apparent in the finer grained phase just described. In some of the thin sections of this phase of the rhyolite, the phenocrysts make up about 30 per cent of the rock. Many of the phenocrysts are broken apart, and the interspaces are filled with much calcite, some quartz, and a very little iron oxide. Most of the fractured feldspar does not have a parallel arrangement in the schist.

The Groundmass.—The groundmass is fine grained, and holocrystalline. It consists of fine feldspar, quartz, green hornblende, calcite, sericite, some iron oxide, and a very little chlorite. The feldspar is abundant in the unaltered rock, while the hornblende, sericite, and calcite, are the principal constituents of the more metamorphosed phases. The feldspar of the groundmass is also in smaller crystals than the other constituents, and is probably a product of the first crystallization of the rock.

A green variety of hornblende is an abundant constituent of the groundmass. It appears to be almost as abundant as the feldspar in the more metamorphosed phases of the rhyolite. The pleochroism is distinct; *a* is yellowish green, *c* is brown, with sometimes a tinge of blue, and *b* is brown. It occurs in prisms with uneven ends, and has a parallel orientation, the *c* axis being in the plane of the rock cleavage.

The sericite has the usual habit of this mineral, and is present only where the rock is much altered. It also has its longer axis in the plane of schistosity. The calcite usually occurs between the fractured parts of the phenocrysts, and as a vein mineral, filling the numerous large and small fractures of the rock. It seems to be an infiltration product, not only from the fact of its occurrence in fractures, but also from the fact of its being so very abundant in the rock.

The quartz occurs in minute grains, so small as to be almost indistinguishable from the fine-grained feldspar. It occurs in small quantities in fairly good sized grains associated with the calcite among the fractured parts of the feldspar phenocrysts. Iron oxide occurs to a small extent within the altered feldspar. Chlorite is not abundant. There are a few quite large crystals of iron pyrite present which may or may not be of secondary nature. The groundmass, and especially the feldspar of the groundmass, often has a radial arrangement about the crystals of pyrite.

ASSOCIATED ROCKS.

The rocks associated with the rhyolite are of three kinds, diorite, granite and conglomerate. The diorite surrounds the rhyolite on three sides, on the north, the east, and on the west, and is in contact with the granite on the south side. There is also associated with this rock a small quantity of conglomerate, lying in the SW. ¼-SE. ¼ of Sec. 14, T. 31, R. 7 E.

RELATION OF ASSOCIATED ROCKS.

The rhyolite is older than any of the rocks with which it comes in contact. Its relation to the granite and diorite is fairly well shown in the NE. ¼ of Sec. 33, T. 31, R. 7 E. At this place, the rhyolite and granite appear in a ledge, not far from one another, and in one place are separated by only a small ravine. The rhyolite is mashed, and has a good cleavage, which dips at a high angle. The granite is massive, and free from secondary structure, and has every appearance of being a large boss intrusive in the rhyolite. Not far from this place is the diorite, which, like the granite, is quite massive, and does not show the dynamic metamorphism of the rhyolite. This diorite in many places is intruded by the granite, as shown in the SW. ¼ of Sec. 2, T. 30, R. 7 E., and likewise in various other places in the Wausau district, where granite and the basic rocks come in contact. The diorite, in a number of places, also comes into direct contact with the mashed rhyolite, and where it does so, it is massive, with all evidence pointing to its intrusion into and between the laminae of the rhyolite. The small quantity of conglomerate in the SW. ¼ of the SE. ¼ of Sec. 14, T. 31, R. 7 E., lies upon the rhyolite, for it is made up of pebbles and fragments, of the rhyolite, and nowhere is any rhyolite found intrusive in the conglomerate.

RHYOLITE IN VICINITY OF MOSINEE.

Southeast of Mosinee, in sections 27, 28, 33 and 34, of T. 27, R. 7 E., and sections 4 and 5 of T. 26, R. 7 E., are a few small ledges of rhyolite. The rhyolite also occurs abundantly in a coarse conglomerate of this vicinity.

CHARACTER AND VARIETIES OF ROCK.

The rhyolite occurs in both porphyritic and non-porphyritic varieties, the porphyritic phase being the most abundant.

Phenocrysts.—The phenocrysts in the rhyolite are feldspar and quartz, the former being more abundant than the latter. The feldspar crystals are plagioclase, and vary in size from a fraction of a millimeter to two or three millimeters in diameter. They are usually somewhat altered to sericite, epidote and chlorite. The quartz phenocrysts are rare, and are quite small.

The Groundmass.—The groundmass of the rhyolite is very fine-grained, and consists of quartz, feldspar, chlorite, sericite, biotite and green hornblende. The fluxion texture occurs to some extent.

Rhyolite Fragments.—Fragments of different phases of rhyolite occur widely distributed throughout the conglomerate formation of the vicinity. Large and small fragments occur together, ranging in size from those of microscopic size to those four or five inches in diameter. They appear to differ somewhat in composition, although this is impossible to tell in the fine-grained fragments. The differences brought out on the weathered surfaces are those of color and texture. The porphyritic fragments usually contain phenocrysts of feldspar. Some, however, contain hornblende phenocrysts. No phenocrysts of quartz were noted in the fragments and pebbles of rhyolite.

RELATIONS TO ASSOCIATED ROCKS.

The rhyolite in the vicinity of Mosinee is surrounded on all sides by the massive granite formation and it then bears the relation of a large fragmentary area enclosed by the granite. The conglomerate associated with the rhyolite, as already described, is largely made up of rhyolite pebbles and detritus. The relation of this rhyolite and conglomerate at Mosinee is therefore the same as that of the rhyolite and conglomerate at Wausau.

RHYOLITE AT EDGERTON'S FARM.

On the farm of L. T. Edgerton in the SW. ¼ of Sec. 6, T. 30, R. 8 E., and also in the NW. ¼ of Sec. 7, T. 30, R. 8 E., are ledges of rhyolite which are of especial interest. The rhyolite is much fractured and broken, and has much the appearance of an intrusive breccia. It is not mashed and schistose, and in this respect is quite different from the Pine river rhyolite. It is everywhere very fine-grained, and contains no porphyritic crystals. It is brittle, breaking with irregular and conchoidal faces. The rock contains numerous small and large reticulating veins. A large amount of fine granular quartz is apparent in the hand specimen, and also a fibrous green mineral.

Microscopic.—The two thin sections of the rock which were examined under the microscope are quite different from one another. One contains a great deal of zoisite, a little quartz and feldspar, and the other contains much fine quartz and feldspar and a very little zoisite.

The zoisite has the usual appearance of this mineral such as parallel extinction, high index of refraction and low birefringence. In color it is greenish gray with a marked tinge of yellow.

In the thin section containing much fine quartz, the zoisite appears as skeleton crystals. The fine grains of the quartz are inclosed by the zoisite. The zoisite does not appear altered, and looks much like a crystal of secondary development with the quartz and feldspar as inclusions. Biotite occurs in small flakes, and magnetite is also present. The quartz is very fine-grained, and with it is mingled some minute grains of feldspar.

A phase of rhyolite identical with this outcrops on the banks of the Trapp river in the NW. corner of Sec. 22, T. 30, R. 8 E. These phases of rhyolite appear to have been much fractured, brecciated and veined, the vein material being largely quartz, feldspar, and zoisite, the main body of the rhyolite being very fine-grained feldspar and quartz without phenocrysts. This rock has been described[1] as an augite schist, the zoisite evidently being considered as augite.

Associated Rocks.—The rock is bounded by the granite formation on the east, and by the greenstone on the northwest and west. It is not found in actual contact with either of these formations, and its relation to them is not known.

RHYOLITE-ANDESITE.

LOCATION AND EXTENT.

There is an occurrence of andesite or rhyolite about 5½ miles north of Wausau, near the center of the SE. ¼ of Sec. 2, T. 29, R. 7 E., on the east side of the Wisconsin river. This andesite outcrops along the C., M. & St. P. railroad for a distance of about ⅛ of a mile, and is therefore of small extent.

CHARACTER AND VARIETY OF ROCK.

The andesite in this small exposure does not show much variety in its composition and texture. It is everywhere densely porphyritic. The weathered rock has a dark gray groundmass, in which are imbedded a very large number of gray feldspar phenocrysts, which are much weathered. The unweathered surfaces of the rock are uniformly dark green. Quartz phenocrysts do not occur.

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[1] Geol. of Wis., Vol. IV., pp. 669, 684.

Feldspar Phenocrysts.—The phenocrysts of feldspar vary somewhat in shape, although most of them are elongated or lath-shaped. Their longer axes are usually from 1/8 to 1/2 inches long, the most of them being from 1/4 to 3/8 of an inch long. Their shorter axes are about 1/6 to 1/4 the length of the longer axes. The feldspar is polysynthetically twinned, and is probably anorthite or labradorite. It is very much altered throughout the thin sections examined, and is somewhat fractured. The feldspar is altered to calcite, green hornblende, some muscovite, chlorite and magnetite. Calcite is the most abundant inclusion and is probably partly due to the alteration of the feldspar and partly due to infiltration. Where replacement and alteration of feldspar are almost complete, the calcite seems to be the most abundant final alteration product.

The Groundmass.—The groundmass is very fine-grained, and has none of the complicated textures of the acid volcanic rocks. Very little of the original constituents of the groundmass remain unaltered. It is now made up of fine particles of chlorite, calcite, feldspar, magnetite, hornblende, sericite, zoisite, epidote, and biotite. A few crystals of apatite were also noted in some of the sections. A phase of the rock contains a great deal of fine quartz, aggregated in rounded and elliptical areas. This quartz has the appearance of chalcedony or chert, and is often associated in this rock with some quartz and calcite, both minerals being probably infiltration products.

This andesite appears to be a very much altered rock, and probably consisted, originally, of phenocrysts of plagioclase with composition of the anorthite molecule, enclosed in a fine-grained groundmass, consisting of a large proportion of feldspar, and a small amount of amphibole or biotite, and perhaps a very little quartz. These have been altered and replaced as above described. The calcite seems to be the most abundant in the altered phenocrysts. The other secondary products seem to be about equally divided in the phenocrysts and groundmass.

RELATION TO ASSOCIATED ROCKS.

This rock is enclosed on all sides, except that side facing the river, by the Marshall Hill conglomerate formation. This sedimentary formation lies above the andesite on the summit of the upland on the east side of the river valley. The conglomerate contains fragments of the andesite, as shown in specimen 5795, and is therefore a younger formation than the andesite. This andesite thus bears the same relation to the conglomerate as the Wausau rhyolite bears to the conglomerate.

RHYOLITE-ANDESITE.

LOCATION AND EXTENT.

Another small area of rhyolite or andesite deserving of mention is located in SW. ¼ of Sec. 24, T. 29, R. 5 E., occurring in a few low outcrops in the road, and in the adjoining field at the SW. corner of Section 25, T. 29, R. 5.

CHARACTER AND VARIETY OF ROCK.

The andesite in these few outcrops is quite uniform in texture and composition. The rock is porphyritic and is made up of uniform small crystals of feldspar, and a dark, fine-grained groundmass. The phenocrysts of feldspar are from three to six millimeters in thickness. Very small flakes of amphibole are also apparent in the hand specimens. The rock is gray on the weathered sides, and greenish black on the fresh surfaces. On the weathered surfaces the andesite is pitted and rough, the feldspar phenocrysts being altered and removed more rapidly than the groundmass. In some exposures the weathering has brought out numerous narrow veinings about ⅜ of an inch apart, and which run straight across the exposures.

Feldspar Phenocrysts.—Under the microscope, the phenocrysts of feldspar are seen to be very much altered and replaced. The feldspar contains numerous inclusions of epidote, chlorite, and green hornblende. The alteration is usually so advanced as to make it impossible to actually determine the species of feldspar present, but it is apparently one of the basic varieties.

Pyroxene and Amphibole Phenocrysts.—Basal sections of both these minerals were seen in thin sections, but they are not nearly so abundant as the phenocrysts of feldspar. The pyroxene phenocrysts are largely altered to green hornblende. The minerals of the groundmass wind about and surround them, as they do about the feldspar phenocrysts, indicating their contemporaneous development in the rock.

The Groundmass.—The minerals of the groundmass are feldspar, green hornblende, epidote, sericite, chlorite and magnetite. The feldspar is the most abundant, and occurs in lath-shaped crystals, with nearly parallel orientation, which wind and curve about the phenocrysts. The feldspar of the groundmass contains fewer altered products than that of the phenocrysts. The parallel arrangement of the feldspar of the ground mass appears to be original, and but little evidence of the deformation of the ground mass or phenocrysts can be detected.

Epidote, which usually occurs in small, rounded grains, is more abundant in the phenocrysts of feldspar than in the groundmass. Epidote also occurs in what appears as narrow veins on the weathered surfaces of the rock. The green hornblende occurs in small flakes, quite irregularly oriented. Magnetite is quite abundant. There appears to be quite a little sericite, or kaolin, included in the feldspar phenocrysts. Some phases of the andesite contain aggregates of a fine-grained quartz, which fills the fractures in the rock, and is not distributed throughout the ground mass.

This rock is very similar to the andesite 5½ miles north of Wausau on the Wisconsin river.

ISOLATED SMALL AREAS OF RHYOLITE.

About ¼ mile east of the SW. corner of Sec. 26, T. 29, R. 6 E., in the road, occurs a fine-grained quartzose rock, at the contact of the granite with diorite. Specimen 5577 is a sample of this formation, and it appears under the microscope to be made up of very fine-grained quartz and feldspar. This rock appears to be a typical non-porphyritic rhyolite. The quartz is in irregular inter-locking grains, and the feldspar is in lath-shaped crystals. There is also present a large amount of green hornblende, chlorite, magnetite and epidote.

A mile southwest of 5577, in the road, a short distance north of the center of Section 34, is another occurrence of rhyolite (Specimen 5578), which appears to be bounded on all sides by granite. This rock is similar in texture and composition to 5577, except that it contains quite a few porphyritic crystals of feldspar. Both of these occurrences of rhyolite may be dikes or included fragments in the granite. Their relation is probably the same in both places.

About ¼ mile south of the NE. corner of Sec. 28, T. 29, R. 6 E., is a ledge of rock much like 5577 and 5578, but coarser. It is also at, or very near, the contact of the granite and diorite. It is a very fine-grained granite or rhyolite-granite. The quartz and feldspar appear to be in two generations. The quartz and feldspar of the groundmass are almost as coarse as the porphyritic constituents. This rock contains numerous veins, the vein material consisting of quartz and epidote together, and sometimes epidote alone. Where the epidote and quartz occur together, they seem to have had a contemporaneous growth, as both are perfectly fresh and interlocked with one another, and appear to have grown from the surface of the vein towards the center. The epidote occurs in large crystals. Besides the quartz, feldspar, and epidote, there is also a small quantity of chlorite sericite, and green hornblende.

In the NE. corner of the SE. ¼ of Sec. 31, T. 29, R. 6 E., in a well, is an occurrence of fine-grained rhyolite, (5587). On the opposite side of the road in the NW.-SW. of Sec. 32 are two wells, one at the farmhouse, and the other at the barn. The rock at the farmhouse (5585) is a granite, containing fragments of diorite. The rock at the barn (5586) is like 5587. The wells containing rhyolite are about 50 paces from the well containing granite, 5586 being about 50 paces north of 5585, and 5587 about 50 paces west of 5585. The exact relation of the mixed granite and diorite to the rhyolite could not be made out at this place.

In SE. ¼ of SE. ¼ of Sec. 31, T. 29, R. 6 E., about ¼ mile north of 5587, in a well, there is a mashed rhyolite which is intruded by diorite. In thin section, this mashed rhyolite (5587) is seen to be made up of a granular aggregate of quartz, feldspar and magnetite, and prismatic crystals of green hornblende. The hornblende has an irregular orientation. The crystals are small; the quartz, feldspar and magnetite being about .04 of millimeter in diameter, and the hornblende from .2 to .5 of a millimeter in longest diameters. In the well of J. Vosgdes near the west 1/4 stake of Sec. 30, T. 29, R. 6 E., is a mashed rhyolite. There are three other wells at this farm-house; two of them containing a reddish granite, and the other diorite. The rhyolite (5531) is schistose and friable, and contains numerous crystals of quartz, fine feldspar and chlorite and sericite. The quartz phenocrysts are small and appear to have been broken and pulled apart. The relation of the rhyolite to the red granite at this place could not be determined.

Mashed rhyolite (5528) occurs in the well of Paul Brandt in SW. 1/4 of SW. 1/4 of Sec. 32, T. 30, R. 6 E. On the opposite side of the road at this place the rhyolite occurs associated with slate. One-half mile north of this place is a large outcrop of diorite, occurring in the road and adjoining woods. The relation of the rhyolite to the diorite and slate could not be determined at this place. This mashed rhyolite (5528) contains phenocrysts of both quartz and striated feldspar. The ground mass consists of a finer quartz and feldspar. The rock does not show much granulation and re-crystallization. It contains numerous veins of quartz.

Rhyolite also occurs one mile SW. of 5528 along the road both north and south of west 1/4 stake of Sec. 6, T. 29, R. 6 E. There are numerous exposures of this rock along the road at this place. The rock is not much mashed, although it is fractured and brecciated in some places, and has more the appearance of tuff. Thin sections of two of the specimens (5496 and 5498) collected here were made, and both show the rock to be a typical rhyolite. Numerous crystals of quartz and plagioclase occur in the ground mass, which is very fine-grained. The ground mass is made up of quartz and feldspar and a large amount of sphene and epidote. The sphene and epidote also occur in the feldspar phenocrysts, and are probably of secondary origin throughout this rock.

Mashed rhyolite (5850) occurs about 1/4 mile south of the NE. corner of Sec. 20, T. 30, R. 6 E. This rock is exposed in the ditch of the road, just north of a small stream. South of the stream is quite a steep hill composed of fine diorite, and the diorite outcrops also at the cross roads at the corner of Sec. 20, T. 30, R. 6 E. This mashed rhyolite has a good cleavage, and thin sections show it to be made up of a fine-grained ground mass of quartz, feldspar, chlorite, sericite and biotite, in which occur quite a few porphyritic crystals of plagioclase, and some of quartz.

Specimen 5573 is schistose rhyolite, occurring in the well of J. Horning in the SE. corner of Sec. 8, T. 28, R. 6 E. This rock is within the area of massive granite, southeast of Marathon City. The rock is quite soft and is much altered. Thin sections show it to be made up of a fine-grained ground mass, in which are numerous phenocrysts of plagioclase. The ground mass consists of quartz, feldspar, and much chlorite and sericite. There are occurrences of schists in NW. ¼ of NW. ¼ of section 8, and also in SW. ¼ of SE. ¼ of Sec. 5, T. 30, R. 6 E., which are very much like 5573. These occurrences are in the cuts of the Chicago and Northwestern railroad, and good exposures are shown. The occurrence in the SW. ¼ of SE. ¼ of Sec. 5 is intruded by diorite dikes, very similar to the diorite a few miles north, where it is intruded by the massive granite formation. The schists 5613 and 5954 at these places are much weathered, and quite friable. A thin section of one of them shows no phenocrysts, but otherwise it is like 5573. In the SE. part of Marathon City is an occurrence of very fine-grained rhyolite (5559), which appears to be a fragment or dike in the granite formation, as the granite entirely surrounds it at this place. The rock is mashed and fractured, and is composed of a very fine-grained ground mass, and a few small crystals of feldspar. This rock is very much like 5573 and 5613 and 5954, above described, and probably belongs with them. They are probably fragments of rhyolite in the massive granite formation like the rhyolite fragments in the granite NE. of Wausau.

In the SE. corner of Sec. 15, T. 30, R. 6 E. is an occurrence of mashed rhyolite, (5317) in the wells of Albert Bauman, and also in the well of William F. Giese ½ mile farther west. It also appears in the ditch of the road at the SE. corner of Sec. 15, T. 30, R. 6 E. It is at, or very near, the contact of the diorite with the granite formation. This rock has much the appearance of the rhyolite schist occurring along the Eau Claire river. Thin sections of it show it to be made up of a very fine aggregate of quartz, feldspar, chlorite, sericite, biotite, and iron oxide. In the ground mass are a few phenocrysts of feldspar, but none of quartz.

Along the road in the SE. 1/4 of Sec. 16, T. 30, R. 6 E., are numerous exposures of granite, diorite and some rhyolite. The greenstone occurs as fragments in the granite. The rhyolites (5326 and 5335) probably bear the same relation as the diorite to the granite. The rhyolite 5335 consists of numerous phenocrysts of plagioclase imbedded in the ground mass of quartz, feldspar, green hornblende, and epidote. The phenocrysts contain inclusions of calcite, epidote and hornblende, and the larger ones are somewhat fractured.

At the SW. corner of Sec. 26 and the SE. corner of Sec. 27, T. 30, R. 6 E., are occurrences of andesite. A rock very similar to this outcrops in numerous well exposed ledges one mile farther west, in SE. 1/4 of SE. 1/4 of section 28, where the Little Rib river crosses the road. The rock at this place is partly an andesite and partly a fine-grained diorite, both of which may be phases of the same formation. Specimens 5355 and 5356 from the SW. corner of Sec. 26 are porphyritic rocks, and contain numerous phenocrysts of feldspar in a very fine-grained groundmass of feldspar, quartz, chlorite, biotite and iron oxide. The rock exposed in road 1/4 mile west of the SE. corner of Sec. 28, T. 30, R. 6 E., is very similar to the above described specimens. The rock at the SE. corner of Sec. 28 is exposed at numerous places on the hill about which the road bends, and has much the appearance of fine-grained basic rock. There is quite a little variation in texture and composition of the rock in this vicinity, and all may not be phases of the same formation.

Mashed rhyolite (5595) occurs in the road in SE. 1/4 of SE. 1/4 of Sec. 34, T. 28, R. 5 E. This rock is schistose, and contains numerous phenocrysts of feldspar and a few of quartz. This rock is very much like 5601, which is found about 1/2 mile SW. of this place. Thin sections show numerous porphyritic crystals of plagioclase and a few of quartz in the fine-grained groundmass consisting of quartz, feldspar, and a small amount of sericite, biotite, green hornblende and calcite. In places the ground mass is crystallized in well developed spherulites.

At E. 1/4 stake of Sec. 2, T. 27, A. 5 E., is mashed rhyolite (5599) which is fractured, and contains numerous veins of quartz. It is within the area of the massive granite formation, and thin sections show it to be made up of phenocrysts of quartz and feldspar, and a fine-grained ground mass of quartz, feldspar and biotite. Two miles west of this at the W. ¼ stake of Sec. 3, T. 27, R. 5 E., in well of G. Rifleman is an occurrence of rhyolite, containing numerous phenocrysts of feldspar. This rock (5601) is not a phase of the granite. It is somewhat more basic than the granite and is also more basic than 5599.

Rhyolite 5550, much like 5559, occurs in well of R. Munkwitz in SW. ¼ of SE. ¼ of Sec. 7, T. 29, R. 5 E. The rhyolite is fine-grained and contains a few phenocrysts of feldspar in a cryptocrystalline ground mass.

Where the Black Creek crosses the road in SE. ¼ of NE. ¼ of Sec. 1, T. 29, R. 4 E., the rhyolite is very much mashed and has much the appearance of the rhyolite schist of the Eau Claire river. It contains a few phenocrysts of quartz and feldspar in a very fine-grained ground mass. About ¼ mile east of NW. corner of Sec. 3, T. 25, R. 4 E., mashed rhyolite, 5965, like 5961, occurs in a well. Along the Black Creek for a distance of ¼ mile SE. of center of section 3, rhyolite and fine-grained basic rock occur in well exposed ledges. The rhyolite is schistose, while the basic rock, mainly fine diorite, is massive. The diorite here, as it does in other places, seems to be intrusive in the rhyolite. At this place, the rhyolite contains numerous parallel veins filled with quartz. Phenocrysts of both feldspar and quartz occur, and both are much fractured and broken apart. The ground mass consists of quartz, feldspar, chlorite and sericite. This rock shows evidences of much mashing and cementation.

In the village of Athens in SE. ¼ of Sec. 31, T. 29, R. 4 E., mashed rhyolite is associated with diorite, granite and slate. Specimen 5974 was taken from the rhyolite formation and contains very few phenocrysts. It is very closely associated with sedimentary slates, and it is therefore difficult in some places to separate the two formations. The rhyolite has a granular ground mass of quartz and feldspar, with some hornblende and sphene in veins. A few phenocrysts of plagioclase occur, which are somewhat fractured. It is difficult, and almost impossible, to separate by microscopic examination, the non-porphyritic, granulated rhyolite from the mashed sedimentary rock at this place. At Athens, these two formations are clearly interlaminated with one another. Speciment 5973 is a fine-grained laminated rock, which may be either a rhyolite or a slate.

Rhyolite occurring intrusive in the basal group of gneiss and schists of the area at Grand Rapids and Pittsville has already been described (Page 23). As perviously stated, it is probable that these intrusives are a part of this rhyolite formation.

SECTION II. THE DIORITE-GABBRO SERIES.

Under this heading is described the various phases of basic igneous rocks such as diorite and gabbro occurring in numerous large and small areas throughout the district. Diorite consists of feldspar and amphibole, with some quartz, mica or pyroxene. Gabbro consists of feldspar and pyroxene, with minor proportions of amphibole, olivine or mica. Most of the basic rock of the area is fine-grained diorite, to which the term greenstone is often applied. Under gabbro are included norite and a gabbro-peridotite rock known as troctolite (Ger. Forsellenstein), and rocks of ophitic texture known as diabase.

GENERAL LOCATION AND EXTENT OF THE SEVERAL AREAS.

The various phases of diorite and gabbro constitute from five to ten per cent of the surface outcrops of the district and occur in separate areas distributed as follows. See general map Pl. I and the several maps showing location of outcrops.

The Stettin Area of Diorite. One of the largest areas consists mainly of fine-grained diorite, located in adjacent parts of Township 29, Ranges 5 and 6, and Township 30, Range 6. It forms an irregular shaped area about 36 square miles in extent, the largest part of which lies in the town of Stettin. This area comes in contact with the Hamburg slate on the north and the intrusive granite mass on the north, east, south and west.

Eau Claire River Area of Diorite.—Irregularly distributed diorite and gabbro occur along the Eau Claire river for a distance of about 15 miles from about 5 miles from its junction with the Wisconsin to Township 30, Range 10 E. Gabbro occurs mainly in the vicinity of Callon. The diorite is generally fine-grained and mashed farther northeast where it is interlaminated with the rhyolite, with which it is closely associated. It is bounded on all sides by the rhyolite and granite.

Pine River Area of Diorite.—Another large area of diorite occurs along the Wisconsin river, south of Merrill, and along and adjacent to the Pine river. It forms an irregular belt along the latter stream, having its longest direction extending northeast and southwest, forming an area 20 or 30 square miles in extent. It comes in contact with the Pine river rhyolite on the south, the staurolite mica slate on the northwest, and the massive granite on the north, east, south, and west.

Area of Gabbro (Troctolite) at Mouth of Copper River.—Along the Wisconsin river a short distance above Merrill, at the mouth of the Copper, is a considerable area of olivine feldspar rock, troctolite. This formation forms almost continuous outcrops along the Wisconsin river for about 2 miles and has a probable extent of 3 or 4 square miles.

Black Creek Area of Diorite.—Fine diorite occurs quite extensively along and adjacent to the Black Creek from its junction with the Rib river westward to the vicinity of the village of Athens. The diorite in this area is usually a mashed rock and is closely associated with the rhyolite formation, as in the Eau Claire river area. It is also associated with sedimentary schists and slates which are the western extension of the Hamburg slate formation. Besides the above formations it comes in contact with the granite, which apparently surrounds it on all sides except the eastern.

Halder Area of Diorite.—In the eastern part of Township 27, Range 5, in the vicinity of Halder Post Office, are numerous exposures of schistose diorite. The exposures occur along and in the vicinity of a branch of the Big Eau Pleine River, and are closely associated with mashed rhyolite, as in the Eau Claire River area. The greenstone and rhyolite together make up an area only 8 or 10 square miles in extent. It is entirely surrounded by the granite formation.

Little Eau Pleine River Area of Diorite.—A narrow belt of diorite extends along and adjacent to the Little Eau Pleine river across the middle of Township 26, Range 4, and in the adjoining sections in range 3 and 5. This occurrence has an extent of about 15 square miles and is surrounded on all sides by the granite.

Isolated Areas.—Isolated and small occurrences of the diorite and gabbro occur widely distributed throughout the district, as may be seen by reference to the maps. Among a few of the occurrences that may be mentioned which are quite fully described in another place, are the diorite at Mosinee, the gabbro at Marathon, and the olivine-gabbro or olivine-norite along the Eau Claire river.

RELATION TO ASSOCIATED ROCKS.

Most, if not all, the basic rocks here described are believed to belong to the same period of eruption. The group is believed to be later in origin than the lower sedimentary rocks, and also the rhyolite formation, and older than the widespread granite-syenite intrusive mass.

Intrusive in the Lower Sedimentaries.—The Pine River area of diorite comes in contact with the clastic rocks near Merrill. The clastic rocks at this place are mica schists and staurolitic schists. In the NW. ¼ of NE. ¼ of Sec. 17, T. 31, R. 7, in the field of Herm. Boechter, the diorite is found very closely associated with the sediments, either as dikes or sheets intruded between the schistose laminae of the latter. The rocks at this place are so closely mashed together that it is difficult to separate the two formations.

The Stettin area of diorite is bounded along its northern border by the Hamburg slate for quite a distance. The slate is a soft, schistose chloritic rock, and decomposes readily, and nowhere was there found exposed at the surface an actual contact of the two formations. At the same time no conglomerate was found along the border and no difference in the texture of the slate adjacent to the diorite was to be noted. The evidence of the gradations of the Hamburg slates into the coarser cordierite and staurolite schists to the east and also to the west where intruded by the diorite has already been discussed.

The sedimentary schists along Big Rib River in Township 30, Range 5 and also along Black Creek, appear to be intruded by the diorite. At various places the two formations were found near one another and no evidence of conglomerate at the border was to be found. The sedimentary rock, besides its bedding structure, generally possesses a prominent secondary structure, a lamination across the bedding, whereas the diorite adjacent to it possesses no marked schistosity.

Basic igneous rocks likewise intrude the white massive quartzite of the district. This is true of the quartzite of Rib Hill, and of Hardwood Ridge. The age of the greenstone intruding the Rib Hill quartzite could not be definitely determined, it may be the older greenstone, or it may be the same age as the greenstone dikes that intrude the granite at Granite Heights. However, the diorite intrusive in the Hardwood Ridge quartzite is there clearly cut by the massive granite at the base of the quartzite hill, along the road near the stream, in SE. ¼ of SE. ¼ of Sec. 22, T. 28, R. 6.

Intrusive in the Rhyolite.—The Pine River diorite is believed to be intrusive in the Pine river rhyolite, for the following reasons. The diorite in this area is generally massive and not schistose, whereas the rhyolite along the Pine River is quite uniformly schistose, having a NE.-SW. strike, and nearly vertical dip. The difference in condition of metamorphism of the two kinds of rock is very striking and indicates that the rhyolite was subjected to considerable dynamic metamorphism before the appearance of the diorite. Another evidence of the intrusive character of the diorite is the fact that the latter cuts across the secondary structure of the rhyolite, as shown by the areal distribution of these two formations.

Along the Eau Claire river where the diorite and rhyolite are closely associated in well exposed ledges the diorite is clearly the intrusive rock.

Intruded by the Granite-syenite.—The intrusion of the extensive granite formation into widespread areas of diorite is shown in a number of places. Along the southern border of the Stettin diorite area, in township 29, range 5 and 6, there is a broad zone of mixed rock consisting of numerous large and small fragments of the diorite enclosed within the granite mass. All degrees of the mixture of the diorite with the granite magma are to be observed in this vicinity.

The intrusion of the granite in the Pine river area was observed in the NE. 1/4 of Sec. 2, T. 30, R. 7, where numerous fragments of the greenstone are imbedded in the granite ledges. Along the Trapp river numerous fragments of diorite were observed in the granite. At Mosinee the diorite is penetrated by the granite in the form of dikes and also by the enclosing of blocks of diorite in the massive granite. In the vicinity of the Halder diorite area numerous fragments of the basic rock were observed in the granite.

A short distance above the dells of the Eau Claire river where the massive granite comes in contact with the mashed rhyolite and diorite, there is much evidence of the intrusive character of the former. The diorite and rhyolite are mashed and schistose, whereas the granite is massive and shows no macrostructural metamorphism. At the contact also the straight cleavage of the rhyolite and diorite generally prevailing in the dells, changes to much folded and wrinkled laminae.

Further evidence of the general intrusion of the massive granite in the diorite could be referred to, but is not believed to be essential. Some dikes of diorite are known to penetrate the granite. It is also possible, even probable, that basic magmas have intruded the upper sedimentary series, although as yet no such intrusions have been observed. But in the main, the large areas of diorite, constituting the principal portion of the basic rock, are later in origin than the lower sedimentaries, and the rhyolite, and are earlier than the massive granite and syenite, the intrusion of which marked the close of a long eruptive period in the Huronian of this district.

THE STETTIN AREA OF DIORITE.

Location and General Character.—This area is located west and northwest of Wausau in Township 29, Range 5 and 6, Township 30, Range 6. It is the largest of the diorite areas, and is separated from the Pine river area by a broad strip of granite. The diorite is usually fine-grained and massive. However, in a number of places it is fractured and veined with granite and epidote.

Brecciated Diorite.—The diorite is much fractured in exposures along the road on the side of the hill a short distance south of the center of Sec. 4, T. 29, R. 6 E. The diorite exposed along the road in SE. 1/4 SW. 1/4 of Sec. 8, T. 29 R. 7 E., is also much fractured. The formation in Secs. 25, 26, 35, 36 of T. 29, R. 7 E., is generally cut by numerous joints and fractures.

Ellipsoidal Diorite.—Ellipsoidal diorite occurs at the NE. corner of Sec. 17, T. 29, R. 6 E. In this vicinity are several good exposures of ellipsoidal diorite similar to that occurring in the volcanic greenstone area in the vicinity of Crystal Falls, Michigan. The ellipsoids vary in size from three or four inches to eighteen inches in diameter. They may have originated in the rotational movement of partly solidified lava blocks in a moving magma or by spheroidal parting.

Mixed Rock.—Along the southern border of the greenstone area there is a belt, in places two or three miles wide, which contains a varying amount of mixed diorite and granite. This mixed rock occurs wherever the intrusive granite comes in contact with the diorite, at the borders of the other areas also, but nowhere was it found so abundant as along the south border of the Stettin area. This mixed rock has its origin in the intrusion of the great granite mass into the diorite. It consists of fragments of the basic rock varying in size from a fraction of an inch in diameter to blocks several feet through, which are surrounded or enclosed within the massive granite. Since the granite is the abundant constituent of the mixed rock it will be considered more fully with the granite and contact phenomena of the latter.

Texture and Composition.—The texture and composition of the diorite varies in different parts of the area. The phases are pre-eminently more or less altered rocks, although it is generally impossible to trace definitely the exact amount of transformation from the originally fresh rocks to their present variously altered condition. The various phases of the rock can perhaps be best described by reference to representative specimens from different parts of the area.

Specimen 5323, from the well of H. Fehlhaber in SW. ¼ SE. ¼ of Sec. 20, T. 30, R. 6 E., is a fine-grained aphanitic rock and was taken fifty or sixty feet below the surface. Under the microscope it is seen to consist principally of plumes of finely fibrous, slightly pleochroic green hornblende, chlorite, magnetite, epidote, feldspar, quartz, and calcite. The fibrous green hornblende constitutes about two-thirds of the rock.

Specimen 5250 is from a low outcrop in the road near the S. quarter stake of Sec. 30, T. 30, R. 7 E. It has a yellowish green color, unctious feeling, and is schistose, and breaks readily across the cleavage. Under the microscope it is seen to consist of parallel fibers of chlorite, and also quite a little brown biotite in parallel orientation. A small amount of fine-grained feldspar and a little epidote and iron oxide are also to be noted. There is nothing in the texture to indicate its igneous origin. This rock is mashed, as indicated by its parallel structure, and metamorphism and weathering have entirely obliterated the original minerals and texture of the rock.

The average phase of the rock (5575) occurring along the road on the side of the hill in the SW. corner of Sec. 25, T. 29, R. 6 E., is very fine-grained and somewhat fractured and veined. Minute fibres of hornblende are the only minerals recognized in the hand specimen. Two thin sections of this rock were examined See Pl. XIX, Fig. 2. Both sections show the rock to consist largely of green hornblende and plagioclase. The average greatest diameter of the hornblende and plagioclase was about ¼mm. The minor constiuents are epidote, magnetite, calcite, sericite, and chlorite. One of the sections in which little secondary mineral, such as epidote, was present, appeared to contain from 50 to 60 per cent of the green hornblende, 40 to 50 of plagioclase, and a small amount of magnetite or other iron oxide. The vein material consists of plagioclase and epidote, with minor portions of magnetite, hornblende and probably some quartz.

Chemical Composition.—The chemical composition of this phase of fine-grained diorite (5575), analyzed by Prof. W. W. Daniells, is as follows:

EXPLANATION OF PLATE

XIX.

EXPLANATION OF PLATE XIX.

PLATE XIX. MICROSECTIONS OF GABBRO AND DIORITE.

Fig. 1. Microsection of the gabbro at Marathon City. Section 4269. With analyzer, x25. The section consists mainly of anorthite feldspar, and augite. These minerals are somewhat altered to kaolinite, chlorite and iron oxide. For analysis of this rock see page 160.

Fig. 2. Microsection of fine diorite or greenstone. Section 5575. Without analyzer, x25. Section consists of a fine felted mass of flaky green hornblende in a background of fine feldspar with much magnetite. For analysis of this rock see page 143. The rock of Fig. 1 and Fig. 2 are quite similar in chemical composition but quite unlike in mineral composition and texture.

Fig. 1.

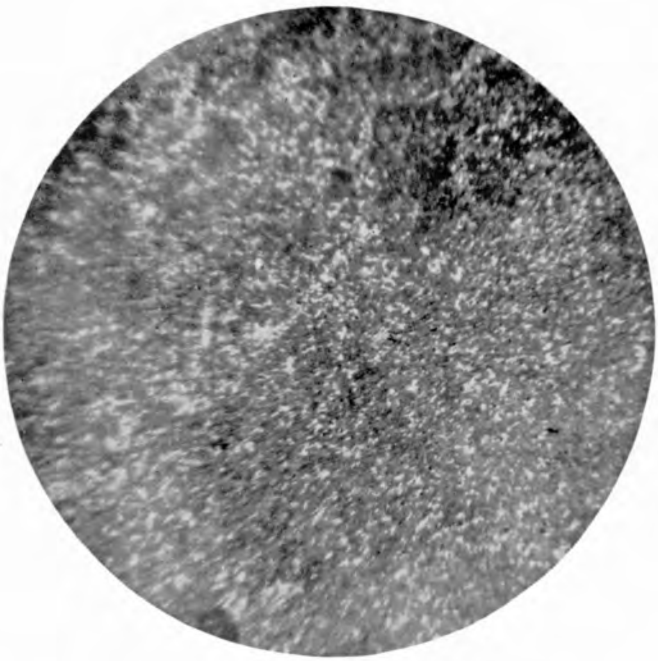

Fig. 2.

MICROSECTIONS OF GABBRO AND DIORITE.

Analysis of Diorite of Stettin area.

SiO_2	48.55
Al_2O_3	18.80
Fe_2O_3	4.61
FeO	7.60
CaO	10.24
MgO	6.08
K_2O	0.12
H_2O	1.27
Total	100.46

The comparatively high content of the Na_2O seems to indicate andesine plagioclase, and the high content of ferrous and ferric oxide probably indicates hornblende high in iron, as not more than a small percentage of iron oxide in magnetite or hematite appears to be present.

Number 5263 was taken from a ledge in the road in SE. ¼ SE. ¼ of Sec. 5, T. 29, R. 7 E. This rock is very much fractured and looks very much like the basic rock found in fragments associated with the nepheline syenite in NE. ¼ of Sec. 27, T. 29, R. 6 E. Under the microscope it is seen to consist of green hornblende and altered plagioclase. The plagioclase is changed to epidote, and a small amount of quartz and calcite. The rock seems to have been made up originally of about two-thirds feldspar and one-third hornblende. About one-half the feldspar is altered to epidote.

Specimen 5387 was taken from a small ledge in the field in NE. ¼ of Sec. 29, T. 29, R. 6 E. is an aphanitic rock consisting of the fine-grained diorite. The thin sections show it to consist principally of fibers and sheaves of non-pleochroic green hornblende, which are much altered to chlorite. The hornblende and chlorite constitute about 95 per cent of the rock. Associated minerals are altered feldspar, vein quartz, and some epidote.

Specimen 5470 occurs in ditch of road in NE. ¼ NE. ¼ of Sec. 27, T. 29, R. 6 E., and is very near the contact of the diorite with the nepheline syenite. It is fine-grained and only altered feldspar and green hornblende can be distinguished in the hand specimen. The thin sections show it to consist of about 55 per cent of feldspar, and perhaps a little quartz, and about 5 per cent of green pleochroic hornblende in short prisms and about

40 per cent of feldspar, and perhaps a little quartz, and about 5 per cent of magnetite. The hornblende and feldspar are fresh, although the rock possesses no igneous texture and apparently is a much granulated phase of the coarse-grained diorite or gabbro.

Specimen 5511, taken from NE. ¼ NE. ¼ of Sec. 29, T. 29, R. 5 E., consists of plagioclase green hornblende, quartz and epidote. Some of the hornblende and plagioclase occur in ophitic texture. This rock is probably a phase of the surrounding granite contact rock.

Number 5500, taken from well of P. Gebbard in NW. ¼ NW. ¼ of Sec. 29, T. 29, R. 6 E., is an aphanitic rock consisting of fibrous green hornblende, plagioclase quartz and magnetite. This rock seems to be quite siliceous and is probably quartz diorite.

Specimen 5524 is a very fine-grained rock, and consists of about 65 per cent of green, non-pleochroic hornblende, 10 per cent of plagioclase, 20 per cent of chlorite, and about 5 per cent of calcite. This rock is much altered.

Number 5525 is a fractured rock taken from the well of E. Redezki in NW. ¼ NE. ¼ of Sec. 8, T. 29, R. 6 E. It is a fine-grained rock and the vein material is calcite. The rock material is altered mostly to chlorite, calcite, and a very little fine feldspar and quartz.

Number 5533 was taken from well of J. Weber in SE. ¼ NW. ¼ of Sec. 23, T. 29, R. 5 E. It is fine-grained and consists of about 75 per cent of fibrous green pleochroic hornblende, occurring in sheaves, 20 per cent of plagioclase, and a small amount of ilmenite and leucoxene.

DIORITE OF THE EAU CLAIRE RIVER.

Location and General Character.—North and east of the area of gabbro along the Eau Claire river, the adjacent rock formation is a fine-grained diorite in chemical composition probably quite similar to the gabbro, but in texture and mineral composition quite different. The gabbro above referred to forms an area along the river from Sections 14 and 23 of T. 28, R. 8 E., to Sec. 18, T. 28, R. 9 E. The fine-grained diorite or greenstone rocks occur in numerous scattered ledges to the east and north of this, being bounded on the east by the coarse hornblende granite and on the north by the rhyolite.

Numerous exposures of the fine-grained diorite occur along the road on the east side of Section 4, T. 28, R. 9 E., and also along the road farther south. Much of the decomposed rock at the Ringle brick yard is diorite, considerably mashed and metamorphosed. North of the river within the area mapped as diorite (See Plate I) similar rock was noted in many of the farm wells.

Within the general area of the mashed rhyolite along the Eau Claire, especially in the vicinity of the lower part of the dells of the Eau Claire, are numerous dikes of fine-grained diorite, presumably apophyses of this formation. As dikes they extend along the cleavage planes of the mashed rhyolite, although they may have originally been lenticular masses, for both rhyolite and diorite are extensively mashed together.

Petrographic Character.—The diorite is usually fine-grained, and is sometimes much mashed and brecciated. In a few instances medium-grained phases were noted.

Under the microscope the fine-grained diorite is seen to consist generally of minute laths of plagioclase and small crystals of green amphibole. The rock is usually more or less altered, the hornblende to biotite and the plagioclase to epidote and mica.

The medium-grained phases of the diorite also consist mainly of plagioclase and amphibole, the latter often predominating. Quartz is often an abundant constituent. Neither pyroxene or olivine were noted as constituents of these amphibole-rich rocks.

PINE RIVER AREA OF DIORITE.

Location and General Character.—The location of this area is along and adjacent to the Pine river at its junction with the Wisconsin. Most of the rock of this area is fine-grained diorite, the principal minerals observable in hand specimens being hornblende and feldspar. The rock usually has a good cleavage, although it is not markedly schistose. In places it is much fractured, and filled with veins of epidote and chlorite.

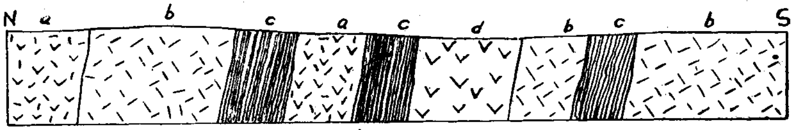

Fig. 4. Section of pre-Cambrian at Merrill. a, Diorite. b, Quartz-syenite. c, Diorite schist. d, Granite.

Under the microscope the rock is seen to consist generally of a large aggregation of common green hornblende, with lesser amounts of plagioclase, biotite, epidote, kaolinite, sericite, calcite, quartz, ilmenite and magnetite.

The original texture of the rock appears to have been partially destroyed through the mineral changes that have taken place in it.

A specimen (5059) from a low ledge a short distance east of south quarter stake of Sec. 8, T. 31, R. 7 is macroscopically very fine-grained. Under the microscope it is seen to consist of small grains of plagioclase and fibres of green hornblende, occurring in about equal proportions. The fibres of hornblende are generally about one-fourth of a millimeter in greatest diameter. The plagioclase occurs in grains usually about one-tenth of a millimeter in diameter. The hornblende is not in parallel orientation.

A specimen (5062) collected near the quarter stake between Sections 15 and 16, T. 31, R. 7, is a fine-grained rock which consists of green hornblende, epidote, zoisite, chlorite, and a small amount of calcite, feldspar, and quartz. The hornblende occurs in large crystals and also in small fibres. The epidote is about as abundant as the hornblende, and with the latter makes up about two-thirds of the rock. The epidote occurs in veins, and is also scattered throughout the section.

A specimen (5063) from the SW. ¼ of Sec. 10, T. 31, R. 7 consists of about 65 per cent of green hornblende and 25 per cent of feldspar. There is also present much chlorite, and a little iron oxide. A small crystal of pyroxene surrounded by hornblende and magnetite is present. The larger crystals of green hornblende are generally about one-half millimeter in length. The fibrous hornblende is often arranged in rosettes.

A specimen (5071) collected from the outcrop a short distance east of the north quarter stake of Sec. 10, T. 31, R. 7, is a very fine-grained rock apparently consisting of about 90 per cent of green, slightly pleochroic hornblende, occurring in short, irregular tabular crystals. The remainder, of the rock consists of epidote, sericite, and a little iron oxide. This rock is very fine-grained, the hornblende largely being but a small fraction of a millimeter in greatest length.

A specimen (5891) from the NW. 1/4, NE. 1/4 of Sec. 17, T. 31, R. 7, is a schistose rock, consisting of about 25 per cent of green, pleochroic hornblende, 20 per cent of brown biotite, 50 per cent of fine granular feldspar, a little quartz, sericite and epidote. The hornblende occurs in long prisms about one millimeter in length and are very much larger than the other constituents. The biotite occurs in short, tabular crystals and appears to be secondary after the hornblende.

Other rocks from the Pine river area were examined microscopically, all of which were quite similar in texture and mineral composition to the above. It is to be noted that the principal constituent is green hornblende, usually pleochroic, and the less abundant constituent is feldspar. The hornblende generally constitutes from 50 to 90 per cent of the rock and is somewhat altered to biotite and chlorite. The length of greatest diameter of the hornblende crystals varied from one-tenth to one millimeter, being from 4 to 6 times the shorter diameter. They occur in parallel structure, in irregularly arranged fibres, in sheaves and in rosettes. The feldspar constituent generally forms from 10 to 50 per cent of the rock. The larger crystals are lath-shaped, and are usually not more than one-half millimeter long. The feldspar alters to small grains of feldspar, epidote, zoisite, quartz, biotite, sericite, and kaolimite.

DIORITE AT MOSINEE.

Location and General Character.—The principal rock forming the rapids of the Wisconsin river at Mosinee is a medium-grained diorite consisting of feldspar, amphibole and some quartz. In a number of places enclosed within the diorite are numerous fragments of a fine-grained basic rock belonging to an older formation. These fragments of older basic rock in the diorite are especially abundant near the wagon bridge and also along the east bank of the river below the bridge. On the east side of the river, east of the railroad, the prevailing rock is fine to medium-grained granite, dikes of which appear in the diorite in the river. In the northern part of the village is coarse-grained quartz syenite like that occurring in the vicinity of Wausau. See Fig. 5.

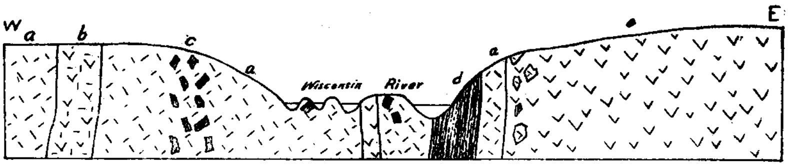

Fig. 5. Section of pre-Cambrian at Mosinee. a, Diorite. b, Quartz-syenite. c, Greenstone fragments. c, Granite.

Under the microscope the diorite is seen to consist mainly of about 60 to 65 per cent of an acid plagioclase, probably albite or oligoclase, about 15 to 20 per cent massive green hornblende, and 10 per cent of quartz. Biotite, magnetite, and apatite are also present. Much of the diorite examined shows an advanced stage of alteration. The hornblende is most altered, apparently mainly changing to epidote, chlorite and fibrous hornblende. The feldspar is altered to sericite and epidote. The most altered phases consist almost wholly of epidote, chlorite and quartz. Below the wagon bridge are several belts of diorite schists, formed by mashing the diorite, and these schists are much altered to epidote and chlorite. The schists reveal a tendency to develop bands of fine granular quartz and epidote.

Under the bridge on the first island on the east side are two large quartz veins in the diorite, several feet in width in their widest parts. The trend of the veins is 50 to 75 degrees E. of N.

Extensive mashing of the diorite has occurred since the veins were formed and small stringers of quartz leading out from the larger veins are much broken, and the broken parts mingled with the general mass of diorite adjacent to the large quartz veins. The mashed diorite has much the appearance of a metamorphic sedimentary.

Two narrow veins of granite were also noted which are faulted, indicating considerable movement in the diorite since their intrusion.

The numerous large and small fragments of fine-grained basic rock, enclosed in the diorite at numerous places in the rapids, consist of lath-shaped basic plagioclase, hornblende and magnetite. The hornblende and feldspar in the slide examined is considerably altered to epidote and biotite. The rock contains much fine-grained quartz.

HALDER AREA OF DIORITE.

Location and General Character.—This area is located in the eastern part of township 27, range 5, in the vicinity of Halder post office. The diorite is usually a mashed, laminated, or schistose rock and is often intricately folded and crumpled. It is closely associated in the vicinity of Halder P. O. with the mashed rhyolite, and the two formations together constitute an area of only eight or ten square miles.

Specimens 5602, 5618 and 5619 are very similar in texture and composition, and may be conveniently described together. 5618 and 5619 occur in the road in the SW. ¼ of Sec. 19, T. 29, R. 6, and 5602 in the northwest corner of Sec. 22, T. 27, R. 5. These specimens occur near the contact of the granite with the greenstone area and may not belong with the foliated greenstone in the near vicinity of Halder P. O., although they bear the same relation to the intrusive granite. These specimens resemble very much the quartz diorite rock in the river at Mosinee. The rock is mashed considerably, although far from being schistose. Under the microscope they are seen to consist principally of about 75 per cent of altered porphyritic plagioclase averaging two or three millimeters in diameter. The finer grained portion of the rock consists of green hornblende, quartz, epidote and magnetite or ilmenite. Number 5602 consists of good sized crystals of green hornblende. On the whole, the rock represented by these three specimens appears to be altered quartz diorite or porphyrite.

The following three specimens, (5934, 5937, 5932) are closely related to one another, and show gradations between a slightly mashed rock rich in pyroxene to an extremely mashed rock in which the pyroxene is completely altered to hornblende.

Number 5934 was taken from the block of the schistose rock in the vicinity of 5932. Glacial material is absent in this vicinity, and there seems little doubt that this rock occurs in place near by. The hand specimen shows tabular crystals of the black mineral occurring in distinct parallel lines in a brownish gray back-ground.

The microscope shows the rock to consist of pyroxene, hornblende, and feldspar. The pyroxene is almost colorless, very slightly pleochroic, has a high index of refraction, and is apparently augite. It constitutes about 40 per cent of the rock, and generally occurs in small grains about ¼ of a millimeter in diameter.

Common green hornblende constitutes about 20 per cent of the rock. It occurs in somewhat larger crystals than the augite and is banded into aggregates drawn out in the cleavage plane of the rock.

Rounded grains of untwinned feldspar constitute about 40 per cent of the rock. The granular feldspar may have developed by the granulation of larger crystals of feldspar, although no cores of such a feldspar were noted in the thin section examined. The granular character of the augite and the lense shaped aggregates of hornblende also suggest granulation.

This rock may have originally been a typical medium-grained gabbro and by mashing the present schistose structure was developed. It is possible also that the texture and arrangement is due to original crystallization.

Specimen 5937 is a schistose, laminated, fine-grained rock, consisting of alternating laminae of dark and light colored minerals. The thin section shows most of the dark mineral to be fibrous green hornblende. The lighter colored mineral is fine granular quartz and feldspar and epidote. There is also present a small amount of chlorite, calcite, and iron oxide. The principal minerals are aggregated into bands. The fibrous hornblende constitutes about 30 per cent, the fine granular quartz and feldspar about 30 per cent, and the coarser granular infiltration quartz about 5 per cent, while there are about equal proportions of the minerals chlorite, calcite, epidote and magnetite.

Specimen 5932 was taken from the outcrop of schistose rock which forms quite a large elevation in the NW. ¼ of Sec. 24, T. 27, R. 5 E. This rock is schistose and crumpled and contains numerous veins of quartz which are likewise crumpled. The massive granite is immediately to the east of this schistose diorite. The thin section shows this rock to consist principally of small crystals of green hornblende in approximate parallel orientation. The laminae of hornblende are folded, crumpled and faulted. The minor constituents are granular quartz and feldspar, and a small amount of chlorite, epidote and iron oxide. The finer granular quartz and feldspar are irregularly laminated with the layers of hornblende.

THE BLACK CREEK AREA OF DIORITE.

This area of diorite occurs along and adjacent to the Black creek from its junction with the Big Rib river to the vicinity of the village of Athens. This rock is associated with the rhyolite and the slate formations of this vicinity. In the field outcrops it is seen in many places to be much fractured and mashed. See Fig. 6.

The rock forming the ledge at the bridge on the east side of Athens is a fair sample of the fresher phases of the formation. The thin section (5971) shows it to consist largely of hornblende and plagioclase. The hornblende is the common green variety and constitutes about 60 per cent and the plagioclase about 40 per cent of the rock. The hornblende varies in size from one to two millimeters in diameter. The plagioclase is somewhat smaller than the hornblende.

Some alteration has taken place, but the whole rock is fairly fresh. It, however, shows an unusual amount of dynamic metamorphism. The plagioclase crystals are bent and granulated. The hornblende is also much granulated and shows much more bending than does the feldspar. The granulated feldspar is altered to calcite, epidote, and some quartz and feldspar. There is an abundance of chlorite where the hornblende is most granulated.

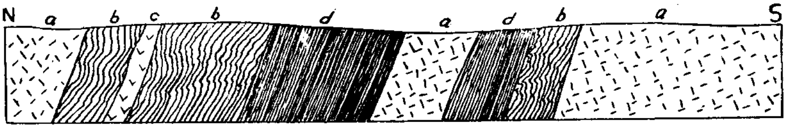

Fig. 6. Section on Black Creek at Athens. a, Diorite. b, Grante schist. c, Granite. d, Rhyolite schist.

The rock (5982) taken from a small ledge in the road a few paces north of the railroad in the SE. ¼ of Sec. 2, T. 29, R. 3, is rather coarse-grained, most of the hornblende, as it appears in the hand specimen, measuring from four to eight millimeters in diameter. Between the hornblende crystals there is much fine-grained feldspar. The hornblende is seen under the microscope to be the common green variety, with the following pleochroism: *a*–brownish green, *b*–yellowish green, *c*–bluish green.

The rock apparently is made up of about 75 per cent of hornblende, from four to eight millimeters in diameter. The interstitial material is principally feldspar in much smaller crystals, which penetrate the borders of the hornblende. Some of the large crystals of hornblende, while compact in the center, appear to be granulated at their borders. The hornblende reveals undulatory extinction, and some of the crystals are bent, broken, and pulled apart. Some vein quartz is also present between the separated parts of the hornblende. The hornblende is but slightly altered to chlorite at the ends of some of the cleavage pieces. The plagioclase is altered to epidote, calcite and quartz.

The rock (6218) occurring in the ditch of road in the NW. ¼ of the NE ¼ of Sec. 5, T. 29, R. 4, near the contact with the slate formation, is very fine-grained and is very much fractured. With the microscope this rock is seen to resemble very much 5971 and 5982. About 75 per cent of the rock is common green hornblende, which has been very much granulated and is considerably altered to chlorite. The feldspar is also granulated and is altered to epidote, calcite, and quartz. There is also quite a little calcite throughout the section and good-sized crystals of epidote in veins. This rock may have developed by mashing and alteration from a phase of the diorite like 5971 and 5982.

Specimen 6221 is from the southeast corner of NE. ¼ of Sec. 14, T. 30, R. 4, on the west bank of the Rib river. Its occurrence here appears to be a dike in the sedimentary staurolite schist. It is schistose, and the principal constituent apparent in the hand specimen is fibrous hornblende. The microscopic examination shows the rock to consist of about 75 per cent of green hornblende; the remainder is quartz and feldspar in about equal proportions, and a small amount of magnetite and ilmenite. The smaller hornblende crystals appear to have their origin in granulated larger hornblende crystals. There is a tendency to parallel orientation of the hornblende, due to the rotation of the granulated parts, rather than the parallel crystal development under pressure, as is supposed to be the case with the parallel oriented biotite in the associated sedimentary schists. The quartz and feldspar appear to be due, in part at least, to the granulation of larger feldspar crystals, with the probable addition of some infiltrated quartz.

LITTLE EAU PLEINE RIVER AREA OF GREENSTONE.

Location and General Character.—This area of greenstone lies along and adjacent to the Little Eau Pleine river and forms a belt extending across the middle of Township 26, Range 4, and in the adjoining Sections of Ranges 3 and 5. The rock is generally mashed and occurs in low outcrops along the streams and is consequently much weathered.

Specimens 6032 and 6036 were taken from the numerous well exposed ledges of greenstone near the sawmill on the Little Eau Pliene river, where the road crosses the river in SW. ¼ NW. ¼ of Sec. 24, T. 26, R. 3 E. The rock at this place is well exposed for a considerable distance along the river and is quite uniform in character throughout. The rock in this vicinity is fractured and veined, the vein material being hornblende and feldspar.

The veins and irregular patches of hornblende are generally parallel to the best cleavage of the rock, while the feldspathic veins are very irregular and usually cut across the cleavage. Thin sections of this rock show it to consist of about 60 per cent of green hornblende and 40 per cent of plagioclase. The plagioclase is usually fresh and translucent, although it is somewhat granulated. Twinning striae were noted in the fresh cores of the plagioclase, while some of these cores were clouded with epidote, calcite, quartz and chlorite. The hornblende is likewise granulated and shows the evidence of extreme pressure in being bent, broken and pulled apart. The hornblende is mingled with the granulated feldspar and it also occurs in minute fibres along the cleavage cracks of the feldspar. Augite occurs to a very minor extent, showing the usual alteration to chlorite.

Specimens 6049 and 6150 were taken from the ledge in the road at the small stream in the SW. 1/4 NW. 1/4 of Sec. 22, T. 26, R. 4 E. Number 6049 is a fairly fresh rock and apparently consists of hornblende and feldspar. Number 6150 is a very much altered rock and apparently consists of a greenish mass of chlorite and serpentine. Under the microscope the former is seen to consist of compact and fibrous green hornblende and plagioclase. Both the hornblende and plagioclase are fractured and granulated. Some calcite and epidote are scattered throughout the section and have probably altered from the plagioclase. Number 6150 under the microscope is seen to consist principally of serpentine and chlorite with quite an abundance of magnetite. Nothing is left of the original constituents of this rock. It appears to have been originally an olivine pyroxene rock. Presence of the pyroxene is indicated by forms of prismatic sections which now wholly consist of chlorite. The olivine is changed to the serpentine and magnetite. Magnetite occurs in good sized irregular areas and is also distributed in fine particles throughout the section.

The latter obviously could not have altered from a rock like 6049 but it is very probable that the two are phases of the same magma. At several other places within the area weathered rocks like 6150 were noted and this indicates that this olivine pyroxene rock may be quite abundant in this area.

GABBRO OF THE EAU CLAIRE RIVER.

Location and General Character.—This rock is exposed on the Eau Claire river in the vicinity of the dam and bridge, in SW. 1/4 SW. 1/4 of Sec. 13, T. 28, R. 8 E., formerly the location of Kelly's upper mill. A number of outcrops occur along the river, below the bridge, on the river bank, and also along the road for a mile or so northeast of the bridge. The rock is medium-grained, the dark gray pyroxene and plagioclase being generally about three millimeters in diameter.

The rock varies from the medium-grained massive phase to finer schistose varieties. On the south bank of the river opposite the dam, there is an exposure of banded rock, the alternating bands consisting of gabbro and granitic material. The banded rock has much the appearance of a metamorphosed sedimentary rock. It, however, grades into the massive and schistose phases of the gabbro and is probably formed by injection of granite into the gabbro. On the opposite side of the river, below the dam, there is a dike of medium-grained reddish pegmatite. This dike has a width of a foot or so, and is probably closely related in origin to the narrower bands of granitic material above described.

Microscopic Character.—Thin sections of the rock examined show the rock to consist principally of plagioclase and pyroxene. Besides these minerals there is a variable amount of magnetite, olivine, apatite, chlorite and amphibole. The principal minerals, plagioclase and pyroxene, are associated in the typical gabbro texture, and are generally about three or four millimeters in diameter.

The plagioclase has an extinction angle of about 33 degrees against the basal cleavage, indicating bytownite, and constitutes about 50 per cent of the rock. The plagioclase is usually somewhat altered, though exceptionally well preserved for a rock of this sort. A very small amount of chlorite is contained in the plagioclase.

The pyroxene constituent forms about 40 per cent of the rock and is apparently the variety augite or diallage. Some of the thin sections show the abundant parting of diallage, while others do not. The pleochroism is distintc, and variable, ranging between shades of green and brown. Twinning is very common, the twining plane being the orthopinnacoid.

Common green hornblende occurs along the borders and regular partings of the pyroxene. It is apparently an alteration of the latter mineral.

Olivine was observed in some of the sections examined, where it appeared to form about 5 per cent of the rock. It is somewhat altered to serpentine but not extensively.

Magnetite is quite abundant in this rock. In specimen 5185 about 5 per cent of the rock is magnetite. The green hornblende is often found closely associated with it.

An amphibole bearing phase is represented by specimen 5192. Macroscopically the rock is like the usual gabbro. Under the microscope the bytownite is translucent, and is not much altered. The pyroxene is surrounded and penetrated by green hornblende, both compact and fibrous, which possesses the pleochroism of actinolite. The actinolite is altered to chlorite. The latter mineral is at the frayed edges of the actinolite and is usually, if not always, separated from the augite or diallage by areas of the actinolite. More than one-half of the dark colored mineral in this phase is amphibole.

On the north side of the river opposite the dam the gabbro is penetrated by a vein or dike of pegmatite a foot or so in thickness. The pegmatite vein consists of large skeleton crystals of pinkish weathered plagioclase, eight or ten millimeters in diameter, which enclose numerous grains of quartz. The quartz is almost as abundant as the feldspar and is distributed within the latter in the manner of graphic granite or pegmatite. On the south side of the river opposite the dike of pegmatite are several exposures of gabbro impregnated with numerous seams and veins of granitic material. The bands of granite and gabbro alternate with one another in seams which vary from an inch in thickness to mere streaks of granite in the gabbro. The seams strike north 70° west, and dip 40° northeast, striking thus parallel to the river, and the veins dip under the river. The seams of vein material vary in thickness along the strike, and some are short and others long, giving to the banded rock much the appearance of cross-bedding in clasitc rocks. Under the microscope the gabbro seams are seen to consist of pyroxene, actinolite and feldspar. The granitic seams consist of plagioclase, quartz and zoisite. The quartz and plagioclase are not indiscriminately mingled, but form alternating zones or veins of quartz and plagioclase. The zoisite forms skeleton crystals which enclose the grains of quartz.

Chemical Composition.—The chemical composition of a representative phase of this gabbro (5185) was analyzed by W. W. Daniells, as follows:

Analysis of Gabbro of Eau Claire River.

SiO_2	46.87
Al_2O_3	17.74
Fe_2O_3	5.28
FeO	7.48
MnO	0.38
MgO	7.01
K_2O	0.28
Na_2O	2.63
H_2O	0.84
Total	99.61

The thin section cut from 5185 contained no olivine, though some of the other slides cut from this formation showed a content of about 5 per cent of olivine. Apatite occurs in small quantity. The norm of this rock as calculated in accordance with the plan described[1] by Messrs. Cross, Iddings, Pirsson and Washington, is as follows:

Orthoclase	1.67
Albite	22.01
Anorthite	35.86
Salic molecules	59.54
Diopside	15.58
Hypersthene	5.81
Olivine	9.80
Magnetite	7.65
Femic molecules	38.84

[1] Jour. of Geol., Vol. X, pp. 644–652.

The actual mineral composition varies considerably from this calculated norm, undoubtedly due to the complex composition of the pyroxene constituent, in which it seems probable that both Na_2O and Al_2O_3 have entered to an appreciable extent, thus leaving sufficient SiO_2 available for a large proportion of pyroxene and smaller quantity of olivine. For this reason, therefore, the feldspar occurs in smaller quantity than that calculated and the pyroxene in larger quantity.

THE MARATHON CITY GABBRO.

Location and General Character.—The gabbro at Marathon City is exposed along the Big Rib river at the wagon bridge and vicinity of the dam, and also a short distance west in the vicinity of the mouth of Scott creek. Southwest of the village between the railroad and Scott creek, and also where the railroad and wagon road cross the creek, the gabbro was seen to be intruded by the granite. Numerous fragments of the gabbro, from mingled stringers to large blocks, occur throughout the granite mass. The rock occurring under the wagon bridge at Marathon is medium to fine-grained. See Pl. XXII.

Petrographic Character.—A specimen collected at Marathon City by A. C. Clark, for the former State Geological Survey, is described by Van Hise[1] as follows: "Hornblendic Gabbro.—Medium-grained, compact, uniform, dark gray, large black crystals of hornblende stand out prominently in the finer mass of the rock." "Microscopic Description.—Diallage in rounded crystals the most important constituent; oligoclase; a few large crystals of hornblende, with cores of diallage, little magnetite, or titanic iron."

Three specimens (Numbers 4268, 4269, 4270), showing phases of the rock at the bridge, were collected and studied by the writer.

These are medium or fine-grained, depending upon the presence of the good-sized compact hornblende crystals. Number

[1] Geology of Wisconsin, Vol. IV, p. 701.

4268 contains an abundance of these hornblende crystals, having diameters usually varying from three to six mm., which are imbedded in the grayish green finer mass. Under the microscope it is seen to consist of plagioclase, pyroxene, and hornblende, and irregular areas of alteration minerals, such as chlorite, calcite, quartz and epidote. The plagioclase constitutes about 50 per cent of the rock and is apparently the variety labradorite, and has altered somewhat to calcite, sericite, epidote and quartz. Pyroxene constitutes about 25 per cent of the rock. It has a slightly greenish color with very little pleochroism, and has the characteristic cleavage of diallage or augite. It shows stages of alteration to grayish masses of fibrous chlorite.

The large, compact crystals of hornblende reveal an interesting method of development. The thin section shows parts of two large crystals of hornblende and also a few smaller individuals. The hornblende forms from 15 to 20 per cent of the rock, as estimated from the thin section and also the hand specimen. One of the large compact crystals of hornblende measures 6mm. in diameter, while the other is somewhat smaller. These large crystals of hornblende contain throughout them a number of the plagioclase crystals and have a habit of occurrence very much like the porphyritic minerals. Near their boundaries the hornblende partly and wholly encloses irregular crystals of augite, the hornblende substance penetrating and surrounding the diallage in the manner of an intergrowth. The plagioclase crystals are scattered throughout the large hornblende crystals, whereas the diallage is mainly found at their borders only.

The compact hornblende and smaller diallage crystals also alter into chlorite. The borders of the hornblende become colorless by the loss of iron which is followed by molecular rearrangement of the bleached hornblende into a fibrous greenish-gray, weakly polarizing mass of chlorite. Analogous change of the augite to chlorite is common in this rock. Hornblende and augite appear to contribute to the development of the areas of chlorite from different sides of these chlorite areas.

Number 4269, closely associated with 4268, is seen to contain a few large crystals of hornblende, and also some irregular patches of magnetite in the fine-grained grayish mass. The thin section shows none of the large, compact, hornblende crystals, but several skeleton crystals of the magnetite are present. Most of the rock consists of plagioclase and augite in about equal proportions, a small amount of hornblende, and their alteration products. The augite or diallage is considerably altered to chlorite and calcite, and the hornblende in turn is altered to chlorite. The patches of magnetite may be due to the alteration of olivine, although olivine was not found in the section examined. See Pl. XIX, Fig. 1.

Number 4270 contains no large crystals of hornblende, but contains porphyritic augite instead. The thin section shows it to consist of augite crystals from one-half to one mm. in diameter, imbedded in a much finer mass of plagioclase and diallage, all of which is very much altered. The augite is altered generally to a grayish chlorite and calcite. The alteration of the augite to chlorite is beautifully shown in one instance in which a large crystal of augite is seen to be surrounded by broad borders of pale green chlorite, having pale blue polarizing colors. In the border of the chlorite are a few crystals of epidote. The augite crystals have irregular borders into which the chlorite penetrates, and the latter also follows along the cross fractures of the diallage. In some cases there is considerable calcite associated with the chlorite.

Chemical Composition.—The chemical composition of the gabbro at Marathon City (4268), analyzed by W. W. Daniells, is as follows:

Analysis of Gabbro of Marathon City.

SiO_2	47.86
Al_2O_3	21.78
Fe_2O_3	2.96
FeO	3.95
CaO	13.30
MgO	6.82
K_2O	0.21
Na_2O	1 56
H_2O	1.00
Total	99.44

The high alumina content, as compared with the silica, indicates the presence of alumina-bearing pyroxene and amphibole. This rock bears considerable resemblance to the gabbro of the

Eau Claire river (p. 157) in chemical composition. It is higher in alumina and lime and lower in iron and the alkalies. The amount of magnesia and silica is approximately the same in the two occurrences. The composition of the Marathon City gabbro does not resemble that of the fine-grained diorite (p. 143) so closely as does that of the Eau Claire gabbro.

About one-half mile west of the exposures at the Marathon City bridge, lying between Big Rib river and the C. & N. W. Ry., are numerous low ledges of the gabbro intruded by the granite. The ledges show much of the gabbro occurring as fragments in the granite. In a number of cases the included fragments have immediately within their borders numerous good-sized feldspar crystals, which are usually from one to four mm. from the contact with the granite, but sometimes much larger feldspars were found scattered a much greater distance from the contact. The feldspar near the contact is generally from two to four mm. in diameter, and lies in sort of layers, while that farther away is isolated and usually from four to eight mm. in diameter.

Specimens 5698 and 5700 collected from this vicinity were examined microscopically. Number 5698 is a small specimen showing the contact of the granite with the gabbro, and the development of a zone of the small feldspar crystals in the gabbro fragments. The thin section cut through the contact shows the granite to be of normal character, medium grained, consisting of plagioclase and quartz, with which are mingled streaks and small patches of fibrous hornblende. The gabbro is fine-grained and consists of laths of plagioclase imbedded in a greenish-gray mass of chlorite. Several large crystals of feldspar occur in zones near the contact. These crystals of feldspar are much altered and are equi-dimensional instead of lath-shaped like the small crystals of plagioclase prevailing in the fine-grained gabbro. Theses large contact crystals of feldspar are altered principally to sericite, and appear to be orthoclase.

Number 5700 is fine-grained but somewhat coarser than 5698. The hand specimen shows several large porphyritic crystals of feldspar imbedded in the normal gabbro. The thin section shows the rock to be much coarser than 5698, and consists mainly of diallage or augite and plagioclase, like the gabbro at the bridge in Marathon City. The plagioclase is altered somewhat to sericite, calcite, quartz and epidote, while the augite is altered mainly to chlorite, and to a small extent to uralite. Magnetite and pyrite are present in considerable quantity. The large porphyritic crystals of feldspar are unstriated and are altered and replaced by sericite, chlorite, calcite, quartz and epidote.

Where the wagon and railroad bridge cross Scott Creek a mile west of Marathon near the southwest corner of Sec. 1, T. 28, R. 5 E., there is much basic rock intruded by the granite, while in the near vicinity are numerous loose and weathered blocks of rock, showing the intricate penetration of the granite material into similar rock (Pl. XXII). The presence of stringers and small irregular masses of the basic rock in the granite indicates that the amount of fusion and melting of the former must have been very great. A specimen of this rock (5556) is fine-grained, and, microscopically, is seen to consist of plagioclase, hornblende, and quartz. No pyroxene was observed in the thin section. Considerable pyrite and magnetite are present. Quartz is quite abundant, and some of the crystals are aggregated in veins and do not appear to be equally distributed in the section. It is probable that the quartz in this rock is derived from the granite and that the silica wandered from the granite at the time of the intrusion of the latter, and impregnated the basic rock. Such an explanation as this is sustained by the fact that numerous large blocks of the rock in the vicinity of the contact consist of veins and masses of quartz in the basic rock. Pl. XXIII. Therefore it is believed that this rock, 5556, which resembles the gabbro, and whirh also bears the same relation to the granite as the gabbro, is a product of the fusion and of contact metamorphism of the gabbro by the intruding granite. The occurrence of the porphyritic feldspar crystals of the gabbro at the contact with the granite and also some distance from it appears also to be due to contact metamorphism.

OLIVINE-GABBRO "TROCOLITE" AT MOUTH OF COPPER RIVER.

LOCATION AND GENERAL CHARACTER.

At the mouth of Copper river in Sec. 4, T. 31, R. 6 E., and farther south at the site of the abandoned dam across the Wisconsin river, near the west quarter post of Sec. 9, T. 31, R. 6 E., are numerous low outcrops of a dark colored basic rock. This rock consists of feldspar, olivine, and a small amount of pyroxene, and is generally much weathered throughout the exposures. The freshest rock has a spotted appearance, owing to the light color of the feldspar and the dark green of the altered olivine. As the rock becomes much weathered it changes to a reddish green, and the sharp outlines of the crystals of feldspar and olivine become indistinct. The surface of the rock also becomes pitted on account of the olivine disintegrating more rapidly than the feldspar and pyroxene.

Specimens 5905 to 5908, 6241 to 6244, and 6532 to 6539 were collected from these ledges, and reveal considerable differences in amount of weathering and also a marked variation in the proportions of the olivine and feldspar in the rock. From the field study it was at first thought that the general variation in the appearance of the rock was mostly due to the relative amount of weathering, but the chemical and petrographic study reveal the fact that there is a wide variation in the composition of the rock. See the phases of troctolite illustrated in Plate XX.

MICROSCOPIC CHARACTER.

The petrographic study shows the feldspar to be anorthite. The pyroxene is orthorhombic, and appears to be enstatite, although some hypersthene may be present in some of the phases. The chemical composition of the rock indicates the olivine to be the magnesium variety. forsterite. The anorthite and forsterite are the abundant original constituents of the rock, and the enstatite is of minor importance. Some phases of the rock contain four or five times as much olivine as plagioclase and in other phases the reverse is true and the rock consists of little olivine and much plagioclase. This variation will be referred to again. The rock is a phase of olivine-gabbro and corresponds to the variety "troctolite" of the English or "forellenstein" of the German petrographers. The secondary minerals are mainly serpentine, kaolinite, bastite, magnetite, and calcite. A few occurrences of corundum picotite and chromite were also noted.

Olivine.—Under the microscope the olivine has the usual appearance of this mineral and shows a variable amount of alteration from crystals of small size completely altered, to those of larger size but partly altered to serpentine. The serpentine varies considerably in color from grayish to green and yellowish. It has the usual habit of occurring in minute fibres lying normal to the fractures of the olivine. See Plate XXI.

Anorthite.—A number of measurements of the extinction angle of the feldspar were made on the plane of the brachypinacoid which averaged about 35 degrees, indicating anorthite. The small percentage of soda in the rock probably enters into the anorthite. The habit and general appearance of the fresh feldspar appears to be quite persistent throughout the thin sections examined. In the phase of troctolite very rich in anorthite the latter is usually quite translucent and free from alteration products. It is always, however, very finely fractured and in these fractures is usually a variable amount of greenish or greyish serpentine and kaolinite. The fractures in the anorthite are wider near the olivine than farther away from it, and in these fractures near the olivine the serpentine and kaolinite are accumulated. Very often small olivine crystals are seen to be entirely surrounded by large areas of anorthite in the sections and in these cases the fractures radiate from the olivine.

The shattering and fracturing of the feldspar is undoubtedly due to the alteration of the olivine to serpentine with the accompanying increase in volume. The necessary expansion in volume involved in the complete change of olivine to serpentine is about 30 per cent. There is however, in the process of alteration, a loss of SiO_2 and MgO, carried away in solution. This increase in volume of the serpentine obviously facilitates the decomposition of the minerals associated with the olivine and aids in the rapid disintegration of the troctolite.

The fresh anorthite begins to alter along the fractures to kaolinite and to calcite. As the alteration increases the calcite

EXPLANATION OF PLATES

XX AND XXI.

PLATE XX. THE GRADATIONAL PHASES OF TROCTOLITE.

Fig. 1. Polished specimen of the troctolite. Specimen 6533, three-fourths natural size. This phase consists mainly of feldspar with a smaller proportion of olivine. The light mineral is feldspar (anorthite) and the dark is olivine.

Fig. 2. Phase of the troctolite. Specimen 6537. This phase consists of about equal proportions of feldspar and olivine.

Fig. 3. Phase of the troctolite. Specimen 6539. This phase consists mainly of olivine, largely altered to serpentine.

PLATE XXI. MICROSECTIONS OF THE PHASES OF TROCTOLITE.

Figs. 1 and 2. Microsections of troctolite. Section 6532. Without analyzer, x20. These sections consist mainly of anorthite feldspar, the light colored mineral, with small quantity of olivine and enstatite, the darker mineral. The enstatite, as in Fig. 1, has a strong tendency to develop as reaction rims about the olivine. In Fig. 2, the olivine is largely altered to serpentine, causing by the increase in volume, the radial shattering of the surrounding anorthite.

Fig. 3. Microsection of troctolite rich in olivine. Section 6536. Without analyzer, x20. The olivine is largely altered to serpentine. No rims of enstatite surround the olivine.

Fig. 4. Microsection similar to the above. Section 6534. Contains no rims of enstatite about the olivine.

Fig. 1.

Fig. 2.

Fig. 3.

GRADATIONAL PHASES OF TROCTOLITE.

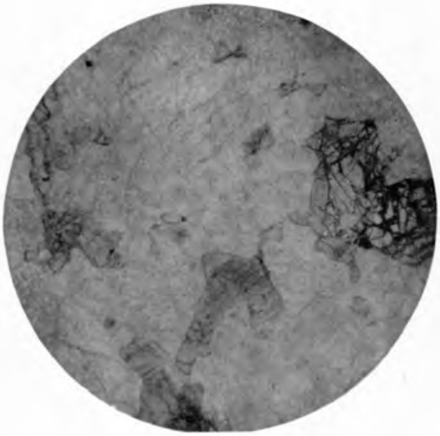

Fig. 1.

Fig. 2.

Fig. 3.

Fig. 4.

MICROSECTIONS OF OLIVINE-FELDSPAR ROCK, TROCTOLITE.

finally leaches out and the final product in the extreme metamorphism of the anorthite is an aggregate of kaolinite entirely free from calcite. Such a change is shown in the rock represented in Analysis II which contains over 9 per cent of alumina and no lime, while the thin section shows this rock to have originally contained from 10 to 15 per cent of anorthite, which is now entirely changed to an aggregate of dense kaolinite. The entire absence of lime in this analysis was somewhat of a surprise to the writer, but a close examination of the thin section of the rock analyzed revealed no calcite nor feldspar.

Enstatite.—The pyroxene reveals a bisectrix in cross-sections showing both prismatic cleavage and possesses the low bi-refringence and greyish color of enstatite. The pyroxene appears to have the character of enstatite rather than bronzite or hypersthene throughout all the thin sections examined. It is closely associated and intergrown with a brownish green mineral with lower single and double refraction, which appears to be the common alteration product of enstatite, bastite. The association of the two minerals is characteristic. The bastite usually surrounds the enstatite, forming irregular borders of variable width. The microstructure of the two minerals is the same, the cleavage and fractures being retained in the bastite. It is distinctly pleochroic and the extinction is not quite parallel to that of the enstatite.

The enstatite free from and associated with its alteration to bastite occurs in small xenomorphic crystals free from olivine and as narrow borders in contact with the olivine. While a good proportion of the enstatite is crystallized in contact with the olivine either as borders or small irregular crystals and hence seems to have been controlled in its crystallization by the olivine, there is also much enstatite separated out without apparently any regard to the olivine.

Magnetite, Chromite, Picotite, Corundum.—Magnetite occurs in considerable quantity in angular compact areas and when occurring in this form is probably an original mineral. In the altered olivine are numerous small grains of black and brown mineral, which may be in part magnetite and limonite developed by alteration. In several of the thin sections rich in olivine including the rock represented in Analysis II are numerous xenomorphic crystals of a violet gray color and also a few of brownish green color without metallic lustre. These minerals have an index of refraction somewhat higher than the olivine, are isotropic and from their color in reflected light the gray mineral is believed to be chromite and the brown picotite. In some instances the chromite is surrounded by a green rim which is probably chrome ochre. There is also present in this section a small xenomorphic, slightly bluish-gray mineral, with high single and low double refraction, which is believed to be corundum, Al_2O_3. The chromite ($Fe\ Cr_2O_4$) and picotite ($(Mg\ Fe)\ Al\ Cr_2O_4$) are in very small quantities, although the former was found in all the slides of the much weathered rock. These spinells appear to be mostly confined to the areas of altered enstatite.

The fact that free silica was not found in any of the thin sections examined of the relatively fresh rock is of especial interest on this point, for it is very probably due to this lack of silica and the inability of the bases to form salts of silicic acid that the minerals chromite, picotite and corundum have separated out. The development of the minerals periclase, MgO, and brucite, $Mg\ (OH)_2$, and bauxite, $Al_2O_32H_2O$, accompanying the above oxides, appears to be possible in the weathered magnesium-rich troctolite, although it was not found in any of the thin sections examined and probably could not be identified, if present, unless in considerable quantity.

VARIATION OF THE TROCTOLITE MAGMA.

The variation in the rock was at first thought to be due in great part to weathering, but the microscopic and chemical analyses show the rocks to differ widely in composition. On a second visit to the exposures, therefore, rock intrusions were searched for with the idea in mind that perhaps the variation was due to rock mixtures or contact metamorphism. However, no contact phenomena were observed in the exposures. The rock phases in the various exposures perceptibly grade into one another, and nothing resembling a sharp contact line is anywhere observable. Evidence of the rock phases belonging to the same geological formation is also shown in the possession of a similar texture and grain and persistent simple combination of olivine and anorthite with a small percentage of enstatite which prevails throughout. And also all gradations between the various proportions of olivine and anorthite can be traced in the rock phases. The microscopic textures and character of these minerals are everywhere alike. It appears, therefore, that the various phases of troctolite originated by differentiation from the same magma.

The variation is very strikingly apparent in the field, for in a very small area, perhaps within one-tenth or one-twelfth of a mile along the river bank at the location of the old dam, the entire rock series is exposed. Away from the dam, especially farther north in the vicinity of the mouth of the Copper river, the troctolite appears to be a phase intermediate between the above analyzed rocks, although at the latter place also the relative amount of feldspar and olivine is quite variable.

While the troctolite is simple and persistent in its mineral composition, it is unusual in the wide range and variation in the proportion of its principal minerals, the olivine and anorthite. Although the orthorhombic pyroxene occurs in all the sections, it does not amount to more than two to five per cent of the rock on an average. The variation, therefore, is in the relative amounts of the olivine and anorthite. This variation generally ranges from a rock having four times as much olivine as anorthite to a rock with these proportions reversed.

Chemical Composition.—The chemical composition of the anorthite-rich and the forsterite-rich phases of the rock is shown in the following analyses by W. W. Daniells, I and II, respectively:

Analyses of Troctolite at mouth of Copper River.

	I	II
SiO_2	40.52	35.34
Al_2O_3	27.33	9.41
Fe_2O_3	5.29	7.81
FeO	1.19	2.62
MnO	......	trace
CaO	8.90	none
MgO	8.55	31.50
K_2O	0.07	0.34
Na_2O	0.85	0.29
H_2O	7.08	13.25
Total	99.79	100.56

I. Anorthite-rich phase of troctolite (6241).
II. Forsterite-rich phase of troctolite (6244).

The alumina and lime very evidently increase and decrease together, and obviously almost entirely enter into the development of anorthite. The magnesia and iron appear to increase and decrease together, although the former has a much greater range than the latter, in fact varying much more than any other chemical constituent of the rock. The content of silica varies relatively but little. Of the seven common chemical elements of rocks, all of which are represented in this magma, the alkalies are of the least importance.

Neglecting for the present the amount of hydration shown by the analyses, it is apparent that these two rock phases differ very widely in amount of alumina, lime and magnesia.

Although the troctolite is very much weathered, the characteristic alteration of the olivine to serpentine and anorthite to kaolinite is such as to furnish a means for the close determination of the original character of the rock.

CALCULATION OF THE MINERALS OF THE UNALTERED ROCK.

The feldspar rock, from which analysis I was made, is much altered, although it was thought to represent a fairly fresh rock when selected for analysis. On account of the small content of FeO and the presence of magnetite in the rock, it may reasonably be assumed that but little, if any, ferrous iron is in either the olivine or pyroxene constituent. As previously noted, therefore, the olivine is very probably the magnesium variety forsterite.

It is impossible to calculate definitely the original composition of the rock, on account of the loss of certain elements by processes of weathering, mainly by removal of the alkali and alkali earth elements and the substitution of H_2O. On the assumption that no alumina has been removed and that all the alumina enters into the feldspar, the original content of anorthite apparently approximated 70 to 75 per cent of the rock. The original content of forsterite is somewhat more problematical, as both silica and magnesia are undoubtedly lost in the process of alteration to serpentine. It is estimated that the original content of forsterite approximated 20 to 30 per cent of this rock phase. The enstatite probably amounted to 2 or 3 per cent and the magnetite 6 to 7 per cent.

On a similar basis of calculation, the olivine-rich rock (6244) represented by analysis II appears to have originally contained about 23 to 28 per cent anorthite, 60 to 70 per cent forsterite, 2 to 3 per cent enstatite, and 5 to 10 per cent magnetite. In this rock also was noted a small quantity of corundum and spinell, both presumably of original crystallization.

It seems quite probable that there are small quantities of troctolite which contain even more than 70 to 75 per cent of anorthite; it is also quite probable that there is present in this area a considerable quantity of rock consisting almost entirely of olivine, thus developing the rock variety dunite, as evidenced by several outcrops of dark-brown-colored rock consisting essentially of serpentine. That these extreme phases of the troctolite are present would seem to be evidenced by the observed tendency to variation in the rocks analyzed.

VARIATION IN THE CHEMICAL CONSTITUENTS OF THE ROCK.

The fresh rock probably contains from 35 to 45 per cent of silica and this constancy is probably the controlling factor in the production of the simple combination of olivine and anorthite in the various phases of rock. This comparatively narrow limit in content of silica is indicated by the study of the rock phases under the microscope as well as by the phases chemically analyzed. The silica content of the anorthite is probably between 43 and 46 per cent, of forsterite 42.9 and of enstatite 60 per cent. The content of oxide in the rock, mainly magnetite, and, to a slight extent, corundum and spinell, probably varies from 5 to 12 per cent. As enstatite occurs only in small quantity the remaining 88 to 95 per cent of the rock, therefore, is mainly anorthite or forsterite which could be developed in various proportions in a magma containing from 38 to 43 per cent of silica. The microscopic study of the rocks, as above stated, indicates a probable maximum range in silica of 35 to 45 per cent.

The content of alumina, lime and magnesia varies widely, and the relative abundance of these constituents determine the development of the different proportions of the olivine and anorthite. The alumina varies, as shown by analysis, from 9.91 to 27.33 per cent. It may reasonably be assumed that the alumina content varies much greater than this, probably from less than 5 per cent to over 30 per cent. Where there is insufficient SiO_2 or CaO to combine with Al_2O_3 to form anorthite, the Al_2O_3 enters into corundum or picotite. The lime in the weathered rock, as shown by analysis, varies from none to 8.90 per cent. The original rock, as shown by the presence of the altered anorthite, contained lime sufficient to develop such anorthite. In order to develop the anorthite noted in the rocks, it may reasonably be presumed that the variation in lime ranged between less than 5 per cent to over 16 per cent in relative proportion with the alumina to produce anorthite. A possible exception may be noted in this connection in phases of the magma where an excess of alumina occurs and the consequent separation of corundum took place, as noted in certain phases of the rock.

As previously noted, the low content of ferrous oxide, FeO, seems to indicate that this constituent does not enter into the olivine or pyroxene constituent but is mainly or wholly combined with ferric oxide to form the magnetic iron noted in the rock. The analysis seems to indicate also that no defined relation exists between the content of ferrous oxide and magnesia. The content of magnesia, as shown by analyses of the weathered rock, varies from 8.55 to 31.50 per cent. In the alteration of forsterite to serpentine a relative loss of magnesia as compared with silica takes place, and in the serpentine-rich rock, like that analyzed, the original content of magnesia must have been considerably greater, presumably as much as 36 per cent.

In a rock consisting almost wholly of magnesia—olivine, over 50 per cent of MgO may reasonably be assumed to be present (pure forsterite contains 57.1 per cent MgO) and hence it seems reasonable to believe that this rock magma may vary in content of MgO from less than 5 per cent in those phases consisting mainly of anorthite to over 50 per cent in those phases consisting mainly of forsterite.

Order of Crystallization.—The orthosilicates, forsterite and anorthite, as shown by their positions with respect to one another, appear to have crystallized simultaneously, and the metasilicate, enstatite, subsequently. Neither the anorthite nor olivine possess proper crystal forms, owing to the mutual interference with each other in their development. The enstatite occurs as rims and borders about the forsterite and in no instance was this order seen to be reversed. The enstatite does not appear to form borders about the anorthite but appears as irregular shaped crystals, evidently in the interspaces between adjacent crystals of the anorthite.

THEORY OF DIFFERENTIATION OF THE ROCK PHASES.

The term, *rock differentiation,* is used to express the idea that phases of rock are formed from a parent body of homogeneous magma. The cause or causes of the processes bringing about the development of different rock phases from a common magma have not been fully demonstrated and the problem will not here be discussed. It is purposed only to point out what seems to the writer to be the dominating cause in the development of the anorthite-rich and olivine-rich phases of the gabbro of this locality.

The relatively uniform content of silica and the tendency to great variation in the amounts of alumina and lime, on the one hand, and of the magnesia, on the other, has been pointed out. The increase in lime and alumina finds expression in the increased proportion of anorthite, and the increase in the magnesia finds expression in the increased proportion of the olivine. The predominating or essential minerals crystallized in this magma, therefore, are anorthite and olivine. The accessory minerals are enstatite, corundum, and picotite, which are developed as remnants or residuals after the olivine and anorthite. The tendency in the process of differentiation of this magma is to develop two rock types, each characterized by one of these predominating minerals, the one consisting essentially of anorthite, the other consisting essentially of olivine, with various intermediate phases between. These rock types have been abundantly developed elsewhere, and are illustrated by the occurrence of the essentially feldspar rock, anorthosite, and the essentially olivine rock, dunite.

The development of a kind or type of rock consisting essentially of a single mineral at once suggests the probability that the development of such type of rock is by the same process as that by which the single or individual mineral is developed, namely, by the energy or process of crystallization. As the anerthite essentially CaO Al_2O_3, 2 S O_2, is a complimentary mineral to the olivine, essentially 2 MgO, SiO_2 in this particular magma, so the types of essentially pure anorthite rock and of olivine rock are complementary rock types or phases. The tendency, therefore, for this rock magma, consisting, originally, of a mixture of the anorthite molecules and the olivine molecules, is to split up into two rock types, the pure type of each being characterized by the occurrence of one of these minerals to the exclusion of the other, just as the chemical elements of the anorthite and olivine molecules themselves separate and congregate to form the crystals of anorthite and olivine.

This process of differentiation, dominantly at least, by process of crystallization, is believed to be well illustrated in another rock magma of this district, namely, in the nepheline-syenite magma, in which the common magma and complementary types are much more complex than those above described, of olivine gabbro, or troctolite. (See page 356.)

ALTERATION OF THE TROCTOLITE.

The analyses I and II on page 169, which show a content of 7.08 and 13.25 per cent of H_2O, indicate to what extent much of the troctolite is altered. In the microscopic descriptions of the original minerals, anorthite, forsterite, and enstatite, the secondary minerals have been referred to. It is now proposed to trace out more fully the principal molecular changes which the rock has undergone in developing these secondary minerals.

Alteration of Forsterite to Serpentine.—This olivine, which is universally one of the first silicates to be decomposed by weathering, is seen throughout the thin sections to be partly or wholly altered to serpentine. The serpentine varies considerably in color from grayish to green or yellowish, and has the usual habit of occurring in minute fibres developed normal to the surface and fractures of the forsterite. As the serpentization advances toward the center of the crystal, new fractures are formed, due to the increase in volume accompanying the development of the serpentine and along these new fractures the fibres develop until finally the complete alterations to a network of serpentine is accomplished. Along with the serpentine is also developed some magnetite or other iron oxide, and although this iron oxide is usually in small quantity it is commonly present.

The nature of the chemical change of forsterite to serpentine is indicated in the following equation:

$$2\ (2\ MgO\ SiO_2)\ (Forsterite) + water\ and\ H_2CO_3 =$$
$$3\ MgO\ SiO_2\ 2H_2O\ (Serpentine) + MgCO_3 + H_2CO_3.$$

In the change of olivine to serpentine, heat is theoretically generated according to Berthollet's law of maximum work. An important change to be noted is the great decrease in the specific gravity of serpentine, 2.55, as compared with the forsterite, 3.25. This change in specific gravity indicates a decrease in density of 27.4 per cent. There is a slight increase in volume, but the change in density is mainly accounted for by the loss of magnesia as magnesium carbonate in solution, with some loss of silica also.

Alteration of Anorthite to Kaolinite.—The principal alteration of anorthite is to kaolinite. The alteration of the olivine to serpentine causes a slight increase in volume and for this reason the rock becomes much shattered and fractures are not only developed in the unaltered olivine but also in the adjacent anorthite. These fractures in the comparatively fresh troctolite are seen to radiate from small serpentinized olivine and thus in an unmistakable manner point to their origin in the expansion due to the growth of serpentine. Along these fractures and also along the cleavage planes of the anorthite, water finds an easy access and numerous grains of calcite and a few blades of actinolite, tremolite, talc, and biotite and much kaolinite are developed. Some iron and magnesium are thus brought in from the adjoining olivine, magnetite and enstatite in order to develop some of these silicates.

As the molecular destruction of the anorthite advances, leaching of the calcium carbonate takes place, and the final product becomes a dense mass of finely granular opaque kaolinite.

The change in the alteration of anorthite to kaolinite is represented in the following equation:

$$CaO\ Al_2O_3\ 2SiO_2\ (anorthite) + water + H_2CO_3 =$$
$$2H_2O\ Al_2O_3\ 2SiO_2\ (Kaolinite) + CaCO_3 + water$$

The alkalies Na_2O and K_2O occurring to a small extent in the anorthite are carried away in solution as carbonates in a manner similar to that of the removal of the lime.

Accompanying this change, therefore, there is an entire loss of the lime and alkali constituents of the orignal feldspar. The entire loss of the lime is shown in analysis II, which represents a rock which originally contained about 25 per cent of anorthite, and hence a consequent loss of 4 to 5 per cent lime is indicated. The rock of analysis I, containing originally from 70 to 75 per cent anorthite, has evidently lost about 5 per cent of lime and alkalies.

In the alteration of anorthite with specific gravity of 2.74 to kaolinite with specific gravity of 2.60 to 2. 63 there is a decrease in density of about 5 per cent. In the process of change, heat is liberated and there is a final loss of CaO, Na_2O and K_2O carried away in solution, and in their place is substituted the H_2O molecule.

Alteration of Enstatite to Bastite.—The orthorhombic pyroxene, enstatite, which constitutes but a small percentage of the rock, has a characteristic alteration to a compact green mineral of lower birefringence than enstatite, which is believed to be the mineral bastite. The enstatite appears to be less easily altered than either the forsterite or anorthite. This change may be about as follows: Enstatite, 3 (Mg O, 2 Si O_2)+water= Bastite 3 Mg O, 2 Si O_2 H_2O+4 Si O_2. This change is accompanied by a decrease in density, 3.2 of enstatite to 2.6 bastite, amounting to 23 per cent, with accompanying loss of silica carried away in solution.

As the alteration of the enstatite advances there is developed in the enstatite areas, besides the bastite, a few blades of talc and a variable quantity of serpentine.

Development of Oxides and Carbonates.—Accompanying the development of kaolinite, serpentine, and bastite, certain oxides and carbonates are also formed in the process of the alteration of the rock. These oxide minerals, like the hydrous silicates, remain as stable and final products of the process of weathering.

Of these oxides, probably magnetite (Fe_3O_4) and limonite are the most abundant and probably constitute 1 to 2 per cent of the mass of the rock, although not of the volume. Most of the magnetite, as already stated, is undoubtedly an original crystallization. The iron oxides occur as minute grains associated with the serpentine and also in the areas of altered bytownite and enstatite. The carbonate, calcite, and very probably magnesite, occur to a considerable extent in the partially altered phases. In the completely altered phases the carbonates tend to be removed by the percolating ground water.

SECTION III. THE GRANITE-SYENITE SERIES.

This series of rocks, as already stated, consists of several phases of granite, quartz syenite, and nepheline syenite, with various related alkali-rich varieties of rock. The various phases of this series, or group of rocks, reveal a well defined relationship of origin in a common magma, as indicated by a chemical similarity in composition. This chemical relationship is expressed by the development of certain minerals, or kinds of minerals, prevailing throughout the series. The various members of this series, also bear a similar relation, stratigraphically, to other rock formations, of both sedimentary and igneous origin. On the other hand, this group of rocks does not consist of a simple intrusion of rock magma but a very complex one. Its various members intrude one another in an intricate manner, although each of these members bear a similar relation to rocks outside the series. This rock series appears to have been erupted during a single prolonged eruptive period, but no order in the intrusion has been determined for the entire series, although well defined intrusive relations are shown in many parts of the area.

GENERAL DISTRIBUTION.

The general distribution of the various rocks of this series is shown on the general geological map, Pl. I. Upon this map this series is divided into three groups or rock families, granite, quartz-syenite, and nepheline-syenite, the distribution of each being represented by areas of slightly different color.

The granite of this series is the most abundant rock found in this area. It constitutes one-half to two-thirds of the entire pre-Cambrian of the region and about 80 to 85 per cent of the granite-syenite series. The granite occurs in variable quantity over the whole of the district and can hardly be said to be more abundant in one portion of the area than in another. Good exposures of the medium-grained granite occur along the Wisconsin river in the vicinity of Granite Heights where it is quarried for building and monumental stone. Similar granite is abundant along the Big Eau Pleine river, and also along the Yellow river in central Wood county. Coarser phases of granite are abundant in the eastern part of Marathon county, and in the vicinity north and northwest of Mosinee.

The quartz-syenite occurs in the vicinity of the Wisconsin river south and southwest of Wausau and constitutes from 5 to 10 per cent of the rocks included in this series. Most of the nepheline-syenite occurs in contiguous localities from five to ten miles northwest of Wausau. It covers a combined area of five to ten square miles and constitutes less than one per cent of this rock series.

KINDS OF ROCK.

It has already been stated that this formation includes three important groups, or families, of rock, viz., granite, quartz-syenite and nepheline-syenite. The reason for grouping these various rocks together into one series has already been briefly referred to and is brought out in the following pages. In descrbing these rocks the granite and its phases will first be treated, followed by the description of the quartz-syenite, and then the nepheline-syenite and related pegmatite rocks.

RELATIONS TO ASSOCIATED FORMATIONS.

The various members of the granite-syenite series, as already stated, bear the same relation to the members of other igneous rock series, such as the rhyolite, and diorite-gabbro, and to the sedimentary series of the area. The granite and syenite intrude the basal group of igneous rocks and the lower sedimentaries, such as Rib Hill quartzite and Hamburg slate, and are likewise intrusive in the rhyolite and the diorite, greenstone and gabbro. This series, therefore, is younger than all the rocks above named.

On the other hand, the series is older than the upper sedimentry rocks, as shown by the occurrence of the conglomerate of this series upon the granite in many places in the area.

GRANITE.

The granite varies considerably in color, composition[1] and texture in the numerous outcrops throughout the area. It is composed in great part of the minerals, feldspar and quartz, and in addition to these important constituents there is usually present a variable quantity of dark-colored minerals, such as mica and amphibole, and very rarely pyroxene.

The granite rocks as usually found in surface outcrops are no longer perfectly fresh, but are more or less altered, through the ordinary processes of weathering, to numerous secondary minerals, such as epidote, calcite, chlorite, zoisite, kaolinite, and sericite.

KINDS OF GRANITE.

The various granites may be divided into several kinds or phases, such as granite, mica-granite, and amphibole-granite, the classification of which is based upon the characteristic minerals, and which also depends roughly upon the chemical composition of the rocks. With these phases occur certain modifications of the above which are classified according to important textural characteristics or habit of geological occurrence, and which include various kinds of granite breccia, dikes, veins and granite-schists.

The various types or phases of granite are not separated from one another sharply, but grade into one another. Like grades of grain and lumber, they lap over one another, and where they overlap must arbitrarily be placed with the one kind or the other. Thus, the granite proper, consisting almost wholly of feldspar and quartz and a very little or no mica, grades into a

[1] The granite as here described has a silica content greater than 65 per cent.

rock having mica, and when the latter mineral becomes important, the rock is called a mica-granite. In the same manner, mica-granite grades into amphibole-granite.

Certain phases of rock, however, stand out as clear-cut types of mica-granite or amphibole-granite, as the case may be, and about these well developed types are grouped the rocks that are most like them. In describing these various phases of the granite, not only the component minerals of the rock will be described, but also their peculiar structures, inter-growths, decomposition products, and the effects of pressure and fracturing.

GRANITE.

Under this name are included the granitic rocks which consist almost wholly of feldspar and quartz with a very little or no mica, amphibole, or other important mineral. This phase constitutes much of the reddish granite of the region and occurs in quantity at Heights, in the vicinity of Mosinee, along the Yellow river, and in various other places in the district. This kind of granite generally contains more quartz and is harder and stronger and resists weathering better than other phases of the granite. It is generally medium-grained. There is usually no apparent parallel arrangement of the quartz and feldspar in the hand specimens, although the capacity to cleave in large masses in definite directions is observable in large exposures of the rock.

The rock quarried at Heights is a fair representative of this phase of granite (5422). The formation in this locality is used extensively for monumental stone, the stone being medium-grained and of a pleasing reddish or brownish color. Under the microscope this granite is seen to consist of almost as much quartz as feldspar, and a small amount of mica. The feldspar is principally finely twinned anorthoclase, and orthoclase and albite in microperthitic intergrowth.

The chemical composition[1] of this phase of granite is as follows:

[1] Bulletin IV., Wisconsin Geol. & Nat. Hist. Survey, p. 136.

Analysis of the granite of Granite Heights.

SiO_2	76.54
Al_2O_3	13.82
Fe_2O_3	1.62
FeO	......
MgO	0.01
CaO	0.85
Na_2O	4.32
K_2O	2.31
H_2O	0.20
Total	99.67

The analysis shows this phase to be rich in soda. The thin section indicates the Na_2O and K_2O to have developed the albite and anorthoclase feldspar, and the microperthitic intergrowths of orthoclase and albite.

The granite occurring in the SE. ¼ of Sec. 18, T. 31, R. 5 E. is a fine-grained reddish granite. Under the microscope this rock (5027) is seen to consist of clear, translucent quartz and feldspar, a variety of the latter containing minute grains and specks of iron oxide. The feldspar consists of the variety anorthoclase with extinction angle on the basal pinacoid (OP) of about 5°, and a reddish variety of plagioclase, either albite or oligoclase. The anorthoclase is quite generally clear and translucent, whereas the albite is stained with minute reddish-brown specks of iron oxide. In some instances these reddish-brown albite crystals occur as well developed idiomorphic crystals within the anorthoclase. It would appear, therefore, from this relation, that the red albite crystallized first. These albite feldspars owe their reddish color to the presence of a small quantity of iron in the albite, which in weathering produces minute grains of hematite or limonite, the reddish-brown specks noted above. The red granites, therefore, owe their color, in this case at least, to the presence of these ferruginous albite crystals.

In the northeast corner of Section 5, T. 29, R. 7 E. is a fine-grained pinkish-gray granite. The microscope shows this granite (5228) to consist of about three-fourths albite and one-fourth quartz, both of which minerals are translucent and practically unaltered. The rock is considerably fractured, however, and along and near these fractures small fibres of bluish-green amphibole, small tabular plates of brown biotite, and grains of epidote and magnetite have developed.

Along the road in SE. ¼ of Sec. 16, T. 30, R. 6 E., about one-half mile north of Naugart Post Office, is medium to coarse-grained granite (5330), occurring in low outcrops and angular blocks along the small creek. This outcrop furnishes a good example of weathered granite. Under the microscope it is seen to consist of about 75 per cent feldspar and 25 per cent of quartz. The quartz usually occurs in smaller grains than the feldspar and has a wavy extinction, under cross nichols, and contains numerous minute fractures, both of which phenomena were evidently developed in the process of mashing of the rock. The feldspar is orthoclase and albite. The crystals of feldspar are in various stages of alteration and consist of an aggregation of secondary minerals, principally epidote, zoisite, kaolinite, calcite, sericite, and quartz. The alteration usually begins in the center, as seen in the cross section, and advances outward towards the boundaries. A rim of rather clear feldspar often surrounds the weathered interior, but as alteration advances this boundary, too, is decomposed. When alteration is complete the secondary minerals form an aggregation containing little sericite and much granular epidote, zoisite, kaolinite and quartz. For the development of most of these secondary minerals more or less material seems to have been brought in from outside the individual feldspar crystals, being brought thither by heated percolating waters permeating the numerous fragments of diorite enclosed in the granite of this vicinity. Most of the lime and magnesium which combined with the alumina of the feldspar to produce the epidote and zoisite and the lime of the calcite, appears to have come from outside the granite. The feldspar is somewhat fractured, but not markedly so, the alteration generally beginning along the fractures and working outward in the direction of definite crystal planes of the parent mineral.

Other phases of the granite occurring in this vicinity reveal a somewhat different method of alteration. In another phase (5332) the quartz grains possess strain shadows, and are considerably fractured and granulated about their boundaries. The feldspar, likewise, shows strain shadows in polarized light, have bent twinning lamellae, and are much fractured. This rock has been subjected to extreme pressure and some differential movement. The resultant alteration product of the feldspar is an aggregate of sericite and quartz with little kaolinite. There is an entire absence of the equi-dimensional minerals zoisite, epidote and calcite, so abundant in the associated granite (5330). The sericite occurs in approximate parallel fibres, bending about the grains of quartz and ungranulated feldspar. The apparent development of sericite in parallel fibres in mashed feldspathic rocks has often been described.[1]

The granite in the SW. corner of Sec. 19, T. 30, R. 8 E., furnishes a good example of rock dynamically metamorphosed and brecciated in the zone of fracture. This phase (5410) is fine-grained and reveals minute veinings threading the rock. Under the microscope with low power it is seen to consist of angular fragments of rock closely fitting and finely cemented together by quartz and feldspar; with high power, hundreds of fractures are seen to permeate the fragments and many of these fractures very clearly are planes of shearing and faulting along which the rock particles have moved past one another. Some of the feldspars are much more granulated and weathered than others. The quartz grains possess strain shadows and are granulated; the plagioclase crystals are much granulated and have bent twinning lamellae. Along the fractures throughout this brecciated granite, alteration and replacement of the feldspar has taken place. The secondary minerals thus formed are mainly epidote and zoisite, which apparently have been developed by the addition of material brought in from outside, through the fracture channels of the brecciated rock. In the SW. ¼ of Sec. 24, T. 31, R. 10 E., is a coarse, mashed and brecciated granite (6234), very much like the above described rock (5410).

In Lot 21, Section 6, T. 29, R. 9 E., is a fine-grained flesh-colored granite. Under the microscope this rock (5124) is seen to consist of almost as much quartz as feldspar. The translucent quartz crystals have the wavy strain shadows due to the effects of pressure. The effects of pressure are also shown by the fractures running through the rock which are now filled with secondary minerals. The secondary minerals in the veins are mostly zoisite, with a very little quartz, and some epidote. The

[1] Williams, G. H., Bulletin U. S. Geol. Surv. No. 62, pp. 62 and 212.

crystals of zoisite have a high refringence and are always without terminal faces, but have distinct cleavage parallel to their vertical axes and across the jointing. The zoisite appears to consist of two intergrown varieties, one being colorless, and the other having a yellowish-red pleochroism. The latter is probably the manganiferous variety of zoisite, thulite. In polarized light, it is seen to be twinned polysynthetically like the albite and has a lower birefringence than the latter mineral and an extinction parallel to the cleavage lines. Fibrous green hornblende is developed in the zoisite in some instances parallel to the vertical cleavage.

The rock forming the ledge along the road in NE. ¼ of Sec. 16, T. 30, R. 6, furnishes a good example of granite containing veins, composed mainly of epidote, zoisite and quartz. The thin section of this rock (5348) shows much more epidote than zoisite. The quartz is most abundant next to the border of the vein and the epidote and zoisite in the center of the vein. The characteristic cleavage, absence of terminal faces, parallel extinction, and low birefringence of the zoisite distinguish this mineral from the epidote, which as a vein mineral has well developed crystal form and orthopinacoidal twinning.

In the south ½ of NW. ¼ of Sec. 27, T. 29, R. 8 E., is a greenish-gray, medium-grained granite (5128). The orthoclase is considerably altered to sericite, calcite and chlorite. These secondary minerals occur in small grains and flakes scattered throughout the feldspar crystals. Numerous veins and crystals of iron pyrite are seen in the thin section and are also apparent in the hand specimen.

MICA-GRANITE.

This phase of the granite consists of feldspar, quartz and an appreciable quantity of mica, which may be either the variety biotite or muscovite, or both. This granite is generally grayish and is usually medium-grained. It is closely associated with the above described phase of granite, containing little or no mica, and readily grades into the latter. In fact, no considerable area of the granite formation occurs in the region without the presence of this phase in some quantity. It is more abundant than the mica-free variety and is probably more abundant also than the amphibole variety, although it forms smaller but more numerous areas than the latter.

In the southeast corner of Sec. 2, T. 31, R. 7 E., is a medium-grained grayish granite rock, a fair representative of the mica-granite. Under the microscope this rock is seen to consist of orthoclase and quartz in about equal proportions. The rock is somewhat mashed and the effect of pressure is shown by the bent twinning lamellae of the feldspar and undulatory extinction of the quartz. The two varieties of mica, biotite and muscovite, are present in about equal proportions and together constitute three or four per cent of the rock. The brown biotite and colorless muscovite occur as free individuals and are also intergrown with one another. The mica occurs in patches and streaks in the thin section, and may, in part, be due to alteration of the feldspar. The presence of both micas in this rock would designate it as biotite-muscovite granite, and the small amount of mica shows its close similarity to the mica-free granite.

In the SE. ¼ of Sec. 26, T. 32, R. 7 E., is a fine-grained gray granite (5078), the thin sections of which show the feldspar to consist of orthoclase with zonal growth and finely twinned albite. The quartz constitutes about one-third of the rock. The orthoclase contains secondary growths of sericite and kaolinite. The mica, which constitutes about five per cent of the rock, is almost entirely the brown variety, biotite, which occurs in tabular plates. Colorless epidote occurs in small quantity, and about the epidote is much brown biotite, the latter to all appearances developing with the former. A small amount of muscovite is also present.

In the NE. ¼, NE. ¼ of Sec. 9, T. 29, R. 9 E., are medium-grained gray granites (5218, 5219) containing porphyritic crystals of orthoclase and small patches of biotite. The granite in this vicinity consists of much orthoclase, little albite, and about thirty per cent of quartz. The quartz possesses strain shadows and the feldspar is somewhat fractured. The feldspar is altered considerably to saussurite and kaolinite. The biotite, which constitutes about 5 per cent of the rock, occurs as compact, good-sized crystals and also as small flakes. In some cases, at least, the biotite occurs as a rim about brown epidote or is closely intergrown with the latter in such a manner as to indicate a contemporaneous development.

Near the W. ¼ post of Sec. 32, T. 30, R. 7 E., is a fine-grained grayish granite (5249) which consists of about 60 per cent of orthoclase and albite and 30 per cent of quartz, and 10 per cent of biotite. The feldspar contains numerous secondary inclusions of small flakes of biotite, sericite, and also some grains of quartz. Most of the biotite, however, in this rock appears to be an early crystallization, for it occurs, like the quartz, intergrown with the feldspar. The large crystals of biotite which occur in broad, tabular forms do not have a parallel arrangement like the smaller flaky crystals which are distributed along the fracture planes in approximate parallel orientation. Some of the biotite is altered to chlorite, and there is also a secondary development of fibrous green hornblende associated with the fibrous biotite.

In the upper end of the Three Roll Falls of the Eau Claire river in NW. ¼ of Sec. 34, T. 30, R. 10 E. is a dike of biotite granite (5299). This rock is medium-grained and grayish in color. The feldspar, which constitutes about 75 per cent of the rock, is mostly orthoclase and microcline, with very little or no albite or oligoclase. Quartz forms about 18 per cent and biotite 7 per cent of the rock. This granite has a tendency to porphyritic development, as shown by the formation of large crystals of orthoclase and microcline, while the smaller grains of feldspar have a tendency to form granophyric intergrowth with quartz. This porphyritic or granophyric structure is probably due to its geological occurrence as a dike and its consequent rapid rate of cooling and crystallization. The biotite occurs in tabular crystals interlocking with the quartz and feldspar in such a manner as to indicate its original crystallization. A few needles of apatite are imbedded in the orthoclase crystals. This rock does not appear to differ essentially in chemical composition from the amphibole granite which it intrudes. In the dike, biotite has developed, whereas in the granite of the vicinity, amphibole has formed.

In the NE. corner of Sec. 4, T. 27, R. 6 E. is a reddish-medium-grained granite (5612) containing good-sized crystals of feldspar and quartz and abundance of biotite. Under the microscope it is seen to consist of about 75 per cent of orthoclase and microcline with a little albite, 25 per cent of quartz and 5 per cent of biotite. The small amount of quartz in this rock shows its close relation to the amphibole granite and the quartz syenite. This rock was collected from comparatively fresh material taken from a well, yet the feldspar contains some secondary inclusions of sericite, reddish iron oxide, and kaolinite, which gives the feldspar a reddish color. The biotite has the usual development of interlocking with quartz and feldspar.

Phases of biotite granite occur in Athens along the north bank of the Black Creek in the vicinity of the mill dam. This granite (5975) is medium-grained and somewhat mashed. It contains good-sized crystals of feldspar from 3 to 6mm. in diameter and much fibrous biotite. Under the microscope the rock is seen to have been subjected to extreme pressure. The feldspar and quartz is granulated and the biotite is apparently distributed through the granulated parts of the parallel fibers. The elongated crystals of biotite bend about the large crystals of feldspar and have the structure or arrangement of having been formed under great pressure during the process of mashing of the granite. Such a rock when subjected to still greater pressure finally becomes completely granulated, loses its granitoid texture, and becomes a type of biotite schist or granite schist.

The granite occurring in the vicinity of W. ¼ post of Sec. 19, T. 30, R. 5 E., along the east bank of the Big Rib river, is very similar to that occurring at Athens in being mashed, and having a granulated texture of feldspar and quartz, and parallel fibrous development of the mica. Both biotite and muscovite are present in this rock, the former the more abundant, and there are also present fine prisms of green hornblende intergrown with biotite.

AMPHIBOLE-GRANITE.

The amphibole granite consists of feldspar, quartz and an appreciable amount of one or more varieties of amphibole. This phase of the granite formation is generally coarser grained than the mica-granite or the mica-free-granite. It is quite abundant in this region and forms a large part of the granite formation in the eastern part of Marathon County and is also in considerable quantity in the vicinity north and northwest of Mosinee. Besides forming the large tracts in the vicinities just mentioned, it is also found in small quantities associated with other phases of the granite throughout the region.

Amphibole granite occurs in abundance in the SE. ¼ of Sec. 35, T. 31, R. 7 E. The granite (5092) in this vicinity is medium to coarse-grained, and consists of feldspar, quartz, and amphibole. The prevailing feldspars are orthoclase and microcline, constituting about 60 per cent of the rock. Quartz forms about 25 per cent, and green hornblende, including a small amount of biotite, about 15 per cent. The rock, which was collected from a well, examined under the microscope, shows but little weathering. Some of the orthoclase crystals, however, contain small flakes of kaolinite and biotite and some granular epidote. This rock is somewhat fractured and the pressure effects are well shown in the strain shadows of the quartz. The amphibole appears to be the common green variety with bluish, brownish, and yellowish green pleochroism. Tabular plates and fibers of biotite are closely associated with the hornblende and in some instances is secondary after the hornblende, as is evidenced by its occurrence about the borders of large crystals of hornblende and along the fractures through the latter. Magnetite and apatite are also present in this rock to a small extent.

Coarse-grained reddish amphibole granite (5298) is abundant at the upper end of the Three Roll Falls of the Eau Claire river in the NW. ¼ of Sec. 34, T. 30, R. 10 E. This rock is characterized by reddish crystals of feldspar, most of them being from one-half to three-fourths inches in diameter. The quartz crystals are generally somewhat less than one-half inch in diameter, and the amphibole is of about the same dimensions as the quartz. Feldspar constitutes about 60 per cent of the rock, quartz about 25 per cent, and amphibole 15 per cent. Granite of this sort appears to be abundant over the western part of Marathon county and along the Eau Claire river in the southwestern part of Langlade county. The feldspar as seen in the thin section appears to be mostly orthoclase and microcline, and is slightly altered in places to kaolinite and sericite. Both the feldspar and quartz are considerably fractured, the latter exhibiting abundant strain shadows. The quartz contains a few crystals of apatite and also some very minute needles, which are probably apatite or rutile. The amphibole is a dark green variety either hornblende proper, or pargasite, having bluish, brownish, and yellowish tints. Brown biotite appears in small quantities. This rock, so far as the thin section of this specimen shows, is very simple in its mineral composition. The chemical composition of this rock as analyzed by Prof. W. W. Daniells is as follows.

Analysis of Amphibole-granite of Three Roll Falls.

SiO_2	67.99
Al_2O_3	15.85
Fe_2O_3 } FeO	5.36
MnO	—
CaO	1.78
MgO	0.41
Na_2O	3.21
K_2O	4.81
H_2O	1.30
Total	99.71

The low content of magnesia, a characteristic of all phases of this series of rocks, is worthy of note.

The amphibole of the granite at Three Roll Falls was separated from the rock and analyzed also. It was desired that the amphibole present in the phase above described be analyzed, but as most of this specimen, 5298, was used for analysis, a large sample, 6655, from the same place, was collected, from which the good sized crystals of amphibole were obtained by a careful hand separation. The analysis of the amphibole, made by Prof. Victor Lenher, is as follows:

Analysis of Amphibole of the Granite of Three Roll Falls.

SiO_2	39.17
Al_2O_3	16.48
Fe_2O_3	21.02
FeO	6.82
MgO	4.95
CaO	6.81
Na_2O	1.50
K_2O	1.26
TiO_2	none
P_2O_5	none
H_2O at 105°–110°	0.28
H_2O, at red heat	0.84
Total	99.13

This amphibole appears to be an unusual one in some respects. It should be classed, probably, as a variety of the alumina-rich amphibole low in silica and low in the alkalies, which have come to be grouped under the general name of pargasite. The amphibole is especially rich in ferric oxide and alumina, being higher in ferric oxide than others recorded of this type. While being unusual in some respects, this amphibole is much like the other amphiboles in alumina and iron oxide occurring in the related rocks of this series.

Amphibole-bearing granite (5247) was collected from the well of Herman Imm in the SE. ¼ SW.¼ of Sec. 32, T. 30, R. 7 E. This rock is grayish and fine-grained, and being from a considerable depth below the surface is quite fresh. It has a streaky appearance and looks like a mashed granulated rock. Under the microscope it is seen to possess almost as much quartz as feldspar. The feldspar is orthoclase and albite in about equal proportions. The feldspar and quartz occur in small, rather uniform grains, and do not reveal the effects of pressure unless it be by their rounded granulated character. The rock appears to have been wholly recrystallized during the mashing process. The amphibole occurs in small crystals and has the pleochroism, extinction, and refringence of common green hornblende. The hornblende is intergrown in places with biotite. Some apatite and magnetite are present.

Amphibole granite, collected from a well in NE. corner of Sec. 32, T. 27, R. 6 E., is very similar in all respects to the above (5247), except that it is finer grained. There is also more biotite in the latter and there is present some epidote intergrown with the hornblende and biotite.

Much of the rock forming the rapids at Merrill is amphibole granite. The granite 5007 forming the ledge below the wagon bridge on the east side of the Wisconsin river is medium to coarse-grained, and consists of feldspar, quartz and amphibole. This phase contains numerous fractures and shows other evidence of dynamic metamorphism. Another phase (5017) from the island above the bridge in Merrill is very similar to the above and may properly be described with it. Under the microscope these rocks are seen to be much fractured and granulated. The thin sections consist of albite, orthoclase, quartz and amphibole. The quartz is granulated and shows strain shadows. The feldspar is likewise granulated about their borders and the twinning lamellae are often bent. Zones of fracture that extend through the rock contain parallel oriented green hornblende and small grains of quartz and feldspar. Large crystals of green-hornblende are also present which appear to be an original crystallization, as shown by the fractures which penetrate them. These large crystals of hornblende contain numerous inclusions of quartz and also of magnetite. Similar quartz grains occur in the feldspar, and in both cases these may have originated through decomposition. The feldspar in places is colored a dirty gray by the presence of numerous inclusions of minute blades of kaolinite, sericite and hornblende. The large crystals of green hornblende contain numerous inclusions of chlorite, epidote, pyrite, and biotite. In some cases the compact hornblende is entirely replaced by these latter minerals. In the fractures the fibrous hornblende is intergrown with chlorite and biotite.

A phase of the amphibole granite (5045), collected from a large block showing contact with diorite, along the road near the east quarter post of Sec. 34, T. 31, R. 5 E., shows very well the development of fibrous green hornblende in the granite. This granite may have been originally a quartz-feldspar rock, but in the process of mashing and granulation of the quartz and feldspar numerous needles and fibres of the hornblende have been developed. Much of the material for the development of the hornblende may have been derived from the adjacent diorite at the time of the granite intrusion.

The coarse amphibole granite (5626) occurring in the vicinity of Dessert Junction contains considerable brown biotite as well as amphibole. The rock is filled with many fracture veins containing fine quartz biotite and epidote. Apatite occurs in numerous small crystals.

GRANITE BRECCIA, VEINS, AND DIKES.

In the foregoing, various phases of the granite formation have been described, whose classification is based upon the mineralogical composition of the rock. With these granites should also be included certain associated phases differing from the latter in possessing definite structures or textures and occurring as breccias, veins, or dikes, either within the granite or the adjacent rocks. These granite breccias, veins, and dikes constitute an important part of the granite formation and are especially significant because they originated in connection with the intrusion of the granite magma.

Granite Breccia.—Under this name is described a mixed rock of intrusive origin consisting generally of angular fragments of fine-grained diorite or diabase, enclosed in a framework, or groundmass, of the granite. The granite breccias differ in origin from the brecciated granite referred to on page 183, which was evidently formed by fracturing due to compression of the granite at a period much later than the intrusion of the magma. The breccia here described is of deep seated origin and was formed at the boundaries of the great boss, or batholite, constituting the intrusive granite of the region. At a number of places along the contact of granite with the rhyolite, angular fragments and ellipsoids of the rhyolite are imbedded in the massive coarse-grained granite at quite long distances from the located contact of these formations. Although at all the contacts of the granite with the older rocks there is more or less of intrusive phenomena, it is only where the granite has intruded the diorite-gabbro rocks that granite breccias have been developed in large quantity.

This granite breccia or mixed rock is best developed in the area of the south ½ of T. 29, R. 6 E., in the vicinity of, and also northwest, of Marathon city. In this area there is a zone of the mixed rock apparently two or three miles in width. In the vicinity of Scott Creek bridge about a mile west of Marathon City there is an abundance of the mixed rock, reference to which, in connection with the gabbro at the latter place, has already been made. In this vicinity the protrusion of the granite into the gabbro is well shown and all stages of the mixture of the two rocks may be seen. The general character of this intermixture of the two formations is shown in the photographs of some phases of the breccia. (Plates XXII and XXIII.)

Aplite Veins.—Aplite is a fine-grained mixture of quartz and feldspar with granitic texture occurring as veins in the granite and adjoining rocks. All stages between the granite breccia and veins penetrating the adjoining diorite-gabbro formation occur in the area northeast of Marathon City. Similar aplite veins penetrate the basal gneiss, already described, being developed in the gneiss in parallel leaves or laminae. These veins extend from the granite mass and may have been formed during the later stages of consolidation of the granite magma, and are of igneous or aqueo-igneous origin. Some of the veins, however, may have formed in fractures and fissures at a period later than the consolidation of the granite magma, through deposition of granitic material carried by percolating waters, and may be of aqueous origin alone. The veins of granite associated with the granite breccia of course are mostly of igneous origin, although the intermixture of the granite breccia with breccia matrix, consisting simply of quartz instead of more complex granitic material, shows the gradation of the breccia of true igneous origin to a phase which may have been developed by solutions rich in quartz only, rather than complex igneous material.

As an example of the intrusive granite veins may be cited those fine-grained granites, consisting of quartz and feldspar, which penetrate the coarse diorite and fine-grained diorite forming the rapids of the Wisconsin river at Mosinee. These veins grow appreciably wider and assume a texture similar to the medium-grained granite as they are followed toward the massive granite ledges on the east side of the river. The granite here is the latest in origin and contains numerous fragments of both the coarse and fine-grained diorite and it appears therefore that the aplite veins are apophyses of the later granitic intrusion.

Similar aplitic veins were noted in the diorite bordering the granite area along the small stream in the NW. ¼ NW. ¼ of Sec. 29, T. 29, R. 6 E., about one-half mile west of Stettin P. O. In this vicinity are numerous veins varying from mere films to sheets nearly a foot in thickness. A short distance south of the area of the aplite veins are numerous low ledges and huge blocks of granite breccia consisting of fragments of the diorite of various sizes, enclosed in the medium-grained granite. In both the above places it appears very probable that the aplite veins are of igneous origin and contemporaneous with the granite associated with them.

On the other hand, granitic veins, or aplite, occur in the granite and overlying sedimentary formation in SE. ¼ of Sec. 4, T. 30, R. 6 E., which unquestionably originated not only later than the consolidation of the granite, but also later than the overlying formation, which is made up of detritus of the granite formation. These veins (5857, 6471) consist of fine-grained feldspar and quartz without any biotite or other ferro-magnesian mineral. They stand nearly vertical and vary in thickness from a fraction of an inch to three or four inches, and rapidly thin out and widen like quartz veins. They were probably formed like quartz veins in fractures of granite and adjacent graywacke, through the agency of percolating waters bearing solutions of granitic material.

Pegmatite-Granite.—Pegmatite-granite or pegmatite occurs in veins or zones and consists essentially of feldspar, quartz, and often a variable amount of white or brown mica. The distinguishing feature of the pegmatite-granite is its extreme coarseness and its tendency to develop the granophyric structure. Pegmatite veins have already been described as forming an important part of the basal gneiss. This phase also occurs to a small extent in the massive intrusive granite.

Coarse granite (5204) near the NE. corner of Sec. 25, T. 28, R. 8 E., furnishes a good example of the pegmatite. It is well exposed along the road near the small stream in the above locality where it occurs as veins or dikes in the medium-grained massive granite. It consists of large crystals of feldspar, probably

EXPLANATION OF PLATES

XXII AND XXIII.

Plate XXII. Diorite in Intrusive Contact with Granite.

Near Marathon City. Natural size. The specimen illustrates the inter mixture of the light colored granite magma with the dark colored diorite. Very commonly small and large angular fragments of diorite are scattered throughout the granite. The boundaries between the two rock formations can usually be easily distinguished.

Plate XXIII. Diorite Containing Quartz at Contact with Granite.

Same locality as above. In places the intruding granitic magma consists largely or wholly of quartz as illustrated in this photograph.

DIORITE AT CONTACT WITH INTRUSIVE GRANITE.

DIORITE CONTAINING QUARTZ FROM INTRUSIVE GRANITE.

orthoclase, many of them apparently measuring nearly a foot in diameter, which enclose small angular areas of quartz in such a manner as to give the quartz when seen in transverse section the appearance of Hebrew writing in the background of the feldspar. The feldspar and quartz have crystallized together with their principal axis in parallel position. Muscovite also occurs in this rock, closely associated with the quartz areas. Pegmatite also occurs in the granite at the dells of the Prairie river. Pegmatite veins and masses are usually regarded as being developed in the final stages of consolidation of the rock magma of which they form a part, and often occur as a zone bordering intrusive bosses of plutonic rock. As such bordering zones of pegmatite it occurs in considerable abundance as a phase of the quartz-syenite and to a small extent of the nepheline-syenite, and will be referred to again in connection with those rock phases.

Micrographic Granite.—Very often granite veins assume the texture of micrographic granite which consists of graphic intergrowth of quartz and feldspar which can only be detected with the microscope and hence called micrographic granite. Rocks of similar texture are called "granophyre" by Rosenbush. Micrographic granite is also called micropegmatite because of its similarity to the coarse graphic pegmatites.

Two phases of micrographic granite may be differentiated which undoubtedly grade into one another. One kind consists of quartz and feldspar forming a micrographic ground mass enclosing idiomorphic phenocrysts of feldspar; and the other kind consists of graphic intergrowth of all the quartz and feldspar without phenocrysts.

A fine-grained vein (5704) in the granite at Marathon City represents the first kind and consists of idiomorphic crystals of plagioclase partially altered to kaolinite and muscovite surrounded by a form of fresher appearing feldspar, orthoclase and microcline intergrown graphically with quartz. The idomorphic plagioclase appears to have been broken apart before the development of the micrographic groundmass.

The fine-grained dike (5413) in the granite at Heights, in the quarry southwest of the depot, is a representative of the second kind. Under the microscope all the quartz and feldspar is seen to be intergrown in a graphic texture.

A dike (5188) in the gabbro at the dam in the Eau Claire river in the SW. ¼ of Sec. 13, T. 28, R. 8 E., is a fine-grained graphic granite like the above, but somewhat coarser.

Ryolite-granite having micrographic phases has already been described in connection with the rhyolite at Wausau. Micrographic granites are transition phases between rocks of granitic and rhyolitic structures and as dike rocks and parts of rhyolite magmas probably solidify under somewhat similar conditions. For this reason it is not always possible from the field relation to correlate isolated occurrences of micrographic granite. Several ledges of rock in the SE. ¼ SE. ¼ of Sec. 36, T. 29, R. 7 E., in Wausau, consist apparently of phases of micrographic granite, which may belong either with the rhyolite, or with the quartz-syenite of this vicinity, or may represent recrystallized rhyolite due to the intrusion of the rhyolite by the granite and quartz-syenite.

In the SE. ¼ of the NW. ¼ of Sec. 22, T. 29, R. 8 E., are species of micrographic granite (5130, 5131) which may be a phase of the rhyolite or of granite dikes. The same may be said of several other occurrences of this phase of rock where the field relation could not be determined.

GRANITE SCHIST.

Granite schist denotes a granite with schistose structure. This structure is a laminated or streaky texture, due to the approximate parallel arrangement of minerals, generally mica or amphibole, and more rarely quartz or feldspar. Most, if not all, the granite schists were formed long after the intrusion of the granite magma, by compression due to earth movements. This variety of granite is abundant in the basal group which has been fully described in previous pages of this report. It also occurs in small quantity in narrow or broad zones of the intrusive granite, where this formation has been subjected to extreme dynamic metamorphism, and where movement has taken place.

The intrusive granite schist, instead of being generally formed by alternating bands of different rock types more or less mashed together, with partial injections of quartz and granitic material, has, on the other hand, been developed generally by mashing of the homogeneous massive granite, with consequent recrystallization and development of new minerals with parallel arrangement. Some of the schistose phases of the granite have already been referred to, for there are all gradations between this rock and the massive granite.

In the SE. 1/4 SE. 1/4 of Sec. 1, T. 30, R. 2 E., is a rock phase 5979, which furnishes a good example of the granite schist. The schistose structure is better seen in the hand specimen or in large exposures of the rock than in the microscopic section. The schist consists of whitish, translucent crystals of feldspar and quartz, seemingly in layers between the parallel plates of brown biotite. The granite has a streaky character, due to the alternating stringers of dark biotite plates and the much broader strips of light-colored feldspar and quartz. Under the microscope this streaky character is not so well shown because large surfaces of the rock cannot be seen. The rock consists of about 75 per cent of feldspar, 23 per cent of quartz, and 2 per cent of brown biotite. The feldspar consists of microcline and orthoclase with very little or no plagioclase. The microcline appears to be the more abundant, and is distinguished from the orthoclase by its characteristic cross-twinning and the grating structure shown in polarized light. A further difference between these varieties of feldspar is also shown in ordinary light, due to the slight discoloration of the orthoclase brought about by the decomposition of the latter. It is a well known fact that the microcline structure is often secondarily developed by pressure, and this may be the explanation of the fresher and newer appearance of the microcline than of the orthoclase associated with it. Evidence of recrystallization of the microcline is also shown by the comparative absence of fractures in the microcline and from their abundance in the orthoclase. The crystals of microcline are somewhat elongated in a plane parrallel to the elongated biotite plates. The quartz crystals are granulated, have an undulatory extinction, and often appear to be arranged with their longer axes approximately parallel to the longer axes of the biotite crystals. The biotite plates without exception have their longer axes in a common direction, but do not have a common crystallograpihc orientation, as shown by their extinction in polarized light. The proportions between the lengths of the short and long axes of the biotite, as seen in cross section, is generally about 1 to 4.

Other examples of granite schist (5099 and 5100) occur at the lower end of Grandfather Falls. In the vicinity of the ledges of schistose granite, all gradations between the schistose and massive varieties are present. The schistose granite was apparently developed by the mashing of the massive granite and is probably distributed in seams or zones of variable width throughout the area of granite rocks, being closely associated with areas of faulting and shearing of the granite.

QUARTZ-SYENITE.

The normal quartz-bearing syenite is a medium-grained rock quite generally having a reddish color, but varying in places to grayish. It is composed mainly of alkali-feldspars, and subordinately of amphibole, pyroxene, quartz, mica, and fayalite. Quite generally, in minor quantity, are fluorite, apatite, zircon, and magnetite. As usually found in surface outcrops, the syenite is altered to a variable extent, and such minerals as epidote, chlorite, zoisite, kaolinite, and sericite are quite generally present.

The quartz-bearing syenites, following the usage of Brögger,[1] include the alkalic rocks containing less than 65 to 67 per cent of silica. Thus, an arbitrary line separates the quartz-syenites chemically from the granites. There is a marked difference mineralogically, however, in the quartz-syenite of average composition and that of the granite, since the former contains abundant pyroxene, and usually fayalite, while in the granite neither of these minerals is developed unless in very minor quantity. The area of the quartz-bearing syenite as shown upon the general geological map, Plate I, is mainly within the central and southern portion of Marathon County, and not far removed from the more basic phases of this rock series, such as the nepheline-bearing syenites and related rocks. It constitutes from 5 to

[1] Zeit-fur Kryst. B. 16, p. 81, 1890.

10 per cent of the area occupied by the rocks of the granite-syenite series.

Kinds of Quartz-Syenite.—The quartz-syenite varies somewhat in character in different parts of the area, and hence several types or kinds may be differentiated. The names here applied are only provisional, and further study, both microscopic and chemical may show it advisable to substitute special names for some of the rocks here described as typical of, or predominating in, certain localities. For the present, however, the provisional naming of these types is of practical value for descriptive purposes and should be an aid in the future study of these rocks.

WAUSAU TYPE OF QUARTZ SYENITE.

A common phase of the quartz-bearing syenite is a medium-grained rock containing a large proportion of alkali feldspars, and a variable minor proportion of amphibole, pyroxene, quartz, mica and fayalite. This rock forms the principle portion of the rapids in the Wisconsin River at Wausau and hence it may be conveniently referred to as the "Wausau type." In Irving's earlier accounts,[1] this rock is described as a syenite, but in the latter report[2] it is called hornblende-granite, presumably a granite on account of the presence of quartz.

Macroscopic Character.

This rock is quite abundant and is generally brownish pink, varying to grayish, in color. On the whole, the rock is medium grained, the coarser phases containing feldspar reaching one-fourth inch in diameter. The predominating rock minerals are associated in the common granitoid texture, in mutually interfering approximately equidimensional grains. The minerals generally apparent to the naked eye are feldspar, amphibole, pyroxene, mica and quartz and fayalite. Feldspar

[1] Geol. of Wis., Vol. II, p. 487.

[2] Geol. of Wis., Vol. IV, pp. 661–663, 670–674.

is the abundant mineral. As the rock becomes much weathered, the feldspar assumes a grayish-yellow tint, in sharp contrast with the dark-colored silicates, which gives the rock a somewhat spotted appearance.

This type is closely associated in the river at Wausau with a finer grained, otherwise quite similar rock. In places, the fine-grained rock is enclosed within the coarse-grained, and in places the coarser seems to be within the finer. In places also, the two are intermingled and grade into one another. Stringers of black basic rock probably fragments of an older diorite formation which the granite-syenite magma intrudes also occur in places in the medium-grained rock. See Plate XXIV.

The rock is quite generally jointed, with large and small joints, which extend in various directions throughout the formation.

Chemical Composition.

The composition of the common phase of the granite-syenite (5917) occurring in the rapids at Wausau, analyzed by W. W. Daniels, is as follows:

Analysis of Quartz-syenite at Wausau.

SiO_2	61.18
Al_2O_3	19.72
Fe_2O_3	3.71
FeO	1.32
CaO	2 64
MgO	none
Na_2O	5.28
K_2O	5.66
H_2O	0.32
Total	99.83

The chemical composition of this rock is quite similar to the akerite (augite quartz-syenite) and nordmarkite (red quartz-syenite) of the Christiana region, described by Brögger[1] and the quartz-syenite of Arkansas described by Williams.[2] It differs

1 Zeit für Kryst, u. Min., B. GVI, p. 81, 1894.

2 Ark. Geol. Survey, Vol. II, p. 99, 1891.

Fig. 1. QUARTZ-SYENITE AT WAUSAU WITH INCLUSIONS OF DIORITE.

Fig. 2. QUARTZ-SYENITE AT WAUSAU WITH INCLUSIONS OF SYENITE.

from these, however, in containing a much smaller amount of magnesia, and, in consequence, there is a marked difference between the dark-colored iron silicate minerals of these Wisconsin rocks and those of the quartz-syenite of Norway and Arkansas.

Microscopic Character.

Under the microscope there are seen in thin sections of this type of syenite, the following minerals: Alkali feldspars, amphibole, pyroxene, quartz, fayalite, mica, magnetite, apatite, and fluorite.

Feldspar.—Feldspar is the most abundant mineral of the quartz-syenite and generally constitutes from 60 to 75 per cent of the rock. The varieties present are the alkalic feldspars, viz., orthoclase, albite, microcline, and microperthite.

Orthoclase in homogeneous individual crystals does not appear to be abundant. The orthoclase present is associated with albite and microperthite, and generally occurs in allotriomorphic crystals with nearly equal diameters. Sometimes it has a tabular development parallel to the clinopinnacoid. The orthoclase has the usual appearance of this mineral, and in the weathered phases of the rock it contains numerous inclusions of sericite, kaolin, and other alteration products.

Albite does not appear to be abundant as individual crystals, but is very abundant as constituent portions of the microperthite.

Microcline with cross-twinning in basal sections according to the albite and pericline laws is very rare as individual crystals The microcline present is mainly intergrown with albite to form microperthite.

The most abundant feldspar of this phase of the quartz-bearing syenite, as well as of all the syenitic rocks, both quartz and nepheline-bearing, is microperthite, consisting of intergrowths of orthoclase and albite, or of microcline and albite. Under the cross nicols, the microperthite is seen to consist of alternating strips of variable and irregular width of two kinds of feldspar substance, which extinguish at different angles and possess different birefringence, and therefore appear as dark and light-colored plates as the section is rotated under the nicols. These strips or lamellae of different polarized feldspars appear to possess definite positions in the microperthite crystals (See page 260).

The composition of the intergrown feldspar constituting the microperthite is variable within narrow limits. Examined in sections approximately parallel to the brachypinacoid and basal pinacoid, these perthite growths are seen to extinguish at the angles corresponding to albite, orthoclase and microcline. Two kinds of feldspar are included in a single microperthite crystal, and albite with either orthoclase or microcline may be found.

Quartz.—The quartz of the quartz-bearing syenite has the usual character of this mineral. It fills the angular interspaces between the feldspars and also forms good-sized equidimensional crystals. The quartz content varies considerably in different thin sections, but on the average it is probably more abundant than either the pyroxene or the amphibole in this phase of rock. It probably forms from 5 to 10 per cent of the rock.

Amphibole.

Barkevikite.—The amphibole is quite strongly pleochroic in tints of yellowish-green and brownish-green. The bluish tones of arfvedsonite are not present. The extinction angle on b(101) with the prismatic cleavage is from 10 to 15 degrees.

The amphibole was separated by use of the silver thallium nitrate fluid, and analyzed by Victor Lenher, with the following result:

Analysis of Amphibole (Barkevikite) of Quartz-syenite at Wausau

SiO_2	42.50
Al_2O_2	9.91
Fe_2O_3	5.07
FeO	22.51
MnO	trace
MgO	2.39
CaO	11.35
Na_2O	1.92
K_2O	3.65
TiO	trace
H_2O at 105°–110°	0.19
H_2O at red heat	0.36
Total	99.85

The analysis shows it to belong with those rare amphiboles especially low in silicia, containing an appreciable amount of alkalies, and, apparently, should be referred to the variety barkevikite rather than arfvedsonite, on account of the relatively high content of CaO and Al_2O_3 and the low content of FeO and Na_2O. This amphibole has a higher content of K_2O than of Na_2O, a feature unusual in amphiboles and pyroxenes.

The barkevikite has a habit of occurrence much more irregular than the pyroxene with which it is closely associated. Besides occurring in good-sized crystals like the pyroxene, it also is present in aggregates and clusters of small crystals. In the small crystals it is quite generaly free from inclusions or intergrowth of pyroxene, whereas many of the large crystals are closely intergrown with the pyroxene, and also closely associated with the iron silicate fayalite. (It is possible that these smaller crystals are another variety of amphibole).

Pyroxene.

Hedenbergite.—Pyroxene is quite a fairly abundant constituent of the Wausau type of quartz-bearing syenite, usually forming about 5 per cent of the rock· So far as observed, only one variety is present. Under the microscope it appears to be characteristically unlike the common or abundant members of the pyroxene group. It is the distinguishing feature of this type.

It is definitely, but not strongly pleochroic in colors ranging from silver through mica to silver nile. In general, therefore, it has the color of coin silver slightly tinted with green. The green tint may be due, in part, to inclusions of the associated green amphibole. In the average rock of this type it usually varies from .5 to 2mm. in diameter, and is generally idiomorphic, with development in many instances of terminal faces. The extinction on b(010) has an angle of about 45° to the prismatic cleavage. The refringence and birefringence are about like that of diallage. Besides the characteristic prismatic cleavage of pyroxene, it has a well developed pinacoidal parting "diallage structure" common to hypersthene and many other pyroxenes.

Chemical Composition.—An analysis of the pyroxene from the quartz-syenite, occurring in the rapids at Wausau, made by Victor Lenher, is as follows:

Analysis of Pyroxene (Hedenbergite) of Quartz-syenite of Wausau.

SiO_2	47.56
Al_2O_3	6.65
Fe_2O_3	1.67
FeO	22.29
MnO	trace.
CaO	19.08
MgO	1.90
Na_2O	0.27
K_2O	0.20
TiO_2	none.
H_2O at 105°–110°	0.12
H_2O at red heat	0.12
Total	99.86

The pyroxene analyzed was obtained by crushing the rock bearing abundant pyroxene and passing through an 80 mesh sieve. After passing through a silver thallium nitrate solution, and making a partial separation from the heavier and lighter minerals asociated with it, a separation of the pyroxene from the associated amphibole barkevikite by hand had to be resorted to. The associated amphibole is dark green, and the pyroxene is silver grey; hence the two minerals could be readily separated from one another by the eye, though the mechanical separation was a tedious one. Probably from one to two per cent of the associated green amphibole was unavoidably included in the material analyzed.

The analysis shows the pyroxene to be especially high in ferrous oxide and lime and to contain an appreciable amount of alumina. It is pre-eminently a calcium-iron pyroxene, and hence is closely related to the species *hedenbergite,* although it contains a much larger amount of alumina than is usually present in this species.

The silver-grey color, and the pronounced pinacoidal parting also, are not usually ascribed to hedenbergite, although in this regard it may be stated (see p. 239) that the pyroxene, in rock phases bearing nepheline, closely related to this type, much resembles hedenbergite in physical properties, and has a chem-

EXPLANATION OF PLATE

XXV.

PLATE XXV. MICROSECTIONS OF QUARTZ-SYENITE.

Fig. 1. Microsection of quartz syenite. Section 5133 A. Without analyzer, x20. The section consists of the dark colored pyroxene and amphibole surrounded by the colorless feldspar and quartz. The intergrowth of the pyroxene (hedenbergite) and the amphibole (barkevikite) is a characteristic feature of the quartz syenite. The crystallization of the amphibole as a pneumatolitic mineral immediately followed that of the pyroxene, forming the outer portions of the intergrowth.

Fig. 2. Microsection of quartz syenite. Section 6639. Without analyzer, x20. The dark colored minerals are fayalite, hedenbergite, riebeckite and magnetite, the light colored are quartz and feldspar. The fayalite is in the upper right hand quadrant and in the lower left hand quadrant.

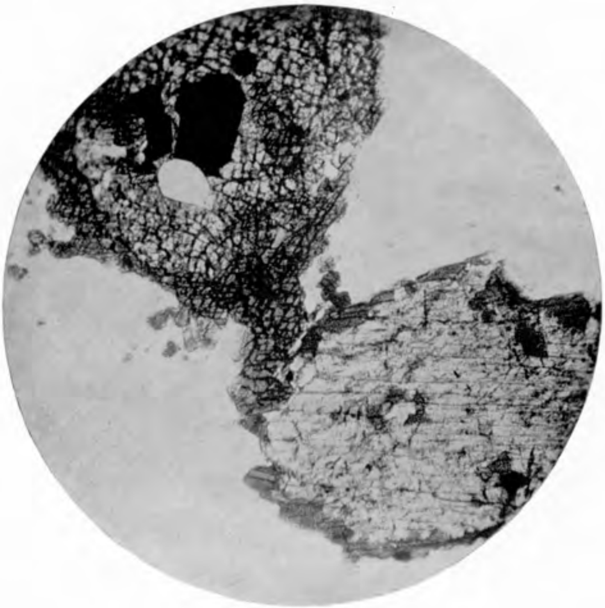

Fig. 1.

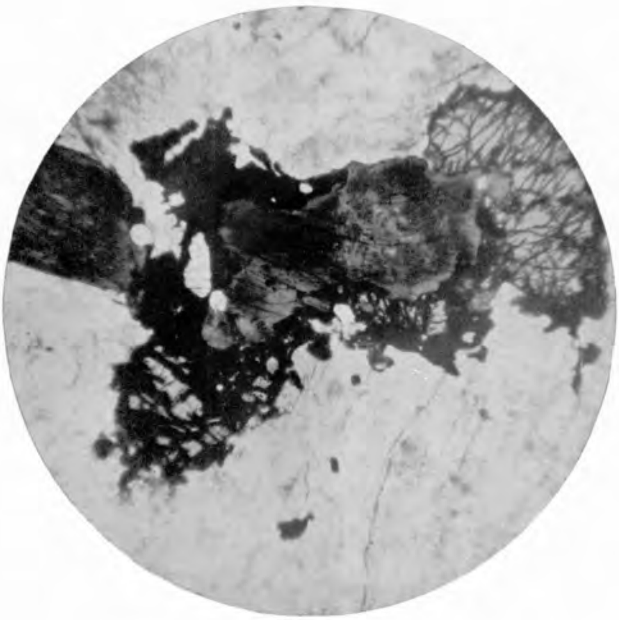

Fig. 2.

MICROSECTIONS OF QUARTZ SYENITE.

ical composition almost identical with the above. This silver-grey pyroxene, with pronounced pinacoidal parting, appears to consist mainly of the hedenbergite molecule, Ca Fe $(SiO_3)_2$, with small amounts of the acmite type of molecule, Na Fe $(SiO_3)_2$. That is, it should not be classed with those iron pyroxenes bearing magnesia, but rather with those in which ferric oxide, alumina and the alkalies are the important constituents.

The grey pyroxene, in the syenite at Wausau, has been referred[1] to as diallage on account of the well developed so-called diallage or pinacoidal parting. Diallage,[2] however, quite generally, if not always, is a magnesia-rich pyroxene and thus radically different from this pyroxene in composition.

The silver-grey pyroxene, as already stated, constitutes in general, about 5 per cent of the rock. It is quite generally closely associated with fayalite and the amphibole barkevikite.

Intergrowths of the silver-grey Hedenbergite and Barkevikite.—The close association and intergrowths of the dark green barkevitkite and silver-grey hedenbergite in the syenite at Wausau is a characteristic feature of this phase of the quartz-bearing syenite. Usually the barkevikite forms imperfect rims or zones of very irregular width surrounding the grey pyroxene, but in many instances also the barkevikite appears as numerous inclusions throughout a large part, or the whole, of the pyroxene. The manner of association is fairly well illustrated in figure 1, Plate XXV.

Such characteristic development of the amphibole as partial rims about pyroxene, or as inclusions within it, is often explained by the theory that the amphibole has been derived from the pyroxene through process of alteration. This explanation, indeed, has been offered[3] for these intergrowths in this syenite. One of the objects of separating and analyzing the pyroxene and amphibole by the writer was to test this theory.

An examination of these intergrown amphiboles and pyroxene crystals clearly shows that the two are in complete crystallographic continuity. Fig. 1, Plate XXV, showing both basal

[1] Geol. of Wis., Vol. IV, p. 663.

[2] Dana's Mineralogy, 6th Ed., p. 360.

[3] Geol. of Wis., Vol. IV, p. 663.

and prismatic sections of the two illustrate this fact better than any written description. There is, however, a sharp boundary between the amphibole and pyroxene substance, each with its characteristic cleavage and optical properties, although there appears to be no tendency whatever to form crystal faces between the two substances.

As to whether these intergrown pyroxenes and amphiboles are developed by processes of alteration, or by primary crystallization in the magma as original intergrowths, only the explanation which seems the most probable can be offered. As a means of throwing some light upon the origin of the intergrowths, the chemical composition of the intergrown minerals may be compared.

Analyses of Hedenbergite and Barkevikite.

	Pyroxene Hedenbergite.	Amphibole Barkevikite.
SiO_2	47.56	42.50
Al_2O_3	6.65	9.91
Fe_2O_3	1.67	5.07
FeO	22 29	22 51
MnO	trace	trace
MgO	1 90	2.39
CaO	19.08	11.35
Na_2O	0.27	1.92
K_2O	0 20	3.65
TiO_2	none	trace
H_2O at 105°-110°	0.12	0.19
H_2O at red heat	0 12	0.36
Total	99.86	99.85

The chemical composition of the pyroxene is seen to be radically different in some respects from that of the amphibole. The most notable difference appears to be in the content of lime and the alkalies, a difference difficult to explain on the hypothesis that the barkevikite is derived from the pyroxene by process of alteration. The occurrence of much of the barkevikite, as individual crystals, unassociated with the hedenbergite and possessing the characteristic crystal forms of amphibole, seems to indicate that the barkevikite has been developed in such instances, at least, as original crystals. The intergrowth of the pyroxene and amphibole is just as common in rock in which the feldspar is free from alteration as in that in which the feldspar is partly altered. While problems of origin of this sort cannot be conclusively proven, it seems to the writer that the most probable explanation of the intergrowths is as a primary development in the magma, and probably is somewhat analagous in origin to the intergrown feldspar substance of the microperthite so abundant in these rocks.

Olivine.

Fayalite.—The occurrence[1] of fayalite as a rock-forming mineral is rare and hence its widespread distribution in many

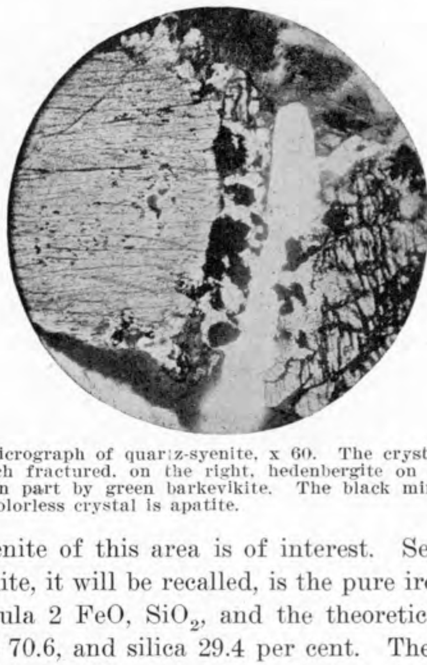

FIG. 7.—Photomicrograph of quartz-syenite, x 60. The crystals shown are fayalite, much fractured, on the right, hedenbergite on the left, both surrounded in part by green barkevikite. The black mineral is magnetite, and the colorless crystal is apatite.

phases of syenite of this area is of interest. See Fig. 8. The mineral fayalite, it will be recalled, is the pure iron olivine, having the formula 2 FeO, SiO_2, and the theoretical composition, ferrous oxide 70.6, and silica 29.4 per cent. The fayalite probably constitutes less than 1 or 2 per cent of this phase of rock, though in some thin sections it seems to form as much as 5 per cent.

As observed in this type of syenite the fayalite has a light stone color with a sage green sheen. Pleochroism is slight, the

[1] Widespread Occurrence of Fayalite in Certain Igneous Rocks of Wisconsin: S. Weidman, Jour. of Geol., Vol. ..II, p. 551-561.

green tinge changing from lighter to darker shades. It has an imperfect pinacoidal cleavage, and an irregular parting or fracture, normal to the imperfect cleavage. The extinction is parallel to the longer axis of the mineral. The refringence is about the same as that of ordinary olivine. The birefringence is strong, apparently about as strong as for olivine.

While this mineral has the general optical properties of ordinary olivine, and has been perviously described[1] as such, the minerals associated with it, such as an abundance of quartz, orthoclase, albite and microperthite were not the usual ones found with ordinary magnesia olivine. The composition of the rock, with its very small amount of magnesia and the alteration product of the mineral wholly to iron oxide, free from serpentine, led to the idea that it might be fayalite.

On account of its occurrence in small grains, and its close association with other minerals, it was very difficult to secure sufficient material from the rock for purpose of analysis. A rock especially rich in fayalite was selected for this purpose, crushed to a fine powder, and the fayalite partially separated by means of the silver thallium nitrate solution. A considerable amount of the heaviest material of the rock, which contained, besides the fayalite, some feldspar and pyroxene, was analyzed to see if any appreciable amount of magnesia was present, and to see if the theory that the yellow mineral was fayalite was probably correct.

The material was analyzed by Dr. Victor Lenher, and is seen to have been largely iron oxide and silica, and almost entirely free from magnesia, as follows:

Analysis of impure Fayalite of Quartz-syenite of Wausau.

SiO_2	32.10
Al_2O_3	3.54
Fe_2O_3	19.86
FeO	37.56
MgO	0.07
CaO	0.57
P_2O_5	none
MnO	trace
TiO_2	none
Undetermined	6.30
Total	100.00

[1] C. W. Hall, Minn. Acad. Sci., vol. III, p. 258.

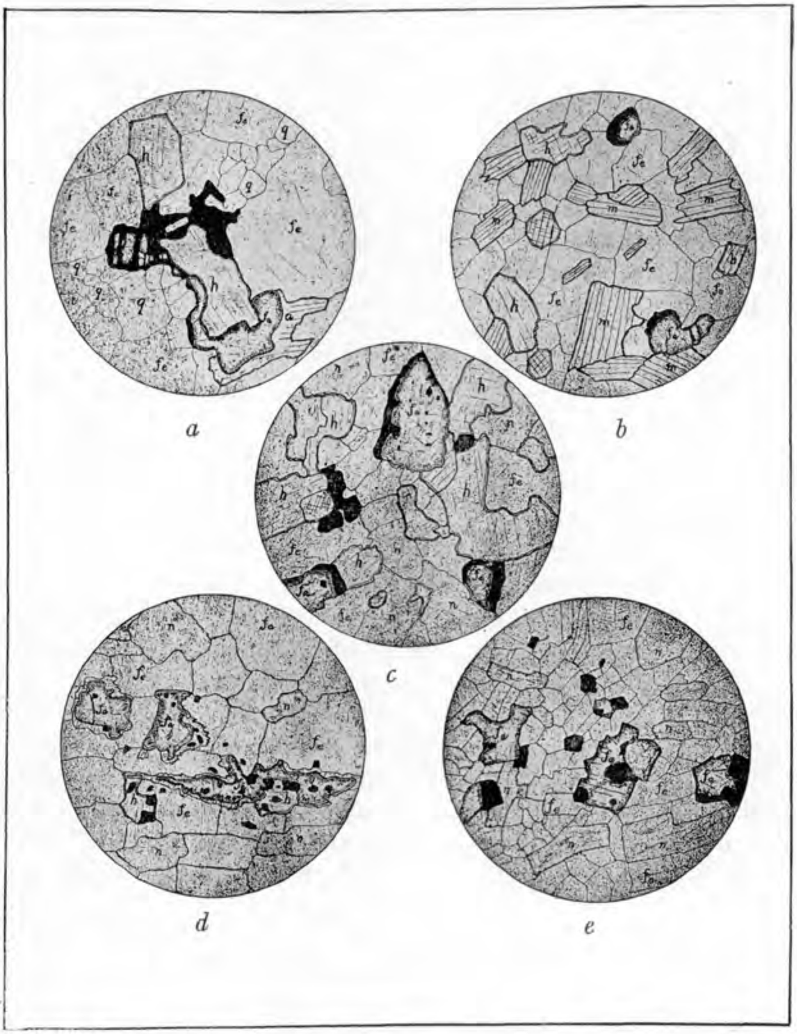

FIG. 8.—*a*. Hedenbergite quartz-syenite (6639); x 20. The minerals shown are: alkali-feldspar (*fe*), quartz (*q*), fayalite (*fa*), hedenbergite (*h*), barkevikite (a), and magnetite, the black mineral. There is also present a small amount of fluorite and apatite.

b. Hedenbergite-mica-syenite (6597); x 20. The minerals shown are: alkali-feldspar (*fe*), brown mica (*m*), hedenbergite (*h*), fayalite (*fa*), and magnetite. A small amount of fluorite and apatite is also present.

c. Hedenbergite-nepheline-syenite (6600); x 20. The minerals shown are: alkali-feldspar (*fe*), nepheline (*n*), hedenbergite (*h*), fayalite (*fa*), and magnetite.

d. Fayalite-nepheline-syenite (5275); x 20. The minerals shown are: alkali-feldspar (*fe*), nepheline (*n*), hedenbergite (*h*), fayalite (*fa*), and magnetite.

e. Fayalite-nepheline-syenite (5275); x 20. The minerals shown are: alkali-feldspar (*fe*), nepheline (*n*), fayalite (*fa*). and magnetite.

After this preliminary test a careful separation of the yellow mineral was made. The heavy minerals of the rock were first separated by the means of the nitrate solution, but it was impossible to separate the magnetic iron oxide from the fayalite, as the two were so intimately mixed by alteration and intergrowth. The magnetite was very largely removed by means of a magnet, and finally, sorting by hand had to be resorted to. After considerable work, 0.3610 grams of the nearly pure fayalite was separated, which was analyzed by Dr. Lenher and found to be as follows:

Analysis of Fayalite of Quartz syenite of Wausau.

SiO_2	33.77
Fe_2O_3	0.23
FeO	62.09
Undetermined	3.91
Total	100.00

The materials associated with the fayalite, and necessarily included in the analysis, were small particles of feldspar, quartz, pyroxene, and amphibole. The undetermined portion in this second analysis, 3.91 per cent, as indicated by comparison with the first rough analysis, is very probably mainly alumina and the alkalies which may be assumed to be combined with perhaps 4 or 5 per cent of silica to form the associated silicate minerals. An additional source of silica, probably 2 or 3 per cent, was due to small included fragments of quartz. After deducting, therefore, an amount of silica—7 or 8 per cent—present in mineral other than fayalite, it will be seen that the ferrous oxide and silica occur in approximately the proportions found in fayalite. If 7.92 SiO_2 be deducted, and the remaining SiO_2, 25.85, be recalculated with the 62.09 FeO, on the basis of 100, the theoretic composition of fayalite is the result, as follows:

SiO_2	29.4
FeO	70.6
Total	100.00

Occurrences of fayalite in other rocks.—The idea has prevailed, to some extent at least, that fayalite, on account of its extremely basic character and its association with quartz in certain rocks, and with spherulites and lithophysae in lavas and in furnace slags probably had only an aqueo-igneous origin in rocks rather than ordinary igneous origin. In this connection it may be well to call attention to the various occurrences of fayalite previously noted.

It has often been observed in crystalline slags. The first natural occurrence of fayalite observed[1] was in 1839 in nodules in volcanic rocks on the island of Fayal (whence the name is derived), one of the islands of the Azores. In the Mourne Mountains of Ireland it occurs[2] filling drusty cavities in granite. Professor J. P. Iddings[3] has described its occurrence with tridymite in spherulites and lithophysae in the obsidian of Obsidan Cliff, Yellowstone National Park; and Iddings and Penfield[4] have described its occurrence in the recent obsidian flows of the Lipari Islands. It also occurs in large crystals, apparently in "vugs," in a soda granite at Cheyenne Mountain, Colorado,[5] and in a pegmatite dike in hornblende granite at Rockport, Mass.[6] In the latter place, as described by Penfield and Forbes it occurs as a lenticular shell of varying thickness, twelve to sixteen inches in diameter, filled on the inside with loose earthy material and enveloped by a layer of magnetite one inch thick. It is a fact worthy of note that this Rockport granite is a phase of the alkali-rich rock of Essex County.[7]

It is also found in cavities in the lava of Vesuvius erupted in 1631, occurring with sodalite and orthoclase. Lacroix has also noted the occurrence of fayalite in cavities in the trachyte lava of Mount Doré[8], and in holocrystalline schist of Collobrières[9], as-

[1] *Poggendorf's Annalen*, Vol. LI, p. 160.

[2] Delesse, *Bulletins de la Société géologique de France*, Vol. X (1853), p. 571.

[3] J. P. Iddings, *Seventh Annual Report*, U. S. Geological Survey (1885, pp. 270, 279.

[4] J. P. Iddings and S. L. Penfield, *American Journal of Science*, Vol. XL (1890), p. 75.

[5] W. E. Hidden and J. B. Macintosh, *ibid.*, Vol. XLI (1891), p. 439, and Vol. XXIX (1885), p. 250.

[6] S. L. Penfield and E. H. Forbes, *ibid.*, Vol. LI (1890), p. 129.

[7] H. S. Washington, Journal of Geology, Vol. VII (1899), p. 466.

[8] M. A. Lacroix, Bull. de la Soc fr. de Min. T. XIV (1891) p. 10–14.

[9] M. A. Lacroix, Comptes Rendus Tome CXXX (1900), p. 1778–80.

sociated with grünerite, garnet, apatite, and magnetite. In all these instances, with the possible exception of the last mentioned, it will be noted that the fayalite occurs either in cavities, veins, or segregations, and on this account it has been thought that it must necessarily be a product only of aqueo--igneous action.

It may be well, therefore, to call attention to, and emphasize, the fact that not only does the fayalite occur as a persistent, and in places a fairly abundant, constituent of the quartz-syenite, in the vicinity of Wausau, as well as in certain other syenites of this area (p. 236), but that it occurs here as a normal rock constituent.

Mineral Association in the Quartz-Syenite.—In this rock at Wausau it does not occur in veins, segregations, or cavities, but as a common constituent distributed throughout the rock, like the feldspar, quartz, amphibole, and pyroxene with which it is associated.. The fayalite does not occur in idiomorphic crystals, but assumes shapes in its development due to the mutual interference of surrounding minerals. It occurs in direct contact in mutual interference with quartz as well as with feldspar, amphibole and pyroxene.

It is more usually, however, closely associated with the pyroxene and amphibole. Quite often there is a rim of the amphibole partly surrounding both the fayalite and pyroxene. The fayalite and pyroxene appear to have developed nearly contemporaneously and the amphibole somewhat later. The development of the pyroxene may have preceded that of the fayalite, for the former sometimes, as seen in section, surrounds the latter, the reverse relations not being observed.

Alteration.—Closely associated with the fayalite, as inclusions, and also as rims and as fine lines in the cleavage cracks, is a variable amount of magnetite, very probably partly original, and partly a secondary alteration of the fayalite. Yellowish-brown inclusions occur to a small extent in irregular areas, and may be the hydroxide of iron, göthite or limonite, developed by alterations of the fayalite.

There are present in some of the thin sections of this type irregular shaped areas like those characterstic of fayalite which consist of an aggregated mass of magnetite and also numerous small grayish minerals with strong refringence and birefringence, the latter often having a semi-rosette structure or a tendency to form in bunches. This unknown mineral is probably ferrous iron silicate derived by alteration from the fayalite. In some of these areas is a small amount of serpentine, evidently derived by alteration of portions of the fayalite, containing the magnesia-iron silicate molecule of ordinary olivine. There is a marked difference, however, in the character of the serpentine and the above undetermined grayish mineral.

Mica-Lepidomelane.—The mica present is usually, if not always, the brown or yellowish-brown variety. While a small amount of brown mica occurs in the main mass of this rock phase, it does not appear to be very abundant. There is present, however, considerable biotite in the pegmatite veins in the rapids at Wausau associatd with quartz, carbonate, graphite and other mineral. (See page 295.)

Fluorite.—This mineral is a fairly persistent though minor constituent of the general mass of the quartz syenite. It is colorless, has low birefringence, and has perfect octahedral cleavage. On account of its extremely low index of refraction, it produces the apparent anamolous appearance under the microscope of having a very high idex of refraction.

Apatite, zircon, and magnetite are present to a variable extent in most thin sections. There is present in some of the slides a reddish-brown mineral, with good pleochroism, which has not been definitely identified. It has good crystal form with fully developed terminal faces. The crystals noted were small and elongated, the longer axes varying from 1 to 5 mm. in length, and the shorter from one-half to one-third the length of the longer axis. The twinning and crystal form appear to correspond to epidote. Faces corresponding to 001, 100 and 101 of epidote, with approximately similar angles of intersection and twinning, and composition face corresponding to 100, were observed. Definite cleavage is not noticeable. Extinction is inclined 30° to the twinning plane. Most of this mineral was noted in the fine-grained phase of the syenite occurring in the rapids at Wausau. In the medium-grained phase, a larger crystal was noted, which appeared to be isotropic. This mineral is probably a member of the epidote group and may be either allanite or piedmontite. It was apparently one of the earliest minerals to develop. Some of the crystals are clouded with inclusions.

STETTIN TYPE OF QUARTZ-SYENITE.

A phase of the quartz-bearing syenite closely related to the Wausau type occurs in various parts of the town of Stettin, northwest of Wausau, and hence it may be conveniently referred to as the Stettin type. This type is more closely associated in occurrence with the nepheline-bearing syenite than is the Wausau type. It also contains less quartz and hence evidently stands as an intermediate rock phase between the Wausau type of quartz-syenite and the nepheline-bearing syenites. This type is well developed on the low ridge near Mr. J. Kolter's place, in adjoining parts of sections 29, 30, 31 and 32 of T. 29, R. 7 E., in the ridge in the NE. 1/4 of Sec. 29, in low outcrops in the northern part of Sec. 20 in the same township; in the vicinity of the center of the NW. part of Sec. 24, T. 29, R. 6 E.; and in Sec. 15, T. 29, R. 6.

Macroscopic Character.

This type of quartz-syenite is fine to coarse-grained and brownish to grayish in color. Feldspar, quartz, amphibole and pyroxene are the principle minerals distinguishable in the hand specimens. This type or phase usually possesses a banded appearance, due to the tabular development of the feldspar parallel to the brachypinacoid (010). The average breadth of these tabular crystals is 10 to 15 mm., but they often reach a breadth much greater than this. The texture of this type, therefore is predominately trachytoid in contra-distinction to the granitoid texture of the Wausau type.

Microscopic Character.

Under the microscope, the principal minerals to be observed are the alkali feldspar, amphibole, pyroxene, quartz, brown mica, fluorite, apatite, zircon, fayalite, and magnetite, and the usual alteration minerals developed from the alkali feldspars. The mineral composition, therefore, is practically the same as that of the Wausau type. The principle difference between the two types is in the character of the pyroxene and amphibole constituent, and in the abundant development of the tabular feldspar. The remaining minerals need not be especially referred to.

Tabular Microperthite.—The tabular feldspars appear to be wholly microperthite. In the dominating occurrence of tabular form of the feldspars, there is a textural similarity to phases of the nepheline syenite described later, see p. 256.

Pyroxene.—The pyroxene of this type has very strong pleochroism varying from light olive green to lizard green. *a* is lizard green, *b* olive green, *c* is lizard green. The extinction is inclined to the prismatic cleavage 40 to 45 degrees. The refringence and bi-refringence is strong, about like that of ordinary augite, and much less than that of aegerite. The strong pleochroism, however, separates it from ordinary augite. It possesses no fine pinacoidal parting planes. In respect to color, and structure, this pyroxene, therefore, is quite unlike the silver-grey pyroxene with pinacoidal parting so characteristic of the Wausau type.

This lizard-green pyroxene occurs in abundance in a prominent type of the nepheline syenite and from this latter type it was separated and analyzed (See p. 240). The writer was somewhat surprised to find it so closely similar to the silver-grey pyroxene in chemical composition. In comparison with the silver-grey pyroxene there is a decrease in FeO and increase in Fe_2O_3 and Na_2O, thus showing a closer relationship than the silver-grey pyroxene to acmite. Both the silver-grey pyroxene and the lizard-green pyroxene should apparently be classed as varieties of hedenbergite.

Amphibole.—The amphibole associated with the lizard-green pyroxene much resembles the barkevikite of the Wausau type, but has the bluish pleochroism characteristic of arfvedsonite. The arfvedsonite and lizard-green pyroxene are intergrown in somewhat the same manner as the barkevikite and the silver-grey pyroxene, but apparently not so intimately.

Relation of Stettin Type to Other Phases of the Syenite.—This type of quartz-bearing syenite does not seem to be so important quantitatively as the Wausau type. As already observed, it appears to stand in chemical composition near to the nepheline-bearing syenite, and its usual occurrence in the field is near to nepheline-bearing rock.

On the other hand, this type also appears to be closely related to abundant contact phases of the syenite, having a similar mineral composition, but differing remarkably from it in texture, due to a peculiar habit of enlargement or secondary crystallization of the alkali-feldspar constituent.

CONTACT PHASES OF QUARTZ-SYENITE.

Rock phases of unusual texture have a considerable distribution in the region west of Wausau where quartz-bearing and nepheline-bearing rocks are contiguous to included masses of quartzite and other older rocks. Surrounding the quartzite of Rib Hill and the Mosinee Hills is a phase of the granite-syenite magma more quartzose than that in the immediate vicinity of the nepheline-syenite which penetrates and encloses in a complex manner the quartzite formation in many places, developing a zone of mixed rock several hundred feet in width.

In the region northwest of Wausau in the vicinity of the lower course of the Little Rib River and within the general area of quartz-bearing and nepheline-bearing syenites, there are enclosed in the syenite comparatively small masses of quartzite varying from minute fragments up to large fragmentary masses one hundred feet or more in thickness.

At the south end of the ridge near Mr. J. Kolter's house in the NE. part of Sec. 31, T. 29, R. 7 E. (see sketch-map, Plate IV) is a fragment of the quartzite about 60 feet across. On the south side of the hill, in sections 27 and 28, and in the NE. part of Sec. 29, of T. 29, R. 7, there is a considerable area of quartzite enclosed within the syenite mass. In the vicinities of these large fragmentary masses of the quartzite are abundant small fragments of the same rock. In some places, also, as in the S. ½ of Sec. 27, other rock is associated with the quartzite as fragments in the contact rock, namely, a phase of black schist and a porphyritic rock. On the northwest slope of Rib Hill near the west end, several kinds of fragments were also noted in the enclosing igneous mass. The principal occurrence of the contact rock is shown upon the outcrop maps,—Plate IV.

Macroscopic Character.—These rock phases are fine to medium-grained, and are quite generally of brownish color. The feldspar usually has a tabular development. Feldspar is the principal constituent, the only other minerals noticeable in the hand specimens being fine granular quartz and a sprinkling of dark colored minerals.

Microscopic Character.—The principal minerals to be observed under the microscope are alkali feldspar, amphibole, pyroxene, brown mica, quartz, zircon, fluorite, apatite and magnetite.

The enlarged feldspar.—The feldspar is mainly microperthite, with minor quantity of albite, orthoclase and microcline in some phases. To a very large extent, the feldspar consists of microperthite which appears to belong to two generations or two periods of crystallization. The first generation consists of medium sized crystals of microperthite in the form of cores within an outer portion which evidently crystallized later than the core. As seen in cross-section, therefore, these feldspars are characterized by a peculiar core and rim structure like that of enlarged feldspar and quartz grains in metamorphic sedimentary rocks.

The general appearance of these enlarged crystals is shown in Plates XXVI and XXVII. The cores are generally bounded by well defined crystal faces, although in some instances the corners are somewhat rounded. Twinning, according to the Carlsbad and Baveno laws, is common. The microperthite of the cores does not differ apparently in optical properties and composition from other microperthite of the syenite.

Along the boundary of the cores, as seen in cross-section, is a line of quartz, magnetite, amphibole, zircon, etc., and outside this line is a sprinkling of similar grains of quartz, magnetite, etc., the whole enclosed within microperthite in crystal continuity with the cores. The cores are free from inclusions, while the enlarged rims are filled with included minerals, the two portions therefore standing out in sharp contrast with one another. The inclusions are especially abundant at the boundaries of the cores forming lines, as above remarked. Between the microperthite crystals with cores and rims are smaller crystals of similar microperthite, with inclusions of minerals throughout. The quartz and associated minerals in the rims of microperthite are small grains usually about 0.01 mm. in diameter, while those outside these rims between the microperthite are about 0.1 mm. in diameter. Bluish-green amphibole and magnetite are abundant inclusions. Zircon, apatite and fluorite are also present. The fluorite in places is relatively abundant. The lizard-green pyroxene is also present in some rocks of the contact phase, and also yellowish-green aegerite.

Phases of Contact Rocks.

A very abundant phase of the contact rock standing very close to the normal Stettin type of quartz-bearing syenite is represented by specimens 6495 and 6496 from the northern part of the ridge in the SE. ¼ of Sec. 30, T. 29, R. 7. A large part of this ridge appears to be made up of syenite mixed with quartzite inclusions, and rock having the characteristic features of the Stettin type. Megascopically, this phase (6495-6) is seen to have well developed tabular feldspars like much of the normal Stettin type. Under the microscope some of these feldspars show the characteristic core and rim structure. The contrast between the cores and rims is not very pronounced, yet the borders of the cores are very distinct. Not all the feldspar, which is wholly microperthite, appears to possess the cores. The other minerals in this phase are the lizard-green pyroxene and bluish-green amphibole in good-sized crystals, and small crystals of apatitie and zircon. The quartz present is in the interstices between the tabular feldspars, as is usual in phases of the syenite with tabular development of the feldspar.

In the NE. ¼ of Sec. 29, T. 29, R. 7, and adjoining portion of Sec. 28, there is a considerable area of quartzite surrounded by various phases of syenite, both nepheline-bearing and quartz-bearing syenite being present. In this vicinity the nepheline-bearing rock contains the pyroxene, aegerite, and some phases of the rock with enlarged feldspars also contain relatively abundant aegerite, although most of the contact rock contains the lizard-green pyroxene, hedenbergite, of the normal quartz-sye-

EXPLANATION OF PLATES

XXVI AND XXVII.

PLATE XXVI. SECONDARY ENLARGEMENTS OF FELDSPAR IN A METAMORPHIC SYENITE.

Fig. 1. Microsection of a contact phase of syenite containing enlarged feldspar. Section 6644. With analyzer, x20. Section consists of microperthite feldspar with small amounts of quartz, amphibole, biotite and iron oxide. Near the centre of the field is shown a nearly square crystal of enlarged microperthite with a smaller one above and to the right.

Fig. 2. Same as above, with increased magnification of the two enlarged crystals, x50. Note the sharp angles in the original form of the two crystals, the distinct line of iron oxide and quartz along the original boundaries, and the mutual contacts of the zones of later developed feldspar.

PLATE XXVII. SECONDARY ENLARGEMENTS OF FELDSPAR IN METAMORPHIC SYENITE.

Fig. 1. Similar to the above. Section 6610, x20. Note the common feldspar twinning of the enlarged crystal in the centre of the field shown by the light and dark portions.

Fig. 2. Similar to the above. Section 6613. With analyzer, x20. Note the parallel microperthite structure in the first and second growths.

Fig. 1.

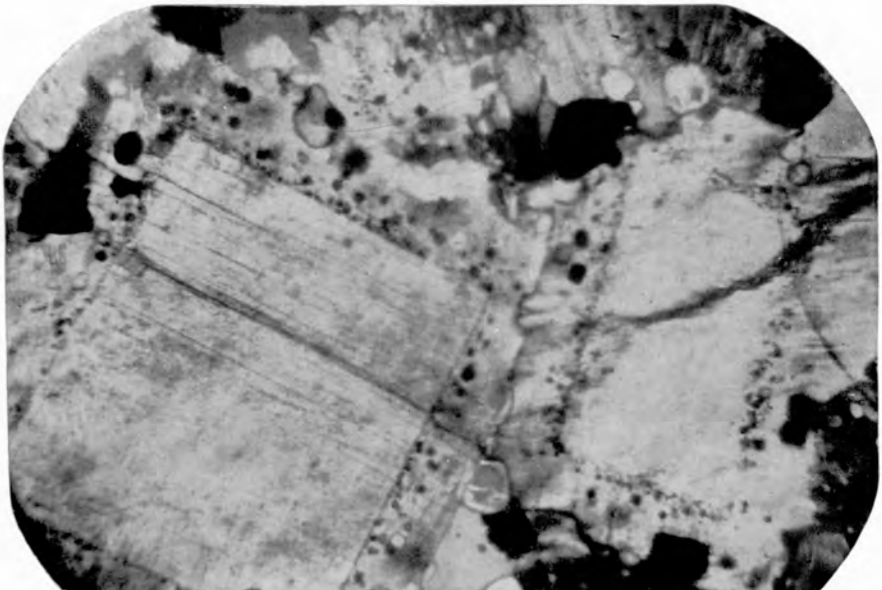

Fig. 2.

SECONDARY ENLARGEMENTS OF FELDSPAR IN SYENITE.

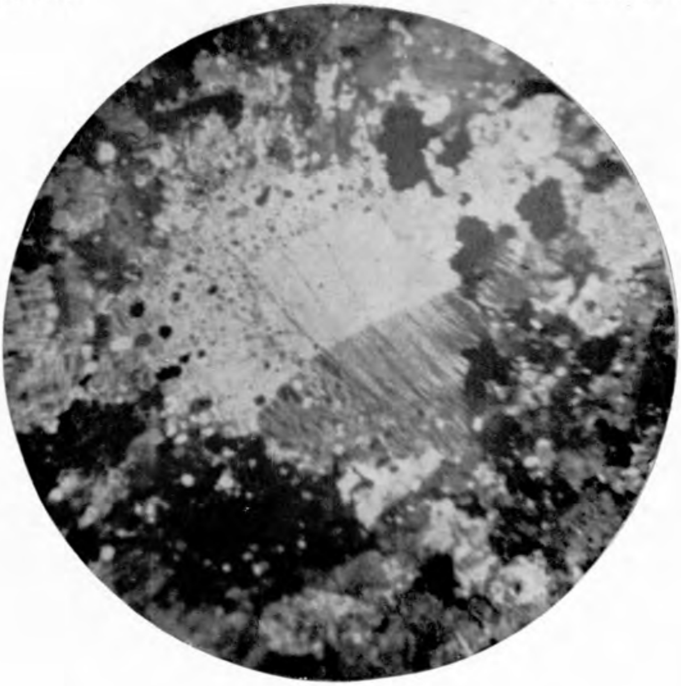

Fig. 1.

Fig. 2.

SECONDARY ENLARGEMENTS OF FELDSPAR IN SYENITE.

nite. The phase containing aegerite also contains considerable fluorite, blue amphibole and magnetite. The blue amphibole is probably crocidolite rather than riebeckite.

In the NE. 1/4 of Sec. 29, as well as at the south end of the ridge near Mr. J. Kolter's house, in NE. 1/4 of Sec. 31 ,various phases of contact rocks, quartzite, nephiline- and quartz-bearing syenites are present.

Near the center of the ridge, near Mr. Kolter's, was observed an unusual rock (6497-8) made up of rock fragments cemented together by rock of medium-grained granitoid texture. Under the microscope, this rock appears to be a quartzite filled with a myriad of colorless, acicular crystals, apparently andalusite and some magnetite and large crystals of brown mica. The rock is probably an intrusive breccia, the andalusite, magnetite and mica being developed by contact metamorphism.

In the NE. 1/4 of Sec. 29, various phases of rock may be observed, made up of quartzite injected with minerals derived from the syenite. All gradations are present, from normal syenite to the normal coarse quartzite, which makes up the summit of the pointed hill of this locality. See Plate XXVIII.

The rock next to the normal syenite is quite generally, if not always, one in which the microperthite has the well developed cores above described. Much of this phase contains numerous fragments of quartzite, the latter containing a variable amount of microperthite, blue amphibole, magnetite and fluorite interspersed throughout. These introduced minerals in the quartzite fragments are interstitial to the large quartz grains. A variable amount of quartz of the fragments is probably derived from the syenite and added to the quartz in crystal continuity. Some of the fragments are nearly black or bluish, on account of the abundance of magnetite and blue amphibole present. As the main body of the quartzite is approached, the quartzite fragments become more numerous and the contact rock gradually changes from a syenite containing quartzite fragments to a quartzite containing veins and stringy masses of syenite. Where the contact rock consists largely of quartzitic material, no cores in the feldspar were noted, and no pyroxene is present.

In the phase of contact rock largely consisting of quartzite, the minerals derived from the syenite magma are the same as those to be observed in the quartzite fragments in the syenite, viz., microperthite, blue amphibole, magnetite and fluorite. These minerals occur in the interstices between the quartz crystals, and thus clearly show their insertion after the quartz was formed. No doubt a large amount of quartz was also added to the quartzite in the interstices between the original clastic grains, but such additional quartz is in crystal continuity with the clastic quartz. No enlargement of the clastic quartz in this phase of the quartzite is to be observed, thus showing its similarity in this respect to the main body of recrystallized quartzite of the Rib Hill formation.

The feldspar developed in the quartzite is microperthite like that of the normal intruding rock. In some phases, the microperthite is red, on account of inclusions of iron oxide.

The amphibole of the phase of syenite in which cores in the feldspar are developed has the character of arfvedsonite, but in the quartzite fragments of the contact rock where the amphibole is probably developed by pneumatolitic processes, it is a bluish variety, apparently riebeckite. This riebeckite occurs in acicular crystals and also in good sized massive forms. They are often developed in a radiate or rosette structure in the interstices between the quartz crystals.

Magnetite and fluorite are quite generally together in small aggregates in the quartzite fragments. The fluorite observed is always colorless, like that in the intruding syenite.

In the NW. ¼ of Sec. 15, T. 29, R. 6 E., on and in the vicinity of the farm of Albert Wendtorf, there is nepheline-bearing and quartz-bearing syenite, quartzite and various mixed and contact phases of rock. Besides the several phases already described, which occur also to some extent in this locality, there is present a peculiar spotted rock, often referred to in the field as "leopard rock."

The spotted character of this phase is due to the occurrence of a dark-colored mineral, amphibole, enclosed in whitish feldspar. Under the microscope, the principal constituents are seen to be microperthite in fairly uniform small grains about 0.25 mm. in diameter, and numerous larger crystals of amphibole, generally between 1 and 2 mm. in diameter. The amphibole has the character of arfvedsonite, and has the form of skeleton-like crystals enclosing numerous smaller crystals of the microperthite. (See Figure 9, page 229). Small crystals of flu-

EXPLANATION OF PLATE

XXVIII.

PLATE XXVIII. QUARTZITE AT CONTACT WITH INTRUSIVE SYENITE.

Fig. 1. Phase of the Rib Hill quartzite formation showing the injection of feldspar in the quartzite. Specimen 5999, three-fourths natural size.

Fig. 2. Similar to the above. Specimen 6003. Consists of fragments of quartzite impregnated with blue amphibole, magnetite, fluorite and abundant feldspar.

Fig. 3. Similar to the above. Specimen 6004. Consists of about equal proportions of the quartzite and of quartz and feldspar from the syenite magma. There is an imperfect banding in this phase not shown in the face photographed.

It is impossible to distinguish under the microscope the magmatic quartz from the recrystallized quartz of the quartzite in these contact phases. However, the fragmentary form of the quartzite and its sacharroidal texture, as observed in hand specimens, is never wholly obliterated by the metamorphism.

Fig. 1.

Fig. 2.

Fig. 3.

QUARTZITE AT CONTACT WITH INTRUSIVE SYENITE.

orite and zircon are often very abundant. A phase of this rock contains nepheline and aegerite. Phases of this rock also contain abundant fragments of quartzite, and inclusions of syenite much like the enclosing rock. In those phases containing quartz-

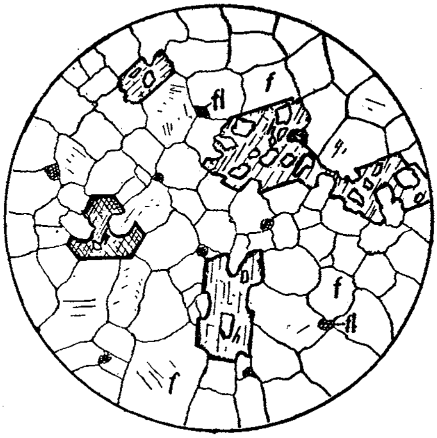

FIG. 9.—Skeleton crystals of amphibole in syenite. h, Amphibole. b, Feldspar. fl, Fluorite.

ite fragments, the minerals developed in the quartzite are similar to those already described in the quartzite fragments elsewhere.

Origin of the Contact Phases.

As already stated on previous pages there are present all gradations between the normal granular syenite and the ordinary pure quartzite where these rocks in the area northwest of Wausau occur. A large portion of the contact rock, namely, that in which quartzite fragments are present in small qauntity or in abundance, was evidently formed by the mechanical mixture of the older quartzite or sandstone by the intruding of the syenite magma. It seems very probable, from the disposition and arrangement of the sedimentary rock in the igneous mass, that the phenomena to be observed at the present land surface was developed some distance below the surface existing when the intrusion took place. Hence the mixed rocks may be referred to as intrusive breccias, rather than extrusive breccias.

The contact phase of syenite of especial interest, is the phase in which the feldspar shows the enlargements. These feldspars, wholly of microperthite, do not show a zonal growth, but have the characteristics of enlarged feldspars with cores and rims so commonly observed in metamorphic sedimentary rocks and in some metamorphic igneous rocks. (See Pls. XXVI and XXVII).

While this phase is now a holo-crystalline hypidiomorphic granular rock, like plutonic rocks in general, it is believed to have been once a porphyritic rock containing phenocrysts of feldspar in a ground mass. The original phenocrysts are now represented by the cores, which, in general, have well defined crystal form. In order to develop such idiomorphic forms, they were probably first developed within a very fine-grained groundmass approaching the character of glass, perhaps later having the size of grain like that of the quartz and amphibole which immediately surrounds the idiomorphic cores and which is of much finer grain than the minerals later developed.

The shape of the original feldspar phenocrysts was both equidimensional and tabular, with all gradations between, the tabular developed feldspar apparently showing a close relation to the normal syenite of the Stettin type. This phase, therefore, resembled a porphyritic rock of trachytoid structure. In this original porphyritic rock no phenocrysts other than feldspar appear to have developed. As the normal syenite is approached a phase intermediate between the syenite and a porphyry (Sp. 6495-6) was developed. in which but a faint line marks the border of core and rim, and such minerals and amphiboles as those occurring in the normal syenite are abundant.

It is believed, therefore, that this contact phase of the syenite was once a porphyritic rock and was intruded as such into the quartzite formation, surrounding and detaching blocks and fragments of various size from the main mass, and also sending out stringers and veins some distance into the main mass. The quartzite formation at the time of the intrusion was probably a partially metamorphosed sandstone approaching the character of quartzite, with abundant interstitial spaces between the clastic quartz grains, into which quartz, feldspar, riebeckite, magnetite, and fluorite were injected by dilute liquids and gases emanating from the intruding porphyritic magma. The stringers and veins of igneous material that left the main body of the magma and penetrated the quartzite appear to have had the texture of the ground-mass, as no enlarged feldspars with cores were observed in them. The intrusion of the porphyritic phase probably marked a single stage in the very composite intrusion of the granite-syenite magma into the older rocks of the region. After this stage of intrusion, when the feldspar porphyry, trachyte, had come to rest in contact with the quartzite, both were metamorphosed by later intrusions and by other thermal and dynamic forces of metamorphism operating in the region.

It is possible that the continuation of the development of crystallization in the porphyritic rock, by which the feldspar phenocrysts were enlarged, and new feldspar crystals and other minerals were crystallized into larger crystals, was immediately following the intrusion or first crystallization, with no important interval between the development of phenocrysts and their subsequent enlargement. The interval between the two periods of crystallization may have been comparatively short or comparatively long. The occurrence of the enlarged feldspars in this phase is taken as evidence conclusive that an actual break or cessation occurred in the process of the consolidation and crystallizing of the rock. The exact manner in which the two periods of the earlier and the later crystallizing was brought about can only be conjectured.

The extreme metamorphism revealed by the Rib Hill quartzite formation (see page 48–52) is a fact of much importance to be considered in connection with the history of this rock phase with enlarged feldspar. The quartzite formation of Rib Hill and adjacent outliers is now wholly recrystallized rock having the microscopic texture of vein or granitic quartz. To have produced such a holocrystalline, even-granular rock from a sandstone or ordinarily cemented quartzite having rounded clastic grains, must have required long continued, strong forces of metamorphism. It is metamorphism of a similar character which the writer is inclined to believe operated to bring about the enlargement of the feldspar in this peculiar contact phase of syenite.

General Contact Effects of the Syenite Intrusion.

The character of the mineralization of the quartzite enclosed in the phases of syenite intrusives has been generally described, and also the mixture of the quartzite and the intrusive along the contacts of the two formations.

The most prominent effect to be noted along the contacts is probably the mechanical mixture of the quartzite fragments in the intruding igneous rock. This is true whether the intruding rock be the quartzose granite as in the region of Rib Hill, or the more basic syenite in the localities just described. In a general way, if not in all cases, it is not difficult to distinguish the quartzite fragments from the enclosing igneous rock, even in the most extensive areas of mixed rocks. While the enclosed quartzite fragments are impregnated with minerals, such as feldspar, riebeckite, magnetite, flourite, and presumably quartz, from the intrusives, the original outlines of the fragments can be readily detected, even in localities where later mashing has tended to modify the resultant rock. There appears, therefore, to be little blending or interfusion of the two rocks at their contacts. The same phenomena is illustrated at the contacts of the granite and gabbro-diorite rocks (see page 193), where, over large areas of contact zones, the intimately mixed diorite-gabbro fragments in the granite is a prominent feature.

The impregnation of the enclosed quartzite with mineral from the intrusive rock extends through all the small fragments, but the larger fragmentary masses appear to be entirely free from injected mineral in their central portions. Quartzite fragments three or four feet in diameter have comparatively slight or no impregnation in their interiors. This fact is especially well illustrated in the quartzite enclosures near Mr. J. Kolter's house, and also in the locality of the NE¼ of Sec. 29, T. 29, R. 7 E. While the intruding magma appears to have filled all the open fractures in the quartzite, and veinlets of syenite abundantly ramify throughout, there seems to be but comparatively little mineral developed through escaping vapors and gases emanating from the molten magma through the minute pore spaces in the quartzite for any great distance from the contacts.

The effect of the quartzite upon the composition of the intruding magma along the contacts appears to have been very slight. The physical effects very probably caused some variation in the texture of the intruding magma, but practically little or no effect by absorbing silica from the quartzite is apparent. This appears to be indicated not only by the sharp boundary lines between the quartzite fragments and the intruding rock, but also by the fact that all the various phases of syenite and granite extend into the quartzite without any apparent modification in composition. While nepheline-syenite was not found in actual contact with quartzite, it is known to occur in direct contact with closely related syenite containing abundant fragments of quartzite. In several localities, the nepheline-bearing rock is well within the zone of mixed quartzite and syenite, an association which would not exist if the endomorphic effect of the quartzite upon the intruded syenite magma was of much importance.

On the whole, therefore, while the mechanical mixture of syenite magma with the quartzite is very extensive, and the development of certain minerals, mainly feldspar, riebeckite, magnetite, and fluorite, characteristically borders the immediate vicinity of the contacts, the endomorphic effect upon the intrusive rock appears to have been unimportant.

NEPHELINE-SYENITE.

The nepheline-bearing syenites occur as shown upon the map, Plate 1, almost entirely in the region from 3 to 10 miles northwest of Wausau. As shown upon the sketch map of rock outcrops, they have a sporadic distribution within an area of about one square township, in the central and eastern part of T. 29, R. 6 E., and in the western part of T. 29, R. 7 E. See Pl. IV.

The largest continuous outcrops of nepheline-bearing rock lie in Sections 1, 2, 11 and 12 of T. 29, R. 6 E. In Sec. 2, there is a low ridge of nepheline-syenite extending north and south, about three-fourths of a mile long and one-fifth of a mile wide. About a mile east of the above, in Sections 1 and 12, there are a number of isolated small outcrops indicating a probable continuous ledge, from half a mile to a mile in length and one-fourth of a mile wide. Between these ridges there is low ground, the rock beneath being unknown, but the prevailing rock may be wholly or in part the nepheline-bearing syenite. On the whole, the nepheline-syenite appears to be very abundant in this vicinity, constituting an area of 3 to 6 square miles, most of the rock being nepheline-bearing.

A considerable area lies in the northeastern part of Sec. 27, T. 29, R. 6 E. and adjoining sections. The nepheline-bearing rock here has an aproximate extent of half a square mile. The other outcrops in this region are small, but may be a part of a considerable body in the immediate vicinity covered with soil.

This region, like other parts of the area of north-central Wisconsin, contains but little glacial drift, but the rocks are deeply disintegrated in general, and a rich agricultural soil lies between the outcropping ledges. Along the ditches of the roads and in the farm-house wells nepheline-syenite is found in many places.

A small outcrop was discovered a considerable distance from this main area, southeast of Wausau, in Sec. 21, T. 28, R. 8 E. The outcrop here is probably not a part of an extensive body, but it is of interest as an indication of the probable occurrence of similar bodies outside the main area northwest of Wausau. It seems very probable that in the future other small areas will be found within the general area of the quartz-bearing syenite and amphibole granite of this district.

ASSOCIATED ROCKS.

Within the area of nepheline-bearing syenite the rocks intimately associated with them are the closely related alkalic syenites occurring in both fine to medium-grained, as well as coarse pegmatitic, phases. Immediately outside this area are massive older rocks, mainly dark-colored gabbro, diorite, etc., commonly called greenstone, with which the nepheline-syenite and associated rocks are in intrusive contact on the southwest, west and northwest. On the southeast, east and northeast, the alkali-rich phases of the series grade into the more quartzose phases of quartz-syenite and granite, which still farther east are likewise in intrusive contact with the older rocks, mainly the greenstone and rhyolite formations. Besides these older igneous formations there are the considerable bodies of Rib Hill quartzite, lying mainly along the southeast side of the nepheline-bearing area, with which the alkali rock series is in intrusive contact. A sedimentary series overlies the associated granites in the region northwest and north of Wausau, but this later sedimentary rock is not known to be in contact with the nepheline-bearing syenite.

KINDS OF NEPHELINE-SYENITE.

Two types or phases of the nepheline-bearing syenite appear to stand in sharp contrast with one another in this area. In one of these types, the yellow-green pyroxene, aegerite, is the prevailing and important dark-colored constituent, and in the other, the lizard-green pyroxene, hedenbergite, and fayalite are the important or distinguishing dark-colored minerals. In the aegerite-bearing phase, sodalite is a more abundant constituent than it is in the hedenbergite-fayalite-bearing phase. There are undoubtedly rock phases intermediate between these types, showing a close relationship to either or both, but the above principal or important types can be readily distinguished from each other in the field, as well as microscopically, and hence it is convenient to describe them separately and group the related or intermediate phases about them.

The mineral composition of these two types of nepheline-bearing rock of course is but the expression of the chemical composition of the differentiated rock magma. The aegerite-bearing phase is developed from a magma somewhat richer in ferric-oxide and silica than the hedenbergite-fayalite phase. The latter is developed from a magma having a higher content of ferrous oxide and lime than the aegerite-bearing phase.

Of the two types, the aegerite-bearing type is a fairly common phase of nepheline-syenite outside of this area. The fayalite-bearing type, however, appears to be unique among the described rocks of the world. For this reason, the latter may be conveniently referred to as the Marathon type, after Marathon county, in which it occurs. The area of occurrence of these types is not shown separately upon the maps.

THE HEDENBERGITE FAYALITE NEPHELINE SYENITE. MARATHON TYPE.

This rock phase or type occurs in Sections 1, 2 and 12 of T. 29, R. 6 E. With the exception of a somewhat similar rock noted in the SE. part of Sec. 14, this type is known to occur only in the above sections, where it forms the largest continuous outcrops of the nepheline-bearing syenite. It is not unlikely that this phase spreads out into some of the adjacent sections and forms a large connected mass in this locality, perhaps two or three square miles in extent. Its apparently large area of occurrence near the center of the nepheline rock area is in sharp contrast with the much smaller areas of aegerite-sodalite-bearing rocks which are scattered over the outer borders of the region occupied by the nepheline-bearing syenite.

Macroscopic Character.

This phase is generally medium-grained, with a variation to fine-grained and coarse-grained phases. The color is grayish, due to the whitish feldspar sprinkled with the bluish-gray nepheline and the greenish-black pyroxene and amphibole. On the weathered surface, the rock is pitted, on account of the weathering out of the nepheline.

The minerals readily recognizable in the hand specimens are feldspar, nepheline and the pyroxene and amphibole. The feldspar with bright pearly lustre generally, if not always, shows a strong tabular development, the plates generally having a thickness between 1 to 4 mm. and breadth of 5 to 20 mm. The bluish-gray or slate-colored nepheline occurs as roughly quadratic and angular crystals, generally from 2 to 4 mm. in diameter. The dark green pyroxene and amphibole generally occur in elongated crystals from 2 to 6 mm. in diameter. The fayalite present in these rocks can hardly be distinguished with the naked eye, on account of its close association and intergrowth with the dark-colored pyroxene and amphibole. The rock is brittle, and, on account of the tabular feldspar, breaks with an uneven fracture.

EXPLANATION OF PLATES

XXIX AND XXX.

PLATE XXIX. PHASES OF NEPHELINE SYENITE.

Fig. 1. Nepheline syenite. Specimen 6570, three-fourths natural size. The light colored grayish mineral is feldspar, the darker flesh colored mineral is nepheline and the black mineral is soda-amphibole (arfvedsonite) and soda-pyroxene (aegerite).

Fig. 2. Fine grained nepheline syenite. Specimen 6002. Consists mainly of feldspar and nepheline. The dark mineral is soda-amphibole, aegerite and magnetite. This syenite contains a small amount of calcite and fluorite, see Fig. 2, Plate XXXVII.

Fig. 3. Nepheline syenite, 5275, contains besides the feldspar and nepheline, from 1 to 5 per cent of fayalite, and considerable lizard green hedenbergite.

PLATE XXX. PHASE OF THE USUAL COARSE NEPHELINE-BEARING PEGMATITE.

Specimen 6024 B, three-fourths natural size. The white mineral is feldspar. The large, dark flesh-colored mineral is nepheline, and the black mineral is mainly aegerite.

Fig. 1.

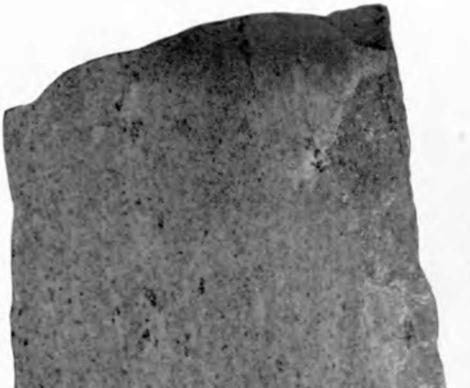

Fig. 2.

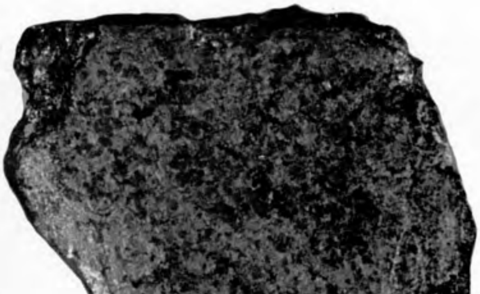

Fig. 3.

PHASES OF NEPHELINE SYENITE.

NEPHELINE PEGMATITE.

Microscopic Character.

The minerals to be observed under the microscope are the alkali feldspar, nepheline, pyroxene, amphibole, fayalite, mica, magnetite, flourite, apatite, and various secondary minerals due to weathering of the rock. On the whole, this type appears to be much more simple and uniform in its mineral and textural composition than the aegerite-sodalite type.

Feldspar.—The predominating feldspar is one of apparent uniform character, without polysynthetic twinning, or perthitic intergrowths. The color is white with pearly lustre and pronounced schiller. On P (001) the extinction is nearly parallel. This feldspar is believed to be anorthoclase. There is also present in minor quantity, feldspar with microcline habit and perthitic intergrowths.

The feldspar occurs quite generally in tabular plates. This is especially true of the larger crystals. The alteration is to grayish and white kaolin, giving the feldspar a cloudy appearance. The alteration advances along the structure planes of the feldspaı.

Nepheline.—Next to the feldspar, the nepheline is the most abundant constituent of the rock. Under the microscope it appears colorless and has the usual character of this mineral, as usually described. It appears to tend strongly to a quardratic development. Its alteration is most commonly to minute crystals of grayish natrolite. Muscovite and kaolinite in good-sized crystals were observed as inclusions in the most altered crystals.

Sodalite.—Sodalite is present in this phase but apparently only in small quantity. It is colorless to grayish and shows the same alteration minerals as the nepheline.

Hedenbergite.—A dark green pyroxene is a fairly abundant constituent, often closely associated with the fayalite and amphibole. The pyroxene has very pronounced pleochroism, varying from light olive-green to lizard-green. a=lizard green; b=olive-green; c=lizard-green. The extinction is inclined to the prismatic cleavage at an angle of 40° to 45°. The index of refraction and bi-refringence appears to be about that of ordinary augite and much less than that of aegerite. Its strong pleochroism separates it from the ordinary augites and diopsides. It possesses no fine pinacoidal cleavage like the silver-gray pyroxene occurring in the fayalite-bearing quartz-syenite. This pyroxene is often intergrown with the fayalite and also occurs as partial rims about it. In some phases of this type the pyroxene shows a variation towards the silver-green tones of the silver-gray pyroxene. The tendency towards this color seems most pronounced in those crystals most intimately intergrown with the fayalite. The pyroxene partially surrounding the fayalite is not an alteration, for it often bears the same relation to magnetite and porphyritic amphibole.

A phase of the rock especially rich in the lizard-green pyroxene was crushed and this mineral separated by means of the silver thallium nitrate solution. The analysis made by Victor Lenher is as follows:

Analysis of lizard-green Hedenbergite of Nepheline-syenite.

SiO_2	45.50
Al_2O_3	5.93
Fe_2O_3	5.77
FeO	18.81
MnO	trace
MgO	1.75
CaO	19.89
Na_2O	1.54
K_2O	0.16
TiO_2	trace
H_2O—105°–110°	0.19
H_2O—red heat	0.33
Total	99.87

It will be observed that in this pyroxene the constituents next in importance to the silica (SiO_2) are ferrous oxide (FeO) and lime (CaO). It should probably therefore be classed with hedenbergite, whose theoretic formula is $CaFe(SiO_3)_2$. Since it contains other constituents in important quantity, especially alumina and soda, it should be classed as a soda-aluminous variety of hedenbergite.

Attention is called to the close similarity in composition of this lizard-green pyroxene with that of the silver-gray pyroxene occurring in the fayalite-bearing quartz-syenite at Wausau (see page 206). The most notable difference is perhaps the appreciably larger amount of Na_2O and Fe_2O_3 in the lizard-green variety, the acmite molecule being the cause of the deeper coloring which it exhibits. This high content of Na_2O and Al_2O_3 in this pyroxene reflects the high soda-alumina content of the rock magma in which it occurs. The relation of these varieties of hedenbergite to the other pyroxenes occurring in this rock magma is referred to in the description of the soda-alumina variety of pyroxene, percivalite (p. 294).

Barkevikite.—The amphibole occuring in this type is distinctly pleochroic in tones varying from yellowish-green to green and bluish-green. It has the general optical appearance of barkevikite, the amphibole associated with the hedenbergite and fayalite in the quartz-bearing syenite (see page 204), rather than the more distinctly bluish arfvedsonite.

The amphibole is quite generally present but it is not so abundant as the pyroxene. It is often closely intergrown with the pyroxene, and also with pyroxene, fayalite and magnetite. In some phases of this type it appears to be a porphyritic mineral with idiomorphic form. In the porphyritic crystals it often shows borders of green pyroxene extending with numerous projections out into the surrounding crystals.

Mica.—Yellow-brown mica in small plates is a common mineral. It is most abundant where the amphibole is in considerable quantity. In those rocks in which fayalite alone, or fayalite and pyroxene, are present, mica was not noted. The color of the mica corresponds to that of lepidomelane, the alkali-rich variety of mica.

Fayalite.—The iron olivine, fayalite, occurs as a persistent, and at times important, constituent of this rock phase. In some phases of the rock it appears to be the only dark-colored constituent present. It probably does not constitute more than 4 or 5 per cent in any phase, and in the average rock probably not more than 1 or 2 per cent. See Fig. 1, Plate XXXI, and Fig. 8.

The general character of the fayalite, as it occurs in the quartz-bearing syenite, has already been described (p. 211). Its microscopic appearance is practically the same in this type as in the quartz-syenite. It probably has more of a honey-yellow color in this type than in the quartz-bearing rock. It is distinctly pleochroic, in tones varying from light stone-color to yellowish-green or honey-yellow tints. The birefringence is about like that of ordinary olivine. In some slides two fairly well defined cleavages are noticeable, which are probably parallel to the pinacoids 001 and 010. (See Fig. 10.)

The fayalite occurs only in small crystals, generally varying from 0.1 mm. to 1. mm. It occurs in very irregular grains, with a tendency to elongation. Usually it is closely intergrown and partially surrounded by pyroxene, or pyroxene, amphibole and magnetite.

FIG. 10.—Photomicrograph of fayalite in nepheline syenite; x 60. The fayalite. light-colored, is surrounded on nearly all sides by a black border of magnetic iron oxide. Portions of it are in contact with feldspar and hedenbergite. The greatest length of the fayalite in this section is along the *c* axis, parallel to which is indistinct parting or cleavage.

The alteration of the fayalite appears to be to iron oxide and yellowish hydroxide of iron. Magnetite occurs partially surrounding the fayalite and also within it in fractures. Much of the magnetite, however, closely associated with the fayalite, is undoubtedly an original mineral, as much magnetite occurs entirely independent of the fayalite. On the whole, the fayalite appears to be a more stable mineral than ordinary olivine under similar weathering conditions, for in rocks in which nepheline is considerably altered, the fayalite shows but slight discoloration along its fractures, and the interior portions are perfectly fresh.

Magnetite.—Magnetite occurs as a persistent and fairly abundant constituent. It appears to be about as abundant as the

EPLANATION OF PLATE

XXXI.

PLATE XXXI. MICROSECTIONS OF SYENITE CONTAINING FAYALITE.

Fig. 1. Microsection of nepheline syenite containing fayalite. Section 5275. Without analyzer, x20. The colorless minerals are feldspar and nepheline. The three minerals extending across the middle of the section are fayalite. The fayalite is associated with some magnetite.

Fig. 2. Microsection of mica syenite. Section 6597. Without analyzer, x20. The section consists of feldspar, brown mica, hedenbergite, barkevikite, and fayalite. The fayalite is near the centre of the upper left hand quadrant. For analysis of this rock see page 274.

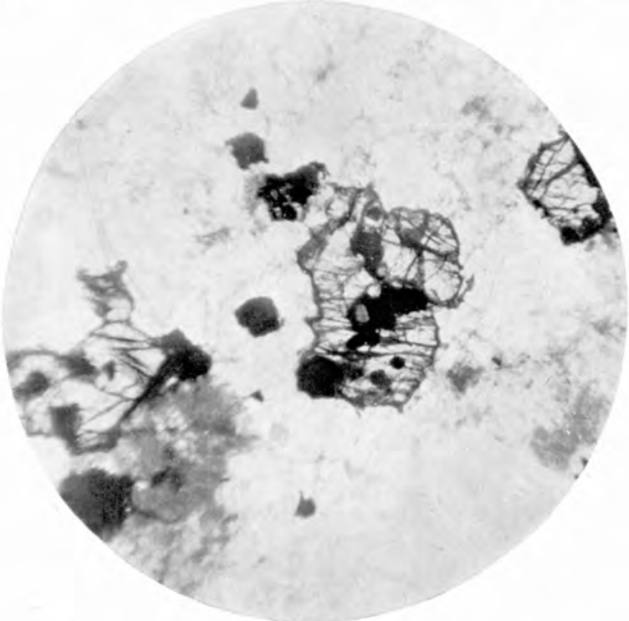

Fig. 1.

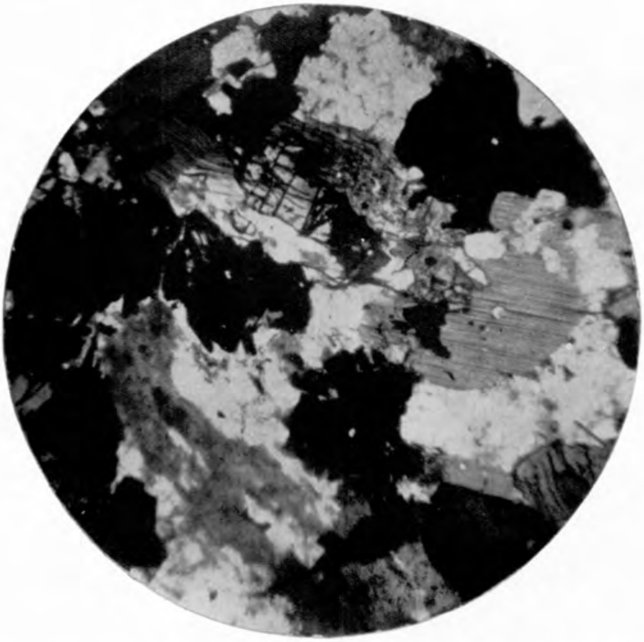

Fig. 2.

MICROSECTIONS SHOWING FAYALITE IN NEPHELINE SYENITE AND MICA SYENITE.

fayalite. It is usually intergrown with the pyroxene and fayalite, but also occurs as free individuals in irregular grains.

Chemical Composition.

The chemical analysis of the fayalite-bearing type of nepheline-syenite (5829) from the SW. 1/4 SE. 1/4 of Sec. 2, T. 29, is as follows:

Analysis of Hedenbergite-Fayalite Nepheline Syenite.

SiO_2	54.76
Al_2O_3	24.72
Fe_2O_3	2.73
FeO	2.35
MnO	none
MgO	0.10
CaO	1.67
Na_2O	10.38
K_2O	2.37
H_2O	0.53
Total	99.63

The noteworthy features of the chemical composition are the high alumina and soda, the relatively low lime and the remarkably low content of magnesia. Potash is low compared with the soda, which probably accounts for the absence of leucite and related potassium silicates in the rock. The molecular ratio of Na_2O to K_2O in the rock, as shown by the analysis, is 6.7 to 1. The alumina and soda are remarkably high, probably bearing the maximum amount of these constituents in normal rock magmas of large extent.

The low content of magnesia explains the development of the fayalite rather than magnesia olivine. The molecular proportions of FeO to Fe_2O_3 is 335.7 to 170.6, or nearly 2 to 1. As much of the Fe_2O_3 occurs in magnetite (combined with FeO in proportion greater than 1 to 1, see p. 251), there is left considerable FeO to enter into the minerals fayalite and the green variety of hedenbergite.

THE AEGERITE SODALITE NEPHELINE-SYENITE.

The aegerite-bearing phase of the nepheline-syenite forms small areas scattered over most of the region of the nepheline-bearing rock. It occurs in considerable abundance in the NE. ¼ of Sec. 27, T. 29, R. 6 E. and vicinity; in the NW ¼ of Sec. 24 and vicinity and the NW. ¼ of Sec. 15, of the same township; and in the NE. Corner of Sec. 31 and the NW. ¼ of Sec. 28 of T. 29, R. 7; and the small outcrop southwest of Wausau in Sec. 21, T. 28, R. 8 E. So far as observed, all the coarse nepheline-bearing pegmatite veins bear aegerite. Isolated occurrences of nepheline-bearing pegmatite occur in the southern part of Sec. 3, T. 29, R. 6 E. and in the NE. part of Sec. 5, T. 29, R. 7 E.

Macroscopic Character.

The character of the rocks forming the outcrops of the aegerite-bearing type varies from place to place, but, in general, the usual rock is fine to medium-grained and of grayish color. The minerals readily observed in the hand specimens are feldspar, nepheline, aegerite, and sometimes amphibole and brown mica. The most abundant mineral is the white or grayish feldspar, quite generally showing a tabular development, and hence the parallel plates of feldspar are a characteristic feature. The nepheline has the usual flesh-colored and vitreous aspect of this mineral, which, with its brittleness, gives the rock in which it occurs a character quite unlike that of any other rock of the region. The aegerite is dark green and occurs in small medium-sized crystals.

The weathering and decomposition of the nepheline-bearing rock, not only of this type but also of the other, is a characteristic feature. The nepheline, and likewise the sodalite, are the first minerals of the rock to be decomposed and to be carried away by action of the rains. Wherever this rock, therefore, has been exposed to weathering, it is seen to be pitted with numerous depressions, due to the weathering and removal of the nepheline. The pitted character of the weathered rock, as well as its vitreous, brittle character, and grayish-flesh color, allows it to be easily recognized in the field, and to be readily separated from the quartz-bearing rocks closely associated with it.

Microscopic Character.

In thin sections, the rock is seen to be made up of the following minerals: Alkalic feldspars, nepheline, sodalite, aegerite, arfvedsonite, lepidomelane, cancrinite, zircon, fluorite, magnetite (idiomorphic mineral with high index of refraction and strong double refraction, an d a grayish-yellow mineral with medium index of refraction and medium double refraction). The usual weathering products, such as natrolite, kaolin, and muscovite, are also generally present.

Feldspar.—The alkalic feldspars consist of anorthoclase, microperthite, microcline, and albite and orthoclase.

The prevailing feldspar of the nepheline--syenite rock, in general appears to be anorthoclase and microperthite, the former occurring as homogenous or finely lamellar crystals, and the latter as a coarser mixture or intergrowth of the alkali feldspars. Anorthoclase is a soda-potash triclinic feldspar with a cleavage angle varying very little from 90 degrees, and a composition in which sodium silicate or the orthoclase molecule is usually present in larger proportion than the potash silicate or albite molecule. Twinning according to the Carslbad law is very common, and according to the Baveno and Manebach laws is rare. The anorthoclase is sometimes twinned polysynthetically according to the albite and pericline laws and usually when twinned the lamellae are very fine. Very often, however, in some of the coarser rocks, polysynthetical twinning is entirely absent.

The anorthoclase, and also the microperthite closely associated with it in the quartz-bearing syenite, generally occur in allotriomorphic crystals of nearly equidimensional axes. On the other hand, in the nepheline-bearing phases of the syenite, the anorthoclase usually assumes a tabular development, parallel to the brachypinacoid. The tabular crystals often measure from 10 mm. to 30 mm. along the *a* and *c* axes, while the length of the *b* axis is usually not more than one-tenth that of the *a* and *c* axes.

In color and general appearance under the microscope, the anorthoclase is quite characteristic. In parallel polarized light, it is clear to translucent, and under the cross-nicols, it has a characteristic schiller or pearly lustre. In fact, the anorthoclase of this rock appears to be very similar, if not identical, in appearance, and in its association with microperthite, with the anorthoclase or cryptoperthite so fully described by Brögger[1] in the syenite rocks of southern Norway.

The alteration of the anorthoclase is similar to that of albite and orthoclase, and kaolin and sericite are the usual inclusions seen in the weathered phases of the syenite.

An abundant feldspathic constituent of some of the aegerite-bearing phases is microperthite, which consists of a mixture or intergrowth of orthoclase and albite or of microcline and albite. This microperthite takes the place of the homogeneous anorthoclase in many of the syenites, and the two are apparently identical in composition. It occurs in nearly equidimensional crystals in some of the syenites, and in elongated tabular crystals in the other phases.

Albite is usually not present in large crystals. Quite generally, if not always, the albite, where present, is of the second generation. This is especially true of the nepheline-syenite in the NE. 1/4 of Sec. 27, T. 29, R. 6 E., consisting of good-sized crystals of nepheline and microperthite or anorthoclase, with parallel laths of albite winding about and between them.

Microcline, with the characteristic rectangular grating structure due to cross-twinning, while present in some of the thin sections of this type, does not appear to be abundant.

Orthoclase, as free individuals, does not appear to be abundant. When present, it is usually as one of the coarsest constitutents of the rock. Orthoclase as constitutent portions of the microperthite is abundant.

Nepheline.—Nepheline is an abundant constitutent of the aegerite-bearing type. In the area of nepheline-syenite, in the NE. 1/4 of Sec. 27, T. 29, R. 6 E., the nepheline appears to be about as abundant as the feldspar. In this locality the nepheline, often reaching from 5 to 10 mm. in diameter, occurs in short, rectangular to quadratic, longitudinal sections. In other phases of the rock in which the feldspars occur in tabular plates, the

[1]Zeit. fur Kryst. Band. 16, p. 524.

nepheline is greatly elongated in the direction of the c axis. The nepheline, as seen in thin section, is colorless, with the low index of refraction and weak birefringence characteristic of this mineral. The most common alteration is to natrolite, which gives the weathered crystals a cloudy appearance. Kaolin and muscovite are also present in the extremely altered nepheline.

Sodalite.—The sodalite occurs in colorless, greatly distorted crystals. This mineral is isotropic, with low index of refraction. It is closely associated with the nepheline and appears to have crystallized about the same time as the nepheline. In some phases it crystallized after the feldspar, and in other phases before. The sodalite appears to be most abundant in the phases of this rock rich in amphibole, as in the amphibolite phases occurring in the NE. ¼ of Sec. 27, T. 29, R. 6 E.

Sodalite is especially abundant in the NW. corner of Sec. 15, T. 29, R. 6 E. In this vicinity the nepheline-syenite was observed in small dikes and veins penetrating fine-grained greenstone (gabbro). These veins are especialy rich in sodalite, and sodalite and fluorite are present in the metamorphosed gabbro rock along the contact.

The sodalite is often clouded with secondary inclusions of natrolite. Kaolin and muscovite are also alteration products. Quite generally the sodalite is clouded with more secondary natrolite than the nepheline.

Analcite was not definitely determined as present, but small interstitial minerals in some phases with very low index of refraction may be analcite.

The isotropic haüyne, nosean, and leucite were searched for but were not observed or recognized. Haüyne and nosean may be present in some of the rocks. Leucite, however, on account of the comparatively low content of potassium in the nepheline rock of this region, is very probably not present, for it will be observed (see analyses, page 339) that these alkali-rich rocks free from quartz are per-sodic and not per-potassic.

Aegerite.—This mineral unlike the common pyroxenes, has strong birefringence and pronounced pleochroism, and is quite generally greatly elongated in the direction of the vertical axis. It occurs in variable quantity in the normal phase of this type, and is the prevailing or only pyroxene of the coarse nepheline bearing pegmatite. The aegerite varies in size, in the normal phases of the rock, from a fraction of a millimeter in diameter to two or three millimeters. The proportional length of the vertical axis to the horizontal ranges between 2 to 1 and 10 to 1.

The aegerite is generally idiomorphic without terminal faces. In some of the mashed and crumpled rocks, the crystals are often bent and broken apart. It is strongly pleochroic: a=pure green;b=yellow-green to moss-green; c=light olive-green to yellowish green. The extinction is nearly parallel to the prismatic cleavage, X to c is 2° to 5°. The pinacoidal parting so common in the silver--gray pyroxene of the quartz-bearing syenites is entirely wanting. Twinning was observed in a few instances.

The aegerite is fresh and unaltered. In one instance a fracture in the aegerite was noted filled with yellow-brown mica, which may have been developed from the aegerite. It is intergrown in some instances in the amphibolitic phases with the bluish-green amphibole, but their boundaries are sharp and distinct.

Arfvedsonite.—A bluish-green amphibole having the character of arfvedsonite is an abundant constituent in some phases of the aegerite-bearing rock. This amphibole is strongly pleochroic: a=pale yellow-green, b=pale bluish-green; c=deep bluish-green. The extinction angle on the prism face 010 is about 15° to the vertical axis.

This amphibole is abundant in small crystals in the banded and schistose phases in the NE. ¼ of Sec. 27, T. 29, R. 6 E., and in the NW. ¼ of Sec. 15. It is especially abundant in the coarse-grained rock with well developed tabular feldspar. In the NE. of the SE. ¼ of Sec. 7, T. 29, R. 7 E., where it is associated with but a small amount of aegerite. Where associated with aegerite the two are often intergrown with one another, sometimes in parallel structure, but the two are always sharply defined.

Lipidomelane.—A brownish-yellow mica is a common constituent closely associated with the aegerite and arfvedsonite. The pleochroism is pronounced. The ray vibrating normal to the cleavage is yellowish-green, much like the yellowish-green tones of the aegerite and arfvedsonite. The ray parallel to the cleavage is almost wholly absorbed. The optical properties are those of the alkali biotite, lepidomelane.

The lepidomelane is often intergrown with the arfvedsonite and aegerite, especially the former. No alteration was observed.

Lepidomelane is very abundant in some phases of the nepheline syenite in the SE. 1/4 of Sec. 22, T. 29, R. 6 E.

Magnetite.—Magnetite occurs to some extent in most phases of the rock, but only in small quantity. In places, however, the magnetite is quite abundant. This is especially true in certain of the outcrops in the SE. part of the SW. 1/4 of Sec. 22, T. 29, R. 6 E. A thin section of this magnetite-rich rock contains, besides the magnetite; alkali feldspar, nepheline, sodalite, cancrinite, aegerite and arfvedsonite. The magnetite occurs in small crystal aggregates, and as good-sized twinned individuals from 1 to 2 mm. in diameter, evidently one of the first minerals to crystallize in the magma. On weathering, the magnetite is the last mineral of the rock to decompose and hence stands up as projections of black, metallic crystals.

The magnetite was separated from the rock, and analyzed by Victor Lenher, with the following result:

Analysis of Magnetite of Nepheline-syenite.

Fe_2O_3	77.03
FeO	21.41
SiO_2	0.44
Al_2O_3	0.10
MnO	trace
H_2O	none
	98.98

As the constituents, other than the iron oxide, occur as inclusions, the pure magnetite is calculated to be:

Fe_2O_3	78.25
FeO	21.75
	100.00

The molecular proportion of Fe_2O_3 to FeO is 4.89 to 3.02, approximately 8 to 5.

Cancrinite.—A colorless cancrinite is an abundant constituent of many of these rocks. The index of refaction is very low, the birefringence is strong, the interference colors being the yellow and blue of the 3rd order. The crystals are usually elongated in the direction of the c axis. Prismatic cleavage is noticeable, parallel to which is the plane of extinction. The cancrinite occurs in long, columnar crystals; in thick prismatic crystals; and in irregular lenticular grains. The columnar forms are most abundant in those rocks in which the other minerals are in elongated forms. Some of the cancrinite is slightly bluish and pinkish. White and yellow, however, are the prevailing colors. The common alteration is to natrolite, which gives it a cloudy appearance.

Fluorite.—The fluorite has the general character of this mineral, as described in the quartz-bearing phases of the syenite. No colored fluorite was observed. Most of it shows very weak birefringence. The octahedral cleavage is distinct and furnishes a ready means of distinguishing it from other colorless isotropic minerals. It occurs in small, irregular crystals, fitting in between the larger associated minerals. It is apparently most abundant in the vicinity of contacts with the older alien rocks, and, in some instances, as in the veins of syenite penetrating the greenstone in the NW. ¼ of Sec. 15, T. 29, R. 6 E., it is present with sodalite, in considerable quantity, along the contact with the greenstone. Alteration or replacement of the fluorite was not observed.

Apatite.—Apatite is present in most of the rock in small quantity. It occurs in thick prismatic crystals and in long needles.

Zircon.—Zircon is present in variable but small quantity in most of the syenite. It generally occurs in short, prismatic crystals with terminal faces. They are quite generally less than a millimeter in diameter. The zircon occurs in abundant small crystals in the aegerite-bearing rock in the NW. ¼ of Sec. 15, T. 29, R. 6 E., and vicinity, and also in the isolated outcrops adjacent to the quartzite in the NE. ¼ of Sec. 31, and in the NW. ¼ of Sec. 28 of T. 29, R. 7 E.

In the thin section of nepheline-syenite from the NE. ¼ of Sec. 27, T. 29, R. 6 E. were observed two minerals which were not identified. One of these has the cleavage and general character of a member of the epidote group and may be piedmontite. The other mineral is distinctly pleochroic in tones of light yellow to pink and corn color. It has an index of refraction about like zoisite, and strong double refraction. It occurs in small rounded grains and in elongated crystals with extinction nearly parallel to the longer axis. This mineral is usually intergrown with aegerite. The general character of this mineral and its association with fluorite and aegerite suggests lavenite or mosandrite. The rock analyzed from this locality contains an appreciable amount of ZrO_2, 0.28 per cent, but no zircon was noted in the thin sections from this locality. Hence it seems likely that one or both of these undetermined minerals may contain zircon and other rare elements.

Chemical Composition.

The aegerite nepheline-syenite occurring in the NE. corner of Sec. 27, T. 29, R. 6 E. may be taken as a fair representative of the type. The nepheline-syenite in this locality varies much in texture, from coarse to fine-grained and to coarsely banded phases. All are aegerite-bearing, however, and contain a variable amount of sodalite and amphibole. The rock material analyzed was made up of representative portions of the various phases (specimens 5462, -'3, -'4, -'5, and -'8) in order to obtain the composition of the average rock of this particular locality. The analysis, made by Victor Lenher, is as follows:

Analysis of Aegerite Sodalite—Nepheline-syenite of NE. ¼ of Sec. 27, T. 29, R. 6 E.

SiO_2	57.82
Al_2O_3	24.23
Fe_2O_3	1.56
FeO	1.03
MnO	trace
MgO	0.28
CaO	1.04
Na_2O	9.20
K_2O	3.03
H_2O—105°-°110°	0.14
H_2O—red heat	0.59
TiO_2	0.30
ZrO_2	0.28
Cl	0.15
Li_2O	none
CO_2	none
F	none
S	trace
P_2O_5	trace
	99.65
Less oxygen equivalent of Cl	.03+
Total	99.62

This phase of the nepheline syenite is somewhat higher in SiO_2 than the other phase analyzed (see pages 245 and 255). The low content of MgO is a notable characteristic of this nepheline syenite, as well as of all the related rocks. The high content of Na_2O as compared with K_2O is worthy of note. The 0.15 Cl indicates the presence of 2.1 per cent of sodalite. One of the specimens, a small portion of which was included in the analysis, contains a small amount of fluorite, obviously too small an amount, however, for the detection of fluorite in the analysis when portions of the other specimens were mixed with it. In some of the specimens represented in the analysis are several undetermined minerals, which constitute, however, but a small portion of the rock as a whole. It is believed that some of these undetermined minerals are some of the rare silicates bearing zirconium.

A phase of the aegerite-sodalite-bearing rock from the NW. ¼ of Sec. 15, T. 29, R. 6 E. was analyzed, with the result as stated below. The rock analyzed probably does not represent the average composition of this type. It contains an abundance of bluish-green amphibole, and very little aegerite. The amphibole appears to be arfvedsonite. The rock, however, is very much like certain phases of the aegerite-bearing rock in the NE. ¼ of Sec. 27, where the phase rich in arfvedsonite appears to show a constant gradation and mingling with that portion in which only aegerite occurs. Tabular microperthite and nepheline are the principal constituents. Besides the sodalite, which is especially abundant in this phase, and amphibole, there is present a small amount of yellow-brown mica, magnetite and fluorite.

The chemical analysis (Sp. 6426) made by W. W. Daniells is as follows:

Analysis of Aegerite-Sodalite Nepheline-Syenite from NW. ¼ Sec. 15, T. 29, R. 6 E.

SiO_2	54.79
Al_2O_3	22.87
Fe_2O_3	1.74
FeO	3.24
MgO	trace
CaO	1.92
Na_2O	10.75
K_2O	4.06
TiO_2	0.31
ZrO_2	0.07
P_2O_5	none
F	0.14
Cl	0.70
	100.59
Less O=F	0.06
Less O=Cl	.16
Total	100.37

It may be noted that the rock is especially rich in Al_2O_3 and Na_2O, and has only a trace of MgO,[1] thus showing its similarity to other members of this soda-rich series. The 0.70 of Cl. indicates the presence of 9.75 per cent of sodalite, a higher content of sodalite than the average sodalite-bearing rock. The relatively high content of FeO indicates the amphibole to be arfvedsonite.

INTERMEDIATE PHASES OF THE NEPHELINE-SYENITE

Besides the two types of nepheline-bearing syenite above described, there are rocks slightly different from these in mineral composition and partaking of the character of both. Some of these intermediate phases differ also from the normal types in textural features.

[1] Attention is called to an error in the statement of the relative amounts of MgO and CaO in this analysis, as printed in the *Journal of Geol., Vol.* XII, p. 552. The analysis should read as above: MgO-*trace*; *CaO*. 1.92.

NEPHELINE-SYENITE WITH TABULAR MICROPERTHITE.

In the northeastern part of the SE. ¼ of Sec. 7, T. 29, R. 7 E., is a coarse-grained nepheline-syenite, a prominent feature of which is the pronounced tabular development of the feldspar.

The rock is exposed in the ditch of the wagon road, and numerous blocks of it have been built into a stone fence along the road. The general varying character of the rock is best shown in the loose boulders. A photograph of one of these, about a foot in diameter, showing the tabular development of the feldspar, is well shown in Plate XXXIV. Other phases of the rock at this place show a less pronounced parallel arrangement of the feldspar, showing a gradation to the normal rock structure of the nepheline-syenite.

A short distance to the south and southeast is a large mass of the older greenstone formation, hence the contact is not far away, probably 300 or 400 feet from the outcropping nepheline-syenite.

Macroscopic Character.

The minerals to be observed by the naked eye are the white tabular feldspar with pearly lustre, nepheline, and very dark green amphibole. The tabular feldspars have a breadth generally varying from 10 to 30 mm. and a thickness from 2 to 6 mm. The distribution of the tabular plates of feldspar is in planes approximating parallelism. The nepheline is greatly weathered in this particular locality and the weathered surfaces of the boulders are greatly pitted. Both the nepheline and the amphibole occur in interstices between the feldspar tables.

Microscopic Character.

The minerals to be observed under the microscope are feldspar, nepheline, amphibole, magnetite, pyroxene, sodalite, cancrinite, apatite, and the usual alteration products of the nepheline.

Micropethite.—The feldspar is almost wholly microperthite in fairly coarse intergrowths. These microperthite feldspars are perhaps better developed in this phase than in any other of

EXPLANATION OF PLATES

XXXII AND XXXIII.

PLATE XXXII. MICROSECTIONS OF MICROPERTHITE.

Fig. 1. Microsection of microperthite. With analyzer, x20. Shows the relation of the microperthite laths to the twinning and cleavage planes.

Fig. 2. Microperthite. Section 5823.3. With analyzer, x20. Shows appearance of the microperthite in random sections.

PLATE XXXIII. MICROSECTIONS OF MICROPERTHITE.

Fig. 1. Microperthite in section 5261.1. With analyzer, x20. Shows appearance of the microperthite in planes normal to the brachypinnacoid twinning.

Fig. 2. Similar to the above. These are from the nepheline syenite having tabular feldspar like specimen represented in Plate XXXIV.

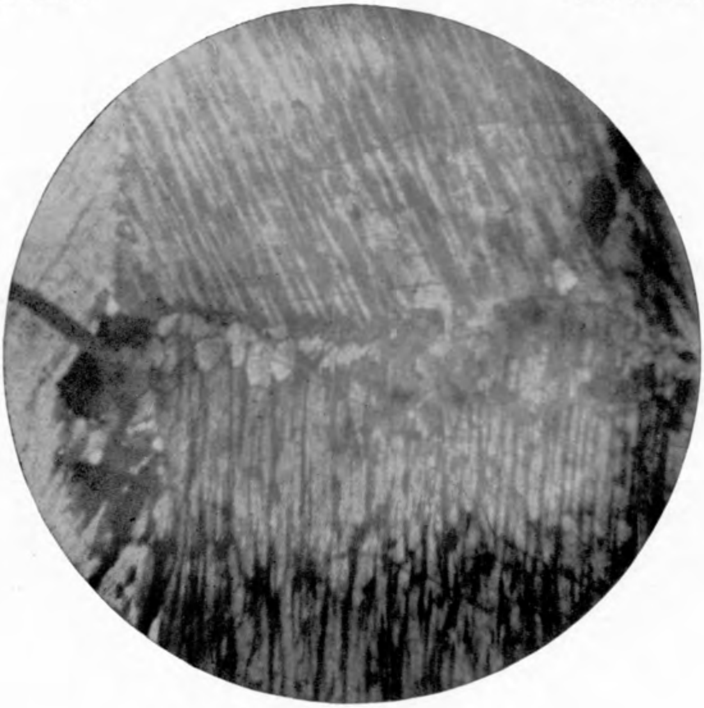

Fig. 1.

Fig. 2.

MICROSECTIONS OF MICROPERTHITE.

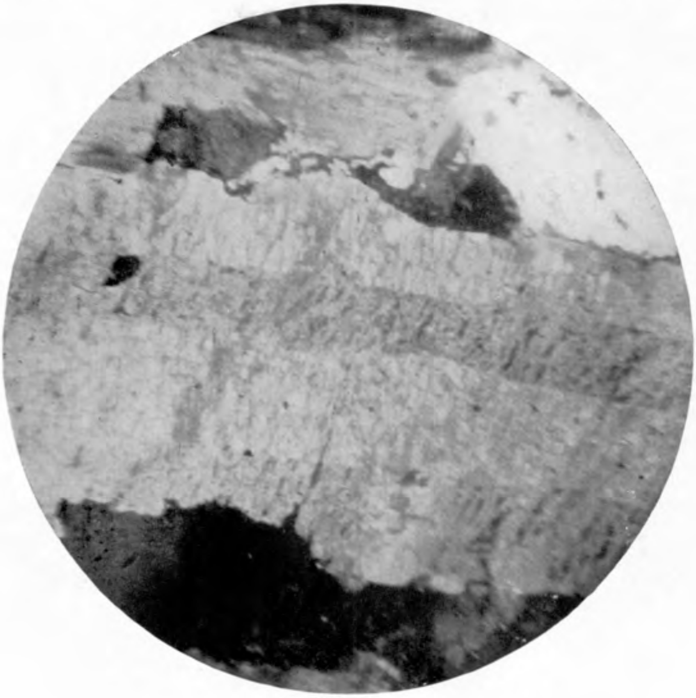

Fig. 1.

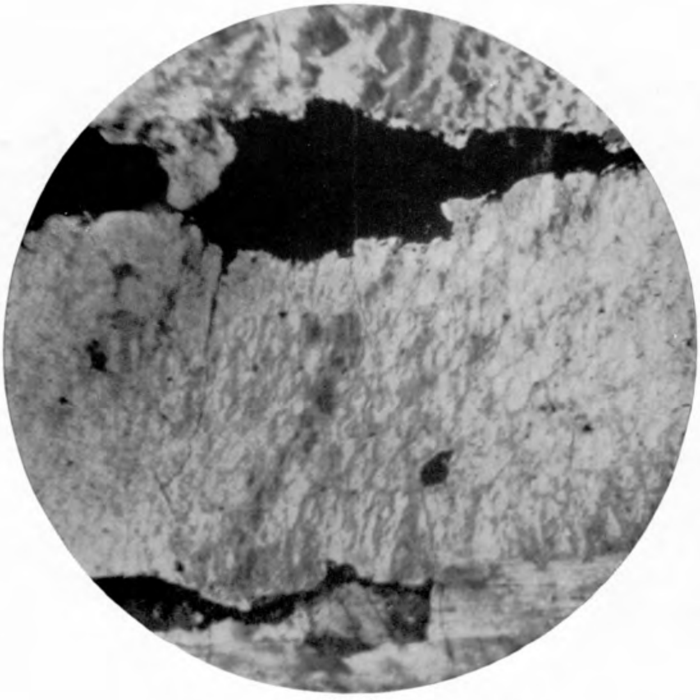

Fig. 2.
MICROSECTIONS OF MICROPERTHITE.

the area. They are quite similar, if not identical, in character, with the microperthite in the Stettin type of the quartz-syenite and in the peculiar contact phase of syenite with the feldspar cores.

In sections cut parallel to the basal pinacoid 001 or nearly so, the strips run from right to left across the crystals, in general parallel to the macro-diagonal axis. The appearance of the microperthetic growths seen in this plane is shown in Figure 1, Plate XXXII.

Thus these strips of differently polarized feldspars are developed, so far as I have been able to determine, in numerous thin sections, in planes parallel to the vertical axis and nearly parallel to the macro diagonal axis; that is, near the plane of the macropinacoid (100). In the tabular crystals, therefore, the lamellae are nearly parallel to the very short axis of the crystals.

Composition of the Microperthite.—The composition of the intergrown strips of feldspar constituting the microperthite is variable within narrow limits. Examined in sections approximately parallel to the brachypinacoid face and the basal pinacoid, these perthitic lamellae extinguish at the angles corresponding to albite and orthoclase. Two kinds of feldspar are thus included in a single microperthite crystal.

Genesis of the Microperthite.—The origin of these microperthite crystals which characterize this phase of the syenite is of interest. It has been stated that the microperthite and anorthoclase appear to take the place of one another in rocks of similar composition, and that the composition of the homogeneous anorthoclase and heterogeneous microperthite is apparently identical. The question now arises as to why the feldspathic substance separates out as homogeneous anorthoclase in one place, and microperthite in the other.

Is the microperthite a secondary development from the anorthoclase through processes of metamorphism? A secondary origin is offered by Brögger[1] as the explanation of much of the microperthite of the syenite-pegmatite dikes of Southern Norway.

Ussing[2] also explains the microperthite of certain Greenland syenites as in part secondary and in part primary, a marked difference in the character of the two kinds being apparent.

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[1]Zeit. für Kryst., u. Min., B. 16, p. 537.

[2]Meddelelelser om Gronland. Heft. XIV, pp. 15–106, 1894.

The writer[1] has described somewhat similar microperthetic feldspars in the meta-rhyolite of Utley, Wisconsin, which reveal their secondary development very clearly. In the Utley metarhyolite the microperthite occurs as phenocrysts in a fine-grained ground-mass along with other phenocrysts of polysynthetically twinned homogenous feldspars.

The microperthite phenocrysts of Utley differ somewhat in their manner of intergrowth from those in the syenitic rocks of this region, and also differ essentially in composition, containing a much larger amount of lime.

The original plagioclase, however, in the rhyolite[2] of Utley shows all the stages of regeneration into microperthite and also contains secondary rims of secondary microperthite surrounding the original cores of microperthitized feldspar.

In the peculiar contact rock characterized by microperthite having the enlargements, it seems clear that the microperthite of the rims is a secondary crystallization (see p. 221). The nucleal microperthite with crystal forms may have been original or may have formed during the second stage of crystallization of the rock.

The genesis of the microperthite in this coarse-grained syenite, however, is more obscure. It is possible that pressure may have exerted considerable influence upon their development.

The lamellae in the microperthite are approximately in the plane parallel to the *c* axis, and diagonal to the *b* axis. In cross-sections, the narrow edges of the lamellae in the planes of the brachypinacoid and basal pinacoid are seen to split off and connect across with one another. They are seen to be nearly or exactly parallel to the *c* axis in the brachypinacoid face, while in the basal pinacoid face they usually are more irregular and run diagonal to the *b* axis, which may be explained by the fact that their development is modified somewhat by the structure planes of the prismatic cleavage.

It is possible that when pressure was exerted upon the crystals subsequent to their original crystallization, these tabular crystals may have had a tendency to rupture along the plane of

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[1]Wis. Geol. and Nat. Hist. Surv., Bulletin No. III, pp. 13–27.

[2]Bulletin No. III, Wis. Geol. and Nat. Hist. Survey, Figs. 1 and 2, Plate VIII, or Bulletin 150, U. S. Geol. Surv., Plate XXVIII, Fig. A.

EXPLANATION OF PLATES

XXXIV, XXXV AND XXXVI.

PLATE XXXIV. NEPHELINE SYENITE WITH PARALLEL TABULAR FELDSPAR.

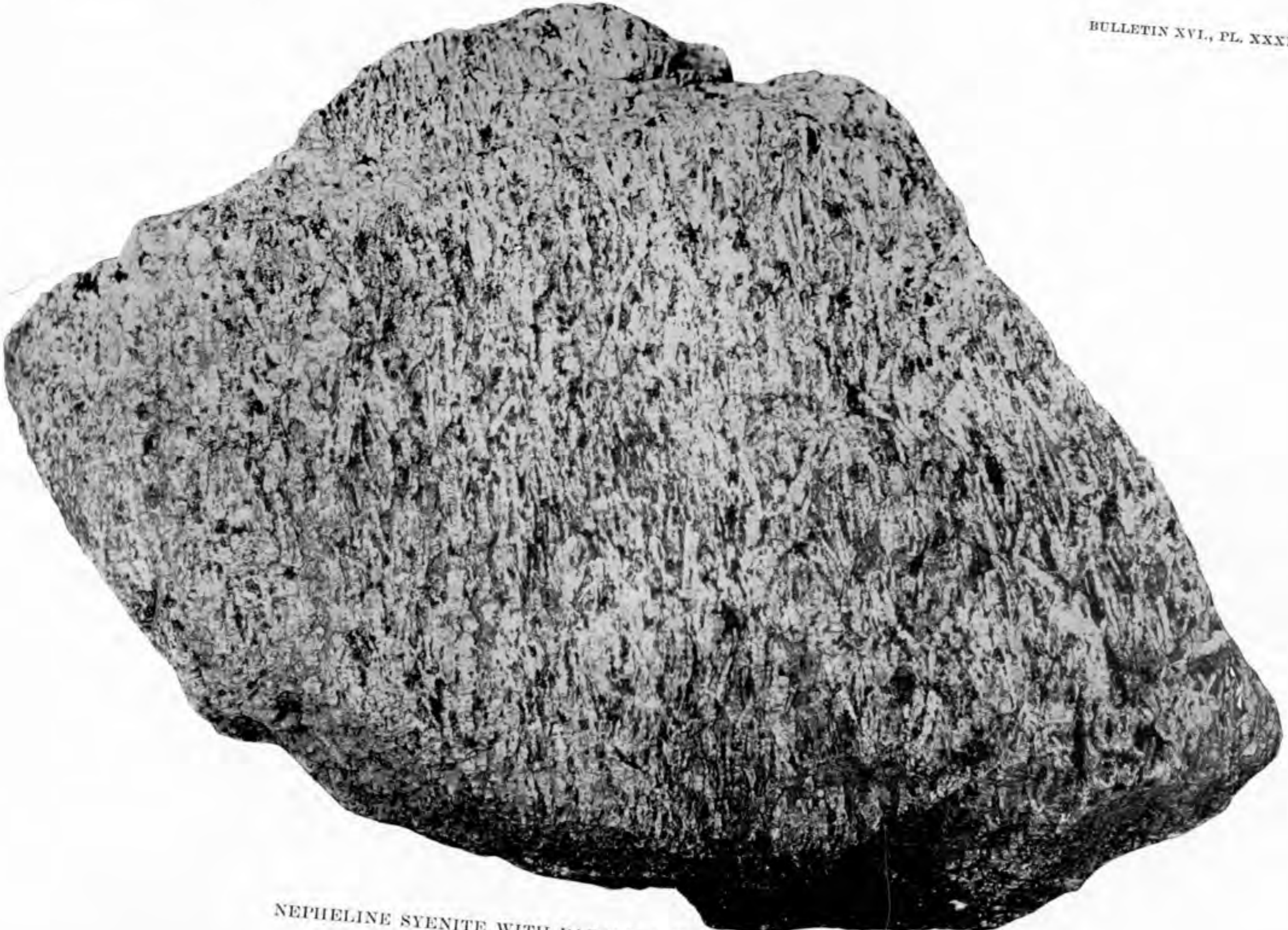
One-half natural size. The black mineral is mainly aegerite. The pitted surface is due to the weathering out of the nepheline, leaving the tabular feldspar, microperthite, to stand out as ridges.

PLATE XXXV. NEPHELINE PEGMATITE, CUT BY DIKE OF NEPHELINE SYENITE.

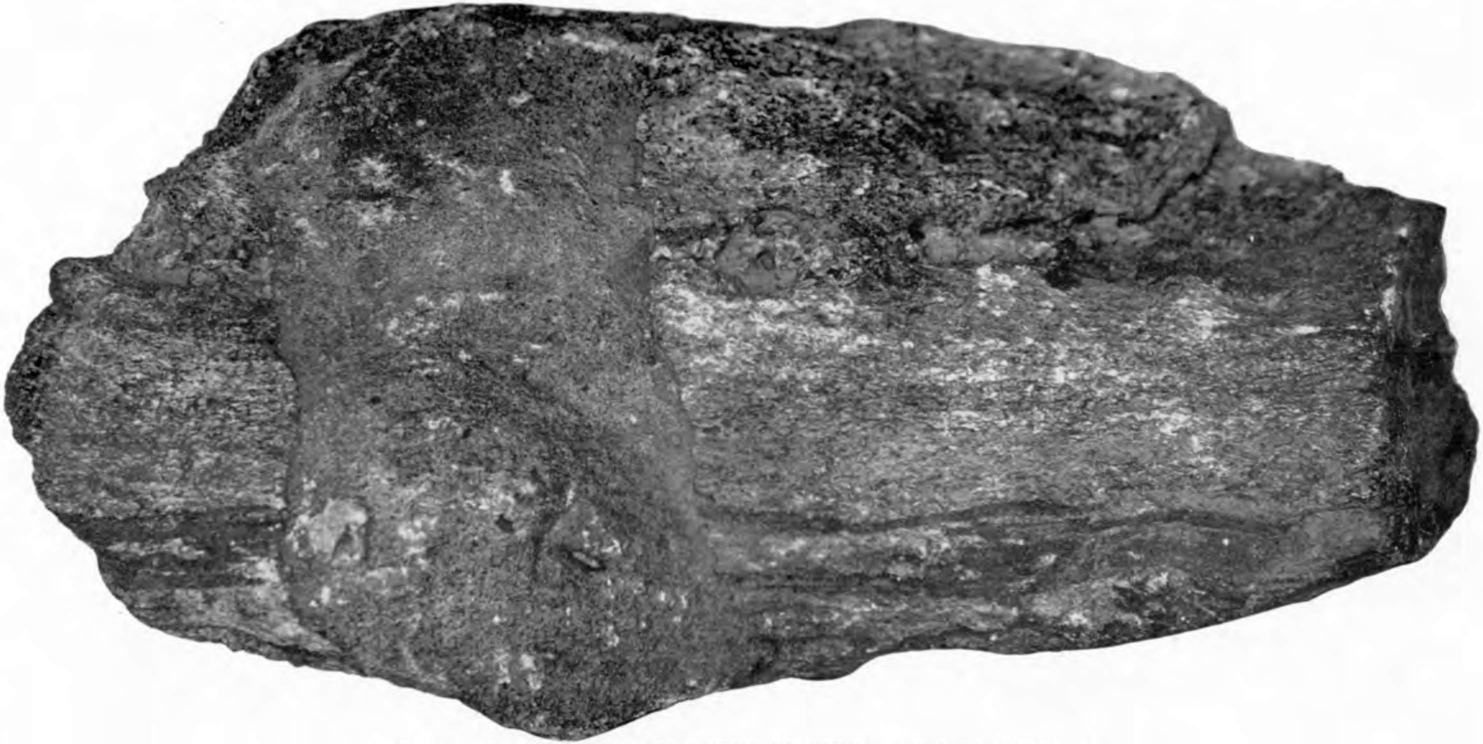
Three-fourths natural size. A pegmatitic phase of the nepheline syenite containing bands of coarse nepheline alternating with bands of finer grained rock rich in soda amphibole and aegerite. The dike which cuts across the banded structure is a porphyritic phase of the nepheline syenite.

PLATE XXXVI. FOLDED PHASE OF THE NEPHELINE PEGMATITE.

Three-fourths natural size. The light colored bands are mainly feldspar and nepheline, the dark bands are mainly aegerite and soda amphibole. The banding is evidently an original structure like the straight banding illustrated in Plate XXXV. The crumpling and folding of the bands is due to compression after crystallization as shown by the bent and broken crystals to be seen in microsections of this rock.



NEPHELINE SYENITE WITH PARALLEL TABULAR MICROPERTHITE.



NEPHELINE PEGMATITE INTRUDED BY DIKE OF NEPHELINE ROCK.

FOLDED NEPHELINE PEGMATITE.

the prismatic cleavage, a plane of weakness, and that these areas, being in a state of strain, re-arrangement there of the feldspathic substance would be likely to take place. The readjustment may have been somewhat analogous, therefore, to the development of the microcline structure. Thus the feldspathic substance which crystallized out as an isomorphous mixture of potash silicate and soda silicate, under a later set of conditions may have become unstable, and as a result the homogeneous anorthoclase was recrystallized and regenerated and the mixture of the two feldspars was developed approximately in the plane of the prismatic cleavage or macro-pinacoid of the parent crystal.

It is not believed that any actual rupture took place, the dismembered parts being later filled with new feldspar substance. For, if actual splitting took place, the fracturing would have extended into the surrounding amphibole and nepheline, which show no breaking apart whatever. It is merely suggested that the original feldspar may have been in a state of strain sufficient to cause a readjustment of the molecules in a manner somewhat similar to what is supposed to take place in the development of cross-twinning in microcline or in the twinning of calcite under strain.

In the development of twinning there is presumably no change in composition, but in the secondary development of microperthite from an originally homogeneous feldspar actual interchange and transference of substance must be presumed to take place.

On the other hand, it is possible also, as Ussing states, that microperthite be developed as an original crystallization in the magma. The absence of evidence of the secondary origin of the microperthite in this particular trachytoid syenite of this region leads the writer to the belief that they are probably an original development in the magma. Their growth as an original crystallization would be somewhat analogous to the parallel intergrowth of hedenbergite and barkevikite (see page 209) or of percivalite, crocidolite and albite (see page 289). These complex silicates, belonging to entirely different groups of minerals, possess certain chemical similarities or affinities which have apparently acted as a bond of attraction or union in the processes of crystallization, and under especially favorable conditions of crystallizing, intimate parallel growths are developed.

Nepheline.—Nepheline is an abundant constitutent. It does not appear to have been abnormally developed in any particular axial direction like nepheline in certain mashed and crumpled phases occurring in the NE. ¼ of Sec. 27, T. 29, R. 6 E. The nepheline is much altered in most of the thin sections examined from this locality. The usual alteration is to natrolite and muscovite. Sodalite and cancrinite are present in small quantity in many of the thin sections from this locality.

Amphibole.—A green amphibole with bluish tones is the principal dark-colored constituent. It does not show any marked development in the direction of the *c* axis. The amphibole is apparently arfvedsonite. It is remarkably fresh and unaltered. The amphibole probably forms 4 or 5 per cent of the rock.

Pyroxene.—Pyroxene is present only in small quantity. It was observed in only two of the slides. It is apparently aegerite, but probably not the pure type, as it is quite dark green in color.

Magnetite is present in irregular crystals, probably constituting 1 or 2 per cent of the rock. Fluorite and apatite were also observed.

On the whole, this phase of syenite with prominent tabular feldspar appears to stand closer to the aegerite-sodalite type than to the hedenbergite-fayalite type.

SOME PHASES OF NEPHELINE-SYENITE OF SMALL OCCURRENCE.

In the SE. ¼ of Sec. 14, T. 29, R. 6 E., there are abundant low outcrops of syenite and coarse pegmatite. There is present a small amount of nepheline-bearing rock, 6590, near the SE. ¼ having the character of the fayalite-bearing type. It contains, besides the alkali feldspar and nepheline, a considerable amount of the dark green hedenbergite, green amphibole, and a small amount of fayalite.

In the immediate vicinity of the nepheline-bearing rock there is much syenite bearing similar pyroxene and amphibole, but apparently free from nepheline and quartz. This phase much resembles the Stettin type of the quartz-syenite and grades into it. This phase constitues most of the rock in Sec. 14 and contains numerous veins of the coarse quartz-bearing pegmatite.

The nepheline-bearing syenite occurring in small quantity in the NW. ¼ of Sec. 24, T. 29, R. 6 E., apparently in lense-shaped bodies or veins, associated with quartz-bearing syenite and coarse pegmatite, is the aegerite-bearing type, having mineral composition and texture of rock similar to that occurring in the NE. ¼ of Sec. 27 and vicinity.

In the NW. ¼ of Sec. 15, T. 29, R. 6 E., the nepheline-bearing syenite bears much amphibole and but a small amount of aegerite. This phase has already been described as being closely related to the aegerite-sodalite type. This rock bears much sodalite, and is in contact with the older greenstone in this vicinity, which may in part explain its variation from the normal type of aegerite-sodalite rock.

The nepheline-bearing syenite in the northeastern part of Section 31 and in the vicinity of the northwestern part of Section 28, T. 29, R. 7 E. is closely associated with the quartz-bearing syenite containing the feldspars with cores. The nepheline syenite at both these localities also is closely associated with the contact phases containing numerous quartzite fragments. In both localities the nepheline-bearing rock is quite similar in texture and composition to the aegerite-sodalite type. The rock is fine to medium-grained. The feldspar is microperthite and albite. Besides the nepheline, sodalite and cancrinite are present. Both aegerite and bluish-green amphibole, arfvedsonite, are present in abundance. Magnetite is also quite abundant, making up 2 or 3 per cent of the rock. Fluorite, zircon, and yellow-brown mica are also present. The zircon occurs in numerous minute crystals scattered throughout the rock. There is also present an undetermined mineral with high index of refraction and strong birefringence, probably a member of the zircon-rutile group.

PHASE OF NEPHELINE-SYENITE CONTAINING CARBONATE, PRESUMABLY CALCITE.

An interesting occurrence of a carbonate is to be observed in the fine-grained nepheline-syenite in the northwestern part of Sec. 28, T. 29, R. 7 E. This carbonate is colorless, and occurs in small grains up to .5 mm. in diameter. It occurs indiscriminately in contact with all the minerals composing the rock. As seen in cross-section, it is sometimes surrounded entirely by small crystals of feldspar, or by a single crystal of aegerite. It is also in contact with sodalite, cancrinite and magnetite. It contains inclusions of zircon. The usual twinning of the calcite group is to be observed in the larger grains. See Pl. XXXVII.

This carbonate may be calcite, siderite, or rhodochrosite, resembling the carbonate occurring in the pegmatite veins of the syenite at Wausau and in the coarse pegmatic veins in T. 29, R. 7. (See page 301).

It is evidently not a product of atmospheric decomposition of the associated minerals of the rock, for the rock is not only poor in lime, but, on the whole, is unaltered, the nepheline and sodalite alone showing a slight cloudiness, due to the secondary development of natrolite. It is apparently not an infiltration or incorporated product from neighboring limestone or other carbonate rocks, for such do not occur in the vicinity. On the other hand, it has every appearance of occurring as primary grains in the rock.

The carbonate in the nepheline-syenite has a habit of occurrence with respect to associated minerals similar to the fluorite in these rocks. The carbonate, however, appears to be only a sporadic development of the magma, for it was observed only in the fine-grained nepheline-syenite from the above locality, whereas the fluorite is quite generally distributed throughout all the rocks. Carbonate was searched for in association with fluorite as a filling of the miarolitic cavities in the coarse feldspar of the vicinity, but was not observed.

The fact that carbonate occurs in drusy cavities and veins of the quartz-syenite at Wausau should not be taken as a proof
fluorite as a filling of the miarolitic cavities in the coarse feld-
the most common minerals filling miarolitic cavities in the syenite of this region is fluorite, and fluorite is also finely disseminated as an original mineral in the syenite and related rocks of this area. Fluorite is generally considered an original constituent of the igneous rocks in which it occurs. The fluorite occurring in the miarolitic cavities of the seynite, as well as that occurring in interstitial openings of the quartzite adjacent to the contact of the syenite magma, was very probably developed by contact metamorphism, by the agency of solutions bearing fluorite and other minerals emanating from the syenite in-

EXPLANATION OF PLATE XXXVII.

PLATE XXXVII. MICROSECTIONS OF NEPHELINE SYENITE CONTAINING CALCITE.

Fig. 1. Microsection of nepheline syenite. Section 5872. Without analyzer, x50. The calcite is near the centre of the field. Some fluorite is present.

Fig. 2. Microsection of nepheline syenite. Section 6002. Without analyzer, x30. The section contains feldspar, nepheline, and the black minerals, amphibole and aegerite. The calcite, with the characteristic rhomohedral cleavage, is shown in the centre of the lower left hand quadrant and in the centre of the upper right hand quadrant.

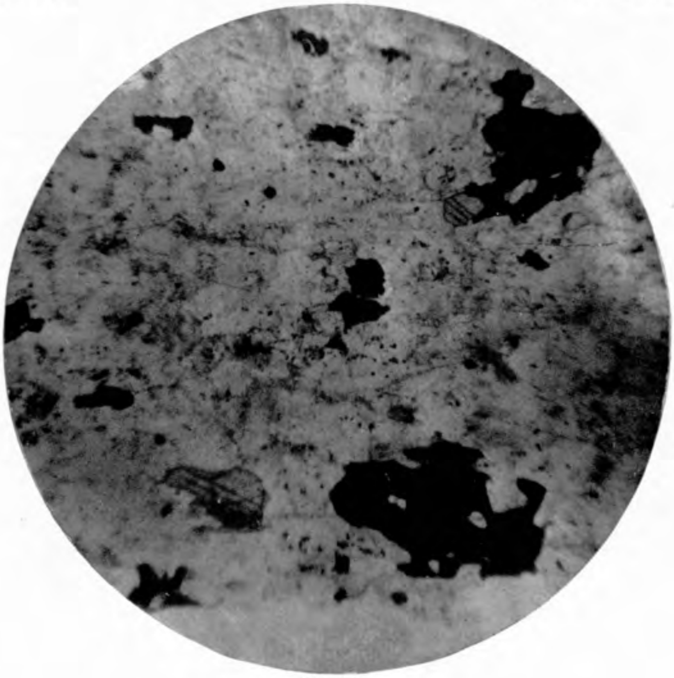


Fig. 1.

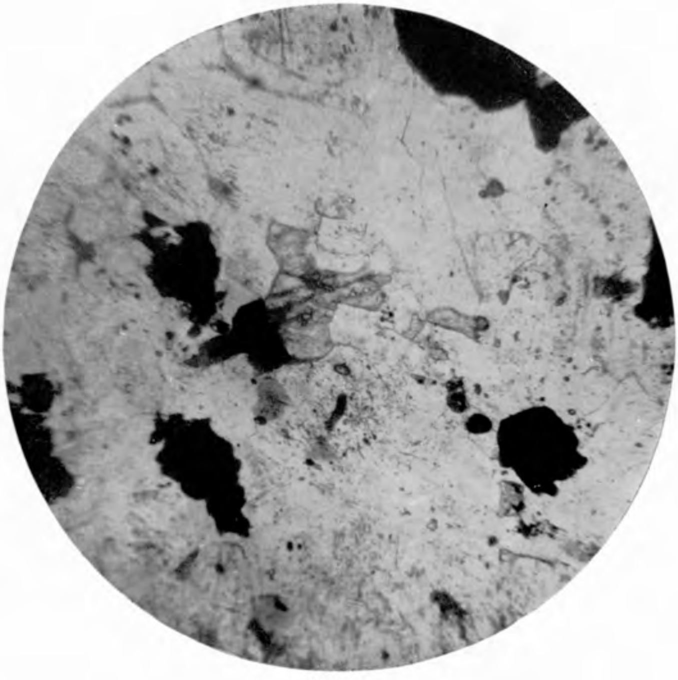


Fig. 2.

MICROSECTIONS OF NEPHELINE SYENITE CONTAINING CALCITE.

trusions. The same explanation may very well apply to the origin of the carbonate and associated quartz and biotite in the drusy cavities in veins in the quartz-syenite at Wausau, as later suggested.

Concerning calcite or other carbonate in igneous rocks, mention should be made of the nepheline-bearing syenite of Ontario, Canada, described by Adams,[1] phases of which contain abundant calcite. The nepheline-syenite-bearing calcite described by Adams is in contact with a widespread formation of crystalline limestone, and calcite does not occur in the nepheline-syenite where the wall rock is not limestone. From the occurrence of the calcite along the contact and its general character, Adams concludes that the calcite is foreign to the original magma and occurs as inclusions derived from the limestone.

It may be mentioned also that the nepheline-syenite of the island of Alnö, described by Hogbom,[2] is characterized by the presence of calcite which is not of secondary origin, whose mode of occurrence in many respects, as stated by Adams,[3] is very similar to that of the calcite found in the nepheline- syenite of Ontario.

The nepheline syenite in this region is nowhere in contact with limestone, the latter formation not being known to occur in the region, though a single small occurrence of calcareous chert occurs about 2 miles north of the locality of the carbonate-bearing nepheline-syenite. (See map Pl. IV).

The rock in contact with and wholly enclosing this particular phase of the nepheline-syenite is the closely related quartz-syenite, and in the immediate vicinity is much vitreous quartzite included in small fragments and large masses in the surrounding quartz-bearing syenite. Abundant inclusions of quartzite, therefore, occur in the immediately surrounding rock, but none of limestone.

The carbonate in this rock, which as previously stated, may be calcite, siderite, or rhodochrosite, has a habit of occurrence like

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[1]Adams, F. D.: On a New Nepheline Rock From the Province of Ontario, Canada. Am. J. Sci., Vol. XVII, p. 271, 1904.

[2]Hogbom, A. G.: Ueber das Nephelinsyenitgebiet auf der Insel Alno. Geol. Fören. i. Stockholm Förh., Häft. 2, 1895, p. 140.

[3]Op. cit. p. 272.

the minerals associated with it, which were clearly developed as original minerals, and in view of the absence of associated rock from which it could have been incorporated as inclusions in the magma, the writer is inclined to the belief that the carbonate is a primary constituent of the the nepheline-syenite of this locality. It is a fact well worthy of note that calcite as a constituent of unaltered igneous rocks, either as an apparently primary mineral or as inclusions, has been observed elsewhere in nepheline-syenite, which also is the only rock known to contain cancrinite, a mineral of primary crystallization containing an abundant carbonate radical. In this connection also attention is again called to the occurrence of calcite and other carbonate in pegmatite veins in the quartz syenite in the rapids at Wausau and in the abundant coarse pegmatite of T. 29 R. 6.

A PHASE OF NEPHELINE-SYENITE CLOSELY RELATED TO QUARTZ-SYENITE.

There is a phase of the syenite associated with the above described nepheline-syenite, and standing intermediate between the latter and prevailing quartz-syenite of the vicinity, which presents several features of especial interest. This intermediate phase has, in general, the reddish color of the quartz-syenite rather than the grayish color of the nepheline-syenite. In texture it is fine-grained, having a more or less distinct foliation or gneissic structure like the associated syenite of the vicinity bearing abundant nepheline.

Mineralogically it closely resembles the syenite containing abundant nepheline on the one hand and the syenite of the vicinity containing quartz on the other hand. It therefore has the texture and mineral composition of a gradational phase of the nepheline-bearing and of the quartz-bearing syenite. For this reason a representative rock of this phase was analyzed and examined microscopically. Under the microscope this phase closely resembled the nepheline-syenite containing calcite, in mineral composition, size of grain, and textural features. Most of the rock consists of feldspar, mainly albite, with some microperthite. The feldspar forms about 85 per cent of the rock. Neither quartz nor nepheline was observed, although a small amount of the latter mineral may be present. There is present an appreciable amount of cancrinite in small rounded grains, perhaps one or two per cent. The presence of the cancrinite would seem to indicate that its common associate, nepheline, also occurs. Fluorite is also present in appreciable quantity. The dark-colored minerals are amphibole, magnetite, yellow-brown mica, and an undetermined member of the titanite or epidote group. The amphibole has the bluish and brownish pleochroism of arfvedsonite, and forms 3 or 4 per cent of the rock. Magnetite occurs in grains in only small quantity. The yellowish-brownish mica also is of small quantity, probably less than one per cent. The undetermined mineral has distinct pleochroism in greenish and brownish tones, and strong refringence and birefringence. It occurs in small irregular-shaped grains, with fairly good cleavage, and appears to be of monoclinic or triclinic crystallization. This mineral forms about one per cent of the rock and may be one of the rare epidotes or titanites. No calcite was observed in this phase.

The chemical composition of this rock (specimen 6011), analyzed by W. W. Daniells, is as follows:

Analysis of Syenite containing very small amount of Nepheline.

SiO_2	57.48
Al_2O_3	20.04
Fe_2O_3	5.64
FeO	3.76
MgO	0.40
CaO	1.70
Na_2O	7.25
K_2O	3.65
H_2O	0.25
Total	100.17

The analysis of this rock is of interest, as it represents a phase very near the border-line between the quartz-bearing syenite and the nepheline-bearing syenite, and just within the area of the nepheline rock, as indicated by the presence of cancrinite, and also by a few grains having the general appearance of nepheline. The proportion of Na_2O to Al_2O_3 is such as to indicate a small percentage of nepheline, as indicated in the table (Plate XXXIX). This phase of the nepheline-bearing syenite, while containing a smaller amount of SiO_2 than the pegmatitic phase (see analysis, page 253), contains very little nepheline, while the latter contains abundant nepheline and sodalite, on account of the higher content of Al_2O_3 and Na_2O. This phase is relatively very high in iron, and while near the contact with quartizite, it is not a border facies of the syenite magma, like the pegmatites and pegmatitic phases of the syenite.

THE PHASE OF NEPHELINE-SYENITE SOUTHEAST OF WAUSAU.

The nepheline-syenite occurring in the northern part of Sec. 21, T. 28, R. 8 E., about 7 miles southeast of Wausau, is 10 or 12 miles from the main area of nepheline-bearing rock. In this locality an outcrop was not observed, but there are present numerous angular blocks distributed along the road throughout the entire section. The angular blocks, to a great extent, are field stone. The ordinary quartz-syenite and also gabbro are present in this vicinity. As there is no glacial drift in this locality the local occurrence of the angular blocks may be taken as a sure indication of the nepheline-syenite in place in the vicinity.

The nepheline rock in this vicinity appears to be of uniform character. It is fine to medium-grained and grayish. A single thin section from the rock of this locality shows a very large proportion of nepheline, in fairly uniform small interlocking grains, and only a comparatively small amount of feldspar, wholly albite. Aegerite is practically the only dark-colored constituent, forming from 5 to 10 per cent of the rock. A small amount of sodalite, cancrinite, zircon, and rutile are also present. This occurrence therefore belongs with the aegerite-sodalite type.

DIKE OF NEPHELINE-SYENITE.

In the NE. ¼ of Sec. 27, T. 29, R. 6 E., was observed a small dike or vein of nepheline--syenite cutting directly across the banded structure of the prevailing nepheline-syenite of this vicinity. The vein observed is not more than 2 inches thick, but contains within it numerous small angular fragments of the intruded nepheline-syenite, thus showing its intrusive character.

Under the microscope the mineral composition of the dike is seen to be almost identical with that of the older intruded syenite. Albite and nepheline are the principal constituents. The albite occurs in elongated laths with a general parallel arrangement. There are present some larger porphyritic crystals, apparently orthoclase, which show zonal growth. The aegerite occurs in quite large crystals of porphyritic development, and also as small crystals. Fluorite occurs in numerous small irregular crystals. Neither amphibole nor mica is present.

The similarity in mineral composition of this porphyritic dike rock with the older nepheline-syenite is worthy of note. It shows conclusively that magmas of similar composition were erupted at quite different periods, for the older syenite, although its strongly marked banded structure was probably developed as an original crystallization, appears to have been subsequently greatly mashed before the dike was intruded. It is very probable also that the banded structure is in part due to parallel intrusions of magma, hence the resultant rock is a composite formation made up of quite similar magmas erupted at quite different periods. The composite nature of the closely related quartz-bearing syenite may be observed wherever any large rock exposures occur.

MICA SYENITE.

In the northwestern part of the SE. ¼ of Sec. 11, 29, R. 6 E., there are numerous low outcrops of a dark-colored rock called mica-syenite in the field. A very similar, if not identical, rock constitutes the prevailing formation in the central portion of Sec. 14. In Sec. 14, closely associated with this phase, is nepheline-syenite and also coarse quartz-pegmatite rocks. A similar mica-syenite also appears as stringers in a later more feldspathic syenite in the SE. ¼ of the NW. ¼ of Sec. 15.

The rock occurring in the NW. ¼ of Sec. 11 is a medium-grained rock, and is especially rich in brown mica. T'
colored constituents form 40 to 50 per cent of the rock.

Under the microscope the light-colored constituents are seen to be mainly alkalic feldspar, apparently anorthoclase and albite. Neither quartz nor nepheline could be identified in the thin sections examined.

The dark-colored constituents are mica, pyroxene, amphibole, magnetite, and fayalite. The mica is the prevailing yellow-brown variety, probably lepidomelane, and forms from 20 to 25 per cent of the rock. The pyroxene is the silver-gray hedenbergite very similar in color to the pyroxene in the fayalite-bearing quartz-syenite at Wausau. The hedenbergite forms 5 to 10 per cent of the rock. A small amount of green amphibole, barkevikite, is present. The fayalite is closely associated with the pyroxene and mica. It has the usual appearance of this mineral and forms not more than 1 or 2 per cent of the rock. It is fresh and unaltered like the associated minerals. Magnetite is present in appreciable quantity, and a few small needle crytals of apatite are scattered throughout the rock. See Fig. 2, Pl. XXXI.

A sample of this rock phase was analyzed, as it was believed to represent the most basic phase of the syenite magma occurring in appreciable quantity in the district. The result of the analysis, made by V. Lenher, is as follows:

Analysis of Basic Mica Syenite.

SiO_2	47.16
Al_2O_3	12.56
Fe_2O_3	11.01
FeO	13.30
MnO	trace
MgO	0.53
CaO	8.63
Na_2O	4.24
K_2O	2.78
TiO_2	trace
P_2O_5	trace
H_2O at 110°	0.03
H_2O at red heat	0.09
Total	100.33

This rock phase differs from other phases of the syenite only in the proportion of the minerals contained and not in the character of these minerals. It is much lower in alumina and the alkalies and much higher in iron and lime than the abundant syenite of the district. The alkalies and alumina have combined mainly to form alkali feldspar, making up about 45 per cent of the rock. Probably 5 to 10 per cent of the iron forms magnetite, the remainder of the iron occurring mainly in the abundant mica, hedenbergite and barkevikite. The lime is mainly in the hedenbergite. The low content of magnesia, the striking characteristic feature of this entire rock magma, is noteworthy. The low content of MgO in this rock is especially remarkable when compared with the high content of associated iron and lime. While the content of iron and lime in this rock is from 4 to 5 times higher than in the average rock of this series, the low content of magnesia remains essentially uniform. The absence of titanium in this basic phase is of interest and suggests the possibility that this constituent increases with the silica and alumina in this series, as it is known to be in appreciable quantity in the coarse pegmatites.

This lepidomelane-hedenbergite-fayalite-syenite is apparently one of the most basic phases of the alkali-rich magma occurring in quantity in this region. It probably represents a rock phase somewhat analogous to the laurvikite or mica-augite-syenite of the alkalic-rich magma of southern Norway, described by Brögger. A closer study of the mica-rich phases in this region, however, is needed before their relative importance can be determined. The occurrence of the hedenbergite and fayalite in this phase, as well as the low content of MgO, establishes its close relationship with the hedenbergite-fayalite-bearing quartz-syenite and nepheline syenite.

THE SYENITE-PEGMATITE.

Traversing the main area of the phases of nepheline and quartz-syenite and bordering them, near the contacts with the older rock formations, are very coarse-grained rocks, or pegmatitic modifications of the syenite magma. Similar coarse pegmatitic rocks have already been described as occurring in the related soda granites of the region, but in the normal-grained granite, pegmatitic modifications appear to be relatively unimportant. In the more basic portions of the soda-rich magma northwest of Wausau, these coarse-grained rocks are relatively abundant and constitute a very important part of the rock formation.

General Mineral Composition.—The pegmatite modifications of the syenite consist for the most part, at least, of the same abundant minerals that constitute the normal-grained syenite. Quartz and nepheline both occur in the pegmatite in about the same proportions as these minerals occur in the phases of the normal syenite. Feldspar is the dominant mineral of the pegmatite. Next to the feldspar in abundance is quartz, as quartz-bearing pegmatite is the most abundant kind of pegmatite. Besides the feldspar and quartz in the quartz-bearing pegmatites, there are amphiboles, pyroxenes, and micas, in varying proportions, and many other minerals, such as fluorite, zircon, rutile, etc. In the nepheline-bearing pegmatite, besides the feldspar and nepheline, occur pyroxenes, amphiboles, and micas of a character differing from those occurring in the quartz-pegmatites, but similar to those occurring in some phases of the nepheline-syenite. In the nepheline pegmatite also occur sodalite. zircon, rutile, and various rare minerals ,not yet fully determined.

It is not known definitely to what extent certain minerals occur in the pegmatite which do not occur in the normal syenite. This subject is discussed more fully later and will only be alluded to briefly here. Fayalite, hedenbergite, and barkevikite, fairly abundant minerals in the normal-grained syenite, have not been observed in the coarse pegmatitic phases. Magnetite occurs in appreciable quantity in the normal syenites, but was not observed in more than minor quantity in the coarse pegmatites. While the abundant minerals, such as feldspar, quartz and nepheline, are of the the same character in the pegmatite as in the normal syenite, there is a marked difference in the character of the dark-colored silicates in the two formations.

The Texture of the Pegmatite.—The pegmatite is a very coarse-grained rock, the principal mineral constituents generally varying in size from one inch (2.54 cm.) to a foot (30.48 cm.) in diameter. To a great extent, the shape and arrangement of the minerals are the same as in the ordinary and coarse-grained syenites. A very common texture is a banding or zonal arrangement of the minerals, the feldspar on the outside, and quartz, amphibole, or mica towards the interior.' Graphic intergrowths of the feldspar and quartz, often referred to as the pegmatitic texture, are not characteristic features, although graphic intergrowths are common in the small pegmatite veins penetrating the acid granites outside the area of the abundant pegmatite.

The pegmatite masses vary greatly in coarseness from place to place. In places the feldspar is crystallized in radiating rosette forms of large size, attaining diameters of two and three feet. In other instances the minerals appear to have crystallized in large drusy cavities and have well developed terminal faces pointed towards the interior of the cavities.

General Form of the Pegmatite Occurrences.—The pegmatite occurs generally in large veins penetrating the syenite and granite. Sharply defined walls between the pegmatite and normal syenite are not always present, but instead a strong tendency to gradation between them or an intricate mingling of them, as in the case of the eruptive masses of the varying phases of normal syenite.

There are numerous narrow veins of pegmatite throughout the entire region, but they are usually not very coarse-grained and they often possess the graphic intergrowths. But the great mass of the coarse pegmatite occurring in the western part of T. 29, R. 7 E. and the eastern and central part of T. 29, R. 6 E. does not appear as narrow veins or dikes in the medium and coarse-grained syenite with which they are closely associated. In the above area of abundant pegmatite, the numerous veins vary in width up to 10 or 20 feet or more, which alternate with about equal amounts of normal rock.

The coarse pegmatite rocks may be divided into two classes, as previously stated, which obviously do not overlap, and which can be readily distinguished in the field, viz., the quartz-bearing pegmatite, and the nepheline-bearing pegmatite.

QUARTZ-BEARING PEGMATITE.

The coarse pegmatite bearing quartz is far more abundant than that bearing nepheline. The principal minerals of the quartz-pegmatite, as already stated, are feldspar, quartz, amphibole and pyroxene. Mica is also abundant. There are also present numerous minerals in small quantity of promising interest, which have not as yet been fully investigated. The abundant constituents of the pegmatite, such as the feldspar, pyroxene, amphibole, and mica, also have not as yet been adequately studied, and hence the present account of the coarse quartz-bearing pegmatite must be considered only a partial or preliminary description.

Distribution.—The quartz bearing pegmatite occurs to some extent throughout the general area of the quartz-bearing and the nepheline-bearing syenite northwest of Wausau. In portions of this area, the magma appears to have crystallized as coarse pegmatite; in other portions, as the normal, medium and coarse-grained syenite. In one part, therefore, the normal rock predominates while in another the pegmatite. No very large area of normal quartz-syenite occurs in the town of Stettin without the presence of pegmatite phases.

There is a marked predominance of the coarse quartzose pegmatite in sections 10, 11, 14, 15, 22 and 23, which is referred to later as an area in which abundant coarse feldspar is present of probable economic value. (See page 653). Besides the quartz-bearing pegmatite, this area contains the normal syenite phases, both quartz and nepheline-bearing. Outside of the sections referred to, considerable coarse pegmatite was observed. Within the main area of the basic syenite magma above referred to, the pegmatite appears to have been erupted mainly as large veins or dikes, as already stated, apparently as eruptive masses, of coarsely crystalline phases of the normal syenite. In other parts of the district there are small veins or dikes of pegmatite which appear to differ somewhat in texture from that of the large coarse veins, and may represent dikes leading out from the large masses of pegmatite.

MINERALS OF THE QUARTZ-BEARING PEGMATITE.

Some of the minerals of the quartz-bearing pegmatite have been examined to some extent by chemical analysis and the microscope. The detailed examination of the minerals has been by no means completed and hence the following account is only a preliminary description of some of the minerals occurring in the pegmatite. It is purposed to continue the investigation of these minerals until a fairly adequate account of them can be presented. Enough has been accomplished in the investigation to show that a rich and promising field for the mineralogist is furnished by the coarse pegmatite rocks of this region.

FELDSPAR GROUP.

The feldspar in the pegmatite throughout the area of abundant pegmatite in sections 10, 11, 14, 15, 22 and 23, T. 29, R. 6 E., occurs in crystals of various sizes ranging from an inch to over a foot in diameter. The feldspar sometimes appears as closely packed crystals, as in an igneous rock of normal texture, and sometimes as large crystals with radiate or rosette structure.

Microperthite.—Several large feldspars occurring in this area were analyzed and found to be almost identical in composition. Those analyzed are microperthite feldspar, the general structural features of which have already been described. The microperthite varies from white to pink in color. No. I is pink microperthite, occurring in the form of a radial growth or rosette.

Analyses of Feldspar of Quartz-pegmatite.

	I	II	III
SiO_2	66.42	65.50	66.07
Al_2O_3	20.23	19.24	19.82
Fe_2O_3	0.95	0.46	0.44
CaO	trace	0.42	1.11
MgO	none	0.26	trace
Na_2O	5.59	5.29	5.63
K_2O	6.62	8.35	7.27
H_2O	0.14	0.14	0.24
Total	99.95	99.66	100.58

I. Microperthite Feldspar: ¼ mi. N. of SE. Cor. Sec. 22, T. 29, R. 6E. Analyzed by Victor Lenher.

II. Microperthite Feldspar: SE. Cor. of Sec. 15, T. 29, R. 6 E. Analyzed by W. W. Daniells.

III. Microperthite Feldspar: ⅛ mi. S. of NE. Cor. of Sec. 22, T. 29, R. 6 E. Analyzed by W. W. Daniells.

The analyses show these feldspars to be very similar in composition. The molecular proportion of soda to potash is greater than 1 : 1 in I and III, and less than 1 : 1 in II.

Albite.—Albite occurs in that phase of the pegmatite which contains the soda-pyroxene and the soda-lithia mica, in the NW. ¼ of Sec. 22, T. 29, R. 6 E.

AMPHIBOLE GROUP.

In the southwestern part of the NW. ¼ of Sec. 22, T. 29, R. 6 E., just north of a small creek which appears to lie along the contact between the greenstone and syenite formations, is much coarse pegmatitic rock, consisting of feldspar, amphibole, pyroxene, and quartz. The minerals vary in size up to several inches in diameter. The rock is exposed at numerous places in this vicinity and abundant fragments of coarse rock picked up from the adjoining field of G. Rodart lie along the road and in several large piles upon the latter's farm. The rock of this vicinity, which is bordered a short distance to the south by the greenstone area, consists largely of very coarse pegmatite rock.

Crocidolite.—In this locality was observed an intimate intergrowth of blue amphibole and bronze-green pyroxene. Sufficient material for chemical analyses was collected, but no well formed crystals of either with terminal faces were obtained.

Megascopically the amphibole is a pronounced bluish-black in color, and has the well developed characteristic prismatic cleavage of amphibole. Under the microscope this amphibole has the characteristic pleochroism of the alkalic amphiboles. Rays vibrating parallel to *c* are blue; parallel to *b*, blue; and parallel to *a*, green. The extinction on the plane approximately parallel to 010 appeared to be very small.

The composition of this amphibole (sp. 6608) from one-third mile south of NW. corner of Sec. 22, T. 29, R. 6 E., analyzed by W. W. Daniells, is as follows:

Analysis of Crocidolite of Quartz-Pegmatite.

	Analysis.	Molecular ratios.
SiO_2	48.20	.803
Al_2O_3	1.16	.011
Fe_2O_3	15.46	.097
FeO	20.40	.283
MnO	2.57	.036
MgO	trace	....
CaO	2.78	.050
Na_2O	6.42	.103
K_2O	2.05	.022
TiO_2	0.54	.007
H_2O	0.26	.014
Total	99.83	....

The specific gravity is 3.32. This amphibole is high in ferrous oxide, ferric oxide, and soda. It is thus a soda-iron amphibole and since it is especially high in ferrous oxide it is referred to crocidolite. This amphibole differs slightly from that usually classed with crocidolite in containing appreciable quantities of Al_2O_3, MnO, and CaO, and in the absence of MgO. The formula approximates $2(Na_2O.Fe_2O_3.4\ SiO_2)+6(FeO.SiO_2)+1(CaO.SiO_2)$.

The material analyzed was selected from a part of the crystal of blue amphibole free from intergrowth with the bronze-green pyroxene, then broken into minute fragments and examined under the microscope before being submitted to the chemist.

Riebeckite.—About a mile northeast of the locality from which the blue amphibole, crocidolite, was obtained, in the central part of the NE. 1/4 of Sec. 15, occurs a very coarse phase of the syenite containing large crystals of amphibole which appeared to be quite similar to the above. This amphibole occurs in large massive crystals. The color of the amphibole is a pronounced bluish-black in the hand specimen. Under the microscope it shows the characteristic blue and green pleochroism of the soda amphiboles. Rays vibrating parallel to *c* are blue; parallel to *b*, blue; and parallel to *a*, green. The extinction on a plane approximately parallel to b, 010, is very small.

The chemical composition of this amphibole, 6610*a*, near south side of NE. 1/4 NW. 1/4, Sec. 15, T. 29, R. 6 E., made by Victor Lenher, is as follows:

Analysis of Riebeckite of Quartz-Pegmatite.

	Analysis.	Molecular ratios
SiO_2	47.39	.790
Al_2O_3	3.18	.031
Fe_2O_3	25.54	.159
FeO	9.52	.132
MnO	1.40	.020
MgO	1.20	.030
CaO	1.91	.034
Na_2O	8.54	.138
K_2O	1.41	.015
H_2O at 105° to 110°	0.14	....
H_2O at 110°+	0.37	.020
TiO_2	none	....
Total	100.60	....

The specific gravity is 3.38. This amphibole is high in ferric oxide, ferrous oxide, and soda. Since it is relatively high in ferric oxide, it is referred to riebeckite, with which it closely corresponds in composition. The principal difference between crocidolite and riebeckite appears to be in the form of the iron oxide, riebeckite being high in Fe_2O_3 and low in FeO, and crocidolite being high in FeO and low in Fe_2O_3. The formula is $2(Na_2O.Fe_2O_3.4\ SiO_2)+2(FeO.SiO_2)+1(CaO.SiO_2)$. The MgO is considered with the CaO, the MnO with the FeO and the Al_2O_3 with the Fe_2O_3. With the increase in the content of ferric oxide in the riebeckite, there is accompanying increase in alumina and soda. The appreciable content of Al_2O_3, notably high for riebeckite, is a characteristic which finds expression in the composition of all the silicates crystallized in these rocks. The material analyzed was carefully selected and examined under the microscope before being submitted to the chemist.

THE PYROXENE GROUP.

The minerals of the pyroxene group thus far investigated, in the quartz-bearing pegmatite, vary in character within certain limits and possess features of composition obviously due to the high soda-alumina content of the rock magma in which they occur. These pyroxenes of the quartz pegmatite are alike in containing a high content of the alkalies, mainly Na_2O, and in this regard are like the prevailing pyroxene of the nepheline pegmatite.

The order in which the pyroxenes are described is the one casually followed out in their investigation. A more logical arrangement may be adopted when these interesting minerals are fully described and their character and relationship more fully understood.

Percivalite.—The pyroxene intergrown with crocidolite in the southwestern part of the NE. ¼ of Sec. 22, T. 29, R. 6 E. is both massive and in large fibrous aggregates. As fibrous aggregates, it occurs with radiated structure and in irregularly intergrown elongated crystals. The color shades from yellowish-green to brownish-green, tending to an olive-green tint. Crystals, either massive or in aggregates, were observed up to 2 or 3 inches (5 cm. to 7.5 cm.) in diameter. This pyroxene is mainly associated with quartz, feldspar, crocidolite, acmite, violet-gray lithia-mica, and other minerals. The mineral for the first analysis of this pyroxene was separated from a fairly massive crystal of intergrown crocidolite and pyroxene. The pure pyroxene formed one end of the intergrowth, and the crocidolite the other, with a mixed intergrowth between. It was the opinion of the writer at the time this material was selected for analysis that the pyroxene might be an alteraiton of the blue amphibole, or vice versa. The olive-green pyroxene was readily distinguished from the dark blue amphibole because of the marked difference in color. The pyroxene was broken up into small cleavage pieces and the material subjected to examination by a lense and microscope before being submitted to the chemist. The olive-green pyroxene portion of the intergrowth, 6607, analyzed by W. W. Daniells, is as follows:

Analysis of soda-alumina Pyroxene (Percivalite) from Quartz-Pegmatite.

	Analyses.	Molecular ratios.
SiO_2	49.81	.830
Al_2O_3	30.97	.303
Fe_2O_3	3.95	.025
FeO	2.21	.030
MnO	0.76	.011
MgO	0.03	....
CaO	trace.	....
Na_2O	11.15	.180
K_2O	0.39	.004
TiO_2	0.83	.010
H_2O	0.50	.028
Total	100.60	....

The analysis showed the pyroxene to be unusually high in alumina and soda. The high content of alumina is especially noteworthy and apparently distinguishes this pyroxene as a new variety, closely allied to jadeite.

Upon a later visit to the locality, this olive-green pyroxene was especially searched for and new material collected for analysis. No crystals with well developed forms were found in the short time spent in the locality. The olive-green pyroxene was observed to be free from, as well as intergrown with, the blue amphibole. A large crystal aggregate of the pyroxene 2 or 3 inches in diameter was broken apart and material carefully selected for a second analysis.

The second analysis, made by Victor Lenher, is as follows:

Analysis of soda-alumina Pyroxene (Percivalite) from Quartz-Pegmatite.

	Analysis.	Molecular ratios.
SiO_2	49.77	.829
TiO_2	trace	....
ZrO_2	none	....
Al_2O_3	28.78	.282
Fe_2O_3	2.99	.019
FeO	0.12	.001
MnO	0.69	.009
MgO	0.11	.003
CaO	0.33	.006
Na_2O	15.71	.254
K_2O	0.84	.009
Li_2O	none	....
H_2O-105°-110°	0.08	....
H_2O-red heat	0.90	.050
F	none	....
P_2O_5	trace	....
S	0.024	....
Rare earths (Th, Ce, Yt, etc	none	....
Cb_2O_5, Ta_2O_5	none	....
Total	100.344	....

This analysis agrees very closely with the former. While somewhat lower in alumina and higher in soda, the two correspond as closely in composition as the average pyroxene or amphibole of the same variety. The pyroxene first analyzed contains meager growths of the blue amphibole, probably less than one per cent, and on this account, as well as that of the close proximity of the amphibole substance, the second analysis is believed to represent the purer type of mineral.

The composition of this soda-alumina pyroxene is remarkably different from that of jadeite in respect to the higher content of alumina and the lower content of silica.

A possible, perhaps the most probable, explanation of the composition of this pyroxene is to view it as a mixture essentially of the two molecules, Na_2O, Al_2O_3, 4 SiO_2 and NaO_2, Al_2O_3, **2SiO_2 the former the jadeite molecule, and the latter a molecule like the nephelite molecule, with a small additional** amount of the hypothetical molecule $(R''.R'_2)$ $(Al.Fe)_2$ SiO_6.

It is regretted that the physical properties of this pyroxene cannot be fully described at the present time. Some of its most obvious features only have been investigated, on account of not finding crystals of well developed forms.

The minerals associated with this pyroxene in the pegmatite have already been mentioned. The color, as observed in specimens is yellowish-green, and it can be readily distinguished from the bluish-black amphibole, and the black acmite associated with it. It occurs in elongated, prismatic crystals, like aegerite, up to several inches in diameter. Large crystals are often found grown together, and these penetrated by numerous small crystals which extend through the larger crystals in various directions. Elongated crystals arranged in radiate structure are also very common.

Under the microscope the color of the pyroxene varies from greenish-gray to pale yellowish-green. Pleochroism is weak as compared with that of aegerite. Rays vibrating parallel to *c* and *b* are gray with slight tinge of green; those parallel to *a* are pale yellow-green. The extinction angle with the *c* axis is small, probably between 7° to 8°. The prismatic cleavage common to all the pyroxenes is very prominent. The birefringence is much weaker than that of aegerite, being comparable to that of acmite. The index of refraction also is lower than that of aegerite.

This pyroxene in chemical composition and physical properties appears to be a distinct variety or species, and the name *percivalite,* in honor of J. G. Percival, at one time state geologist of Wisconsin, is given to it. Percivalite may be defined as a pyroxene containing about equal proportions of the jadeite molecule Na_2O, Al_2O_3, $4SiO_2$ and the molecule Na_2O, Al_2O_3, $2SiO_2$, with a small but unimportant amount of other pyroxene molecules.

It is possible that percivalite should rank as a distinct species, comparable to acmite, spodumene, or jadeite, or it may be considered as a variety of jadeite. Its real significance or importance will necessarily be decided by the general opinion of mineralogists, after it has been fully investigated.

It is believed that the orthosilicate molecule of this pyroxene, $Na\ Al\ SiO_4$, is of much significance and importance in a number of the pyroxene minerals, being present in the so-called basic aluminous varieties. As various quantities of the diopside, hypersthene or acmite molecules form constituent portions of

EXPLANATION OF PLATE XXXVIII.

PLATE XXXVIII. MICROSECTIONS OF INTERGROWTH OF ALBITE, PERCIVALLITE-ACMITE, AND RIEBECKITE-CROCIDOLITE.

Fig. 1. Microsection number 6610 a. Without analyzer, x60. The black mineral is riebeckite (see analysis page——) the gray mineral is very probably percivallite, and the colorless mineral is albite.

Fig. 2. Similar to the above. Section 6612 b. Without analyzer, x30.

These parallel growths are obviously original and not a secondary alteration, for in immediate juxtaposition occur large crystals of each of these minerals. The intergrowths were evidently developed away from the centres in which the large pure mineral of each was formed, namely at the contacts. The structural parallelism in the growth of these minerals probably finds its explanation in the remarkable similarity of their composition, as illustrated in the following type formulae:—

Albite—Na_2O, Al_2O_3, 6 SiO_2.

Percivallite—1(Na_2O, Al_2O_3, 4 SiO)+1(Na_2O, Al_2O_3, 2 SiO).

Riebeckite—1(Na_2O, Fe_2O_3, 4 SiO)+1(FeO, SiO_2).

In this connection attention may be called to the discussion of the composition and origin of jadeite in the extensive work on Jade, published by the Bishop estate, Vol. I., pages 121–166.

Fig. 1.

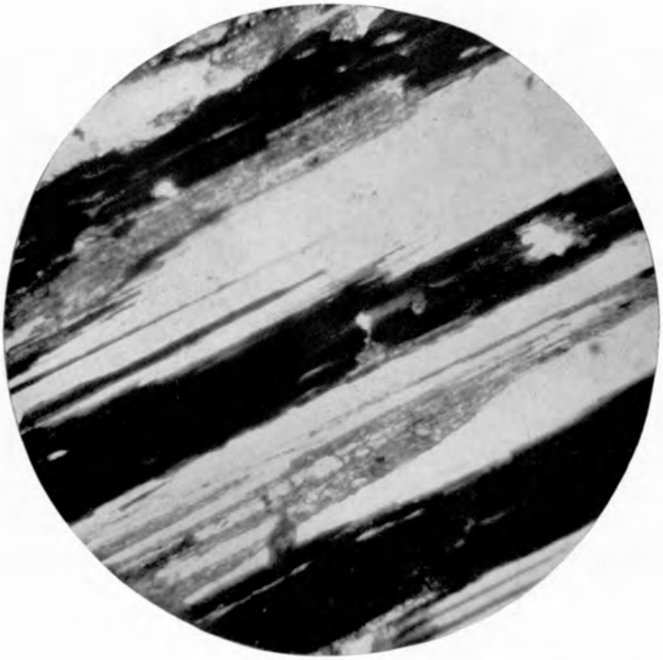

Fig. 2.

PARALLEL GROWTHS OF ALBITE, PERCIVALLITE AND RIEBECKITE.

various pyroxenes, in a like manner this orthosilicate molecule probaly enters into the constitution of various aluminous members of the pyroxene group.

The soda-alumina silicate minerals closely associated with this alumina-rich pyroxene are worthy of mention. Besides the intergrowths with crocidolite already described, there is also to be observed an intimate parallel intergrowth with the soda feldspar, albite. The albite, percivalite and crocidolite intergrowths are shown in Plate XXXVIII. In certain rocks in which percivalite is an abundant constituent, large, black, well-formed acmite crystals abound. In that phase of the rock in which the two pyroxenes, acmite and percivalite, were both present, the amphibole crocidolite was not observed.

Acmite of Analysis 1.—In the coarse feldspar rock occurring along the road in the SE. ¼ of Sec. 22, T. 29, R. 6 E., there occurs a grayish- green pyroxene somewhat different in color and general features from the predominating pyroxene in the quartz pegmatite rock. It occurs abundantly in the coarse rock in the interstices between the feldspar, apparently as a crystallization after the dominant feldspar. No crystal forms were observed, but abundant fresh homogeneous material was readily obtained for laboratory examination. The pyroxene subjected to chemical analysis was crushed to a fine powder and passed through a solution of silver-thallium nitrate, and the small amount of quartz, feldspar, and fluorite associated with it was removed. The analysis of this pyroxene, made by V. Lenher, is as follows:

Analysis of acmite 1.

SiO_2	50.03
TiO_2	trace
Al_2O_3	5.28
Fe_2O_3	30.89
FeO	0.60
MnO	trace
MgO	0.22
CaO	0.17
Na_2O	11.14
K_2O	1.01
Li_2O	none
H_2O at 110°	0.03
H_2O at red heat	0.33
Total	99.70

The composition of this pyroxene in general resembles that of acmite and aegerite. It differs, however, from both the latter in containing an appreciable quantity of Al_2O_3, and from acmite in containing very little FeO, and from aegerite in containing very little CaO as well as very little FeO.

The microscopic examination of this pyroxene shows it to resemble acmite more closely than aegerite. It differs from both acmite and aegerite, however, in color and pleochroism. It is very slightly pleochroic, the predominating color in thin section being a grayish-green, the axial colors varying but slightly from a shade of grayish-green to light green. The brown of acmite is not apparent and the deeper brown and yellowish-green of aegerite is wholly absent. The maximum angle of extinction with the vertical axis is approximately 3° to 4°.

Acmite of Analysis 3.—The black pyroxene already referred to as occurring in association with the brownish-green percivalite in the SW ¼ NW. ¼ of Sec. 22, T. 29, R. 6 E. occurs in well developed, greatly elongated crystals. This pyroxene occurs in a rock containing much quartz and feldspar. The crystals are greatly elongated parallel to the vertical axis, their length generally being from 6 to 10 times their breadth and thickness. The crystals are, so far as observed, elongated prisms with M(110) prominent. The orthopinnacoid (100) and clinopinnacoid (010) are often wholly absent. Terminal faces are entirely wanting so far as observed. Repeated striations, however, are sometimes present, indicating a tendency for the development of steep pyramid faces, presumably O(661). The crystals occur in aggregates and nests, in contact with one another at various angles. Parallel growths and twins are also common.

A chemical analysis was made by V. Lenher, of carefully selected material, with the following result:

Analysis of Acmite 3.

SiO_2	49.48
TiO_2	trace
Al_2O_3	5.56
Fe_2O_3	29.43
FeO	1.81
MnO	0.20
MgO	trace
CaO	0.38
Na_2O	8.14
K_2O	4.27
H_2O at 110°	0.02
H_2O at red hoat	0.55
Total	99.84

The features of interest in the analysis of this pyroxene is the notable quantity of Al_2O_3 and especially the high content, 4.27 per cent, of K_2O. The relatively high content of K_2O is especially noteworthy and apparently distinguishes this pyroxene from all other analyzed pyroxenes to which reference can be found in the literature. The chemical relation of this pyroxene to the one just referred to, analyses No. 1, is obvious and proves that it differs from the latter only in degree and not in kind.

The optical properties of this pyroxene also indicates its close relationship to the other two aluminous acmites described. The microscopic examination shows this pyroxene to be essentially identical in color and pleochroism with the others. In thin section it is grayish-green and light green, with but slight change in tint in the axial planes. The black color of the crystals as seen in the hand specimens is obviously due to a minute dissemination of magnetite in the microscopic fractures of the pyroxene. Quartz is also present in small quantity in the fractures. The maximum angle of extinction with the vertical axis on 010 is approximately 7° to 8° as compared with 3° to 4° of the pyroxene, analysis 1. Twinning parallel to (100) repeated in narrow lamellae was observed and is probably of frequent occurrence. The index of refraction and also the double refraction are relatively high for pyroxene, but apparently not so high as in aegerite. With regard to refraction, as well as pleochroism, it stands nearer acmite than to aegerite.

Acmite of Analysis 2.—In the same locality in which the above pyroxene (analysis 3) was observed, the SW. 1/4, NW. 1/4 of Sec. 22, T. 29, R. 6 E., much smaller pyroxene, in a somewhat finer grained phase of the pegmatite, was observed. It occurs in the rock in which the new variety of pyrochlore (see page 308) was observed, and from which the latter mineral was obtained for analysis. The principal minerals associated with it are quartz and feldspar.

This pyroxene, as seen in the hand specimen, is black, and in crystal form and general occurrence is essentially identical though much smaller than the coarser crystallized pyroxene of analysis 3. The crystals are greatly elongated along the vertical axis, with strong development of the prism faces and very slight development of the pinacoids. The clinopinacoid (010) is quite generally absent in these smaller pyroxenes. Terminal faces are wanting.

Fresh homogeneous material was selected for analysis, powdered, passed through a 100 mesh sieve, and separated by means of the specific gravity solution of silver thallium nitrate. The analysis, made by Victor Lenher, is as follows:

Analysis of acmite 2.

SiO_2	51.14
TiO_2	trace
Al_2O_3	4.82
Fe_2O_3	30.44
FeO	1.43
MnO	trace
MgO	0.15
CaO	0 06
Na_2O	9.99
K_2O	1.50
Li_2O	none
H_2O at 110°	0.08
H_2O at red heat	0.16
Total	99.77

In composition this pyroxene stands nearer to that of analysis 1, than to that of analysis 3. This is specially true with regard to the content of K_2O. With respect to the other constituents, however, the three analyses are essentially identical. The microscopic appearance of this pyroxene is essentially identical with the others. The black color is not inherent in the mineral but due to finely disseminated magnetite in fractures. The angle of extinction is 3° to 4° to the vertical axis, and in this regard is like the pyroxene of lower content of K_2O. Twinning lamellae parallel to (100) are present.

General Relations of the Acmite.—These pyroxenes, of analyses 1, 2 and 3, are essentially alike, as already described, in chemical composition, and in general physical properties. They are essentially identical chemically, with the exception of the pronounced variation in the content of Na_2O and K_2O. In the following table the analyses may be compared, and also their molecular ratios:

Comparison of analyses and molecular ratios of acmite.

	Analyses.			Molecular ratios.		
	1.	2.	3.	1.	2.	3.
SiO_2	50.03	51.14	49.48	.834	.852	.825
TiO_2	trace	trace	trace	....	....	....
Al_2O_3	5.28	4.82	5.56	.052	.047	.054
Fe_2O_3	30.89	30.44	29.43	.193	.190	.184
FeO	0.60	1.43	1.81	.008	.020	.025
MnO	trace	trace	0.20	....	....	.003
MgO	0.22	0.15	trace	.005	.004	....
CaO	0.17	0.06	0.38	.003	.001	.007
Na_2O	11.14	9.99	8.14	.180	.161	.131
K_2O	1.01	1.50	4.27	.011	.016	.045
Li_2O	none	none	not det.	....	....	....
H_2O at 110°—	0.03	0.08	0 02	....	....	....
H_2O at 110° +	0.33	0.16	0.55	.018	.009	.030
Total	99.70	99.77	99.84	....	....	....

The content of SiO_2, Al_2O_3 and Fe_2O_3 is essentially alike in the three analyses. The content of FeO is small and quite variable. The content of MnO, MgO and CaO is unimportant. The total alkalies are essentially identical, but the proportions of the alkalies Na_2O and K_2O are remarkably variable, and obviously the two alkalies mutually replace one another. As the content of Na_2O decreases, the K_2O increases, as in feldspar. A fairly constant ratio exists between the total alkalies and the total Fe_2O_3 and Al_2O_3, the proportion of the latter to the alkalies, however, being greater than 1:1.

The predominating molecule is the acmite molecule $Na_2Fe_2Si_4O_{12}$ with K and Al isomorphous respectively with Na and Fe. Then there is, as suggested by Prof. S. L. Penfield, a small amount of $R''O$ (R=Fe, Mn, Mg, and Ca) making perhaps some $RSiO_3$. And in addition some Al_2O_3, Fe_2O_3 and H_2O in apparent excess to satisfy the theory.

With regard to the apparent excess of Al_2O_3 and Fe_2O_3 in this variety of pyroxene it may be stated that this feature is characteristic of all the pyroxene and amphibole as well as many other silicate minerals occurring in the granite-syenite of this region.

The high content of K_2O in anlysis 3 strongly suggests the possibility that a pure potash pyroxene of the type K_2O, Al_2O_3, $4SiO_2$ may occur in nature.

Both the chemical composition of these pyroxenes and their physical properties clearly indicate their position as members of the acmite species. The very persistent presence of Al_2O_3 in considerable quantity in these pyroxenes from different localities in the quartz pegmatite and in rocks of slightly variable character is obviously a fact of much importance, and probably indicates the presence of this pyroxene as the predominating one in the quartz pegmatite of this region, as is the aegerite in the nepheline pegmatite. The molecular ratio of Al_2O_3 to Fe_2O_3 is fairly constant, varying from 1:3.4, 1:3.7 and 1:4. The variable proportions of Na_2O and K_2O is a common characteristic of the alkali silicates. In analysis 3 the K_2O rises to marked importance the ratio of K_2O to Na_2O, being 1:2.91, the potash silicate molecule approximating 20 per cent, and the soda silicate 60 per cent of this pyroxene.

In two additional analyses of the acmite, made since the above was in press, 5.80 and 6.77 per cent Al_2O_3 are present. Thus a fairly constant and important quantity of Al_2O_3 is shown to occur in the acmite of this locality, and in this respect it differs from the acmite of Rundemyr, Norway. In this connection attention may be called to the appreciable and constant amounts of Al_2O_3 which especially distinguishes the hedenbergite of this region. It seems probable that the high alumina in these pyroxenes and in the pyroxene percivallite is to be explained by the presence of the hypothetical molecule R $(Al)_2$ SiO_6 in which R may be any of the usual bases including hydroxyl.

MICA GROUP.

Lepidomelane.—The mica present in the pegmatite veins in the rapids at Wausau has the usual greenish-black or black color of lepidomelane. Pleochroism is strong, in colors varying from yellowish to brown. The chemical composition of one phase of the biotite in the pegmatite veins, as determined by W. W. Daniells, is as follows:

Analysis of Lepidomelane from Quartz-syenite of Wausau.

SiO_2	36.32
Al_2O_3	11.91
TiO_2	4.036
Fe_2O_3	7.87
FeO	26.01
MnO:	1.34
CaO.	....
MgO	0.76
Na_2O	1.15
K_2O	7.055
H_2O.	2.76
Total	99.211

The analysis reveals an unusually high content of FeO, and a very low content of Mg O, thus showing the same chemical characteristics as the other associated dark-colored silicates in this rock. The high content of TiO_2 is also worthy of note. With respect to TiO_2 it is like the lepidomelane in similar rocks of southern Norway.[1]

This mica should be classed as a non-magnesian variety of biotite, lepidomelane, a variety observed elsewhere in a number of localities, though apparently not in general of abundant occurrence. Partial analyses of other micas occurring in these coarse segregations show a variation in the composition within certain limits, the Mg O varying from less than one per cent to 3 or 4 per cent.

Mica occurs to some extent in most phases of the quartz pegmatite. In the northeastern part of the NW. ¼ of Sec. 15, T. 29, R. 6 E., in the vicinity in which the riebeckite (page 281)

[1] W. C. Brögger, Zeit f. Kryst; B. 16, p. 189–194.

is present in the pegmatite, black mica was observed forming an abundant constituent of the coarse rock.

Lepidomelane.—An analysis of this mica 6612*a*, made by Victor Lenher, is as follows:

Analysis of Lepidomelane from Quartz-Pegmatite.

SiO_2	31.97
Al_2O_3	22.83
Fe_2O_3	20.51
FeO	10.85
MnO	trace
MgO	trace
CaO	trace
Na_2O	2.59
K_2O	5.28
H_2O at 105°–110°	1 71
H_2O at red heat	4.19
TiO_2	0.22
Total	100.15

In composition this mica corresponds closely to lepidomelane. The absence of magnesia is worthy of note. The low percentage of silica, and high percentage of alumina, characteristic features of lepidomelane, are especially noteworthy of this mica. The color is nearly black, with tinge of green. Under the microscope, the yellowish color of lepidomelane is prominent.

Lithia-mica, Irvingite.—A nearly colorless mica with tinge of yellow and red, and having pearly lustre, is a prominent mineral in certain phases of the quartz-bearing syenite. Especially well developed crystals occur in the phase of the quartz-bearing pegmatite in the SW. 1/4 NW. 1/4 of Sec. 22, T. 29, R. 6 E., which contains the soda-alumina pyroxene, percivalite, and the crocidolite, acmite, feldspar and quartz.

The analysis of this mica, made by Victor Lenher, is as follows:

Analysis of Lithia-mica (Irvingite) from Quartz-Pegmatite.

SiO_2	57.22
Al_2O_3	18.38
Fe_2O_3	0.32
FeO	0.53
MnO	trace
MgO	0.09
CaO	0.20
K_2O	9.12
Na_2O	5.14
Li_2O	4.46
H_2O–105°–110°	0.42
H_2O–red heat	1.24
F	4.58
TiO_2	0.14
	101.84
Less oxygen equivalent of F	1.93
Total	99.91

The analysis shows the mica to contain a considerable amount of lithia and fluorine and is unusually high in silica and soda. It has some of the features of zinnwaldite, cryophyllite, and lepidolite, but differs from all of these in containing a larger amount of soda, and in its higher content of silica. In content of silica, it is more like the variety polylithionite occurring in a somewhat similar rock in Kangerdlaursuk, Greenland. It differs, however, from polylithionite in containing a much larger amount of alumina and in possessing different proportions of the alkalies, potassa, soda and lithia.

The physical properties of this lithia-mica also appear to differ somewhat from those of other lithia micas. Many of the larger crystals have, besides the well developed basal cleavage of mica, a very prominent prismatic parting. This parting enables it to separate into laths and needles of variable width. The color varies from grayish-white to yellowish and reddish. It is extremely tough and elastic, and possesses easy fusibility. The interference figure in convergent light appears to indicate an axial angle somewhat larger than that of the lithia-micas lepidolite and zinnwaldite.

In the following table the analysis of this lithia-mica is compared with that of representative analyses of lepidolite, zinnwaldite and cryophyllite, and with that of the single occurrence of polylithionite:

Comparison of analysis of the varieties of lithia-mica.

	I.	II.	III.	IV.	V.
SiO_2	57.22	59.25	51.52	51.96	46.44
Al_2O_3	18.28	12.57	25.96	16.89	21.83
Fe_2O_3	0.32	....	0.31	2.63	1.41
FeO	0.53	0.93	undet.	6.35	10.06
MnO	trace	....	0.20	0.24	1.89
MgO	0.09	....	0.02	0.03	....
CaO	0.20	....	0.16	1.12	....
K_2O	9.12	5.37	11.01	10.66	10.58
Na_2O	5.14	7.63	1.06	0.92	0.54
Li_2O	4.46	9.04	4.90	4.93	3.36
H_2O at 110° −	0.42	....	0.95	1.22	....
H_2O at 110° +	1.24				
F	4.58	7.32	5.80	6.78	7.62
TiO_2	0.14	....	....	....	....
Tota	101.94	102.11	101.89	102.73	103.74
Less O=F	1.93	....	2.44	2.86	....
	99.91	....	99.45	98.87	....

I. Irvingite, from Wausau, Wis.; anal. by V. Lenher.
II. Polylithonite, from Kangerdlaursuk, Greenland. (Quoted by Dana's Min., 6th Ed., p. 627).
III. Lepidolite, from Rumford, Me., anal. by Riggs. (Quoted by Clarke; Bull. 220, U. S. G. S., p. 73).
IV. Croyphyllite, from Auburn, Me., anal. by Riggs. (Quoted by Clarke; op. cit. p. 74).
V. Zinnwaldite, from Zinnwald, Bohemia. (Quoted by Dana's Min., 6th Ed. p. 626).

It will be observed on comparing the analysis of the lithia-mica from this locality with that of the other varieties of lithia-mica that each has characteristic chemical features not possessed by the others. The cryophyolite, IV, and zinnwaldite, V, are characterized by high content of iron and low sodium, while the lithia-mica, I, and polylithionite, II, are essentially free from iron and are high in sodium, while lepidolite, III, is low in sodium and free from iron. The lithia-mica from this region, I, differs esentially from polylithionite, II, in containing a higher content of aluminum and lower content of fluorine, as well as possessing different proportions of the alkalies. On the whole, this lithia-mica, I, differs essentially from the other varieties, apparently being a new variety of this interesting group of lithia-fluorine micas, and hence the name *Irvingite*, after R. D. Irving, is proposed for it.

Theoretical formula of Irvingite.—The percentage composition and the molecular proportions of the constituents of this lithia mica are shown in the following table:

Analysis and molecular ratios of Irvingite.

	Analysis.	Molecular ratios.
SiO_2	57.22	954
TiO_2	0.14	2
Al_2O_3	18.38	180
Fe_2O_3	0 32	2
FeO	0.53	8
MgO	0.09	....
CaO	0.20	3
K_2O	9.12	96
Na_2O	5.14	83
Li_2O	4.46	149
F_2	4.58	120
H_2O at 110°	0 42	....
H_2O at red heat	1.24	69
Total	101.84	....
Less O=F	1.93	....
	99.91	....

As suggested by the late Prof. S. L. Penfield, the ratio of the essential constituents is approximately, $SiO_2 : Al_2O_3 : (K\ Na\ Li)_2O : F_2+OH$ as 6:1.2:1. It will be noted that there is not quite enough SiO_2 in the analysis to satisfy the requirement of this formula, but the agreement is fairly close. The ratio, as suggested by Prof. Penfield, corresponds to the formula of a tri-silicate, R_2O, $(Al\ F_2OH)$ O. 3 SiO_2. The alkalies in R_2O approximate the following ratio, $K_2O : Na_2O :\ Li_2O$ as 1:1:2 and in F_2OH, F_2:OH as 2:1. Assuming these proportions, the calculated approximation to the theory for the above ratios is shown in the following table:

Prof. F. W. Clarke has pointed out that the ratios in this lithia-mica are very near R'_2 Al X (F. OH), in which X represents the acid radicals Si_3O_8 and SiO_4 in the ratio of 4:1. Regarding all the OH as F it could be written: $4 R'_2$ Al Si_3O_8 F, + 1 R'_2 Al SiO_4 F.

Theoretical composition of Irvingite.

Molecular ratio.		Per cent.
6 SiO_2	360	60.00
1 Al_2O_3	102	17.00
2 { ½ K_2O	47.1	7.83
2 { ½ Na_2O	31	5.17
2 { 1 Li_2O	30	5.00
1 { ⅓ H_2O	6	1.00
1 { ⅔ F_2	24	4.00
	600	100.00

FLUORITE.

Fluorite, a persistent mineral of this rock series, occurs in the quartz-bearing pegmatite. It was noted in considerable abundance in the coarse pegmatite in the eastern part of Sec. 22, T. 29, R. 6 E. In this phase it occurs in crystals up to 6 or 8 inches (.2m.) in diameter. It is closely associated with quartz and with pseudomorphs after carbonate. Soda-amphibole, and soda-pyroxene also occur in these coarse pegmatite rocks. On weathered surfaces the fluorite is removed in solution, leaving characteristic square depressions.

The fluorite in the pegmatite varies in color from white to purple. The purplish color is especially noticeable, and in this regard it is unlike the generally colorless fluorite observed in minute crystals in the normal rock. The bluish tones appear to be most prominent where conditions of weathering and exposure to ground water occur. The fluorite was tested qualitively, and found to agree in physical and chemical properties with calcium fluoride, $Ca\ F_2$.

CALCITE GROUP.

The quartz-syenite forming the predominating rock formation of the rapids of the Wisconsin river in Wausau is traversed by numerous narrow veins of pegmatite, varying from a few inches up to a foot in thickness. These veins of pegmatite are relatively very small as compared with the much coarser pegmatite veins occurring in great abundance within the general area of the nepheline-syenite and related rocks in the town of Stettin from 6 to 12 miles northwest of Wausau. Very often the small pegmatitic masses in the rapids at Wausau are merely small lenses apparently having no connection with continuous veins which traverse the syenite. Whether occurring in the form of lenses or veins, however, these pegmatite occurrences clearly have a common origin, as they are wholly identical in mineral composition and texture.

The predominant minerals of the small pegmatite veins at Wausau are feldspar, quartz, brown mica, and amphibole. Occurring in minor quantity, though quite generally present, are fluorite, calcite, and occasionally graphite.

The general character and composition of the mica has already been referred to (page 295). The occurrence of carbonate and its alteration, as well as graphite, in these pegmatite veins is of special interest. Carbonate also occurs in the abundant coarse pegmatite veins in the town of Stettin, as later described, and it also occurs in fine-grained nepheline-syenite, as already described (page 265). The carbonate therefore occurs in several distinct rock phases in this area in localities some distance from one another.

The occurrence of calcite and other carbonate in the pegmatite veins in the rapids at Wausau was discovered by finding pseudomorphs formed by the alteration of carbonate and in the succeeding investigation of the source of these pseudomorphs. The order in which the investigation of the pseudomorphs and the original carbonate, therefore, was carried out is the reverse adopted in the present account of the carbonate and its alteration.

In the small pegmatite veins in Wausau, calcite was observed in crystals from 1 to 2 inches (20 to 40 mm.) in diameter, intergrown with brown mica, quartz, feldspar, and amphibole. The calcite varies slightly in color from pure white or colorless to slate-colored. On surfaces long exposed to weathering, the calcite has been largely removed by solution, leaving numerous depressions in the rock surface.

The phases of white and slate colored carbonate were kept separate for analysis, as it was apparent that the carbonate probably varied in composition from place to place. The results of partial analysis of the two samples made by Victor Lenher on a relatively small quantity of material are as follows:

Analysis of Calcite from Pegmatite veins in Quartz-Syenite at Warsau.

	I.	II.
Insoluble matter	2.18	2.24
Al_2O_3	0.56	1.28
Fe_2O_3	0.21	2.56
FeO	1.01	none
MnO	1.72	2.70 or { MnO 1.55, MnO_2 1.41 }
MgO	trace	trace
CaO	52.26	50.28
CO_2	42.42	40.46
Total	100.00	99.52 or 99.78

I. White carbonate (calcite).
II. Slate-colored carbonate (calcite).

The insoluble matter in both analyses is mainly SiO_2 occurring throughout the carbonate, mainly in biotite and some quartz, so finely disseminated as to make it impractical to separate them. The CO_2 was determined by evolution and was weighed after absorption in caustic potash. In the white carbonate (I) there is almost sufficient CO_2 to satisfy all of the Ca O, Mn O and Fe O. Essentially all of the maganoüs oxide and ferrous oxide is therefore combined with the lime as carbonate. The Fe_2O_3 probably occurs as limonite.

In the slate-colored carbonate (II) the manganese constituent was calculated as Mn O. If the lime is completely combined with the C O_2 there would be 0.96 per cent C O_2 left over which might be combined with 1.55 per cent Mn O, leaving a balance of 1.15 per cent, which, if calculated as Mn O_2, in view of the presence of Mn O_2 in the pseudomorph, would give 1.41 per cent Mn O_2.

The slate-colored carbonate differs chemically from the white carbonate in containing a larger percentage of iron and manganese, and differs also in the form of combination of these elements, since essentially all of the manganese and iron in the former occurs as carbonate, while all the iron and a large part of the manganese of the latter probably occurs as hydroxide, probably as limonite and pyrolusite. As iron carbonate, siderite, is well known to change, under conditions of weathering, to the ferric hydroxide, limonite, a somewhat analogous change probably also takes place in the manganese carbonate to the hydrous manganese manganate, pyrolusite, although the latter alteration has not been described. Thus the slate color of this carbonate is very probably due to alteration.

PSEUDOMORPH OF PYROLUSITE AND LIMONITE AFTER CARBONATE.

In the course segregations of syenite forming the rapids at Wausau was observed a black mineral with pronounced rhombohedral cleavage with metallic lustre on fresh cleavage faces, which at first sight was taken to be iron carbonate. This mineral occurs in crystals up to an inch in diameter, in drusy cavities and in veins, and is closely associated and intergrown with quartz, feldspar, and biotite.

While this mineral is not apparently very abundant, in this place yet sufficient quantity was obtained for a chemical analysis, which was made by Victor Lenher, as follows:

Analysis of Pseudomorph of Pyrolusite and Limonite after Carbonate.

SiO_2	3.64
Al_2O_3	0.42
TiO_2	none
Fe_2O_3	67.28
FeO	none
MnO_2	14.91
CaO	0.38
MgO	0.14
CO_2	trace
P_2O_5	trace
H_2O-at 105°-110°	2.32
H_2O at red heat	10.72
S	0.07
F	none
Copper	trace
Nickel	none
Cobalt	none
Total	99.88

The analysis shows the material analyzed to be largely Fe_2O_3, $Mn O_2$, and H_2O. Most of the insoluble matter is quartz, which occurs closely associated with the pseudomorph. The small amounts of Al_2O_3, Ca O, and Mg O are present as some silicate, feldspar, mica, amphibole, or pyroxene abundant in the syenite included in the material analyzed. The small amount of sulphur probably occurs as iron sulphide.

The manganese present was determined as $Mn O_2$ by Dr. Lenher, *and it was definitely shown that all of the manganese exists as manganese dioxide.* It is obvious, therefore, that the manganese does not occur in the form of the hydroxides, pyrochroite or manganite, as might be the case if it was present as Mn O or Mn_2O_3. On the other hand, the iron is obviously present as the hydroxide, very probably limonite. As limonite, the 67.28 per cent of Fe_2O_3 would unite with 11.41 per cent of H_2O, very probably the most of the water of crystallization present.

The occurrence of the limonite and manganese dioxide in rhombohedral crystals at once suggested a pseudomorphous origin after a carbonate of lime, iron, or manganese, and upon a subsequent visit to the locality, as already stated, carbonate was found similarly associated with quartz, feldspar and biotite in the pegmatite veins in the syenite.

The manganese dioxide of the pseudomorph probably occurs as pyrolusite or psilomelane, more probably the former. It is possible, of course, that the $Mn O_2$ present is not pyrolusite, and yet its close association with the ferric hydroxide in the pseudomorph, in view of the fact that pyrolusite contains a small amount of the hydroxyl molecule, so strongly suggests its occurrence as such that it seems reasonable to refer it to pyrolusite, tentatively at least.

The pseudomorph, free from inclusions of quartz and the probable silicates containing the small amounts of Al_2O_3, CaO, Mg O, assuming the theoretic amount of H_2O with Fe_2O_3 in limonite, and the usually small amount of H_2O in pyrolusite

*Dana's Minerology, 6th Ed., p. 244.

consists of the following calculated proximate percentage of limonite and pyrolusite:

Limonite	83.82
Pyrolusite	16.18

Origin of the Pseudomorph.—The rhombohedral crystal form and the chemical composition of the black mineral analyzed strongly suggests its pseudomorphous origin after a mineral of the calcite group, and, as above stated, on a second visit to the locality, carbonate in the pegmatite veins of the syenite was searched for and found.

The carbonate is associated with quartz and mica in the same manner as the pseudomorph. A considerable change in the color of the carbonate was noted, the variation being from white or colorless calcite to a slate-colored carbonate. No gradation or mixture of the complete pseudomorphs of metallic lustre with the carbonate was observed where the carbonate was found. The slate-colored carbonate, the white carbonate, and the pseudomorph all occurred in different pegmatite veins in the syenite.

An examination of the composition of the material of the pseudomorph shows a complete absence of $C\ O_2$, no trace remaining of the original carbonate substance. The pseudomorph and the white and the slate-colored carbonates, however, all occur under similar conditions of weathering, in separate, though near-by, coarse phases of the syenite. While the two phases of carbonate analyzed do not differ much in composition, yet they are not identical. and show appreciable variation. Two hypotheses concerning the manner of development of the pseudomorph are possible. The pseudomorph of limonite and pyrolusite may be interpreted as having developed mainly by replacement of a calcium carbonate like those above analyzed, or it may be interpreted as a direct alteration in place, by process of oxidation, of a manganese-bearing siderite.

The manner of the alteration of the analyzed calcite, I and II, is of interest, as it is believed to throw much light upon the origin of the pseudomorph of limonite and pyrolusite above described. A close examination of the slate-colored carbonate shows the grayish slate color to be due to finely disseminated specks of black mineral throughout the mass of carbonate, obviously specks of the limonite and pyrolusite. These alteration products do not form a shell surrounding the carbonate, nor are they concentrated in zones along fractures and cleavage cracks, but are throughout the body of the calcite. The analysis of the slate-colored carbonate, as compared with the colorless carbonate, shows a complete change of the iron carbonate of this phase to limonite. Very apparently, therefore, the original iron carbonate disseminated in isomorphous combination with the calcium carbonate throughout the crystal has altered in place by the process of substitution of the $C\ O_2$ of the ferrous carbonate by H_2O to form ferric hydroxide. That is, from the study of the analyses and of the distribution of the secondary limonite throughout the body of the carbonate, the limonite in the slate-colored carbonate is interpreted as the direct alteration in place.

The marked difference in the composition of the pseudomorph and that of the phases of the carbonate above analyzed is difficult to explain as wholly due to processes of alteration, in view of the fact that all have been subjected to the same conditions of weathering. The complete alteration of the iron carbonate of the slate-colored carbonate to limonite, as indicated by the manner of occurrence, is obviously wholly due to alteration in place. The writer therefore is inclined to the opinion that the pseudomorph of pyrolusite and limonite is a direct alteration of a carbonate differing from those above analyzed, being derived very probably from a manganese-bearing iron carbonate containing but a small amount relatively of calcium carbonate, rather than a replacement of a nearly pure calcium carbonate by the introduction of limonite and pyrolusite.

Subsequent examination of the minerals of the abundant coarse pegmatite veins in the syenite of the town of Stettin in Section 22 and in the surrounding area led to the finding of abundant large crystals of limonite pseudomorphs after carbonate. At a number of places in Section 22 these pseudomorphs were found. In a coarse pegmatite vein exposed in a field near the center of the N.W. ¼ of Sec. 22, near Mr. Radant's house, these pseudomorphs were observed over a foot in diameter. They form one of the most resistent minerals to final weathering in the pegmatite, being removed mainly by mechanical processes of disintegration rather than by solution. The cleavage of the altered carbonate is distinct, the pseudomorph breaking readily into rhombohedral cleavage fragments, as in carbonate. In the above locality, coarse crystals of bluish and purple fluorite are often intergrown with the pseudomorps. None of the original siderite or manganic siderite was identified in the weathered veins containing the large pseudomorphs, but there can be little doubt that a few feet below the surface in the fresh rock, unaltered siderite will be found in abundance, from which the pseudomorphs are derived.

GRAPHITE.

Graphite was observed in small quantity in vein like streaks in the pegmatite veins of the quartz syenite at Wausau. In the recent construction of the dam for the electric light plant a considerable quantity of the syenite was removed by blasting and in the fresh surfaces of the blasted rock the shining black crystals of graphite are readily seen.

Graphite is also present in the narrow pegmatite veins of the quartz-syenite at the quarry recently opened in the eastern part of Sec. 14, T. 29, R. 6 E. The occurrence of graphite at these widely separated localities may be considered as the indication of the presence of graphite in many of the pegmatite veins of the area.

The graphite occurs in scaly foliated masses often showing the characteristic rhombohedral form. It has the usual physical properties of graphitic carbon and is unaltered by acids and is infusible before the blow pipe.

The occurrence of the graphite is of interest especially in connection with the carbonate and fluorite with which it is associated. Other minerals associated with it in the pegmatite are feldspar, biotite, quartz and amphibole.

The graphite occurs in contact with and in intergrowth with all its associated minerals, apparently as often with one as with another. The manner of association of the graphite appears to indicate that it was developed essentially contemporaneously with the other minerals of the pegmatite, probably from heated solutions of igneous origin.

Graphite is well known to occur in many phases of igneous rock and also in meteorites and hence it is without doubt in many instances an original constituent of molten magmas. The occurrence of free carbon in the pegmatite is of interest as strongly suggesting the probable explanation of the carbonate minerals directly associated with it as contemporaneously developed from magmatic solutions of igneous origin.

In connection with the origin of the carbonate associated with the graphite reference should also be made to the occurrence of the finely disseminated carbonate in unaltered nepheline syenite (see p. 265) in which occurs the original mineral cancrinite which contains a considerable percentage of the carbonate radical. The large massive crystals of carbonate now altered to pseudomorphs of limonite in Sec. 22 of the town of Stettin, from their massive character and association, likewise indicate their development as original minerals of the pegmatite.

PYROCHLORE GROUP.

In that phase of the quartz pegmatite occurring along the road in the SW. ¼ NW. ¼ of Sec. 22 T. 29 R. 6 from which the acmite of analysis 2 (see p. —) was obtained there was observed a number of small well formed octahedron crystals a detailed examination of which showed them to be a variety of the rare group of pyrochlore[1] and consisting mainly of the rare earth elements.

The minerals directly associated with the pyrochlore are mainly alkali feldspar, acmite and quartz. In associated pegmatite phases of the immediate locality occur the lithia mica, irvingite, the alumina pyroxene, percivalite, and crocidolite, rutile and zircon.

The pyrochlore observed is small, ranging from very minute crystals up to those attaining diameters of about ⅛ in. (2 mm). It was observed in a phase somewhat weathered and disintegrated phase of the pegmatite which could be readily broken up and crumble and on this account allowed the easy separation of the pyrochlore from the associated minerals of the rock.

The pyrochlore occurs as previously stated in octahedrons, the

[1]For a more detailed account of the mineral see S. Weidman and V. Lenher. "Marignacite, a new variety of pyrochlore" Am. J. Sci. 1907.

the regular octahedron without development of other forms so far as could be absorbed. (See fig. 11). Some of the crystals are somewhat distorted. Aggregates in parallel growths are common. (Fig. 11).

Cleavage is indistinct, fracture conchoidal. The mineral is brittle with hardness of 5 to 5.5 and specific gravity of 4.13. The lustre is resinous. The color is brown, varying from dark brown to light brown. Streak is yellowish brown. Under the microscope the color is reddish brown to yellowish brown. The index of refraction is relatively high.

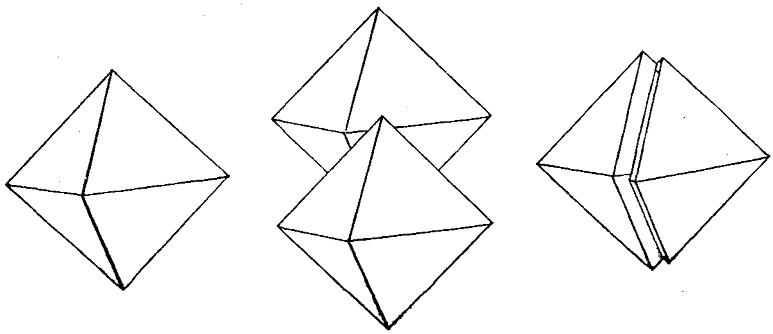

FIG. 11. CRYSTALS OF MARIGNACITE.

The well developed unmodified octahedron crystals unlike the usual forms of the pyrochlore group and a preliminary chemical test by Dr. Lenher showing the mineral to consist mainly of the rare metals columbium (niobium) and tantalum with but a small amount of lime led to the conclusion that the mineral was probably a new variety of pyrochlore and hence material was collected for as complete an analysis as possible.

The mineral collected for analysis was first sorted from the crushed rock by hand and then powdered and separated from the small inclusions of quartz, feldspar and pyroxene by means of the specific gravity solution of silver thallium nitrate. Before being powdered the crystals were carefully examined by a hand lens, and most of the associated mineral was removed. Small inclusions of quartz and feldspar which were necessarily included in the powdered material, were easily removed by the gravity method and hence it is believed that practically pure material was submitted for analysis.

The analysis, made by Prof. Lenher upon approximately 5 grams of mineral is as follows:

Analysis of Pyrochlore (Marignaete).

Cb_2O_5	55.22
Ta_2O_5	5.86
SiO_2	3.10
TiO_2	2.88
Al_2O_3	trace
Fe_2O_3	0.50
FeO	0.02
CaO	4.10
MgO	0.16
Ce_2O_3	13.33
Yt_2O_3	5.07
ThO_2	0.20
Na_2O	2.52
K_2O	0.57
H_2O–110°	0.54
H_2O+110°	5.95
Total	99.93

A careful examination showed small traces of WO_3, SnO_2, MnO, Di_2O_3, La_2O_3, Er_2O_3 and the entire absence of F, ZrO_2 BeO, UO_2, Di_2O_3, Li_2O.

The analysis shows the mineral to consist of a columbate and tantalate with some silicate and titanate of cerium, yttrium, calcium and sodium. In small amounts also occur iron, potassium, magnesium and thorium and in traces are a number of the rare metals as indicated.

The manner of combination of the various constituents in the composition of the pyrchlore is not understood. Attention will be called mainly to certain features of the analysis which distinguish this pyrchlore from those analyzed and described in the literature. The amount of the acid radiclas, Cb_2O_5, Ta_2O_5 and TiO_2 is about the same as in other pyrochlore and related mineral but the presence in essential quantity of SiO_2 has not been recorded in pyrochlore or the related columbates and tantalates. The absence of Al_2O_3 and the very low content of Fe_2O_3 indicates that practically no feldspar or pyroxene substance was included in the material analyzed and it may reasonably be presumed that very little or no free silica as quartz was included. It is believed therefore that the SiO_2 is clearly an essential constituent and is probably combined with TiO_2 as in various titano-silicate minerals which often contain the rare elements and which show a close relationship to the columbate minerals.

In regard to the occurrence of SiO_2 as an original constituent reference may be made to the composition of the pyrochlore from Greenland analyzed by Flink.*

Analyses of Varieties of the Pyrochlore Group.

	I.	II.	III.	IV.	V.	VI.
Cb_2O_5	58.27	61.94	55.22	34.24	26.22	7.74
Ta_2O_5	....	....	5.86	29.83	27.39	68.43
TiO_2	5.38	0.52	2.88	1.61	4.20	....
SiO_2	....	....	3.10	....	....	....
Fe_2O_3	....	....	0.50	....	0.26	0.42[3]
FeO	....	3.01	0.02	2.19	6.32	....
MnO	....	....	....	....	....	....
CaO	10.93	16.61	4.10	8.87	6.00	11.80
MgO	....	1.62	0.16	0.15	....	1.01
Na_2O	5.31	3.58[6]	2.52	1.37	3.15	3.15[4]
K_2O	....	0.36[7]	0.57	trace	....	....
Ce_2O_3	5.50	6.89[2]	13.33	....	12.34	0.17[5]
Yt_2O_3	....	....	5.07	....	....	0.23
Di_2O_3	....	....	....	....	0.63	....
La_2O_3	....	....	....	....	0.71	....
ThO_2	4.96	....	0.20	....	....	....
UO_3	5.53[1]	....	none	15.50	8.33	1.59
SnO_2	....	....	trace	} 0.30	....	1.05
WO_3	....	....	trace		....	0.30
BeO	....	....	....	....	....	0.34
ZrO_2	....	3.39	none	....	....	....
F	3.75	trace	none	....	1.90	2.85
H_2O at 110°+	} 1.53	....	5.95	} 4.49	} 1.45	} 1.17
H_2O at 110°		....	0.55			
Total	101.16	....	99.93	98.55	98.90	100.25

[1] With FeO; [2] with La, Di; [3] with 0.13 Al_2O_3; [4] with 0.29 K_2O; [5] with Di; [6] calculated as Na; [7] calculated as K.

I. Pyrochlore from Brevik, Norway, anal. C. F. Rammelsberg, cited by Brögger, Zs. Kr. 16, p. 511.

II. Koppite, from Schelingen, Baden. G. H. Bailey, J. Ch. Soc. 49, p. 153. 1886.

III. Marignacite, from Wausau, Wisconsin, anal. V. Lenher. 1906.

IV. Hatchettolite, from Mitchell Co., North Caroline. O. D. Allen, Am. J. Sci., 14, p. 128. 1877.

V. Pyrochlore, from Batum, G. P. Tschernik, Zeit. Kryst, 39, p. 624. 1904.

VI. Microlite, Amelia Court House, Virginia, Dunnington, Am. Ch. Soc. 3, p. 130. 1881.

* See Jour. Chem. Soc. (London) Vol. 28 p. 212, 1900.

In the preceding table the analysis of the Wausau pyrochlore is shown in comparison with representative analyses of the several varieties of the pyrochlore group.

The content of cerium oxide, Ce_2O_3 and yttrium oxide Yt_2O_3 is higher than in other described varieties of the pyrochlore group. The content of lime, CaO is lower than common while the amount of soda Na_2O is about the average for pyrochlore.

Fluorine, which is present in some pyrochlore, is absent in this variety. The high content of water is worthy of note and while it may be due to alteration it seems much more likely to be an original constituent of the mineral. While many of the pyrochlore crystals tend to crush easily a microscopic examination shows them to be homogeneous in character and without the usual character of altered mineral. It will be observed also that all varieties of the pyrochlore group either contain fluorine or water in essential quantity, and since these constituents are well known to be isomorphous it seems reasonable to believe that the water in this variety, like the fluorine in other varieties, is original. The relationship here indicated between fluorine and the hyroxyl radical also occurs in the mica group of minerals as illustrated for example in lepidolite and muscovite.

This mineral differs in composition as well as crystal form from the several varieties of pyrochlore described in literature and hence the name *marignacite,* after the celebrated chemist Marignac, is proposed for it. Marignacite may be defined as a variety of pyrochlore containing a small quantity of silica and a relatively high content of cerium and yttrium oxide, low content of lime, and without fluorine but with important content of the hydroxyl molecule. In some features it is like certain previously described pyrochlore but as a whole it is unlike any of the known varieties of this group.

ZIRCON GROUP.

Just before going to the press the completion of the analyses of three zircons by Mr. E. B. Hall was announced. The zircons analyzed are from the N. W. ¼ of section 22 T. 29 R. 6 E. The zircon of analyses 2 and 3 are from the southwest part of the N. W. ¼ of Sec. 22, and that of analysis 1 from the northeast part. The zircons differ from one another in crystal form and appearance and hence the separate analyses were made. The analyses are as follws:

Analyses of aluminous zircon.

	Analyses.			Molecular ratios.		
	1.	2.	3.	1.	2.	3.
SiO_2	28.87	30.89	31.01	.481	.514	.516
ZrO_2	57.79	60.89	62.12	.471	.496	.506
Al_2O_3	7.80	5.11	4.28	.077	.050	.042
Fe_2O_3	4.47	1.54	1.21	.028	.010	.008
H_2O at red heat	1.61	1.41	1.76	.090	.078	.092
H_2O at 105°	.43	.56	.24	....	....	....
Total	100.97	100.40	100.62	....	....	....
Sp. Gr	4.28	4.30	4.65			

Lime, titanium and fluorine were looked for but not found. Previous to the analyses by Mr. Hall, Prof. Lenher had made a partial analysis of each showing the absence of thoria and other rare earths and the presence of alumina in appreciable quantity.

No detailed account of these zircons will be attempted at this time and only their principal features will be briefly described. All occur in the quartz-bearing phases of the pegmatite.

The zircon of analyses 1 was observed in very coarse pegmatite which contained besides feldspar and quartz, abundant fluorite and also much altered carbonate. The crystals varied from those of very small size up to those ½ inch in length. The zircon of this analysis invariably occurs in the usual or common form of zircon, namely the forms bounded by the elongated prisms (110) and terminated by the pyramid (111). The color is reddish brown. Under the microscope the zonal growth so characteristic of zircon is observed. In basal sections the prismatic cleavage is distinct. Geniculated twinning like that of rutile is observed.

The zircon of analyses 2 occurs in a somewhat finer grained phase of the pegmatite. The zircon analyzed was from a rock thickly studded with the zircon varying in size up to ⅛ inch in diameter. The zircon made up about 25 per cent of the rock, which might be termed a zircon syenite. This zircon appears to occur mainly or only in crystals bounded by the pyramid faces. The color of the crystals is reddish brown. Under the microscope the zonal growth and distinct prismatic cleavage are characteristic. The dark opaque and light transparent zonal bands or shells alternate. Sometimes there is a dark essentially opaque interior with lighter transparent exterior, and sometimes the reverse is true. The crystals as seen in the hand appear to be invariably distorted from the usual tetragonal form. This distortion may be due to the unequal development of the pyramid faces or to the unequal zonal growth.

The zircon of analysis 3 occurs in good sized crystals some of them reaching over ½ inch in diameter. Its color is pale yellowish to brownish and reddish yellow, much resembling in color and clear transparency the gem variety, hyacinth. Some simple short prismatic forms were observed but most of the crystals are complex in form being bounded by various crystal faces, the crystals being approximately equidimensional. Under the microscope the basal sections show the usual well developed basal cleavage. No zonal structure was observed. The translucency of this type as observed in the crystals selected for analysis would seem to indicate that the zonal structure is rare or absent.

In general the color of each of the analyzed zircons, as seen under the microscope, is the same, namely nearly colorless with slight tinge of yellow. This colorless portion, in those showing the zonal structure, alternate with the zones which are apparently nearly or wholly opaque. The sections cut nearly normal to the base and showing the distinct prismatic cleavage in each of the types analyzed show the characteristic uniaxial figure in convergent polarized light.

In the above table showing the analyses of the zircons and the molecular proportions of the constitutents, in addition to the principal constituents of $Zr\ O_2$ and $Si\ O_2$ the occurrence of Al_2O_3 and H_2O is shown in appreciable quantity. While the occurrence of Fe_2O_3 in small quantity is usual in zircon, the presence of Al_2O_3 is unusual and this constituent is known in but very few occurrences. The highest content of Al_2O_3 is 2.52 per cent in the variety beccarite. In those minerals classed under thorite which contain thoria and other rare earths as essential constituents in place of zirconia Al_2O_3 is quite generally present but only in very small quantity.

The presence of the appreciable quantity of Al_2O_3 in the several phases of zircon analyzed from this locality shows them to be a very unusual variety. However, as Fe_2O_3 is a usual constituent of zircon, and since Fe_2O_3 and Al_2O_3 are mutually isomorphous in the silicates and other minerals, it is wholly reasonable to expect the occurrence of Al_2O_3 in appreciable quantity in zircon. The occurrence of these aluminous varieties of the zircon is but another illustration of the unusually high content of alumina in the syenite magma of this region.

The H_2O occurring in appreciable quantity, is believed to be an original constituent. The microscopic appearance of these zircons is not that of altered minerals. While the zonal structure may indicate a difference in composition of the alternating zones, yet the zonal structure is a characteristic feature of most zircons. The fresh translucent to transparent homogeneous character of the zircon of analyses 3 is especially worthy of note and yet this type bears essentially the same amount of H_2O as the others. While it is true that iron stain permeates the strong cleavage fracture of the zircons, there is no characteristic bleaching or decomposition products developed at the expense of the zircon substance. It is believed that the H_2O, especially that driven off above 105 degrees, plays the same role in the original composition of these zircons as the H_2O in mica, amphibole and other minerals.

The molecular proportion of the constituents indicated in the above table of analyses shows the ratio of ZrO_2:SiO: as 1:1. The molecular proportion of the Al_2O_3, Fe_2O_3 and H_2O is important. While the proportion of the sesquioxides vary, the ratio of ZrO_2 to SiO_2 to H_2O remains essentially constant. The crystal form of the zircons differ from one another, as already described, but their difference in form may not be due to the variation in the chemical composition. Additional light may be thrown upon this phase of the subject through later study.

Nepheline-Bearing Pegmatite.

Distribution.—Nepheline-bearing pegmatite occurs about one-fourth mile north of the center of Sec. 5, T. 29, R. 7 E., in a small ravine on the farm of A. Leubki: in the SE. ¼ of Sec. 1, T. 29, R. 6; in the SE. ¼ of Sec. 4, T. 29, R. 6 E.; in the northern part of Sec. 15, T. 29, R. 6 E., and in the NE. part of Sec. 27, T. 29, R. 6 E. The nepheline-bearing pegmatite is probably present in many localities not yet discovered. In Sec. 1 no outcrop was observed, but numerous large crystals of nepheline, up to one foot in diameter were noted imbedded in the soil. Most of these occurrences of nepheline-bearing syenite occur at or near the outer border of the area of the syenite rocks.

SOME MINERALS OF THE NEPHELINE-PEGMATITE.

The coarse pegmatite containing nepheline is not so abundant as that containing quartz. Only a few of the minerals of the nepheline-bearing pegmatite have been examined in detail and hence only a very general description of this phase can be given.

Feldspar is the principal constituent. Nepheline is also very abundant. Aegerite and alkali amphibole are also generally present, especially the former. Mica is present also in certain phases.

FELDSPAR.

The most abundant mineral of the netheline-bearing pegmatite is feldspar, although locally in some phases the nepheline probably predominates. Feldspar, however, is not so abundant a constituent of the nepheline-pegmatite as of the quartz-pegmatite.

Albite.—The predominating feldspar is albite of characteristic white or colorless aspect. Microperthite, orthoclase and microcline are also present in some phases. The feldspar of the pegmatite often occurs in two generations, the first or older generation represented by large crystals and the second by much smaller ones interstitial to the larger mineral constituents of the rock. Albite is quite generally the predominating feldspar of the second generation, as well as of the first.

NEPHELINE.

In some phases of the pegmatite, nepheline appears to be the most abundant constituent. It generally occurs in the pegmatite in large individual crystals, as well as small intergrowths of many crystals. It possesses the usual features of this mineral. In thin section it is colorless, but the characteristic color in the hand specimen is bluish-gray. It has a brittle fracture and vitreous or greasy lustre. Quadratic forms of the crystals are common. It weathers more readily than its associated minerals and hence forms depressions, giving the rock an uneven, pitted aspect. The most common alteration product is greenish to grayish natrolite. Muscovite and kaolinite are also present as secondary inclusions.

Two analyses of the nepheline occurring in the coarse pematite at A. Leubki's place in Sec. 5, T. 29, R. 7 E., by Prof. W. W. Daniells, are shown in the following table in comparison with the analyses of nepheline from other regions:

Analyses of Nepheline from Wausau and other localities.

	I.	II.	III.	IV.	V.	VI.	VII.
SiO_2	44.68	42.28	44.46	43.74	45.10	44.04	44.98
Al_2O_3	34.16	35.33	30.97	34.48	33.28	34.06	34.49
Fe_2O_3	0.87	0.93	2.09	....	....	0.44	....
MgO	0.14	0.07	....	tr.	....	....	....
CaO........	0.30	3.04	0.66	tr.	....	2.01	0.43
Na_2O.......	15.13	13.83	15.61	16.62	16.36	15.91	15.60
Ka_2O	3.89	3.55	5.91	4.55	5.05	4.52	4.65
H_2O	0.47	0.52	0.95	0.86	0.70	0.21	....
Total...	99.64	99.55	100.65	100.25	100.49	101.19	100.15

I. Nepheline from Wausau, Wis.; anal. by W. W. Daniells.
II. Nepheline from Wausau, Wis.; anal. by W. W. Daniells.
III. Nepheline (Eleolite) from Hot Springs, Ark; anal. by J. S. Smith, Am. J. Sci., 2d Ser., Vol. XVI, p. 371, 1853, cited Ark. Geol. Sur., Vol. 2, p. 210.
IV. Nepheline (Eleolite) from Litchfield, Me; anal. by F. W. Clarke, Am. J. Sci., 3d. Ser, Vol. XXXI, p. 268. 1886.
V. Nepheline (Eleolite) from Fredrikvarn, Norway; anal. by J. Lemberg. Zs. G. Ges., Vol. 28, p 548-9, 1876.
VI. Nepheline from Mt. Vesuvius, Italy. (Quoted by Dana's Mineralogy, Sixth Ed., p. 425).
VII. Nepheline from Mt. Vesuvius, Italy. (Quoted by Dana's Mineralogy, Sixth Ed., p. 425).

The nepheline from this district, as shown in analyses I and II, differs slightly from the average nepheline in the relatively higher content of alumina, Al_2O_3, and the appreciably lower content of K_2O as compared with Na_2O. In most analyses of nepheline Na:K as 4:1 or 5:1, whereas in the two analyses of this nepheline Na:K as 6:1 approximately. The molecular ratio of the alkalies and lime to alumina in most minerals, and especially in the nepheline and feldspar groups, is 1 to 1. In both the analyses of the nepheline, however, there is an apparent excess of Al_2O_3 over K_2O, Na_2O and CaO. In analysis I the excess of Al_2O_3 is .033 molecules, and in II the excess of Al_2O_3 is .045 molecules. The nepheline from this district, however, is not wholly unique in this regard, for it may be observed on calculating the molecular ratios of the nepheline from Litchfield (IV) analyzed by F. W. Clarke that this nepheline contains an excess of .032 molecules, and that from Vesuvius (analysis VII) contains an excess of .030 molecules over that required for the usual formula. In fact, most analyzed nephelines show an excess of Al_2O_3 over Na_2O+K_2O+CaO. It seems most probable, therefore, that H_2O, usually present in appreciable quantity, is an isomorphous constituent with Na_2O and K_2O in nepheline as it is in many other alumino silicates.

An unusual feature of analysis II is the relatively high content of lime, namely, 3.04 per cent. In the analysis VI of the Vesuvius nepheline, a content of 2.01 per cent of CaO is to be noted. Lime appears to be a very common constituent of nepheline, as it is of the feldspar group. The molecular ratio of $CaO:K_2O$ in analysis II is 54:38; hence the lime plays a more important role than potash. The nepheline analyzed was examined under the microscope and found to be essentially uniformly homogeneous and unaltered. The only inclusions contained were very small crystals of albite, much less than one per cent, and it was deemed impractical to attempt to make any separation by specific gravity methods.

In reality, the formula of the nepheline of analysis II conforms more closely to the synthetic formula of nepheline, $NaAlSiO_4$ than any analyzed natural nepheline. In this nepheline, it appears that, not only does potassium, but also lime and hydroxyl, partly replace the sodium.

SODALITE.

Sodalite is present in the nepheline-bearing pegmatite, but it does not appear to be very abundant. No bluish sodalite has been noted. The sodalite varies in color from grayish to yellowish-gray. Natrolite and kaolinite are the common alteration minerals.

PYROXENE.

The prevailing pyroxene constituent of the nepheline-bearing pegmatite is aegerite.

Aegerite.—This mineral appears to be by far the most abundant dark-colored constituent of this rock phase. The bluntly terminated crystals of aegerite prevail rather than the sharp-pointed ones of acmite.

The larger crystals in the pegmatite generally vary in size from an inch to 6 inches (25.4 mm. to 152.4 mm.) in diameter.

To the naked eye the aegerite has a greenish-black color. The distinct prismatic cleavages which cross each other nearly at right angles (87°) is a prominent feature. The usually, nearly rectangular prismatic forms of the crystals are characteristic. Under the microscope it is seen to be strongly pleochroic in colors varying from pure green to yellowish green. The refringence and birefringence are high, being greater than for any other pyroxene. The extinction is nearly parallel (2° to 5°) to the prismatic cleavage.

The aegerite is free from alteration. Its fresh appearance is in marked contrast with the associated minerals in the coarse pegmatite long exposed to weathering. The aegerite stands out as the most resistant mineral of the rock, forming sharply angular protuberances below which the relatively deep pits of the nepheline crystals lie embedded. The fractures in the aegerite are sometimes filled with yellowish mica and albite, but these are believed to be due to infiltration rather than alteration.

Chemical Composition.—Fragments of the large crystals occurring in the pegmatite in Sec. 5, T. 29, R. 7 E. were carefully sorted and submitted to W. W. Daniells for analysis, with the following result: (Analysis I of the table).

Analyses of Aegerite from Wausau and other localities.

	I.	II.	III.	IV.	V.
SiO_2	49.57	51.41	51.74	51.11	49.91
Al_2O_3	2.33	1.82	0.47	2.47	1.24
Fe_2O_3	23.17	23.30	26.17	22.80	22.83
FeO	7.67	9.45	3.48	8.40	13.95
MnO	1.04	....	0.46	....	0.42
MgO	0.39	0.31	1.79	0.41	0.21
CaO	5.56	2.03	5.07	2.60	1.72
Na_2O	9.70	11.88	11.02	12.10	9.49
K_2O	0.31	trace	0.34	....	0.32
TiO_2	....	0.13	....	....	....
H_2O	0.19	....	....	0.30	....
Total	99.93	100.33	100.54	101.19	100.09

I. Aegerite from Wausau, Wis ; anal. by W. W. Daniells.
II. Aegerite from Hot Springs, Ark.; anal. by J. L. Smith (Am. J. Sci., Vol. X, 3rd Ser., p. 60, 1875; cited Ark. Geol. Sur., Vol. II, p. 250).
III. Aegerite from Barkevig, Norway; anal. by C. Doelter (Tscherm. Min. Mitth., Vol. I, p. 378; cited Zr. Kr. B. 16, p. 297).
IV. Aegerite from Brevik, Norway; anal. by F. Pisani (Camptes Rendus, LVI, p. 847, 1863; cited Ark. Geol. Sur., Vol. II, p 365.)
V. Aegerite from Kangerdlaursuk, Greenland. (See analysis 5, Dana's Min. 6th Ed , p. 365.)

The above analyses of aegerite from various localities essentially agree in composition. The aegerite from this locality is unusually high in CaO and Al_2O_3, and unusually low in Na_2O It is like III in its content of CaO, like IV in Al_2O_3 and like V in Na_2O. With respect to the high content of Al_2O_3 attention is called to the alumina-rich variety of acmite in the associated quartz-bearing pegmatite of this locality, described on page 289–294.

AMPHIBOLE.

Amphibole does not appear to be an abundant constituent of the nepheline-bearing pegmatite.

Arfvedsonite.—In the NE. part of Sec. 27, T. 29, R. 6 E., an amphibole closely associated with aegerite is present. This amphibole has the lavender and yellowish pleochroism and other optical properties of arfvedsonite. It occurs only in small crystals in the above locality. It has not yet been found in large crystals like the aegerite in this rock phase.

MICA.

Dark-colored mica having the general character of lepidomelane occurs in some phases of the nepheline-bearing pegmatite, but does not appear to be very abundant.

OTHER MINERALS.

Titanite, rutile, zircon, fluorite, and several minerals which have not yet been definitely determined occur in small crystals in the nepheline phase of the pegmatite.

Relative Distribution and Composition of Pegmatites and Normal-grained Syenites.

The distribution of the nepheline-pegmatite with reference to the prevailing type of normal nepheline-syenite, the Marathon type, is obviously in localities near the border of the dominant nepheline type of syenite, as shown by the occurrence of the pegmatite at contacts with the older rocks. This is clearly the relation at least of the known occurrences of the aegerite nepheline-pegmatite and of the dominant type of the nepheline-syenite. The finer grained phases of aegerite nepheline syenite having a mineral composition closely resembling the pegmatite occur in the region between the pegmatite and Marathon type of syenite with an apparent closer association with the pegmatite than with the Marathon type.

It might be urged, since the distribution of the nepheline-pegmatite and associated phase is at the outer border of the main area of nepheline-syenite, that the pegmatite and also the related aegerite phases of the syenite occur as dikes and veins leading out from the dominant type. The explanation of origin may in part be true of the aegerite-bearing nepheline syenite of some occurrences, for instance, of those occurrences which lie some distance from the main area of nepheline rock, as near Mr. Kolter's house, in the NE. part of Sec. 31, and in the NW. part of Sec. 28 of T. 29, R. 7 E., and in the occurrence southeast of Wausau in Sec. 21, T. 28, R. 8 E. In these occurrences, however, another interpretation of origin seems possible. In these localities, the nepheline rock possesses such a close mineral and textural similarity to the associated syenite as to indicate a possible origin by local differentiation from the immediately surrounding rock magma. The coarse nepheline pegmatites and the aegerite phases of syenite also have not been found out in the area of the rock formation older than the syenite-granite, as already stated, but occur within the general border of the quartz and nepheline-syenite rocks.

The distribution of the abundant quartz-bearing pegmatite of the region with respect to the normal-grained quartz-syenite, Wausau type, is not in a zone or belt surrounding the latter, but rather within an area lying on the northwest border of the main quartz-syenite area. The quartz-bearing pegmatite is within the general area of the nepheline-bearing rocks, the two together forming a tongue or lobe extending northwest from the general area of quartz-syenite and amphibole-granite surrounding the region about Rib Hill and Wausau. The area of the quartz-pegmatite also lies to the northwest of the quartz-syenite with trachytoid structure (the Stettin type), the latter lying between the two and possessing a mineral composition showing a gradation between the Wausau type of syenite and that of the coarse quartz-pegmatite.

With respect to the occurrence of the quartz-pegmatite on the northwest border of the medium-grained quartz-syenites, the same relative distribution is emphasized as shown in the nepheline-pegmatite and normal nepheline-syenite, for the occurrences of the latter mainly lie to the northwest and to the southwest of the nepheline-syenite, and is probably absent immediately southeast of the main type of the nepheline-syenite.

Intrusive Relation of Pegmatite to the Normal Syenite.

Numerous veins of the quartz-bearing pegmatite are known to penetrate the medium-grained quartz-syenite. The relations of the larger masses of pegmatite to the normal syenite is not so clear, but the smaller masses occurring in veins very probably are connected in origin with the larger masses and thus indicate the relation of intrusions in the normal-grained rocks. The main masses of nepheline-pegmatite were not found intrusive in the dominating phase of nepheline-syenite, but the clear cut dikes and dike-like masses of nepheline-syenite have the prevailing mineral composition of the pegmatitic phases and hence it is reasonable to presume that the intrusion and consolidation of the nepheline pegmatite was also subsequent to that of the predominating phase of the nepheline syenite, the Marathon type.

Comparison of the Mineral Composition of Quartz-Pegmatite with that of the Quartz-Syenite.

While the feldspar and quartz are dominant minerals in both the quartz-syenite and the pegmatites, a notable difference in the character of the prevailing dark-colored silicate minerals of these rocks is very apparent as already stated. In the normal-grained quartz-syenite, fayalite, hedenbergite, and barkevikite are the prevailing dark-colored constituents. This is not only true of the predominating quartz-syenite with granitoid texture but also largely true of the phase with tendency to develop the trachytoid texture. In the quartz-pegmatite, on the other hand, none of these more basic minerals were observed.

Magnetite also is a fairly abundant constituent of the normal-grained quartz-syenite, but was not observed in the quartz-pegmatite. The mica, lepidomelane, and fluorite occur in both the normal-grained rock and in the coarse pegmatite.

The dark-colored silicates in the quartz-pegmatite are mainly the pyroxenes, acmite and percivalite, and the amphiboles, crocidolite and riebeckite, none of which are known to occur in the normal granitoid quartz-syenite. Aegerite and riebeckite, however, occur in some phases of the contact quartz-syenite with trachytoid texture. The mica, lepidomelane, apparently occurs in certain phases at least of both the quartz-syenite and quartz-pegmatite. The minerals containing rare elements, such as the rutile, lithia-mica and the pyrochlore, are known to occur only in the pegmatite.

Comparison of Minerals of Nepheline-Syenite and Nepheline-Pegmatite.

The very abundant minerals, feldspar, nepheline, and sodalite occur in both the normal syenite and the pegmatite. The dark-colored silicates of the abundant phase of normal syenite, however, are fayalite, hedenbergite, and barkevikite or arfvedsonite, none of which except arfvedsonite was observed in the pegmatite. The dark-colored basic silicates of the abundant phase of nepheline-syenite are much more like the basic minerals of the abundant quartz-syenite than the minerals of the nepheline-pegmatite. The dark basic minerals of the nepheline-pegmatite are mainly aegerite with smaller proportion of arfvedsonite and lepidomelane. Lepidomelane locally occurs in all phases of the nepheline rock. Aegerite occurs only in the pegmatite and a phase of the nepheline-syenite occurring as "Schlieren" associated with pegmatite phases and near contacts with other rocks presumably usually as dikes. Magnetite is a fairly abundant constituent of the normal-grained syenites of both phases, but was not observed in the coarse pegmatite. Fluorite occurs in all phases of the nepheline rock. Several minerals, presumably rare members of the epidote group containing the rare elements, was noted in considerable abundance in some phases of the pegmatite, but were nowhere seen in the fine-grained nepheline rocks.

A marked characteristic difference in the mineral composition of the predominating phases of both the quartz and nepheline-syenite, and the coarse nepheline and quartz-pegmatites, is the presence of fayalite, hedenbergite, barkevikite and probably magnetite in the former, and the presence of aegerite without any of the above mentioned minerals in the latter. On the other hand, the phases of medium-grained rocks, with the tabular developed feldspar, (trachytoid structure,) and the medium-grained contact phases, and dikes, contain aegerite and some of the other characteristic minerals such as the blue soda amphiboles, which occur abundantly in the pegmatite. Fluorite is a persistent though minor constituent of all the rock phases but is believed to be most abundant in the pegmatites.

Comparison of Chemical Composition of Normal Quartz-Syenite with that of Quartz-Pegmatite.

As the coarse pegmatite rocks have not been analyzed, a comparison of the composition of the normal-grained and of the pegmatite phases of the rock magma can not be made by means of a series of direct chemical analyses. But a comparison of the mineral composition of the coarse and fine-grained rocks, combined with the analyses of the latter, appears to show certain marked differences in the relative acidity and basicity of these rock types.

The analysis of the normal-grained quartz-syenite (analysis III, p. 339) shows a silica content of 61.18 per cent and a lime content of 2.64 per cent. As no analysis of the coarse quartz-pegmatite has been made, no direct comparison can be made, but judging from the relative abundance of the chemically determined minerals, the pegmatite appears to be higher in silica and lower in lime than the corresponding normal-grained syenite. The feldspar, which constitutes the dominant mineral of the pegmatite, has a silica content varying from 65.50 to 66.42 per cent (p. 280). Where the feldspar is not by far the predominating mineral, quartz and the soda amphiboles riebeckite and crocidolite, and the soda pyroxenes, acmite and percivalite, are prominent minerals. The amount of quartz in the pegmatite relatively increases locally at least with the increase in the amount of the amphibole and pyroxene. The amphiboles and pyroxenes of the pegmatite contain little or no lime, while those of the normal syenite are high in lime. Magnetite and fayalite are abundant in the normal syenite, but are absent or very rare in the pegmatite.

On the whole, while only an estimate of the chemical composition of the coarse quartz-pegmatite is available, yet, basing judgment on the composition of the dominant minerals and their proportions, the composition of the pegmatite as compared with that of the normal syenite is believed to be considerably higher in silica, probably 65 or 66 per cent, as compared with 61 to 62 per cent of the normal syenite, and much lower in lime and ferrous oxide, as indicated by the character of the soda pyroxenes and amphiboles of the pegmatite as compared with lime-iron pyroxenes and amphiboles of the normal quartz syenite. The magnesia content is too small to be considered of importance in any of the syenite rock phases.

With the increase of silica and decrease in lime in the pegmatite there is very probably a notable decrease in total iron, with a much greater decrease in ferrous oxide than in ferric oxide as indicated by the high content of FeO in the composition of the fayalite-hedenbergite-barkevikite group of minerals of the normal syenite as compared with the high content of Fe_2O_3 in the acmite crocidolite and riebeckite of the pegmatite. The mica in the quartz-syenite is also high in FeO, while that in the pegmatite is high in Fe_2O_3. The abundance of magnetite, in which Fe_2O_3 greatly predominates over FeO, explains the high content of Fe_2O_3 in the normal syenite rocks.

There appears to be no decrease in the alumina as the silica increases from the normal syenite to the quartz pegmatite. That is, the Al_2O_3 appears to hold its own, and may possible increase locally, as the silica rises and the lime and iron fall.

The approximate uniformity of the Al_2O_3 is indicated by the composition of the quartz-syenite (analysis III, page 339), as compared with that of the microperthite feldspars (page 280) which constitutes the greatly predominating mineral of the quartz-pegmatite.

The total alkalies tend to rise and fall with the alumina, as is usual in igneous rocks, the two alkalies occurring in about equal quantity, as expressed in the abundance of microperthite feldspar. This fact is readily seen on comparing the alkali content of the quartz-syenite of analysis III with that of the feldspar of the pegmatite (see page 280). But there is a strong tendency locally for the soda to greatly predominate over the potassa in the quartz-pegmatite, just as the soda greatly predominates in a general way in the phases of the nepheline-syenite rocks.

The great predominance of soda in the quartz-pegmatite, a feature not present in the normal quartz-syenite, though obviously tending to develop in the trachytoid phases, finds expression in the predominating development of the soda pyroxenes and amphiboles over the micas. This predominance of soda with presumably no change in alumina finds its culminating expression in the development of albite and the soda pyroxenes, percivalite and acmite, the composition of which indicates that with the decrease in potassa the soda increases, as in the differentiation of the magma of nepheline-syenite rock.

In chemical composition, therefore, the quartz-syenite of normal texture is obviously lower in SiO_2 and higher in lime and iron than the quartz-pegmatite. While the SiO_2 increases towards the pegmatite, the Al_2O_3 and total alkalies remain essentially the same, thus relatively increasing with the strong tendency locally for Na_2O to greatly increase over the K_2O.

Comparison of Chemical Composition of Normal Nepheline-Syenite with that of Nepheline-Pegmatite.

A comparison of the chemical composition of the prevailing normal nepheline-syenite with that of the nepheline-pegmatite may be readily seen by examining the two following analyses:

Analyses of nepheline-syenite (I) and nepheline pegmatite (II).

	I.	II.
SiO_2	54.76	57.82
Al_2O_3	24 72	24 23
Fe_2O_3	2.73	1 56
FeO	2.35	1.03
MnO	none	trace
MgO	0.10	0.28
CaO	1 67	1.04
Na_2O	10.38	9.20
K_2O	2.37	3 03
H_2O-105°110°	0.55	0 14
H_2O-red heat		0 59
TiO_2	not det.	0 30
ZrO_2	not det.	0.28
Cl	not det.	0.15
Li_2O	not det.	none
CO_2	not det.	none
F	not det.	none
S	not det.	trace
P_2O_5	not det.	trace
	99.63	99.65
Less oxygen equivalent of Cl	....	03+
	....	99.62

While analysis I, of the Marathon type of nepheline-syenite, is probably a very good representative of this rock type, analysis II, of the aegerite-bearing phase, does not represent the prevailing type of nepheline-pegmatite, but only a phase intermediate between normal aegerite-nepheline syenite and the aegerite-nepheline pegmatite. The character of the variation in composition, however, is indicated in the pegmatitic phase, and thus the tendency, in the character of the chemical variation, supported also by the mineral composition of the pegmatite, may be pointed out. The analysis shows the aegerite pegmatitic phase (II) notably higher in SiO_2 than the normal-grained syenite, Marathon type, (I). The content of total iron and lime is notably higher in I than in II, with a relative increase of Fe_2O_3 over FeO in II. This chemical difference is expressed mineralogically by the presence of the fayalite, high in FeO, and hedenbergite and barkevikite, high in CaO and FeO, in the Marathon type of syenite as compared with the aegerite, high in Fe_2O_3 in the aegerite phase. The MgO is relatively unimportant.

The content of Al_2O_3 is essentially the same in the two analyses, and the same is true of the amount of total alkalies. The content of Na_2O greatly exceeds that of K_2O in the nepheline-syenite, and there appears to be a relative increase of the K_2O as compared with the Na_2O in passing from the normal abundant nepheline-syenite, Marathon type, to the aegerite arfvedsonite-bearing phase of analysis II. In the prevailing nepheline-bearing pegmatite, however, aegerite is the abundant dark-colored silicate, the very coarse pegmatite containing but little arfvedsonite.

In the prevailing type of nepheline-pegmatite, therefore, there is not only very probably no marked change in the relative greater abundance of Na_2O over K_2O as compared with their proportions in the normal rock, but very probably a still greater predominance of Na_2O over K_2O.

In chemical composition, therefore, the abundant type of normal nepheline-syenite is lower in SiO_2 and higher in iron and lime than the prevailing type of nepheline-pegmatite. While the content of SiO_2 increases in the pegmatite, the Al_2O_3 and total alkalies remain essentially the same with a strong tendency for the Na_2O to increase over the K_2O.

Origin of the Pegmatite.

On the whole, the very large and abundant veins and irregular masses of pegmatite, such as occur in Sec. 10, 11, 14, 15, 22 and 23 of T. 29, R. 6 E., appear to be merely the coarsely crystallized phases of the syenitic magma of this region, evidently developing into coarse pegmatite rock on account of favorable conditions for the development of large crystals. The conditions favorable to the development of such coarse-grained rocks may have been due to physical conditions of temperature, causing slow and long continued crystallization, or to the chemical composition of the magma or because of the presence of mineralizers, or to a combination of these causes.

It is the writer's view, therefore, that these pegmatites are of truly eruptive origin, like the normal syenites of the district. This belief is based upon various phenomena among which may be mentioned the fact that the two phases of the pegmatites correspond to similar phases of the normal syenite of the district, namely, the quartz-bearing and the nepheline-bearing syenites. The texture also of the pegmatite differs mainly from that of the normal syenite only in the coarseness of the crystals and in the peculiar association of minerals which large minerals are likely to bring about. The occurrences of the pegmatite are, to a very large extent, in large rather than in narrow veins and dikes, and appear therefore to have been erupted in the main like much of the normal syenite. The veins of pegmatite ramify throughout the normal phases of syenite, and very obviously prove their eruption after that of the normal-grained rocks. The normal phases of all the granite-syenite rocks, as a whole, constitute a great batholitic mass, obviously formed by long continued complex intrusions rather than a single simple intrusion. The pegmatites and syenites constitute phases of the very extensive complex intrusion and were themselves composite in character.

Pegmatites are usually regarded as representing the final stages of eruption of the rock magma from which they are form-

For a discussion of the origin of pegmatite, see the following: W. C. Brögger, Zeit. fur. Kryst. B. 16 pp. 215–235; G. H. Williams, 15th Ann. Rept. U. S. Geol. Sur. pp. 675–684; C. R. Van Hise, Mon. 47, U. S. Geol. Sur. pp. 720–728.

ed, and they are also usually regarded as invariably showing a coarser texture and a more acid composition than the main mass in which they occur. In this region the pegmatites do not represent the most acid composition of the granite-syenite magma as a whole, but very probably represent the more acid crystallization of certain closely related and closely associated portions of this general magma from which the granite-syenites and pegmatites as a whole are derived. As already stated, the pegmatites occur in two types or phases, the quartz bearing and the nepheline-bearing.

The nephelinne-bearing pegmatite, which contains an abundance of aegerite, is characterized by the same minerals as the aegerite-nepheline syenite, which on the whole is appreciably more acid than the hedenbergite-fayalite-nepheline syenite. The most abundant nepheline-bearing syenite is the phase containing fayalite, hedenbergite, barkevikite, and magnetite, and none of these basic minerals were observed in the nepheline-bearing pegmatite. On the other hand, in the nepheline-pegmatite, the principal dark-colored silicate is aegerite, and numerous rare minerals like those of the normal aegerite-nepheline syenite. In fact, the normal aegerite-nepheline syenite, appreciably more acid than the fayalite-bearing type, stands so close to the nepheline-pegmatite in its field relations and in its texture and mineral composition that it is difficult in most places to draw any sharp line between them.

In a noteworthy manner also the quartz-bearing pegmatite does not contain the basic minerals fayalite, hedenbergite, barkevikite, and magnetite, but is rich in quartz and in such silicate minerals as acmite, riebeckite, soda-alumina pyroxenes and micas, and various rare minerals. The quartz-bearing pegmatite, therefore, is obviously a more acid rock than the normal quartz-syenite of this region, the most abundant type or phase of which is characterized by the presence of fayalite, hedenbergite, barkevikite, and lepidomelane.

The two phases of quartz and nepheline-pegmatites, therefore, appear to represent the more acid crystallization of the corresponding quartz and nepheline-syenite magma immediately associated with the pegmatites rather than the more acid excretions of the great mass of magma of granite-syenite intrusions as a whole.

The views of the writer, therefore, are in general accord with the views of Brögger,[1] who ascribes an eruptive origin to the extensive pegmatite dikes of the nepheline-syenite and quartz-syenite of southern Norway. The mineral composition and textures of the pegmatites and related syenites of Wisconsin have much in common with the pegmatites and syenites of southern Norway. The Wisconsin magma differs from the Norwegian magma chemically in containing a lower percentage of magnesium and potassium, and in a higher content of alumina and soda but on the whole the broader features of the two magmas with respect to general composition, rock textures, and crystallization have much in common. The similarities and dissimilarities of the magmas of the two regions will be more apparent as the Wisconsin rocks are studied in more detail.

SECTION IV. RÉSUMÉ.

THE GENERAL CHARACTER AND RELATIONS OF THE IGNEOUS ROCKS OF NORTH CENTRAL WISCONSIN.

In the preceding sections of the present chapter an account has been given of the igneous rocks intrusive in the lower sedimentary series and in the older igneous rocks of the region. These intrusive rocks constitute by far the most abundant formation of the district, forming from 75 to 80 per cent of the rocks of the area. They fall into three groups, viz., the rhyolite series, the diorite-gabbro series, and the granite-syenite series, named in the order of their eruption. In the order of their apparent abundance, as indicated by their surface extent and outcrops, these rocks appear in reverse order from that of their eruption, the rocks of the granite syenite series being by far the

[1] Zeit, für, Kryst, B. 16 (1890), pp. 215–235.

most abundant, forming from 60 to 70 per cent of the rocks of the area, the diorite-gabbro from 5 to 10 per cent, and the rhyolite from 4 to 8 per cent.

Chemical Character of the Rhyolite.

In the two analyses of the rhyolite, both of which were representative of the average rhyolite of the locality, the content of Na_2O greatly exceeds that of K_2O. Similar soda-rich rhyolites, described by the writer[1] and by W. H. Hobbs[2] and C. K. Leith occur over a wide area adjacent to the Fox river valley of southern Wisconsin. In the following table the composition of the rhyolite of this area is compared with that of several localities (Anal. III to VI described by the writer and VII to XIII described by Hobbs and Lieth), in southern Wisconsin.

Analyses of Wisconsin Soda-rhyolites.

	Rhyolites of North-Central Wisconsin		Rhyolites of Southern Wisconsin.			
	I. Wausau rhyolite.	II. Pine River rhyolite.	III. Utley meta-rhyolite.	IV. Berlin rhyolite gneiss.	V. Baraboo Kerat-ophyre.	VI. Baraboo Kerat-ophyre.
SiO_2 ...	72.68	74.60	73.09	73.65	73.00	71.24
Al_2O_3 ...	16.40	13.04	13.43	11.19	15.61	12.20
Fe_2O_3 ...	0.99	0.76 }	2.57	1.31	....	1.71
FeO....	1.53	3.34 }		3.25	1.95	5.44
CaO....	1.56	....	2.29	2.78	.79	0.98
MgO ...	0.48	0.61	1.03	0.51	....	.13
Na_2O ..	3.85	5.40	3.85	3.74	4.95	4.29
K_2O....	2.10	0.82	1.58	1.86	0.88	1.86
H_2O ...	0.37	1.06	0.72	0.44	1.06	0.81
SO_3....	....	....	....	....	....	.97
Total.	99.96	99.63	98.56	99.23	99.00	99.63

[1] S. Weidman, Bull. III, Wis Geol. & Nat. Hist. Survey, p. 2.
[2] The pre-Cambrians volcanic and intrusive rocks of the Fox River Valley, Wisconsin. Bull. Univ. of Wis., 1907.

Analyses of Wisconsin Soda-Rhyolites,

	Rhyolites of Southern Wisconsin.						
	VII. Observatory Hill Aporhyolite.	VIII. Marquette Aporhyolite.	IX. Marquette Aporhyolite.	X. Endeavor Aporhyolite.	XI. Taylor's Farm Aporhyolite.	XII. Marcellon Aporhyolite.	XIII. Marquette Aporhyolite.
SiO_2	74.46	73.30	73.09	72.80	78.23	79.03	73.84
Al_2O_3	15.28	15.32	15.40	15.50	11.11	13.23	16.44
Fe_2O_3.	1.95	1.21	.65	2.04	1.73	.34	.50
FeO	.74	.96	2.10	.60	1.03	.18	.68
CaO	.92	1.33	1.74	.52	.28	.25	.65
MgO.	.08	.39	.12	.08	trace	.07	trace
Na_2O	2.57	3.47	4.57	5.70	3.44	3.95	4.23
K_2O	•3.01	3.86	2.01	2.52	4.08	2.28	3.07
H_2O	.58	.26	.17	.43	.25	.19	.44
Total ..	99.59	100.10	99.85	100.19	100.15	99.52	99.85

An examination of the analyses shows a very close agreement in the composition of the rhyolites over a very large area of central and southern Wisconsin, as indicated by the characteristic feature of the marked molecular excess of Na_2O over K_2O in all of them. From two of the localities the rhyolite is exceptionally high in Al_2O_3. These rhyolites also all appear to have been erupted in the same period, as indicated by their geological relations. These rhyolites are essentially soda-rhyolites, and their geological relations and close agreement in chemical features indicates their consanguinity of relationship, as rocks erupted from a common or parent magma.

With respect to analyses of rhyolites outside of this area and that of southern Wisconsin, very few are available. In the Menominee district Williams[1] describes a schistose quartz-porphyry in which the percentage amounts of Na_2O and K_2O are respectively 2.46 and 5.23. Williams quotes four analyses of quartz-porphyries from the same locality, previously analyzed by Credner, in all of which the K_2O greatly exceeds the Na_2O. In the Marquette district, in the city of Marquette, is a phase of

[1] G. H. Williams. Bull. 62, U. S. Geol. Survey, p. 121.

rhyolite, described as novaculite by Williams[1] which contains 3.65 per cent of K_2O and 0.56 per cent of Na_2O.

The red porphyritic rocks of Pigeon Point, Minn., described by Bayley[2] contain much more K_2O than Na_2O. These porphyritic rocks, however, Bayley thinks may be of metamorphic rather than of eruptive origin.

The analyses of the rhyolites of the Lake Superior region, therefore, so far as information is available, appear to differ essentially from the rhyolites of central and southern Wisconsin in the proportion of the alkalies K_2O and Na_2O. The rhyolites and quartz-porphyries farther north, and those of central Wisconsin, may have been erupted at different periods, but whatever their age relations may be, they are unlike in composition.

Chemical Character of the Diorite-Gabbro Series.

The three analyses of the diorite-gabbro series closely agree in chemical features. The rocks analyzed were selected as representative of the unweathered phases of diorite or gabbro of their respective localities.

Analyses of the Diorite-gabbro rocks of North Central Wisconsin.

	Stettin diorite.	Marathon City gabbro.	Eau Claire river gabbro.
SiO_2	48.56	47.86	46.87
Al_2O_3	18.80	21.78	17.74
Fe_2O_3	4.61	2.96	5.28
FeO	7.60	3.95	7.48
MnO	....	....	0.38
CaO	10.24	13.30	11.10
MgO	6.08	6.82	7.01
Na_2O	3.17	1.56	2.63
K_2O	0.12	0.21	0.28
H_2O	1.28	1.00	0.84
Total	100.46	99.44	99.61

[1] Op. cit. p. 152.
[2] W. S. Bayley, Bull. 109, U. S. Geol. Survey, p. 56.

Noteworthy features of the composition of these basic rocks are the marked excess of CaO over MgO, and of Na_2O over K_2O and the relatively high content of Al_2O_3. In all these features the three analyses closely agree. While the content of Na_2O usually exceeds that of K_2O in the basic rocks, the comparitively low content of K_2O in these rocks, while not unknown, is at least exceptional. The excess of CaO over MgO is characteristic of a large class of basic rocks, although as a whole the amount of MgO in the basic rocks probably exceeds that of CaO. The high Al_2O_3 usually attends the high CaO and high Na_2O in igneous rocks, and finds expression in the development of dominant lime-soda feldspar mineral.

The two analyses of the troctolite (page 169), the olivine-anorthite rocks, are not included in the above table, as these were selected to represent extreme and unusual phases of local variation of the basic magma, and they are also very much weathered rocks. The three analyses of the above table very probably represent the average composition of 95 per cent of this basic rock series.

The nearest areas of gabbro rocks to this region are those of northern Michigan and northern Minnesota. An examination of analyses of all the comparatively fresh and presumably representative rocks which have been cited by Washington[1] among his superior analyzed femic rocks reveals the fact that in the great majority of the gabbro-diorite rocks of northern Michigan, the molecular proportion of MgO greatly exceeds that of CaO. On the other hand, in the otherwise similar rocks of northern Minnesota, the molecular proportion of CaO exceeds that of MgO. Of the 10 analyzed rocks from northern Michigan, which also includes one or two along the Wisconsin boundary, 8 contained more MgO than CaO, and of 13 rocks of northern Minnesota 9 contained more CaO than MgO. Thus the basic (femic) rocks of northern Michigan are characterized by dominant magnesia and those of northern Minnesota by dominant lime.

These facts may be illustrated by citing the analyses of representative fresh rocks from the two regions. From the northern Michigan region may be selected the three analyses of gabbro

[1] H. S. Washington, Professional Paper, No. 14, U. S. Geol. Survey.

and gabbro-diorite rocks from the Menominee district described by Williams.[1]

Analyses of Gabbro-diorite of Menominee district, Michigan.

	Upper Quinnesec Falls gabbro-diorite.	Sturgeon Falls gabbro.	Lower Quinnesec gabbro-diorite.
SiO_2	48.35	51.46	47.96
Al_2O_3	15.40	14.35	16.85
Fe_2O_3	4.04	3.90	4.33
FeO	4.63	5.28	4.17
CaO	10.38	9.08	13.25
MgO	11.61	9.54	9.15
Na_2O	1.87	2.92	1.25
K_2O	.35	.24	.30
H_2O	3.60	3.30	2.89
CO_2	.08	.20	.08
Total	100.31	100.27	100.23

It will be seen on comparison that these gabbro-diorite rocks from the Menominee district essentially differ in composition from those of north-central Wisconsin. While the silica content is the same in the analyzed rocks of the two districts, the relative amount of the bases is radically different. The Menominee rocks are especially characterized by a much lower content of Al_2O_3 and a much higher content of MgO, the amount of CaO being essentially alike. With respect to the alkalies, while Na_2O greatly predominates in both districts, the Na_2O is relatively lower and the K_2O relatively higher in the Menominee rocks as compared with the central Wisconsin rocks.

While the chemical composition of the basic rocks of the two districts is unlike so far as known from available analyses, the geological evidence seems to show that the basic rocks of both districts were probably erupted during the same geological period.

From northern Minnesota may be taken analyses of the gabbro of Pigeon Point, Duluth, and Minnesota Falls.

[1] G. H. Williams, Bull. 62, U. S. Geol. Sur. p. 104.

Analyses of Gabbro of Northern Minnesota.

	I. Olivine-gabbro Pigeon Point, Minnesota.	II. Gabbro Duluth, Minn.	III. Gabro-gneiss Minnesota Falls, Minn.
SiO_2	49.88	45.65	48.29
Al_2O_3	18.55	15.20	20.87
Fe_2O_3	2.06	6.71	1.13
FeO	8.37	13.81	4.93
CaO	9.72	6.33	14.32
MgO	5.77	2.95	7.54
Na_2O	2.59	3.09	1.77
K_2O	0.68	1.05	0.38
H_2O	1.04	2.29	0.89
Other	1.46	2.62	....
Total	100.12	99.70	100.12

I. W. S. Bayley, Bull. 109, U. S. Geol. Sur., p. 37 (as cited in Bull. 228, p. 88).

II. A. N. Winchell, Am. Geol., Vol. XXVI, p. 293.

III. W. S. Bayley, Bull. 150, U. S. Geol. Sur., p. 372.

It will be seen on comparison that the chemical composition of the gabbro rocks of northern Minnesota resemble quite closely those of central Wisconsin. They are relatively high in Al_2O_3, Ca O and Na_2O, indicating a predominance of lime soda feldspar among the mineral constituents.

While the chemical character of the central Wisconsin rocks and those of northern Minnesota are essentially identical, their geological age appears to be quite unlike, for the great mass of gabbro of northern Minnesota is generally considered to be of early Keweenawan age and thus of a much later pre-Cambrian age than the chemically similar rocks of this region.

As previously stated, the analyses of gabbro here quoted from northern Michigan and northern Minnesota are presented mainly to emphasize the difference in chemical character of the basic rocks of the two regions. All the basic rocks of northern Michigan are not dominantly magnesic, nor are all those of northern Minnesota dominantly calcic. The relative abundance of the dominantly magnesic rocks in northern Michigan and the dominantly calcic rocks of northern Minnesota is indicated, in part at least, by the relative molecular proportions of magnesia and lime, as above described (page 335) from the analyses quoted by Washington.

The region of northern Minnesota, and of the Rainy Lake region farther north in Canada, contains an abundance of gabbro, diabase, and a widespread distribution of the anorthosite gabbro, the plagioclase composition and abundant occurrence of which strongly emphasizes the high lime, alumina and soda of the prevailing basic magma of that region. The anorthosite gabbro essentially a nearly pure anorthite-bytownite feldspar rock, is known to occur in various localities farther east in Canada and in the Adirondacks of New York. Their greatest abundance, however, appears to be in a region centering about the western end of Lake Superior.

In chemical features, therefore, the gabbro-diorites of north-central Wisconsin, with relatively high lime, alumina and soda, bear a close resemblance chemically but not in age to the predominating gabbroitic rocks of the west coast of Lake Superior. The central Wisconsin calcic gabbro-diorites may be considered as the complementary facies, apparently, of the dominantly magnesic rocks of northern Michigan since they appear to be of the same geological age.

Chemical Features of the Granite-Syenite Rocks.

Eight analyses of the granite-syenite have been made, the rock material of each being selected to represent an average rock of the locality and of the phase. The relative number of analyses of the various phases of the syenites and of the granites, however, do not represent the relative abundance of these rocks, but rather the opposite.

Unlike the other series of rocks analyzed, these have a wide range in content of silica and in the basic constituents, the range in silica being from 47.16 to 76.54 per cent. As the chemical composition of these rocks, therefore, are viewed as a whole, a considerable range in all the chemical constitunts is to be noted. In the following table are gathered all the analyses of the granite-syenite rocks:

Analysis of rocks of the granite-syenite series.

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.
	Granite Heights granite.	Amphibole granite.	Quartz syenite.	Syenite.	Nepheline syenite.	Nepheline syenite.	Nepheline syenite pegmatitic) phase).	Mica syenite.
SiO_2	76.54	67.99	61.18	57.48	54.79	54.76	57.82	47.16
Al_2O_3	13.82	15.85	19.72	20.04	22.87	24.72	24.23	12.56
Fe_2O_3 .. } FeO .... }	1.62	5.36	3.71	5.64	1.74	2.73	1.56	11.01
			1.32	3.76	3.24	2.35	1.03	13.30
CaO	0.85	1.78	2.64	1.7,	1.92	1.67	1.04	8.63
MgO	0.01	0.41	trace	0.40	trace	0.10	0.28	0.53
Na_2O	4.32	3.21	5.28	7.25	10.75	10.38	9.20	4.24
K_2O.......	2.31	4.81	5.66	3.65	4.06	2.37	3.03	2.78
H_2O	0.20	0.30	0.32	0.25	....	0.55	0.73	0.12
TiO_2	....	....	....	....	0·31	....	0.30	trace
MnO	.00	....	....	....	trace	......	trace	trace
ZrO_2......	....	....	....	....	0.07	....	0.28	....
F.........	....	....	....	....	0.14	....	none	....
Cl........	....	....	....	....	0.70	....	0.15	....
Total..	99.67	99.71	99.83	100.17	100.59	99.63	99.65	100.33
Less O=F+Cl	....	....	....	....	0.22	....	.03+	....
					100.37		99.62	

It will be observed on examination of the analyses that certain chemical features characterize the entire series. As the content of SiO_2 decreases from the granite to the nepheline-syenite, the Al_2O_3 and also the Na_2O show a steady and marked increase, the Ca O is variable and shows a comparatively small increase, while the content of Fe_2O_3 and FeO and MgO and K_2O though variable remains comparatively stationary. The dominant features in the composition of this rock series, therefore, is the relatively high content of alumina and the alkalies, especially soda, which finds expression, of course, in the development of the nepheline-syenite and associated rocks, relatively high in nepheline and sodalite, and free from leucite. The content of total iron, lime and magnesia remains essentially stationary throughout the series, thus quite unlike that which would accompany the decrease in silica in a granite-diorite-gabbro series. One of the most remarkable features of this rock series is the very low content of MgO throughout, a feature more fully discussed in comparing the nepheline and associated syenites of central Wisconsin with those of other regions.

Nepheline-syenite and the associated syenites are comparatively rare rocks, and hence similar rocks do not occur in the immediately surrounding region. Granites, however, are common in the surrounding region and a few chemical analyses are available sufficient for comparison.

Comparison of the Granite with that of the surrounding Region.

In the immediately adjacent region to the south, among the isolated pre-Cambrian outliers of the Fox River valley of Wisconsin, are a number of occurrences of granite of which two representative analyses have been made, namely, of the Waushara granite and of the Montello granite.

In the following table, the composition of the two granites of this region may be compared with two from the Fox river valley:

Analyses of Granite from Central and Southern Wisconsin.

	Granite Heights Granite.	Amphibole Granite, Eau Claire River.	Montello Granite.	Waushara County Granite.
SiO_2	76.54	67.99	73.78	74.62
Al_2O_3	13.82	15.85 }	}	10.01
Fe_2O_3	} 1.62	} 5.36	17.18	3.85
Fe_2O_3	}	}		
CaO	0.85	1.78	.85	2.43
MgO	0.01	0.41	....	0.33
Na_2O	4.32	3.21	2.82	3.33
K_2O	2.31	4.81	4.48	3.38
H_2O	0.20	0.30	0.12	0.24
Total	99.67	99.71	100.87	99.91

A characteristic feature of all of these analyses is the relatively high Na_2O as compared with K_2O, the molecular proportions of the Na_2O being equal to, or greatly exceeding, the K_2O in all the analyses.

Another characteristic feature of all these Wisconsin granites analyzed is the very low content of Mg O as compared with the Ca O.

All the available analyses of granites from northern Michigan and northern Minnesota are shown in the following table:

Analyses of Granites from Northern Michigan and Northern Minnesota.

	I. Felch Mountain, Mich.	II. Felch Mountain, Mich.	III. Felch Mountain, Mich.	IV. Pigeon Point, Minn.	V. Pigeon Point, Minn.
SiO_2....	76.10	72.17	69.69	72.42	68.36
Al_2O_3...	12.95	14.49	15.64	13.04	13.76
Fe_2O_3...	0 65	1.02	0.90	0.68	2.65
FeO	0.09	0.99	1.62	2.49	2.75
CaO.....	0.12	0.69	1.22	0.66	0.70
MgO.....	0.14	0.70	0.66	0.58	0.68
Na_2O....	2.36	3.65	3.34	3.44	3.56
K_2O.....	6.50	4.84	5.30	4.97	4.48
H_2O.....	0.65	not det.	not det.	1.21	0.98
Other....	0.09	0.27	0.29	.84	12.90
Total..	99.65	98.77	98.66	100.37	100.48

I. H. L. Smyth, Mon. 36, U. S. Geol. Sur., p. 389.
II. H. L. Smyth, Mon. 36, U. S. Geol. Sur., p. 389.
III. H. L. Smyth, Mon. 36, U. S. Geol. Sur., p. 389.
IV. W. S. Bayley, Bull. 109, U. S, Goel. Sur., p. 59.
V. W. S. Bayley, Bull. 109, U. S. Geol. Sur., p. 901

These analyses of granites from Felch Mountain, Mich., and Pigeon Point, Minn., are quite similar to one another. They are in general higher in K_2O and MgO than the Wisconsin granites and correspondingly lower in Na_2O and Ca O. So far as known, the above are the only representative granites analyzed available for comparison with the Wisconsin granites.

Comparison of Quartz-syenite and Nepheline-syenite of Central Wisconsin with similar rocks of other regions.

In comparing the relatively unusual nepheline-bearing and closely associated rocks of this district with other similar rocks, it is necessary to go outside the immediately surrounding region of Wisconsin, Michigan and Minnesota.

Probably the nearest known large area of nepheline-syenite is that occurring in Hastings county and vicinity in eastern Ontario, Canada, described by Adams[1] and others. In this region, nepheline-syenite and closely related rocks appear to be in comparatively great abundance, locally scattered over a large area, very coarse nepheline-pegmatite being especially prominent in many places. A detailed account of the various phases of nepheline-syenite and related rocks, with chemical analyses, has not yet been published, and hence a close comparison cannot be made of the chemical character of the nepheline rocks of Ontario with those of Wisconsin.

On the whole, however, there appears to be a close resemblence in the chemical composition of the nepheline-syenites of these two regions. From petrographic description, as indicated by the abundance of sodalite, corundum and cancrinite, the Ontario rocks appear to be relatively high in alumina and soda, and the character of the dark-colored minerals seem to indicate minerals low in magnesia. The Ontario rocks, however, while relatively high in CaO, do not appear to be so low in magnseia as the Wisconsin rocks.

The geological age of the Ontario nepheline rocks is pre-Cambrian and may or may not be contemporaneous with those of Wisconsin.

In other parts of western Ontario, for instance at Heron Bay on the northern shore of Lake Superior, analcite-bearing rocks are known to occur which are relatively high in soda and alumina.

The nepheline[2] rocks of Ice River, British Columbia, presumably of post-Cambrian age, present a fairly complete rock

[1] Am. J. Sci. Vol. XVII, p. 269–276 (1904).

[2] A. E. Barlow; Ottawa Naturalist, Vol. XVI, pp. 70–76 (1902).

series, and, while relatively high in Na_2O and Al_2O_3, contain more magnesia than the nepheline rocks of Wisconsin and eastern Ontario.

The nepheline-syenites and associated rocks of southwestern Arkansas described by Williams[1] and Washington[2] are relatively higher in CaO, Mgo, and K_2O, and lower in Al_2O_3 and Na_2O than the Wisconsin rocks. The higher content of MgO is indicated not only by the chemical analyses, but also by the presence of aegerite-augite[3] and diopside as a common mineral constituent although the MgO is not high enough to produce olivine except in some of the dike rocks. The high K_2O content is expressed in the abundant occurrence of orthoclase in the Arkansas rocks.

In Essex County,[4] eastern Massachusetts, occur nepheline-syenites and related quartz-syenite and granites, which, on the whole, appear to stand very close to these Wisconsin rocks. The diorite-gabbro rocks represented by Analyses XX to XXIV,[5] as given by Washington, are also very similar to the gabbro-diorite rocks of Wisconsin. The quartz-syenites and nepheline-syenites of Essex County are probably very slightly lower than the Wisconsin rocks in Al_2O_3 and CaO and Na_2O, and apparently very slightly higher in K_2O and MgO. The chemical analyses, however, of the granite-syenite rocks from these regions are remarkably close in agreement. Mineralogically also they are alike in certain phases containing fayalite. and the blue soda amphiboles.

In the Highwood Mountains of Montana, described by Pirrson[7] and others, occur nepheline-bearing rocks as subordinate phases of a rock magma which is relatively high in K_2O, CaO and MgO. In central Montana, as Pirrson[8] has pointed out is a large petrographic province of genetically related rocks relative-

[1] J. F. Williams, Ark. Geol. Sur., Vol. II.

[2] H. S. Washington, Geol. Soc. Am., Vol. XI, p. 389–416.

[3] H. S. Washington, op. cit., p. 401.

[4] H. S. Washington, Petrographical Province of Essex County, Mass., Jour. of Geol. in Vols. VI and VII.

[5] Opus cited, Vol. VII, p. 481.

[6] Penfield & Forbes: Am. Jour. Sci., Vol. I, p. 129, 1896.

[7] L. V. Pirrson; Igneous Rocks of Highwood Mountains, Bull. U. S. Geol. Sur., No. 237.

[8] Am. J. Sci., Vol. 170, p. 35 (1905).

ly high in the alkalies, the magma having a composition intermediate between nepheline-syenite and gabbro-diorite. In the syenitic rocks of central Montana, K_2O appears to be a more important constituent than Na_2O, and leucite is a more common mineral constituent than nepheline or sodalite.

The nepheline-syenite of the well known region of southern Norway, described by Brögger,[1] which, on the whole, is very similar to the Wisconsin nepheline and associated rock is relatively higher in MgO and K_2O, and lower in Al_2O_3, CaO and Na_2O than the latter. An important difference in the composition appears to be the especially lower content of Al_2O_3 in the Norwegian syenite.

In comparing the quartz and nepheline-syenite and associated rocks of central Wisconsin with similar rocks of other regions, it is readily seen that while the main chemical features of the nepheline-syenites are usually alike, there are minor differences in the composition of these rocks which appear to be characteristic of each region. These minor differences in the chemical composition of the syenites of the various regions become marked features of distinction and are very important in studying and understanding the petrology of each.

Without calling further attention to the varying differences in the various nepheline and associated rocks above referred to, it may, however, be well to emphasize those features of chemical and mineralogical composition, which, so far as known, appear to distinguish these Wisconsin alkalic rocks from all others.

The granite-syenite rocks of this series, on the whole, are comparatively high in Al_2O_3, Na_2O and CaO, and relatively low in K_2O and MgO. While K_2O is abundant and may even predominate in certain coarse microperthite pegmatites, it is clearly of much less importance than Na_2O in the series as a whole. On the other hand, the low content of MgO is a very remarkable feature of this rock series. The MgO may well be classed as an unimportant constituent in these rocks, a fact not only shown by analyses, but also by the mineral composition of all the rock phase studied under the microscope. The conspicuous unimportance of MgO finds expression in the widespread occurrence

[1] W. C. Brögger, Zeit für Kryst; B. 16, p. 81. Die Gesteine der Grorudite Tingiait Serie Dar Ganggefolge des Laurdalits.

CHEMICAL ANALYSES OF IGNEOUS ROCKS OF NORTH CENTRAL WISCONSIN.

	Name.	Locality.	Chemical Constituents.											Analyst.	Position in Quantitative Chemical System.				
			SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	H_2O	Other.	Sum		Norm.	Class.	Order.	Rang.	Sub-rang.
Rhyolite.	Rhyolite.	Dells of the Pine River.	74.60 *1.243	13.04 .128	0.76 .005	3.34 .046	0.61 .015	....	5.40 .087	0.82 .009	1.06	....	99.63	W. W. Daniells.	Q. 37.7 hy. 6.9 orth. 5.0 mt. 1.2 alb. 45.6 C. 3.3	I Persalane	3 Columbare.	1 Alaskase	5 Westphalose.
	Rhyolite.	Wausau: Near High School.	72.68 1.211	16.40 .161	0 99 .006	1.53 .021	0.48 .012	1.56 .028	3.85 .062	2.10 .022	0.37	....	99.96	W. W. Daniells.	Q. 37.4 hy. 2.7 orth. 12.2 mt. 1.4 alb. 32.5 an. 7.8 C. 5.0	I. Persalane	3 Columbare.	2 Alsbachase..	4 Alsbachose.
Gabbro-diorite.	Diorite.	Stettin: S. W. Corner of Sec. 25, T. 29, R. 6.	48.56 809	18 80 .184	4.61 .028	7 60 .105	6.08 .152	10.74 .192	3.17 .051	0.12 .001	1.28	....	100.46	W. W. Daniells.	orth. 0.6 di. 13.6 alb. 26.7 hy. 6.4 an. 36.7 ol. 9.1 mt. 6.5	III. Salfemane	5 Gallare	4 Auvergnase..	3 Auvergnose.
	Gabbro.	Marathon City: Rib River Bridge.	47.86 .797	21.78 .213	2.96 .018	3.95 .054	6 82 .170	13.30 .237	1.56 .025	0.21 .0022	1.00	....	99.44	W. W. Daniells	Q. .36 di. 11.3 orth. 1.1 hy. 16.4 alb. 13 1 mt. 4.2 an. 51.7	III. Salfemane	5 Gallare	5 Kedabekase..	
	Gabbro.	Eau Claire River: S. W. Cor of Sec. 12, T. 28, R. 8.	46.87 .781	17.74 .174	5.28 .033	7.48 .104	7.01 .175	11.10 .198	2.63 .042	0.28 .003	0.84	MnO 0.38 .005	99.61	W. W. Daniells.	orth. 1.7 di. 15.6 alb. 22.0 hy 5.3 an. 35.9 mt. 7.7	III. Salfemane	5 Gallare	4 Auvergnase..	3 Auvergnose.
Granite Syenite Series.	Granite Heights Granite.	Granite Heights: Cohn's Granite Quarry	76.54 1.277	13.82 .135	†1.62 1.12 .007	.50 .007	0.01 .00	0.85 .015	4 32 .070	2.31 .025	0.20	....	99.67	W. W. Daniells.	Q. 40.6 mt. 1.62 orth. 13.9 alb. 36.7 an. 2.6	I. Persalane	3 Columbare.	2 Alsbachase..	4 Alsbachose.
	Amphibole Granite.	Three Roll Falls: Eau Claire River.	67.99 1.133	15.85 .155	†5.36 3.70 0.23	1.66 .023	0.41 .010	1.78 .032	3.21 .052	4.81 .051	0.30	....	99.71	W. W. Daniells.	Q. 26.5 hy. 1.0 orth. 28.4 mt. 5.4 alb. 27.2 an. 8.89 C. 2 04	I. Persalane	4 Britannare.	2 Toscanase...	2 Dellenose.
	Quartz Syenite.	Wausau: Rapids of Wisconsin River.	61.18 1 019	19.72 0.193	3.71 0.023	1.32 .018	None	2.64 .047	5.28 .085	5.66 .060	0.32	....	99 83	W. W. Daniells.	Q. 3.9 ac. 2 3 orth. 33.4 mt. 4.2 alb. 41 9 an. 13.1 C. .61	I. Persalane	5 Canadare..	2 Pulaskase...	3 Pulaskose.
	Nepheline Syenite.	N. E. part of Sec. 29, T. 29, R. 7.	57.48 .958	20.04 .196	5.64 .035	3.76 .052	0.40 .010	1.70 .030	7.25 .117	3.65 .039	0.25	....	100.17	W. W. Daniells.	orth. 21.7 ol. 2.4 alb. 54.5 mt. 8.2 an. 8.3 ne 3.7 C. 1.1	I. Persalane	5 Canadare..	2 Pulaskase...	4 Laurirkose.
	Nepheline Syenite.	N. W. ¼ of Sec. 15, T. 29, R. 6.	54.79 .913	22.87 .224	1.74 .010	3.24 .046	Trace	1.92 .034	10.75 .173	4.06 .043	....	TiO_2 0.31 .009 ZrO_2 0.07 F. 0.14 .007 Cl. 0.70 .020	100.59 O=F+Cl .22	W. W. Daniells.	orth. 23 9 hy. 2.9 alb. 34.1 fa. 1 9 an. 4.9 mt. 2.3 ne. 19.3 fl. 0.3 so. 9.7 il. 0 5	I. Persalane	6 Russare ...	2 Viezzenase ..	4 Viezzenose.
	Nepheline Syenite.	S. E. ¼ of Sec. 2, T. 29, R. 6.	54.76 .913	24.72 .242	2.73 .017	2.35 .032	0.10 0.02	1.67 .030	10.38 0.167	2.37 0.025	0.55	....	99.63	W. W. Daniells.	orth. 13.9 fa. 1.7 alb. 47.2 mt. 3.9 an. 8.3 ne. 21.9 C. 2.0	I. Persalane	6 Russare ...	2 Viezzenase ..	4 Viezzenose.
	Nepheline Syenite Pegmatite Phase.	N. E. ¼ of Sec. 27, T. 29, R. 6.	57.82 .964	24.23 .237	1.56 .010	1.03 .014	0.28 007	1.04 .019	9.20 .148	3.03 .032	0.63	TiO_2 0.30 .004 ZrO_2 0.28 .002 Cl. 0.16 .004	99.65 O=Cl .03	V. Lenher.....	orth. 17.8 ol. .49 alb. 57.1 mt. 2 3 an. 5.3 il. .61 ne. 8 8 so. 1 9 zn. .37 C. 4.1	I. Persalane	5 Canadare..	1 Nordmarkase	4 Nordmarkos
	Mica Syenite.	N. W. ¼-S. E. ¼ of Sec. 11, T. 29, R. 6 E.	47.16 .786	12.56 .123	11.01 .69	13.30 .185	0.53 .13	8.63 .154	4.24 .70	2.78 .30	0.12	Trace	100.33	V. Lenher.....	Q. .60 mag. 16.00 orth. 16 68 hed. 33.52 alb. 36.68 an. 6 39	III. Salfemane	5 Gallare ...	3 Camptonase.	4 Camptonose.

* Figures in small type indicate molecular ratios.

† Equal molecular proportion of Fe_2O_3 and FeO assumed to be present.

of the magnesia-free olivine, fayalite, as well as in the presence of the pyroxenes, amphiboles and micas, in which MgO enters in only very subordinate amount. It seems probable also that the content of Fe_2O_3 and FeO is relatively high in these granite-syenite rocks. While not unusual, the content of iron may be somewhat above the average for similar rocks elsewhere.

With respect to the minor chemical constitutents, ZrO_2, TiO_2 and F, these are relatively abundant. Indeed ZrO_2 and TiO_2 very probably are both more important constituents of this rock series than MgO, for in the several analyses in which ZrO_2 and TiO_2 were searched for, they were found, and in each case the quantity of each was greater than that of the MgO present. MnO appears to be an unimportant constituent. Fluorine is a persistent constituent, as indicated by the presence of the mineral fluorite as a persistent though a minor mineral constituent. Lithium is present in the lithia-mica, and such very rare elements as tantalum, columbium, cerium, yttrium, etc., are known to be present in the pegmatite. These rare elements are especially apt to occur in rocks high in soda and alumina and hence the rare elements may very well be relatively abundant in these rocks.

The General Chemical Character of the Igneous Rocks.

In the accompanying table, Pl. XXXIX all of the representative analyses of the intrusive rocks of the district are given, with the molecular proportions of the chemical constitutents. The position of the various rocks analyzed in the recently devised quantitative chemical system is also indicated.

An examination of the table reveals the fact that in all the analyses the moleular porportion of Na_2O exceeds that of K_2O, and in only two is the percentage weight of Na_2O less than that of

K_2O. The proportion of CaO also exceeds that of MgO in all the rocks except one. These characteristic chemical features are especially emphasized when the means of the several analyses of each group or rock series are compared with one another, as in the following table:

Mean of Analyses of the Several Rock Magmas and of the Combined Magmas.

	I.	II.	III.	IV.
SiO_2	73.64	47.76	59.71	59.03
Al_2O_3	14.72	19.44	19.47	18.59
Fe_2O_3	0.87	4.28	3.91	3.52
FeO	2.43	6.34	3.40	3.93
MgO	0.54	6.64	.22	1.76
CaO	0.78	11.71	2.53	4.34
Na_2O	4.63	2.45	6.83	5.48
K_2O	1.46	0.20	3.58	2.49
H_2O	0.72	1.04	.39	.60
Total	99.80	99.66	100.04	99.74

I. Mean of 2 analyses of rhyolite.
II. Mean of 3 analyses of gabbro-diorite.
III. Mean of 8 analyses of granite-syenite.
IV. Mean of the above 13 analyses of rhyolite, gabbro-diorite, and granite-syenite.

When the means of the several analyses of each rock group or magma are compared with one another, it is seen that each and all of them are characterized by the same chemical features. Each of the three rock groups or magmas are characterized by relatively high Al_2O_3, Na_2O and CaO, and relatively low K_2O and MgO. The total iron, as well as the proportions of Fe_2O_3 to FeO are not unusual when considered alone, but when compared with the low MgO, the FeO is probably unusually high.

It is of special interest and importance, therefore, to note that certain dominant chemical features of the rhyolite, the earliest of the intrusives to be erupted in the lower sedimentaries, also characterize the later eruption of gabbro-diorite magma, and also the still later eruption of the great mass of granite-syenite.

The characteristic chemical features of the intrusive magmas are emphasized in the mean of all the analyses which may be taken to represent an approximation of the average composition of the several intrusive magmas as a whole. The chemical features of the intrusive rocks of central Wisconsin reveal their dominant characteristics, when compared with the average composition of igneous rocks the world over, as calculated by Clarke, Harker, and Washington.

In the following table the mean of the several analyses of central Wisconsin igneous rocks is compared with the average composition of igneous rocks in general.

Comparison of composition of Central Wisconsin Igneous rocks with that of Igneous rocks in general.

	I.	II.	III.	IV.
SiO_2	59.03	59.71	58.75	58.239
Al_2O_3	18.59	15.38	15.64	15.796
Fe_2O_3	3.52	2.63	5.34	3.334
FeO	3.93	3.52	2.40	3.374
MgO	1.76	4.36	4.09	3.843
CaO	4.34	4.90	4.98	5.221
Na_2O	5.48	3.55	3.25	3.912
K_2O	2.49	2.80	2.74	3.161
H_2O at 100°	.60		2.23	.363
H_2O ab. 100°		1.52		1.428
TiO_2	....	.60	.12	1.039
P_2O_5	....	.22	.02	.373
Total	99.74	99.22	99.56	100.583

I. Mean of 13 anaylses of igneous rocks of Central Wisconsin.
II. Mean of 830 analyses of American igneous rocks. (F. W. Clarke; Bull. U. S. Geol. Sur., No. 168, p. 14).
III. Mean of 397 analyses of British igneous rocks. (A. Harker: Geol. Mag., Decade IV., Vol. IV., p. 220.
IV. Mean of 1,811 analyses of igneous rocks in general. (H. S. Washington; U. S. Geol. Sur., PP. No. 14, p. 106).

The method of calculating the mean of the analyses by the several authors quoted varied somewhat, but for the present purpose need not be discussed. The main object of the comparison is to show wherein the composition of the igneous rocks of this region differs from that of igneous rocks over much wider areas or of the world. It would not be expected, of course, that the composition of the several rock magmas of a limited area should closely approximate that of igneous rocks in general. Such a view would not, at least, be held at the present time, although it might have been held up to within the last decade or two.

The table of mean analyses serves to emphasize the dominating chemical features of the Wisconsin rocks. While the number of analyses of the rocks of this particular area is small as compared with the much larger numbers represented in the other calculated means, the analyses are believed to be at least as representative of the rocks they profess to illustrate, as the larger number of analyses are representative of the igneous rocks of the much larger areas.

When the proportions of the several families or classes of rocks represented in the mean analyses of rocks of central Wisconsin are compared with those in the much larger number represented in the calculation by Washington, they are found to agree fairly well, as may be noted on comparison of the table (Pl. XXXIX) with the table cited by Washington.[1]

While details are hardly warranted in a discussion of the comparison of the several means of igneous rock analyses above referred to, it may be emphasized that on the whole the mean of the Wisconsin rocks very probably represents a fair approximation of the average composition of the igneous rocks of the region.

It will be observed that the content of SiO_2 of the several mean analyses is essentially alike, leaving the same remainder to be distributed among the several basic constituents.

It will be seen in comparing the basic constituents of the Wisconsin rocks with the basic constituents in igneous rocks in general that the most prominent feature of these Wisconsin rocks is the high Al_2O_3 and Na_2O, the Al_2O_3 being about 3 per cent and the Na_2O about 2 per cent higher than the Al_2O_3 and Na_2O in the average igneous rocks. The Fe_2O_3 and FeO are about the same in all the mean analyses. The remaining constituents, MgO, CaO, and K_2O, because of the high Al_2O_3 and Na_2O, are lower than these constituents in the other mean analyses, II, III, and IV. In comparison, the K_2O is about .5 per cent lower; the CaO is notably lower, about 1 per cent; while the MgO is very much lower, being as much as 2 to 2.5 per cent lower than the MgO in the mean analyses of igneous rocks in general.

As compared with igneous rocks in general, therefore, these

[1] Op. cit., table VIII, p. 110.

Wisconsin rocks are relatively high in Al_2O_3 and Na_2O, and relatively low in K_2O, CaO and MgO, especially in the latter. As previously pointed out, these chemical features, which distinctively characterize the Wisconsin rocks are not only true of the average composition of all the rocks, but also of each distinct rock group or magma.

The most distinctive features of the several rock magmas represented, as abundantly emphasized in the comparison with igneous rocks in general, are the high Al_2O_3 and Na_2O, and the low MgO, and these dominant features find their fullest and completest expression in the development of the rock phases of the nepheline-syenites of the granite-syenite magma. And further, the dominant chemical features of the rock magmas, such as the high Al_2O_3 and Na_2O, find an even more emphatic expression, a culminating expresison as it were, not only in the widespread development of such minerals as nepheline and sodalite, but also in the occurrence in certain rock phases of such high soda-alumina minerals as the soda-alumina pyroxene, percivalite; while the very low content, or essential absence of MgO, finds its absence emphasized by the occurrence of pyroxenes, amphiboles, and micas low in MgO, and especially in the widespread occurrence of the magnesia-free olivine, fayalite, in many of the quartz and nepheline-syenites of the district.

THE RELATIONSHIP OF THE INTRUSIVE IGNEOUS ROCKS.

It has been pointed out in the foregoing account of the igneous rocks of the district that the rocks of each of the several groups or series closely resemble one another in chemical composition, mineral composition, and rock texture. All the rhyolites of the region not only resemble one another very closely, but are also like the rhyolites of the adjoining region in southern Wisconsin. All the rhyolites of the region also, so far as can be observed, were erupted in the same period of igneous activity, for all bear the same relation to the older and younger rocks of the region.

The rocks of the gabbro-diorite series are also essentially identical in chemical and mineral composition and textural features, and were obviously erupted in the same period, as shown by their geological relations. The essential identity of the various phases of the granite-syenite rocks have also been shown to exist, by the marked similarity in chemical and mineral composition, and their identical geological relations to other rocks of the region.

The similarity in character of the various rocks of each group indicates a close relationship in origin of the members of that group or series, a relationship to which the term "consanguinity" has been applied. The formulation of the principle that certain rocks of a given region may be genetically related was made by Judd,[1] who described such areas of genetically related rocks as petrographic provinces. Later the same idea of the relationship in origin of certain rocks was elaborated by Iddings[2] under the term "consanguinity of igneous rocks."

At the present time a number of petrographic provinces of igneous rocks in various parts of the world have been studied and described, among which may be mentioned that of Central Montana, described by Pirsson;[3] of Essex County, Massachusetts, described by Sears and Washington;[4] and that of southern Norway, described by Brögger.[5]

It is obvious, on a perusal of the literature of igneous rocks with reference to the subjects of petrographic provinces and consanguinity of igneous rocks, that various writers have not applied the same meanings to these terms. The term "magma" also appears to be indefinite in its application. The general usage of these terms need not be discussed in this place, and attention is merely called to the fact that in the present discussion of the relationship of the igneous rocks of this district the

[1] J. W. Judd; Quart. Jour. Geol. Soc. London; Vol. 42, p. 44, 1886.

[2] J. P. Iddings; Bull. Phil. Soc. Washington; Vol. XII, p. 128, 1892.

[3] L. V. Pirsson; Am. Jour. Sci., Vol. 170, p. 35, 1905.

[4] H. S. Washington; Jour. of Geol., Vols. VI and VII.

[5] W. C. Brögger; Zeit. für Kryst; B. 16.

writer may not use these terms in the same sense that others have used them.

The rhyolite rocks, with their andesitic phases, are similar to one another in porphyritic texture, general mineral composition, and chemical composition, and were erupted in the same period of igneous activity. The eruption of the rhyolite was either in the form of surface flows or sills or both, with a variable amount of volcanic breccia about the volcanic centers. The eruption was obviously not a simple one, but complicated and complex, and extended over a considerable period of time. The rhyolite rocks are associated with proportions of andesite, indicating that the variation in composition was towards a relative increase of CaO and MgO over the alkalies as the SiO_2 decreased. This fact is indicated by the occurrence of the common green amphibole and the lime feldspars in the andesitic phases. The rhyolite rocks, with their more basic andesitic phases, are believed to have been derived from a common magma.

The gabbro-diorite rocks of the district are similar to one another in granular texture and chemical and mineral composition, and were erupted in the same period, as indicated by their geological relations. The eruption of the gabbro-diorite rocks was complex, as illustrated at Mosinee, where several distinct eruptions of the high lime and magnesic rocks are to be noted. The variation in the rocks indicates that as the silica decreased, the content of lime and magnesia increased, as in the rhyolite series. These rocks are believed to have been derived from a common magma whose eruption clearly followed that of the rhyolite magma.

The granite-syenite rocks are similar to one another in granitic texture, chemical and mineral composition, and the various phases bear similar relations to the associated rocks. The variation in the granite-syenite rocks was along an entirely different line from that exhibited in the earlier intrusive rocks. As the silica decreased, the content of alkalies, especially the soda, increased. The eruption of the granite-syenite rocks was a very complicated one and a variety of rocks were developed, intrusive in one another. All the rocks of the granite-syenite series are believed to be closely related in origin and to have been derived from a common magma.

It is the view of the writer, therefore, that the rocks of the rhyolite group, gabbro-diorite group, and granite-syenite group, each represent a distinct magma, and that the various phases within each group represent rocks of consanguineous origin or a petrographic province.

When the chemical features of these separate and distinct rock groups or series are compared with one another, it is obvious that all of them reveal similar chemical features, as already emphasized, of high Al_2O_3 and excess of Na_2O over K_2O, and CaO over MgO. It seems obvious, therefore, that in the association of these broader, chemically similar groups there is indicated a still higher order of relationship or the existence of a more remote common origin. It is this more remote relationship existing between the separate rock groups which the writer wishes to keep distinct from that exhibited by the members within each group. These relationships are of different orders and indicate different degrees of consanguinity, in the broad sense, although, as above stated, the term "consanguinity", it is believed, should be applied only to the closer relationship exhibited by the various rock phases derived from the same magma, the members of which exhibit the same textural and mineralogical characteristics, and, as proven by their geological relations, were erupted during the same period of igneous activity.

The close relationship of the various rock phases within each group is not only exhibited by a close correspondence in chemical character, but also by essential identity in mineral character, textural features, the development of local gradational phases, and the close association and intrusion of rocks of almost identical character. In fact, the various kinds of evidence cited by Iddings, mineralogical, chemical, and geological, as proof of consanguinity and derivation from a common magma, is illustrated by the various rock phases of each group. This close relationship is best shown in the granite-syenite series, especially by the quartz-syenite and nepheline-senites, but the opinion is justified from the microscopic study of the other groups that if the latter were as abundant and as closely studied, the same close relationship would be found to exist, although very presumably not to the same degree of detail as exhibited in the highly differentiated nepheline-syenite and closely associated rocks.

The more remote relationship existing between the three rock groups, or series, erupted into the lower sedimentary formations and older igneous rocks of the district is *mainly expressed by their close correspondence in dominant chemical features.* These dominant chemical features, as previously emphasized, are the relatively high alumina, excess of CaO over MgO and of Na_2O over K_2O repeated in each group. This close correspondence in the pronounced chemical features of the three magmas is not believed to be accidental or by chance, but asignable to definite causes, although the causes may not be understood. As additional evidence of relationship in origin may be cited the fact of associated occurrence and eruption in the same geological age. In the character of the rocks themselves, however, the more remote relationship between the rock groups or magmas is mainly, if not entirely, chemical, for mineralogically, texturally, and in mode of eruption or character of consolidation, they vary widely.

If a comparison of the three groups or magmas of igneous rocks intrusive in the lower sedimentary rocks be made with the older igneous rocks in the district and with younger igneous rocks of widespread occurrence in the surrounding region of northern Minnesota, since younger igneous rocks are absent or of very slight importance in this district, a still more remote relationship will probably be found to exist between the igneous rocks over a very wide region, as illustrated and indicated in the broadly similar chemical features repeated in each and all of them.

Chemical analyses are not available at present showing the composition of the abundant granitic rocks of the basal group whose extensive metamorphism and geological relations indicate their probable eruption in the period preceding the deposition of the lower sedimentary formations, and long antedating the abundant intrusive rocks of the district. These older schistose and gneissoid phases of granite, however, are predominantly characterized by the soda-feldspar, albite, rather than the potash feldspar, orthoclase, and hence indicate a chemical similarity in composition of excess of soda over potash.

A much more pronounced similarity is to be noted in the gabbro-diorite magma of this district when compared with the extensive gabbros, diorites and diabases surrounding the west coast of Lake Superior erupted in the Keweenawan period and much later in age than the gabbro of this district. Some of the representative analyses of these Keweenawan gabbros have already been referred to (page 337) and the marked similarity to the Wisconsin gabbros in chemical features pointed out.

The facts here referred to briefly comparing the intrusive rocks of this district with much older rocks, and also with much younger ones seems to indicate a still more remote relationship between the igneous rocks over wide regions and of quite different geological ages. This more remote relationship has often been pointed out and the suggestion has been made that broad areas or zones within the continents may be shown to possess igneous rocks of similar chemical features showing intermediate characteristics from one region to another.

The igneous rocks of any given region may therefore closely approximate one another in character, although erupted at entirely different periods. For this reason, therefore, it is imperative that the consanguinity of the rocks derived from a common magma should be proven by their geological relations as well as by chemical and mineralogical and textural similarities.

THEORY OF ROCK DIFFERENTIATION.

The preceding account of the very intimate relationship of the variuos rock phases of the same group or series of the district, and of the more remote relationship of the several groups, as well as of the still more remote relationship exhibited by all the igneous rocks of the district and of the outlying region, logically leads to a discussion of the origin of the various igneous rocks, a problem largely hypothetical, and, in our present state of knowledge of this subject, generally admitted to be fraught with many difficulties.

The variation in igneous rocks is generally assumed by students of petrology to have been formed through processes of differentiation, although the manner and causes of the process or processes of differentiation are not fully understood. Various theories of differentiation have been proposed, among which may be mentioned those depending upon or determining the act of crystalization and those depending upon some form of differentiation antedating crystallization.

The character of the variation of the rocks of the granite-syenite magma, especially of the highly differentiated phases of nepheline-syenite and quartz-syenites with their pegmatitic phases appear to strongly suggest the probability that the process of crystallization was instrumental in causing a part of the differentiation. The phenomena appealed to as evidence favoring this view is the mineralogical character and distribution of the nepheline-syenite and corresponding pegmatitic facies, and of the quartz-syenite and corresponding pegmatitic facies already described (pages 321–8). In the description of the pegmatites and related syenites, it has been shown that the phase of the nepheline-syenites forming the main body of the nepheline rock is more basic than the pegmatitic phases, the latter appearing about the border or partly surrounding the former on three sides at least. The main body of the nepheline-syenite, the Marathon type, is characterized by the abundant presence of fayalite, hedenbergite and barkevikite, silicates high in ferrous oxide or ferrous oxide and lime, while the pegmatitic phases are characterized by the silicates high in soda and ferric oxide, such as aegerite and arfvedsonite and riebeckite. The mineral and chemical composition, as well as the relative distribution of the phases of nepheline-syenite with the more basic and uniform grained rock in the centre and the more acidic pegmatite and related trachytoid phases about the border seems to indicate a variation due to progressive crystallization, the dominating basic type first crystallizing in the interior and the more acidic phases having higher alumina and soda with accompanying rare elements being consolidated later along the border. (Compare with order of differentiates at Magnet Cove,[1] Ark.)

[1] Washington: Bull. Geol. Soc. Am., Vol. II, p. 389–416.

A similar relation in character and manner of distribution of the normal quartz-syenites with respect to the corresponding quartz-pegmatites also holds, and may therefore, for the same reason, be urged as evidence of the operation of the force of crystallization in the differentiation of these phases, and the same phenomena applies to the amphibole granite and associated normal grained granite as compared with the aplitic and pegmatitic dikes which are developed.

A phase of the gabbro-diorite magma also, namely, the troctolite rocks, with the marked variation locally in content of anorthite, on the one hand, and of olivine, on the other, with the tendency to develop a pure anorthite rock, in one case, and a pure olivine rock, in the other, strongly suggests the force of crystallization as being effective in producing such a rock variation, namely, by the same forces and in the same manner that the anorthite, on the one hand, and the olivine, on the other, are developed as minerals from the liquid magma.

On the other hand, when the more remote relations of one rock group with another, one distinct magma with another, is considered, it seems obvious that the force of crystallization could not have been operative in producing the broader phases of variation. Differentiation more remote than that of crystallization must have prevailed in the development of the individual groups. Even in the rhyolite andesite series itself, rocks which were originally largely uncrystallized material when brought to the surface and consolidated, the main differentiation or the acquirement of certain chemical features appears to have been developed before eruption.

It is the view of the writer, therefore, only tentatively expressed, that the principal part of the differentiation, the acquirement of certain dominent chemical features, of these igneous intrusives was probably of remote origin, and that locally, under favorable conditions, both chemical and physical, the processes of crystallization have been important factors in modifying the individual magmas, producing thereby some of the more highly differentiated rocks, such as the phases of the troctolite of the gabbro-diorite magma, and phases of the quartz and nepheline-syenite, and associated pegmatites of the granite-syenite magma.

CHAPTER V.

THE UPPER SEDIMENTARY SERIES.

The various formations believed to constitute the oldest series of sedimentaries in the district have already been described. Overlying this older series of sediments and also overlying most of the igneous formations of the area are numerous outcrops and patches of sedimentary rocks here grouped into an Upper Sedimentary Series. These isolated areas of sedimentaries for the sake of clearness and brevity are described separately and are givens special names, after the places in or near which they occur. In accordance with this plan, therefore, the formations of this series are described as the Marshall Hill graywacke, the Marathon City conglomerate, the Mosinee conglomerate, the Arpin quartzite, the North Mound quartzite, and certain isolated areas of conglomeratic rock forming areas too small to be given a special name.

MARSHALL HILL GRAYWACKE.

This formation is mainly a graywacke grading into conglomerate on the one hand and into a shale on the other ,and forms a large part of the broad upland known as Marshall Hill, located about 6 miles north of Wausau.

GENERAL DISTRIBUTION AND EXPOSURES.

The Marshall Hill graywacke makes up a quite continuous area five or six miles north of Wausau (See map, Pl. I), lying on both the east and west sides of the Wisconsin river, and covering the whole or portions of sections 6 and 7 of T. 29, R. 8 E., and of sections 1, 2, 3, 4, 10, 11, and 12 of T. 29, R. 7 E., and of sections 33, 34, 35, and 36 of T. 30, R. 7 E. A smaller area of this formation lies in Sec. 19, T. 29, R. 8 E., and vicinity, and also several outcrops in the southeastern part of Sec. 8, T. 29, R. 8 E. Small isolated outcrops of this formation also occur in the near vicinity of the sections above referred to.

TOPOGRAPHY.

On account of the resistant character of the graywacke and conglomerate it forms rather steep sloopes along the Wisconsin river in the area of its occurrence about the Brokaw Paper Mill. Northeast of Wausau, in the vicinity of Sec. 19, T. 29, R. 8 E., it forms a few abrupt exposures protruding through the soil along the hill sides. The formation appears to be approximately as resistant to weathering and erosion as the rhyolite and massive phases of the granite associated with it and appreciably more resistant than the coarse phases of granite and quartz-syenite about Wausau.

PETROGRAPHICAL CHARACTER.

Microscopical.—The rocks of this formation are mainly graywacke and conglomerate. Small portions of the formation may be termed a shale and still smaller portions may be called slate. But by far the most abundant rock is graywacke, which is prevailingly a medium to fine-grained variety, and is usually closely associated with beds of conglomerate. The conglomerate is composed in many places, especially near the base of the formation, of coarse pebbles and boulders, the latter often a foot or so in thickness.

The most extensive exposures of this formation occur in the vicinity of the paper mill at Brokaw, where there is exposed a nearly vertical wall about 200 feet high of the graywacke and

FOLDED BEDDING IN THE MARSHALL HILL GREYWACHE.

conglomerate. On the west side of the Wisconsin river, at the end of the dam, the basal conglomerate forming the lower portion of this formation is seen to be resting upon the rhyolite formation. The conglomerate, in places in this vicinity, contains fragments and boulders of the rhyolite a foot or more in diameter. Farther north, on the same side of the river, the prevailing rock is a medium grained graywacke, interstratified here and there with coarser conglomeratic beds, and dipping to the northward at an angle of 30 to 45 degrees.

The conglomerate lying upon the rhyolite along the railroad a short distance north of the small stream in the northwest quarter of Sec. 12, T. 29, R. 7 E., contains boulders of the rhyolite, many of which are over a foot in diameter. The conglomerate quickly passes upward into medium to fine-grained graywacke and slate, the finer grained beds being often closely folded and crumpled. The graywacke exposed along the wagon road on the south slope of Marshall Hill in Sec. 12 apparently dips to the westward at a low angle of 30 to 40 degrees. Along the Wisconsin river on the west side of the hill the bedding appears to dip mainly to the east at a low angle. Immediately northeast of the village of Brokaw in the vicinity of the southwest quarter of Sec. 35, T. 30, R. 7 E., along the south side of a small stream, is a nearly vertical wall 20 to 30 feet high, of the medium grained graywacke, containing some beds of conglomerate, the graywacke being quarried and used for foundation walls in Brokaw. In this exposure the bedding dips slightly to the south.

The outcrops of this formation along the south side of the small stream near the center of Sec. 12, T. 29, R. 7 E., consist for the most part of angular fragments of volcanic tuff and rhyolite imbedded in a matrix of water worn sediment. For a time it was believed that this conglomerate was of volcanic origin, the matrix being composed of lava or volcanic mud; but the close association of the beds of conglomerate containing the angular fragments of volcanic rock with conglomerate containing ordinary rounded fragmental material would seem to indicate that the rock most probably is a sedimentary deposit formed adjacent to a rocky shore of volcanic tuff and rhyolite.

This formation in the area of Sec. 19, T. 29, R. 8 E., is mainly conglomerate, the pebbles and coarse fragmental material of which consists of a much larger proportion of sedimentary rock, such as shale, slate, chert, and quartzite, than is found in the conglomerate about Marshall Hill.

The graywacke is much mashed near the granite formation northeast of Brokaw in Sec. 35, T. 30, R. 7 E. There is also considerable shearing to be seen at the west end of the dam at Brokaw. While this formation is much folded, schistose phases are rare and the formation as a whole does not show effects of extreme metamorphism like the formations of the older sedimentary series.

Microscopic.—The thin sections of the prevailing rock of this formation, the graywacke, show the graywacke to consist of a variable amount of fragmental grains of quartz and feldspar imbedded in a matrix mainly of fine quartz and chlorite with lesser amounts of mica, sericite, calcite, magnetite, and sometimes epidote. Phases of the graywacke vary from those containing a large proportion of the coarser grained quartz and feldspar to phases containing no large grains and wholly composed of the fine-grained matrix portion. Thus there are all gradations between what was originally very fine-grained silt and very coarse arkose.

The thin sections of the conglomerate show the presence of a variety of rocks in the pebbly contents of this formation. In the thin sections examined, rhyolite pebbles appear to be the most abundant. Next to the rhyolite various phases of sedimentary rock, such as fine-grained quartzite, chert, slate and graywacke, were noted. A few rounded grains of diorite and granite were also noted. The thin sections of the conglomerate made up of the angular fragments, near the center of Section 12, T. 29, R. 7 E., show this conglomerate to have a matrix of water deposited material and not of lava. Mingled with the larger angular fragments in the conglomerate are many small, rounded grains and pebbles of water worn rock not apparent in the hand specimens.

The thin sections of the conglomerate show the conglomerate to be made up of detritus of the subjacent formations in much larger proportion than would be suspected from an examination of the hand specimens. About Marshall Hill on the east side of the Wisconsin and also west of Marshall Hill, on the west side of the Wisconsin river, the conglomerate is mainly made up of pebbles and detritus derived from the rhyolite formation;

while farther south in the vicinity of Wausau in Section 19, T. 29 R. 8 E., and also in the vicinity of Sections 8 and 9, T. 29, R. 7 E., the conglomerate contains a large proportion of sedimentary rock.

THICKNESS.

The thickness of this formation exposed on the west side of the Wisconsin river at Brokaw, where the base of the formation is seen to be resting upon the rock floor of rhyolite and where the formation has a dip to the north at an angle of 30 to 45 degrees for a distance of one-third to one-half of a mile along the river north of the rhyolite, would appear to approximate 1,500 to 2,000 feet. The formation exposed about Marshall Hill seems to lie in gentle undulating folds, showing an approximate thickness of 300 to 500 feet. On the whole, while the estimate of the thickness of this formation must be considered only an approximation, it seems reasonable to believe, when the large continuous area of this formation north of Wausau, as well as the considerable thickness of this formation, exposed on the west side of the Wisconsin river north of Brokaw, are considered, that the Marshall Hill graywacke formation is somewhere between 1,000 and 2,000 feet thick.

RELATIONS TO ADJACENT FORMATIONS.

The basal character of the conglomerate forming the lowest portion of the Marhsall Hill graywacke has already been mentioned, and a number of locations where the conglomerate is seen resting against an older floor have been described. The character of the conglomerate is such as to indicate that the Marshall Hill graywacke is separated from the associated formations by a great unconformity. As already described, the conglomerate contains pebbles of all the surrounding widespread formations of the vicinity where this formation occurs, such as granite, diorite, the various phases of the rhyolite formation, and also of the oldest sediments of the district, such as graywacke, slate, and quartzite. It has already been shown in the previous chapters of this report that in the immediate area about Wausau the oldest rocks are the Rib Hill quartzite and the Wausau graywackes and slates. Following the deposition of these oldest sediments came the intrusion of the rhyolite formation, and then a vast body of basic igneous rock, described as various phases of diorite, and gabbro. Following the extrusion of the basic rocks and the rhyolite, there was intruded the widespread granite and syenite rocks whose magma penetrated throughout the older formations, metamorphosing them, and separating them into many areas. Long after the intrusion of this complex plutonic magma represented by the granite, the quartz-syenite, and the nepheline syenite, the sea came in and the period of igneous intrusion and erosion gave way to a period of sedimentation, during which the Marshall Hill formation was laid down.

MARATHON CITY CONGLOMERATE.

This formation is mainly a conglomerate occurring in the near vicinity of the village of Marathon in Marathon county.

AREA.

The Marathon City Conglomerate has but a small extent. The formation forms small patches lying against the granite on the south side of Rib river, in Marathon City, and for a mile immediately west. It forms small outcrops in the vicinity of the southwest corner of Section 6, T. 28, R. 6 E., and in the sauthern part of Section 1, and the adjoining northern part of Section 12 of T. 28, R. 5 E., as shown on the map (Pl. I).

PETROGRAPHIC CHARACTER.

Macroscopic.—As already stated, the formation consists mainly of conglomerate. Various kinds of boulders and fragments make up the conglomerate, some of the boulders being over a foot in diameter. The conglomerate is quite generally mashed, having the usual aspect of conglomerate-schist. The pebbles making up the conglomerate are of quartz rock, fine-grained quartzite, slate, rhyolite, diorite and granite. At a number of places good sized pebbles and boulders of the granite, to all appearances like that forming the side of the hill on which this formation rests, were noted. The various phases of sedimentary pebbles occurring in the formation indicate the occurrence at an earlier date of a considerable variety of older sedimentary rocks in this vicinity. A fine-grained quartzite or novaculite-like rock was struck in one of the wells in the eastern part of the village, having much the character of certain fragments and pebbles in the conglomerate. Thin layers of silt-like sediment were also noted interbedded with the conglomerate and hence it is uncertain whether the rock in the well is an older formation or is a part of the conglomerate formation.

Miscroscopic.—Under the microscope the thin sections of conglomerate show the pebbles and fragments of the latter to be enclosed in a medium to coarse grained matrix consisting mainly of quartz and feldspar. The matrix has the appearance of arkose, being evidently formed from the detritus of the granite rocks adjacent. The microscopic appearance of the pebbles of granite is similar to the microscopic appearance of the granite formation adjacent. There were also noted in the thin sections small fragments of basic rock and of slate. One of the thin sections shows a portion of a rhyolite pebble, the rhyolite being a banded phase and much devitrified.

THICKNESS.

The thickness of this formation at Marathon City is not great, and probably does not exceed 100 feet. It appears to be the basal conglomerate portion of a much thicker sedimentary formation which has been eroded away.

RELATIONS TO ADJACENT FORMATIONS.

The rock formations immediately adjacent to the conglomerate are two, the granite formation and the diorite-gabbro formation. It has already been stated that the conglomerate contains pebbles and boulders of the granite formation against which it lies on the valley slope at Marathon. The character of the pebbles and boulders of granite in the conglomerate is such as to leave no doubt that the granite forms the rock floor upon which the conglomerate was deposited, and that the granite and conglomerate are separated by a great unconformity. The diorite and gabbro formations which are exposed in several low ledges on the south side of the Big Rib river in the southeast quarter of Section 1, T. 28, R. 5 E., are intruded by the granite formation. Along the wagon road just west of the Scott Creek bridge about a mile west of Marathon, and also where the railroad crosses Scott Creek in this vicinity, the granite is seen to be intrusive in the basic rocks. Small pebbles and fragments of basic rock were also noted in the conglomerate, and since the granite is intrusive in the greenstone it is clear that the conglomerate rests unconformably upon the basic rocks as well as upon the granite. The pebbles of rhyolite, of quartzite, and of slate, indicate also that the conglomerate is later in origin than the rhyolite and an older sedimentary series.

THE MOSINEE CONGLOMERATE.

This formation, like that occurring at Marathon City, is mainly conglomerate.

AREA.

The conglomerate near Mosinee occurs in scattered exposures on the upland area east and southeast of Mosinee, as shown on the map (Pl. I). Most of the outcrops noted are along the wagon road on the section line in the SE. ¼ of Sec. 28, and along the south side of Sec. 27 of T. 27, R. 7 E. The conglomerate also occurs in loose blocks in the SE. ¼ of Sec. 32, and the adjoining portion of Sec. 33, and in the well in the SE. corner of Sec. 32 of T. 27, R. 7 E. This formation occurs along the road south of the west quarter stake of Sec. 4, T. 26, R. 7 E., for half a mile or more, being well exposed in the vicinity of the small stream flowing southeast in the SW. ¼ of Section 4.

PETROGRAPHIC CHARACTER.

Macroscopic.—As stated above, this formation as observed in its isolated exposures is mainly a conglomerate. In only one or two places was finer grained rock noted, mainly in the SW. ¼ of Section 27, T. 27, R. 7 E., where the rock is mainly a fine-grained brittle slate or chert. In the NW. ¼ of the SW. ¼ of Section 33, a mashed graywacke-like rock was struck in digging a well. The conglomerate throughout the area contains more pebbles of rhyolite than of any other rock. So numerous are the rhyolite pebbles and boulders that the rock resembles closly a volcanic conglomerate, formed by a surface flow of acid lava enclosing fragments of an older rhyolite flow. In a few places, conglomerate like specimen 5929, made up mainly, if not entirely, of granite fragments and pebbles, was noted. The granite of the pebbles is in all respects like the granite formation having a widespread distribution in this vicinity. Besides the rhyolite and granite found abundantly as pebbles in the conglomerate, there are also pebbles of slate and of fine-grained diorite.

Microscopic.—The several fine-grained phases of this formation, such as graywacke and brittle quartzose slate, when examined under the microscope, are seen to be wholly crystalline and appear to be very much like rocks of igneous origin. In the absence of traces of bedding in the field exposures, it is often difficult and sometimes impossible to separate the arkose and the fine-grained slates from the granite and the rhyolite. The thin sections of the conglomerate made up mainly of rhyolite fragments show the matrix to be composed of very fine quartz, sericite and chlorite. The pebbles of granite in the granitic conglomerate are often much altered to epidote.

THICKNESS.

The thickness of this formation can only be surmised, but is not thought to be great. Its distribution in small patches would seem to indicate that it is only the small remaining portion of a much more extensive formation long since eroded away.

RELATIONS TO ADJACENT FORMATIONS.

Associated with this conglomerate formation are the granite, rhyolite, and basic rock formations. Pebbles of each of these formations are found in abundance in the conglomerate, and hence there can be no doubt of a vast unconformity separating this conglomerate formation from the associated igneous formations of the vicinity. While no older sedimentary formations were found in this vicinity, the presence of sedimentary fragments and pebbles in the conglomerate indicates the presence of an older series of sediments in the rock floor upon which this formation was deposited.

THE ARPIN QUARTZITE.

In the vicinity of Powers Bluff and immediately south of Arpin in Wood county is a considerable formation of quartzite which may be conveniently described as the Arpin Quartzite.

AREA.

This formation is shown in numerous exposures on the southwest slope of Powers Bluff. As shown on the map (Pl. I), it is mainly confined to the whole or portions of Sections 26, 27, 28, 33, 34, 35, and 36 of T. 24, R. 4 E., and Sections 1, 2, 3, 4, 5, 8 and 9 of T. 23, R. 4 E. The formation lies near the base of Powers Bluff, forming low, sloping land, which, though covered with only a thin layer of drift and soil, has a relief so slight that the quartzite is very generally hidden from view. The places where the formation is known to be exposed are shown on the detailed sketch map (Pl. XII). One of the best exposures of this formation is in the railroad cut near the center of Section 34, T. 24, R. 4 E. The formation crops out in several places along the wagon road running east and west through the middle of Section 33, and several good exposures also occur near the road in the SE. ¼ o fthe NE. ¼ of Section 5, T. 23, R. 4 E.

This formation is not so resistent to weathering and erosion as the fine-grained quartzite making up the main portion of Powers Bluff adjacent, on the northwest. The formation, however, is neither so flat-lying as a large portion of the surface of the pre-Cambrian formation of the immediate area adjoining it.

PETROGRAPHIC CHARACTER.

Macroscopic.—Although quartzite is the predominant rock of this formation, conglomerate, graywacke, and probably slate, with all gradations between these different phases, also occur. The quartzite is generally medium-grained and grayish in color, thus having the usual appearance of graywacke. The conglomerate, in its several exposures examined, apparently contains more pebbles and fragments of quartzite than of any other formation. Slate is also represented in the pebbles of the conglomerate in the outcrop in the railroad cut near the center of Section 34, T. 24, R. 4 E. Along the wagon road in the SE. ¼ of the NE. ¼ of Section 5, T. 23, R. 4 E., conglomerate is exposed in the near vicinity of the Powers Bluff quartzite. The conglomerate at this place consists of rounded and angular pebbles of the various phases of the Powers Bluff formation, such as coarse-grained and very fine-grained chert-like quartzite imbedded in a matrix of coarse and fine quartz. (See Pl XLI, Fig. 1.)

The conglomerate and quartzite exposed in the railroad cut, above referred to, is considerably mashed and much weathered. On account of its weathered condition many of the pebbles could be readily taken out of the conglomerate and these were closely studied. Most of these pebbles, as above stated, were of quartz rock, the various phases of the Powers Bluff quartzite, such as the coarse-grained quartzite and gradations of fine-grained pinkish iron-stained chert-like quartzite, being abundant. Angular and partly rounded fragments of slate were also frequently noted. Pebbles of granite and diorite were searched for at the railroad cut, but none were found to a certainty. Several granite and diorite pebbles were noted, at this place, but these may have been derived from the thin layer of drift covering the quartzite and conglomerate.

Microscopic.—Under the microscope the quartzite is seen to consist of rounded grains of quartz and of quartzite imbedded in a matrix of fine-grained quartz and sericite and chlorite. The rounded grains of quartzite are very small and in all respects are like the close fitting interlocking quartz of the Powers Bluff formation. This matrix portion of the quartzite makes up from twenty to thirty-five per cent of the formation. There is a marked difference in the microscopic appearance of the Arpin quartzite formation and the Powers Bluff quartzite, which is represented in the pebbly constituent of this conglomerate. A specimen of the older Powers Bluff quartzite, or of a pebble of it in the conglomerate, consists of similarly sized grains of quartz, which are not separated from one another by a fine-grained matrix, but which interlock and dovetail with one another in an intricate manner. On the other hand, the Arpin quartzite formation with its basal conglomerate, always possesses a matrix of fine-grained material in which the larger grains of quartz and pebbles of quartzite are imbedded.

The fine-grained graywacke occurring in a well in the NW. ¼ of the SW. ¼ of Section 36, T. 24, R. 4 E., is an evenly granular rock consisting of about equal portions of clastic quartz and plagioclase in a fine-grained matrix of quartz, chlorite, sericite, biotite and iron oxide.

Thus there is a wide difference in the microscopic character of the Arpin quartzite and the Powers Bluff quartzite formations, the older formation being apparently a wholly recrystallized rock, whereas the younger, while firmly consolidated and cemented, still retains its original fragmental character. The difference in the amount of metamorphism of these two formations is again referred to in a later portion of this report.

THICKNESS.

As the position of the bedding could not be determined in the few exposures of this formation it is impossible to estimate the thickness with any degree of accuracy. Only an intelligent guess can be hazarded. On account of the fairly continuous distribution of this formation over an area of eight or ten square miles, it seems not unlikely that this formation is 200 to 500 feet thick and probably represents the remnant of a much thicker formation.

EXPLANATION OF PLATE XLI.

PLATE XLI. SPECIMENS OF CONGLOMERATE AND FOLDED SCHIST.

Fig. 1. Conglomerate phase of the Arpin quartzite formation Specimen 6547, three-fourths natural size. The specimen consists of pebbles of the Powers Bluff quartzite embedded in the usual matrix of fine quartz and feldspar. The specimen illustrates the relation of the Upper Sedimentary Series to the Lower Sedimentaries, the latter being represented in the pebbles of quartzite.

Fig. 2. Folded and crumpled greenstone schist. The specimen illustrates a miniature mountain fold, a characteristic feature of the pre-Cambrian formations.

Fig. 1. ARPIN QUARTZITE CONGLOMERATE.

Fig. 2. FOLDED DIORITE SCHIST.

RELATIONS TO ADJACENT FORMATIONS.

The pebbles of the Powers Bluff quartzite in the conglomerate of this formation point clearly to the Powers Bluff formation forming a part of the rock floor upon which this conglomerate and quartzite were deposited. It is also believed that the massive granite formations of this vicinity formed a portion of the rock fioor upon which this conglomerate was deposited.

NORTH MOUND QUARTZITE.

DISTRIBUTION AND TOPOGRAPHY.

North Mound is located about 5 miles northwest of Babcock in the southeast corner of Section 6 and adjoining parts of Sections 5, 7 nd 8 of T. 21 N., R. 3 E. The base of the mound covers an area of about one-fourth of a square mile. Its highest portion probably does not rise more than 125 to 150 feet above the surrounding area, but being located in the broad, marshy tract of this part of Wood and adjoining counties it can be seen for many miles about.

The rock forming North Mound is mainly a quartzite grading into a fine conglomerate. Laminated and schistose rhyolite also occur to a small extent. Some low elevations about 40 feet high lie about a mile east of North Mound in the SW. ¼ of Section 4, consisting of quartzite similar to that of North Mound.

South Mound, which lies about 4 miles southwest of North Mound, in Sections 25 and 26 of T. 21 N., R. 2 E., which was tentatively referred to in a report of the former Geological Survey[1] as probably consisting of Pre-Cambrian quartzite, consists wholly of Potsdam sandstone.

[1] Vol. II, p. 503.

PETROGRAPHICAL CHARACTER.

Macroscopic.—The rock of North Mound, as above stated, consists of quartzite and conglomerate and a small amount of rhyolite. The rhyolite is mashed and laminated and looks so much like fine-grained sedimentary rock that it generally requires a microscopic examination to distinguish it from the quartzite. The quartzite is medium to coarse-grained, with rapid changes to conglomeratic phases. The conglomerate is not generally coarse, and in only a few places were pebbles as large as 5 inches in diameter noted. The rounded pebbles and angular fragments in the conglomerate consist of rhyolite, fine-grained quartzite, and coarse quartzite. One especially large pebble or boulder about 10 inches in diameter was seen on the northeast side of the Mound, which consisted of fine-grained pinkish quartzite very similar to the fine-grained quartzite of Powers Bluff. Stratification is well marked in the quartzite, and cross-bedding is shown at several places.

Microscopic.—Under the microscope the quartzite is seen to be made up of rounded grains of quartz and of rounded and sub-angular pebbles of fine and coarse grained quartzite. The conglomerate contains an abundance of these rounded pebbles of quartzite. The matrix of the conglomerate and quartzite consists of fine quartz, occasionally some feldspar, and an abundance of chlorite and sericite. The quartzite of these pebbles consists of close fitting grains of quartz without matrix, having the character of the recrystallized quartzite of the Rib Hill and the Powers Bluff formation. Granules of iron oxide, probably hematite and limonite, are scattered through the rock, and also forms films surrounding the quartz grains. Biotite, muscovite, and epidote are also important constituents of the matrix. Some phases of the conglomerate are made up entirely of angular and rounded fragments of rhyolite, the latter showing principally the spherulitic and poicilitic textures. The quartzite and conglomerate are generally mashed, as shown in the fracturing and granulation of the pebbles, the undulatory extinction of the quartz grains, and the streaky arrangement of the chlorite and sericite in the matrix.

STRUCTURE AND THICKNESS.

The quartzite is much folded on North Mound, but further than this nothing determinative could be made out concerning the prevailing position of the beds of the rock. The thickness of the quartzite may be from 200 to 500 feet. The quartzite now exposed in North Mound is only a remnant of a formation much more extensive in pre-Cambrian time.

RELATIONS TO ADJACENT FORMATIONS.

The only formation of pre-Cambrian rock found in contact with the quartzite and conglomerate are a few exposures of rhyolite which very evidently forms a portion of the rock floor upon which the quartzite was deposited, as indicated by the abundant rhyolite pebbles and fragments occurring in the conglomeratic phase of the quartzite. The conglomerate also contains abundant pebbles of an older vitreous quartzite formation, and in this respect this conglomerate resembles the conglomerate phases of the Arpin quartzite, about 18 miles northeast of North Mound, which lies upon the Powers Bluff quartzite.

ISOLATED OCCURRENCES OF CONGLOMERATE.

SECTION 4, TOWNSHIP 30 NORTH, RANGE 6 EAST.

In the southeast quarter of Sec. 4, T. 30, R. 6 E., fine conglomerate and graywacke is exposed along a small stream flowing to the southwest. The fine conglomerate, as shown by thin sections, contains an abundance of small rounded pebbles of quartzite, slate, granite, and basic eruptive rock. The matrix of the fine conglomerate and the graywacke is fine quartz, chlorite, and sericite. The formation is somewhat mashed and the bedding crumpled. Nothing concerning the thickness or the position of the bedding in the small exposures of this area could be made out. The relations to the adjacent formations, however, are very clear. The massive granite formation exposed on the east side of the outcrops of graywacke is apparently a part of the floor upon which the latter was deposited, as the conglomerate is quite coarse next to the granite, and pebbles of massive granite were noted in the fine conglomerate. The extensive Hamburg slate, though not found in contact with this formation, is believed to be represented in the slate fragments which are abundant in some of the outcrops of fine conglomerate. Most of the pebbles in the conglomerate in this vicinity seem to be made up of an older sedimentary series, and the fact that the belt of fissile slate lies immediately west of this makes it appear very probable that the black Hamburg slate is a portion of the floor upon which the graywacke and fine conglomerate were deposited.

Section 25, Township 31 North, Range 6 East.

Three miles south of Merrill, a short distance south of the small stream in the NW. ¼ of the SW. ¼ of Sec. 25, slate crops out in the ditch of the road. Similar slate was also struck in rear of farm house at a depth of 8 feet in drift. Back of the house, also, are a number of angular blocks of conglomerate, similar to the conglomerate of the upper series, which are believed to be not far removed from their original position.

Section 4, Township 30 North, Range 7 East, and Vicinity.

About five miles south of Merrill, in Section 4, T. 30, R. 7 E., and vicinity, along the wagon road and in the farmers' wells, there are a number of occurrences of slate and conglomerate, indicating an area of sedimentary rock perhaps two square miles in extent. Most of the sedimentary rock in this vicinity is slate. In two places, however, conglomerate occurred, one in the well of C. Dumman in the NW. ¼ of the NW. ¼ of Sec. 4, and the other a surface exposure in the road in the SE. ¼ of the SW. ¼ of Sec. 3. The conglomerate taken from the well has a quartzose matrix, and contains rounded fragments of fine-grained quartzite and of basic igneous rock. The conglomerate exposed in the road is approximately in contact with the granite of that vicinity, and consists of a matrix of arkose containing fragments and pebbles of granite.

The slate associated with the conglomerate in the above localities in Sections 3 and 4, T. 30, R. 7 E., and in Section 25, T. 31, R. 6 E., is ordinary fissile slate, and it is not known whether the slate belongs to a formation of which the conglomerate is the basal portion, or whether it is an older formation upon which the conglomerate is deposited.

Section 7 and 8, Township 29 North, Range 5 East.

As shown on the sketch map, the SW. ¼ of Section 8, the southern portion of Section 7, and vicinity, contain several occurrences of graywacke and conglomerate. In this vicinity is a small valley opening eastward into the Rib River valley. The south slope of the valley consists of granite, but in the valley bottom at the corner of the road in the NE. corner of Section 18, graywacke, slate, and conglomerate occur, having the usual character of arkose, containing fragments and pebbles of the granite formation exposed in the near vicinity. In the field in the SE. part of the NW. ¼ of the SW. ¼ of Section 8 is a small outcrop of conglomerate, showing large pebbles of the granite, of fragments of slate, and of rhyolite-schist. In the well at the farm house in the SW. ¼ of the SE. ¼ of Section 7, a fine-grained chert-like rock occurs, and on the south side of the road, opposite the farm house, in Section 18, is an outcrop of conglomerate containing pebbles and fragments of rhyolite and fine-grained diorite. At the last named place the rock is not mashed, but the exposures to the east and also to the west are generally schistose conglomerate, or slate. On account of the lack of sufficient exposures, the position of the beds of the conglomerate and graywacke could not be made out. This locality of sedimentary rocks appears to be about a square mile in extent, and is bounded on the south as stated, by the massive granite, while to the north occurs the rhyolite and diorite. The composition of the conglomerate, as above described, is such as to indicate that it was deposited upon the granite, diorite, and rhyolite of the vicinity, and also upon an older sedimentary series of rocks.

AT PONIATOWSKI, SECTION 14, TOWNSHIP 29 NORTH, RANGE 4 EAST.

About two miles west of the last mentioned locality near the center of Section 14, T. 29, R. 4 E., southwest of the store at Poniatowski, conglomerate and granite occur in contact, in the bed of a small stream. This conglomerate is mainly made up of angular fragments of granite, but it also contains pebbles and fragments of various phases of basic igneous rock and quartz rock.

SECTION 16, TOWNSHIP 24, RANGE 6 EAST.

About two miles southwest of Junction City conglomerate was found in an old test pit, located in the NE. ¼ of the NE. ¼ of Section 16, T. 24, R. 6 E. This conglomerate is massive, and contains numerous fragments of the quartzite, having the character of the medium grained pink quartzite of this vicinity. No granite pebbles were found, either in the hand specimens, or in the thin sections, though the massive granite occurs in another test pit a few paces south of the one showing conglomerate.

SECTION 22, TOWNSHIP 24 NORTH, RANGE 6 EAST.

About two miles south of the locality last described, in the SW. corner of Section 22 along the railroad and the wagon road, is an outcrop of graywacke and fine conglomerate, and in the adjoining field to the southeast are numerous loose blocks of conglomerate. The outcrop on the railroad consists of fine-grained laminated graywacke with phases of fine conglomerate. The conglomerate contains a good sized pebble of chert or fine quartzite, and numerous fragments of granite diorite, and shale. The matrix portion of the rock consists of fine quartz and feldspar, biotite, sericite, chlorite, and some epidote.

SECTIONS 13 AND 14, TOWNSHIP 24 NORTH, RANGE 6 EAST.

At the farm house wells and also along ditch of the road in the SW. ¼ of Section 13 and SE. ¼ of Section 14, graywacke and conglomerate were found. Conglomerate also occurs in numerous loose fragments in the adjoining fields. The conglomerate contains pebbles and fragments of fine quartzite, and has the general character of the conglomerate of the Upper Series.

RÉSUMÉ.

The various formations and occurrences of sedimentary rock above described have much in common. All are largely coarse sediments and all bear similar relations to the rock formations associated with them. With regard to the associated formations the well defined areas in all cases rest upon them, as abundantly shown by the character of the coarse debris making up the conglomeratic phases of the formations. Where these formations are associated with the Powers Bluff quartzite, the rocks of the latter formation furnish the principal pebbly material of the conglomerate; where they lie in contact with the Wausau graywacke the latter forms the pebbly content; where they lie in contact with the Hamburg slate the latter occurs as pebbles in the conglomerate, and where they are associated with the massive igneous intrusives, as at the Mosinee and Marathon City occurrences, these igneous intrusives constitute the predominating material from which the conglomerate is formed.

Because these various formations, quite widely separated from one another, are similar with respect to character of rock and relation to associated formations, they are placed in the same series. They appear to belong not only to the same series, but, on account of their close similarity, they may very well belong to the same formation. But while it is true that all these sediments lie at the base of the series to which they belong, it cannot be stated that all of them were deposited contemporaneously, hence it is possible that not all of the formations described belong to the same horizon as formations of the pre-Cambrian rocks. They are therefore placed in the same series, but the question as to their relative position in the series is left an open one. The position of this series in the stratigraphy of the pre-Cambrian as a whole is discussed in following pages.

CHAPTER VI.

THE CORRELATION OF THE PRE-CAMBRIAN AND THE UNIFORMITY BETWEEN THE PRE-CAMBRIAN AND PALEOZOIC.

SECTION 1. THE CORRELATION OF THE PRE-CAMBRIAN.

The Basal Group.—The oldest rocks of the area consist of a complex mass of igneous rocks such as contorted and crumpled granite-gneiss, diorite gneiss, granite schist, syenite-schist and fine-grained diorite schist. The gneiss and schist forms a belt which can be fairly well outlined, extending from the vicinity of Stevens Point and Grand Rapids in a northwesterly direction to Neillsville. The various members of this basal group are closely interwoven and intermingled with one another and have been subjected to extensive dynamic and thermal metamorphism. Each small area of this belt contains 3 or 4 members of the group mingled together and in complexity of intrusion and metamorphism these members are quite different from the younger and more massive formations. The zone or belt in which this group is largely comprised lies between the areas of later igneous and sedimentary rock to the north and those to the south, and hence appears to have the position of the arch of an anticline. This basal group is intruded by later formations of rhyolite, diorite and granite. Schists of sedimentary origin were not observed as a portion of this basal group although such sedimentaries may possibly occur. Sedimentary rocks were not found in contact with this group, and hence its position in the stratigraphy of the pre-Cambrian can only be inferred. On the whole, however, it seems very probable that this group is very near, or at the base of the generally recognized pre-Cambrian column, and it is believed should be placed with the igneous formations lying below the Huronian sedimentaries, presumably the Laurention as defined[1] in the recent revision of the pre-Cambrian nomenclature.

Lower Sedimentary Series.—The next group of rocks are of sedimentary origin and consist of quartzite, slate and graywacke. These formations include the quartzite of Rib Hill and vicinity, the quartzite of Powers Bluff and vicinity, and the quartzite in the vicinity of Junction and Rudolph, the slate of the towns of Berlin, and Hamburg, and the graywackes in the vicinity of Wausau. These formations are almost entirely of fragmental origin and only rarely contain phases of carbonaceous, calcareous or ferruginious deposits. The floor upon which these sediments were deposited could not be definitely determined or located, the contacts with associated formations showing either later intrusive igneous rocks, or later overlying conglomerate. The quartzites throughout are extremely metamorphosed and to all appearances completely recrystallized. The slates and graywackes do not reveal as much metamorphism as the quartzites although in places rocks presumably belonging with the slate formation have been changed to staurolite cordierite and garnet-bearing schists. These sedimentary formations appear to bear the relation of great fragmentary masses entirely surrounded by later igneous intrusives. They constitute the lower, or oldest sedimentaries of this area and while their stratigraphic position in the pre-Cambrian column can only be inferred they are believed to be of Lower Huronian age.

The Group of Igneous Intrusives.—The next group of rocks in the stratigraphy of this area is of igneous origin. This group forms about 75 per cent of the rocks of the area and in the order of their intrusion are: 1st-rhyolite; 2nd-basic series of diorite, gabbro and peridotite; and 3rd-a series consisting of gran-

[1] Report of International committee on Lake Superior Geology. Jour. of Geol. Vol. 13, pp. 89–104, 1905.

ite quartz-syenite, nepheline syenite and related rocks. Of these the last named is the most abundant, the granite alone forming nearly 50 per cent of the surface rocks of the area. The various members of this large group of igneous rocks are intrusive in the oldest, basal group of the area, and also in the lower sedimentary formations. They are in turn overlain by later pre-Cambrian sediments. The period involved in the outflow of the various igneous formations of this group must have been a very long one and evidently constitutes an important portion of the pre-Cambrian era for the granite-syenite series itself represents a complex magma of variable, though related, rocks, intruded at different dates. In the stratigraphy of this area this group of igneous intrusives is one of the most important, not only in quantity of rock formations represented, but also presumably in the time required for its origin and development. It occupies a well defined position between the Lower and Upper pre-Cambrian sedimentaries of this area and may be appropriately referred to as the Huronian group of igneous intrusives in contra-distinction to the older basal group, presumably of the Laurentian group.

The Upper Sedimentary Series.—The second or Huronian period of igneous intrusion was followed by a very long period of erosion, and subsequently by a period of sedimentation. This period of sedimentation was probably a long one, though but remnants of the formation deposited during this period now remain in the area. This group of sedimentary rocks is represented by the Marshall Hill conglomerate and quartzite, the Arpin conglomerate and quartzite, and the conglomerate at Marathon City, at Mosinee, at North Mound, and at various other places in the district. This group constitutes the Upper sedimentary rocks of this area and is mainly conglomerate and other fairly coarse clastic deposits, evidently the basal portion of a once widespread and more abundant sedimentary formation. No pre-Cambrian sediments are known to overlie this group nor are later intrusives known to penetrate them. This group, however, has but a small areal extent and it is not unlikely that dikes of igneous rock may later be found intruding them.

The Upper sedimentary series of this area may be the equivalent of the basal portion of the Upper Huronian (Animikie), or it may be at the base of the series preceding the Animikie (the Middle Huronian). It is believed to be more likely the basal portion of the Middle Huronian than of the Upper Huronian, for reasons which may best be brought out in a discussion of the probable correllation of the upper sedimentaries of this area with the Baraboo series of pre-Cambrian in the southern part of the state and of the Middle Marquette of the Marquette district in northern Michigan.

In the Baraboo district[1] of southern Wisconsin is a well defined pre-Cambrian sedimentary series unconformably overlying igneous rocks, the sedimentaries consisting of the following formations, beginning with the youngest:

Baraboo Series:

Freedom Formation (dolomite and iron-bearing rock)

Seeley Slate (gray clay slate).

Baraboo Quartzite (quartzite with conglomerate at base).

Unconformity.

Igneous Rocks.

Rhyolite, Diorite, Granite.

The rhyolite of the Baraboo district is very similar to that of north central Wisconsin which occurs abundantly near Wausau, with respect to general massive character, comparative deformation, and metamorphism, and is also practically identical in chemical composition, the rhyolite from both districts being unusually rich in soda. The granite and diorite of the Baraboo district are massive and not schistose rocks, and can be readily duplicated among the prevailingly massive and abundant granite and diorite rocks farther north. The lithological similarity of the igneous rocks of the Baraboo district to the massive igneous intrusives of central Wisconsin, is, on the whole, quite marked.

The sedimentary formation immediately overlying the igneous rocks in both districts is conglomerate and quartzite. The character of Baraboo quartzite is very similar to the uppermost quartzite of north central Wisconsin occurring at

[1] The Baraboo Iron-bearing District, Bull. XIII, Wis. Geol. & Nat. Hist. Survey, 1904.

North Mound, west of Babcock, and at Arpin. In each, as seen under the microscope, the quartzite reveals about the same amount of metamorphism and the original clastic grains can be readily in all cases distinguished from the secondary interstitial quartz material. On the other hand, the Baraboo quartzite and the older quartzites farther north, such as the white quartzite of Rib Hill, are strikingly dissimilar, not only in structural relation to the associated igneous rocks, but also in the general texture of the rock, for the older quartzites have throughout been wholly recrystallized and all trace of boundaries between the original clastic sand grains and secondary interstitial quartz material has been obliterated. It may be added that the conglomerate of the Baraboo quartzite formation, like the conglomerate at the base of the quartzite of the upper sedimentaries in north central Wisconsin, contains pebbles and fragments of older highly metamorphosed quartzite as well as of slate and jaspilite, thus indicating that in the surrounding Baraboo region there are sedimentary rocks older than the Baraboo quartzite, similar to the older quartzites and slates in the central Wisconsin region.

On the basis of unconformable relationship to similar igneous rock and to older sediments, and of similar lithological character, the Baraboo quartzite formation might well be the equivalent of the quartzite of the uppermost sedimentary series of the pre-Cambrian in the north central Wisconsin district. At the same time, it should be noted that the upper quartzite in north central Wisconsin, so far as known, is nowhere such an extensive or thick formation as the Baraboo quartzite, and also is nowhere known to be associated with overlying slate, iron formation, or dolomite, or other later conformable sediments, as is the case with the Baraboo quartzite. Formations later than the quartzite of the Upper sedimentary series of central Wisconsin may once have been present, however, which have been removed by erosion, just as without doubt is the case with the entire series of the Baraboo quartzite and overlying formations, in the region immediately surrounding the Baraboo district. On the whole, therefore, while the question of the equivalence of the two series must remain unsolved for the present, it seems probable that the uppermost series of pre-Cambrian sediments in north central Wisconsin is contemporaneous with the quartzite of the Baraboo series.

The writer[1] has previously noted the marked similarity of the Baraboo series with the middle series of the Marquette district, as indicated in the following table:

BARABOO DISTRICT.	MARQUETTE DISTRICT.
Unconformity.	
Freedom formation. (Dolomite and iron bearing formation).	Negaunee formation. (Iron bearing formation).
Seeley slate.	Siamo slate.
Baraboo quartzite.	Ajibik quartzite.
Unconformity.	

While the character and succession in these two series are nearly identical, there is some variation in the thickness of the individual formations in the two districts. The Ajibik quartzite is probably between 700 and 1000 feet thick, while the Baraboo quartzite is probably from 3000 to 5000 feet thick. The Siamo slate and Seeley slate have approximately the same thickness of 500 to 1000 feet. The Neguanee iron bearing formation has a thickness of 1000, to 1500 feet, while the Freedom iron-bearing formation has a known thickness of 1000 feet and may have a thickness considerabbly greater. It should be noted in regard to the iron-bearing formation of the two districts that only the lower member of the Freedom formation is iron bearing, whereas the Negaunee formation is ferruginous throughout its whole thickness of 1000 to 1500 feet. There is, however, considerable ferruginous carbonate and ferruginous chert throughout the Negaunee formation, thus indirating conditions of origin similar to those of the dolomite of the Freedom formation. While there is more or less dissimilarity between the Baraboo series and the Middle Marquette series, on the whole their main features, the general character of the formations and the succession, are the same, and hence it is not unlikely that the two series are stratigraphically equivalent.

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1 Baraboo Iron Bearing District, Wis. Geol. & Nat. Hist. Survey, Bull. XIII, pp. 170–171.

While it is impossible to definitely or correctly locate the Upper Sedimentary series of this area in the pre-Cambrian column it seems probable that it is the equivalent of the basal portion of the Baraboo series, as previously noted. Since the Baraboo series closely agrees in character with the Middle Marquette series, (Middle Huronian, as recently defined) then the Upper sedimentary series of central Wisconsin may likewise be correlated with the Middle Huronian.

If the Upper sedimentary series is pre-Animikie then the entire pre-Cambrian of central Wisconsin is in the lower portion of the pre-Cambrian column, which conforms very well with the igneous intrusive geology of the area and the extreme metamorphism of the lower quartzite. It is, of course, possible, that while the igneous intrusives and Lower Sedimentaries are of Lower Huronian age, the Upper Sedimentary series may be separated from them by a double gap, and that the Upper series may, therefore, be equivalent to the Upper Marquette series, the Upper Huronian (Animikie). In the absence of definite proof, however, it seems more reasonable to place the Upper series in the series next overlying the Lower Huronian, and thus with the Baraboo series which lies upon similar igneous formations, as already pointed out.

If this view of the stratigraphy of the pre-Cambrian of this area be correct, then it is at once apparent that the two later pre-Cambrian series of sediments, the equivalent of the Upper Huronian (Animikie) and the Keweenawan, are not represented in this area. If they were once present in the area they have since been entirely eroded. Whether it is more probable that either or both of these absent series were once present, and have been subsequently eroded, or whether neither was ever present in this area, nothing can be said, except, perhaps, that there appears to be ample evidence of sufficient pre-Cambrian erosion in the area to remove rock formations the equivalent of either or both of these unrepresented series.

SECTION II. THE UNCONFORMITY BETWEEN THE PRE-CAMBRIAN AND THE PALEOZOIC.

The rock formation next overlying the Upper Sedimentary series of pre-Cambrian in this area is the nearly horizontal formation of Potsdam sandstone (Upper Cambrian of the Paleozoic System) described in the succeeding chapter. Between the pre-Cambrian and the Paleozoic is an unconformity signifying a long period of erosion during which was developed a class of geological phenomena of significance and interest comparable to that developed during a period or periods of sedimentation or of igneous intrusion.

The general surface features of the pre-Cambrian are those of a broad plain capped here and there with ridges and hills of sandstone and glacial drift and trenched by valleys of varying depth and width. The extensive erosion of the pre-Cambrian land is, perhaps, nowhere more impressibly shown than in this area where the various rocks of the pre-Cambrian are seen in tilted and close-folded positions, overlain by the approximately horizontal beds of Upper Cambrian sandstone.

In the sequence of geological events of this area, therefore, it appears appropriate that a brief description of the erosion and weathering of the Pre-Cambrian in pre-Potsdam time be given in this place. In a following chapter, the results of this erosion are described from the view point of the physiographic development of the area.

THE PRE-CAMBRIAN PENEPLAIN OF EROSION.

If one should climb the hill immediately northwest of Wausau and look eastward across the narrow valley of the Wisconsin to the flat-topped uplands, ridges, and valleys beyond, he would see that the uplands rise approximately to his own elevation and form an even crest-line along the horizon. If he should look northward, the even sky-line would seem to rise gently but persistently to the northeast. Looking to the west, the even crests of the hills are seen to return to an elevation equal to his own. However, if he should turn to the south, Rib Hill and the adjoining Mosinee hills, six miles southwest of Wausau, would rise before him and obstruct his view of the even sky-line which swings away beyond and falls not only far below the summits of Rib Hill, but also much below his own position. The approximately even surface of the main upland area is the most striking feature of the landscape and at once suggests an ancient plain sloping downward to the south, below which the Wisconsin River and its tributaries have sculptured their valleys, and above which project a few isolated pointed ridges and hills like Rib Hill and the Mosinee hills.

The great variety of rock and the tilted and folded structure of the pre-Cambrian has already been described. Wherever the rocks are exposed, their schistosity and bedding are seen to be dipping steeply at various angles, and along the valley bottoms the streams flow over the upturned edges of the formations. Hand specimens chipped from ledges show rock crumplings on a minute scale, and the dipping beds of hillsides are the remnants of large rock folds that once roofed over broad spaces from a few hundred to a thousand feet across. Everywhere the rocks stand on edge and are folded and crumpled, and reveal a structure like that seen in the Alps, the Alleghanies, or the Rockies. (See Plate XLII.)

While the rocks of the pre-Cambrian area have typical mountain structures, there is nothing in the present land surface to suggest mountain topography. The tilted beds and schists stop abruptly at the even sky-line formed by the crests of the flat-topped hills. There is thus an entire lack of sympathy, a striking unconformity, between the topography of the gently sloping summits of this main upland area and the internal structure of the rocks. This indifference of surface form to internal structure could be developed in only one way, namely, by the process of degradation of a pre-existing mountainous region.

Discordance of land surface and rock structure of other regions like that of this pre-Cambrian area has been so adequately explained and so generally accepted by geologists, for the last two or three decades, as the resultant of long-continued erosion, that it seems reasonable to conclude at once that the sloping, flat-topped uplands about Wausau are the remnants of what

Fig. 1. TRUNCATED PRE-CAMBRIAN GNEISS OF THE PENEPLAIN AT NEILLSVILLE.

Fig. 2. TRUNCATED AND WEATHERED GNEISS OF PRE-CAMBRIAN PENEPLAIN, STEVENS POINT.

was formerly a level land surface formed by the wearing down by erosion of a once mountainous region to an approximate plain. The mountain folds of the pre-Cambrian have been cut off by erosion at the sky-line of the area, just as the fibres of a great tree are cut across at the even surface of its sawed stump. The complete degradation of the mountains was not accomplished, as is evidenced by such isolated hills as Rib Hill and the Mosinee hills which project above the flat-topped uplands, and hence the region must have been, not a plain, but a peneplain of erosion.

Out of this ancient plain of erosion the present valleys about Wausau are seen to be in process of construction, and hence this part of the region may be described as a dissected peneplain.

As one goes south from the vicinity of Wausau, however, the dissection of the peneplain gradually grows less, and the Wisconsin valley, and also the side valleys, gradually grow shallower, until their floors approximately coincide with the level of the peneplain (compare Figs. 1 and 2, Pl. LXVII). Cappings of erosion remnants of Potsdam sandstone begin to appear in the slightly dissected peneplain in northern Wood and Portage counties, and become quite numerous about Grand Rapids at the border of the sandstone district. South of Grand Rapids, at the rapids of Grand Rapids, Port Edwards, and Nekoosa, the Wisconsin river has exposed crystalline rock, showing the latter in the river bottom, and the overlying, nearly horizontal Potsdam sandstone outcropping above it in thin patches along the river bank. Away from the river the sandstone extends in low ridgy exposures dotting the low plain of the surrounding sandstone district. The dissected peneplain about Wausau thus gradually changes to the undissected peneplain about Grand Rapids, where it is covered with thin sandstone outliers, and for some distance into the sandstone district the pre-Cambrian rocks are seen only in the river bottom, the adjacent flat-lying land being covered with Potsdam sandstone. The descent of the peneplain (summits of the even-topped hills) 7 miles north of Merrill to Grand Rapids, a distance of about 60 miles, is between 550 and 600 feet, indicating an average slope of 10 feet per mile.

West of the Wisconsin river are the Yellow and Black rivers, which also lie across the pre-Cambrian districts, showing at numerous places the truncated edges of pre-Cambrian covered by the horizontal sandstone. The descent of the pre-Cambrian surface along the Yellow river is approximately between 11 and 12 feet per mile. The rate of descent of the crystalline area along the Black river from Neillsville, with an elevation of 996 feet, to Black River Falls, with an elevation of 812 feet, is about 9 feet per mile.

The Age of the Peneplain.—The deeply dissected peneplain seen about Wausau thus passes into the slightly dissected peneplain covered with isolated sandstone remnants, in northern Wood and Portage counties, and at Grand Rapids, Pittsville, and Neillsville it is seen to slip under the Potsdam sandstone and become a buried peneplain (see Fig. 3, Pl. LXVII). Hence we must conclude that this plain was made in pre-Potsdam time.

From the foregoing it has been concluded that the pre-Cambrian land was a worn-down country, a peneplain of erosion, before the Potsdam sandstone was deposited upon it, and that later it was elevated, and through the work of erosion is in the process of being uncovered and dissected. The evidence upon which the pre-Potsdam age of the crystalline peneplain is based is the uniformity in slope of the dissected and buried portions of the pre-Cambrian land. Ordinarily such evidence as this would be deemed conclusive, and it may be so considered in this instance; but, besides the evidence of the uniformity in slope, which may be considered purely physiographic, there are other geological evidences in the partially uncovered portions of the pre-Cambrian area which also point clearly, it is believed, to the pre-Potsdam age of the peneplain.

Residual Clay at the Surface of the pre-Cambrian.—Lying at the contact of the gently sloping pre-Cambrian and the Potsdam, apparently everywhere except about the pre-Cambrian monadnocks, is a widespread formation of partly decomposed crystalline rock and clay. The clay occurs not only at the edge of the sandstone outcrops, but, as shown by a number of well borings, it is also at various distances from these now exposed places and beneath a widely variable thickness of sandstone. The clay varies considerably in thickness, but generally has a depth of 10 to 20 feet, though in places it is known to reach the unusual thickness of 40 feet. It occurs in such abundance that it has been used quite extensively for many years for making brick, and is outlined on Buckley's[1] and Ries's[2] maps of clay deposits of Wisconsin, and shown to be distributed along the boundary of the crystalline and sandstone district. It contains no evidence of sedimentation, and hence could not have been deposited by water. On the other hand, as pointed out by Irving[3] a number of years ago, there is every evidence, as shown by correspondence in structure and composition, as well as gradation downward into the hard rock beneath, that the clay formation had its origin in the weathering and decomposition of the crystalline rocks. It was Irving's belief that the clay, though confined to the pre-Cambrian region, having more or less of a sandstone

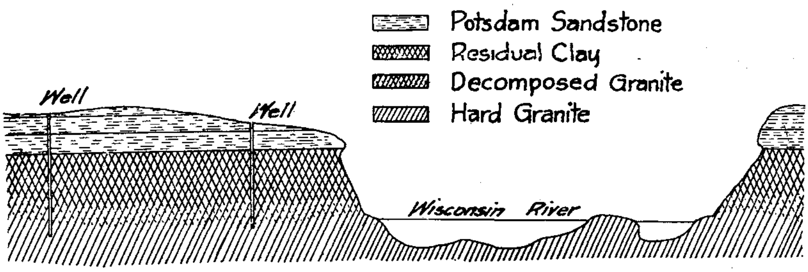

FIG. 12. Section at Stevens Point showing relation of the residual clay to the sandstone and the underlying crystalline rock.

covering and often occurring beneath a few layers at least of sandstone—which fully agrees with the writer's definition of the area—had nevertheless been formed subsequent to the decomposition of the Potsdam sandstone which covers it, instead of antecedant, as believed by the writer.

In the two sections on the Wisconsin river, (Figs. 12 and 13), the position of the clay beneath the sandstone is clearly shown. Immediately south of the Wisconsin Central Railway bridge at Stevens Point on the west side of the Wisconsin river, relations similar to those appearing in the above section are shown. At this place is 10 or 12 feet of decomposed pre-Cambrian rock, overlain by sandstone along the river bank, while 40 feet west

[1] Bull. VII, Wis. Geol. & Nat. Hist. Surv., Plate I.

[2] Bull. XV, Wis. Geol. and Nat. Hist. Surv. Plate II.

[3] Trans. Wis. Acad. of Sci., Vol. II, pp. 13–17; and Geol. of Wis., Vol. II, p. 468.

of the river is a well showing 4 feet of sandstone overlying 12 feet of clay, and 100 feet still farther west, on the west side of the wagon road, on higher ground, is a well showing 12 feet of sandstone and below this 12 feet of the kaolonized pre-Cambrian rock overlying hard crystalline rock. Similar thicknesses of the clay formation were noted beneath the sandstone mounds in which the sandstone quarries are located, on the west side of the river at Stevens Point. Instances of sandstone mounds overlying the clay is shown in many localities. About a mile north of Stevens Point is located the Langenberg brick-yard, the source of the clay here used being a thickness of 15 or 20 feet of the decomposed pre-Cambrian schists. This clay-bed is

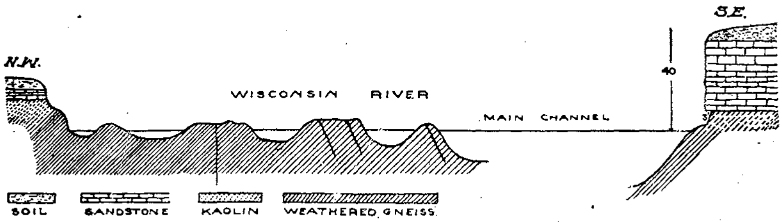

FIG. 13. Section at Grand Rapids showing relation of the kaolin to the underlying weathered rock and the overlying sandstone. After Irving.

about a mile and a half from the Wisconsin river and is not overlain with sandstone, though the latter formation lies at a higher level, forming a low broad hill one-fourth of a mile to the north.

It seems hardly necessary to multiply instances of the occurrence of a variable thickness of the decomposed pre-Cambrian lying beneath an equally variable thickness of the Potsdam sandstone. The relations shown in the above sections are found wherever the sandstone and pre-Cambrian occur, whether it be in natural exposures along the river banks or in the wells dug through the sandstone located far from the streams.

As already stated, it was Irving's belief that the clays were formed *after* the deposition of the sandstone, two possible explanations[1] being offered by him: one, that the clays were formed by processes of weathering during the existing cycle of erosion, but mainly in pre-glacial times; and the other, that "surface

[1] Geol. of Wis., Vol. II, p. 464.

waters, percolating through the porous sandstone—in earlier time much thicker than now—have formed natural water courses along the junction between it and the less easily penetrable crystalline rocks, and have thus exerted an unusual disintegrating action; whilst the sandstone itself has subsequently acted as a preserver of the kaolinized rock from the ordinary eroding agencies." It seems hardly necessary to enter into the details of the explanations offered by Irving[1] and accepted by Buckley[2] for the post-Potsdam development of these clay deposits. It should be borne in mind that the evidence of the peneplain character of the pre-Cambrian land of central Wisconsin formed before the deposition of the Potsdam sandstone, which is believed to be a fact of great significance in conncetion with the origin of the clay, was unknown to Irving. Indeed, the idea of peneplains or base-levels of erosion had hardly been promulgated at the time of his writing in 1876. While it is probable that the processes suggested by Irving may have operated to some extent in the development of the clay formation, it is not thought that either or both combined could have been important factors. It is believed by the writer that the wide-spread occurrence of the thick deposit of clay as a subjacent formation of the Potsdam sandstone obviously points to its origin and its presence there before the sandstone was deposited upon it. This view is entirely in harmony with and strongly supported by what has already been stated concerning the geographic evidence of the peneplain character of the pre-Cambrian land in pre-Potsdam time; for if the pre-Cambrian land surface were degraded to the near level of the sea, it is very evident that the conditions for deep weathering and decomposition of the surface would prevail over large portions of the plain. In the process of degradation of the pre-Cambrian, the less resistent rocks would first be cut down to the limit of slope below which the streams could no longer transport the loose material from the surface, and at this stage of the degradation, when erosion would cease, the most favorable conditions for chemical metamorphism would prevail, and the weathering and decomposition of the rock into clay would be likely to extend even to depths below the

1 Ibid., pp. 463, 464.

2 Bull. VII, Wis. Geol. & Nat. Hist. Surv., p. 217.

level of the sea. In fact, we could hardly expect the degrading of a land area consisting mainly of the silicate minerals like the pre-Cambrian rocks, to the near level of the sea without considerable weathering of the flat-lying surface. Hence the position of the clay beneath the sandstone, in view of the peneplain character of the pre-Cambrian land in pre-Potsdam time, obviously points, it is believed, to its development there before the deposition of the Potsdam formation.

The Time of the Construction of the Peneplain and the Deep Weathering of the Surface.—The period of the uplift of the pre-Cambrian horizon and the construction of the peneplain of central Wisconsin, and the deep weathering and decomposition of the surface, must have occupied a long period, even as time is reckoned in geological chronology. This period is certainly somewhere between the age of the youngest rocks of the peneplain, the Middle or the Upper Huronian, and the age of the sandstone overlying them, the Upper Cambrian. It seems very probable that pre-Cambrian rocks younger than the Middle or Upper Huronian, namely, the Keweenawan, may also be included in this old peneplain in adjacent parts of the state on the south slope of the crystalline district, for these later pre-Cambrian rocks are abundant in the adjoining pre-Cambrian area of the north slope along the shore of Lake Superior. It seems, therefore, that this period of erosion represents at least the whole of the Lower and Middle Cambrian periods, and that it may also have reached back for some distance into pre-Cambrian time.

The Peneplain Buried Beneath the Cambrian.—It will at once be seen that if the pre-Cambrian land of north-central Wisconsin is an old peneplain of erosion formed in the period preceding the deposition of the Potsdam sandstone, it is extremely probable that this peneplain has a wide extension beyond the border of the area here described. It may be of interest, therefore, to point out briefly the general slope of the surface of the pre-Cambrian beneath the adjacent area of the Paleozoic rocks.

It has already been shown that the general slope of pre-Cambrian of the area is about 9 to 12 feet per mile. Thirty miles south of Pittsville, at Necedah, is a mound of pre-Cambrian quartzite having an elevation of 75 to 100 feet above the surrounding alluvial plain. Recent explorations in that vicinity with the diamond drill shows the pre-Cambrian to lie between 200 and 225 feet below the general surface at Necedah (see page 519). The elevation of the railroad at Necedah is 908 feet above the sea level, while that of the buried pre-Cambrian at 4 places about the quartzite knob is shown to be about 700 feet above sea level. The general elevation of the pre-Cambrian surface at Pittsville is 1033 feet, while 30 miles south at Necedah the buried pre-Cambrian surface has an elevation about 700 feet or 330 feet lower, indicating an approximate downward slope to the south of 11 feet per mile.

Fifty-five miles south of Grand Rapids, at Kilbourn City, (shown in Pl. LXVII, Fig. 3), the pre-Cambrian surface is struck at a depth of 385 feet, or 515 feet above sea-level.

In the Baraboo district, where explorations for iron ore have been carried on, the maximum depth of the surface deposits and the Potsdam sandstone appears[1] to be about 570 feet below the 860-foot contour line, indicating the general elevation of the pre-Cambrian plain to lie about 300 feet above sea level.

At Madison, the pre-Cambrian occurs at a depth of 810 feet, or 70 feet above sea-level. In the wells at both Kilbourn City and Madison the pre-Cambrian rock struck was called a shale, and it is apparently very similar to the decomposed clayey schists about Grand Rapids. Furthermore, no conglomerate was found at the base of the sandstone. From Grand Rapids to Madison, therefore, a distance of about ninety miles, the surface of the pre-Cambrian descends from an elevation of 1000 feet to 70 feet above the sea, and thus the slope of the buried pre-Cambrian surface to the south continues in a remarkable manner at the same rate of descent, about 10 feet per mile, that is exhibited by the uncovered and dissected peneplain between Merrill and Grand Rapids (see Plate LXVII, Fig. 3). Between Grand Rapids and Kilbourn City is the Necedah pre-Cambrian quartzite bluff with an elevation of about 1080 feet, and between Kilbourn City and Madison are the Baraboo pre-Cambrian quartzite bluffs, whose highest points reach an elevation of 1600 feet. The Necedah quartzite probably attained an approximate elevation of 280 feet and the Baraboo quartzite ranges an eleva-

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[1] Baraboo Iron Bearing District, Wis. Geol. & Nat. Hist. Survey, Bull. 13, p. 94–5.

tion of 1200 to 1400 feet above the surrounding pre-Cambrian plain. These two elevations of the pre-Cambrian surface consist of hard, resistant rock, and bear a similar relation, it is believed, to the surrounding buried pre-Cambrian that the Powers Bluff and Rib Hill quartzite monadnocks bear to the slightly dissected and deeply dissected portions of the peneplain farther north.

Southeast of the pre-Cambrian area and also southwest there is a much steeper slope to the pre-Cambrian surface, as indicated by the artesian wells at Oshkosh and La Crosse. To the southeast are the pre-Cambrian outliers of rhyolite and granite along the Fox river, which are believed to have been monadnocks in the pre-Cambrian plain.

The uplift and consequent warping of the region which has produced the present slope of the uncovered pre-Cambrian in central Wisconsin, as well as that of its buried portion farther south, is of interest. Briefly stated, as generally accepted,[1] there is a broad anticlinal extending southward from central Wisconsin into Illinois, with a corresponding synclinal depression extending into Michigan on the east and a similar one into Iowa and southern Minnesota on the west. The uniform upward slope of the buried pre-Cambrian from Madison, Baraboo and Kilbourn City, to the uncovered peneplain about Wausau, is thus along the anticlinal. It is believed that the buried pre-Cambrian to the east, at Oshkosh, and to the west, at La Crosse, also had a common peneplain slope with the now exposed portion of the pre-Cambrian, in pre-Potsdam time, and that the steeper slope in these directions at the present time is to be explained as the corresponding synclinals, in the pre-Cambrian, formed since the beginning of Potsdam time.

The Magnitude of the Unconformity.—The unconformity between the pre-Cambrian and the Paleozoic of this region, therefore, is very great, and in the hiatus represented by this unconformity the pre-Cambrian was reduced, by sub-aerial erosion, to the peneplain, and over most parts of this peneplain deep residual soils and clays were developed before being submerged by the Upper Cambrian sea. The general degradation of the pre-Cambrian land to an approximate plain in adjacent portions

[1]T. C. Chamberlin, Geol. of Wis., Vol. IV, p. 424.

of the now exposed pre-Cambrian of the Great Lakes region, as well as of large portions buried beneath the surrounding Paleozoics, is now quite generally accepted. It indicates a generally wide extension of the pre-Cambrian continent in the period preceding the general submergence of the land by the early Paleozoic sea. The unconformity between the pre-Cambrian and the Paleozoic may therefore be considered as one of the first magnitude. Perhaps nowhere else can this great unconformity be seen to better advantage from a purely physiographic, as well as geologic point of view, than in this region of north-central Wisconsin, especially in the driftless area along the Wisconsin river, where not only has the original slope of the pre-Cambrian land been preserved with very slight change through all the long subsequent ages following the pre-Cambrian, but here also this early land surface has not been buried and obscured by the accumulations of the Pleistocene glaciers.

PALEOZOIC GEOLOGY.

CHAPTER VII.

THE POTSDAM SANDSTONE.

The only formation of the Paleozoic series occurring in this area is the Potsdam (Upper Cambrian) sandstone. In adjoining parts of the state, to the southeast, south and southwest, near the outer borders of the state, overlying the Potsdam sandstone, occur later formations of limestone and sandstone belonging to the Ordovician, Silurian and Devonian systems.

In the following table is presented a statement showing the complete succession of the Paleozoic systems in North America and those portions of these systems represented in the southeastern, southern and southwestern part of Wisconsin, and also the single formation occurring in the area of North Central Wisconsin:

TABLE OF PALEOZOIC FORMATIONS IN AMERICA AND WISCONSIN.

North America.		Southern Wisconsin.	North Central Wisconsin.
Permian system			
Pennsylvanian system			
Mississippian system			
Devonian system	Upper		
	Middle	Hamilton limestone	
	Lower		
Silurian system	Upper	Waubakee limestone beds	
	Middle	Niagara limestone beds	
	Lower		
Ordovician system	Upper	Hudson River shale	
	Middle	Galena limestone Trenton limestone	
	Lower	St. Peter sandstone Lower magnesian limestone	
Cambrian system	Upper	Potsdam sandstone	Potsdam sandstone.
	Middle		
	Lower		

An examination of the table shows that in the southern portion of Wisconsin only portions of the Cambrian, Ordovician, Silurian and Devonian systems are represented. The Mississippian and Pennsylvanian systems, formerly known as the Carboniferous system, and the Permian system are wholly unrepresented. In North Central Wisconsin only a portion of one formation of the Cambrian, the Potsdam sandstone, is present.

POTSDAM (UPPER CAMBRIAN) SANDSTONE.

Forming the base of the Paleozoic strata in Wisconsin is the Potsdam sandstone formation, a fairly uniform rock in composition and general character. In those parts of the state where the entire formation remains intact beneath overlying strata, this sandstone attains a thickness, generally varying between 700 and 1000 feet. In this area, however, only the lower portion of the formation is present, as remnants in isolated patches and mounds, in certain portions of the district. It probably does not exceed, in the mounds and ridges of this area, a thickness of 300 feet.

DISTRIBUTION.

As shown on the general map (Plate I), the Potsdam sandstone occurs in isolated patches in the southeast and western parts of Marathon County, in the southern and western parts of Taylor County, and over the whole of Clark, Wood and Portage counties. This formation appears to be entirely absent in Lincoln County, and those parts of Langlade, Price and Rusk counties included in this area.

The general base level condition of the pre-Cambrian rocks, previous to the Paleozoic era, has already been briefly referred to. The sandstone, therefore, lies upon a comparatively flat-lying rock floor or peneplain. In the northern part of the area, where the pre-Cambrian crystalline rocks mainly constitute the surface formations, the sandstone occurs only in a few isolated patches. The streams flowing southward from the area of the pre-Cambrian have cut through the sandstone beds to the crystalline rocks for many miles after entering the main sandstone district of the southern part of the area. The sandstone district and the pre-Cambrian therefore dovetail with one another, the sandstone outliers extending far north upon the divides into the general pre-Cambrian district, and the crystallines being abundantly exposed along the stream beds far to the southward within the general area of the sandstone.

In the report[1] of the former Geological Survey, the sandstone boundary was placed in the vicinity of Stevens Point, Pittsville, Marshfield, Neillsville, and where the Eau Claire river crosses from Clark County into Eau Claire County. The present investigation of the writer, however, on account of the greater accessibility of the district and from data derived from farmers' wells, has shown that the sandstone extends much farther northward into the pre-Cambrian district than was formerly supposed. The occurrences in the various counties are described in some detail in subsequent pages.

GENERAL CHARACTER.

The sandstone largely consists of rounded grains of sand partially cemented by silica and by iron oxide. The formation varies from a fairly pure sandstone to a rock containing much clay material associated with the sand. The formation is rarely a firmly cemented rock, but generally consists of a mass of incoherent sand which readily disintegrates and falls to pieces when exposed to the weather. There is therefore a considerable variation in the firmness and coherency of the various beds of the formation, and for this reason certain beds disintegrate and are eroded with much greater ease than others. Because of unequal resistance to weathering, therefore, the mounds of sandstone which occur in certain portions of the area present rock walls formed of a series of projecting and receding beds. Invariably a hard bed of coherent sandstone forms the capping layer of these mounds, which has served as a protection to the underlying strata. The underlying beds crumble away readily

[1] Geol. of Wis., Vol. II, pp. 529–532; and Geological Map, Plate I.

and form either the vertical walls of receding and projecting beds, or gentle talus slopes of loose sand leading down from the resistant caps to the low-lying ground surrounding.

In a few places only is the sandstone firm enough to be used for building purposes. In the northern part of the sandstone district, where the sandstone occurs as a remnant outlier, lying upon the crystalline rocks, the sandstone is useually a hard, coherent formation—in fact, its hardness and coherency have undoubtedly been the cause of these patches remaining intact while the surrounding less resistant portions were eroded. Hence these small mounds in the interior of the area constitute fairly firm rocks and many of them are quarried for building stone. In certain parts of the area, as in southwestern Clark County, the formation appears to contain considerable clay material, the rock approaching a sandy shale which disintegrates into a sandy, or a sandy loam soil. Further west, in Eau Claire County, the upper portion of the Potsdam contains many calcareous beds.

Fossils were not noted in the sandstone of this area. While fossils were not especially searched for, the Potsdam formation throughout the area appears in general to be deficient in traces of life. The most likely places for the occurrence of fossils are the clayey strata intercalated with the sandstone. The calcareous beds farther west in Eau Claire County contain abundant fossils.

The sandstone occurs in beds lying in approximately horizontal position, with slight dip to the south and southwest. These beds vary in thickness from a few inches to a foot or more. Jointing is common, both horizontal and vertical joints being present, thus causing the formation to weather into rectangular masses.

At the base of the sandstone formation occur, in a few places, the coarse conglomerate beds made up of the debris of the underlying crystalline rocks. The conglomerate is especially abundant about the quartzite and granite knobs which apparently formed monadnocks in the peneplain of the pre-Cambrian continent. While conglomerate consisting largely of quartzite pebbles is abundant about the quartzite knobs, coarse beds at the base of the sandstone are generally absent over the residual clay deposits of the crystalline peneplain. The occurrence of the coarse conglomerate about the monadnocks in the peneplain seems to clearly indicate that these hard rock hills furnished rocky shore lines against which the waves of the Potsdam sea eroded and deposited coarse debris.

TOPOGRAPHY.

The sandstone furnishes distinctive features to the topography only in Portage, Wood and Clark counties, where it forms mounds varying in height from 15 to 20 feet up to 200 feet. The sandstone mounds are especially abundant only in the area of the thin drift or the alluvial flats of these counties. While sandstone is known to occur farther north, it is there usually covered with the drift formations.

Sandstone forms vertical walls from 10 to 20 feet high along many of the small streams and the rivers in the main sandstone district in the southern and southwestern parts of the area. The mounds of sandstone in Portage, Wood and Clark counties add a picturesque appearance to the otherwise monotonous plain in which they occur.

With the progress of erosion the sandstone mounds come to assume various forms according to the different degrees which their several parts are weathered and eroded. The mounds are capped with thick coherent beds of sandstone, beneath which lie less coherent and resistant ones. Two types or kinds of mounds may be specified, those with relatively resistant beds beneath the protecting caps and those with relatively soft beds beneath the capping strata. The former weather into mounds with approximately vertical walls, the erosion proceeding chiefly along the joints and along the layers of softer sediments, dividing the mass into fluted and corrugated escarpments of great beauty, as shown in Plate LXIX. The latter weather into mounds with gentle talus slopes of loose sand capped above by the projecting resistant strata, as shown in Plate XLV.

DETAILED DESCRIPTION.

Marathon County.—In the southeastern portion of Marathon County, sandstone is known to occur in Sec. 30, T. 28, R. 9 E. This occurrence of sandstone is of small extent, perhaps not more than 2 or 3 feet thick, lying immediately upon crystalline rock. A sandstone ledge occurs in the N. ½ of NE. ¼ of Sec. 26, T. 26, R. 8 E. In Town 26, Range 9 E. are several other occurrences of sandstone, some of which are quarried for building stone. In townships 26 and 27, R. 10 E., isolated occurrences of sandstone probably occur beneath the thick drift covering, although in this vicinity none were observed by the writer.

In western Marathon County, sandstone was not found farther east than T. 29, R. 2 E.; sandstone outcrops along the road where the small stream crosses in the NW. ¼ of NW. ¼ of Sec. 21, town of Holton, (T. 29, R. 2 E.). In a number of wells in sections 18 and 19, in Holton, sandstone was struck. Sandstone occurs in several wells in the village of Abbotsford.

In the town of Hull, T. 28, R. 2 E., found sandstone only at one place, in well of H. Weller, Sr., in the SW. ¼ of SE. ¼ of Sec. 30. The sandstone appears to be but a few feet thick and occurs in the wells on both sides of the road at this place.

In the town of Brighton, T. 27, R. 2 E., sandstone was struck in a number of wells about 2 miles southeast of Unity, in sections 7, 8, and 17. The sandstone in this vicinity lies beneath 18 to 30 feet of drift and but a few feet of sandstone is reported.

In the town of Spencer, T. 26, R. 2 E., sandstone is quarried at several places in the southern parts of sections 33 and 34, largely used for building stone in the city of Marshfield. The sandstone in this vicinity attains a thickness of 30 or 40 feet. There is no record of the occurrence of sandstone in other parts of this town, although it probably occurs in many places beneath the drift.

About 6 miles northwest of Wausau upon the farm of A. Luebke, in Sec. 5, T. 29, R. 7 E., occur a number of loose blocks of sandstone, indicating the probable presence of sandstone in place in the near vicinity. These loose blocks occur in an area of very thin drift and probably are not far removed from their original position, although no outcrop was found.

Portage County.—Isolated areas of sandstone occur over the whole of Portage County. They are especially numerous in the southern part and but sparsely distributed over the northern portion. East of the Wisconsin river occurrences of sandstone were noted along th road in the NE. ¼ of Sec. 36, T. 25, R. 7 E., and in considerable abundance in the vicinity of the NE. corner of Sec. 31, T. 26, R. 8 E. Sandstone also occurs in considerable abundance along the road in the SE. 1/4 of Sec. 21, T. 25, R. 8 E.

Farther east, in the towns of Sharron and Alban thick drift is abundant and no outcrops of sandstone were noted. But few wells in this region penetrate entirely through the drift and in the few recorded instances crystalline rock was struck beneath the drift.

In the town of Hull which includes a portion of T. 24, R. 7 E., and the whole of T. 24, R. 7 E., sandstone is fairly abundant. Some of the more prominent occurrences are in Sec. 11, T. 24, R. 7 E., in Secs. 1 and 2 of T. 24, R. 8 E., and near the centre of NE. 1/4 of Sec. 36, T. 24, R. 8 E., at the latter place the sandstone is quarried for building stone.

In the NE. 1/4 of the NW. 1/4 of Sec. 7, T. 24, R. 9 E., in town of Sharron, are several knobs and low hills of sandstone, furnishing excellent stone for building purposes. The Polish Catholic church in Polonia was constructed of this stone.

In the northwestern part of Portage County, west of the Wisconsin river, sandstone was observed at only a few places in the town of Eau Pleine. Low hills of disintegrated sandstone occur in the NE. 1/4 of the SE. 1/4 of Sec. 27, T. 25, R. 7 E. Sandstone occurs along road near centre of SW. 1/4 of SW. 1/4 of Sec. 23, T. 25, R. 6 E., and near Milladore, along road in NW. 1/4 of Sec. 30 and also NW. 1/4 of Sec. 31, of T. 25, R. 6 E. In the town of Carson sandstone is fairly abundant, and in the town of Linwood are numerous large low mounds and hills of this formation. Sandstone is especially abundant, as shown on the general map, forming ridges in Secs. 7, 8, 9, 11, 12, 14, 15, 16, 17 and 18, of T. 23, R. 7 E.

The southern half of Portage County is very probably quite generally covered with sandstone beneath the alluvium and drift. These later formations, however, are so abundant in this portion of the county that few occurrences of sandstone appear at the surface. Two sandstone outcrops occur in the NW. 1/4 of Sec. 12, T. 23, R. 8 E. Numerous sandstone mounds occur in the vicinity of Stevens Point on both sides of the river, as shown on the map. Those in the western part of the city are extensively quarried. A low sandstone mound quarried considerably lies in the NE. 1/4 of the SE. 1/4 of Sec. 15, T. 23, R. 8 E. Several sandstone mounds and pinacles occur in the vicinity of Bancroft, in Secs. 14, 23 and 24 of T. 21, R. 8 E. All of these mounds furnish quarry stone. They have an elevation varying from 75 to 175 feet (estimated) above the surrounding alluvial plain. Mosquito Mound in the SW. 1/4 of Sec. 24 is the most prominent of these, having an elevation of about 175 feet. The topmost layers only are quarried for building stone the lower beds of the mound being too incoherent for constructional purposes. Over the summit of the mound is a thin covering of glacial drift. The thickness of alluvium in the vicinity of Bancroft, at the C. & N. W. R. R. station is at least 97 feet and hence the sandstone formation of Mosquito Mound is very probably at least 300 feet thick.

In the eastern part of the county, that portion covered by the thick Wisconsin drift, numerous outcrops of sandstone were observed. The formation undoubtedly rapidly grows thicker toward the southeast, though the formation is quite generally covered by the thick terminal moraine deposits of the Wisconsin drift sheet.

Wood County.—The sandstone occurs in isolated patches, as already stated, over the entire area of Wood County, being sparsely distributed over the northern part and fairly abundant over the southern portion. As shown on the outcrop map, (Plates XII and XV) the occurrences in the northeastern part are generally quite small. They are also relatively of slight thickness.

Sandstone is abundant in the southern part of the county the general distribution of which is shown on the general map, (Plate I). Outcrops of considerable extent occur along the Yellow river in the NE. 1/4 of Sec. 27, and in the SE. corner of Sec. 35 of T. 25, R. 2 E. A sandstone mound of considerable extent occurs about a mile north of Lindsay, in the NW. 1/4 of Sec. 17, T. 24, R. 2 E. Sandstone is abundant in low hills in the southern part of the towns of Hansen, of Sigel, and of Rudolph. In the NE. 1/4 of Sec. 30 and NW. 1/4 of Sec. 29, of Rudolph, the formation is a fairly hard firm rock and is used to a considerable extent for building purposes. Sandstone is exposed in numerous places along the Wisconsin river from Biron's Mill to Nekoosa overlying the residual clays and crystalline rocks.

In the broad alluvial plain of southern Wood only one noteworthy outcrop of sandstone occurs,—the South Mound about 6 miles southwest of Babcock, in the vicinity of the NW. 1/4 of Sec. 25, T. 21, R. 2 E. South Mound is probably not more than 50 or 60 feet high but it is a feature of considerable prominence in the surrounding alluvial plain.

Clark County.—Clark County like Wood and Portage counties lies wholly within the area covered by isolated outcrops of the sandstone. The northeastern part of the county is covered with thick drift and in this portion most of the outcrops noted are located along the streams. Quite generally, however, in this part the wells have struck sandstone. The wells as a rule do not penetrate more than 5 to 10 feet of sandstone, a few feet of the sand furnishing an abundance of water.

Where the Wisconsin Central railroad crosses Black river in the NE. corner of the SE. 1/4 of Sec. 32, T. 29, R. 2 W., is a sandstone quarry on the east bank of the river showing the following section, as described by W. D. Smith:

Covering of drift	4 feet.
Loose sand, white and yellow	1 to 2 feet.
Alternating layers 3 to 6 inches thick of shaly sandstone and sandstone	3 feet.
Sandstone beds 6 to 12 inches thick	3 feet.
Alternating strata of red and blue shale and thin strata of sandstone	2 to 3 feet.
Thick bed of sandstone	7 feet.
Bluish shale	6 inches.
Yellow sandstone beds 6 to 12 inches thick	3 feet.

The sandstone becomes thicker in the central part of Clark County. In T. 27, R. 2 W. are numerous wells reported by Mr. Sundemeyer of Greenwood, which show a thickness of 15 to 25 feet of sandstone. In the northern part of T. 26, R. 3 W. (see map Plate I) are three large and prominent sandstone mounds known as South Mound, Middle Mound, and North Mound. These mounds reach an elevation of 100 to 150 feet above the surrounding low plain.

In the southwestern part of the county in the area of thin drift, the sandstone or its disinegrated equivalent very largely forms the surface rock, forming numerous ridges and hills.

A few miles northwest of Neillsville are several sandstone mounds (see Plate XLIX), which lie within the area of thick drift. In the southern part of the county prominent sandstone knobs occur in the eastern part of Sec. 28, T. 23, R. 1 E., and in the NE. 1/4 of SW. 1/4 of Sec. 23, T. 24, R. 1 E. Sandstone hills are very abundant in the town of Dewhurst, T. 23, R. 3 W.

Prominent hills of sandstone also occur in the SE. 1/4 of Sec. 12, T. 24, R. 1 E., and in sections 11 and 12 of T. 24, R. 1 W.

Taylor County.—Sandstone is known to occur in only a few places in Taylor County. This formation in thin strata caps the decomposed pre-Cambrian rock along the Black river in the NE. 1/4 of NE 1/4 of Sec. 8, T. 30, R. 1 E. Sandstone was struck in a well beneath 50 feet of drift at Halliday's mill in the SE 1/4 of Sec. 30, T. 30, R. 1 E., and also in a well in the SE 1/4 of SW 1/4 of Sec. 36, T. 30, R. 1 W The above are only the occurrences of sandstone in Taylor County on record, but it seems very probable that this formation lies in considerable abundance in isolated patches beneath the thick drift in the southwesern part of the county.

In Lincoln Couny, and those portions of Langlade, Price, and Rusk counties described in this report, no occurrences of sandstone were found. Lincoln County and Price County are well within the general area of the pre-Cambrian rocks, and it is very probable that no sandstone occurs in these counties. The southeastern portion of Langlade County and the western part of Rusk County are probably within the area of sandstone outliers.

FORMER EXTENSION OF THE PALEOZOIC OVER THE PRE-CAMBRIAN OF NORTHERN WISCONSIN.

How far to the north, over the pre-Cambrian district, the Potsdam sandstone was once distributed is not now definitely known. As already stated, the present survey has shown the presence of remnants of the sandstone much nearer the centre of the pre-Cambrian ditrict than it was formerly supposed to occur. The Paleozoic formations of Wisconsin surrounding a central core of older pre-Cambrian rocks appear to owe their characteristic zonal distribution to a general uplift of the region combined with subsequent erosion. The period elapsing between the uplift of the Paleozoic and the present is certainly long enough for a vast amount of erosion to take place with the subsequent removal of vast quantities of rock.

A set of phenomena is presented in this region which appears to strongly support the theory that the pre-Cambrian of a large part, if not the whole, of northern Wisconsin was submerged by the early Paleozoic sea and covered with thick deposits of the Paleozoic formations.

The class of evidence referred to is physiographic and is furnished by the history of the development of the drainage system of this area, which is fully described in the following chapter on physiography. Pages (617–621).

The abnormal features of the valleys in the pre-Cambrian of this area indicate clearly that the drainage lines which carved these valleys out of the pre-Cambrian had their inception upon overlying Paleozoic strata in consequence of uplift, and, that, finally sinking through overlying gently sloping beds, at last met with the underlying pre-Cambrian crystallines and was superimposed upon the latter.

Briefly stated, therefore, the position and course of the valleys in the pre-Cambrian rocks are obviously those developed, not by consequent streams upon the pre-Cambrian, but by streams which were originally developed consequent upon uplift of overlying Paleozoic strata, and were later superimposed upon the pre-Cambrian. The superimposed character of the drainage is best illustrated in the region about Wausau, in the non-glaciated area, but it is obvious from the study of the drainage in the driftless area that the rivers and valleys have the character of superimposed drainage over a large portion of the surrounding region, if not the entire surrounding region, of the drift-covered pre-Cambrian, in which no trace of the Paleozoic now remains. This supposition, if true, can be fully demonstrated when the location of the pre-glacial valleys in the drift-covered parts of northern Wisconsin are studied in detail and mapped with respect to the various pre-Cambrian formations.

Another set of phenomena, of paleontologic nature, which lies outside this particular area, but within this general region, may be appealed to in connection with the theory of the former extension of the Paleozoic formations. It is well known that large areas of the formations overlying the upper Cambrian, such as the Trenton and Niagara, occur in considerable abundance north of, and essentially surrounding, the Lake Superior region. The occurrence of fauna in the Niagara formation north of Lake Superior similar to that farther south is of such a character as to indicate that the Niagara sea may very likely have extended continuously across the Lake Superior region, thus giving rise to favorable conditions for the similar life development north and south of Lake Superior.

To the above evidence may also be added that furnished by the general and widespread degradation by erosion of the pre-Cambrian continent in pre-upper Cambrian time, the condition of the low-lying pre-Cambrian being obviously such as to greatly facilitate submergence during the Paleozoic transgression.

Furthermore the general incoherency and unconsolidated character of the Potsdam sandstone and of the later sandstones and shales of the Paleozoic of this part of the continent is such as to indicate that these formations could easily have been eroded with relatively slight uplift during the long period since the Paleozoic.

Thus not only the evidence of the secondary character of the drainage superimposed upon the pre-Cambrian but also paleontologic evidence in the surrounding region, to which may be added the evidence of the base-leveled condition of the pre-Cambrian continent, and the easily weathered character of the Paleozoic formations all support the view that not only the Potsdam sandstone, but also the overlying formations, up to the Niagara, may once have extended over the pre-Cambrian of northern Wisconsin, and have long since been eroded.

THE EROSION INTERVAL FOLLOWING THE PALEOZOIC SEDIMENTATION.

To what extent the deposition of the lower Paleozoic formations extended over this region as above stated, is not definitely known. The formations in the general geological column between the Potsdam sandstone and the next overlying formation in this area, namely the Pleistocene drift and alluvium, are indicated in the following table:

Table of Geological Formations.

North America.	North Central Wisconsin.
Cenozoic Series:	
Pleistocene	Pleistocene drift
Tertiary:	
Pliocene	
Miocene	
Oligocene	
Eocene	
Mesozoic Series:	
Triassic	
Jurassic	
Cretaceous	
Paleozoic:	
Permian	
Pennsylvanian	
Mississippian	
Devonian	
Silurian	
Ordovician	
Cambrian	Potsdam Sandstone (Upper Cambrian)

As indicated in the table, nearly the whole of the Paleozoic series, namely, all above the Upper Cambrian (Potsdam), the whole of the Mesozoic series and the Cenozoic series up to the Pleistocene is unrepresented in this area.

This region, during the deposition of these unrepresented systems, was evidently above sea level (with the probable exceptions above referred to) and was therefore subject to the usual process of degradation of land masses, such as weathering and erosion. The degradation of the land during this long interval of sub-aerial erosion was one of profound extent. In magnitude, it is, perhaps, comparable to that earlier period of land waste during which the pre-Cambrian land was worn down to base level.

PLEISTOCENE OR GLACIAL GEOLOGY.

CHAPTER VIII.

THE GENERAL CHARACTER AND ORIGIN OF THE DRIFT AND OF ICE SHEETS.

GENERAL INTRODUCTION.

The long period of weathering and erosion of the Cambrian sandstone and later Paleozoic formations of Wisconsin continued to the beginning of the Pleistocene or Glacial Age. This long interval between the Paleozoic and Pleistocene, as already stated, is represented in geological history by the whole of Mesozoic and Tertiary time. So far as at present known, there are no records of marine or other deposits formed in Wisconsin in this interim. Deposits of the Cretaceus period (Mezozoic Age) are known to occur, however a few miles west of Wisconsin, in Minnesota, and it seems quite probable that the land of Wisconsin was not only near sea level but partly or wholly submerged during the Cretaceus period, and possibly also during other geologic periods, but, as above stated, no records of a Cretaceous or other submergence have ever been found. From the Paleozoic to the Pleistocene the State appears to have been subjected to erosion, very probably however, at a very non-uniform rate, because of changes in the elevation of the land which we may reasonably suppose must have occurred.

The beginning of the Pleistocene period was not, however, brought about by submergence of the land below sea level, but by the inception of marked climatic changes, and the invasion of the region by a succession of ice sheets. Under the name of the Glacial Period, or the Ice Age, an unusual episode in the geological history of the Northern Hemisphere is denoted. The change of temperature from the comparatively warm climate, which marked the close of the immediately preceding Tertiary, to the alternating cold and warm intervals of the

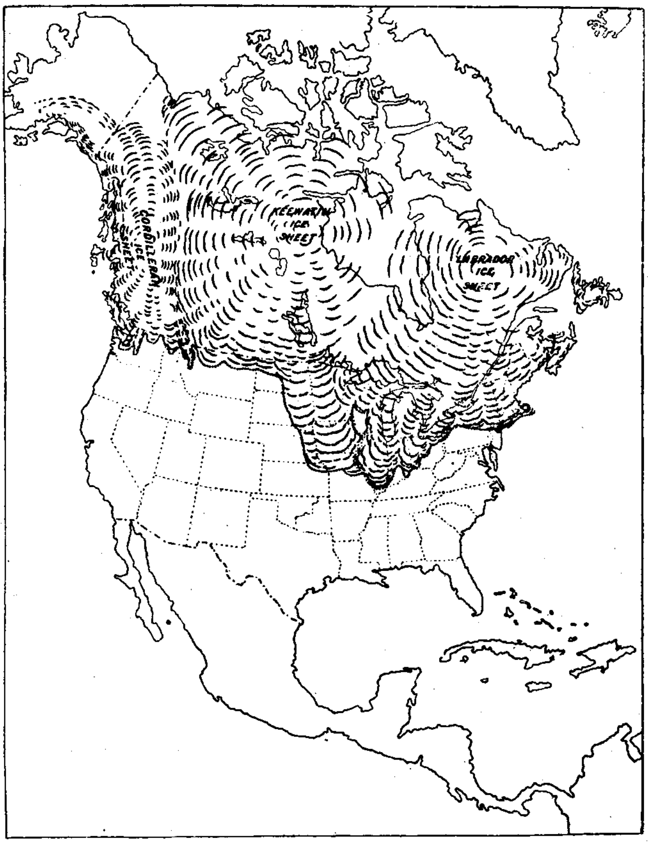


FIG. 14. Map of North America showing portion covered by the ice in the glacial period.

Glacial or Pleistocene, not only affected the northern portion of North America, but also extended over a large part of Europe. In the Western Hemisphere the ice invasions extended as far south as central New Jersey on the Atlantic coast, to the Ohio and Missouri rivers in the Mississippi Valley, and into northern Washington on the Pacific Coast (see map Fig. 14). In Europe the ice sheets extended over most of the British Isles, northern Germany and north-western Russia.

The work of a glacial invasion includes that of the erosion and the removal of the soils and superficial deposits, as well as that of the deposition of the various heterogeneous materials carried forward by the ice. Glaciers, like mighty rivers, are powerful agents shaping land topography, and like rivers, carry on the work of erosion in certain portions of their courses, while in other portions they are mainly occupied with the work of deposition. In the district of north central Wisconsin the work of the various ice sheets was mainly that of depositing rock debris, rather than that of the erosion and removal of such material. The reasons for this can best be understood as the general succession of events in the glacial history of the area is described.

The rock debris, eroded, transported, and deposited by an ice sheet is called glacial drift, or merely drift, and is spread, with unequal thickness, like a mantle, over the surface of the land. The drift consists of a mass of clay, sand, gravel and boulders, the materials of which may be confusedly commingled, or more or less assorted and separated into stratified layers. The character of the drift varies, therefore, from place to place; here there are heaped up ridges of coarse bouldery material, and there there are broad plains of sandy stratified deposits, and in still other places there occur a commingling of various types of deposits. The variation in the character of the drift deposits very largely depends upon the manner of deposition, whether directly by the ice, or by water accompanying the ice.

It has already been inferred that the Glacial Period consisted of a succession of ice invasions, each of which extended over a considerable time. After each invasion there was a long interlude of mild climate during which the fauna and flora spread northward and occupied their former habitats. The general succession of events has been largely the same in Europe and in America with various local modifications.

Since the Glacial geology of the district here described is complex, and includes a series of glaciations, it is thought advisable, first, to discuss briefly the general origin and work of glaciers, the origin and nature of glacial deposits and their manner of distribution, and then to treat each stage of glaciation occurring in the district in detail in the order of its succession.

THE DEVELOPMENT OF AN ICE SHEET.

The origin of alternating long periods of cold and warm climate need not here be discussed. There is abundant evidence in geologic history that climatic change is a common feature of the earth's atmosphere, and especially is this true of the later geologic periods. Changes in climate are undoubtedly slow, and, measured in years, require considerable time, very probably tens of thousands of years. Suffice it to state that as the temperature of a region gradually grows colder and colder, and the winters grow longer and longer, the summer's heat, finally, is insufficient to melt the winter's snow and perennial snow fields are formed. When once this process is inaugurated the depth of the snow would increase from year to year, until finally in the course of time, and under favorable conditions, the extent of the snow fields would reach very large dimensions, and the depth of snow would become very great.

As the snow field attains great thickness its lower portion would eventually be converted into ice, on account of the slow granulation and crystallization of the snow as it assumes a more compact form, on account of the seepage of water from the partial melting at the surface, and of the pressure of the overlying snow. When the thickness of the snow and ice has become considerable, the pressure upon its lower portion will become great. Under progressive granular growth and great pressure ice exhibits the characteristics of a semi-fluid body and is capable of flowing with extreme slowness. The ice field would, therefore, flow outward from the center of the field, and the region surrounding the area of accumulating snow would be gradually invaded by the spreading ice.

Fig. 1. VIEW OF GLACIER SHOWING DEBRIS AND STRUCTURE OF THE ICE

Fig. 2. CHARACTERISTIC END OF A GREENLAND GLACIER.

VIEWS OF THE GREENLAND GLACIERS.
(From Chamberlain & Salisbury's Geology.)

An excellent example of the conditions surrounding the growth and movement of a vast ice sheet is afforded by Greenland to-day. A large part of the half million square miles which this island contains is covered by a vast sheet of snow and ice thousands of feet thick. In the interior portion of the island the snow is accumulating and gradually changing to ice. In this vast field there is continual, but slow, movement, and the ice creeps slowly towards the border of the island, moving forward until its margin finally becomes melted and evaporated by the warmer climate adjacent to the ocean. In many places the margin is pushed out into the sea and broken off in fragments that float away as icebergs. See Plate XLIII.

On a smaller scale the growth and movement of glaciers is well illustrated in the Alps and the Rockies, and other regions of high altitude. In the mountains the snow fields accumulate on the upper slopes whence they move down into the ravines and valleys, changing to ice and becoming veritable rivers of ice, moving slowly but steadily to the lower levels and eroding and depositing rock fragments, clay, and sand along their courses. The glaciers descend until they reach the lower and warmer portions of the mountain slope, where they are melted, and their course down the rest of the valley is taken by a stream of muddy water formed by the melting of the ice.

Glaciers, though naturally more abundantly developed at the present time in the frigid climate of the Arctic and Antarctic regions, are also in any latitude where a sufficient snow fall accumulates and remains throughout the year. They occur in the Himalayas and the Andes along the equator as well as in the Alps and the Rockies in the temperate zone.

The glaciers in the mountainous regions are typical valley glaciers, or rivers of ice, and are confined to the steep valley slopes, whereas those developed in the broad tract of Greenland and elsewhere in the polar region can best be designated as ice sheets. In the regions of the ice-sheets, or ice-caps, the ice attains a thickness of thousands of feet (in the South Polar Circle estimated to be 10,000 feet thick), and only the highest mountain tops remain unconcealed.

The drift mantle distributed over parts of North America and Europe during the Ice Age was undoubtedly deposited by broad ice sheets like those now prevailing in Greenland and the polar regions rather than by valley glaciers such as those now existing in the high mountains. During the Ice Age most of the northern half of the North American continent was covered by successive ice sheets which had their origin in the region of Hudson Bay and from there moved outward from one or more centers under the pressure of their own weight, and advanced to the southward. The total area of the maximum development of the North American ice sheet has been estimated at 4,000,000 square miles, about 10 times that of the present ice field of Greenland.

THE WORK OF AN ICE SHEET.

As the ice advanced over the land it gathered up and carried forward in its mass more or less debris from the surface over which it moved. The work of an ice sheet, therefore, is very much like that of a river as it moves along its channel, and consists of erosion, transportation and deposition. The beds of glaciers now living in the Alps and in Greenland present the same features as those exhibited by the drift mantle of this region where glaciers no longer exist; hence we can obtain a clear conception of the effects of the Pleistocene glaciation in this region by examining the phenomena now attendant upon living ice sheets.

Eroding Work of an Ice Sheet.

The erosion by an ice sheet is affected only to a small extent by the direct contact of the moving ice against the hard rock; it is mainly accomplished by the rubbing of boulders, gravel and sand held within the mass of the ice. The debris in the grasp of the ice as it creeps along is pressed against the hard rock surface, moves over each little inequality, and is continually wearing, grinding and polishing the rock over which it advances.

The work of the ice sheet as it slowly moves, therefore, consists in gathering up the loose material in its course, wearing down the inequalities in the land surface, and polishing and grooving the rocks in its wake. The material held within the ice is also ground up and made finer and finer as the ice advances.

The abrasive effect of a moving sheet of ice like that which prevailed over the North American Continent was very great. Almost every inch of land surface over which the ice moved

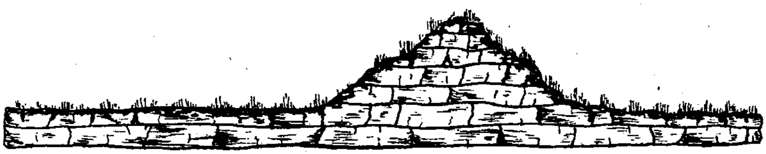


FIG 15. A hill before the ice passes over it.

would be subjected to loss of material. The sharp, pointed hills and the angular faces of cliffs would be filed off and smoothed down to such forms as would offer less and less resistance to the moving ice.

The erosive effect upon the land surface depends largely upon local conditions of topography. Hilly regions, which necessarily offered greater resistance to the invasion of the ice, would be more affected than flat plain-like areas. Valleys, when they were parallel to the ice movement, would tend to be widened

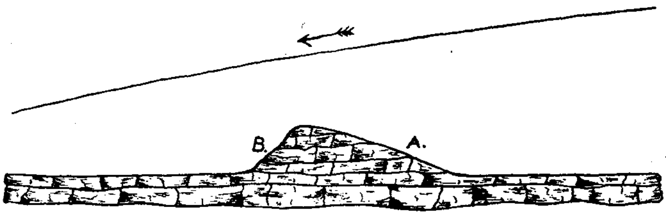


FIG 16. The same hill after it has been eroded by the ice. A is the stoss side, B the lee side.

and deepened and would be subjected to much greater erosion in general than those lying transverse to the direction of ice movement. The character of the rock, of the land surface, whether relatively hard or soft, as well as that held within the ice, as abrasive tools, would cause a relative variation in amount of erosion. The general total effect of ice erosion, while deepening valleys here and there, would in all cases be a softening of the land relief, and a modifying of rugged contours to those more gentle.

Transporting Work of an Ice Sheet.

The transporting power of a vast ice sheet is enormous. Due to the semi-rigidity of its mass it is capable of carrying forward great blocks of solid rock as well as the finest particles of sand and clay.

The larger part of drift transported by ice is carried in the basal portion of an ice sheet and hence the work of transporting and eroding is accomplished in the same movement. The basal drift of an ice sheet is especially abundant in plain-like areas devoid of hills.

In a rough country there is a marked tendency for the drift to work up towards the interior portions of the ice sheet, the elevation to which it would rise apparently being closely related to the height of the hills and mountains.

In valley glaciers most of the glacial debris is carried on the surface of the ice on account of the falling of debris from the steep slopes and cliffs above. In thick ice sheets, however, which advanced over comparatively gentle slopes, like those prevailing over northern Wisconsin, but little drift was probably carried on the surface of the ice. There is more or less shifting, however, of the ice drift, due to various causes, in its forward movement, especially at the margin of the ice, tending to distribute the drift from base to surface of the sheet.

The distance to which drift is transported is known to be very great, and is only limited by the center and circumference of the ice sheet. The great majority of the stony material, however, can be traced to the local rock of each district where it occurs, and has come mainly within a distance of a few miles. While much the larger percentage of the rock debris travelled but a few miles, yet there is always present more or less drift which must have been carried hundred of miles in the ice, and in regions of vigorous glaciation great quantities of foreign material are present.

The direction of ice movement is indicated by transported debris from known sources and by the rock striae and grooving made by the eroding ice.

Depositing Work of an Ice Sheet.

On melting, the ice sheet leaves in its bed the debris, eroded and transported during its advance. The usual tendency is for the ice to carry forward to its margin a large part of its load and there drop it as the ice edge is wasted by melting and evaporation. Much of the drift, however, as above stated, is carried but a short distance from its source before it is lodged. Hence the drift is accumulating along the base of the ice sheet as well as at its margin.

A characteristic feature of the glacial deposits is their structural heterogeneity. See Fig. 1, Pl. XLIV. The unequal distribution of the drift is another feature of the deposits. Figs. 17

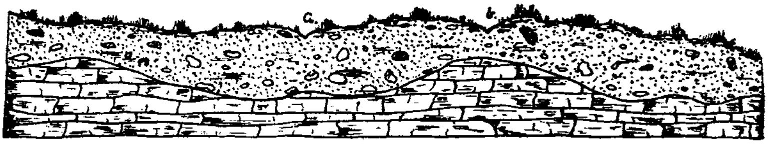


FIG. 17. Diagrammatic section showing relation of drift to underlying rock, where the drift is thick relative to the relief of the rock. *a* and *b* represent the location of post-glacial valleys.

an 18. Unequal distribution is due to the varying conditions of ice erosion, as well as a variation in the deposition of rock debris. In hilly and rocky regions more debris would be removed from the land surface, the ice would carry larger loads, and more drift would by deposited by the ice. Where it was hilly also more drift would be lodged beneath the ice. As a great proportion of the drift is left at the margin of the ice on melting, it follows that the longer the marginal portion remained stationery, the larger would be the quantity of drift accumulated there. On account of various causes, such as the inequalities in the ruggedness of the land surface, the unequal hardness and resistance of the rock to ice erosion, the varying thickness of loose material along the course of the ice sheet which would be available for collection by the ice, the unequal amounts of material carried by different portions of the ice, and the varying conditions of deposition under the ice and at its margin, the mantle of drift left by an ice sheet must necessarily vary greatly in thickness, both locally and over large areas, of the glaciated regions.

The great ice sheets modified greatly the topography of the regions they invaded, not only by the erosion they effected, but also by the deposits they formed. Valleys were filled and hills covered. New hills and ridges of drift were accumulated and even plains and broad valleys were formed through the distribution of the ice-borne debris. Along the margin of the ice

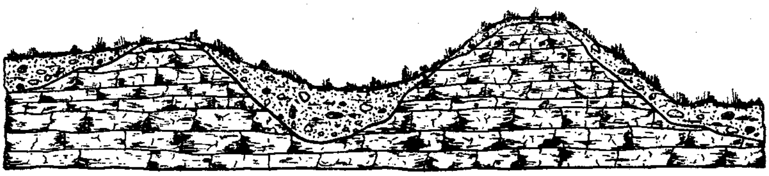


FIG. 18. Diagrammatic section showing relation of drift to underlying rock where the drift is thin relative to the relief of the underlying rock.

sheet, belts of drift hills and ridges were constructed, and on account of the unequal deposition of material, depressions were left on retreat of the ice in which water usually collected, thus forming the numerous lakes and ponds characteristic of drift covered regions.

CHARACTER OF THE DEPOSITS OF AN ICE SHEET.

The outward forms and shapes and the internal structure of the deposits made by an ice sheet and its accompanying water varies greatly from place to place, the general character depending upon whether deposited by ice alone, water alone, or by a combination of ice and water.

Deposits Formed by Ice Alone. Unstratified Drift. Till.

The deposits made by ice alone are not stratified, but are made up of a heterogeneous mixture of various kinds of boulders, gravel, sand and clay. This is because ice cannot assort material, as water does, but on melting the debris is left commingled, the finer parts forming a matrix for the coarser boulders. So characteristic is the heterogeneity of glacial drift with regard to physical structure and character of rock material, that, taken together, these two features afford a safe criterion

Fig. 1. CUT IN DRIFT SHOWING ITS CHARACTERISTIC HETEROGENEITY.

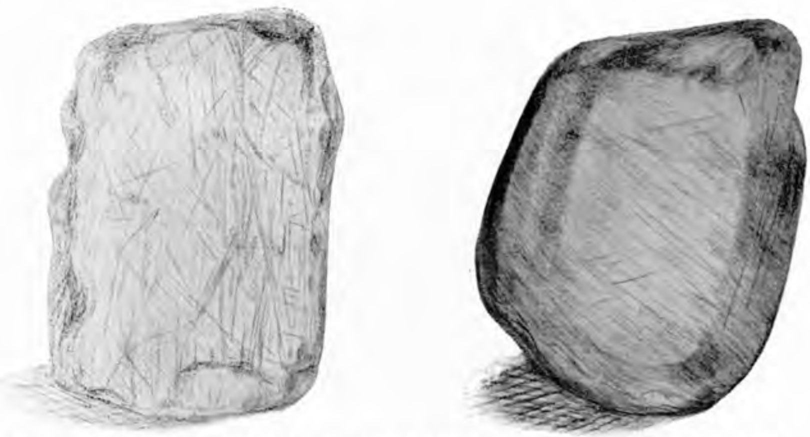


Fig. 2. CHARACTERISTIC GLACIATED STONES. (From Bull. V., Wis. Sur.)

for distinguishing ice-made deposits from all other formations. The striation and grooving made upon the transported blocks of rock by the rubbing of the boulders against the surface of the rock passed over, and also by the wear of boulder upon boulder within the ice are also characteristic features of glacial deposits. See Fig. 2, Pl. XLIV.

The shapes or topographic forms assumed by glacial deposits on account of the internal movement of the ice are usually characteristic, the topography depending upon the place of deposition, whether at the margin of the ice or some distance back of the margin beneath the ice. In the broad sense, all deposits made by glacier ice are moraines, and those made beneath the ice and back of its edge constitute ground moraine, and those made at or near the ice margin are terminal moraines.

Deposits Formed by Water Accompanying the Ice. Stratified Drift.

All the ice of an ice sheet, except that portion which was transformed into vapor, finally passed away as water, and to this was added the rains of the summer seasons which fell upon the ice field. While a very small amount of erosion may be attributed to glacial water, its principal work was that of depositing the finer glacial debris in the region of the ice margin. Since an ice sheet has a marginal belt throughout its whole history, water must have been active along this belt, not only at the margin of the farthest advance of the ice, but also at the margin during its entire advance and retreat. Therefore, the deposits made by water combined with ice, or by water alone, occur throughout the entire region of glaciation.

One of the principal characteristics of the water-formed deposits is the assortment and stratification of the material. Stratified drift, therefore, is considered to be the work of glacial water or the combined work of ice and water. The stratified deposits consist of the finer debris carried by the glacier, such as clay, sand, and gravel, the coarser boulders obviously being too heavy to be transported any distance and assorted by the water. While the stratification of deposits made by the water is much like that of other stratified formations, yet the great variety of rock represented in the pebbles and finer material of the deposits is such as to indicate that they have been carried long distances by the ice and are derived from the same rock formations that the large boulders have come from.

Stratified drift deposits assume various forms, depending upon the relative position of the water and ice. Many deposits are found in the comparatively stagnant waters of lakes and ponds associated with the ice margin. The work of the water may be wrought at and beyond the margin of the ice sheet, or upon, or within, or beneath the ice sheet. The shape of the deposits depends upon the conditions under which they are formed, whether beneath the ice, in sub-glacial streams, or at the edge of the ice by streams or beyond the edge of the ice as outwash plains or valley trains, or in stagnant water at the margin of the ice.

But few deposits are probably formed by the water flowing upon and within the ice sheets. Beneath the ice, however, sub-glacial streams in tunnels were able to build up extensive and characteristic deposits. The bases of the tunnels were of rock or drift and the sides and top of ice. Along these sub-glacial channels deposits of sand and gravel of varying width were formed. Sometimes the deposits were in the form of long sinuous ridges of gravel, called eskers, which vary from a fraction of a mile to several miles in length. Very often also the sub-glacial stream elbowed sideways and built up irregular plain-like deposits. At the edge of the ice sheet there are characteristic deposits built up by sub-glacial streams on emerging from beneath the ice. These deposits at the edge of the ice, in the reentrant angles of the ice sheet, commonly have the form of short ridges of gravel and sand, and are known as kames.

Beyond the edge of the ice the glacial water often formed extensive stratified deposits. If a valley led out from the ice margin, and if the valley slope was of proper gradient to cause deposition, valley trains of gravel and sand were built up. Sometimes, however, the waters that issued from the margin of the ice found themselves on an ordinary plain or slope and in such case they tended to build up a plain of stratified material in the shape of an alluvial fan. These plains are known as overwash plains, or outwash plains, and where conditions of slope were favorable extend for several miles beyond the edge of the ice sheet. The waters that issued from the edge of the ice sometimes flowed into stagnant water, or a lake fringing the ice sheet, and in such cases delta deposits and sub-aequeous outwash plains would be built up. These latter deposits would differ from the former in having steep delta fronts.

Deposits Formed by Ice and Water Combined. Intermingling of Stratified and Unstratified Drift.

The stratified and unstratified drift are sometimes distinctly separate from one another, but more usually they are intermingled with great complexity. The work of water combined with that of the ice gave rise to deposits which neither alone could form. The intermingling of the water and ice deposited

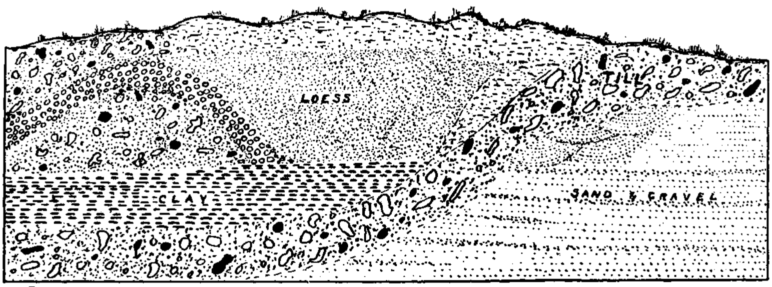


FIG. 19. Cut through a terminal moraine showing the intermingling of stratified and unstratified drift.

material is readily understood when it is remembered that glacial waters are active in all stages of an ice sheet movement, both during the advance and retreat of the ice edge, and that the ice edge is subject to more or less oscillation in advancing and retreating, so that at each advance the stratified material is likely to be covered up with the unstratified material. Furthermore, most land areas have been subject to more than one glacial invasion or ice epoch and hence the stratified and unstratified drift of different epochs would tend to be more or less mingled. The glacial streams associated with the ice, those back of the margin, either upon the surface, within, or beneath the ice, would be active in assorting the drift encountered and would tend to mingle the stratified with the purely ice deposited material at the margin and beneath the ice in all stages of glacial invasion.

While there are certain characteristic forms of glacial deposits, therefore, largely due to deposition by ice, and others entirely due to deposition by the water accompanying the ice, there is also much drift deposited by the combined work of ice and water.

ZONES OF GLACIAL EROSION AND OF DEPOSITION.

The work of an ice sheet has been described as that of erosion, transportation and deposition. The importance of each phase of this work varies in different parts of the course of the ice sheet. At the margin of the ice sheet, where the ice is melting, the greatest amount of material is dropped, as shown by the great accumulation of drift at the edge of the living glaciers, as well as by those marginal ridges of drift undoubtedly marking the border of the extinct ice sheets. The zone of greatest erosion is neither at the margin of the ice sheet nor at its center, but somewhere between; it is more probably nearer the margin, however, than the center. While from the center to the circumference of the ice sheet, erosion, transportation and deposition would be carried on, the maximum erosion would be some distance back of the margin, and the maximum deposition at the margin. And it follows also that because the margin of the ice sheet is continually advancing during the expansion of an ice sheet and continually receding during its retreat or contraction, the area or zone of greatest erosion and of deposition is continually changing. However, the rate of advance and retreat of an ice sheet was not uniform and the margin stood in certain areas much longer than in others, hence there was much greater deposition in certain places than in others. The margin of the ice sheet, however, probably stood in equilibrium, without much retreat or advance, when the ice sheet was at its maximum expansion, hence usually the extreme border of an ice sheet is marked by an excessive accumulation of drift as compared with that deposited farther back in its course.

The district of north central Wisconsin happens to be a region where the several successive North American ice sheets reached their maximum extent, and hence, as shown in succeeding pages, it is largely an area of glacial deposition rather than of glacial erosion.

GLACIAL DEPOSITS.

The deposits formed by an ice sheet, as above described, have an internal structure and outward form dependent upon the manner of their deposition, whether by ice alone, water alone, or by a combination of ice and water; and also dependent upon other conditions under which they are formed, whether beneath the ice or at the edge of the ice, and in the case of water alone, beyond the edge of the ice, whether within valleys, or upon plains, or in the standing water of marginal lakes. Glacial deposits, therefore, are classified according to the manner of their origin, and have received names upon this basis.

Ground Moraine.

The ground moraine, namely that which is lodged beneath the ice and that left on its retreat, forms a large part of the body of the glacial drift. It is sometimes referred to as boulder clay, or till, and is almost as widespread as the area of the ice sheet itself. The ground moraine is unstratified and has the general characteristics of glacial debris entirely deposited by the ice, and is, therefore, a mixture of boulders, gravel, sand and clay. The thickness of the ground moraine of any single ice sheet varies from place to place, depending on the readiness of the rock surface passed over by the ice to yield material to the ice, and also to the irregularities in the land surface invaded. Much of the soil and the loose rock material covering the land invaded entered into the composition of the ground moraine.

The topography of the ground moraine, as left by the ice in its final retreat, is usually gently undulating. The undulations do not take the forms of abrupt hills and depressions but of broad swells and shallow depressions, producing land forms of gentle contours and slight surface relief.

Terminal Moraine.

The terminal moraines are the thickened belts of drift accumulated at the margin of the ice sheets, where the edges of the ice remained essentially constant for any length of time. All materials gathered by the under surface of the ice would finally find themselves at the margin of the ice sheet, if not dropped before, on account of the general advance of the ice and the wastage of the margin by melting and evaporation. Both in its advance and retreat the margin of the ice sheet must have stood at all points covered by it, hence there would be a tendency for terminal moraine to be deposited over the entire area glaciated. But it is only where the ice edge stood in equilibrium, where melting of the margin kept pace with the advance of the ice for a comparatively long period, that thick accumulation of marginal drift was accumulated. As the margin of the ice sheet remained stationery, on account of climatic changes, at various intervals, both in its general advance and general retreat, terminal moraines of variable extent were built up, locally, throughout the entire course of the ice sheet.

Since there is an abundance of water at the ice margin it follows that there is more or less stratified drift closely intermingled with the drift of the terminal moraine.

The character of the drift of the terminal moraine is much like that of the ground moraine. It differs from ground moraine, however, in generally carrying a larger proportion of coarse boulders that have been transported long distances, and there is also usually a much greater abundance of stratified drift mingled with it. The thickness of terminal moraine is generally much greater than that of the ground moraine, the former usually being from 3 to 5 times as thick as the ground moraine back of it. The comparative thickness of terminal and ground moraine deposited by the several ice sheets varies a great deal, but most drift sheets, if not all have a distinctly more pronounced accumulation of drift formed at the extreme ice margin than back of the margin.

The topography of the well developed and prominent terminal moraines is a strikingly charcteristic feature of the latest drift formations, especially of the Wisconsin formation. The most distinctive features of the later terminal moraines are the billowy forms of the hillocks and short ridges of drift, closely mingled with which are abrupt depressions and sags without outlets. Sometimes there is a well developed frontal ridge running parallel to the ice margin, back of which is a belt or zone of variable width characterized by abrupt "knobs" and "kettles." The width of a terminal moraine may vary from 2 or 3 miles up to 15 or 20 miles. There are belts of terminal moraine marking the recessional stages in advance or retreat of an ice sheet as well as at the margin of farthest advance. Because the advancing ice overrode the terminal moraines built up while advancing, it is only those which were left in the recessional movement that now remain as characteristic topographical features. Generally the largest terminal moraines are built up at the farthest advance of the ice sheet. The belt of terminal moraines marking the margin of the last great ice sheet (the Wisconsin) is a pronounced feature of the landscape, its drift hills often rising 100 to 200 feet above the surrounding land. This moraine can be traced not only across the area of north central Wisconsin, but also across the entire North American continent, from Long Island on the Atlantic to Vancouver Island on the Pacific. Other glacial epochs, however, have not developed so pronounced terminal moraines and hence they vary in importance from those giving distinct topographic features to the land surface, to those consisting of mere swells of thicker drift at the margin of the drift sheets, and to those having very thin or attenuated edges. For views of the late terminal moraines see Plates LV and LVI, of the old moraines see Plates XLVI and LI.

Outwash Plains and Valley Trains.

Outwash plains and valley trains consist of stratified gravel, sand and clay, and were built up out beyond the edge of the ice sheet by the waters issuing as streams from beneath the ice, which were formed by the melting of the ice and from the rains. Under favorable conditions of slope where the waters issuing from the edge of the ice flowed out into valleys, gravel trains would be built up; and where the water flowed out on gentle slopes, alluvial fans would be formed, which would tend to join one another, thus building up plains marginal to the ice sheet, called outwash plains, overwash plains, morainic plains or morainic aprons. Valley trains may follow valleys for long distances from the ice margin and hence have their greatest extension in the direction leading away from the ice sheet. The outwash plains generally do not extend more than 2 or 3 miles beyond the ice margin, and therefore have their greatest extent parallel to the ice margin. Not everywhere along the ice margin were stratified deposits by the glacial waters built up, but only where the slope of the land, the character of the formation especially with respect to porosity, and the level of the ground water in front of the ice sheet were favorable for the development of such formations.

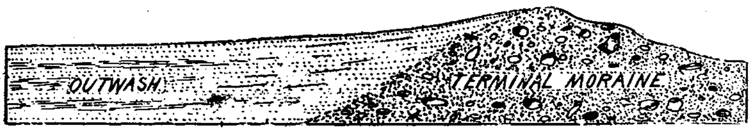


FIG. 20. Characteristic outwash plain bordering the terminal moraine. The outwash is generally built up to the crest of the moraine.

The surface features of the valley trains and outwash plains are similar to alluvial deposits in general. The character of the material and the distinct slope of the surface away from the terminal moraine which marked the location of the ice edge indicates that quite generally the deposits were formed in rather swiftly flowing water. The deposits theoretically consist of coarser material near the terminal moraine and finer material farther away. Large boulders caught in the grip of ice floes are often transported by glacial streams down valleys some distance from the margins of the ice sheets.

Drumlins.

Drumlins are hills or domes of drift elongated in the direction of ice movement, and are generally in the area of ground moraine. They are supposed to be formed beneath the ice, probably mainly by erosion of drift previously deposited. No well defined drumlins are known to occur in this district.

Kames.

Kames are stratified deposits of gravel and sand forming short ridges, generally in the area of terminal moraines. They are believed to be made by sub-glacial streams as they emerge from the edge of the ice sheet and are probably made in the embayments of the ice margin.

Eskers.

Eskers or asars are ridges of gravel and sand formed by glacial streams flowing in tunnels beneath the ice. They often assume the form of railroad embankments and vary in length from a few hundred feet to 10 or 20 miles. Eskers are relatively rare and none, well developed, are known to occur in this district.

Loess.

Loess consists of fine silt and clay of a varying mineral composition which may or may not be stratified. The origin of loess is a problem which has given rise to much discussion. By some it is thought to have been formed by wind and by others to have been formed by glacial waters. Whether deposited by eolian or fluviatile agencies, it appears to be closely connected in origin with glacial conditions. Loess is often associated with the older drift sheets, that associated with the Iowan formation in Iowa, Kansas and Missouri, being of exceptional extent. Loess occurs as a widespread mantle in southwestern Wisconsin, in valleys associated with alluvium, and upon the uplands far above the alluvial deposits. In this area of north central Wisconsin deposits of loess are not known to occur, although deposits of loess have been observed a few miles farther west in the adjacent counties of Eau Claire and Chippewa.

GLACIAL AND INTERGLACIAL STAGES.

Having described the general character of glaciation, the work of ice sheets and the deposits made by them, it seems essential that a brief view of the succession of the epochs or stages of glaciation which constituted the Glacial Period be alluded to.

It was customary when the drift first began to be studied to refer all the glacial deposits to a single ice invasion. Subsequently, however, as the drift was more closely examined, it was thought that all the drift was not deposited by a single ice sheet, but by at least two ice sheets which were more or less distinct from one another. The custom of referring all the drift to a single ice sheet is illustrated in one of the earlier reports, namely, Vol. II, 1877, of the former State Geological Survey, and to two glacial epochs in the later general report, Vol. I, 1881. As the investigation of the glacial deposits was continued, however, the drift came to be referred to three distinct stages, and then to four, until now there are recognized as many as six distinct stages of glaciation, separated by well defined intervals of deglaciation.

In what has already been considered it will at once be seen that the main theme has been that of glacial phenomena, that which has occurred during a glacial phase, when the ice was on, and not the phenomena of the intervals between glaciations when a mild climate predominated over the land and the ordinary geological forces, such as those now existing, prevailed in the region. The glacial deposits, while they constitute an important portion of the rock material of the land, do not furnish, in themselves, the entire records of the Ice Age. During the long interludes between the periods of glaciation, after each of the ice sheets had disappeared, there were developed important rcords of geological phenomena, which, while not furnishing prominent features of the landscape, are none the less significant and important in geological history.

The evidence of the separation of the glacial deposits into drift sheets of distinct epochs consists of the occurrence of deposits that could not have been formed by glaciation, which lie inter-bedded between drift formations and which indicate the prevalence of an intervening period of mild climate before the next overlying drift was deposited. These interglacial deposits are forest beds, soils, deposits containing remains of land animals, deposits of bog iron ore, and lake, and sea deposits containing fossils of animals which could thrive only in a mild climate.

Greater amounts of weathering and erosion shown by one drift sheet as compared with that of another also indicate differences in age of the drift. The greater amount of weathering of the drift materials of the older drifts as compared with the younger is a characteristic feature. Differences in direction of ice movement as indicated by distribution of terminal moraine, ice grooving, and transported boulders are also lines of evidence for the separation of the drift sheets into distinct epochs.

The origin of the cold and warm climates which brought on the glacial and interglacial phases of the glacial period is a mooted question and need not here be discussed. It is sufficient to state that the glacial epochs necessitate the frigid climate of the polar region, and the interglacial epochs the mild climate of the temperate zone. There is a marked difference in the general character, topographic forms and distribution of the drift in the several parts of this district, such as to warrant the differentiation of several distinct glacial epochs. There is abundant evidence, not only in this region but elsewhere in the area of the Pleistocene ice sheets, for the conclusion that a general displacement of climatic zones took place and that these displacements occurred at irregular intervals in glacial times.

THE PLEISTOCENE FORMATIONS OF THE MISSISSIPPI VALLEY.

The deposits of drift left by a single glacial invasion is called a glacial formation, and the more superficial deposits formed during an interglacial phase are interglacial formations. The succession of glacial and interglacial formations and sub-stages now recognized in the Mississippi valley, where the series is probably best developed and has been most fully studied, is as follows,[1] beginning with the youngest or uppermost:

13. The Champlain Sub-stage (Marine).
12. The Glacio-lacustrine Sub-stage.
11. The Late Wisconsin formation: Glacial.
10. Interglacial deposits.
9. The Early Wisconsin formation: Glacial.
8. Interglacial deposits (Peoria, Toronto Beds).
7. The Iowan formation: Glacial.
6. Interglacial deposits (Sangamon beds).
5. The Illinoian formation: Glacial.

[1] Chamberlin and Salisbury. Text-book of Geology. Vol. III, p. 383.

4. Interglacial deposits (Yarmouth Soil, etc.).
3. The Kansan formation: Glacial.
2. Aftonian beds: Interglacial.
1. The Sub-Aftonian formation: Glacial.

In the glacial series there are 6 well defined glacial formations and 5 less well defined interglacial formations. The discrimination of interglacial formations largely depends on the separation of the glacial formations, and interglacial deposits furnish, therefore, only part of the criteria for this separation. For this reason, therefore, the interglacial formations have not been so fully differentiated as the glacial formations.

LIFE OF THE GLACIAL PERIOD.

The terrestrial life of the non-glacial parts of North America during the glacial period was characterized by the presence of gigantic sloths, armadillos, and water hogs which had migrated from South America during the close of the Pliocene period. Their remains are found as far north as Pennsylvania and Oregon.

Another group in the temperate zone inhabiting the region, included the mammoth and mastodon, both of which appear to have lived through the glacial period, and to have become extinct after the latest ice invasion. The remains of both mammoth and mastodon have been found in various parts of Wisconsin within the driftless area, namely in Richland, Grant, and Vernon counties.

Several species of horse have been found in the West. A gigantic elk ranged from New York to Kansas and Mississippi. Two or three species of buffalo ranged over the Mississippi valley to the Gulf of Mexico. Arctic animals such as the muskox and reindeer, have been found as far south as Virginia and Kentucky.

In the glaciated parts of the continent the whole fauna and flora was forced to migrate before each ice invasion, or become extinct. The arctic species along the ice border crowded upon the sub-arctic forms immediately south of them, and the latter crowded upon the cold temperate forms, and these in turn upon the warm temperate types. When the ice border retreated to the north during the periods of deglaciation of the interglacial stages, a reversed migration took place. It is believed that five or six migrations were experienced during the glacial period in Europe and America, and that the southward and northward swing of these movements was from one or two hundred miles to, perhaps, one or two thousand miles.

In a general way the life of the interglacial stages was probably the same as at the present time. Migrations of the flora and fauna took place on account of the glacial invasions, as above stated but no significant change in the life development of the continent has been wrought since the beginning of glacial time.

DURATION OF THE GLACIAL PERIOD.

The duration of the glacial period is interesting, largely, perhaps, because the events of this period approach, so closely upon our own period of human affairs. Geologists who have studied the drift in the Mississippi valley have furnished estimates at various times, the results of which may here be briefly stated.

The time unit in calculating the duration of the Pleistocene is the period which has elapsed since the Wisconsin drift began to be exposed to erosion, and for the entire glacial period has been expressed as follows:[1]

From the Late Wisconsin to the present...........	1	time-unit.
From the Early Wisconsin to the present..........	2 to 2½	time-units.
From the Iowan to the present.....................	3 to 5	time-units.
From the Illinoian to the present..................	7 to 9	time-units.
From the Kansan to the present	15 to 17	time-units.
From the sub-Aftonian to the present....	X	time-units.

Estimates of the number of years that have elapsed since the retreat of the last ice sheet have been based on the rate of erosion of the Niagara River below the Niagara Falls and of the Mississippi River in the gorge below St. Anthony Falls. There is a wide range in the estimates of the time required for the erosion of these gorges, varying from 10,000 to 30,000 years for the Niagara, and 8,000 to 16,000 for the St. Anthony gorge, to which the estimates of the retreat of ice must be added. The total approximates 20,000 to 60,000 years since the climax of the last

1 Chamberlin & Salisbury, Text-book of Geology, Vol. III, p. 414.

ice invasion. Using the table of relative duration above given, the following dates for the climaxes of the several ice invasions may be calculated:

Climax of the Late Wisconsin	20,000	to	60,000	years ago.
Climax of the Early Wisconsin	40,000	to	150,000	years ago.
Climax of the Iowan	60,000	to	300,000	years ago.
Climax of the Illinoian	140,000	to	540,000	years ago.
Climax of the Kansan	300,000	to	1,020,000	years ago.
Climax of the sub-Aftonian	y	to	z	years ago.

The main value of these estimates lies in the sense of proportion which they give to the periods of the various invasions, rather than as a statement of the actual number of years for the glacial period.

THE PLEISTOCENE FORMATIONS OF NORTH CENTRAL WISCONSIN.

The Pleistocene formations of the district, which includes, besides the glacial drift, some deposits in the driftless portions, as well as the alluvial formations in the valleys, are described in the following order:

The Glacial Formations.

The First drift formation.
The First interglacial stage.
The Second drift formation.
The Second interglacial stage.
The Third drift formation.
The Third interglacial stage.
The Wisconsin drift formation.

The Alluvial Deposits.

Valley terraces.

The Driftless Area.

CHAPTER IX.

THE GLACIAL FORMATIONS.

In the present account of the drift of this area of North Central Wisconsin no attempt will be made to definitely correlate the drift formations older than the Wisconsin, with those outside the area. The Wisconsin drift formation received its name because of its typical development in Wisconsin. On account of the fact that it is the latest and therefore the uppermost of the series, and also on account of the abundance and prominence of its deposits, it can readily be traced and correlated in all parts of the continent invaded by the Wisconsin ice sheet. The older drift formations of this area, however, are widely separated from adjacent regions where the older formations have been studied, and hence cannot, without much more detailed study, be correlated and definitely placed in glacial stratigraphy.

Since the field work in the district of North Central Wisconsin has been completed a large part of the adjacent region further to the west has been surveyed. The writer has been assisted in this areal work farther west mainly by Mr. E. B. Hall. During the summer of 1906, Mr. Frank Leverett, of the United States Geological Survey, with R. T. Chamberlin as field assistant, began the work of mapping the Pleistocene formations of southeastern Minnesota with a view of correlating the northern Wisconsin and Minnesota formations with those of Iowa and of the southwest. Probably one or more field seasons will yet be required before the work of correlating the pre-Wisconsin drifts of northern Wisconsin and Minnesota can be completed.

During the past two years the several drift sheets of north-central Wisconsin have been traced to the Minnesota border, and the continuation of these formations to the west are shown upon the map, Fig. 21. It is not unlikely that some changes will be made in the mapping of the several formations by later work, but such changes it is believed will be of only minor importance.

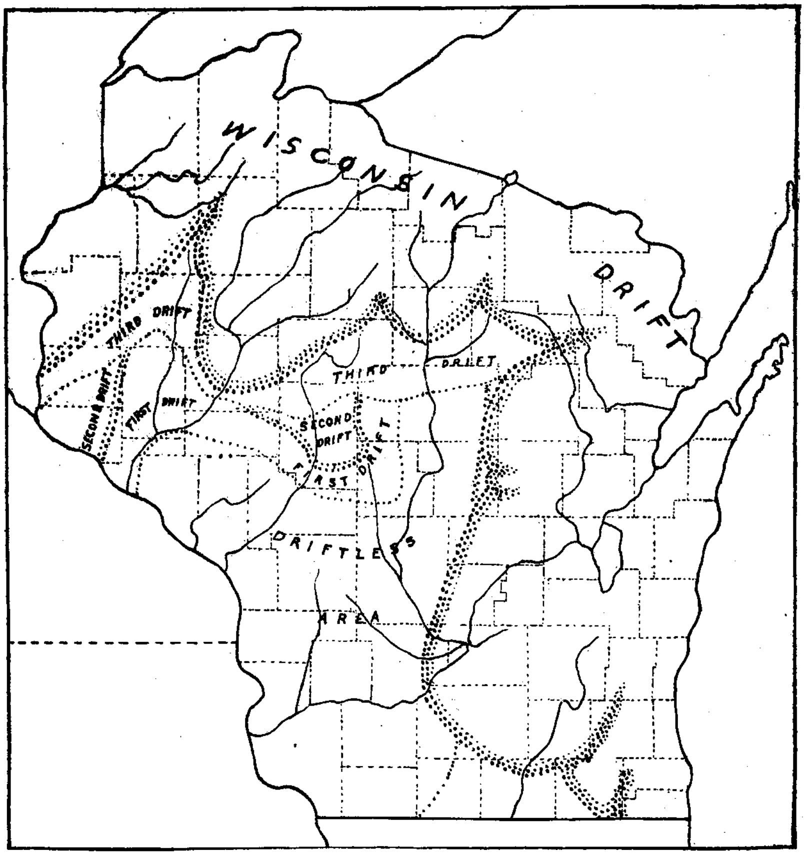


FIG. 21. Map of Wisconsin, showing the four drift sheets. (A preliminary map.)

This preliminary map is presented at this time in order to show the general extent of the several pre-Wisconsin drifts in northern Wisconsin. As stated later, when the geological report of the northwestern part of the state is completed we will probably be able to indicate definitely the position of the several drift formations in the Pleistocene series.

The greater portion of this district of North Central Wisconsin, the exception being only its southern margin in Portage Wood and Clark counties, has been previously considered as drift covered, and has always been mapped as such. The present more detailed study of the drift, however, shows a much larger part of the district than was formerly supposed to be essentially free from glacial drift, namely, an area of considerable width along the Wisconsin River (see map, Plate II) in Portage, Wood, and Marathon counties. The account of the driftless portion of the district can best be given after the description and distribution of the several drift formations is understood.

In the following account of the glacial deposits of North Central Wisconsin no specific names will be given to the older drift formations, but these will be referred to numerically in the order of their succession. The present account of the glacial geology of the district, therefore, may well be considered a preliminary, or a first, report of this phase of the geology.

SECTION I. THE FIRST DRIFT FORMATION.

The drift of the glacial stage here referred to provisionally as the First in this district is a comparatively thin formation. As shown on the map (See Pl. II) it appears as the surface formation in the southwestern part of Marathon, over most of Wood, and the southwestern part of Clark counties. It probably lies under the later drift of the northwestern part of Marathon County, most of Lincoln and the whole of Clark and Taylor counties. It is not believed to be present in Portage County although it is near the northwest border, nor in the eastern part of Marathon County. It may not be present in southwestern Lincoln County and adjoining parts of Langlade, though it is believed to be present in most of the first named county. In the region farther to the west it is known to extend southward over most of Eau Claire, Dunn and western Pepin counties.

This formation varies in thickness up to 65 or 70 feet. In many places the till is very thin or entirely absent although scattered boulders are generally present. It has a probable average thickness of less than 5 or 10 feet. Usually the soils of this area are either much modified or wholly of glacial drift origin. However, in the sandstone area of southwestern Clark County the drift is quite generally too thin to appreciably affect soil conditions. This formation extends out to the driftless and forms the boundary of the glacial and non-glacial tracts over a large part of the district. The edge or border will first be described, and then the area of the ground moraine back of the border.

BORDER OF THE FIRST DRIFT.

In Western Marathon County.

In the vicinity of the village of Rib Falls, 13 miles west of Wausau, there emerges from one of the younger drift sheets (Third Formation) an old drift whose border extends nearly south and thus nearly at right angles to the east-west border of the overlying formation. The border of this older drift has been traced to the south for a distance of nearly 40 miles, to the vicinity of Grand Rapids, where it makes an abrupt turn to the west.

In the vicinity of Rib Falls, where this older formation emerges from the younger, no striking difference in the topography of the borders of the two is to be noted, such as that which may invariably be seen where the older drifts emerge from beneath the great terminal moraines of the Wisconsin drift formation. The comparatively slight difference in the surface features of the two borders in the vicinity of Rib Falls is due mainly to the small magnitude of the two formations and the relatively slight effect wrought by the occurrence of each upon the uneven surface of the underlying crystalline formation.

However, a detailed examination of the two formations unmistakably reveals much younger features of topography, such as slight ridges and shallow depressions locally developed here and there in the overlying formation, which cannot be found in the underlying one. An examination of the till also shows a relatively sharp difference in the amount of weathering and decomposition of the two formations, a difference clearly indicating the overlying formation to be much later in origin than the underlying formation.

Where the drift of the two borders, therefore, has some considerable thickness, and exposures of till are available for examination, they can be discriminated from one another, but where scattered boulders only occur in the vicinity where the two borders are in close proximity, the source of these scattered boulders cannot always be determined.

The main border of the younger drift extending east-west across the Rib River valley, crosses the valley a mile or two above Rib Falls. The much older drift border of the First formation attains appreciable thickness also in the vicinity of Rib Falls, and, hence, the ice border of the two sheets, apparently, came to rest in approximately the same part of the valley of the Rib River. Extending down the valley of the Rib are numerous boulders and fluvio-glacial gravels contributed very probably by both ice invasions. While the main border of the two sheets can be separated the source of the material of the outlying bouldery belts cannot be definitely discriminated. The erosion of the Rib River in this locality also has undoubtedly tended to commingle the drift of the two formations along this part of the valley since the drift of the two formations was deposited. Hence the location of the border of the two ice sheets in the vicinity of Rib Falls can only be approximated. The border indicated upon the map is based on observations made of the limit of the drift several miles back from the Rib River.

Going west from the village of Marathon on the road over the uplands bordering Scott Creek no drift is found until the vicinity of the small branch stream in the eastern part of Section 10, T. 28, R. E., (Cassel) is reached. Here occur boulders whose polished glaciated surfaces are in marked contrast with angular surface stone of residual origin along the road to the east. Boulders occur in increased numbers on the main travelled road to Edgar until the upland in Sections 17 and 20 is reached, where till is abundant at the surface, and the well records show a thickness of 10 or 15 feet of drift. In this locality the underlying rock is granite which is often disintegrated to depths of 5 or 10 feet. Drift is well exposed in the cuts of the Chicago and

Northwestern railroad in sec. 24, T. 28, R. 4 E. (Wein) and shows a thickness of 5 to 10 feet. Along the slopes of Scott Creek at Edgar the till is generally thin. The valley of Scott Creek itself is broad and flat and very probably contains alluvial filling to depths of 100 feet or more in conformity with the depth of alluvial filling of the Wisconsin valley at Wausau.

North of Edgar and west of Rib Falls, upon the flat summited uplands, in the area of Sections 19 and 20 of T. 29, R. 5 E., and Sections 24 of T. 29, R. 4 E., the drift has a known thickness in a number of wells of 25 to 40 feet. In the southwestern part of Sec. 19, T. 29, R. 5, no rock is reported to depth of 64 feet. The depth of drift reported in this well is unusual and may be open to question, but in several wells upon the flat uplands farther southwest, in the western part of the town of Wein, 40 to 60 feet of drift is reported. The thick drift of the above mentioned localities has the character of the older First formation, while that north of Edgar is within two miles of the border of the later Third drift. In the southwest part of the town of Cassel a few wells show depths of 20 to 30 feet of drift.

In general it may be stated, that the border of the old First drift in western Marathon County is marked on the outer side, next to the driftless, by a fringe of scattered boulders with very little or no observed till. This outer fringe of scattered boulders is generally from one to two miles wide, and may in part be due to original deposition by the ice, and in part to subsequent transportation by wash and stream work. Within the fringe of boulders the drift generally attains a thickness of 10 to 30 feet on the uplands, with very little drift along the valley slopes where conditions for effective erosion are prevalent. Unusual thicknessess of the drift along the border reach 40 to 64 feet.

As shown upon the map the border of this drift extends southward from Rib Falls through the central portion of the town of Cassel, through Emmett and Bergen, crossing the Little Eau Pleine River in the vicinity of Rice Lake.

The general character of the thickened edge of the drift sheet remains the same throughout this portion of Marathon County. There is no apparent change in the external surface of the land along the terminus, but there is a marked change in the internal character of the surface and soil formations. As one zigzags across the border, noting the character of the surface formation exposed along the ditches of the roads, the change observed is a striking one. Out in the area of the drift, glaciated boulders are abundant, and the farm wells show a fairly constant depth of drift varying from 5 feet to 10 and 20 feet. In marked contrast with the glacial soil is the comparatively thin residual soil containing angular stone in the driftless area.

The terminus of this drift formation in western Marathon County can be located fairly definitely where the lands are opened to agriculture, and farm wells and graded roads have been constructed. Where these conditions do not prevail, however, there is little to guide one in locating the edge. Furthermore, the unsettled parts were usually not traversed because of the difficulty of travel and because the generally prevailing geological conditions did not appear to warrant it.

Through the western parts of the towns of Cassel and Emmet, therefore, the terminus is approximately located on the map. South of this to the central part of the town of Milladore, Wood County, the country is not settled, and hence the terminus between these points is conjectured. The soil conditions along the east-west road between the Big Eau Pleine and Little Eau Pleine rivers indicate that the terminus continues southward crossing the Little Eau Pleine at Rice Lake. This lake is a broadened portion of the river and its presence may be due to an accumulation of terminal moraine in the valley at this place.

In Wood County.

There is an abundance of drift along the line of the Wisconsin Central railroad from Marshfield as far southeast as the village of Sherry, farther east of which the surface deposits are those prevailing in the driftless area. The terminus therefore extends south from Rice Lake through Milladore, crossing the railroad in the vicinty of the village of Sherry and thence extending southward to the vicinity three miles west of Grand Rapids. The border lies approximately across the central parts of the towns of Milladore, Sherry, and Sigel, in Wood County. There are no ridges of drift in this vicinity and the border is somewhat obscure, but it is believed to be approximately as indicated upon the map.

In the vicinity about 2 miles west of Grand Rapids, the border apparently makes a sharp turn to the west. The border in this vicinity is characterized by considerable drift apparently in the form of hills and ridges, the general composition of the drift being typical of terminal moraine. These drift ridges are in part at least merely drift remnants capping the sandstone and owe their present form wholly to the work of erosion. Several of these drift covered hills lie in the western half of Section 10, T. 22 N., R. 5 E., and immediately west in the northern half of Sections 7, 8 and 9 in the same township. The elongated hills and ridges stand from 20 to 40 feet high, and are covered with sand, pebbles of quartz, and various igneous rock, and large blocks of the Powers Bluff fine-grained pink quartzite, and boulders of diorite and granite. The hills and ridges do not lie in parallel positions, but trend in various directions, though several of the longest ridges trend NE-SW.

An especially long ridge, about a mile long, trends NE-SW from the N. W. ¼ NW. ¼ of Sec. 8 to the NW. ¼ SW. ¼ of Sec. 7, T. 22 N., R. 5 E.

This ridge is from 15 to 30 feet high and from 150 to 300 feet wide. Most of the drift of this ridge consists of sand, with which is mingled many angular and rounded pieces of fine-grained quartzite and a few large blocks of the fine-grained Powers Bluff quartzite and of granite and diorite.

About a mile and a half farther northwest, in the vicinity of Altorf Postoffice, there are several drift ridges and much drift present. There are drift-covered ridges also in the northern part of section 31 and southern part of Section 30 of T. 23 N., R. 4 E. Three miles southwest of Pittsville, in sections 8, 9, 16 and 17, a group of drift ridges were noted extending east and west and varying in elevation from 10 to 25 feet.

Thus there appears to be a zone 2 or 3 miles wide marked by scattered drift covered ridges, extending east and west across Wood County, from Grand Rapids westward. This belt lies immediately north of the Green Bay and Western Railroad and is approximately at the boundary of the flat, marshy portion of the county on the south and the well-drained land to the north.

There is therefore a marked difference in the surface formation south of these drift ridges as compared with that to the north. The formation overlying the sandstone to the south in the marshy area is sand and gravel capped with peat and muck, the ground water level being approximately a few feet below the surface, while to the north boulders are abundant and coarse drift forms a mantle varying from 2 to 20 feet in thickness overlying the hard rock formation.

In Jackson County.

The terminus of this drift continues westward from Wood County through Jackson, very probably lying immediately north of the East Fork of the Black River.

In the immediate vicinity of City Point and to the south is the broad flat expanse of sandy and marshy land. In the bed of the river at City Point is a large boulder of diorite lying upon the sandstone formation. About half a mile north the slightly rolling surface is covered with coarse boulders and drift, and coarse drift appears abundantly farther north.

At Pray similar conditions prevail. No boulders occur at Pray and to the south, but immediately north they begin to be abundant. Going north of Pray from the East Fork of Moore's Creek in the SE. ¼ of Sec. 21, T. 23, 1 W., in Clark County, the drift gradually grows more abundant, the soil being a sandy loam to a sandy soil. North of Moore's Creek the soil is appreciably more clayey, the drift averaging from 1 to 3 feet thick with here and there a well defined ridge covered with drift.

In Clark County.

The drift border can be traced across the southwest corner of Clark County from the vicinity of the mouth of the East Fork of the Black River in a northwestern direction to the northwest corner of the town of Dewhurst, crossing the Neillsville branch of the Chicago, St. Paul, Minneapolis & Omaha railroad about 5 miles northeast of Merrillan, and crossing the main line of the same railroad about 5 miles northwest of Merrillan. About 2 miles southeast of Humbird, there are a few sandstone ridges covered with drift, and a variable amount of coarse bouldery drift was observed along the wagon road leading northeast to Neillsville. A mile or so west of Humbird, however, coarse crystalline boulders are rare, and upon the slopes and summits of the uplands is a mantle of loess like that prevailing in the region of the southwestern part of the state. This loess is a later formation than the first drift but was not found to extend as far east as Clark County.

Outside of this district, in northwestern Jackson and southwestern Eau Claire counties, the edge of this drift sheet has been followed to some extent and found to continue some distance to the northwest as shown by Chamberlin and Salisbury in 1884,[1] as the border of the drift and driftless areas. The lobate form of this drift sheet is of considerable interest and importance in understanding the occurrence of the driftless area in Marathon County farther east, and this feature will therefore be more fully discussed in the account of the driftless area of the district.

THE GROUND MORAINE.

Back of the border of this drift, between the border and the next overlying drift sheets, namely, the Third formation in northwestern Marathon County, and the Second in southwestern Marathon County, northwestern Wood and in Clark County, this drift presents no features of special interest.

The drift is quite generally present upon the summits of the upland areas but along the valley slopes and in most of the smaller stream bottoms the underlying indurated rocks prevail. The drift appears to be thicker in general in the western part of Marathon County than eleswhere. In Wood County also the drift is relatively thick. In Marathon and Wood counties the thickness generally varies up to 20 or 30 feet, the probable average thicknes being about 5 feet.

In Clark County, on the other hand, in the area where the Potsdam sandstone is the prevailing underlying rock, considerable areas are almost wholly devoid of drift. This difference, it is believed, is very largely due to the greater ease of erosion weathering and disintegration of the sandstone. Drain-

1 Preliminary paper on the Driftless Area of the Upper Mississippi Valley; U. S. Geol. Survey. VI Ann. Rept., Plate 27.

age of the Black River system, which has steeper gradient and the stream a more rapid flow than the drainage of the Wisconsin, also would tend to bring about greater erosion of the drift in Clark County.

In Marathon County.

The drift in the cuts along the railroad between Fenwood and Edgar shows at least as much alteration and decomposition as the drift in the terminal moraine of the Second drift formation at Marshfield. The drift at Marshfield is later in origin and therefore the earlier First drift should reveal as much, if not more, than the drift of the Marshfield moraine. It is compared with the Second drift at Marshfield in view of the fact that well exposed deposits of the latter were examined in company with Prof. T. C. Chamberlin, who pronounced it, in the locality studied to be as deeply weathered and decomposed as any drift ever observed by him. This advanced alteration should not be interpreted as indicating the drift to be older than some other formations such as the Kansan or sub-Aftonian, but that its extreme weathering indicates the probable position of these older drift formations near the base of the Pleistocene series. In general, the basic rock pebbles and also some of the large granite boulders of the First drift have entirely disintegrated and the feldspar constituent is largely altered to kaolin. Where the underlying granite is exposed beneath the drift it is disintegrated to depths of several feet.

Some sandstone was noted in the drift in the southwestern part of Marathon County, thus indicating that the ice movement was from the west or northwest in this locality, an indication of the direction of ice movement in harmony with that indicated by the location of the terminal moraine of this formation immediately to the east.

In Wood County.

The area of this drift formation in Wood County, as indicated on the map, extends from the vicinity of Grand Rapids to the vicinity of Marshfield where the terminal moraine of the Second drift formation is located. In central Wood County, the Potsdam sandstone is a common surface rock, and hence, where abundant, the drift is appreciably more sandy than that prevailing in northern Wood and farther north.

Along the line of the Wisconsin Central Railroad, from Marshfield to Sherry, the drift of this formation is unusually thick. At Hewitt the known maximum thickness is 55 feet, at Auburndale 67 feet, at Sherry 32 feet. This belt of thick drift forms the divide between Mill Creek on the south and a number of small streams flowing north to the Little Eau Pleine River. Both to the north and to the south the drift is very much thinner than along this divide. In other parts of the county this drift formation is characterized here and there by eroded ridges and hills of drift. The belt of drift covered ridges of the border extending east and west in the southern half of the county has already been described. North of the border also are to be found a few ridges of drift, among which may be mentioned the ridge extending northwest-southeast across the northeastern part of the NW. ¼ of Sec. 34, T. 24, R. 3E., showing a thickness of 50 feet of drift. Considerable accumulations of drift also occur in the southern half of Sec. 2, T. 23, R. 3 E.

In the area of this drift formation in southern Wood County there is a variable amount of clay derived from the decomposition of the pre-Cambrain crystalline rocks, which evidently was formed in pre-Potsdam time, as it often forms a thick layer beneath the sandstone, as well as upon portions of the crystalline peneplain from which the sandstone has but recently been removed. This clay is worked up into the drift and gives it a much more clayey content than it would otherwise obtain.

The Powers Bluff Boulder Train.

A feature of special interest concerning the drift of this formation in Wood County is the well developed boulder train derived from and extending southeast of Powers Bluff This bluff, whose summit reaches an elevation of 300 to 400 feet above the surrounding valley bottoms consists of a much fractured and jointed fine-grained pink quartzite, quite unlike the prevailing igneous rocks of the vicinity. When the First ice sheet invaded this region it enveloped this quartzite hill, and as the ice moved onward it dislodged and carried from it thousands of quartzite boulders, which are now found strewn over the land to the southeast, indicating in no unmistakable manner the direction of the ice movement in this vicinity.

Going westward from Grand Rapids on the Pittsville road, boulders of the Powers Bluff qaurtzite are first seen in the vicinity of the school-house in Sec. 3, T. 22, R. 5 E. In this vicinity and immediately southwest in the drift covered ridges, the fine-grained pink quartzite occurs in large boulders as well as small ones, and constitutes perhaps 40 per cent of the stony material of the drift. With the quartzite were also observed boulders of the pre-Cambrian conglomerate formation overlying the Powers Bluff quartzite. Sandstone forms 40 to 50 per cent of the stony material of the drift in this vicinity.

Boulders of the Powers Bluff rock are abundant as far west as Hemlock Creek, being quite abundant in the road about one-third mile east of Hemlock Creek in the NE. 1/4 of Sec. 34, T. 23, R. 4 E. West of Hemlock Creek the quartzite is scarce or entirely absent. The drift covered ridges about two and a half miles east of Pittsville contain no Powers Bluff quartzite, and the boulders along the road are quite abundant in this vicinity, though none of quartzite were observed.

The general direction of ice movement in this vicinity, as indicated by the distribution of the quartzite boulders, was S. 45 degrees E., the same direction of movement as that indicated by the location of the drift border in this part of the area. See map, Plate II.

The occurrence of this well developed boulder train leading out from the Powers Bluff quartzite, and the absence of boulder trains etxending from such similarly situated high, rocky quartzite hills as Rib Hill, the Mosinee Hills and Hardwood Hill, in the driftless area, indicates the marked difference in the character of these adjacent areas, with respect to evidence of glaciation.

In Clark County.

That portion of Clark County, the southern and southwestern part, covered by this drift formation, is largely within the sandstone district, the crystalline formation occuring mainly only along the beds of the streams. The drift therefore is a sandy formation, and clayey drift containing abundant crystalline boulders is the exception in this part of the area. The sandstone becomes very abundant in the western part of the county, where numerous hills of sandstone dot the rolling plain.

In the southern part of the county there are a number of drift covered ridges, among which may be mentioned the group in the northern part of Sec. 8, T. 23, R. 1 E., and single ridges in the southern part of Sec. 12, in the northwestern part of Sec. 14, and in the southeastern part of Sec. 27 in T. 23, R. 2 W.

West of the Black River the area of this formation is mainly sandy land, and the country is opened but very little to agriculture. But little of this part of the county was traversed outside of the railroads and two or three wagon roads crossing it. So far as could be observed, the drift was seen to have a thickness of 15 to 20 feet in but comparatively few places. Throughout there is a plentiful scattering of coarse crystalline boulders over the surface. On the whole, however, the drift covering southwestern Clark County is relatively very thin. On the Butler farm in the N. W. ¼ of sec. 14, T. 27, R. 4 W., a large drift ridge shows a thickness of 42 feet of drift.

Along the railroad between Greenwood and Fairchild, drift is shown abundantly along the track as a veneer to many of the low sandstone hills. Upon the tops of the high mounds, such as South Mound, in sec. 21, T. 26, R. 3 W., no drift could be found.

THICKNESS.

The thickness of this drift formation at various places in the area has been referred to. The maximum known thickness is 67 feet at Auburndale in northern Wood County. In a large number of places the drift is but a few feet thick, and over considerable areas in certain parts, the drift is nearly entirely absent.

There is an appreciably greater thickness of drift in a zone 3 to 6 miles wide forming the border of this drift sheet than there is farther back in the area of the ground moraine. If an estimate be made of the average thickness of the belt of terminal moraine, a fair approximation would appear to be about

15 to 30 feet in Marathon and eastern Wood and in Clark counties. The thickness back of the terminal moraine is very probably less than 5 or 6 feet. If the entire drift, including the thickened edge and back of it, was spread out evenly over the area of this formation, it very probably would not exceed a thickness of 5 or 10 feet.

EFFECT UPON TOPOGRAPHY.

The effect of the deposition of drift and the erosion of the ice sheet of this glacial stage unquestionably tended to variously modify the pre-existing topography. In places this modification must have been appreciable and in other places hardly noticeable. While the main features of the pre-existing topography remain, there can be no doubt that the older land surface was greatly modified in many places. It is not improbable that some large valleys have been obliterated by the drift of this formation. Many small irregularities in the older land surface, must have been smoothed over, and very probably in many cases small streams had their courses changed. In Marathon County, along the Wisconsin River, the deep valleys of the small streams, as well as the large ones, seem to have no regard for the occurrence of the drift of this formation, but in Wood and Clark counties, along the divide between the Wisconsin and Black rivers where the streams are not deeply intrenched, the terminus of this drift sheet appears to form the divide between some of the small streams.

The head streams of the East Fork of the Black River have an unusual course, the features of which are referred to again in the chapter on physiography. The branches of the East Fork flow towards the Yellow River for a distance of 15 or 20 miles and have the characteristic location and course of streams that were originally developed as branches of the Yellow River. A few miles west of the Yellow River at Dexteriville are numerous ridges of drift constituting the terminal moraine of this drift formation, and in this vicinity these streams now forming the main branch of the East Fork of the Black River make a sharp turn and flow west to the Black River. The occurrence of eroded drift ridges in the vicinity where the sharp turn to the west of the East Fork is made would seem to indicate that the accumulation of drift here may have been a partial cause of the change in the deflection of these streams from the Black to the Yellow River.

The features of many of the valleys within the area of this drift sheet has been greatly changed by extensive alluvial filling in their lower courses. But the valley filling took place subsequent to the first glacial invasion, the alluvium being superimposed upon the drift. The change in topography due to alluvial deposition should therefore be kept distinct from that wrought by the earliest glaciation of the district alone. It is possible that the above changes referred to in the drainage of the Black and Yellow rivers were brought about by alluvial filling rather than by glacial deposition.

The glacial erosion wrought by this ice sheet was very probably considerable in the area. A good example of glacial erosion of a rocky point whose prominence made it a special object of wear by the moving ice is furnished by Powers Bluff. The well developed boulder train leading out from this rocky point indicates in a noteworthy manner the amount of rocky material dislodged and carried away in the course of the moving ice sheet.

The sandstone hills of this area were very likely also much eroded, although the incoherent character of the sand-rock would furnish only loose material and but few boulders. It might be urged that the rugged, pinnacled forms of most of the sandstone hills in Clark and Wood counties indicate an absence of glacial erosion. In the vicinity of Neillsville there are summits of sandstone mounds which possess only the corrugated forms due to sub-aerial erosion (Plate XLIX), whose bases, however, are surrounded by nearly a hundred feet of glacial drift of the Second formation. These summits, like those within the area of the First drift, undoubtedly once possessed the rounded, subdued forms of glaciated hills, but a sufficient period has elapsed since their glaciation to obliterate

Fig. 1. SANDSTONE MOUNDS IN AREA OF FIRST DRIFT, CLARK CO.

Fig. 2. CHARACTERISTIC SANDSTONE MOUND IN SOUTHWESTERN CLARK CO.

the rounded glacial contours and to develop in their place, under later sub-aerial conditions, the forms due to weathering and erosion.

AMOUNT OF EROSION AND WEATHERING OF THE FIRST DRIFT.

If the drift had been deposited with uniform thickness over a level surface, as is generally the case with marine and alluvial deposition, the amount of material removed by erosion could be closely approximated. But the drift was deposited by the ice sheets in deposits of unequal thickness upon an uneven land surface, and hence the amount of drift eroded cannot be definitely measured.

An idea of the general or approximate amount of erosion of the drift, however, can be obtained by the examination of the relative distribution of the drift in valleys where erosion must have been greatest, and upon the upland divides where erosion has been least. A study of the distribution of the drift shows it to be comparatively thick upon the broad uplands, relatively thin on the upland slopes, and nearly wholly absent in the valley bottoms of most of the streams. (In this connection it should be remembered that the broad flat-bottomed valleys of large parts of the region are filled with alluvium of comparatively recent origin.) Upon the summits of the uplands the drift of this formation is known to attain a maximum thickness of 64 to 67 feet, and over most of the uplands and upper slopes it varies from 10 to 30 feet. In the region where these thicknesses of drift prevail the streams flow upon bed rock, thus indicating the probable removal of 10 to 60 feet of drift.

The general features of stream erosion superimposed upon the drift, in place of the features due to glacial deposition, also indicate a great amount of erosion wrought in the drift, for the complete removal of glacial features of topography requires a very large amount of subaerial degradation. In the southern part of Wood County and in southeastern Clark the drift is appreciably thinner than in northern Wood and western Marathon, the marked differnce in present thickness probably being due, as already stated, to the greater ease of weathering and erosion of the sandstone prevailing in the former region, combined with the steeper gradient and swifter streams of the Black River drainage in Clark County as compared with that of the Wisconsin in Marathon and Wood counties.

The amount of weathering of the First drift is well shown by the brownish yellow color of the boulder clay, a feature due to the extensive oxidation and disintegration of the iron-bearing minerals of the drift. The feldspar in the igneous rocks of the drift are often changed to kaolinite to depths of 10 and 15 feet from the surface. Thin seams of clay and grit usually have the consolidated character of shale. The drift is compact and well consolidated, a characteristic only attained by extensive disintegration, settling and cementation of the material. Most of the boulders and pebbles of the basic rock, and also many of the granitic boulders are readily cleaved with the spade in excavating the drift, and fall to pieces upon exposure to the air.

The extent of erosion wrought in the First drift sheet is therefore very great as compared with the very little erosion of the latest drift formation of the region. The glacial features of topography, which once characterized the formation, have long been removed and the more rugged features, due to long continued stream erosion, sustituted in their place. The deep erosion of this drift evidently has required a relatively long time, corroborative evidence of which, is also shown by the deep weathering and alteration of this drift formation.

SECTION II. FIRST INTERGLACIAL EPOCH.

After the drift of the First glacial epoch was deposited, a long interval elapsed in which the ordinary present day climatic conditions prevailed in the region. This interglacial epoch probably lasted at least as long as the preceding glacial epoch, and, measured in time, extended over thousands of years. Soils were developed upon the drift of this formation and are now encountered in sinking wells through the overlying formation in various parts of the district. A buried soil occurs on the farm of C. Ehlert one-sixth mile west of the N. E. corner of sec. 15, T. 26, R. 1, W. In this well, which has a total depth of 89 feet without striking rock bottom, a thickness of about 2 feet of black soil is reported at a depth of 58 feet, below which is 27 feet of drift. The record of this well is as follows:

Surface soil	2 feet.
Clay	13 feet.
Sand	5 feet.
Clay containing pebbles	38 feet.
Black soil like that at surface	2 feet.
Sand	2 feet.
Clay and sand	25 feet.
Total	87 feet.

The principal evidence at hand of this interglacial epoch lies in the difference in character, location and thickness of the two drift sheets mapped and described as the First and Second formations. The unconformity of the two is shown in the following account of the Second drift. The difference in character and areal distribution in the two formations is such as to indicate that they were formed by distinct ice sheets separated from one another by a well defined interglacial epoch.

SECTION III. THE SECOND DRIFT FORMATION.

Forming a broad, curving ridge, upon which are located Neillsville and Marshfield, is a pronounced thickening of drift which obviously represents the terminal moraine of one of the older sheets of the drift series. This ridge has been followed for a distance of about 7 miles across southwestern Marathon, northwestern Wood, and through Clark County. Its continuation to the northwest has also been located in the adjacent area of Chippewa County, where it disappears beneath the late drift of the Wisconsin epoch just east of the Chippewa River. Its continuation to the north of Marshfield, across northeastern

Clark County into Taylor County, is less definite, but its approximate location in this vicinity is believed to be about as located upon the map. A thick ridge of very old drift also occurs in the eastern part of this district, being exposed in eastern Portage County and in northwestern Langlade County, whose general surface features, internal characters and thickness indicate it to belong very probably with the same formation as the moraine extending from Marshfield to Neillsville. Outside of this district, in northwestern Wisconsin corresponding thick ridges of drift have been traced across Barron, St. Croix and Pierce counties. See map, Fig. 21.

THE TERMINAL MORAINE IN THE WESTERN PART OF THE AREA.

The Second moraine extends across northwestern Marathon, northwestern Wood, and through Clark counties in such a manner as to form a broad letter "U," the base of the "U" being directed toward the southeast and the arms spreading outward to the north and the northwest, being covered with the thin Third drift in northern Clark and finally disappearing under the thick Wisconsin drift in eastern Taylor and central Chippewa counties. It has the location, therefore, of a moraine deposited at the terminus of a great lobe of ice that moved into this particular locality from the north-northwest.

This terminal moraine may be conveniently referred to as the Marshfield moraine or the Marshfield-Neillsville moraine, since it has, perhaps, its most pronounced development in the immediate vicinities of Marshfield and Neillsville, and between these cities. This portion of it, therefore, may appropriately be described first, and then its continuation to the northwest into Chippewa County, and to the northward into Taylor County.

The Marshfield Moraine.

This moraine, as indicated on the map, (Plate II) forms a broad curve, upon which are located, besides the cities of Marshfield and Neillsville, the villages of Bakerville, Lynn and Granton. Throughout its course from Marshfield to Neillsville it stands out as a broad ridge from 75 to 150 feet above the surrounding lower land to the south and southeast, and

THE MARSHFIELD MORAINE SEEN FROM THE FRONT, SOUTHEAST OF NEILLSVILLE.
The crest of the moraine is one mile distant.

THE MARSHFIELD MORAINE SEEN FROM THE REAR, NORTH OF NEILLSVILLE.
The crest of the moraine is two miles distant.

CHARACTERISTIC EROSION FEATURES OF THE MARSHFIELD MORAINE, NEAR NEILLSVILLE.

from the south it can be seen for distances of 10 to 20 miles. From the northwest, in the region of thicker drift back of this moraine, it appears less pronounced, but still is a distinct topographic feature of the landscape.

A view of the moraine four miles east of Neillsville, as seen from the front (from the south), is shown in Plate XLVI. This view was taken one and one-half miles from the summit of the ridge. The appearance of the moraine at Neillsville as seen from the rear (from the north), is shown in Plate XLVII. The two views are taken from directly opposite sides of the moraine.

The moraine is nowhere a sharp ridge, but is broad, with gently sweeping slopes. A view about half way down the south slope is presented in Plate XLVIII. The base of the moraine is generally from one to three miles wide, and the summit from one-half to two miles wide. The moraine does not possess the abrupt forms of recent glacial topography, but quite generally exemplifies the features of long continued erosion of the drift by streams and rains.

Both slopes of the moraine are gentle, with the outer slope to the south in general somewhat less gentle than theinner slope. The steeper outer slopes are pronounced in the vicinity of Marshfield and Lynn. At Neillsville the O'Niell Creek is cutting against the inner side of the moraine, which probably explains the less gentle slope of the north side of the moraine at this place.

Numerous wells upon the slopes and summits of the moraine reveal thicknesses of drift varying from 60 to 170 feet. The ground water level is approximately at the base of the moraine at the level of the streams of the vicinity, and hence all or nearly all the wells penetrate to the bottom of the moraine in their respective localities. Upon the sketch map (Plate L) is represented the thickness of the moraine from the vicinity of Marshfield to Neillsville, as shown by well data. At Marshfield the maximum known depth of drift is 87 feet, at Bakersville, 156 feet, about three miles north of Lindsay, 160 feet, and in the vicinity of Neillsville are several wells 120 to 160 feet in drift.

Northwest of Neillsville.

A mile west of Neillsville the morainic ridge turns to the north, extending northward along the Black River as far as Greenwood, and thence to the northwest, entering the southeast corner of Chippewa County. The bend in the moraine west of Neillsville stands out sharply when seen from the south and west. Along the Black River the erosion of the river has greatly modified the moraine, yet it stands out prominently when seen from the west. The marked difference in the rich soil conditions of the moraine as compared with the light soils of the thin First drift overlying the sandstone farther west is a pronounced characteristic of this part of the country. The moraine and the thick drift to the east is laid out into thriving farms, while to the west the sandy land has been avoided by the farmer.

For some distance northwest of Greenwood the moraine lies in a thickly wooded country and cannot be well defined, but southwest of Thorp, and south of Stanley, in Chippewa County, farms have been developed upon it and it is seen to stand out in marked contrast to the flat sandy land to the south. Its lack of prominence in this locality is probably due to removal by erosion. It has been traced across southeastern Chippewa County and is found to be crossed by the Yellow River a short distance west of Cadott and passes beneath the terminal moraine of the Wisconsin formation just east of the Chippewa River.

North of Marshfield.

At Marshfield, as at Neillsville, the moraine makes a sharp turn to the north. The moraine stands out as a distinct flat-topped rise of land as far north as McMillan, where it is crossed by the Little Eau Pleine River. Along the road between Sections 28 and 29 of T. 26, R. 3 E., wells show thicknesses of 90, 106, 108, and 120 feet of drift. A mile or so far-

SANDSTONE MOUND SHOWING OLD EROSION FEATURES IN THE SECOND DRIFT NEAR NEILLSVILLE.

ther northeast the moraine is broader and the wells are not so deep but show thicknesses of drift varying from 30 to 75 feet.

The moraine bends to the northwest from McMillan, and, owing to the dense forest covering this part of the moraine, could not be well outlined. Between McMillan and Unity there is appreciably higher land on the east side of the Little Eau Pleine River, where the drift in places is known to be at least 90 feet thick.

At Unity there is an appreciable thickening of the drift, as shown by both the topography and well records. North of Unity to the vicinity of Medford the moraine is not well defined topographically, but there is somewhat higher land along the line of the moraine, as located upon the map, the drift along this line being much thicker than in the area to the east. From Unity to the Black River at Little Black, the moraine is believed to form the divide between the streams flowing to the Wisconsin River on the east and those flowing to the Black on the west.

In the vicinity of Colby and Abbotsford, the moraine is over ridden by the Third drift whose relatively thin deposits have tended to obliterate the surface features of the older moraine. The erosion by the head streams of the Little and Big Eau Pleine rivers in this locality, and some distance farther south, also tended to reduce the prominent features of the old moraine. By a combination, therefore, of stream erosion and later glaciation, the moraine is indistinct in northeastern Clark County and along the border of Marathon County farther southeast.

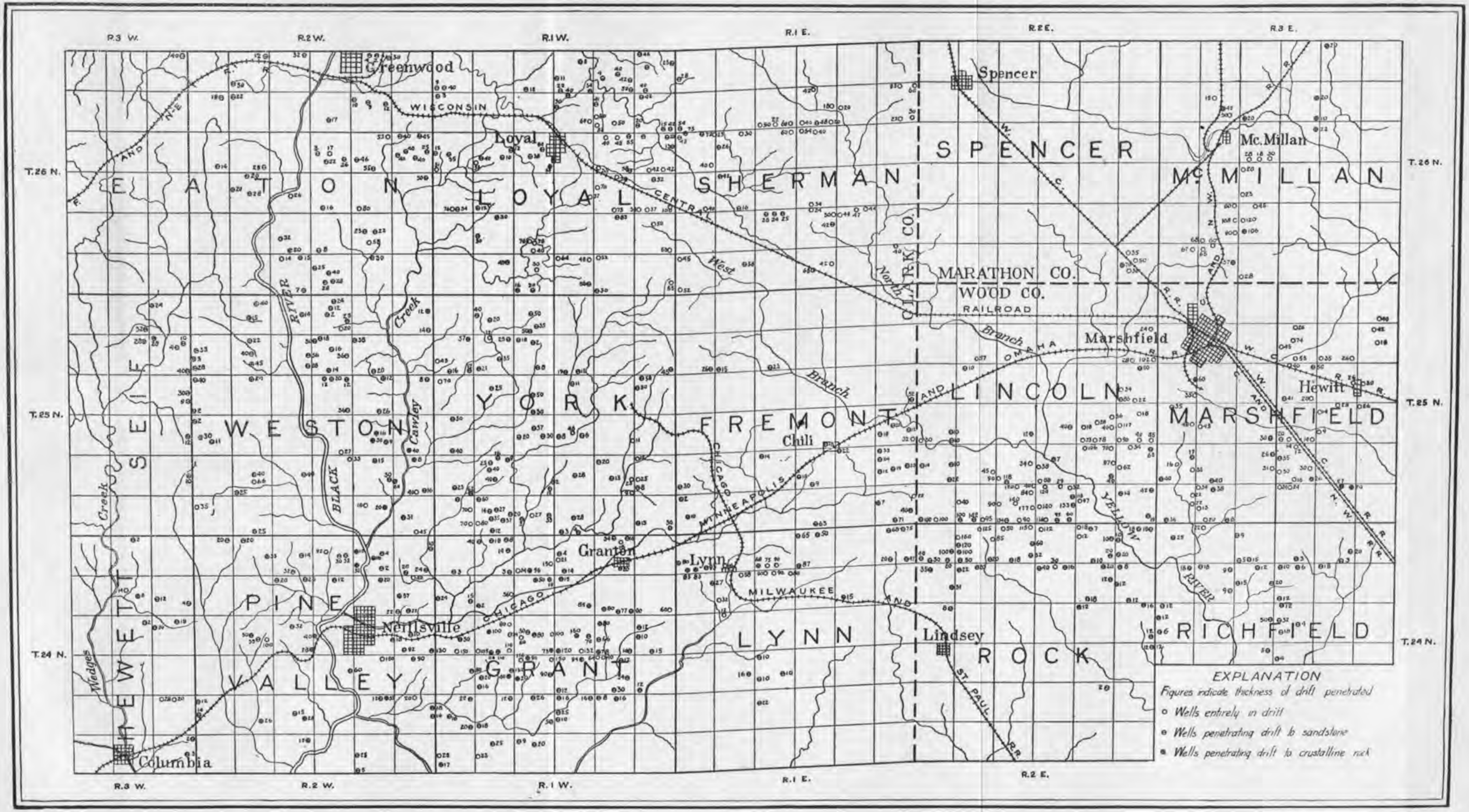
There is an appreciable thickening of the drift into a more pronounced broad ridge immediately west of Little Black, extending northward on the east side of the Black River and disappearing under later drift northeast of Medford. The general surface features of this old drift ridge are similar to the moraine at Marshfield and Neillsville, and it is believed to represent a portion of the same moraine. The drift of this ridge is well exposed beneath the bridge across the Black River 2 miles south of Medford, and the general character of the formation exposed at this place, with respect to alteration and consolidation, is strikingly similar to that of the drift of the moraine at Marshfield. In both places the drift has the characteristic features of a very old glacial formation. To the east of this ridge, at Medford, and also to the west, the drift forms an appreciably thinner mantle. The drift outside of the moraine, in western Marathon County, has the general characteristics of the First drift formation, as already described, the thickness of drift in this part of the district being much less than that prevailing within the area of the Second moraine.

THE TERMINAL MORAINE IN THE EASTERN PART OF THE AREA.

In eastern Portage County, about 6 miles east of Stevens Point there emerges from the billowy terminal moraine of the Green Bay lobe of Wisconsin drift an old ridge of drift which extends southward for about 20 miles and there disappears again beneath later alluvial deposits and Wisconsin moraine. In this locality where the old ridge is exposed to view the border of the Wisconsin formation makes a mild re-entrant to the east. This re-entrant is evidently the place of separation of two minor lobes of the Green Bay lobe of the Michigan glacier. As described later the upper minor lobe lies opposite Green Bay, while the lower lies opposite Lake Winnebago.

The Arnott Moraine.

It is in this re-entrant, therefore, formed by the secondary lobation of the Green Bay lobe of the Michigan glacier, that the old ridge of drift, which may be conveniently referred to as the Arnott moraine, lies exposed to view. It forms a prominent and picturesque feature of the broad plain fronting the Wisconsin moraine, appearing like an ancient redoubt thrown



MAP SHOWING THICKNESS OF DRIFT OF THE MARSHFIELD MORAINE AND ADJACENT AREA.

The moraine extends through Marshfield and Neillsville, the crest being where the drift is 75 to 177 feet thick.

out in advance of the broad belt of billowy drift hills of the much younger moraine to the east.

While the border of the older drift can be traced 3 miles north of Stockton and Custer, it is only in the locality of these places on the Wisconsin Central Railroad that the old drift begins to appear as a distinct ridge. From Stockton it extends southward as an essentially continuous ridge to the vicinity of Bancroft, where the Chicago and Northwestern crosses its southern end. It is broken down in only two places, namely, at Keene, where the head of the Buena Vista Creek crosses it, and two miles farther south where it is crossed by one of the branches of Duck Creek.

The ridge is not narrow and sharp but has a broad summit with gently sloping sides deeply trenched by stream erosion. The average width of the base is about one-half mile and the summit about one-fourth of a mile. The height generally varies from 50 to 80 feet. Its western flank is somewhat more abrupt than its eastern, but only slightly so. (See figures 1 and 2, Plate LI.)

The ridge retains its average height of 50 to 80 feet above the adjacent alluvial plain as far south as the head branches of Duck Creek. South of this it gradually decreases in height and appears as a mere swell where crossed by the railroad near Bancroft. South of this it is wholly absent, there being a broad open gap occupied by the alluvial plain between its southern end and the Wisconsin terminal moraine to the east. North of the distinct ridge at Stockton, as already stated, the border of the old drift has been traced about 4 miles, to the vicinity about a mile southwest of Polonia. Between Stockton and Polonia where the old border appears, the later drift has overridden the continuation to the north of the old drift ridge. For a long distance north of Polonia the older drift is completely buried by the Wisconsin drift. In northeastern Marathon County and in Langlade County, however, the old drift, as described later, again appears outside of the Wisconsin moraine.

South of the south end of the ridge at Bancroft, the presence of scattered boulders and also the character of the soil, indicates that the old border continues southward in line with the ridge farther north, very probably to the vicinity of Plainfield, beyond which it is wholly buried by the later drift.

The topographic features of the old drift ridge from Stockton to the vicinity of Bancroft were obviously wrought by long continued subaerial erosion, the erosion features of the old Arnott moraine being in marked contrast with the glacial features of the much younger Wisconsin moraine to the east. Perhaps nowhere in the Mississippi valley is there a better locality for a comparison of these two types of topography so characteristically developed in the earlier and the later Pleistocene formations. The break in the ridge at Keene is an interseting one for it has every feature of a gap cut through the ridge by a stream. Farther south where the head streams of the Duck Creek cross it the features of long continued erosion are apparent. Hence it seems very probable that its entire absence a few miles farther south may be largely due to removal by erosion. Its disappearance in this locality may also be due, in part, to burial by the subsequent filling of 100 to 200 feet of gravel and sand of the alluvial formation.

The character of weathering and oxidation of the drift of the Arnott moraine is like that of the Marshfield moraine. One mile west of Arnott where the Green Bay and Western railroad cuts through the ridge, the sandy, bouldry, drift shows the usual features of an extensively weathered formation. The clayey content is brownish yellow, the sand is brownish red through surface weathering, and many of the basic pebbles are wholly disintegrated. In the vicinity of Custer where the later drift is present the older weathered drift is worked up into the overlying deposits and can be distinguished from the latter with comparative ease.

The farm wells on the slopes of the ridge penetrate to depths of 30 to 75 feet in the drift, the depth depending on their position on the ridge. Judging from the thickness of the later alluvial gravel and sand in the plain adjacent to the ridge, and the height of the later above the plain, it is reasonable to estimate an average thickness of 75 to 150 feet for the drift ridge.

The general internal character, surface features and thickness of drift of this bouldery ridge in eastern Portage County is apparently identical with that of the Marshfield moraine

Fig. 1. VIEW OF ARNOTT MORAINE FROM THE FRONT, FROM THE WEST.

Fig. 2. VIEW SHOWING THE EROSION OF THE ARNOTT MORAINE AT KEENE, FROM THE EAST.

and hence it is correllated with the latter, as forming the border of the Second drift sheet, though formed at the margin of a different lobe of this early Pleistocene ice sheet.

In Northeastern Marathon and Langlade counties.

In northeastern Marathon County, in the vicinity of the eastern part of the town of Harrison, are deposits of very old drift whose weathered character and surface features readily distinguish them from the drift formations to the east and also to the north. This older formation is bounded on the east by the Wisconsin terminal moraine, on the north by the Third drift, on the west by the driftless area.

The drift is a clayey, bouldery formation of a prevailing yellow brown color, much decomposed and consolidated, the weathered character of the drift being in sharp contrast with the fresh deposits of drift to the east and to the north. The old drift in this locality is not of notable thickness, varying from nothing up to 30 or 40 feet. In this region also it does not have a ridged character, but has the appearance of representing merely the remnants of much thicker deposits which may have originally been in the form of moraine ridges.

Nowhere to the east, because of the complete burial by the thick formation of Wisconsin drift, has this older formation been observed, but to the north, in western Langlade County, under the comparatively thin Third drift, this old ridge has been recognized. In the western part of Langlade County, forming the divide between the branches of the Eau Claire River on the east, and the Pine River on the west, is a thick formation of old drift deeply trenched by streams and having the general aspect of the Second terminal moraine. This old moraine is covered here and there with small ridges of drift and shallow sags the usual features of the Third formation. In regard to the surface features, the drift in this locality is essentially identical with the general appearance of the old moraine in Taylor, Chippewa and Barron counties where it is covered by the thin deposits of the Third formation.

The thickness of the old drift in western Langlade is considerable, wells in the eastern part of sec. 28. T. 33, R. 9 E. showing depths of 54 to 62 feet without striking rock. Wells in the eastern part of T. 32, R. 9 E. and western part of T. 32, R. 9 E. and western part of T. 32, R. 10 E. show similar thickness of 50 and 60 feet up to 122 feet without rock bottom. The farm well in the N. E. ¼ of S. E. ¼ of section 24 T. 32, R. 9 E. and the western part of T. 32, R. 9 E. has a depth of 122 feet in the drift.

Considered alone, the drift in northeastern Marathon County and western Langlade County might be viewed as belonging with the First drift formation rather than with the Second. The thickness of this drift, in one place at least 122 feet, however, is much greater than that known to occur anywhere in the area of the First drift. In fact the thickness at this place is nearly twice that of the maximum thickness of the First drift. The location of the old drift in this locality is also much more in harmony with the view that it is the continuation to the north of the old drift border represented by the Arnott ridge in eastern Portage County. As already stated, also, the surface features of the drift in western Langlade, where the old drift is overridden by the Third ice sheet, is strikingly similiar to the features of the overridden Second moraine in Taylor and Barron counties.

The various ice invasions of the Pleistocene were undoubtedly guided in their advance to the south by the large basins of the Great Lakes and the occurrence of the old drift in eastern Marathon, western Langlade and eastern Portage counties, forming a border line approximately parallel with the western boundary of the Lake Michigan basin. is fully in harmony with the view that the old drift border in this part of the state was very probably deposited by an ice sheet that spread out over the depression of Lake Michigan.

It seems very probable therefore that the worn down drift ridges in eastern Portage continue northward beneath the thick Green Bay moraine of the Wisconsin formation, reappearing again where the latter bends to the east to join with the Langlade lobe in the re-entrant east of Antigo. Where the old drift border passes beneath the Langlade moraine in northwestern Langlade County, it is still represented by thick drift deposits but farther south, in the town of Ackley, Langlade County and in northeastern Marathon County, the old moraine is very largely removed.

At first thought it would seem improbable that so considerable a part, some 15 or 20 miles in length, of the old thick moraine was so largely removed, but knowledge of the great erosion of this terminal moraine in other parts of the state, is fully in harmony with this view. It seems likely, as later pointed out that a much larger river than the present Eau Claire, once flowed through this great gap in the old moraine west of Antigo.

THE GROUND MORAINE.

The area within the lobe of the Marshfield Moraine may conveniently be described as the region of ground moraine, although probably not all the drift deposits in this region are of ground moraine origin. The area within the lobe of this moraine is characterized by a much greater abundance of drift, as should be expected, than that imemdiately outside of it in the region of the First drift.

The topography of the ground moraine has none of the characteristic features of recent glacial deposits, but has the features of complete drainage wrought into a thick mantle of drift by streams eroding for a considerable period. The area contains no lakes, or swamps holding stagnant water. The streams flowing through the area of the ground moraine, like those cutting across the terminal moraine, have, in general, penetrated to the underlying pre-Cambrian crystalline rocks or to the Potsdam sandstone. Numerous rapids occur in the Black River and tributaries, but none are known of boulder origin.

THICKNESS.

The general thickness of the drift of this formation, as is usual with glacial formations, varies between wide limits. It may be said to vary in thickness from zero to at least 170 feet. In many places there was no drift deposited originally, and in many places also, as shown by the fact that most of the streams are flowing on bed rock, the drift has been subsequently removed. By processes of consolidation also, this drift formation has become more compact than when originally deposited, a fact which should be considered when comparing the thickness of the drift of the older formations with those of comparatively recent origin.

The known thickness of the terminal moraine varies from 30 to 170 feet. The average thickness of the moraine in its thickest portion, that is, the broad summit of the ridge from one-half to one mile wide, is probably between 50 and 75 feet. This thickness will atleast hold for that portion between Marshfield and Neillsville where best exposed to view, and where numerous wells have penetrated it.

The drift back of the moraine varies from a few feet up to 100 feet. No wells were noted in the region of the ground moraine having a greater depth than 100 feet of drift. Many well records show a thickness of 20 to 70 feet of drift. It should be remembered, however, that most of the farm-houses are built upon the gently sloping uplands, where the drift is appreciably thicker than along the stream bottoms. If the drift of this formation, including also the drift of the First formation underlying it, were spread out with uniform thickness over the area it would form a mantle probably between 20 to 30 feet thick. In Marathon and Wood counties the thickness of the Second drift is probably 3 or 4 times as great as that of the First drift. In Clarke county on the other hand where the soft sandstone is the underlying rock the second drift is apparently about 10 times as thick as the First.

EFFECT UPON TOPOGRAPHY.

The effect of the deposition of the drift of this formation upon the pre-existing topography is quite marked. It has not only filled up valleys but has also buried many hills and ridgy divides. The entire area of this drift formation is underlian, here and there, by the Potsdam sandstone. The northeastern part of Clark County and the adjacent area of Taylor County lie in the region of the gently sloping pre-Cambrian peneplain. In the southwestern part of Clark, outside the area of this drift formation, there are numerous sandstone hills and ridges. This area of hilly land extends for some distance beneath the thick drift farther east. The surface of the drift, therefore, is less rolling in the northeastern part of Clark county than in the southwestern part, on account of the more rugged character of the pre-existing topography.

VIEW FROM THE ARNOTT MORAINE. LOOKING EAST ACROSS THE ALLUVIAL PLAIN TO THE GREEN BAY MORAINE.

The Marshfield moraine as a topographic feature has already been referred to. It stands out for a large portion of its course as a well defined ridge from 50 to 150 feet above the surrounding lower land. Its outer slopes are in general steeper than the inner slopes, as is usually the case with terminal moraines. The moraine is gently sloping along the sides, and the summit also is a broad slope, the whole features of the moraine being in sharp contrast with the pointed ridges and steep slopes of the later terminal moraines.

The Arnott moraine in eastern Portage County is of lesser height than the Marshfield moraine, but otherwise has similar features of topography. Its lesser height is probably partly due to partial burial by alluvium.

The terminal moraine, as well as the ground moraine, has no undrained areas, the topographic forms being those of stream erosion, a sufficient period having elapsed since the deposition of the drift for the streams to erode through it to the underlying bed rock.

AMOUNT OF EROSION AND WEATHERING OF THE SECOND DRIFT.

Erosion.

The extent of the erosion of the Second drift cannot of course be quantitively measured in feet. Qualitatively it may be said to be very great, as compared with very little erosion wrought in the latest, Wisconsin, drift of the region. The drift is comparátively thick upon the flat topped uplands, relatively thin along the valley sides, and practically absent in the valley bottoms, thus indicating unmistakably, the extensive work of stream and river erosion The terminal moraine of this drift sheet where streams cross it is entirely cut down to the bed rock beneath, indicating in these trenches through the moraine, the removal of 75 to 150 feet or more of drift. Over a considerable area, also, the terminal moraine ridges are entirely gone, though they originally must have been present, as the great magnitude of this drift sheet indicates the extreme probability that a fairly continuous belt of thick drift ridges must have marked its entire border. The absence in many places of thick drift ridges along long stretches of the border of this formation may therefore be taken as due to removal by ero sion. In some instances the removal of the moraine may be traced to the work of streams which now extend across it, but the largest gaps in the old moraine, as in southern Langlade County, were very probably wrought by large rivers of the earlier Pleistocene time and which, through changes caused by later glaciation or crustal warping, no longer persist or are replaced by minor streams.

The amount of erosion wrought since the depositon of this drift formation may also be comprehended from a study of the topographic features of some of the mounds of sandstone that project through the drift upon the upland areas. Plate XLIX illustrates the very pronounced erosion features characterizing these sandstone mounds. The view here presented is of a castellated mound far removed from stream action, and, hence the rock erosion is entirely that of weathering combined with corrasion by rains and the winds. The erosion proceeds along the joints which traverse the rock, and along the beds of softer sedimentation dividing the cliff faces into sharp projections and recesses, and also along horizontal and vertical joint lines. These erosion features are in sharp contrast to the smoothened surfaces made by glaciers and such castellated mounds as these are often cited as evidence that the regions in which such topographic forms occur have never been invaded by glaciers. Yet the mounds here depicted are in an area twice glaciated, and portions of their bases are buried beneath nearly a hundred feet of drift. These sandstone mounds also have such an abundance of talus debris lying upon the drift and surrounding them on all sides as to indicate a period of considerable length in the process of accumulating such debris.

Such castellated mounds as these are common in southwestern Clark County in the area of the First drift. They were once undoubtedly smooth and rounded by glacial action, but a sufficient time has elapsed since their glaciation for the characteristic features of sub-aerial erosion to be superimposed upon them.

Weathering.

The amount of weathering of this drift formation is extensive down to depths of 10 to 20 feet, the clay and sand matrix being oxidized to a characteristic yellow brown color. Many of the pebbles and boulders of basic rock are wholly decomposed and have lost their identity. Some of the granite boulders and pebbles, also are wholly disintegrated, and are readily cleaved with the spade and crumble to pieces when exposed to the air. Numerous veinlets ramify through the till which mark the passage of percolating under ground water and the extensive oxidization of the clay and sand along these openings is a pronounced feature of the alteration of the deposits. Thin layers of sand mixed with clay have assumed through processes of cementation the consolidated character of shale. The extensive weathering and consolidation of the drift is well shown wherever exposures have been made to any appreciable depths. Excellent exposures for the study of the drift of the Second terminal moraine are shown in the Wisconsin Central railroad cut in the northern part of Marshfield, and also in the south bank of the Black River, at the bridge about two miles south of Medford.

The drift of the earlier as well as the later formations of this part of the state contains no appreciable content of limestone material, and hence the method of determining the relative age of the drift by ascertaining the depth of the leaching of the lime carbonate cannot be applied. In most other parts of the Mississippi valley, where the old drift sheets have been studied this method of determining the relative age of the drift by the amount of leaching of the lime carbonate has been successfully applied and it can also be applied in studying the old drift farther west of this particular area in Wisconsin. In this part of the state, however, the amount of weathering and the age is indicated by the extent of the oxidization and kaolinization of the minerals, the cementation and consolidation of the drift, and the disintegation of the boulders and pebbles.

On visiting the railroad cut in the moraine in the northern part of Marshfield with Prof. Chamberlin a few years ago, when the cut had but recently been made, and the exposures were fresh, the later pronounced the extent of weathering of this drift to be as great as that of any ever observed by him. This opinion of course should not be interpreted as expressing the belief that this drift belongs to the oldest drift sheet, but merely that the amount of weathering that it reveals is apparently equivalent to that of any of the other older drift sheets. As a matter of fact, both the Kansan and the pre-Kansan drifts appear to be so old that very little difference in the extensive weathering of the two can be detected.

SECTION IV. THE SECOND INTERGLACIAL STAGE.

After the deposition of the Marshfield terminal moraine and its accompanying ground moraine and the Arnott moraine in Portage, Marathon and Langlade counties there followed a long period of sub-aerial erosion before the next overlying drift formation of this district was deposited. The interglacial deposits above the Second formation and beneath the next overlying formation are believed to be the extensive alluvial deposits of the region. The principal evidence for the separation of the Second drift from the next overlying, however, is the extensive erosion and weathering of the former previous to the deposition of the latter, for the next overlying formation as subsequently described has the general topographic aspects of drift comparatively little changed by subsequent erosion and weathering. Hence it may safely be presumed that a very long period has elapsed between the deposition of the formation just described as the Second drift of the area, and that following described as the Third.

SECTION V. THE THIRD DRIFT.

Extending over the northern part of Marathon, (See map, Plate II) southwestern Langlade, southern Lincoln, southeastern Taylor and northern Clark counties is a drift formation which is here provisionally designated as the Third in the series exposed in northern Wisconsin. The border of this drift

CHARACTERISTIC DRIFT OF THE THIRD FORMATION, AT DEERBROOK, LANGLADE CO.

formation is not everywhere marked by prominent terminal moraine features, but is obscure and indistinct in many places. When examined over any considerable area, however, the border can be fairly accurately located. This formation has been mapped in the region farther west and its border found to lie across southwestern Chippewa, southern Barron and Central St. Croix counties, crossing the St. Croix River into Minnesota from the northwest corner of Pierce County. (See map, Fig. 21.)

THE DRIFT BORDER.

The border of this drift formation extends from northeastern Marathon County across the northern parts of Marathon and Clark counties in a direction slightly south of west. The border, as a rule, produces no prominent feature of the landscape, being marked only here and there by drift ridges and morainic topography.

Marathon County.

The drift of this formation is exposed just outside the prominent Wisconsin terminal moraine in the northeastern corner of Marathon County, in the eastern part of the town of Harrison. In this particular area, the much older drift of the Second formation also occurs, and being in a locality as yet but little opened to farming the border of the Third drift can only be approximately located. Farther west, however, in the towns of Hewitt and Texas, where the older drift is not present, and, therefore, where the Third drift border marks the boundary between the driftless and drift covered regions, the border can be accurately located. The border through Texas and Hewitt where it has been definitely located, to all appearances continues eastward through the central part of Harrison and passes under the Wisconsin moraine in the eastern part of section 24, T. 30 R. 10 E.

The border in the town of Texas, Hewitt and Harrison is not known to be marked by any morainic topography, such as sharp ridges and basins, but such features will very probably be found later when the region is more opened to agriculture and better facilities for study are at hand. In the town of Harrison and northeastern Hewitt the land at the border and farther north is characteristically more poorly drained than the land to the south beyond the border. Semi-swampy tracts occur here and there within the border of this drift and other features of comparatively new surface topography are prevalent. In the town of Texas and in northeastern Hewitt, the comparatively deep valley of the Trapp River lies close within the border of this drift. The border is generally characterized by glacial boulders and thin till deposits along the margin, back of which, within a mile or two, the till often attains a thickness of 30 or 40 feet, as illustrated by well records in the central part of section 14 in the eastern part of Texas.

There is perhaps no better locality in the immediate vicinity of Wausau than in the town of Texas for a comparative study of the driftless area and the area of one of the older (pre-Wisconsin) drifts. The contrast between the glaciated and non-glaciated parts of this locality lies mainly in the difference in the internal character of the soil and surface deposits. There is no sharp difference in the topographic features or in the relative abundance of the field stone in the two areas. The lack of any sharp contrast in the topography is due to the relative thinness of the Third drift formation, the want of sufficient accumulations of drift to produce pronounced topographic features. The crystalline character of the rock of the region, through the weathering of which a stony residual soil has been developed in the driftless area, has tended to produce no essential difference in quantity of loose field stone in the two areas. But as one examines the character of the surface deposits and of the stone in the two tracts, a sharp difference is at once apparent. South of the drift border the clay-loam soil is uniformly thin, the underlying crystalline rock, mainly granite and greenstone, generally being present within a foot or two below the surface. The stones from the soil picked up from the cultivated farms and accumulated along the highways, in stone fences, and in heaps in the fields, are remarkably angular and sub-angular, and all are of the same kind as the immediately underlying rock. In the drift area, on the other hand, there are deposits of clay and stone of variable thickness up to 10 or 20 feet upon the underlying country rock, and the smooth and polished surfaces of most of the loose stone are in sharp contrast with the rough surfaces of the stone in the driftless soil. The great variety of the polished stone and boulders in the drift, many of which are derived from rock ledges many miles to the north, is also quite different from the uniform character of the field stone in the soil of the driftless area.

West of the Wisconsin River, in Marathon County, the border of the Third drift has been traced and found to mark the boundary of the driftless as far as the vicinity of Rib Falls. West of Rib Falls this drift sheet lies upon the much older, First drift already described. As shown upon the map, the main border continues in a southwesterly direction from the vicinity of Granite Heights on the Wisconsin to Rib Falls on the Rib River.

The border in the northwestern part of Section 33, T. 30 R. 7 E. and in the adjoining part of sec. 32, is marked by some relatively large drift ridges. The drift ridge in sec. 33 is well exposed along the wagon road. These ridges are not sharp but broad at the top, with relatively steep sides and lie upon the south slope of the valley of a small stream. They are from 30 to 50 feet high and consist largely of gravel and other stratified material. They may be kame deposits formed at the ice margin by glacial streams issuing on a steep southward slope.

The main border of the drift appears to continue nearly westward from the above locality to Rib Falls, and is everywhere marked by relatively thick deposits of drift. But there is a thin covering of drift in the valley of the Little Rib River, out beyond the main border, which seems to have been deposited during a temporary advance of the ice down this valley. At first thought it would seem more likely that the ice would have advanced farther down the channel of the main stream of the area, namely, the Wisconsin, rather than one of its small tributaries, but an examination of the topographic maps[1] shows that the Wisconsin River valley in this locality is only a narrow gorge, while the valley of the Little Rib River is comparatively very broad. The highest upland areas of Marathon County (excepting the monadnock peaks of the Rib Hill quartzites) are in the vicinity of the border of this drift on

[1] Wausau and Marathon Special Topographic Maps. U. S. Geol. Survey.

both sides of the Wisconsin River, at Granite Heights and Brokaw, and these heights very evidently were effective in holding back the ice margin from advancing down the narrow channel of the Wisconsin River, while the Little Rib River immediately west allowed an easy advance of the ice down its broad valley.

Over the slopes of the valley of the Little Rib, therefore, occurs a scattering of boulders as far south as the broad fill of the Big Rib River. These boulders are found well up on the divide between the Little Rib and the Wisconsin, and their occurrence here is in marked contrast with the absence of glacial boulders on the east side of the Wisconsin River immediately northeast of Wausau. The drift seems to be most abundant on the east side of the Little Rib, there being apparently no glacial boulders upon the divide, between Stettin postoffice and Rib Falls.

The most prominent deposits known in the area of this temporary advance down the Little Rib valley is near the center of the N. W. ¼ of Sec. 28, T. 29, R. 7 E., just south of the edge of the broad table land of this locality. Here there are two small mounds of drift lying about half way down the south slope of the upland. The drift consists, apparently, mainly of gravel and sand with some boulders on top, and seems to have been deposited by streams issuing from the ice margin when the latter was located upon the upland above. The surface features of these drift mounds are like those prevailing in the Third drift, and this fact combined with the relative position of the Little Rib River Valley with regard to the Third drift ice sheet is taken as sufficient evidence for classifying these drift mounds with the Third drift, rather than with the First drift, or with some other drift sheet.

In the vicinity of Rib Falls, as already stated, the Third drift comes in contact with and overrides the First drift. East of Rib River in sections 9, 10 and 11 of the town of Rib Falls, the Third drift is relatively thick. West of Rib River, about one-half mile north of Poniatowski, there are ridges of the Third drift. Between the above places, namely, down the valley of the Rib River, the ice advanced a few miles farther than upon the uplands adjacent, its southern limit apparently extending as far south as the village of Rib Falls.

It is impossible to exactly locate the thin border of this drift upon the older First drift in the northwestern part of the county. The approximate border may be located, however, by a general difference in topography which in some places is quite marked, while in others it is but slight. As a rule the area of the Third drift is marked by swampy, poorly drained tracts, with now and then a gravel ridge or a low hummocky tract characterized by shallow sags and mounds. The two drifts where exposed to a depth of a few feet can readily be separated from each other, but very often no such exposures are available along the border. The border in this part of the county is therefore only approximately located, and later work may require some change in the map, although, very probably, the border will not be shifted more than a mile or so in any locality.

In Clark County.

One mile west of Colby, in the southeast corner of section 14, Town of Colby, is a gravel pit having the general character of the Third drift rather than that of the older First or Second formations. In sections 16, 17 and 20 of Colby are considerable ridge-like accumulations of drift whose surface features and character of drift indicate them to be Third drift. Similar drift hills occur a few miles farther west in the valley of the South Fork of Poplar River, in the southeast one-fourth of sec. 22, town of Green Grove, and also in the vicinity of Longwood.

In the vicinity of Colby the Third drift overrides the Second drift but in this locality the Second moraine is apparently greatly eroded and is barely distinguishable. In the area north of these drift ridges there are occasionally shallow sags and undrained areas indicating comparatively young topography, while to the south the land surface is characterized by relatively sharp valleys and complete drainage everywhere. The drift of these ridges and that of the surface to the north is quite fresh and not much weathered, while that to the south is characterized by the yellowish brown color and advanced decomposition of the older drift formations.

West of the Black River the border is marked by a belt of shallow sags and low hummocky drift ridges extending through the central parts of the towns of Reseburg and Worden. As in the eastern part of the county, the land north of this belt of isolated patches of sags and low ridges is marked by the younger features of the Third drift while that to the south is characterized by the features of the much older drifts.

A few miles west of Clark County, in Chippewa County, the border of the Third drift runs approximately parallel for a short distance to the terminal moraine of the Second drift.

The extension of the Third drift, somewhat farther south in Clark than in Marathon County to the east, or in Chippewa County to the west, is in harmony with the southward extension of the other drifts in his locality. The First and Second ice sheets developed a very prominent lobe in this portion of the state, as shown upon the map. The Wisconsin ice sheet which came to rest farther north, also developed in this region a large lobe, though located somewhat farther to the west. The southward extension of the Third ice sheet in Clark County is therefore in harmony with the general lobation of both the earlier and the later ice invasions. The lobation of the Third, however, is not so pronounced or so prominent as that of the other periods. The possibility of a more pronounced lobation of the Third sheet in this locality was kept in mind, however, and a careful search was made for the occurrence of the Third drift farther south along the Black River, than it is shown on the map;. but farther south, only the older drift with the characteristic pronounced erosion features are to be observed.

RECESSIONAL MORAINES AND GROUND MORAINE.

The area of this formation, as shown on the map (Plate II), extends over the northern parts of Marathon and Clark counties, the southwestern part of Langlade, southern part of Lincoln and the southeastern part of Taylor counties. North of the border of this drift sheet, and thus within the general area of this formation, there are a number of interesting features which may be briefly described. Usually the drift is relatively thin throughout the area and in many places of considerable extent it is scarce or entirely absent. Where absent

CHARACTERISTIC LOW RIDGES OF THE RECESSIONAL MORAINES OF THE THIRD DRIFT.
Four miles southeast of Bloomville.

the want of drift may be due to lack of original deposition or to removal by subsequent erosion. Immediately north of the driftless portion of the area only the Third drift appears to be present, and over the uplands of this part there appears to be but a relatively small amount of drift. A good locality illustrating the conditions of very thin drift is the high upland area west of the Wisconsin River, opposite Granite Heights. This locality reaches an elevation of 1500 to 1560 feet, and the granite bed rock is almost wholly free from glacial boulders and drift.

In those parts of the area where one or both of the earlier drifts lie under the Third drift, the underlying rock formations are quite generally covered with drift. In the areas of the underlying older drift, however, the yellow brown clay of the older formations often shows through the Third formation, showing that the latter formation usually makes but a thin covering upon the earlier glacial deposits.

In many places, however, throughout the area of this formation there are relatively thick accumulations of the Third drift, developing in such localities typical features of glacial topography, such as drift ridges and hummocky mounds associated with sags and basins. The sags and basins are sometimes occupied by swamps and sometimes by shallow ponds and lakes. The occasional occurrence of small areas of knobs and basins is a characteristic feature throughout the Third drift, and in this respect the surface features of this formation are quite unlike those of the older, deeply eroded, drift sheets.

The knob and basin areas constitute typical terminal moraine deposits, and undoubtedly indicate where the margin of the ice stood for some time in the recessional movement to the north. The knobs and ridges of these terminal deposits usually rise but 10 or 15 feet above their surroundings, and the basins and depressions fall but a few feet below. (See Plate LIV.) In places, however, the ridges may rise to 30 or 40 feet and the depressions are correspondingly deeper.

The drift material of these knobs and ridges generally consist of a few good sized boulders on top with much gravel and sand beneath the surface, the gravel greatly predominating. Locally these ridges are often called "gravel knolls" or "gravel ridges." Some of the ridges, however, are made up of course boulders to a very large extent. These terminal moraine deposits of knobs and basins sometimes occur apparently in wholly isolated patches, but more often they appear to lie in short belts extending in an east-west direction. The deposits undoubtedly represent recessional moraines, and while they do not form a continuous belt for any great distance, they are at least as continuous and are as pronounced morainic features as are developed along the border of this formation at the farthest advance of the ice sheet. The recessional moraines of this formation, therefore, are approximately of the same magnitude as the terminal moraines.

On account of the general similarity of drift features, both to the south and to the north of these recessional moraines, they cannot be traced continuously across the area. It may be possible, however, at a later date, when the region is everywhere cleared of the dense forest and the extent of farming lands greatly increased, that these small recessional moraines may be traced out with some considerable degree of accuracy, in a manner somewhat like that of the much more prominent recessional moraines of the Wisconsin drift. For the present, however, only the most prominent of these moraines of the Third formation can here be described. Their occurrence is shown by appropriate symbol upon the map. (Plate II.)

In the vicinity of Merrill there is relatively a great abundance of the Third morainic deposits as compared with their abundance in other parts of the area of this formation. These knobs and sags are especially numerous in the valley of the Wisconsin River, and occur as far southward as the mouth of Pine River. As shown upon the map (Plate II), this belt of moraine extends along the Pine River for several miles and then apparently ends, though it is probably a part of the same recessional moraine as that to which some of the terminal deposits belong farther east. West of the Wisconsin River this morainic belt can be traced fairly continuously for 10 or 12 miles and lies along the divide separating the waters of Devil Creek and Copper River on the north, and those of the Rib River on the south. Farther southwest it may be represented by the knobs and basins in sections 16 and 17, Town of Hamburg, and possibly with the ridges lying across Black Creek about a mile northwest of Athens.

Some of the drift ridges and knobs in the vicinity of Merrill attain a height of 30 to 50 feet above their immediate surroundings. The most prominent ridges appear to be in the northern parts of sections 21 and 22 of T. 31, R. 6 E. Most of the knobs, however, are from 10 to 20 feet high. The northern part of Merrill, on the west side of the Prairie River, is characterized by numerous depressions and bouldery drift. These depressions, with occasional drift ridges, are common features of the broad, flat area north and northeast of Merrill in the vicinity of Lake View and along Little Hay Meadow Creek. This locality appears to be an old valley bottom, perhaps once occupied by the Wisconsin River whose earlier channel seems likely to have been along the present line of the Chicago, Milwaukee and St. Paul railroad. It is in the broad flats of wide valleys that morainic deposits of this drift formation are the most abundant. This is not only true of the morainic deposits in the Wisconsin Valley at Merrill but has also been observed to be a characteristic feature of the Chippewa Valley and of the St. Croix Valley farther west.

The greater abundance of terminal moraine deposits in the broad valleys lying parallel to the course of the ice sheet, than upon the adjacent uplands, is probably due to a somewhat greater thickness of the ice in these valleys, and to a higher rate of movement thereby accomplishing more glacial work in the valleys. The greater abundance may also be due to the fact that the drift in the broad valleys lies in a position more favorable to preservation from erosion, than that lying upon the upland slopes.

The absence of terminal moraine deposits along the Wisconsin River at the border of this drift sheet is very probably due to the narrow gorge-like channel of the river at the border. Farther north on the other hand, where the valley is broad, the moraine deposits are abundant.

Terminal moraine deposits also appear to be unusually abundant in the large valley of the Pine River. The valley of this river is unusually broad and was probably once occupied by a very much larger river than the present Pine, perhaps the Wisconsin whose earlier Pleistocene course may have extended from the vicinity of Rhinelander through this channel. Moraine ridges are especially abundant in the vicinity of section 11, T. 31, R. 8 E. and in sections 27, 28 and 29 of T. 32, R. 9 E.

In places where these broad valleys lead back from the Third drift to the Wisconsin drift and morainic deposits are abundant in the earlier drift, the exact border of the two drifts cannot always be discriminated. Where the borders of the two formations, however, can be traced to the adjacent uplands, the distinction can readily be seen.

In the western part of the area there appears to be a belt of recessional moraine extending along the boundary of Clark and Taylor counties. In sections 4, 9 and 16 of the town of Hixon the drift is accumulated in ridges of considerable size, some of the ridges reaching heights of 30 or 40 feet above their surroundings. The ridge near the south quarter post of sec. 4 is cut across by the wagon road and coarse bouldery drift is exposed. This ridge trends slightly west of north. Near the center of section 9 the Wisconsin Central railroad has cut through 10 or 15 feet of drift, showing the characteristic fresh drift of the Third formation overlying 5 or 10 feet of the very old yellow red till of the Second formation. The lower drift is very much weathered and consolidated and is quite different in these respects from the overlying fresh gray drift. East of the moraine ridges in this vicinity the land is flat without any observed terminal moraine features to the vicinity of section 2, 3 and 4 of the town of Hoard. These isolated patches of moraine deposits, however, may very well mark the border of one of the recessional stages of the Third ice.

In the western part of the town of Little Black is a fairly continuous belt of gravel ridges which extend northward to the vicinity of Medford and farther northeast. Drift ridges are especially pronounced in the northeast part of sec. 8, and northwest part of sec. 9, of the town of Little Black just south of the bend in the Black River. South of the bend of the Black River, in places, there appears to be a considerable valley leading southwest towards the North Fork of the Poplar River. As later described, this valley may represent the course of an early Pleistocene river of considerable size, but it is now blocked up with morainic deposits.

Within a radius of about two miles of Medford there are abundant occurrences of the characteristic knob and basin topography of the Third drift. Not far below the surface in Medford, however, the old yellow brown drift is present, and in the bend of the Black River in the southeast one-fourth of Sec. 3, Town of Little Black, is well exposed, a deep section of the very old drift formation underlying the Third drift.

KAMES.

In a few places within the area of this formation there are considerable accumulations of drift in the form of gravel hills that are not usually immediately associated with morainic ridges. These hills and ridges, which consist almost wholly of stratified gravel and sand with a few large boulders, appear to be usually, if not always, located on the lower slopes or in the bottoms of valleys. An interesting example of this sort is the ridge of gravel in the southern part of Athens which is used to a considerable extent as railroad ballast. A similar gravel ridge occurs in the valley of the Little Black River, in the northeast corner of Sec. 1, town of Little Black, Taylor County. Another gravel ridge of the same sort occurs in a valley in the southeast part of Sec. 5 in the northern part of the town of Maine, Marathon County. These gravel ridges and hills appear to be kames, formed by glacial streams issuing from the margin of the ice sheet.

OUTWASH.

Outwash gravel in the form of a valley train extends from the recessional moraine at the mouth of Pine River several miles down the Wisconsin Valley. As is usual with glacial outwash, the gravel deposits reach nearly to the top of the moraine at Pine River and rapidly thins out over the older valley filling, within three or four miles down the valley.

No outwash, however, appears to be present in the valley of the Wisconsin at the border of this drift sheet. As already described, the valley at the border is but a narrow winding gorge, and conditions, very probably, were not favorable for the deposition of terminal moraine or outwash in this locality. Even if outwash had been deposited in the valley at this place it would have been subsequently removed by erosion for the river now occupies nearly the entire width of the channel at this place.

None of the usual features of outwash gravel deposits border the margin of this drift where it crosses the Rib or the Black Rivers. Very likely, however, considerable gravel was carried far down these valleys by streams during the period of ice invasion.

LOESS.

Loess, a fine clayey deposit occurring over the uplands in abundance in the western and south western part of the state is present just outside the area of this report in western Jackson and in eastern Eau Claire and Chippewa counties. Deposits of loess however are not known to occur in this area although it is possible that they may be present. The most likely locality for their occurrence is the western part of Clark county.

The loess of southern Chippewa County lies upon the terminal moraine deposits of the Third drift, and thus bears an interesting and important structural relation to the Third formation. The loess of this locality, though occurring in a relatively small area, about 15 or 20 square miles in extent, possesses the characteristic features of the main area of loess of widespread distribution farther southwest.

THICKNESS.

The thickness of this drift formation along the border varies from a few feet up to 50 or 60 feet. Some of the drift hills along the border and also those which mark the stand of the ice at recessional moraines have a height of 10 or 15 feet up to 40 or 50 feet above their immediate surroundings. The ground moraine probably does not exceed anywhere a thickness of much more than 10 or 15 feet. Over large parts of the area it is but a few feet thick, merely a very thin mantle of 2 or 3 feet, and over other parts of the area the drift of this formation is absent. On the whole, therefore, the thickness of this formation probably does not exceed an average of 5 or 6 feet, and very probably the thickness is even much less than this. It was by far the thinnest drift formation, at time of deposition, of the series represented in this area.

TOPOGRAPHY.

Topographic Features of the Third Drift.

The topographic features of the Third drift are the small knobs and basins which occur in discontinuous belts or isolated patches throughout the area, and also the broad flat lands which prevail over many parts of the formation. The most prominent morainic features have already been pointed out and need not be discussed again. It is the knob and basin features of this drift, however, combined with the features of the flat lying tracts, which especially charaterize this formation, and which distinguish it topographically from the earlier drifts of the area. The morainic features and the broad flat poorly drained tracts are the characteristics of comparatively young topography, a topography still retaining many of the features due to glacial deposition, while the older drifts to the south, have all the features of an old topography in which the work of ordinary stream and rain erosion have greatly modified the formations, and have completely obliterated and worn away all the glacial features which they once possessed.

Owing to the comparative thinness of the Third drift, it is usually where the drift has been accumulated in morainic deposits that these most prominent characteristic topographic features are developed. Over most of the area of this formation predominates the older features of the land surface existing before the Third drift was deposited. For this reason, therefore, large parts of this formation may be passed over without observing any difference between its features of topography and of that of the older drift or the driftless to the south. However, no considerable portion of the area can be traversed without observing, here and there, small accumulations of drift ridges and morainic deposits, or flat tracts in which drainage is immature, all of which indicate clearly a relatively recent glaciation as compared with that of the region farther south. The fresh character of the Third drift also is fully in harmony with the topographic evidence that this formation is one of the latest in the Pleistocene series.

Effect on the Earlier Topography.

The deposit of Third drift laid down unequally throughout its area of distribution has wrought certain changes in the earlier land surface over which it is spread. These changes and modifications of the earlier topography are a class of phenomena distinct from the topographic features of this drift itself and, hence, may be discussed as the general effect of the deposition of this drift upon the earlier topography. Perhaps the most obvious effects wrought by the deposition of the drift are those which have caused changes in the courses of rivers and streams.

One of the most interesting of these changes in the river courses is that of the Pine River near its junction with the Wisconsin. The lower course of the Pine, within two miles of the Wisconsin, is a narrow V-shaped valley, mainly a mere gorge with a series of rapids known as the Dells of the Pine. Above this gorge the valley is broad for many miles, the difference in the size of the valley in the two parts being a striking one (See Plate LXXIV). The apparent continuation of the broad portion of the valley lies about half a mile north of the gorge and is now filled with glacial drift, as shown by well data. The deposits of a recessional moraine lie across this portion of the Pine River and there appears but little doubt that the course of the Pine, previous to the deposition of this moraine, was in the drift-filled larger valley to the north, the river then joining the Wisconsin a mile above its present junction.

The large size of the Pine valley farther up stream strongly suggests its occupation by a much larger river than the Pine in early Pleistocene time, a larger river whose course may have been changed near the headwaters of the present Pine by the deposition of this drift sheet. Such a change, however, may have been wrought at an earlier date as a result of the general alluvial filling of the valleys of the region, similar to some of the changes in the river courses of other parts of the state.

The Wisconsin river north of Merrill, also, seems likely to have once occupied a course in the valley of Little Hay Meadow Creek, along the present location of the Chi. Mil. & St. Paul railroad. Such a change of course, if it occurred, took place during or before the deposition of the Third drift, and possibly, therefore, by the deposits of the Third drift in this valley.

Southwest of Medford in the northern part of the town of Little Black, where the Black River turns to the north, there is, apparently, an old valley filled with morainic deposits. The natural drainage slope of this locality is to the southwest, and on time of floods, the water from the Black overflows the south bank and joins one of the tributaries of the main river flowing southwest. The drift-filled valley crosses the Black at the bend of the river and continues nearly south apparently joining the north Fork of the Poplar. The earlier course of the Black seems to have been through this valley now obstructed by morainic ridges.

There are other changes in the courses of the streams, wrought by the deposition of this drift formation but they have not been worked out in sufficient detail to be described.

The general result of the Third deposition has been to soften the rugged contours of the earlier land surface. The modifying influence of this drift has been much more appreciable in the western part of the district, namely, in northern Clark County, where the rugged hills of sandstone occur, than in Marathon and Lincoln counties, where the gently sloping uplands of crystalline rocks dominate. The flat lying tracts of this formation within the area of the crystalline rocks were probably originally nearly level surfaces of the old pre-Potsdam peneplain, the drift merely modifying the older surface and by the unequal distribution of the drift causing changes in the earlier drainage. These broad gently sloping tracts are most pronounced in the region of the southeast part of Lincoln County and in adjacent portions of Marathon and Langlade counties, and in northwestern Marathon and in eastern Taylor counties near the outlying divides of the Wisconsin and Fox river drainage on the east and of the adjacent Wisconsin and Black River drainage on the west. It is upon the divides in these parts of the area that the old crystalline peneplain was but little trenched by stream erosion, and hence in these parts the thin deposits of the Third drift have tended only to slightly modify the pre-existing mild features, and to obstruct the earlier immature drainage.

AMOUNT OF EROSION AND WEATHERING OF THE THIRD DRIFT.

Erosion.

The erosion of the Third drift varies in amount in different parts of the area. In that part of the area in which the hard crystalline formation forms the bed rock, namely in Marathon County and vicinity, the erosion has been less than in that part in which the Potsdam sandstone is the predominant bed rock. In that part of the area also in which the surface slope is more gentle namely within the drainage of the Wisconsin system the erosion has been less than upon the steeper slopes of the drainage area of the Black and Chippewa systems. This difference in erosion in the different parts of the area also characterizes all other formations of the region; but it is especially important that it should be taken into account in considering the erosion of this relatively thin Third drift sheet. There is a notable difference in the amount of erosion of the drift in different parts of the area, therefore, which is due to a difference in the underlying rock structure, and in the slope of the land, and not due to any special difference in the character and thickness of this drift itself in different parts of the area.

The amount of erosion of the Third drift as compared with that of the two earlier drift sheets, the First and the Second is small, for as already described, the older drifts have the characteristic deep valleys and other features developed by a mature stream drainage, while the surface of the Third formation where the drift is abundant is usually characterized by glacial features of topography.

The surface features of the Third drift, as already stated, are more like those of the Wisconsin formation than those of the older drifts, yet there is ample evidence not only in this area but especially farther west in Barron County, that this drift has been much more eroded than the Wisconsin formation.

The shape and form of the valleys eroded in the Third formation as well as the configuration of the terminal moraine deposits both indicate greater amount of erosion than corresponding features developed in the Wisconsin formation.

With regard to the character of the valleys, direct comparison can be made with those developed by the main branches of the Wisconsin River in the Third drift with those of similar tributaries of the Wisconsin in the Wisconsin drift. A comparison of the valleys in the two formations shows those of the Third drift to be much broader and to exhibit much greater lateral erosion than the valleys of similar streams in the Wisconsin drift. The essential difference in the configuration of the valleys in the two formations is in their width and not in their depth, for the depth is mainly determined by the ever-present crystalline rocks of the region, whose hardness and resistance to erosion has been sufficient to prevent but little downward corrasion since the deposition of the several drift sheets. The greater width of the valleys in the Third drift than in the Wisconsin, wrought by a greater meandering of the streams sideways, is well illustrated by the valleys of the Pine and Eau Claire Rivers, within the area of the third drift as compared with the narrow valleys of similar tributaries of the Wisconsin within the latest drift. The lateral erosion of the lower part of the Prairie River, and of the little Hay Meadow Creek in the vicinity of Merrill, as well as that of Devil Creek, in the Third drift is much greater than that of the Somo and Tomahawk rivers at Tomahawk in the Wisconin drift.

In a similar manner the tributaries of the Black and Chippewa in the Third drift in the western part of this area show a greater amount of lateral erosion than the streams in the Wisconsin drift. This difference is illustrated by the larger valleys of the Little Black River in the Third drift as compared with the smaller valleys of the main branch of the Black River within the Wisconsin drift. A similar difference is illustrated by the valleys of the branches of the Eau Claire River of the Chippewa system within the respective areas of the two drift sheets.

The configuration of the terminal moraine deposits, including also the kame deposits, of the Third drift appear to show the effects of greater sub-aerial erosion than similiar glacial deposits of the Wisconsin drift. There is a difference of course in the magnitude of these deposits in the two formations which may, in part, account for the milder features of the smaller Third deposits, as compared with the more rugged and more abrupt contour of the larger Wisconsin deposits. The milder features of the Third deposits with their characteristic shallow sags and basins, and low and broad ridgy accumulations, are such as would be developed by rain and stream erosion, and hence it seems reasonable to attribute a part at least, of the less abrupt features of the Third deposits, as compared with those of the Wisconsin moraine deposits, to the greater extent of erosion of the Third formation.

The amount of general erosion of this drift upon the hill slopes as compared with that of Wisconsin drift is difficult to estimate an account of the relatively slight thickness of the Third formation. Over large parts of the area very little Third drift was originally deposited and hence the total absence or small amount of Third drift over considerable parts of the area cannot be attributed to subsequent removal by erosion.

In the eastern part of Barron County and in the western part of Rusk County, a locality outside of the area described in this report, there are topographic features which furnish conditions for a comparison of the erosion of the Third drift and of the Wisconsin drift. The features referred to are within the area of the Barron quartzite hills, which are in part covered by the Wisconsin drift, and in part covered only by the Third drift. A direct comparison, therefore, can be made between the features of erosion developed in the quartzite hills since the Third glacial invasion. Such features as the more rugged cliff walls of the quartzite and the much greater accumulation of the talus debris about the quartzite hills within the area of the Third drift as compared with that developed within the area of the Wisconsin drift indicates a much greater erosion and weathering of these hills since the Third glacial invasion, than that which has taken place since the Wisconsin invasion. The difference in erosion features in the quartzite hills within the areas of the two drifts, therefore, is thoroughly in harmony with the evidence of the greater erosion of the Third drift as compared with that of the Wisconsin exhibited in Clark, Marathon, and adjacent counties.

Weathering.

The amount of weathering of the Third drift appears to be small. Decomposition and disintegration of the stony material of the drift is relatively slight. On the whole this drift appears to be about as fresh and unconsolidated as the Wisconsin drift. There is a marked difference in the fresh character of the drift as compared with the deeply weathered and oxidized character of the two older drift sheets of the area. There is a very great difference, therefore, in the amount of weathering of this drift sheet as compard with that of the older drifts, and a very slight difference as compared with that of the latest or Wisconsin drift.

SECTION VI. THE THIRD INTERGLACIAL STAGE.

During the later stages of the ice invasion which deposited the Third drift sheet just described, a change of climate is believed to have occurred causing the ice field to melt away and finally to disappear from the land. The succeeding interval of mild climate was probably characterized by temperature conditions similar to those prevailing in the region at the present time. The length of this interglacial stage is unknown, but comparatively it must have been much shorter than the epoch intervening between the period of glaciation in which was built up the Marshfield moraine and the period of the deposition of the formation just described. The reason for this belief is based upon the fact that the morainic deposits of knobs and basins of the Third drift, still retain the characteristic features of glacial topography and are but little modified by the forces of sub-aerial erosion to which they have been exposed since the ice sheet retreated. However, it is believed that the period elapsing between the deposition of the Third drift of this area, and that of the succeeding Wisconsin formation should rank as a distinct interglacial epoch.

The Third drift possesses distinct topographic features, and as such can be separated and mapped. Its border is not parallel to the border of the Wisconsin drift but is overridden and crossed by the large Wisconsin terminal moraines. The unconformity in the distribution of the Third drift and that of the Wisconsin is even more evident in the region farther west (See Fig. 21.) Furthermore the two drift formations each extending over large areas are not of the same magnitude. The Third moraine and its accompanying drift indicates a mild period of glaciation quite unlike that of the Wisconsin stage, which apparently was a period of very extensive glaciation.

The non-conformity of the two drift sheets, therefore, and also their marked differences in amount of drift indicate that they were formed by distinctly different ice sheets.

The length of the interglacial period intervening between the deposition of the Third drift and that of the Wisconsin drift is indicated mainly by the difference in the amount of erosion of the two formations and also by certain evidences of a change in the elevation of the region which took place in the interval between the two glacial periods.

The valleys carved by streams and rivers in the Third drift are distinctly wider, as already described, than those in the Wisconsin drift. The Little Hay Meadow Creek, for example, northeast of Merrill, has developed a meandering channel in the Third drift, the erosion of this stream being in marked contrast with that accomplished by similar streams in the Wisconsin drift immediately north. The streams in the Wisconsin drift, even the most prominent ones, like the Wisconsin river itself have wrought but little erosion in the Wisconsin drift.

Farther west in the drainage area of the Black River and of the Chippewa, the stream erosion has been greater in both the Third drift and in the Wisconsin drift than in the area of other drifts in the Wisconsin River drainage, but here also, the river valleys in the Third drift show distinctly the effect of greater erosion than those in the Wisconsin drift. There are no prominent rock hills in this region upon which to make a comparison of relative amounts of erosion wrought in the bed rock since the Third drift was deposited, but farther west, in eastern Barron County, there occur the prominent hills of

Barron quartzite which are located along the border of the Wisconsin drift and out in the area of the Third formation. The evidence of much greater erosion and weathering of these quartzite hills in the Third drift than that shown by these hills in the Wisconsin drift is at once apparent, the extensive accumulation of talus stone on the slopes of these hills in the Third drift being in marked contrast with the general absence of accumulated talus debris in the area of the Wisconsin drift.

A change of elevation during the interglacial interval seems to be indicated by the occurrence of the well developed outwash deposits in the Wisconsin River valley south of Merrill fringing the recessional moraine of the Third drift, while such outwash deposits are absent a few miles farther north where the Wisconsin terminal moraine crosses the valley though the general width and topography of the valley in the two places are very similar.

Conclusive evidence of a change in elevation between the two periods appears to be shown outside the area of this report in the northwestern part of Barron county, near Brill, where the Long River has developed a broad erosion terrace in the outwash deposits of the Third drift, upon which was later deposited the Wisconsin terminal moraine, without the accompanying development of outwash along the latter. In this locality the character and relation of the glacial deposits and the features of erosion indicate that favorable conditions prevailed for the deposition of fluvio-glacial gravels when the Third ice sheet was present, and that this locality was subsequently elevated, developing conditions for the erosion of the gravel formation, and that still later the Wisconsin moraine was deposited upon the eroded gravel formations without the accompanying conditions of elevation and slope favorable for the deposition of outwash along the Wisconsin ice.

There is another geological relation exhibited just outside the area of this report, in southeastern Chippewa County, which indicates a marked difference in the age of the Third drift, and that of the Wisconsin formation. This relation is the occurrence of loess upon the Third drift like the loess overlying the driftless area of the southwestern part of the state and which is not known to occur anywhere upon the Wisconsin drift formation.

An account of the loess and its relation to the Third drift will be discussed in a later report of the geology of the northwestern part of the state. The occurrence of the loess upon the Third drift is fully in harmony with the various evidences above cited, for the essential unity of the Third formation and its separation from the Wisconsin formation by a distinct interglacial stage of some considerable length.

SECTION VII. THE WISCONSIN DRIFT FORMATION.

The Wisconsin drift formation constitutes the latest glacial deposits in the district. This formation forms the surface deposits over a large portion of the northern part of North America. Its terminal moraine, throughout, is a distant topographic feature, forming a belt of billowy drift hills from 5 to 20 miles wide which rise from 50 to 200 feet in height. This terminal moraine can be traced across the entire continent, from Long Island on the Atlantic Coast to Victoria Island on the Pacific.

This formation in the district of North Central Wisconsin, as elsewhere, is a very prominent one, and was evidently deposited during an epoch of long continued and vigorous glacial activity. The formation is not only characterized by prominent terminal deposits built up at the farthest advance of the ice sheet, but also, in places, by recessional moraines formed at the margin of the ice sheet during its retreat. The ground moraine also is a mantle of considerable thickness which has appreciably modified the pre-existing topography.

A glance at the map, Plate II, shows the terminal moraine of this formation to lie across the eastern and northern parts of the district. The terminal moraine enters the southeastern part of the district about midway across the southern border of Portage County, thence trends northward, crossing to Marathon County in the vicinity of the Plover River. In eastern Marathon the front of the moraine faces the northwest, the terminal deposits being distributed along the course of the Plover River. The moraine forms the divide in northeastern Marathon between the Plover and Eau Claire rivers, whence

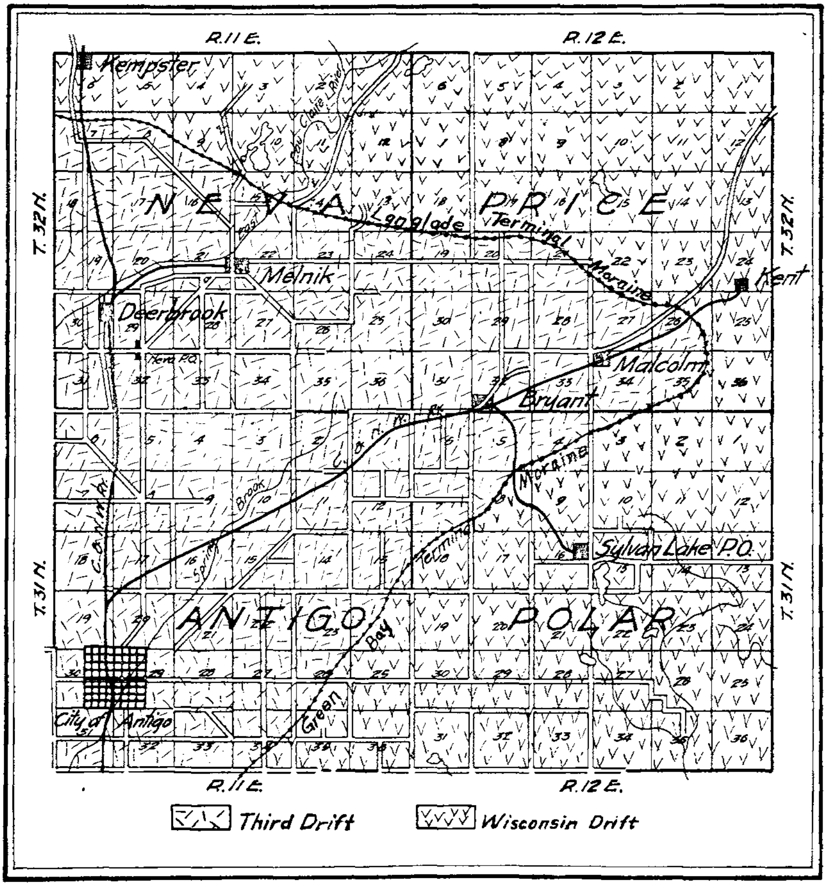


FIG. 22. Map of the drift in the vicinity of Antigo.

it swings to the northeast into Langlade County, keeping well to the south and east of Antigo.

Twelve miles northeast of Antigo (See small sketch map, Fig. 22) the terminal moraine changes its course and bends sharply to the northwest, forming a sinuous belt to the northwestern corner of the county.

In the northwest corner of Langlade County the belt of terminal moraine again makes a sharp turn to the southwest, so that its position is parallel to that of the moraine located 25 miles to the southeast in southern Langlade County and in the adjacent portion of Marathon. The southwest-northeast trend of the moraine extends from the northwestern part of Langlade County across Lincoln County to the vicinity of the Wisconsin River, where it changes to a northwesterly course to the vicinity of Spirit Lake in northeastern Taylor County.

From northeastern Taylor County it bends to the southwest again, making minor lobate curves across Taylor County, entering Chippewa County from the southeastern corner of Taylor.

It will thus be seen that the belt of terminal moraine makes wide detours, curving in various directions across the several counties of the district. The location of the terminal moraine and its curvatures can perhaps be best explained when the ice sheet producing it is considered in some detail.

THE WISCONSIN ICE SHEET.

The great continental ice sheet of the Wisconsin epoch very probably had its origin in Labrador, from which source the ice advanced into the outlying regions. The position of the terminal moraine in the Great Lakes region obviously indicates that the direction of ice movement was largely governed by the Great Lake basins into which the ice was deflected, and from which it flowed out beyond into adjacent portions of the bordering region.

A great ice tongue crept down the the basin of Lake Michigan, taking the general form of the lake but being much larger. Another tongue passed down Green Bay and the Fox River Valley and spread out over the eastern part of the State. Other important tongues evidently came through the larger bays of the south shore of Lake Superior, such as the Keweenaway Bay depression and the Chequamegon Bay region, passing southward through the valleys of the Wisconsin and Chippewa rivers. A very large ice lobe evidently was thrust down through the head of Lake Superior into the northwestern portion of the state and the adjoining portions of Minnesota and Iowa. (See map, Fig. 23.)

The greater of these ice tongues occupied the main basins

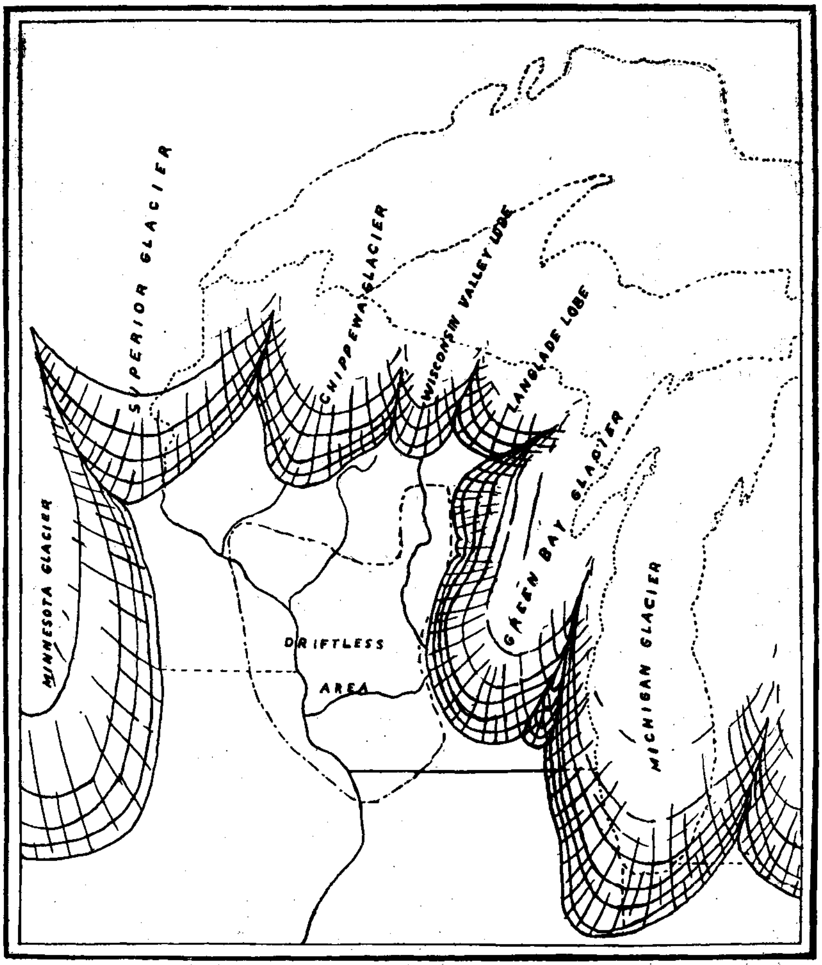


Fig. 23. The lobation of the Wisconsin ice sheet.

of Lake Michigan and Lake Superior, the minor tongues their principal bays. The tongues of the great ice sheet that lay across this portion of the state were those deflected through Green Bay and the large bays of Lake Superior.

The Green Bay Ice Lobe.

The margin of the ice lobe extending through Green Bay, and known as the Green Bay ice lobe or glacier, separated from the Delavan[1] lobe of the Michigan glacier in Walworth County, whence it curved westward as far as the Baraboo Bluffs in Sauk County, and thence continued in a northeasternly direction across Adams and Waushara, entering this district and forming the terminal moraine which extends across eastern Portage and Marathon to the western part of Langlade County.

In eastern Portage County the terminal moraine makes a slight re-entrant to the east near the center of the town of Beuna Vista, and again in the southern part of the town of Sharon at the village of Polonia. These re-entrants indicate a secondary lobation of the Green Bay lobe, probably, as later described, corresponding to the depression of Lake Winnebago on the south, and Green Bay proper on the north.

The Langlade Ice Lobe.

Into Langlade County there evidently advanced a distinct ice lobe, the direction of ice movement being towards the southwest.. The terminal moraine of this ice lobe extends from the southeastern part of Langlade to the northeast corner of this county. This terminal moraine may have been deposited by a tongue which passed through Keeweenawan Bay, although this cannot be finally known until the retreatal moraines are mapped between Langlade and the lake shore. The drift of this ice lobe is described as the Langlade moraine.

The Wisconsin Valley Ice Lobe.

From this comparatively small Langlade lobe of moraine another lobe separates extending across Lincoln County to the vicinity of Rib Lake and Spirit Lake in Taylor County, practically reaching across the drainage system of the Wisconsin River. The ice lobe, depositing this portion of the Wisconsin formation, evidently was moving directly towards the south through the Wisconsin Valley, the portion of ice confined to

[1] W. C. Alden, The Delavan lobe of the Lake Michigan Glacier, P. P. No. 34, U. S. Geol. Survey.

the center of the valley keeping well in advance of that which lay back upon the divides. The margin therefore lies across the Wisconsin drainage in the form of a curve, convex towards the south, the principal axis of the ice lobe approximately coinciding with the course of the Wisconsin River. The drift of this lobe is referred to as the Wisconsin Valley Moraine.

The Chippewa Valley Ice Lobe.

Across the drainage system of the Chippewa River there extends another lobate margin, reaching from the Wisconsin River divide on the east, to the St. Croix divide on the west. The ice tongue depositing this lobate margin advanced towards the southwest, the principal axis of the ice lobe coinciding with the valley of the Chippewa River, the ice advancing farther to the southwest, through the center of the valley, than along the sides, upon the divides. Only a portion of this margin is represented in this district, namely, that part lying across Taylor County, extending from the northeastern part to the southwestern part of the county. The drift of this lobe is referred to as the Chippewa Valley moraine.

GENERAL CHARACTER OF THE MORAINE.

The areal extent of the terminal moraine deposits of the Wisconsin drift is quite large in this portion of the state. The entire area of this formation in Portage, Marathon and Langlade counties, with the exception of some outwash plains, appears to be wholly occupied by drift accumulated at the margin of the ice sheet, either at its farthest advance or at its edge when retreating towards the east. Lincoln County also, east of the Wisconsin River, appears to be wholly covered with terminal moraine drift. That portion of the moraine west of the Wisconsin is only three or four miles wide and hence the northwestern one-fourth of Lincoln is largely an area of ground moraine. In Taylor County the width of the terminal moraine is about 10 or 12 miles, the northwestern part of the county and adjacent portions of Rusk and Price being occupied by areas of ground moraine.

The distinctive feature of the terminal moraines is the peculiar topography of abrupt hillocks and short ridges associated with depressions without outlets. The hills and ridges of the moraine generally vary from 50 to 250 feet in height. The terminal drift hills are in general of much less height in Portage and Marathon counties than in northern Langlade, northeastern Lincoln, northeastern Taylor and adjacent portions of Price counties.

THE GREEN BAY MORAINE.

The glacial drift deposited by the ice of the Green Bay lobe or glacier in the eastern part of this district is to a very large extent terminal moraine. But a small portion of the area is covered with ground moraine.

An old ridge of Second drift which lies just west of the Wisconsin moraine forms a conspicuous feature of the drift topography in Portage County. This ridge, as already described, evidently marks the farthest advance of the ice of one of the early Pleistocene stages. Immediately east of the old drift ridge is the belt of short ridges, hillocks and depression of the Wisconsin moraine which in places, extends up to the earlier moraine. The topographic features of the two moraines are in sharp contrast and the drift of the two can be readily separated in the field.

Between the old moraine and the main belt of Wisconsin moraine to the east there is a broad flat area of sand and gravelly loam having a width of one or two miles to four miles. A glance at the general map (Plate II) shows the location of these moraines and the intervening areas described.

The Terminal Moraine.

The terminal moraine of the Wisconsin drift is characterized throughout by the peculiar topography of terminal moraine deposits, such as billowy drift hills and short ridges associated with many depressions without outlets, usually occupied by lakes, swamps and bogs. The abrupt undulating features of the terminal moraine (See Plate LV) are very largely due to the unequal amounts of debris carried by the ice margin and to the periodic oscillations of the margin primarilly caused by unequal rate of melting or changes in the rate of the flow of the ice. In its recession the ice margin probably did not always remain

THE GREEN BAY TERMINAL MORAINE, EAST OF ARNOTT.

parallel to its former position and thus the deposits built up at the margin in its new position would have an irregular distribution. If the margin advanced again temporarily the deposits made during the period of recession would be over-ridden and modified.

If the ice margin retreated and advanced repeatedly during a considerable period, the details of the margin would frequently change and there would result a complex mass of ridges and hills of variable height. Between these irregular ridges and hills there would be depressions of various sizes and shapes.

The tangle of terminal moraine in eastern Portage continues for an undetermined distance eastwards into Waupaca County. It is not everywhere so billowy and uneven as within 3 or 4 miles of its western border, but throughout the county the characteristic terminal moraine topography associated with numerous lakes and basins prevails. For some considerable areas the land is gently sloping, with few abrupt depressions or hills, and with these are areas of nearly level-stratified deposits of outwash which reach from one morainic ridge to another. The sharp bends in the wagon roads, as shown upon the general map, to avoid depressions and abrupt hills and the numerous lakes, indicate the uneven land surface of the area. The area is characterized by but a few swamps, doubtless due to the sandy porous character of the drift.

The Minor Lobation of the Green Bay Lobe.—The distribution of the terminal moraine in eastern Portage County obviously indicates a minor lobation of the Green Bay lobe. As shown upon the map, the terminal moraine in the town of Almond trends northeastward, the northeast trend continuing to the central part of the town of Buena Vista where there is a sharp re-entrant in the moraine to the east. From this re-entrant the moraine bends out to the west turning to the east again and forming another re-entrant near the village of Polonia. From Polonia the moraine trends northwest into south eastern Marathon County, then northeastward to join the Langlade moraine northeast of Antigo.

The minor lobation of the Green Bay glacier in eastern Portage appears to have developed a small lobe lying between two larger lobes, the larger lobe on the north probably being due to the influence of the depression of Green Bay proper on the advance of the ice and the larger one on the south to the influence of the depression of Lake Winnebago. The minor lobation of the moraine between these two large lobes is probably due to some minor depression lying between the larger depressions to the north and to the south.

The Green Bay moraine in Marathon County does not present so many distinctive features as in its course across Portage County. The Plover River lies between a narrow belt of terminal moraine hills and ridges on the west and the main belt of the moraine on the east. No well defined plains of outwash of any extent are associated with the terminal moraine either in front of the moraine or along the Plover River within the moraine. The western border of the moraine is quite pronounced from the southern border of the county northward to the C. & N. W. railroad. For a few miles north of the railroad the drift hills are small, but reappear again in considerable force 3 or 4 miles to the north and thence continue in considerable prominence across the remaining portion of the county, passing about a mile east of Hogarty post office and crossing the county line about 3 miles northeast of Hogarty.

A large part of the towns of Franzen and Elderon do not possess the pronounced hummocky topography of terminal moraines, but depressions, swamps and drift hills occur here and there sufficient to give it the prevailing features of terminal moraine rather than of ground moraine. The broad streams of the Wolf River drain a large portion of this corner of the county and the land over large areas is fairly well drained.

Crooked Lake, Pike Lake, Gatoit Lake and Sunflower Lake are some of the larger lakes of this portion of the moraine. The drift hills range from 50 to 100 feet in height. Occasionally there are a few level stretches of outwash fringing the outer moraine and also occuring within the moraine belt, but these are of small extent. The rock of the pre-Cambrain plain generally appears as the surface formation but a short distance west of the moraine.

The terminal moraine of the Green Bay lobe in Langlade County extends northeastward across the northern half of the town of Rolling, the southeastern part of the town of Antigo,

THE GREEN BAY TERMINAL MORAINE, EAST OF ANTIGO.
From the plain west of the moraine.

the northern part of the town of Polar to the vicinity of the northeast corner of Polar. The location of the moraine east of the city of Antigo in Langlade County is shown on the small map. (Fig. 22.)

This portion of the moraine appears to be a continuous formation and not separated into frontal and recessional moraines. Merely the location of the front of the moraine was studied in this portion of the county. Fringing the moraine in this vicinity there appears a broad stretch of land consisting mainly of gravel, sand and clay, which widens out into a broad area of considerable extent spreading about Antigo and reaching to the terminal moraine to the east and north.

The terminal moraine in the town of Rolling, west of the Chicago and Northewestern railroad, lies immediately east of Springbrook Creek. East of the railroad the moraine stands up prominently above the plain in front, and as this portion of the county is fairly well settled the terminal moraine can be seen for some distance. At no place, however, do the drift ridges appear to have an elevation over 100 feet above the plain in front. The moraine as seen from the fringing, gravelly plain in front is illustrated in Plate LVI. The Green Bay moraine joins the Langlade moraine in the vicinity of the northeast corner of the town of Polar. The Green Bay moraine continues as a portion of a morainic belt formed jointly at the margins of the Green Bay lobe and the Langlade lobe. The continuation of this interlobate moraine to the northeast has not been outlined.

The Outwash Deposits.

Under favorable conditions of deposition outwash gravel and sand often form deposits fringing the border of an ice sheet. In eastern Portage County is a broad nearly level tract of sandy, and in places gravelly, land which at first might be taken as typical deposits of outwash from the Green Bay ice lobe. The sand and gravelly plain of eastern Portage County, however, is a part of the great plain which extends for many miles to the westward along the Wisconsin River, and like the broad sandy plain along the Black and Chippewa rivers farther west is believed to be mainly, if not wholly, of alluvial origin and also much older than the Wisconsin drift. The origin of the sandy plains of Portage and Wood counties is described under the alluvial deposits of the district, and will therefore be only briefly referred to here.

The material of the plain surrounding the very old drift ridges in eastern Portage consist of sand and gravel mixed with clay and a variable quantity of very coarse boulders. This clayey and bouldery material is not found far beyond the recognized surface distribution of the old drift of the Arnott moraine, the part of the plain extending farther away consisting mainly of sandy material. Farther north along the Plover River, where the Wisconsin moraine over-rides the older drift, and also farther south where the same conditions prevail in Waushara County the sandy plain extends up to the Wisconsin drift. There is, therefore, an appreciably more fertile soil in the plain immediately surrounding the old drift ridges, named the Bancroft gravelly loam in the soil report, and which can be readily separated in mapping from the more sandy soil bordering the Wisconsin River and its main tributaries. It is the opinion of the writer that the material of the gravelly loam fringing the old drift ridge is due mainly to the local erosion of the old drift, and the more sandy tracts outside to the work of streams and rivers carrying material from a more distant source.

While some outwash material was probably deposited along the border of the Wisconsin ice in this locality, the amount of this material is believed to have been small and unimportant. The broad sandy and gravelly plain of this locality was apparently formed long before the Wisconsin stage of glaciation.

Farther north in southeastern Marathon County the Wisconsin moraine lies upon the gently sloping crystalline rocks and in northeastern Marathon County upon a thin covering of old drift over the crystalline rocks. Along the moraine some outwash gravel was deposited, but no well defined important deposits occur.

In the vicinity of Antigo fronting the Green Bay moraine on the southeast and Langlade moraine on the north, is a broad, gently sloping tract which spreads out for some considerable distance to the west. This tract is generally characterized by gravelly loam, with some boulders, with an occasional depres-

CHARACTERISTIC DRIFT OF THE GREEN BAY TERMINAL MORAINE, NEAR ANTIGO.

sion or sag, and by swells of coarse drift. This plain about Antigo has the characteristic features of an old alluvial plain over-ridden by the Third drift, and, like the plain in Portage County, is believed to have been formed before the Wisconsin stage of glaciation. It is difficult to separate the gravel and sand of this older plain from that which may have been formed as outwash from the Wisconsin ice, but material of the latter sort is believed to be insignificant in amount. The slope of this gravelly plain in front (north) of the Green Bay moraine in this vicinity is downward to the south, thus sloping downward towards the moraine, a condition of slope inconsistent with the theory that any important part of it was deposited by streams issuing from the Green Bay ice lobe.

THE LANGLADE MORAINE.

This name is applied, as already stated, to a well defined, comparatively short lobate moraine, which separates from the Green Bay moraine about 12 miles northeast of Antigo, and extending northwest across Langlade County, joins the terminal moraine of the Wisconsin Valley lobe in the northwest corner of the county. This moraine was obviously formed by an ice lobe which advanced southwest into this district, whereas the portion of the Green Bay lobe that moved into this area advanced towards the northwest, and the lobe which deposited the moraine lying across the drainage of the Wisconsin River moved directly southward.

The Langlade moraine, unlike the adjacent moraines, does not appear, however, to have been formed by an ice tongue advancing through a valley. The ice probably advanced into this area directly across the region now drained by the streams flowing to Green Bay, and along the divide between the Green Bay and Wisconsin waters. It is probable that when the recessional moraines are mapped, lying between the terminal moraine and the Great Lake basins, that the general course of this ice lobe will be fully understood. It may be that the more vigorous and larger ice lobes advancing either side of it governed its course; or it may be that topographic conditions farther back near the lake basins guided the ice movement.

The Terminal Moraine.

The location of the Langlade terminal moraine, as shown on the maps Pl. II and Fig. 22, is entirely within Langlade County. The terminal moraine is in the form of a curve, convex towards the southwest, the center of the ice lobe advancing farther to the southwest than the sides.

The moraine consists of short ridges and billowy hills, associated with depressions forming a belt of undetermined width, probably 10 or 12 miles. The drift hills and ridges are appreciably higher for a large part of the moraine than those of the adjacent Green Bay moraine in Marathon and Portage counties. In general they reach an elevation of 100 to 150 feet above the surrounding lower land to the southwest. The railroad elevations, above sea level, along the Chicago & Northwestern railroad from Antigo northward across the plain, and for some distance into the hilly moraine, are as follows: Antigo, 1483 feet above sea level; Deerbrook, 1536; Koepenick, 1683; Summit Lake, 1729; and Elcho, 1639. The elevation at Summit Lake, in the midst of the moraine, is probably at the present time, 1906, the highest railroad elevation in the state. In general, the slope of the plain upward to the moraine from Antigo is about 10 feet per mile, while that of a line extending through the low gaps in the moraine is about 20 feet per mile upward to Summit Lake and from Summit Lake about 20 feet per mile downward to Elcho. The hills and ridges of the moraine, of course, stand from 50 to 100 feet above the elevation of the slope just indicated. If the irregularities in the terminal moraine were leveled off, the slope of the moraine would probably average 40 to 50 feet per mile.

Where the Langlade moraine separates from the Green Bay moraine, 12 miles northeast of Antigo, the moraine presents a complex tangle of drift hills and ridges. Following northwestward across the county, the front of the moraine forms a fairly continuous ridge standing out prominently and sharply from the low land in front, as is usually the case along these portions of the moraines where fringed with alluvial deposits. In the northwestern part of Langlade County, west of the head

THE PLAIN ABOUT ANTIGO, SEEN FROM THE GREEN BAY MORAINE.

waters of the West Branch of the Eau Claire River, the moraine lies upon a high upland area.

A group of numerous lakes lies among the drift hills of the terminal moraine in the town of Upham, the more important lakes being Great Bass Lake, Swamp Lake and Lower Bass Lake. Some of the small lakes in the moraine are without outlet but the large ones are drained by the Eau Claire and Prairie rivers, flowing to the Wisconsin River, and to the Wolf River, a tributary of the Fox. Swamp Lake and Great Bass Lake are but a few rods apart, the former being joined with the Eau Claire River, a part of the Mississippi drainage system, and the latter with the Wolf River of the St. Lawrence system.

The Outwash Deposits.

The broad plain in the area surrounding Antigo strongly suggests the possibility, as already inferred, that this plain may have been developed as an outwash plain bordering the Langlade ice lobe on the northeast and the Green Bay lobe on the southeast. This plain, however, as already stated, is believed to be older in origin than the Wisconsin drift. It is probable, however, that some outwash gravel was deposited along the border of the Langlade moraine, although deposits of such a character were probably small.

The topographic features of this plain and the material of which it is formed indicates that it is very probably an old alluvial filling over which is spread the thin mantle of the Third drift. Plains of this character far removed from the border of the Wisconsin ice sheet are common throughout the district.

THE WISCONSIN VALLEY MORAINE.

The Wisconsin Valley terminal moraine was formed at the margin of an ice lobe which advanced southward into this area through the Wisconsin Valley. The belt of terminal moraine forms a curve, convex towards the south, indicating the lobate form of the ice, due evidently to the more rapid advance of the ice down the centre of the valley than along the higher slopes of the divides. The drift of this lobe lies between the Langlade moraine on the east and the Chippewa Valley moraine on the west.

The Terminal Moraine.

As shown upon the map, this terminal moraine separates from the Langlade moraine in the northwest corner of Langlade County and extends in a southward bending curve across the central portion of Lincoln County, and beyond into the adjacent portions of Taylor and Price counties, coalescing with the Chippewa moraine in the southeast corner of Price County. The width of the belt of terminal moraine varies greatly, being wide and prominent east of the Wisconsin River and narrow and much less conspicuous west of the Wisconsin. The minor curves in the frontal border of the moraine indicate the minor lobate character of the ice margin.

The moraine east of the Wisconsin River stands up conspicuously above the lower land to the south bordering the Prairie River. Its highest hills and ridges probably reach an elevation 150 to 300 feet above the surrounding lower land and can be readily seen for 10 or 15 miles from the south. The entire area of northeastern Lincoln County, east of the Wisconsin River, is characterized by the usual topography of terminal moraines. The terminal moraine continues northward into Oneida County for an undetermined distance beyond Woodboro and Rhinelander. Throughout this area occur the billowy drift hills and depressions formed at the margin of the ice sheet in its retreatal movement. The moraine is dotted with numerous lakes, the more important ones being Tug Lake, Bass Lake and Pine Lake.

The terminal moraine west of the Wisconsin River lies in the vicinity of the course of the New Wood River, crossing into Taylor County in the vicinity of the headwaters of the Big Rib River. Throughout its course in Lincoln County it appears to be but a narrow belt 2 or 3 miles wide, the highest hills being about 100 feet in elevation. Farther to the northwest, in the vicinity of Wood Lake and Spirit Lake, the morainic belt is more prominent. In the town of Hill in Price County, where the Wisconsin and Chippewa moraines meet, the moraine presents a complex tangle of high billowy drift hills, many of them apparently reaching an elevation of 200 to 300 feet above the surrounding lower land.

The Ground Moraine.

That portion of Lincoln County lying west of the Wisconsin River north of the narrow belt of terminal moraine, along New Wood River and south of the Somo River, is largely an area of ground moraine. The land is gently rolling, with numerous large swampy areas, but without steep drift hills and pronounced depressions. This area of ground moraine is continued westward into Price County, covering large portions of the towns of Brennan, Knox and Prentice. In the vicinity of Spirit postoffice, the land has been opened to agriculture and many thriving farms have been developed. The gently rolling topography of the ground moraine in this vicinity is in sharp contrast with the abrupt drift hills of the terminal moraine bordering it on the west. Seen from the area of the ground moraine in the towns of Brennan, Knox and Prentice, the inner border of the belt of terminal moraine stands up prominently, being as sharply defined from the area of ground moraine to the north as the frontal border of the terminal moraine is from the older drift areas bordering the south.

Recessional Moraine.

About 10 to 15 miles north of the inner border of terminal moraine is located a belt of hilly moraine which marks the stand of the ice margin for a considerable period in its retreat to the north. This recessional moraine lies along the course of the Somo River in northern Lincoln County, trending northeast across the southwest corner of Oneida County and coalescing with a well developed recessional moraine of the Chippewa Valley lobe 5 or 6 miles north of the Soo railroad, near the boundary of Oneida and Price counties.

Between the terminal moraine and this recessional moraine, on the west side of the Wisconsin, lies the area of ground moraine above referrd to, with gently undulating relief, whereas east of the Wisconsin the entire region is occupied with terminal moraine. North of the Somo and Wisconsin rivers in Lincoln County, the topography is mainly that of marginal drift deposits. In the vicinity of Heafford Junction is a group of lakes, the principal ones being Clear Lake, Portage Lake, Deer Lake and Lake Muscallonge.

Outwash.

There appears to be very little stratified sand and gravel fringing the front of the terminal moraine of this lobe. The terminal moraine on the west side of the Wisconsin River extends through a thickly forested area not yet opened to farming and hence not readily accessible to study. Wherever observed, however, there appears to be very little or no outwash material along this portion of the moraine. About one mile north of the Copper River, extending over an area from 2 to 6 miles west of the Wisconsin is a broad marshy tract which may be due to outwash but the topography between this area and the moraine does not appear to favor such an origin.

East of the Wisconsin River there is some outwash fringing the moraine along the Prairie River in the vicinity of Parrish and for some distance to the southwest. There appears to be very little outwash material adjacent to the junction of the Langlade and Wisconsin moraines. The same also apppears to be true, as already inferred, where the Wisconsin and Chippewa moraines meet. The lack of outwash deposits at these places where the ice lobes joined would seem to indicate that the topographic conditions bordering the ice margins were not favorable to the formation of such deposits.

THE CHIPPEWA VALLEY MORAINE.

The Chippewa Valley moraine was formed by an ice lobe which advanced southwestward into this district through the Chippewa Valley. The terminal moraine stretches entirely across the drainage system of the Chippewa River, forming a lobe convex towards the southwest, due to the more rapid advance of the ice down the middle of the valley than along the divides. This moraine lies between the Wisconsin Valley moraine on the east and the moraine deposited by an ice lobe passing through St. Croix Valley on the west.

The Terminal Moraine.

Only the eastern extension of the terminal moraine of the Chippewa Valley lobe lies across the area included in this report. As shown upon the map, it separates from the adjacent Wisconsin Valley terminal moraine in the town of Hill in southeastern Price County. From this vicinity it sweeps to the southwest in a sinuous belt across Taylor County, entering Chippewa County about 5 miles north of Stanley.

The width of the belt of terminal moraine varies from 6 to 20 miles. The abrupt drift hills constituting it are especially prominent east of Ogema in the town of Hill where it is joined to the adjacent Wisconsin Valley terminal moraine. The belt is about 6 miles wide in the vicinity of Ogema, widening out to the southwest where it forms a broader area of terminal deposits but of lesser height.

Quite generally the frontal border stands out sharply from the lower land to the southeast. Exceptions to a sharp contrast, however, prevail in front of the moraine between Medford and Rib Lake where the terminal deposits of an earlier drift sheet form a belt of much smaller drift hills and ridges. The terminal moraine is sharply separated from the area of ground moraine to the north, the change of topography being equally as abrupt as that between the area of older drift to the south and the terminal moraine.

There are a number of lakes scattered throughout the terminal moraine, among which may be mentioned those north of Rib Lake, and in the vicinities of Chelsea and Perkinstown. Branches of the Black River and the Big Rib River extend for some distance up into the terminal moraine but much the larger portion of it is drained by branches of the Chippewa River.

The Ground Moraine.

Bordering the terminal moraine on the north is a broad area of ground moraine, characterized by undulating slopes and nearly level plains. As already stated, the topography of this area of ground moraine is in sharp contrast with the abrupt drift hills and deep depressions of the belt of terminal moraine lying to the south.

The ground moraine extends over the entire portions of Rusk and Price counties included in the area of this report. It is known to extend about 6 miles north of the line of the Soo railroad to a prominent recessional moraine trending northeast and southwest which marks the second stand of the Chippewa Valley lobe in its retreatal movement. This recessional moraine is joined to the corresponding recessional moraine of the Wisconsin Valley lobe which extends along the course of the Somo River.

Between the recessional moraine on the north and the terminal moraine on the south lies the area of ground moraine which is mainly drained by the Jump River and its branches. The area is very largely unopened to agriculture. The soil is a clay loam, the land surface being gently sloping and usually well drained.

Outwash.

There was observed no appreciable amount of outwash material fringing the terminal moraine in Taylor County. It is not unlikely that small areas occur, but if present they are of comparatively small extent. Usually the gently sloping plains of outwash are especially valuable for agricultural purposes and are generally cleared and settled for farming earlier than adjacent lands in the immediate surroundings. But no such areas have been cleared along the border of the moraine in this area.

Where the Wisconsin valley glacier and the Chippewa valley glacier coalesced, a large amount of water probably issued from the ice margins, but no area of outwash of any extent was observed in this vicinity. The Big Rib River appears to have drained the glacial margins of this vicinity but the branches of this river south of the terminal moraine appear to have cut their channels entirely in the older drift formation.

CHARACTER AND THICKNESS OF THE WISCONSIN DRIFT FORMATION.

The drift deposited by an ice sheet necessarily consists of the débris of the rock formations over which the glacier advanced. If the course of a glacier is through a region mainly of crystalline formations the drift is largely of crystalline rock, and if through an area of limestone or sandstone, the drift is mainly the rock of such formations.

The Green Bay ice lobe entered this area from the east, its course being through the region of the Paleozoic sedimentaries of the eastern part of the state and hence the drift of the Green Bay moraine consists largely of boulders and pebbles of sandstone, limestone and chert mingled with a large amount of loose sand. This is especially true of the moraine in Portage County and the southeastern part of Marathon County. Farther north in Marathon County and the adjoining portion of Langlade County the moraine contains many coarse granite boulders derived from the coarse granite formation prevailing throughout this section of the area. While the Green Bay moraine in Portage County and the adjacent portion of Marathon in the region of the Potsdam sandstone is a sandy formation, farther north in the crystalline area the drift contains a larger proportion of clay. Throughout the sandy portion there are of course numerous coarse boulders of the crystalline formations and much crystalline gravel derived from the crystalline region far to the northeast.

The Langlade moraine, the Wisconsin Valley moraine, and the Chippewa Valley moraine in this area, consist almost entirely of crystalline rock material. Boulder clay is an abundant constituent of the drift, and clayey soils therefore prevail over a very large portion of the area of these moraines. Exceptions to this general rule of clayey soils, however, occur in the area of the recessional moraine in Lincoln County. In northeastern Linclon County the hilly terminal moraine is characterized by the presence of much gravel derived from the disintegration of coarse granite, while north and northwest of Tomahawk are broad, gently sloping plains of sandy formation.

The thickness of the Wisconsin drift formation varies widely throughout the area. It probably ranges from zero up to 350 feet in thickness. Judging from the elevation of the belt of terminal moraine as compared with that of the land lying to the front and rear, the maximum thickness of the terminal moraine appears to be about 125 feet for the Green Bay moraine and somewhat greater for the terminal moranies trending across the northern part of the district. The Langlade terminal moraine is especially prominent and the same is true for a large portion of the Wisconsin valley terminal moraines east of the Wisconsin River. The thickest portion of the terminal moraine is very probably in the town of Hill in southeastern Price County where the terminal moraines of the Chippewa Valley and of the Wisconsin Valley coalesce. The highest drift hills in this vicinity, as previousy stated, appear to reach 250 to 300 feet above the surrounding area of ground moraine to the east, north and west and therefore probably represent a maximum thickness of 350 feet.

The average thickness of the terminal moraine is of course much less than its maximum thickness. If the drift of the terminal moraine was locally leveled off within its area of distribution and made of uniform thickness, the average thickness would probably be found to be 75 to 100 feet.

The thicknes of the ground moraine probably has an average of 25 to 50 feet. The area of ground moraine of this drift formation in this area is not well settled and sufficient well data showing thickness of the drift is not at hand. In considering the probable thickness of this formation of drift, account should be taken, of course, of older underlying sheets of drift.

EFFECTS ON TOPOGRAPHY.

The topography of the drift, the characteristic features of the terminal moraine, and of the ground moraine, have been described. It now remains to discuss briefly in a general way the more prominent features of topography due to this sheet of drift upon the area as a whole.

The general slope of the area and its principal valleys are features much older than the Wisconsin drift formation. Usually, therefore, the drift mantle only modifies the relief of these older land forms. Generally, however, the belts of terminal moraine furnish important features of the landscape. The terminal moraine is not a prominent feature when compared with the reliefs in mountainous or even moderately hilly regions, but over the gentle slopes of this area, as over other portions of the plains of the Mississippi valley, the moraine stands out as a prominent feature of the land surface.

The topographic reliefs wrought by the Wisconsin ice sheet appear to be mainly due to the distribution of the deposits of drift, and not to ice erosion. This is probably because the area is one in which the ice mainly halted, and not one where it was largely going forward in its course.

The Green Bay ice lobe advanced into this area from the east, over a rising slope, up the valley of Green Bay and the Fox River, the ice margin coming to a halt approximately on the divide between the Fox and the Wisconsin Rivers. Farther south, in Sauk County, this lobe advanced beyond the divide and even beyond the Wisconsin River itself, its margin resting upon the high ridges of the Baraboo Bluffs. The location of the extreme ice margin, therefore, does not appear to have been controlled either by the divide or the valley of the Wisconsin. It is not unlikely that the distribution of the drift of the terminal moraine over the gentler slopes of this area may have shifted the divide between the Fox and the Wisconsin somewhat to the west, and a larger area is now drained by the Fox than before. It is not probable, however, that the divide was shifted to the west more than a few miles. The Green Bay moraine in this area and as far south as Kilbourn in Columbia County forms the divide between the Fox and the Wisconsin, and hence this portion of it separates the drainage systems of the St. Lawrence and the Mississippi.

The Green Bay moraine in this area, as previously described, consists of ridges and undulating hills and depressions, the hills and ridges varying from 50 to 100 feet high. The moraine lies upon a slope rising to the north, the vertical range in the elevation of the slope being about 600 feet. In southern Portage County the elevation of the plain upon which the terminal moraine rests is about 1100 feet; about 30 miles farther north at the boundary of Portage and Marathon Counties it is about 1160 feet, a rise of about 2 feet per mile. Across Marathon and into Langlade County to the junction of the moraine with the Langlade moraine the slope is steeper, rising about 450 feet up to an elevation of about 1600 feet, in a distance along the moraine of 45 miles. The lower gradient of the slope is in the district of Potsdam sandstone, the higher gradient over the slope of the pre-Cambrian peneplain.

The terminal moraine is approximately parallel to a line drawn through Green Bay up the lower Fox River to and through Lake Winnebago, probably the axial center of the Green Bay ice lobe. As indicated by the location of the terminal moraine, the ice advanced about an equal distance into the interior of the state from its axial centre, without special regard to the local differences in the elevation of the land of the interior.

The terminal moraine, extending across Langlade County referred to as the Langlade terminal moraine, was evidently formed at the margin of an ice lobe that advanced to the southwest along the region of the divide between the streams flowing into Green Bay and those flowing to the Wisconsin River. In the absence of a topographic survey of this region, only approximate elevations of the terminal moraine can be stated. The approximate elevation of the plain bordering the front of the terminal moraine where it is crossed by the Chicago & Northwestern railroad at Kempster is about 1600 feet. The slope of the land in this vicinity is downward to the southeast and this portion of terminal moraine lies at a higher elevation than at the reentrant, northeast of Antigo where this moraine separates from the Green Bay moraine. Northwest of Kempster the land is notably high, but in the direction of the Wisconsin Valley moraine it appears to have a slight descent towards the Prairie River.

The elevation of the Langlade terminal moraine at the apex of the lobe where the ice advanced farthest to the southwest is evidently as high or higher than where it is joined to the adjacent moraines. The direction of the flow of drainage both back of the terminal moraine and in front of it also indicates that the axis of the ice lobe was located upon higher land than the margins where joined to the adjacent lobes.

The Eau Claire, the Pine and the Prairie Rivers flowing southeast to the Wisconsin River find their source in this terminal moraine, these streams evidently leading off the glacial waters during the halt of the ice sheet in this vicinity.

The Wisconsin terminal moraine, as already stated, lies directly across the Wisconsin River drainage, forming the divide between its minor side streams. The range in elevation across the valley along the course of the terminal moraine is between

200 and 250 feet, being about 1450 feet above sea level in the center of the valley and about 1600 feet upon the divides. The belt of terminal moraine is 3 or 4 miles wide on the west side of the river but on the eastern side it covers the entire area of the northeastern part of Lincoln County.

The Chippewa valley is nearly twice as wide as the Wisconsin valley and probably twice as deep, yet the ice lobe occupying each advanced about equal distances from the Lake Superior basin. With regard to the depth of the valleys of the Wisconsin and the Chippewa rivers perhaps a word of explanation is necessary. The elevations given refer to the elevation of the terminal moraine where it crosses the Wisconsin and Chippewa rivers and where the moraine crosses the divide from 12 to 20 miles farther north. If the elevations were taken directly normal to the trunk streams, no notable slope would be apparent, for in many cases the Chippewa and Wisconsin are located in deep and narrow valleys with the high upland areas continuing up to the rivers' banks. The valleys as a whole, therefore, are not notable sags and are slight depressions compared with the enormous thickness of the ice sheet. The Chippewa terminal moraine in that portion of its course which is included in the area of this report has a width varying from 6 to 15 miles. It is of considerable prominence throughout the gently sloping area over which it extends. It is especially prominent, its highest elevation reaching 200 to 300 feet, in southeastern Price County, where it is joined with the moraine of the Wisconsin Valley lobe. The area of the ground moraine immediately north of the terminal moraine, like that north of the Wisconsin terminal moraine west of the Wisconsin River, is a gently undulating plain, but a slight modification of the pre-existing topography.

On the whole the topographic effect of the terminal moraine deposits of the Wisconsin formation including the recessional moraines and the interlobate moraines is quite prominent over the gentle slopes of this area. These marginal deposits of drift. varying generally from 75 to 150 feet in thickness and sometimes considerably more, serve to modify, or form entirely, the divides between the small rivers of the area. With regard to the divides between the large rivers, such as the Fox, the Wisconsin and Chippewa, the moraine very probably only modifies the pre-existing divides, but in case of many of the smaller side streams of the Wisconsin and Chippewa the terminal moraine in this flat lying district may, in numerous instances, have controlled the drainage and formed entirely new divides.

The deposits of the drift probably filled a number of the pre-existing river channels and may have deflected many of the small streams and even some of the larger ones from their former courses. These changes in old channels by drift filling however can only be determined after a topographic survey of the region is made and when the area is well opened to agriculture and abundant well data is available showing depth of drift.

EROSION AND WEATHERING OF THE WISCONSIN DRIFT.

The Wisconsin formation is the latest of the Pleistocene or Glacial series, and is therefore the last drift to be deposited in this area and in the adjoining regions. The period which has elapsed since the disappearance of the last ice sheet, usually called the Recent Period or the Age of Man is clearly very short compared with the time which elapsed between the earliest ice invasion and the Wisconsin invasion. The youth of the Wisconsin drift as compared with the old age of the older drifts is shown by various geological phenomena, chief of which is the extensive erosion and weathering of the older drifts as compared with that of the Wisconsin drift.

The lack of erosion and weathering of the Wisconsin formation is one of its distinguishing characteristics. And yet since the deposition of this drift sheet the ever present forces of erosion and weathering have been active, and have wrought some appreciable, though comparatively slight, change in the topographic features of the formation.

Erosion.

With respect to erosion the streams and rivers have developed fixed lines of drainage in the drift. The depth of the drainage channels is very shallow within the area of the Wisconsin River system. Within the area of the Black and Chippewa river systems the channels are appreciably deeper than those of the Wisconsin system. The stream erosion mainly or entirely has been confined to downward corrasion.

The features of the lakes and ponds, formed by the unequal distribution of drift, have changed somewhat in all parts of the area. The lakes and ponds tend to grow smaller as the drainage lines in the drift become deeper, and as other modifications in the topography take place. Many of the lakes therefore are seen to have been once of larger extent than at present, as indicated by old shore lines and swampy tracts about their present borders. Considerable change has been wrought in the lake features of Portage County since this section was opened to agriculture. But even before this part of the area had been opened to settlement the extent of the lakes had been greatly changed from the original size. As an example Clauds Lake occurring in the terminal moraine near Almond may be cited. This lake once had a well established outlet (See map, Plate II.) leading to Ten Mile Creek which, however, became extinct long before the first white settlement of the region. Clauds Lake is now greatly contracted as compared with the extent indicated by its original shore lines.

Weathering.

The amount of weathering of this drift is very slight. The drift is relatively fresh and unaltered as compared with the characteristic features of extensive alteration of the First and Second drifts of the area. Disintegration of the stony material of the drift has taken place to some extent but chemical decomposition and consolidation and cementation is hardly appreciable. The small amount of weathering and erosion of this drift indicate its relatively very recent deposition, the latest of the glacial formed deposits of the region.

CHAPTER X.

THE ALLUVIAL DEPOSITS.

The streams flowing through the land are constanty at work, and are either eroding, transporting or depositing sediment. In times of extensive floods, during the rainy seasons of the year, the streams, on account of the increased velocity and volume become very active, and in places along their courses where ordinarily they were depositing material, or were merely passive, they become effective agents of erosion and of transportation.

During periods of increased elevation of the land or of subsidence of the land, the change in the slope and gradient of the streams has a marked effect upon the character of the work of streams. If the region is uplifted, the erosive power of the streams is increased and the valleys are deepened; and if the region is lowered the streams become sluggish and erosion ceases, the streams deposit sediment along their courses, and the valleys become filled.

Changes in the volume of streams, due to a general increase or decrease in rainfall, or in the periodic distribution and occurrence of the same amount of rainfall, or changes in the vegetal protection of the land surface, also affect the character of stream work. Thus for various reasons the work of the rivers and streams changes. At one period the streams may be deeply eroding their channels, while at another, they may be occupied in filling them with great quantities of land waste.

An examination into the history of the streams of this region, reveals the fact that, at an earlier period, all the streams flowed in much deeper channels than they do at present. Subsequently

LOOKING EAST ACROSS THE FILLED VALLEY OF THE WISCONSIN, NORTHERN PART OF WAUSAU.
The level horizon in the distance is the pre-Cambrian peneplain.

a change was wrought, causing large portions of the valleys to become filled with debris, and the streams to flow over deposits of their own construction. Still later another change was made, the streams were revived, and they began to erode through the alluvial sediment previously deposited in portions of their valley courses. The present valleys, therefore, are in part filled and terraced valleys.

Over a large portion of the southern part of the area, in Portage, southern Wood and Clark counties, and the adjacent counties outside of this area to the south and southwest, the surface formation consists largely of these alluvial deposits. In the southern part of the area in the region of the soft Potsdam sandstone, the characteristic topographic forms are the broad valley bottoms, with but few hills and rock pinnacles along the stream divides. In the central and northern portion of the area, characterized by the undulating hills of hard crystalline rock mantled with a variable amount of glacial till, where the land is of higher elevation, the valleys are comparatively narrow and deep, and valley deposits occur only along the courses of some of the large rivers and certain portions of their side streams. The distribution of the alluvial deposits is shown on the general map of the Pleistocene. Plate II.

GENERAL CHARACTER.

The valley deposits consist of clay, sand, gravel, and occasionally large pebbles or boulders. It mainly consists of sand and gravel. a quite porous formation, into which the rainfall readily sinks to the approximate level of the adjoining streams. Here and there. also, are clay deposits, suitable for brick making, interbedded with the sand and gravel. These clay beds appear to be lenses of variable thickness up to 10 and 20 feet, underlain and overlain by a variable thickness of stratified sand and gravel. Brick clays occur as a portion of the valley deposits near Wausau in Section 31, T. 29, R. 8 E., and along the Little Rib River in Section 29, T. 29, R. 7 E.

In the vicinity of Stevens Point and Grand Rapids, clays derived from the decomposition of the crystalline rocks are extensively used for brick making, and it is not unusual to find alluvial clays immediately overlying these residual clays, and the whole overlain with considerable gravel and sand. Brick clays have also been observed in the broad valley plain of Juneau County, at Necedah and near Mauston.

Rarely, large boulders occur in the valley deposits imbedded in the stratified gravel and sand. These boulders occur not only along the present river courses but also far out in the sandy plains of the southern part of the area. Boulders have been encountered in the ditches of the cranberry farms of southern Wood County.

The coarser material of the stratified valley deposits consists mainly of crystalline rock of various kinds, abundantly occurring throughout the region of the pre-Cambrian formations. In southeastern Portage County some Paleozoic chert pebbles were noted.

THICKNESS.

The thickness of the stratified valley deposits is quite variable from place to place, although it seems quite probable that the thickness in the deepest parts of the valley in the southern part of the area is quite uniform. The thickness is known to vary from zero up to a maximum of 200 feet. The greatest known thickness occurs in the broad valley bottom of the sandstone district. Throughout the valley plain, deep wells are not necessary for water supply, and hence there is a lack of data relating to the thickness of these deposits.

The Wisconsin River from Merrill to the lowest crystalline rapids at Nekoosa flows over a series of rock rapids alternating with long, gently sloping stretches of river deposit. Nowhere do these rapids occur in the narrowest portions of the valley, and it is certain that if the river was shifted to one side or the other, a deeper portion of the buried channel would be uncovered and the rapids thereby avoided.

At Merrill the valley deposit of purely river origin has a considerable but unknown thickness probably at least 100 feet for here glacial outwash and other glacial deposits occur in the valley and mainly from the glacial formations has been carved the present channel of the river.

LOOKING SOUTHWEST ACROSS THE FILLED VALLEY OF THE WISCONSIN, SOUTHERN PART OF WAUSAU.
Rib Hill is on the right, Mosinee Hill on the left, the level horizon between is the peneplain.

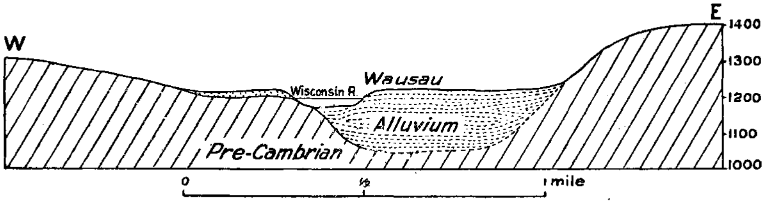


FIG 24. Section at Wausau showing relation of the filled valley to the present course of the river. Base line is 1,000 feet above sea level.

A test well at the Wausau water works near the level of the river in Wausau shows a thickness of 134 feet to the crystalline rock. The alluvium in the Wisconsin Valley at Wausau therefore has a probable thickness of 150 to 200 feet. The deepest part of the Wisconsin channel lies to the east of the present course of the river which now flows over a series of rock rapids. The relation of the Wisconsin river to the filled valley is illustrated in Fig. 24.

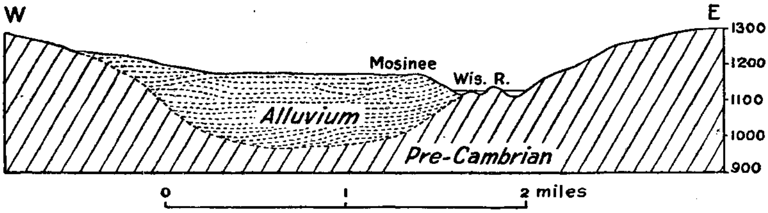


FIG. 25. Section at Mosinee showing relation and extent of the filled valley.

The river immediately south of Wausau, at the junction of the Eau Claire and the Big Rib, has carvel benches and terraces into the valley deposits to a depth of 40 to 60 feet, which, combined with depth of wells sunk into the lowest terraces, shows in many places a thickness of 100 feet or more of the stratified gravel and sand.

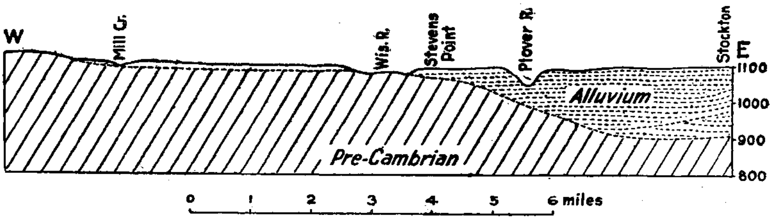


FIG. 26. Section at Stevens Point showing extent and relation of the filled valley. The old valley extends some distance farther to the east.

South of Wausau the valley deposits are considerably wider than to the north, and hence it may be inferred that they have generally greater depth. At Stevens Point, Grand Rapids, and Nekoosa, there is exposed a thickness of only 30 to 40 feet of alluvium, but at these places the river flows upon the untrenched pre-Potsdam peneplain, and entirely outside of its old channel which obviously lies farther east of its present location.

At Bancroft, on the line of the Chicago and Northwestern

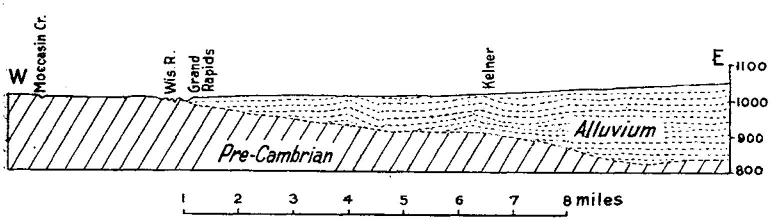


FIG. 27. Section at Grand Rapids. The present location of the Wisconsin river is at the western margin of the filled valley.

railroad a deep well was sunk to a depth of 97 feet in gravel and sand without striking rock bottom.

In Figs. 25, 26 and 27 are illustrated the relations of the present Wisconsin River course to the filled valley and to the older pre-Cambrian formations. At Mosinee the present course of the river is on the east side of the filled valley. At Stevens Point and Grand Rapids the river is at the western margin of the old valley. The earlier course of the river very probably lay some miles to the east of Stevens Point and Grand Rapids. (Note the difference in the horizontal scale of these cross sections.)

Alluvium at Necedah, Juneau County.

Perhaps one of the most instructive localities showing the thickness of the alluvial deposits of the Wisconsin Valley is at Necedah, about 15 miles south of the area described in this report, but in the continuation of the alluvial formation of Portage and Wood counties. Recent explorations about the Necedah quartzite by diamond drill show a thickness of 30 to 198 feet of sand and gravel overlying the buried sandstone of this locality. The location of the drill holes about the Necedah

THE BROAD ALLUVIAL PLAIN OF SOUTHERN WOOD COUNTY.
Four miles west of Grand Rapids.

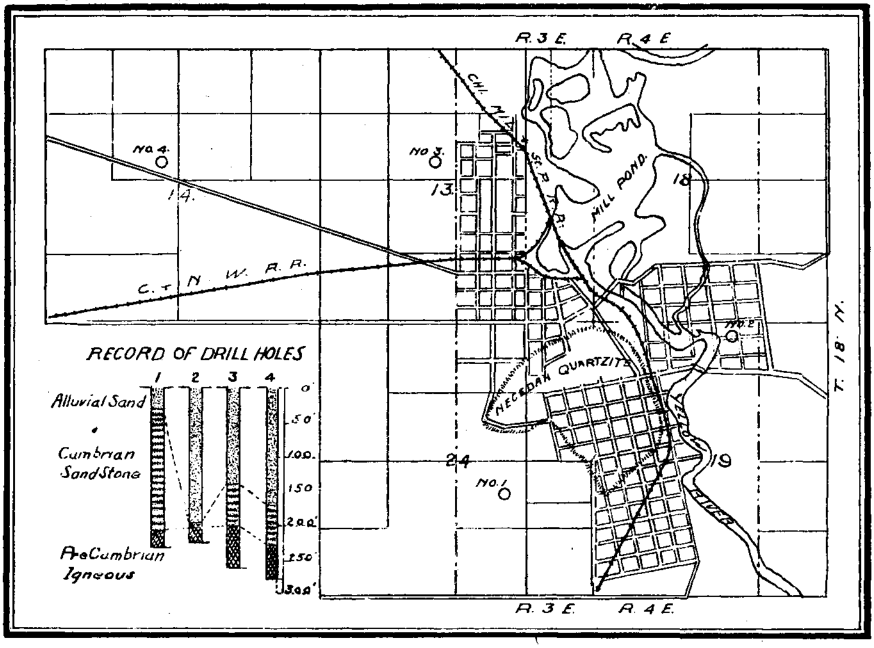


FIG. 28. Map of the vicinity of Necedah showing location and log of drill holes.

quartzite knob and a diagram of the drill hole sections are shown on the accompanying sketch map. (Fig. 28). A generalized cross section showing the formations is presented in Fig. 29. Hole No. 2, showing 198 feet of sand and gravel, is located on the present flood plain of the Yellow River about 20 feet below the level of the broad valley plain. At this place, therefore, the original thickness must have been about 220 feet.

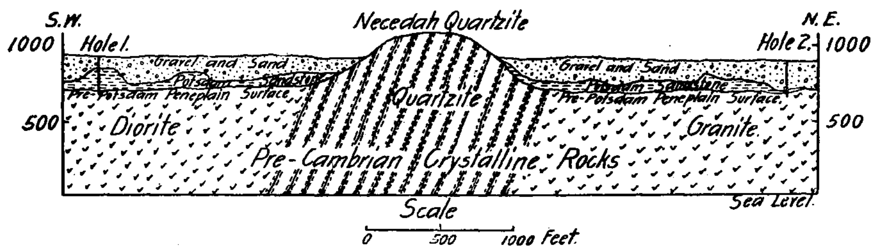


FIG. 29. Section at Necedah showing extent and relation of the alluvial gravel and sand to the underlying Potsdam sandstone and pre-Cambrian rocks.

The material overlying the sandstone and pre-Cambrian in the plain about Necedah is very largely sand and gravel, although in places at the surface, good brick clay is interstratified with the sand. No large boulders were struck, though the drillers report that in some of the drill holes small boulders were crowded aside in driving down the casing. Most of the material is sand and silt, with smaller amounts of gravel, the latter varying in size up to 2 or 3 inches in diameter, and consisting largely of crystalline rock.

Valley Deposits in the Baraboo District, Sauk County.

Still farther south of the area described in this report, in the Baraboo district,[1] an area bearing the same geographic relation to the Wisconsin River valley and to the region of thick drift formations of the state as the area about Necedah, the valley filling is known to reach a maximum thickness of 218 feet.

Alluvial Deposits in Other Parts of the State.

In the broad valley plain of northeastern Monroe County, in the vicinity of Tomah, are several wells 100 feet deep in the sand and gravel, and at Valley Junction is a well 100 feet in sand and crystalline gravel.

It is well known that the Wisconsin River valley in the southwestern part of the state in several places is filled to a depth of 150 feet or more, and the same is true of many of the other large rivers of the southern part of the state, the Rock River at Janesville being filled to a depth of 350 feet.

The Black River at Black River Falls a few miles outside the area of this report exposes a thickness of about 90 feet of river deposit overlying the crystalline rock rapids. Further up the Black, the valley deposits grow shallower, while down stream, towards the Mississippi, they are undoubtedly much deeper. The valley deposit in the Chippewa River valley, indicated by depth of erosion, at Eau Claire has a known thickness of 140 feet, and at Chippewa Falls 110 feet. The entire thickness at Eau Claire is very probably much greater than 140 feet.

[1] S. Weidman: Baraboo Iron-bearing District, Bulletin 13, Wis. Geol. & Nat. Hist. Survey, pp. 80–89.

These various places outside the immediate area of this report are mentioned in order to show the widespread distribution and depth of the valley filling in the central and southern parts of the state, the geology of which, it is believed, is identical with that of the valley filling of this area in north central Wisconsin.

DETAILS OF EXTENT AND DISTRIBUTION.

The stratified deposits of sand and gravel filling the valleys of portions of the area are important formations in Wood, Portage, Marathon, and Clark counties. They are of especially widespread distribution in Wood and Portage counties, extending over an area of about 325 square miles in each, or one-third of each of these counties. (See map—Plate II). In Marathon and Clark they are of lesser extent; in the former county they have an area of about 100 square miles, and in the latter apparently not more than 25 square miles. In Taylor and Lincoln, with the exception of a small area along the Wisconsin River in the latter county, the surface deposits in the valleys are glacial drift, into which the streams are eroding their channels.

In the southern part of the area the valley deposits of the Wisconsin River extend westward from the border of the Wisconsin drift in the central part of Portage County entirely across southern Wood County. In this part of the area the alluvial plain occupies almost the entire width of the valley of the Wisconsin and its tributaries, joining across with the alluvial plain of the Black River along the course of the East Fork of the Black, in the towns of Dexter and Remington, of Wood County. In this broadest portion of the valley plain are a number of islands of sandstone and pre-Cambrian crystallines, projecting above the plain.

Farther north in the area at Stevens Point, the valley plain has a width of 6 or 8 miles, and at Mosinee only about 3 miles. Immediately south of Wausau, where the tributary valleys of the Big Rib and Eau Claire rivers join the Wisconsin, the valley plain is 5 or 6 miles wide, and this considerable width extends for some distance up the side valleys. Immediately north of Wausau the valley narrows to a width of one-half to two miles, with steep valley escarpments of crystalline rock rising two and three hundred feet on either side.

At Merrill the valley of the Wisconsin is occupied by drift of the Third formation, with undulating pitted plain topography, into which the river channel has eroded in a few places to the crystalline rock beneath. North of Merrill the river channel is carved out of the Third and Wisconsin glacial formations, which form a thick blanket extending over the northern part of the area.

On the east side of the river, the main tributaries of the Wisconsin are bordered by alluvial filling for certain distances up their courses. The Plover River has alluvium extending up to and probably beneath the Wisconsin drift sheet. The alluvial plain along the Big Eau Claire does not extend beyond the lower end of the gorge of the Dells, in Section 23, T. 29, R. 9 E. The Trapp has its valley filled with alluvium only a few miles up from the Wisconsin river. The old channels of the Pine and Prairie rivers are probably filled in part with alluvial deposits, although their present channels are carved from overlying glacial formations.

On the west side of the Wisconsin river the Little Eau Pleine has an exceptionally broad alluvial plain quite unlike that of the Big Eau Pleine immediately north. Along the Little Eau Pleine the alluvial plain has an average width of about 2 miles as far as Rice Lake, a broad portion of the river, beyond which it gradually grows narrower and shallower and finally ends in the vicinity of Section 28, T. 26, R. 4 E. In the valley of the Big Eau Pleine, the alluvial deposits extend up stream about an equal distance from the Wisconsin river, the valley, however, being comparatively narrow throughout.

The Big Rib river has well defined alluvial formation as far up stream as Rib Falls. Beyond Rib Falls, the river descends rapidly from the northwest, quite generally flowing over bed rock, but showing abundant terrace remnants along the valley sides as far up stream as section 30, T. 30, R .5 E. The branches of the Big Rib, such as Little Rib River, Scott Creek, and Black Creek, have alluvial plains some distances up their courses as indicated upon the map (Plate II). Farther north in Lincoln county the tributaries have no terraced alluvial valleys.

The Yellow River, which joins the Wisconsin some distance south of this area, has alluvial bottom-lands extending up along its course to the vicinity of Pittsville.

The Black River, showing extensive valley filling at Black River Falls, posseses alluvial terraces as far up stream as Section 8, T. 23, R. 2 W., about 7 miles south of Neillsville. Farther north the swift current of the river finds its way through glacial drift and bed rock of sandstone and crystalline formations.

The tributaries of the Chippewa River in the northwestern part of the area, within the area of the Wisconsin drift, have no alluvial deposits. The extensive alluvial filling of the lower part of the Eau Claire River extends far up this river, but ends within the western part of Clark County.

It may be urged that alluvial filling once extended up these rivers beyond the localities here given as the termination of the filling, and that it has been subsequently removed by erosion. The most important phenomena for the determination of the extent of the valley filling is the fact of the actual thinning out of the alluvial filling in the localities indicated. The alluvium becomes shallower and shallower as the rivers are followed up stream. At the limits indicated they thin out, and beyond, no terraces are found.

Distribution of Alluvium Relative to the Drift Formation.

The general distribution of the alluvial deposits has been described. It is now purposed to discuss briefly their distribution relative to the four glacial formations of the district. For the sake of clearness it may be necessary to repeat some of the statements already given.

It will be recalled that the Wisconsin river rises far within the area of the Wisconsin drift sheet, flows southward through drift hills and the recessional moraines, emerging from the Wisconsin drift about 6 miles north of Merrill. Between Merrill and Wausau it crosses the border of the Third drift the formation next older than the Wisconsin drift, as indicated upon the map (Plate II). In its entire course south of Merrill through this area it is flanked by alluvial deposits. Beyond this area it continues its course in an alluvial valley as far as Kilbourn, where it re-enters the Wisconsin drift sheet, re-emerging again at Sauk City and then continuing again through terraced alluvial deposits to its junction with the Mississippi.

At Merrill the drift sheet older than the Wisconsin formation described as the third of this district has well developed recessional moraine extending along the south divide of Devil Creek on the west side of the Wisconsin, and the south side of the Prairie River on the east side, the moraine forming a loop projecting for several miles further south down the narrow channel of the Wisconsin to the vicinity of the mouth of the Pine River. The formation in the valley of the Wisconsin at Merrill has the characteristic features of terminal moraine such as ridges of coarse drift and depressions. Several well exposed sections of the drift may be seen along the Prairie River in the northeastern part of the city, showing a thickness of 15 to 20 feet of unstratified and stratified glacial formation overlying stratified sand and gravel; the latter may be either glacial or fluviatile in origin. This drift very evidently, as previously noted (page 480), filled the lower end of Pine Valley next to the Wisconsin River and caused the Pine River to flow in its new channel through the dells of the Pine.

All the terraces at Merrill therefore appear to be carved out of the third glacial formation, the upper terrace being a terrace of erosion and not of deposition, as is the case with the alluvial terraces along the river south of this drift sheet.

The margin of the ice sheet of the Wisconsin epoch lay across the valley about 6 miles north of Merrill, building up a very prominent terminal moraine. The alluvial formation fringing the present course of the Wisconsin River, however, as already stated, does not extend north of Merrill. Neither does a formation of stratified gravel and sand lead up to the terminal moraine along the Prairie River and Little Hay Meadow Creek. There is indeed an entire absence of outwash fringing the Wisconsin terminal moraine in this vicinity, the formation immediately in front of the terminal moraine, and evidently extending northward beneath it, being the bouldery drift of the Third drift sheet with its undulating topography of low drift hills and undrained areas, basins and small lakes. In like manner the alluvial formation, also, filling the old valley of the Wisconsin River above Merrill, probably extended much farther north in the old valley but is now buried beneath later drift.

While it is true that there are deposits of sand and gravel fringing the banks of the Wisconsin River north of Merrill, both in front of, and within, the Wisconsin drift formation, these stratified deposits are believed to have the general nature of glacial and not of alluvial deposits.

The east tributaries of the Wisconsin in Portage County have their source in the terminal moraine of the Wisconsin drift sheet, and their channels in front of the moraine are carved throughout from stratified sand and gravel formations. On the other hand, the Eau Claire river, in Marathon County, has alluvial terraces only along its lower course, terminating some distance below the Wisconsin moraine within the driftless part of the district. The Big Sandy Creek and the Trapp River, neither of which reach up to the Wisconsin drift sheet, have alluvial bottoms extending some distance up their lower courses, the former being wholly within the driftless, and the latter wholly within the area of the Third drift formation.

On the west side of the Wisconsin, in Wood and southern Marathon counties, the Yellow River, Mill Creek, Little Eau Pleine and Big Eau Pleine rivers did not connect with any drainage courses leading from the Wisconsin ice sheet, nor with that of the ice sheet next older than the Wisconsin; yet they have well defined alluvial bottoms long distances up their courses. In the valleys of these tributaries the alluvial bottoms do not terminate at the terminal moraine or border of any of the drift sheets, but end within the area of the oldest (First) drift formation.

The main branch of the Big Rib River drained the Wisconsin and next older ice sheets, but alluvial deposits occur only below section 19 of the town of Hamburg. Black Creek, Scott Creek, and Little Rib River, branches of the Bib Rib wholly located within the areas of the First and Third drifts, have well developed alluvium at about the same elevation as the alluvium on the main branch of the Big Rib.

The Black River bears much the same relation to the various drift sheets and stratified deposits as the Wisconsin River. The Black has the source of many of its streams in the terminal moraine of the Wisconsin drift sheet, flows southwestward across each of the older drift formations, and across the stratified gravel and sand plain of the southwestern part of the area and beyond, to the Mississippi. Beginning at the south, the stratified gravel and sand extends up along the Black, spreading out for many miles on either side, as far as the vicinity 6 or 7 miles below the well defined terminal moraine of the Second drift sheet which lies across its valley at Neillsvile. From its source to 7 miles below Neillsville the river flows through formations of bouldery drift, sandstone and crystalline rock, its channel being in marked contrast with the terraced river deposits beginning 7 miles south of Neillsville. Thus along the Black River, the valley deposits do not continue northward to the Wisconsin terminal moraine, nor even to the thick moraine of the Second drift.

The Eau Claire River in western Clark County has well developed alluvial deposits far up its course from the Chippewa River, but these terminate within the area of the oldest drift of the district in western Clark County.

With respect to the distribution of the alluvial filling and the several drifts, it may be stated that the filled valleys extend indiscriminately across the area of the First drift sheet.

The alluvial filled valleys, are present in the area of the Second drift sheet in Portage County. Valleys filled with alluvium, also, occur in the Second drift in the western part of the state. In most cases the alluvial filled valleys in this district end far below the terminal moraine of the Second formation, as illustrated by the Black River alluvium below Neillsville and by the alluvial deposits of the Eau Claire River in western Clark County. The filled valleys of the Big Eau Pleine do not reach up to the Second terminal moraine but end far within the area of the First drift.

With respect to the later drift formations, the Third, and the Wisconsin drift, it has been shown that some of the tributary valleys on the east side of the Wisconsin, mainly those in Portage County, have alluvial filling extending up to the deposits of the Wisconsin drift, but farther north, in Marathon County, the valley filling ends far below the Wisconsin sheet. The alluvial filling of the main valley of the Wisconsin River extends up to the Third drift formation, but not beyond, except as it is continued beneath the Third drift, and does not reach the Wisconsin formation. The Big Rib River, which has its source in the moraine of both the Third and the Wisconsin drifts, has alluvial filling only in its lower course. While alluvial deposits occur up the Big Rib as far as section 19 town of Hamburg, it is believed that these deposits have been over ridden by the Third ice sheet.

It appears, therefore, that the alluvial filling, when considered as a whole, bears no relation in distribution to the terminal moraines of any particular one of the several drift formations of the area. On the other hand when the distribution of the filled valleys is studied in comparison with the general elevation and slope, well defined relations are observed to exist.

Distribution of Alluvium Relative to Elevation and Slope.

A topographic map of only a part of this district is available. Combining other data of elevation with the topographic map, however, a general account of the relative distribution of the alluvium, sufficient for the purpose, can be given.

The elevation of the alluvial plain at Wausau, where the Eau Claire and Big Rib rivers join the Wisconsin, is between the 1,200-foot and 1,220-foot contour lines. If the Eau Claire River be followed up stream, this alluvial plain is found to slope upward more slowly than the river. The alluvial filling grows shallower and shallower until it finally ends in the vicinity of the southeast corner of Sec.22, T. 29, R. 9 E., some distance below the gorge of the Dells. The alluvial plain ends approximately at an elevation of the 1260 to 1280 contours. Above this for 10 or 12 miles the channel of the river is mainly bottomed in crystalline rock, for this is within the driftless part of the district. Within this lower part of its course of 10 or 12 miles, the river valley ascends 150 feet, and beyond this is the more gently sloping region of the Third drift and of the Wisconsin drift, through which the main branch and its tributaries have their course. The Big Sandy creek, the main tributary of the Eau Claire in Marathon County, has alluvial filling up to approximately the same elevation as its main, namely, to the 1260 to 1280 contour. The tributary, unlike its main, is wholly confined to the driftless part of the district.

The alluvial filling of the Big Rib river extends as far up stream as Sec. 19, T. 30, R. 5 E., to the elevation of the 1260 contour. The alluvial plains bordering its main tributaries, the Little Rib River, Scott Creek, and Black Creek, reach aproximately to the same elevations. Thus there is a marked uniformity in the maximum elevation reached by the alluvial filling of these two opposite tributaries of the Wisconsin river. As indicated upon the map, Plate II, the alluvial deposits along the Big Rib and also the Little Rib river are believed to have been overridden by the thin formation of Third drift.

In the vicinity of Merrill the purely alluvial filling is some what obscured by outwash and drift deposits of the Third formation, and as previously stated the upper terrace at Merrill appears to have been formed by erosion rather than by deposition. The lower portion of the valley filling at Merrill is wholly or mainly stratified gravel and sand, while above it lies a coarser deposit tentatively ascribed to the Third drift formation, very probably of outwash and glacial origin.

In the vicinity of Merrill, purely alluvial deposits do not appear to extend higher than the 1260 to 1280 contour line. North of Merrill the present river course is in crystalline rock and glacial drift, but in its earlier channel now filled with drift the alluvium probably extended for many miles above Merrill.

Alluvial filling along the Trapp River extends up to the 1280 contour. There is no alluvial filling of the Pine Valley unless it lies beneath the glacial deposits filling this valley (See page 480), and the same also very probably holds for the Prairie River.

In the vicinity of Knowlton on the Wisconsin river, the elevation of the alluvial plain is between the 1120 and 1140 foot contours, nearly 100 feet lower than that of this formation at the mouths of Eau Claire and Big Rib rivers at Wausau. Joining in this vicinity are two large tributaries from the west, the Big Eau Pleine and the Little Eau Pleine. The alluvial filling along the Big Eau Pleine extends up to the 1160 contour line and that of the Little Eau Pleine approximately to the same elevation. Similar elevations are reached by the alluvial deposits along the Little Eau Claire and Little Sandy creeks on the east side of the river. The alluvial deposits of the Little Sandy join across with those of Bull Jr. Creek farther north, and the latter with the filling along the Eau Claire, as shown upon the map.

The broad alluvial plain in Portage County extends up to the Wisconsin drift. All the tributaries of the Wisconsin from the east in this part of Portage County flow through the alluvial plain from the terminal moraine to join the main stream. Although this part of the district has not been surveyed topographically, the elevations of railroads available, seems to indicate that nowhere does the alluvium lie more than 30 or 40 feet above the general level of the plain immediately adjacent to the Wisconsin river. Where the elevation is greater than this no alluvium is present. On the west side of the river the alluvial filling on Mill Creek extends to an elevation of 30 or 40 feet above the plain along the Wisconsin.

The plain of the alluvium on Yellow River extends but a few miles above Pittsville, to the same elevation as the alluvial filling of the tributaries flowing into the Wisconsin River in the vicinity of Grand Rapids.

In the western part of the district the alluvial filling of the Black River extends up to an elevation of 900 to 920 feet. Slightly higher elevations are reached by the alluvial plains along Chippewa River and its main tributary, the Eau Claire, in western Clark County.

It will thus be observed that there is a close agreement in the elevations to which the alluvial deposits extend along the tributaries of the Wisconsin. Tributaries joining the main in the same locality, whether on the same or the opposite sides of the main, have alluvial filling extending up stream to approximately the same elevation. The distance to which the alluvial filling extends up the tributaries from the main depends upon the slope or gradient of the valley, the steeper valleys reaching the maximum elevation within shorter distances than those of more gentle slopes. On account of the steepness, therefore, the alluvial deposits bordering the Trapp River extend but a short distance up this stream, while those along the Eau Claire, having a valley of more gentle slope, the deposits extend much farther, and those of the Big Rib, with a still more gentle slope, extend still farther up stream. The stream volume is a factor of minor importance to be considered in connection with the valley gradient in the deposition of alluvium.

The elevation attained by the alluvial filling of the Black River is much below that of the Wisconsin, but agrees closely with that of the Chippewa River. This difference is obviously due to the difference in relative position of these tributaries to their main, the Mississippi, with respect to valley slope and other factors of drainage depending for their development upon the law of land structure. As a result of structure and relation to main, the Wisconsin valley has a gentler slope than that of the Black and Chippewa and hence reached grade earlier, and its alluvial filling necessarily extended farther up stream to higher elevations. The Black River as later described (page 630) is very probably post Second glacial in origin.

In connection with the distribution of the alluvial deposits of the district, attention should perhaps be called to some earlier maps[1] of the Pleistocene formations of this and adjacent regions. Upon these maps the alluvium (valley trains) is erroneously shown to extend continuousy up the rivers to the Wisconsin drift formation.

ORIGIN OF THE ALLUVIAL DEPOSITS.

The alluvial deposits in the valleys of the district were very obviously deposited by water flowing as rivers through their valleys. The character of the deposits, as well as their distribution along the rivers, is proof of their alluvial origin. The coarseness of the material, such as the coarse sand and gravel deposited in alternating layers, indicates that the material was transported and deposited by the swiftly flowing water of rivers and not by the stagnant waters of lakes or estuaries. The sur-

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[1] Quarternary Map of the Driftless Area and Environs, Plate 27, Sixth Annual Report; U. S. Geol. Survey, 1885.

Quarternary map of Wisconsin, Illinois, and Adjacent Area (based in part on above) P. P. No. 34, U. S. Geol. Survey, 1904.

face of the plains, as well as the constituent strata, slopes downward in the direction in which the streams flow, and indicates that the deposits were very evidently built up by successive floods and overflows of the rivers. No other explanation of origin could possibly apply to the formation in the narrow valleys of the area, and since the narrow valley plain of the Wisconsin in the hard crystalline region is continuous both in slope and character with its broad valley in the soft sandstone district farther south and passes gradually into the latter, it seems reasonable to believe that the entire valley filling was formed under similar conditions and by the same agency. It is not improbable that floating ice, either as detached blocks from the margins of ice sheets during glacial periods, or as ice floes derived from the frozen rivers during glacial or interglacial periods, may have been instrumental in transporting some of the large boulders associated with the sand and gravel.

The conditions necessary for the extensive filling of a valley by its river is usually due to a decrease in the velocity of the current sufficient to cause the river to drop its load instead of carrying its load forward and eroding its channel deeper. The decrease in velocity of current is brought about by decrease in the gradient of the river sufficient to change the work of the river from that of erosion to that of deposition, from that of degrading to that of aggrading its course. Other factors may enter. such as change in volume of the stream and in character and supply of sediment induced by glacial invasions, but the primal cause of an extensive system of valley filling is the decrease in the gradient of the river and in the velocity of current accompanying subsidence of the land.

The probable age of the alluvial deposits is briefly discussed following the accounts of the erosion terraces which have been developed in the filled valleys.

THE RIVER TERRACES.

Origin of the Terraces.

River terraces may be formed in two ways,—by erosion and by deposition. River terraces, as a rule, are formed by erosion rather than by deposition. The evidence upon which the erosion of the terraces is based is two-fold, and is furnished by the structural relations of the terraces and by their surface features.

If the terraces were the records of sedimentation rather than the records of erosion, an unconformity and evidence of weathering would exist between the successive deposits, as indicated

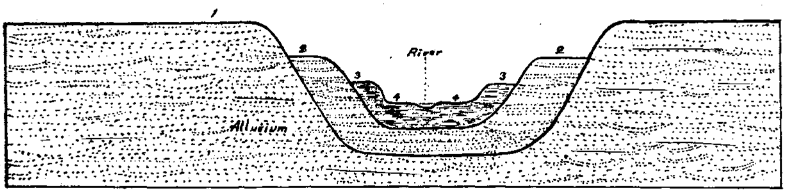

FIG. 30. Diagram illustrating the formation of river terraces by deposition. Of unusual occurrence.

in the sketch, figure 30. On the other hand, if they are the records of erosion, no break would occur in the strata below the point where the terraces meet, as illustrated in the sketch, figure 31. These terraces consist of conformable strata like that represented in figure 30 rather than unconformable strata represented in figure 31.

Terraces due to erosion are usually, if not always, furrowed by old river channels and do not possess the even surfaces of built-up plains formed by successive overflows. The surfaces of these terraces carved below the alluvial plain are remarkably furrowed and uneven, and are in marked contrast with the highest flat of the alluvial plain of the valley.

After the valleys of the district were filled with waste, the rivers were revived and began to erode channels into the built-up flood plain. This change in the action of the rivers was primarily due to elevation of the region and a consequent increase in the gradient of the rivers, with accompanying increase in velocity of current. Other contributory causes may have operated, such as decrease in the supply of land waste from the headwaters, or because the lower courses of the valley were deepened. Uplift seems to have been the most probable cause of the change of action in this area, since the change appears to have had a widespread application over the region.

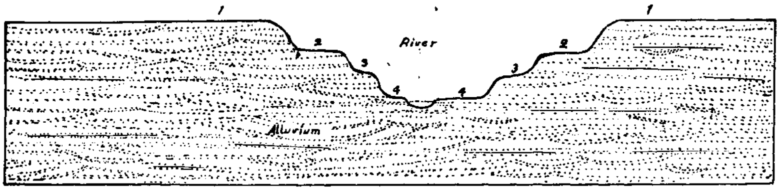

Fig. 81. Diagram illustrating the formation of river terraces by erosion. Of usual occurrence. The upper terrace, 1, is due to deposition while 2, 3 and 4 are due to subsequent erosion.

The streams since their uplift, therefore, have intrenched new channels in the previously filled valleys, and in the process of excavating new channels, the terraces or benches have been eroded out of the alluvium of the filled valleys. The part of the valley plain remaining above the new channel is called an alluvial terrace or simply a terrace. The present flood plain may be conveniently referred to as the Lower Terrace, and the oldest flood plain, the plain of the filled valley, the Upper Terrace. The terrace developed by the present flood plains of the rivers are usually much wider than the narrow course occupied by the ordinary volume of the stream.

Distribution of Terraces Along the Rivers.

The depth which the rivers have intrenched themselves into the old flood plain varies considerably along different streams and also along different portions of the same streams. Where important side streams join the Wisconsin, there is usually considerable erosion of the valley deposits and the construction of one or more erosion terraces. The presence of rapids also appear to have caused more or less meandering of the rivers and the construction of minor local terraces.

The Wisconsin River from the vicinity of Merrill to the southern border of this district and beyond has intrenched its course in the filled valley to a depth of 10 to 50 feet. Over the rapids the new channel is not intrenched so deeply as through the level stretches of alluvial deposits between. The side streams have cut down to the level of the trunk stream and have terraced valleys as far up their courses as the alluvial filling extends. Upon the accompanying map, Plate II, is shown the location of the principal erosion terraces and abandoned courses of the Wisconsin and some of its side streams along those portions of the river where especially well developed.

Sixteen miles south of this district, at Necedah, the alluvial filling has a thickness of at least 198 feet. In this locality the buried surface of the pre-Cambrian formation lies at a depth of 202 to 229 feet below the present surface. The rapid rise of the pre-Cambrian slope to the north brings it to the level of the Wisconsin River channel at Nekoosa, and to the general land surface in the vicinity of Grand Rapids. Below Nekoosa the river is intrenched wholly in alluvial deposits, but above, the crystalline formations often occur forming rapids in the river bottom. Below the Nekoosa rapids there are two erosion terraces, and in places a third of minor importance, between the upper terrace (surface of alluvial plain) and the present flood plain of the river. As a rule, the terrace system does not remain intact on directly opposite sides of the river, on account of removal by erosion, and hence the cross-sections showing profile of the terraces are usually from immediately subjacent parts of the river. About a mile south of the Nekoosa rapids on the west side of the river are two erosion terraces below the alluvial plain, approximately 20 and 35 feet below the upper terrace. Just below the rapids on the east side are three, approximately 15, 20 and 35 feet below the upper terrace. A generalized cross-section is shown in figure 32.

Profile of Wisconsin River from Mouth to Source.

No.	Station.	Distance. From mouth.	Distance. Between points.	Elevation	Descent between points. Feet. Total.	Descent between points. Feet. Per mile.
1	Mouth of river, low water	0	0	604.	......	......
2	Muscoda bridge	43.5	43.5	669.	65.	1.5
3	Prairie du Sac	93.5	50.0	740.	71.	1.4
4	Merrimac	102.	8.5	754.	14.	1.6
5	Portage	118.	15.5	784.	30.	1.9
6	Kilbourn, below dam	138.	20.	815.	31.	1.5
7	Lemonweir river, mouth of	148.5	10.5	836.	21.0	2.0
8	Yellow river, mouth of	159.5	11.0	858.	22.0	2.0
9	Petenwell bridge, opposite Necedah	174.5	15.0	878.5	20.5	1.36
10	Nekoosa dam, below dam	207.6	33.1	921.8	43.3	1.38
11	Nekoosa dam, above	......	......	938.8	17.0	......
12	Port Edwards dam, below dam	211.1	3.5	948.5	9.7	2.8
13	Port Edwards dam, above dam	......	......	958.5	10.0	......
14	South Centralia dam, below	212.6	1.5	962.0	3.5	2.3
15	South Centralia dam, above	......	......	971.	9.	......
16	Grand Rapids dam, below	215.1	2.5	982.	11.0	4.4
17	Grand Rapids dam, above	......	......	1004.	22.	....
18	Biron dam, below	218.1	3 5	1008.	4.	1.3
19	Biron dam, above	....	......	1018.	10.	.. ..
20	Plover Paper Mill dam, below	231.6	13.5	1034.6	16.6	1.2
21	Plover Paper Mill dam, above	......	......	1043.6	19.0	......
22	Wis. R. Paper and Pulp Co. dam, below	232 3	0.7	1044.3	0.7	1.0
23	Wis. R. Paper and Pulp Co. dam, above	......	......	1060.9	16.6	......
24	Stevens Point W. C. Bridge	234.8	2.5	1066.0	5.1	2.0
25	Jackson Milling Co. dam, below	235.0	0.2	1069.7	3.7	17.5
26	Jackson Milling Co. dam, above	......	......	1076.7	7.0	......
27	Little Eau Pleine River	250.7	15.7	1089.0	12.3	0.8
28	Knowlton C., M. & St. P. R. R. bridge	256.	5.3	1097.6	8.6	1.6
29	Line between Rs. 6 and 7, E	263.	7.	1106.	8.4	1.2
30	Mosinee Highway bridge	265.2	2.2	1114.	8.	3.7
31	Mosinee dam, foot	265.4	0 2	1122.	8.0	40.
32	Mosinee dam, crest	......	......	1127.7	5.7	......
33	Black Creek, mouth	268.8	3.4	1129.3	1.6	0.5
34	Cedar Creek, mouth	272.3	3.5	1133.5	4.2	1.2
35	Eau Claire R., mouth	277.6	5.3	1142.	8.5	1.6
36	Big Rib River, mouth	278.9	1.3	1145.8	3.8	3.0
37	Wausau lower bridge	281.	2.1	1153.5	7 7	3.7
38	Wausau dam, foot	282.	1.	1174.	20.5	20.5
39	Wausau dam, crest	......	......	1180.	6.	......
40	Brokaw, below	287.3	5.3	1185.7	5.7	1.1
41	Brokaw, above	......	......	1201.2	15.5	......
42	Trapp R., mouth of	292.	4.7	1203.7	2.5	0.5

Profile of Wisconsin River from Mouth to Source.

Continued.

No.	Station.	Distance. From mouth	Distance. Between points	Elevation.	Descent between points. Feet. Total.	Descent between points. Feet. Per mile.
43	Pine R., mouth of	296.4	4.4	1216.3	12.6	2.9
44	Lindore dam, Merrill, below	301.8	5.4	1233.0	16.7	3.1
45	Lindore dam, Merrill, above	......	......	1244.4	11.4	......
46	Upper dam, Merrill, below	304.1	2.3	1245.5	1.1	0.5
47	Upper dam, Merrill, above	......	......	1250.8	5.3	......
48	Copper R., mouth of	307.2	3.1	1256.7	5.9	1.9
49	Bill Cross Rapids, Sec. 13 and 14, T. 32, R. 5 E.	311.2	4.1	1274.	17.3	4.2
50	Bill Cross Rapids bet. R. line 5 and 6	311.6	0.4	1280.	6.0	15.
51	Grandfather Falls, foot, T. 32 T. 33	314.4	2.8	1293.5	13.5	4.8
52	Grandfather Falls, bet. Sec. 30 and 31	315.4	1.0	1340.5	47.	47.
53	Grandfather Falls, head of	316.2	0.8	1385.	44.5	55.6
54	Grandmother Falls, bet. Sec. 3 and 10, T. 33, R. 6. East	321.4	5.2	1401.	16.	3.1
55	Little Pine Creek, mouth	324.1	2.7	1410.	9.	3.3
56	Gilbert Station	326.4	2.3	1415.5	5.5	2.4
57	Tomahawk dam, below	328.4	2.0	1417.0	2.5	1.2
58	Tomahawk dam, above	......	......	1431.	14.	......
59	Nigger Island	344.4	16.0	1454.7	23.7	1.5
60	Whirlpool Rapids, head of	346.4	2.	1470.1	15.4	7.7
61	Hat Rapids	351.4	5.	1482.7	12.6	2.5
62	Rhinelander dam, below	357.4	6.	1528.5	45.8	7.6
63	Rhinelander dam, above	......	......	1558.5	30.	......
64	Otter Rapids, head of	392.4	35.	1570.7	12.2	0.35
65	Sec 30, T. 41, N. R. 10, East	402.4	10.	1592.7	22.	2.2
66	Sec 6, T. 41, N. R. 10, East	416.4	14.	1644.	51.3	3.6
67	Lac Vieux Desert	428.7	12.3	1650 ±	6.0	0.5

Authority No. 1–No. 5 and 53 to 55 and 64 to 67 inclusive U. S. Engr. 6–58 Wis and U. S. Geological Co-operative surveys in charge of L. S. Smith. 59 to 67, C. P. Pride's Survey.

Above Nekoosa the erosion terraces on the west side of the river gradually thin out and entirely disappear at Grand Rapids, 8 miles above. On the east side of the river, however, there is, at Grand Rapids, a well developed erosion terrace, about 20 feet above the present flood plain and 15 feet below the upper terrace.

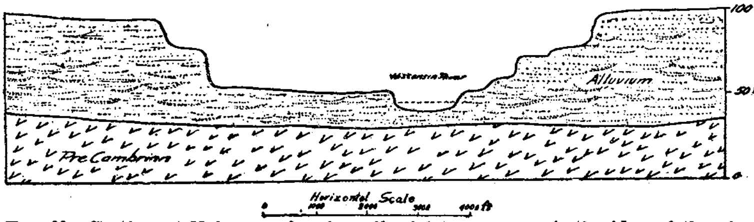

FIG. 32. Section at Nekoosa, showing alluvial terraces on both sides of the river.

The profile directly across the river at Grand Rapids is shown in figure 33. The absence of terraces on the west side of the river is obviously due to the entire removal of the alluvial deposits on that side down to the general surface of the pre-Cambrian formations. The presence of the terraces on the east side is due to the greater thickness of the alluvial formation on the east side. The conditions existing here indicate that the

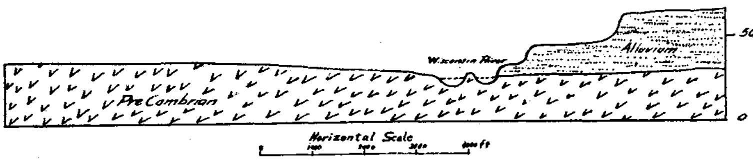

FIG. 33. Section at Grand Rapids, showing the alluvial terraces only on the east side.

deepest part of the filled valley lies farther to the southeast. The tributaries below Grand Rapids on the east side, Buena Vista Creek, Duck Creek, and Ten Mile Creek have intrenched their valleys deeply from 30 to 40 feet into the alluvial formation. The first two join the Wisconsin at the Port Edwards rapids. For a considerable distance up stream these branches have developed a system of erosion terraces, located, however, far above the elevation of the rapids at their junction with the main stream.

From Grand Rapids to Biron's Mill, the river bottom is crystalline rock, and in this stretch of the river is a long series of continuous rapids known as the Grand Rapids of the Wisconsin. Above these rapids to the foot of Conants Rapids, 3 miles below Stevens Point, the river channel is in the alluvial formation.

The vicinity of Grand Rapids and Stevens Point is at the border of the sandstone and the crystalline districts. In this region the ancient pre-Cambrian peneplain dips downward to the south beneath the nearly horizontal sandstone at a much higher angle than the much later plain of the alluvial filled valley. Where the river flows directly down the slope, as at Stevens Point and Conants and from Grand Rapids to Nekoosa, rapids occur, but where the river flows obliquely along the peneplain slope the river winds lazily through deep terraces in the filled valley plain. Throughout the rapids the river is corroding vertically, and through the level stretch between, or at least in certain portions of it, lateral erosion is mainly in process. Between Biron's Mill (below dam) and Grand Rapids (below dam) there is a fall of 25.7 feet within 4 miles, an average descent of 6 4 feet per mile. (See table, Profile of Wisconsin River.) In this section of the river the terrace benches are not prominent, the channel being generally not more than 20 feet in depth. Between the foot of Conants Rapids, (Lower Paper Mill), and Biron's Mill, there is a fall of 16.1 feet in 12.5 miles an average fall of only 1.3 feet per mile, and in this stretch of the river, with comparatively slow current, considerable meandering and lateral erosion has been accomplished, as indicated upon the map. In this vicinity the present flood plain is intrenched nearly 40 feet below the old flood plain.

Upon the map (Plate II) are shown some abandoned channels in the vicinity of Stevens Point and channels through which a flow takes place in times of high water. The channel along Rocky Run, as its name implies, is through almost continuous crystalline rock. The cut-off through the spur below Conants Rapids in the southeast part of Section 17 is of special interest. The government land survey made in 1854 does not show this channel occupied by the river. Previous to 1880 the bed was a slough, and between 1880 and 1900 at times of high water only it was occupied by overflow from the river. Since the high water of 1900, a time of unusual flood, the cut-off has been continuously used and at present is the channel of probably one-eight to one-sixth of the volume of the river. The flow from this cut-off is continually increasing, and, left to itself, it seems only a question of a comparatively short time when all the water of the Wisconsin will take the course of the cut-off and desert the bend to the east, thus developing an abandoned meander.

Between Stevens Point and Mosinee the channel is very broad up to the vicinity of the mouth of the Little Eau Pleine River, and beyond this point it is comparatively narrow throughout. For 12 miles above the rapids at Stevens Point the river has accomplished much lateral erosion, much more, indeed, than within any other part of this district. The accompanying map (Plate II) shows the width of the erosion terrace in this section and the location of several abandoned and new courses of the river.

The comparatively extensive lateral erosion of the river above Stevens Point is due, of course, to the slow current of the river between Knowlton and the Stevens Point rapids. The total descent of the river between Knowlton and Sec. 23, T. 24 N., R. 7 E., where fast water begins, is only 16.4 feet within a distance of 17 miles an average fall of only .97 feet per mile. This section of the river possesses the lowest gradient and slowest current of any portion of the river and on this account there is extensive lateral erosion in this locality.

At Stevens Point the present flood plain is but a few feet below the level of the old flood plain, the two nearly coinciding, the river being able to erode but little into the crystalline rock obstruction forming the rapids since elevation and the revival of river erosion. There can be little doubt that the deeper part of the filled valley lies to the east, as the Plover a few miles east has eroded a deep channel 40 or 50 feet below the level of the alluvial plain. The low slope of the river for 17 miles above fast water at Stevens Point has allowed it to reach grade in this portion of its course, and for a long time it has been mainly occupied in lateral erosion. As time goes on, the graded portion will extend nearer and nearer to the rapids at Mosinee until its base-level of erosion between these rapids is finally completely established. The utilization of water power by the erection of dams at the rapids will very probably reduce vertical erosion at the rapids to a minimum; therefore unless crustal warping takes place the grading of the entrenched valley between these rapids will eventually be completed.

At the mouth of Hay Meadow Creek above Stevens Point the erosion terrace of the Wisconsin has considerable width. During the high water of 1880, 1881, and 1900 and 1905, this lower terrace was flooded. The Hay Meadow Creek at an earlier date was perhaps of larger volume than at present, as indicated by an abandoned channel leading up to the terminal moraine of the Wisconsin drift. Immediately east of the Hay Meadow (see map) is an abandoned channel extending from the Wisconsin River to the swampy tract bordering the terminal moraine. It is possible that this abandoned channel was formed by a stream during the last glacial period, through the gathering in of glacial waters.

The Big Eau Pleine and the Little Eau Pleine have wide channels for some distances up their courses, the former but a short distance, but the latter from 2 to 3 miles up stream. The bend of the Wisconsin at the mouth of the Little Eau Pleine is nearly a cut-off spur, as indicated upon the map. Another cut-off is being formed on the west side of the river, beginning at the bend just below the mouth of the Little Eau Pleine. These cut-offs are now occupied by the river only in times of floods.

Between Mosinee and the mouth of the Little Eau Pleine River, the channel is comparatively narrow, as above stated. The total descent in the river from the rapids at the south line of Sec. 31, T. 27, R. 7 E. to Knowlton is 11.8 feet in 7.5 miles, an average descent of 1.57 feet per mile. In this part of the river, therefore, the current is sufficiently strong to cause vertical erosion rather than lateral erosion.

Another noteworthy locality where the Wisconsin has meandered to a considerable extent is immediately above the rapids at Mosinee. The meandering here is evidently due, like that above the Stevens Point rapids, to the hard crystalline rock forming the rapids at Mosinee, and the inability of the river to cut its channel through these rapids to grade with its channel above and below. However, in this favorable locality for lateral erosion and the development of meanders, the Wisconsin has not formed a wide erosion terrace, the record of erosion being a series of abandoned meanders and oxbow lakes. (See map, Plate II). The oldest abandoned meander is one of considerable size, the channel shifting resulting in the shortening of the river course two or three miles. The forming of the oxbow lake in section 20, nearly finished by the river, was artificially completed, in 1845, by lumbermen, in order to shorten the course and facilitate the rafting of logs and lumber.

Immediately south of Wausau, where the Big Rib flows into the Wisconsin from the west and the Eau Claire from the east, there are broad erosion terraces extending far up along these side streams as shown upon the map. There appears to be little meandering of the Wisconsin River itself in this vicinity, the principal development of erosion terraces in the valley being due to shifting of the side streams where joined to the Wisconsin.

Several abandoned courses of the Eau Claire are shown upon the map (Plate II). The oldest abandoned channel appears to have been joined to the present course of Cedar Creek. It seems very probable, from the extent of the erosion at the mouth of Cedar Creek, that the channel of the Eau Claire persisted in this course for some time. It was deflected from this old course by coming in contact with hard crystalline rock in the SW. ¼ of section 21. After abandoning this course, and before assuming its present one, it occupied a channel passing through the SW. ¼ of section 16, section 17 and section 18, joining the Wisconsin in the southwest corner of section 13, as indicated upon the map.

The Big Rib River has cut broad terraces of variable width for a distance of about 5 or 6 miles up its course. The development of meanders along the lower course of the Big Rib is especially noteworthy. Erosion by cutting sideways is a much more prominent feature in the lower courses of the Big Rib and Eau Claire rivers than of the Wisconsin River adjacent.

Side-cutting of streams and the development of meanders do not begin until the streams have graded their valeys. It is evident, therefore, that in this particular locality the Big Rib and the Eau Claire, for several miles, probably 8 miles of the Big Rib and 3 miles of the Eau Claire, have developed graded valleys in the old valley deposits, while the Wisconsin has not yet reached this stage. This difference in stage of development of tributary and trunk in the same locality is in part due to the difference in the volume of the tributaries, as compared with the volume of the trunk, the tributaries of smaller volume reaching grade earlier on steeper slopes than the main trunk of larger volume. The valley slope of these tributaries for a considerable distance up stream, however, is actually not so steep as that of the Wisconsin above their junction. This is due to the relative position of the tributaries and the main with respect to the slope of the region, for the slope of the area is downward to the south, and down this slope the Wisconsin flows, while the Big Rib and Eau Claire, where they have reached grade, flow east and west respectively, and obliquely across the slope. It is not unlikely that both causes, the smaller volume as well as the relative position of the streams with respect to the land slope, may have contributed in bringing the development of meanders to the tributaries earlier than to the trunk immediately adjacent.

Farther south the Big and the Little Eau Pleine rivers are likewise graded in their lower courses and are meandering in their flood plain terraces to a greater extent than the Wisconsin River immediately adjacent.

Between Wausau and Merril the valley of the Wisconsin is comparatively narrow and in the narrowest places the present flood plain of the river extends entirely across the valley floor to the rock walls on either side. In the broader portion of the valley, however, there are eroded bottoms of considerable width. At the mouth of the Trapp there is a well developed erosion terrace 20 to 30 feet below the upper surface of the filling.

At Merrill (see map Pl. II) there are well developed eroded terraces and also an interesting abandoned river channel of the Wisconsin River. In the abandoned channel the river had cut down through the drift deposit to hard rock beneath, the rock obstruction evidently causing the change in the course. It seems probable that the older course was abandoned at a period earlier than the construction of the lower erosion terrace upon which the principal part of Merrill is built.

*Profile of Black river.**

No.	Station.	Distance. From mouth.	Distance. Between points.	Elevation above sea level.	Descent Between Points. Total.	Descent Between Points. Per mile.
		Miles.	Miles.	Feet.	Feet.	Feet.
1	La Crosse (near)	....	....	628	....	....
2	Black River Falls, below dam	55	55	749	121	2.2
3	Black River Falls, above dam	55	0.0	763	14	......
4	R. R. bridge. C., St. P., M. & O.	58	3.0	766	3	1
5	Halls Creek, mouth of	61.6	3.6	776	10	2.8
6	Halcyon	67	5.4	793	17	3.1
7	Hatfield R. R. bridge	71.2	4.2	838	45	10.4
8	East Forks, mouth of	74.2	3.0	846	8	2.7
9	Dells Dam, below	77.5	3.3	874	28	8.5
10	Wedges Creek, mouth of	78.5	1.0	893	19	19
11	Cunningham Creek, mouth of	84.8	6.3	909	16	2.5
12	Center Sec. 22, T. 24, N., R. 2 W	86.8	2.0	929	20	10
13	O'Neill Creek, Neillsville	90.8	4.0	989	60	15
14	Bridge, Sec. 9 and 16, T. 25 N., R. 2 W	98.8	8.0	1,034	45	5.6
15	Bridge, Sec. 21 and 28, T. 27 N., R. 2 W	103.5	4.7	1,070	36	7.9
16	Bridge, Fairchild & N. E. Ry	107.8	4.3	1,094	24	5.6
17	Site New Greenwood Dam	109.3	1.5	1,105	11	7.3
18	Between Sec. 27 and 22, T. 27 N., R. 2 W	110.3	1.0	1,107	2	2.0
19	Hemlock Dam, 600 feet below	113.5	3.2	1,132	25	8.0
20	Hemlock Dam, above	113.6	0.1	1,151	19	....
21	Bridge, Sec. 20 and 29, T. 29 N., R. 2 W	119.6	6.0	1,167	16	2.7
22	Bridge, Wis. Cen. Ry. West of Withee	125.1	5.5	1,187	20	3.6
23	Bridge, Wis. Cent. Ry. Duluth Branch	131.7	6.6	1,198	11	1.7

*L. S. Smith, Preliminary Report on Water Powers of Wisconsin. W. S. Bull, 156 U. S. Geol. Survey, 1906.

Authority. No. 1 (low-water elevation) Mississippi River Commission. 2 to 23 Joint Survey of Wis. Geol. and Nat. Hist. Survey and United States Geological Survey.

Well developed erosion terraces occur in the alluvial formations bordering the Black River in the southern part of Clark County. The profile of the Black River from its junction with the Mississippi to the Wisconsin Central railroad near Withee is shown in the table. As previously described, the alluvial filling of the Black River valley extends as far up stream as Sec. 6 T. 23, R. 2 W., about 8 miles below Neillsville.

The Black River throughout this area and as far south as Black River Falls flows intermittently over crystalline rock and sandstone with a very steep gradient from Withee to Black River Falls, as shown by the profile of the river. The steep gradient continues farther north with approximately the same slope. At Neillsville the course is in the old glacial deposits, but beginning 6 miles south it flows through the alluvial plain which rapidly widens out to the south. Within the glacial drift, as well as within the alluvial plain, it is a downward cutting stream, as would be expected with such a steep gradient. Where the river enters the alluvial plain below Neillsville, crystallline rapids are on the level of the alluvial plain, but as the river flows southward, its valley, eroded down to the buried crystalline peneplain, becomes entrenched deeper and deeper into the alluvial deposits. At Black River Falls, the southern-most point at which the crystalline peneplain has been uncovered of its alluvium, the valley is narrow and deep, the river below the rapids being approximately 90 feet below the level of the alluvial plain.

OCCURRENCE OF SAND DUNES ALONG THE WISCONSIN RIVER.

Sand dunes which consist of mounds and ridges of sand formed by the action of the wind, occur along the east side of the Wisconsin River about 5 miles north of Stevens Point. The dunes form a narrow belt extending through the eastern part of section 11, southeast part of section 2, and northwest part of section 1 of T. 24, R. 7 E. The dunes are generally from 10 to 20 feet high but some of them may reach 30 or 40 feet above the upper terrace of the alluvium upon which most of them are located. Depressions and undrained basins are associated with the dunes producing topographic features resembling recent glacial moraines.

In the southeastern part of Section 11 is a small pond surrounded by marshy land formed by the construction of a sand dune across a small valley. The pond is now artificially drained through an opening cut through the dune. Some of the dunes are located upon the crystalline rock bordering the alluvial plain and the basins between the dunes are often covered with stone from the crystalline formation. In places the farmers have picked up the loose stone and thrown them along the fences upon the sides and summits of the dunes, giving the dunes superficial features indicating an origin other than by the action of the wind. Some of the dunes are relatively old, though upon some the shifting movement of the sand is a feature of present day occurrence.

The occurrence of sand dunes elsewhere along the Wisconsin River bottoms was not observed, though they are likely to be present. They probably occur only on the east side of the river for they universally owe their origin to the prevalence of strong winds from the southwest.

Over the broad sandy alluvial plain of the southern part of the area there occur a few shallow sags and low mounds of sand that may have been formed by the work of the winds. The mounds of sand however may in part be due to the disintegration of Potsdam sandstone mounds.

AGE OF THE ALLUVIAL DEPOSITS AND TERRACES.

It will not be attempted at this time, to express any final conclusion concerning the age of the extensive alluvial deposits of this area. In a forthcoming report on the Pleistocene geology of the northwestern part of the state, a part of the state in which the alluvial deposits are relatively a more important surface formation than they are in this area and where their relations to associated formations are more clearly shown, a more detailed account of the geology of these formations will be given.

Since rivers and streams are continually at work during the entire period of their existence it is possible that the age of the alluvial deposits may vary greatly in different valleys or in different parts of the same valley. Some parts of this area, and of the entire state, have been exposed to the conditions of subearial degradation, not only throughout the entire period of the Pleistocene, but also for a long time before. But the conditions most favorable for the depositions of the alluvial formations and the extensive filling of the valleys of the area apparently did not prevail throughout the entire period of subaerial degradation, but only throughout a certain part of this period.

Briefly stated the geology of the filled valleys indicate the existence of three periods in their development: first, a period when the land stood higher than at present and the rivers with relately high velocity flowed over the bed rock in the valley bottoms; second, a following period when the land was lowered and the stream gradient decreased producing the condition of stagnant rivers, and thereby causing the valleys to be filled with alluvial sediment; and third, a period in which the stagnant rivers were revived by elevation of the land, followed by the consequent erosion of terraces in the filled valley deposits.

These periods were probably not characterized by simple uniform movements, but each was probably complicated and the three were very probably of unequal duration. The change in the elevation and slope of the land was probably not great, nor was the rate of movement uniform. It may be said that the total result of the geological work of the rivers during the first period referred to was that of erosion and the development of deep valleys, during the second period that of alluvial deposition and filling of the deep valleys, and during the third, that of the erosion of the filled valleys.

With respect to the probable age of the period of alluvial deposition it is the belief of the writer that it occurred in the interval between the deposition of the Second drift of the area and that of the Third. This interval is a long one as indicated by the great amount of erosion and weathering developed in the First and Second drift sheets previous to the deposition of the Third drift. It seems most likely that the preceeding period of extensive erosion of valleys in the First and Second drift, as well as the succeeding period of erosion of the valleys filled with the alluvium, was also largely, and perhaps wholly, within this long interval.

This belief as already stated, is not presented as a final conclusion, though it is based upon considerable evidence concerning the age of the erosion terraces as indicated by their extent of weathering, as well as the relation indicated by the stratigraphic position of the alluvial deposits and erosion terraces to the several drift formations, not only within this area, but also within other parts of the state.

It may be stated perhaps that the view here expressed concerning the probable age of the valley alluvium is thoroughly in harmony with the extent and distribution of these deposits and their origin as already described.

CHAPTER XI.

THE DRIFTLESS AREA.

A glance at the map of the surface formations of the district shows an area of considerable extent in the central part of Marathon and adjoining parts of Portage and Wood counties, mapped as non-glaciated or driftless. This driftless area is bounded on the east by the Wisconsin and Second drift formations, on the north by the Third drift and on the west by the First drift, while on the south it is covered with alluvial deposits and is evidently continuous with the large driftless area of the southwestern part of the state. In previous accounts of the Pleistocene formation of Wisconsin in the reports of the State Survey,[1] and of the United States Geological Survey [2] this particular area has been mapped, with adjoining parts of the district, as drift-covered.

It may be observed, on comparing these earlier maps of the drift formations with one another, and with the present map, that the tendency has been to considerable change the extent of the driftless area as the Pleistocene formations are studied in greater retail. In the earlier map referred to of the Quarternary formations of Wisconsin, the drift-covered area is mapped as extending over the whole of Dunn, Pepin, and Buffalo counties. Later, when a closer study of this portion of the state was made, it was shown that the large driftless area of

[1] T. C. Chamberlin: General Map of Quarternary Formations of Wisconsin; Atlas, Plate II, 1881.

[2] T. C. Chamberlin & R. D. Salisbury: Quarternary Map of the Driftless Area and Environs; U. S. Geol. Survey, Sixth Ann. Rept., Plate 27, 1885.

the state extended much farther north than had previously been supposed, and that a large part of southeastern Dunn, Pepin, and northern Buffalo counties was driftless. The northward extension of the driftless area in the western part of the state bears the same relation to the west side of the central lobe of old drift in Clark and Wood counties as the northward extension here described, in Portage and Marathon counties, to the east side of this central lobe. Both northward extensions of the driftless area, therefore, bear the same relation in position to the old drift sheets, and evidently owe their occurrence to the same influences governing the movement of the Pleistocene ice sheets. The probable origin of the driftless area will be briefly referred to after the driftless portion of the district is described.

The extent of the driftless area of this district is about 1500 square miles, nearly half of which is covered by valley deposits which are believed to be mainly of purely alluvial origin. The alluvial deposits form the surface formation in southern Wood and southwestern Portage counties, and in a belt of considerable, but variable width, farther north along the Wisconsin River. It is only upon the upland areas of the district, therefore, above the valley bottoms and valley plains, that the features of erosion and the residuary products characteristic of the driftless area are discerned.

CHARACTER OF THE DRIFTLESS AREA.

The absence of glacial deposits, which form so characteristic a feature of glaciated districts, is of course the principal phenomena for the recognition of a driftless area. The residual character of the soil, the development of which is hardly consonant with a glaciated district, is an equally prominent feature of the driftless area. These two features, therefore,—the absence of glacial drift, and the presence of a mantle of residuary products,—constitute the principal evidence of the non-glaciated character of the area.

The Absence of Drift.

The occurrence of glacial till, consisting of coarse boulders in a matrix of clay, or clay and sand, possessing the characteristic heterogeneity of a glacial formation, was not observed within the area mapped as driftless. There is, however, to be observed within this area, pebbles and gravel, sometimes occurring in thin deposits of stratified sand and clay, but more often merely as scattered pebbles in the soil, which suggests at first sight the possibility that the area is covered with a very thin coating of glacial drift. This gravel will be fully described later. It is sufficient to state at this time that this gravel and the associated deposits occurring upon the uplands do not possess the characteristic features of a formation deposited by ice, such as coarse boulders, or unstratified deposits of boulders and clay, but possess, on the other hand, the characteristics of material deposited in water. Some of the larger pebbles reach 6 or 8 inches in diameter, but most of them are less than 4 inches in diameter. Aside from the occurrence of the gravel and finer material scattered over the area, no foreign material was observed in the driftless area.

A tongue of the Third glacial drift is shown upon the map, northwest of Wausau, extending some distance beyond the general border of the Third drift, but this minor drift lobe can be traced back, as already stated, to the main drift sheet farther north. It is not unlikely however, that much smaller extensions of the drift project out beyond the main sheet in the unsettled parts of the district, which escaped observation. Aside from the possible occurrence of minor undulations along the border of the drift, as mapped, and the occurrence of glacial boulders carried out beyond the drift border by subsequent erosion, it is believed that no glacial drift occurs in the area mapped as driftless.

Perhaps the most convincing evidence of the non-glaciated character of this driftless area is furnished by a comparative study of the prominent rocky quartzite hills, such as Powers Bluff, within the oldest drift formation, and Rib Hill and the Mosinee Hills in the driftless area.

The well developed boulder train extending southwest of Powers Bluff, consisting of boulders of the hard, resistant, fine-grained quartzite of which this bluff is composed, has already been described (page 444). This boulder train is characterized by a large quantity of angular, sub-angular, and rounded quartzite boulders of various demensions up to several tons weight strewn over the land to the southeast of the bluff, in the direction of the ice movement. The development of this train illustrates in a noteworthy manner the peculiar, and, at the same time, powerful, erosion effects wrought by an ice sheet.

In striking contrast, on the other hand, is the entire absence of trains of quartzite boulders leading out from the rocky quartzite hills, such as Rib Hill, the Mosinee Hills, and Hardwood Hill, in the adjacent driftless area. Indeed, there was nowhere observed in any direction beyond the base of these hills even the sporadic occurrence of quartzite boulders, although the character of the rock of these hills is such as to readily produce talus slopes of angular quartzite blocks, which could readily have furnished abundant material for the development of boulder trains. The absence of quartzite boulders strewn about these prominent hills furnishes the strongest kind of evidence of the non-glaciated character of the vicinity, for it would seem inevitable that if an ice sheet, even of a very weak or non-vigorous character, passed over this locality, evidence of it would be abundantly shown in the distribution of glacial boulders about these prominent quartzite hills.

The absence of a commingling of the rock fragments of one crystalline formation with those of adjacent formations is also a noteworthy feature of the driftless area. The surface rocks of the driftless area in Marathon and adjacent counties consist of the crystalline formation of various igneous rocks and of metamorphic sedimentaries. In many places the weathering and disintegration of these formations have developed upon the surface great quantities of small and large angular fragments. These loose fragments in the driftless area, however, are not scattered indiscriminately over the land, but are confined to their respective formational areas. These abundant fragments are universally angular and quite unlike glacial boulders. The metamorphic sedimentaries and schistose igneous rocks usually weather out into abundant angular fragments, along cleavage planes, and it is the rock of these formations that furnishes the most abundant surface stone. The lack of the commingling of the angular fragments of adjacent formations, to be observed in the fields of the cultivated uplands, combined with data furnished by the rock exposures along the wagon roads and in farmers' wells, enabled the writer to map the various crystalline formations in the driftless area with a fair degree of accuracy. Such favorable conditions for the delineation of the boundaries of the crystalline formations, however, do not prevail over the drift-covered portions of the district, and could not have prevailed in the driftless area if it had been over-ridden by an ice sheet.

The Residuary Products.

A prominent feature of the driftless area is the mantle of residual rock products which constitutes the prevailing surface formations within its border. This mantle usually consists of clay mixed with angular fragments of the underlying rock of

FIG. 34. Section in a driftless area showing relation of residual soil to the solid rock beneath. Compare with figures 15 and 16.

various sizes. The gradation downward of the finer-grained portion of the mantle into coarser phases, with a larger proportion of rock fragments, and finally into the partially disintegrated rock, and then the solid rock beneath, is shown abundantly in the shallow ditches along the country roads of the driftless area. The character and relation of the residuary mantle conclusively shows its origin through processes of surface weathering of the underlying rocks. (See Plate LXII and Fig. 34.)

The mantle of residuary products produces an excellent loam soil over most parts of the non-glaciated area, and has been described and mapped in the soil report as the Marathon loam.[1]

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[1] Bulletin No. 13, Wisconsin Survey, pp. 39–43. Map, Plate I.

Fig. 1. CHARACTERISTIC WEATHERING OF FINE CRYSTALLINE ROCK.

Fig. 2. CHARACTERISTIC WEATHERING OF COARSE GRANITE.

Over that part of the area, however, underlain by coarse-grained granite and syenite, a coarse gravelly soil has been developed, described as the Mosinee gravelly soil.[1] The photographic views, Figs. 1 and 2, Plate LXII, illustrate the characteristic features of these types of residual soils. The character of the overlying residuary soils depends very largely upon the grain of the underlying rock rather than the mineral composition, the fine-grained rocks developing a fine-grained, fertile soil, containing much clay, while the coarse-grained rocks produce a mantle of coarse soil, containing but little clay.

The thicknes of the residuary mantle of decomposed and partly disintegrated rock in the driftless area varies considerably, but is generally from 2 to 3 feet in thickness upon the fine-grained formation, and much thicker than this, though much coarser, upon the coarse-grained rocks. Upon the fine-grained rock formation the clay loam portion generally has a thickness of 4 to 8 inches, grading rapidly downward through clay mixed with abundant angular fragments to much-fractured disintegrated rock at a depth of 3 or 4 feet. The coarse-grained rocks, on the other hand, have but a thin covering of clayey loam, probably in general only 1 or 2 inches in thickness, grading down to a loose mass of angular fragments of quartz and fieldspar about one-half inch in diameter, having a thickness often reaching 10 or 15 feet, and sometimes even 20 feet. The rain readily sinks deeply into the coarse residuary mantle, but is retained near the surface in the fine-grained type, thereby causing in the latter still greater rock decomposition near the surface and furnishing other more favorable conditions of soil fertility.

The abundant angular stone in the soil of the driftless area has already been remarked, the angular fragments being most abundant in the areas of fine-grained crystallines having cleavage and jointing structure highly developed.Through weathering processes. mainly by freezing of water in the minute rock crevices, and by the penetrating growth of roots, a large amount of loose, angular stone is formed which lies sprinkled thickly throughout the residuary mantle of the respective formational areas. Where favorable condition for the de-

[1] Op. Cit. p. 43–44.

velopment of such angular stone occur, farmers, in cultivating the soil, have gathered the fragments into great heaps, which dot the fields, and, in many instances, have used them in the construction of stone fences. The quantity of surface stone suggests the presence of glacial debris, but the character of the material, the angularity of shape, and uniformity of rock composition is wholly unlike the rounded, heterogeneous boulders of glacial deposits. The only foreign stone to be observed mingled with the angular blocks are the scattered pebbles and gravel which lie over portions of the driftless area. These pebbles, as later described, are believed to be mainly derived from the disintegration of Potsdam conglomerate which once extended over the crystalline peneplain, and thus are probably of residual origin.

The greatest thickness of the purely residual products is upon the flat-topped upland areas of the crystalline formations. Along the valley slopes it has a tendency to removal by erosion. In the valley bottoms there is quite generally abundant filling by wash from the uplands, under present conditions, and also, even to much greater extent, by filling, probably due to widespread alluvial deposition during an earlier period.

Erosion Features of the Driftless Area.

The reliefs of the driftless area, with the exception of the filled valley bottoms, have the characteristic forms developed under conditions of rain and stream erosion. As the topography developed in the area of the older drift formations of the district is likewise principally due to the erosion of rain and streams of the very old drift sheets, there is to be observed no striking difference in the topography of these adjacent areas There is a difference in relief due to the differences in character of surface formations, but, on the whole, it is of minor consequence, because in a notable manner the erosion of the old drift, superimposed upon the pre-glacial topography, has produced broad slopes with gently sweeping contours quite similar to those carved out of the resistant crystalline rocks of the pre-Cambrian formations. There is, on the other hand, a marked difference in the sub-aerial erosion features of the driftless area and those of the two latest drift formations both of which are usually characterized by the glacial forms of topography.

The similarity in surface reliefs of the old drift sheets to that of the driftless area of this district and its marked dissimilarity to that covered by the drift of the Wisconsin epoch has already been referred to. It is very probable that this similarity in topography of the area of the old drifts and of the driftless led to the error of considering this driftless area as drift-covered in former reports upon the geology of this part of the state.

The peculiar surface relief of the thick residuary mantle developed from the coarse-grained granite and syenite in the town of Mosinee, and adjacent area, constitutes features of erosion thoroughly in harmony with all other evidences of the non-glaciated character of the area described as driftless. The relief developed upon this covering of residuary material, which in many places in this locality reaches from 10 to 20 feet in thickness, consists of a peculiar hummocky topography, at first sight suggesting the abrupt topography of characteristic terminal moraine. The abrupt relief developed upon the coarse-grained rocks is in striking contrast with the surrounding area of gently sweeping broad contours developed upon the fine-grained rocks. The hummocky topography of this coarse residuary mantle, however, unlike terminal moraine, is thoroughly drained. The hummocks have a height usually varying between 15 and 30 feet, the height very probably depending upon the thickness of the residual mantle, into which the small drainage lines forming an intricate network have eroded their narrow valleys. The topography much resembles that to be observed in places in the deeply weathered, coarse crystallines in the non-glaciated portions of the Southern Appalachains, and the necessary conditions for its development in this locality could hardly have prevailed over so considerable an area, or have been so characteristic a feature of the coarse-grained rocks, if the area had been subjected to glaciation.

THE PEBBLE AND ASSOCIATED DEPOSITS OF THE DRIFTLESS AREA.

Over the non-glacial portion of this district there is present a sporadic occurrence of scattered pebbles, sometimes mixed with stratified clay and sand, but much more often as isolated pebbles imbedded in the upper portion of the residuary mantle. While the prevailing soil of the area may be classed as mainly residual, yet no portion of the area of any extent can be passed over without observing more or less transported water-worn material, such as pebbles and gravel, either lying in place in the soil or scattered along the roadside, where it has been thrown by farmers from the adjacent cultivated fields.

Character and Distribution of the Pebble Deposits.

The pebbles rarely reach a diameter of 7 or 8 inches. Much of the gravel is 4 to 6 inches in diameter, but by far the greater portion of it is much less than 4 inches in diameter. In a few places upon the upper slopes and upon the summits of the broad uplands, the gravel has a thickness of 5 to 15 feet, but in such deposits the gravel occurs mainly or only at the base, and the overlying material is stratified sand and clay. The gravel deposit upon the uplands, in the few places where it shows an appreciable thickness, is quite unlike that to be found in the valley bottoms of the district. In comparison, that upon the uplands consists of a much larger proportion of clay, the stratification is less pronounced, and the deposits show much more decomposition than the sandy gravel formation filling the valley bottoms. The deposits upon the uplands are a clay loam, while those in the bottoms are very sandy loams or sandy soils. The predominance of the gravelly portion, mainly at the base of the deposits, whereas coarse gravel occurs at all horizons in the valley deposits, also appears to be a characteristic difference of the two formations.

A good illustration of the character of the pebbles is shown in the upland district in the vicinity of Wausau. In examining the soil and rock east of Wausau along the road and adjoining fields, through the central portion of Section 32 and 33, T.

29, R. 8 E., nothing but scattered pebbles, varying from one inch to two or three inches in diamerter, were noted. Along the road on the eastern side of Section 28, T. 29 R. 8 E., no large boulders of foreign origin were seen, although scattered pebbles occur in considerable abundance. In the vicinity of the east quarter post of Section 29. T. 29, R. 8 E., there is much gravel, and in the well of J. Riedelfauch, in the NW. ¼ of Sec. 29, there is reported 12 feet of clay with 2 feet of gravel at the bottom. An abundance of water is furnished by this well, and hence the gravel bed is probably quite extensive. The cultivated fields in this vicinity showed the presence of considerable gravel, but no large boulders.

Farther east in this part of the county, between the Wisconsin River on the west and the border of the drift formations on the east, there are abundant scattered pebbles mingled with the soil. The soil is quite generally a comparatively stony soi, mainly of residual origin, the stone being angular and like that of the solid rock formation beneath. Mingled with the angular stone is an abundance of rich clay loam, partly of residual origin and partly of transported material. In the cultivated fields, as already described, there are great heaps of stone picked out of the soil, the prevailing angularity of the stone being in striking contrast with the rounded, polished boulders of the stone piles in adjacent areas where glacial debris constitutes the soil formation. Upon many farms also there are well constructed stone fences made almost entirely of angular rock, from the formations abundantly exposed along the roadside and outcropping in the adjacent fields.

West of the Wisconsin River the character of this gravel is in all respects like that east of the river. In the SW. ¼ of the SW. ¼ of Section 23. T. 29, R. 6 E., there is exposed along the road, and also in a basement of a large barn, a thickness of 3 or 4 feet of transported material consisting of fine gravel scattered through a sandy loam. Over the upland area, upon the tops of the even-summitted hills and along their slopes the stony material is mainly angular, and of local residual origin, with here and there a well-rounded and polished large pebble, up to 6 or 8 inches in diameter, and abundant scattered small pebbles. The ditches along the road continually expose the prevailing crystalline rocks, such as granite, greenstone, and rhyolite.

About the lower slopes of the quartzite mounds of Rib Hill and Hardwood Ridge there occur numerous pebbles scattered up the slopes to an elevation approximating the 1400 to 1460 foot contour lines. Above this elevation, which is about that of the general elevation of the even-summitted uplands in the vicinity, no pebbles or small boulders were noted, although they may occur.

Along the roads west of Hardwood Hill and south of Marathon City, pebbles and small boulders appear to be quite numerous. Sometimes for quite a distance none were found, and then again they could be seen imbedded in the disintegrated crystalline rock in the ditches of the road, but nowhere were they too numerous to be easily counted. The largest pebbles were generally not more than 4 or 5 inches in diameter.

The northwestern part of Portage County lies within the driftless area, and this portion of the county, being underlain by the crystalline formations, the gravel formation is in all respects like that prevailing in the driftless area of Marathon County. In the southern part of Portage and Wood counties the hard rock formation is mainly sandstone, and upon the surface of the mounds of this formation no pebbles and gravel were to be observed. In the low areas between the mounds of sandstone, occupied by the old peneplain surface, there is more or less clay, which may in part be due to wash from the uplands, or to the residual weathering of the crystalline peneplain.

In the southern part of Portage County, in the SE. ¼ of Sec. 23, T. 21, R. 8 E., is located Mosquito Mound, which reaches an elevation of about 200 feet above the surrounding alluvial plain. The summit of the mound consists of very hard sandstone, which is quarried for building purposes. Upon the summit is a thin covering of surface material, reaching in places 3 feet in thickness, while on the sides of the mound there is considerable gravel. The surface material consists of small crystalline rock pebbles, most of them being less than 5 or 6 inches in diameter, mingled with angular and polished subangular blocks of sandstone, reaching over a foot in diameter, the whole mixed with much sand. At the base of the mound is a large, fine-grained granite boulder, 5 or 6 feet in diameter, in the road in front of the farm-house just east of the mound, and a large, coarse granite boulder was noted in the field immediately south of the farm house. Granite boulders like these, however, were observed in considerable abundance in the ridge of old terminal moraine of the Second drift formation, about a mile east of Mosquito Mound.

The pinnacle of sand rock, about a mile south of Bancroft, near the center of Sec. 14, T. 21, R. 8 E., likewise shows the presence of numerous crystalline pebbles near its upper slope about 70 feet above the alluvial plain. This latter sandstone peak is about 2 miles west of the terminal moraine of the Second drift.

A deposit of clay of unusual character in this district occurs near Milladore, mention of which perhaps should be made in connection with the surface deposits in the driftless area. The deposit occurs on the property of Mr. Wells, in the NE. ¼ of Sec. 23, T. 25, R. 5 E., near the border of the driftless area. The deposit is covered by from 4 to 6 feet of surface clay, beneath which is calcareous clay, in places extending to depths of at least 33 feet. The partial chemical analysis made by A. S. Mitchell is as follows.

SiO_2	52.60
Al_2O_3	12.60
Fe_2O_3	3.82
CaO	12.77
MgO	3.22
Loss on ignition	12.49
	97.50

The calcium carbonate occurs in lumps as well as finely disseminated particles throughout the body of the clay. No other calcareous clays were found in the vicinity, though especially searched for. The upper 4 to 6 feet of surface clay probably represents the ordinary clay of the deposit leached of its lime centent.

The probable origin of this calcareous clay is unknown. It lies so near the drift border that it may have been developed by glacial agency.

In southwestern Clark County is the border of the oldest drift sheet and outside of this border lies the driftless area extending over a large part of southwestern Wisconsin. About 3 miles west of Merrillan, in Jackson County, along the Green Bay and Western Railroad, several deposits, mainly made up of chert and crystalline pebbles, were noted. The chert of these deposits is derived from the Paleozoic limestones, and chert deposits of this character are abundant in the driftless region of the state farther southwest.

Origin and Age of the Pebble Deposits.

The pebbles scattered over the uplands of the driftless area, and the stratified deposits with which they sometimes occur, as previously stated, do not possess the characteristic features of glacial deposits. Their area of distribution is identical with the driftless portion of the district, the non-glaciated character of which, as already described, is believed to be fully demonstrated by the widespread occurrence of residuary clays, and the entire absence of distinctive evidence of glacial erosion or glacial deposition.

The scattered pebbles occurring upon the summits of the crystalline uplands in Marathon County and adjacent parts of Portage and Wood counties are wholly of crystalline rock, so far as observed, and their character and their occurrence upon the uplands strongly suggests their origin, as remnants of the Potsdam conglomerate which once extended over the area. The even summited uplands as already described (page 392), represent the old peneplain surface of the pre-Cambrian rocks formed by erosion in pre-Potsdam time and upon this peneplain, as shown in the southern part of the area, where the plain is still preserved, was deposited a variable thickness of gravel in the form of the Potsdam conglomerate. The occurrence of conglomerate at the base of the Potsdam sandstone upon the crystalline rocks is a common feature though this conglomerate is not usually thick.

Through the process of erosion to which the region has been subjected the sandstone has been wholly removed from the northern parts of the area, and only in the southern part is there an abundance of the sandstone remaining upon the crystalline peneplain. The isolated pebbles therefore occurring upon the crystalline uplands in the northern part of the driftless area are not now directly associated with sandstone or with conglomerate yet they occur upon remnants of the peneplain surface of the old land upon which the Potsdam formation was but recently removed by erosion. It seems reasonable to believe, therefore, that so long as parts of the old peneplain surface remain the resistent pebbles of the once overlying formation may be found upon them.

Direct evidence of the origin of the isolated pebbles upon the crystalline uplands, in the manner indicated, is well illustrated in the vicinity of Casimir five miles north of Stevens Point. In this locality, namely in the northwest one-fourth of section 12 T. 24 R 8 E. and adjacent vicinity, is an abundance of polished rounded and sub-angular pebbles and small boulders, strewn over the surface and gathered in heaps along the road.

At first sight the large quantity of polished pebbles and boulders strongly suggests the occurrence of a glacial deposit. A closer examination however reveals the fact that the pebbles and small boulders are largely of quartz rock, both vein quartz and quartzite, with but few pebbles of other crystalline rocks, and that these occur in a number of places still enclosed in a cemented sand matrix in the form of angular and partly disintegrated blocks of Potsdam conglomerate. Along the road in the same locality may be observed the usual deposits of residual clay derived by weathering of the crystalline rock lying between the disintegrated Potsdam conglomerate above and the granite formation below.

This locality of disintegrated conglomerate at Casimir so well illustrates the origin and source of the pebbles over the crystalline rocks of this particular part of the driftless area that it seems reasonable to conclude, that a large part, if not the whole of the pebbly formation upon the crystalline peneplain farther north, originated in the same manner. It may be urged however that the locality about Casimir and Stevens Point is well within the general area of the Potsdam sandstone, and quite unlike that farther north about Wausau where remnants of sandstone or conglomerate upon the uplands is not known to occur.

The amount of erosion of the crystalline rocks in the two parts of the driftless area however does not differ greatly. Immediately adjacent to the locality of the disintegrated conglomerate at Casimir is the valley of the Wisconsin River, probably filled to a depth of 150 to 200 feet, indicating conditions of extensive erosion of the crystalline rocks quite comparable to that existing in the area farther north. The conditions for the disintegration of the Potsdam conglomerate and the retention of its pebbly content upon the remnants of the peneplain would not differ greatly in the southern and northern parts of the driftless area.

The entire absence of the sandstone over the northern part of the driftless area, where residual pebbles still remain is very probably due to the unconsolidated character of the Potsdam formation and the comparative readiness with which the soft friable sandstone is removed by disintegration and erosion.

If therefore the pebbles and gravel occurring upon the crystalline uplands is derived from the disintegration of the Potsdam conglomerate formerly extending over this area, most, if not all the pebbles and gravelly deposits occurring along the slopes of the valleys and hills may be readily understood as having originated by the wash of rains and streams from the uplands above.

Only the gravel upon the crystalline rock areas are probably the residuary pebbles of the Potsdam conglomerate. There is present upon the high sandstone mounds in southern Portage County some crystalline gravel whose position far above the horizon of the Potsdam conglomerate requires some other explanation of origin. Since these mounds, namely, Mosquito Mound and those in the immediate vicinity, are near the border of the known deposits of the Second drift formation, it may be possible that the gravel upon the sandstone in this locality may have originated in some manner by glacial agency, either as outwash or by ice transportation.

It is also possible that some of the pebbles occurring upon the uplands in the crystalline area may have an origin similar to that of well known high-level gravels so widely distributed in the Mississippi Basin south of the limits reached by the Pleistocene ice sheets. Such gravels are known to occur at various points in southern Illinois, in Indiana, Missouri, Arkansas, Kentucky, Tennessee, and farther south. Similar gravels are widespread in the western states.

Similar gravel[1] has been found at various points as far north as Adams County, Illinois, where it was found to underlie the glacial drift. More recently Prof. Salisbury[2] has described the occurrence of gravels on the Baraboo bluffs near Devils Lake, and has suggested the correlation of this gravel with other gravelly deposits in Wisconsin and farther south. It has long been known that gravel occurred at various points in Wisconsin from Crawford County, on the south, to Dunn County, on the north. These gravels generally consisted of nothing more than scattered pebbles, though beds a few feet in thickness have been found in the village of Seneca, in Crawford County.[3]

While it seems likely that most, if not all, the gravel over the crystalline rocks in the driftless area is derived from the disintegration of the Potsdam conglomerate and is of residual origin, it is possible that some of it may have originated in the same manner as the gravel occurring upon the Paleozoic uplands in the main driftless area farther southwest, and in other localities, though the origin and source of these high-level gravels is not understood.

The chert and crystalline pebble deposits in the vicinity of Merrillan in eastern Clark County occur along the streams and are not unlikely derived by subaerial wash from higher levels during the period of the general filling of the valleys with alluvium.

The source of the gravel in the valley bottoms may be easily accounted for as the work of streams and rains under present conditions of erosion. That occurring upon the uplands of the driftless area, however, dates back to a much earlier origin as already indicated.

ORIGIN OF THE DRIFTLESS AREA.

The driftless portion of this district in Marathon County and adjacent portions of Portage and Wood is obviously connected in origin with the large, driftless area of the southwestern part of the state, as it is but a contiguous portion of this larger area. The same causes, therefore, which operated to form the driftless

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1 R. D. Salisbury, Bull. of Geol. Society of Am., Vol. III, p. 183, 1892.
2 Pre-glacial Gravels of the Quartzite Range of Baraboo Bluffs; Journal of Geology, Vol. III, pp. 655–667.
3 M. Strong: Geol. of Wis., Vol. IV, p. 88.

region as a whole obviously governed in the development of all its details. The location of a large, non-glaciated tract in the midst of a region covered not merely by one, but by several successive ice sheets, is a striking phenomena, and various suggestions have been made to explain the seemingly anamolous occurrence. The very fact, however, that the adjacent regions were repeatedly glaciated, and the driftless area repeatedly avoided, demonstrates that the cause was a constant one, operating throughout each of the glacial incursions.

The region of the driftless is not a conspicuous elevation, but rather the opposite. In topographic features and attitude it is essentially like the surrounding region. The cause of its driftlessness, therefore, does not appear to be due primarily to the area itself, but to causes and influences operating outside of the district. The most plausible explanation, as suggested by Winchell,[1] Irving,[2] and Chamberlin,[3] lies in the topographic features of the land farther north, which tended to divert the glacial currents from the driftless area.

The topographic features believed to have been mainly instrumental in influencing the glacial movements in the adjacent region are the highlands of the northern part of Wisconsin and upper Michigan, in combination with the adjacent capacious valleys of Lake Superior, leading to the west, and of Lake Michigan, leading to the south. When the ice sheets of the several successive epochs, moving in a southward course from Canadian territory, reached these lake valleys, they were led off to the southwest through Lake Superior and to the south through Lake Michigan, the highlands between acting as a wedge tending to assist in diverting the ice to either side. The highlands, offering greater resistance to the ice movement, prevented the advancement to the south of those sheets which succeeded in surmounting it, while the ice lobes diverted into the adjacent lake

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[1]N. H. Winchell: Geol. & Nat. Hist. Surv. Minn., 5th Ann. Rept., p. 36, 1877.

[2]R D. Irving: Geol. of Wis., Vol. II, pp. 632–634, 1877.

[3]T. C. Chamberlin: Wis. Geol. Survey, Ann. Rept. 1878, p. 21-32. Geol. of Wis., Vol. I., p. 269, 1881. T. C. Chamberlin & R. D. Salisbury, U. S. Geol. Survey, 6th Ann. Rept., pp. 312–322, 1885.

valleys tended to advance for to the south into Illinois, Iowa and Missouri.

The main driftless area of the upper Mississippi Valley lies immediately south, in the lee of the highlands, and therefore beyond the limits of the ice which surmounted it, and to the north of the point of union of the glacial lobes deploying farther southward through the depressions of Lake Superior and Lake Michigan. The absence of glaciation in the driftless area, therefore, is believed to be due to its position relative to the highlands and depressions situated to the northeast.

The non-glaciated area of Marathon County and adjacent territory extends to the north from the main driftless region, similar to the northward extension of the driftless into Eau Claire, Pepin and Dunn counties, farther west, the two extensions reaching north, nearly to the same latitude. The extension in Marathon County is to the east, while that of Dunn County is to the west, of the lobes of old drift in Clark, Wood, and western Marathon counties. The relative position therefore of the two minor extensions of the driftless area to the north is the same with respect to the early ice invasions.

The altitude and general features of topography of the driftless area in Marathon and adjacent counties is in all respects like that of the surrounding drift-covered regions. This driftless area in Marathon County, like the main area of the driftless of Wisconsin, therefore owes its origin, not to its altitude and other features of topography, but to its position with respect to the highlands and great valleys farther northeast, which diverted the glacial currents outside of its borders into the surrounding region.

RESUME OF PLEISTOCENE OR GLACIAL GEOLOGY.

The account of the Pleistocene formations of the area naturally falls into three parts one part relating to the glacial formations, one part relating to the alluvial formations, and one part relating to the character and features of the driftless portion of the area. The account of the geology is not in chronologic order, for the formations of the several parts overlap one another with respect to age and geologic succession. The division into the three parts is based upon origin, the geologic phenomena of the several parts being unlike in general character and origin.

The Glacial Formations.

There are four glacial formations in the area, each believed to have been developed by a distinct glacial invasion.

The drift of the two earliest invasions, the First and Second formations, forms a distinctly lobate area in the west central part of the area. This lobate area of the old drift may be conveniently referred to as the central Wisconsin lobe. The boundaries of each formation can be definitely determined over a large portion of this lobe of old drift wherever the region of the border of either formation is well settled and conditions for its study are favorable. These lobate areas of drift were obviously formed by two distinct ice sheets. A well defined border marks the limits of large portions of each formation. The borders of the two drift sheets are not parallel to one another, as is usual with retreatal moraines of the same drift formation, but they widely diverge in their course across the area.

The terminal moraines of the Second formation occur in eastern Portage County and also farther north in Marathon and Langlade counties. Its occurrence in the eastern part of this area along the border of the Green Bay lobe of Wisconsin drift indicates its origin here as the terminal moraine of an ice lobe of the second ice sheet which advanced into this area across the basin of Green Bay and Lake Michigan. This lobe may be referred to as the Lake Michigan lobe of the second ice sheet.

The average thickness of the First drift formation, as indicated by numerous wells, is probably between 5 and 10 feet, whereas the average thickness of the Second drift appears to be between 20 and 30 feet. The maximum thickness of the drift at the border of the First drift is 50 to 70 feet, while in many places, the terminal moraine of the Second sheet shows a thickness of 100 to 160 feet. Hence the Second drift formation is from two to three times as thick as the First formation. This result, based upon numerous well records, corresponds very well with the relative topographic appearance of the drift deposits.

The presence of buried soils between the First and Second drifts indicates that a period of mild climate prevailed over the region in the interval between the deposition of the two drift sheets and that the later ice sheet rode over the weathered deposits formed upon the earlier one.

The ice invasion producing the thinner drift, the First formation, advanced much farther south in the central lobe than the ice sheet which deposited the thick Marshfield moraine, which marks the terminus of the Second drift in the central lobe. On the other hand in the eastern part of the area the lake Michigan lobe of Second invasion advanced further than the First invasion. Whether either or both of these ice sheets had their inception in the glacial center west of Hudson Bay, the Kewatin, or the center to the east, the Labrodorian, can only be conjectured.

The location of the central lobe of First and Second drift, with respect to the topographic features and drainage of the region and the distribution of the later drift, seems to indicate that the later ice sheets pursued a course quite independent of the earlier ones in the northern part of the state. This of course applied only to this particular region, for if the distribution of the older and younger drifts of adjacent regions is compared, the advances of the various ice sheets appear to have been along broadly similar courses.

The First and Second ice sheets advancing towards the southeast moved diagonally across the southwestward sloping portion of this district. There seems little doubt that the pre-Cambrian area of northern Wisconsin has served as a water-shed for a very long period and that the general courses of the drainage of a large portion of the state has suffered little change throughout long geologic periods, probably long antedating the Pleistocene. These ice lobes, however, evidently did not advance through an immediately local valley into this area, but appear to have moved independently of both the dominant slope of the region and the minor valley features. It seems likely, therefore, that this part of the state has been tilted somewhat through crustal warping, since the earliest ice invasions.

The weatheing of the two drifts was studied, but no appreciable difference in amount of weathering could be determined.

Both drift sheets are deeply weathered and both are deeply trenched by sub-aerial erosion. Weathering has extended to a depth of 10 to 20 feet in both formations, and in both most of the streams have cut down to bed rock. The thickness of the First drift in the area of the sandstone is much less than it is in the crystalline area, the difference probably being due to greater erosion in the sandstone area.

The topographic effect of these drifts upon the area is marked. The Second drift posesses a ridge of terminal moraine constituting a fairly prominent feature of the landscape over considerable portions of the district. A thickened border also occurs along certain portions of the margin of the First drift, as well as within the area of the ground moraine of both drift sheets. These ice sheets added a mantle of rock debris 25 to 30 feet thick to the area as a whole through which the streams subsequently operating through a long period, have cut to the bed rock beneath, and by process of weathering and erosion have, superimposed upon the glacial formations the topographic forms of sub-aerial erosion.

The Third drift sheet is a much younger formation than either of the older drifts, as indicated by its glacial features of topography and its unweathered drift. The topography of this drift resembles that of the Wisconsin, but this formation was evidently formed during a period of glaciation antedating the Wisconsin stage.

The Third drift emerges from the Wisconsin drift in the northeastern part of Marathon county and extends over northern Marathon and Clark. It has a well defined terminal moraine in places, the general thickness of the terminal and ground moraine being somewhat comparable to that of the First formation. The terminal moraine of this drift sheet is roughly parallel to the terminal moraine of the Wisconsin formation, but is over-ridden by the latter in several places, the Green Bay lobe apparently advancing over it entirely. This drift formation is very much thinner than the Wisconsin sheet and evidently was formed during a much shorter or less vigorous period of glaciation than that of the Wisconsin epoch.

The Third drift formation had produced a considerable effect on the topography of its area. Its terminal moraine consists of drift hills from 20 to 50 feet high and within its area are lakes, ponds, drift ridges and other features of glacial topography.

The Wisconsin drift formation the latest in origin covers the eastern and northern parts of the district. This formation has a distinctly lobate character, and at its margin is a well developed terminal moraine of variable but considerable width. The drift of this formation in this district is largely terminal moraine, deposited at the terminus of the Green Bay lobe advancing towards the west, of the Langlade lobe advancing towards the southwest, of the Wisconsin Valley lobe advancing towards the south, and of the Chippewa Valley lobe advancing towards the southwest.

The terminal moraines of the various lobes of the Wisconsin ice sheet usually form the divides between streams. The terminal moraine of the Green Bay lobe forms the divide in this area between the Fox River drainage and the Wisconsin River drainage, that is, between the St. Lawrence and Mississippi systems. The Langlade terminal moraine also largely separates the drainage flowing to the Fox river and Green Bay from that flowing to the Wisconsin river. The Wisconsin Valley and the Chippewa Valley terminal moraines lie across their respective valleys, forming the divide between some of their side streams.

The Wisconsin formation is very probably the thickest formation of the area, although the Second formation may originally have approached very closely the magnitude of this formation.

The topographic effect of the Wisconsin drift sheet upon the area covered by it is very pronounced in this gently sloping region. The terminal moraine consists of drift hills and ridges mingled with depressions and undrained areas. The drift hills generally rise from 50 to 100 feet above the surrounding lower land, and in a few places, as in southeastern Price County, they stand much higher than this, probably reaching 250 feet in height.

The Correlation of the Drift and Alluvial Formations.

The correlation of the drift formations older than the Wisconsin formations, as already stated, cannot be determined at the present time. The position of the three older sheets, the

First, Second and Third, in the stratigraphy of the Pleistocene, cannot be definitely known until they have been traced into Minnesota and Iowa, and their positions there relative to the older drift sheets are discovered. It is hoped that when the report on the northwestern part of the state is completed the position of these drift formations will have been determined.

It may not be out of place, however, to state at the present time what seems to be the most probable position of these older formations in the drift series. The two older drift formations of the district, the First and Second, are clearly very much older than the two younger formations, the Third and Wisconsin. It is the opinion of Prof. Chamberlin that the extreme weathering and the advanced sub-aerial erosion of the Second drift at Marshfield is at lesat equal to that of the oldest well developed drift sheets in Iowa and Kansas, the Kansan formation. The thickness of the Second drift also is about equal to that of the Kansan formation. Hence it is suggested that the Second formation may be the equivalent of the Kansan formation in Iowa. The First drift may be the Sub-Aftonion, or the pre-Kansan with which it is closely comparable in general thickness and extent of weathering and erosion. It is possible, however, that the Second drift may be of the pre-Kansan age, and the First of still earlier date.

The Third drift has some of the characteristic features of the Early Wisconsin stage, as developed in southern Wisconsin and in Illinois, in its topographic features and thickness. This formation, however, is characterized by erosion features which are much older than those of the Wisconsin formation and its position beneath deposits of loess in Chippewa County and farther west seems to indicate that it is the Iowan drift.

The sand and gravel deposits occurring in the valleys of large portions of the district, are believed to be largely, if not entirely of alluvial origin. The broad alluvial plain of the southern part of Portage and Wood counties is continuous with the narrow filled valleys of the northern part of the area, and was evidently formed in a similar manner by rivers and streams depositing sediment through valleys of low gradient. The distribution of the alluvial filling is determined by the slope and the elevation of the valleys with respect to main trunk streams and not by the distribution of any of the drift formations or the ice sheets producing them.

No final conclusion is reached concerning the age of the alluvial deposits but the belief is expressed that they were largely if not entirely formed during the long interval intervening between the deposition of the Second and the Third drift formations.

A considerable part of the area occurring in the central part of Marathon County and the eastern part of Wood County and the western part of Portage County is driftless. This driftless area has an extent of about 1500 square miles and is not only characterized by the absence of glacial drift but also by other features of non-glacial tracts. The driftless portion of this area is bounded on the east by the Second and the Wisconsin drifts, on the north by the Third drift and on the west by the First drift while on the south it is continuous, beneath the alluvial deposits, with the main driftless area of southwestern Wisconsin.

PART II.

PHYSIOGRAPHIC GEOLOGY.

OUTLINE.

Under physiographic geology is described the origin and development of the present land surface of the area. This part deals with the history of the present scenery, the origin and development of the plains, hills, valleys and the rivers and lakes.

The physiographic geology is presented in one chapter, Chapter XII, which is divided into three sections:

Section I. The general topographic features.

Section II. An outline of stream and rain erosion.

Section III. The origin of the topographic features.

CHAPTER XII.

PHYSIOGRAPHY.

In the foregoing chapters an account has been given of the various rock formations of the area in the order of their age and stratigraphic succession. These rock formations fall into three large groups: The crystalline rocks of pre-Cambrian age; the sandstone of Potsdam, or Upper Cambrian, age; and the glacial and alluvial formations of Pleistocene and Recent age. The topographic aspect of each formation has already been described in some detail, mainly, however, for the purpose of imparting a knowledge of the geology of the formation—that is, the character or origin of the rock.

It has been observed that the surface features of some parts of the area are very old, while those of other parts are comparatively young. The method of origin of the land surface of some parts, also, is quite different from that of other parts. It is purposed, therefore to present a brief account of the surface features from the viewpoint of their age and origin—that is, a history of the development of the topography of the area.

In a noteworthy manner the surface features depend largely upon the character and arrangement of the rocks that underlie the surface. Hence it is logical that the history of the topography of the area should follow the description of the character and distribution of the various rock formations.

The study of the rocks of the area has revealed the fact that they have originated in various ways and that the region, as a whole, has passed through many changes. The volcanic rocks, the sediments of marine, glacial and alluvial origin, furnish the records of past physical conditions which have prevailed throughout the whole or parts of the area and indicate the various vicissitudes through which the region has passed in its evolution. It is only, however, those records of the past that throw light upon the history of the present surface features of the area that will be appealed to in the account of the physiography.

SECTION I. GENERAL TOPOGRAPHIC FEATURES.

The general elevation and slope of the area has already been briefly referred to, page 1. The area slopes to the south and southwest. The lowest elevation in the area is on the Black River at the southern boundary of Clark County which is very probably about 845 feet above sea level. About 40 miles to the east, the Wisconsin River at the southern border of Wood County has an elevation of about 915 feet, and thus about 70 feet above the lowest elevation on Black River. The highest point in the area is the summit of Rib Hill, near Wausau, which reaches 1942 feet above sea level. The summit of Rib Hill however is about 500 feet above the surrounding upland area about Wausau.

In the absence of a topographic survey of the entire region only estimates of the elevations of most parts of the area can be given. Farther north the main upland area has in many places elevations exceeding 1600 and 1700 feet. The railroad at Pennington, in southern Price County has an elevation of 1635 feet, and at Summit Lake in Langlade County, 1729 feet. There are elevations in southern Price County, in the town of Hill, which probably exceed 1750 feet and some of the drift hills of the terminal moraine near Summit Lake, in Langlade County, probably exceed 1850 feet.

The highest elevation of the general upland area is probably in the northeastern part of the area. The lowest elevation is on Black River in the southwestern part of the area.

Valley and Upland Features.

The southern part of the area in southern Portage, Wood and Clark counties is characterized by broad valley bottoms; the central and western part in Marathon and Clark by comparatively narrow and deep valleys; and the northern and eastern part, in Lincoln, Langlade and Taylor generally by shallow and broad valleys. The valley bottoms in the southern part of the area constitute the main land area there being but few divides and upland ridges. In the central part the valleys where narrow lie from 100 to 300 feet below the main upland area. A view of the broad valley bottoms west of Grand Rapids in southern Wood County is shown in Plate LXI. A view of the narrow valley north of Wausau is shown in Plate LIX. A view of the relatively broad valley south of Wausau is shown in Plate LX. There is a gradual increase in the width of the valleys in passing from the northern to the southern part of the area; and *vice versa,* an increase in the upland area, in going from the southern to the northern part of the area.

The topography of the region however as illustrated in valley and upland area is not simple but complex, the change from one part of the region to another being characterized by a lack of simple uniformity and regularity. The lack of simple uniformity in the main topographic features is due to the geological character and structure of the rocks, as well as changes due to elevation and glaciation, as later described in the account of the origin of the topographic features of the area.

Drainage of the Area.

The principal rivers draining the area are the Wisconsin and the Black, and numerous branches of the Wolf River on the east and of the Chippewa River on the northwest.

The Wisconsin is the principal system of the area draining about two-thirds of the district. The Wisconsin River flows southward through the eastern portion of the area. Its principal tributaries from the east are the Plover, Eau Claire, Trapp, Pine and Prairie rivers. Its principal tributaries from the west are the Yellow, Little Eau Pleine, Big Eau Pleine, Big Rib, Copper, New Wood, Somo and Tomahawk rivers.

On the eastern border of the area are the head streams of the Wolf River the principal tributary of the Fox River. The Wolf River belongs to the Great Lakes and the St. Lawrence system. The Wisconsin River is a part of the Mississippi system. Hence the eastern border of the area represents a portion of the continental divide between two of the great drainage systems, the St. Lawrence and the Mississippi rivers.

The Black River in the southern part of the area has but a narrow drainage basin. The principal tributaries in the northwestern part of the area, flowing to the Chippewa River, are the Eau Claire, Yellow and Jump rivers.

DATA RELATING TO THE TOPOGRAPHY AND ELEVATIONS OF THE AREA.

A topographic survey of a large part of Marathon County and the adjoining parts of Langlade, Lincoln and Taylor, namely two 30 minutes quadrangles, has been made by the United State Geological Survey. These topographic maps[1] are designated the Wausau Special Map and the Marathon Special Map, and are readily available, and should be utilized by students and others especially interested in the geology and topography of the area.

The elevations of the bench marks, established by the United States Geological Survey, within the two quadrangles surveyed are indicated upon general maps Plates I and II. Upon the map, Plate II, is shown the railroad elevations of most of the stations in the entire area. Additional elevations of stations are shown in the following tables of elevation. The data refers to the elevation of the rail at the station as determined by the railroad companies.

There is also shown on the map; Plate II, the elevations in a large number of places of the water level on the Wisconsin River and the Black River as determined by the joint River Survey of the Wisconsin and United States Geological surveys. These elevations are also indicated in the tables, pages 535 and 543. The elevations of the water level were determined largely when the river was at ordinary flowage.

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1 These maps may be obtained for 5 cents each from the Director of United States Geological Survey, Washington, D. C.

There is shown in the following table the elevations of the railroad stations in the area.

Elevations of Railroad Stations in North Central Wisconsin.

County.	Station.	Elevation.
Clark	Abbotsford	1,420
	Chili	1,233
	Colby	1,353
	Curtiss	1,370
	Dorchester	1,420
	Eidvold	1,135
	Granton	1,112
	Humbird	1,022
	Lynn	1,139
	Neillsville	997
	Omaha Jct.	1,177
	Owen	1,242
	Romadka	1,212
	Thorpe	1,217
	Withee	1,268
Taylor	Chelsea	1,523
	Hannibal	1,262
	Little Black	1,414
	Medford	1,408
	Stetsonville	1,445
	Westboro	1,502
	Whittlesey	1,463
Marathon	Dancy	1,130
	Dessert Jct	1,167
	Eau Pleine	1,122
	Hatley	1,258
	Heights	1,219
	Kellys	1,209
	Knowlton	1,123
	Marathon	1,286
	Mosinee	1,155
	Norrie	1,277
	Schofield	1,206
	Spencer	1,306
	Trap City	1,219
	Unity	1,331
	Wausau (C., M. & St. P. R. R.)	1,218
	Wausau Jct	1,191
Lincoln	Bradley	1,473
	Combs	1,344
	Gilbert	1,437
	Heafford Jct	1,492
	Irma	1,508
	Merrill	1,263
	Pine River	1,233
	Tomahawk	1,450

Elevations of Railroad Stations in North Central Wisconsin.—Continued.

County.	Station.	Elevation.
Portage	Amherst	1,065
	Amherst Junction	1,099
	Bancroft	1,086
	Custer	1,173
	Junction City	1,140
	Lake Emily	1,124
	McDill	1,079
	Nelson	1,053
	Plover	1,074
	Stevens Point (W. C. R. R.)	1,084
	Stockton	1,144
	Webster	1,091
Wood	Arpin	1,149
	Auburndale	1,213
	Babcock	977
	Dexterville	994
	Grand Rapids (C., M. & St. P. R. R.)	1,010
	Hansen	1,064
	Hewitt	1,253
	Marshfield (W. C. R. R.)	1,283
	Milladore	1,192
	Nekoosa	959
	Pittsville	1,032
	Pittsville Junction	1,015
	Port Edwards	969
	Sherry	1,184
	Veedum	1,021
	Vesper	1,090
Langlade	Antigo	1,483
	Deerbrook	1,536
	Elcho	1,639
	Koepenick (Weather Bureau)	1,683
	Summit Lake	1,729
Price	Ogema	1,459
	Pennington	1,635
	Prentice	1,540
	Prentice Junction	1,542
Rusk	Hawkins	1,365
	Ingram	1,301

Before taking up the discussion of the origin and development of the principal physiographic features of the area, however, it may be well to describe briefly, the general processes and forces operating in the production of the topography.

SECTION II. AN OUTLINE OF RAIN AND RIVER EROSION.

The general process of sculpturing and shaping the land surface is divisible into several sub-processes, such as weathering, erosion, transportation and deposition.

Weathering is the term applied to the processes of disintegration and decomposition of the rocks. It is mainly accomplished by the solvent action of the water, changes in temperature causing the disruption of rock particles by expansion and contraction, and the work of plants and animals. Soils are developed mainly by processes of weathering.

The products of weathering are transported by the force of gravity, by winds, by glaciers, and by running water.

The work of the wind is not relatively important in this area under present climatic conditions at least, though in the past the wind may have been an effective agent in shaping the land surface. The action of the wind is not a negligible factor, however, for in the dry sandy formations of the area, wind blown sands are a common feature. The sculpturing of the sandstone mounds of certain parts of the area is probably largely due to the action of the wind. The sand dunes occurring in certain parts of the area (page 544) also are products of wind action.

Glaciers are no longer active, though in the past they were effective in the development of the topographic features of the region. The work of glaciers, in eroding, transporting and depositing rock debris, has already been described (Chap. VIII) and need not be repeated here.

The most important agent of sub-aerial erosion is running water. As soon as the sea bottom is elevated into a land area it is attaked by the rain and the streams, and these rapidy modify its surface. Some of the water that falls as rain evaporates at once and has but little effect; some of it sinks beneath the surface to join the ground water; and some of it runs off over the surface developing streams and performing the work characteristic of streams. It is only the water that gathers into streams that modifies the land surface.

The Development of Gullies and Valleys.

The rains that fall upon the land surface tend to gather into the depressions, however slight they may be, and once concentrated in the depressions, both the volume and rate of flow are increased. The water, flowing faster, erodes the depressions deeper and as a result gullies are started. This tendency for the rains to gather into rills and to wash out gullies is illustrated upon amost every hillside after any considerabe shower. Should there be no irregularities in slope the rain at the outset would fail of concentration. But though the rain would flow off in sheets the lines of easy erosion in the underlying material would soon develop into depressions and become sites for greater erosion. Either original inequality of slope or inequality of material would determine the location of a gully, and one of these conditions is usually present. Once started, each gully tends to perpetuate itself, for the gully started by one shower is inevitably enlarged by the next. The enlargement effected by successive showers effects the gully in all dimensions. The water coming in at the head of the gully carries the head farther back into the land, thus lengthening it; the water coming from the sides widens it; and the water flowing along the bottom deepens it. Thus the gullies grow into ravines and the ravines grow into valleys by the simple process of wash by running water. The conditions of inequality of land slope and inequality of material which determined the development of the initial gully, also govern the development of the tributary gullies. In its growth the tributary repeats the history of its main.

How a Valley Gets a Stream.

Valleys sometimes attain considerable size without possessing permanent streams, for at the beginning gullies and valleys are started by merely the run off of rains after heavy showers or from the melting snow. Sooner or later however the valley gets a permanent stream. And this is acquired when the valley bottom is cut down to the level of the groundwater of the surrounding area. When the valley bottom reaches just below the level of the ground water, below which level all the openings in the

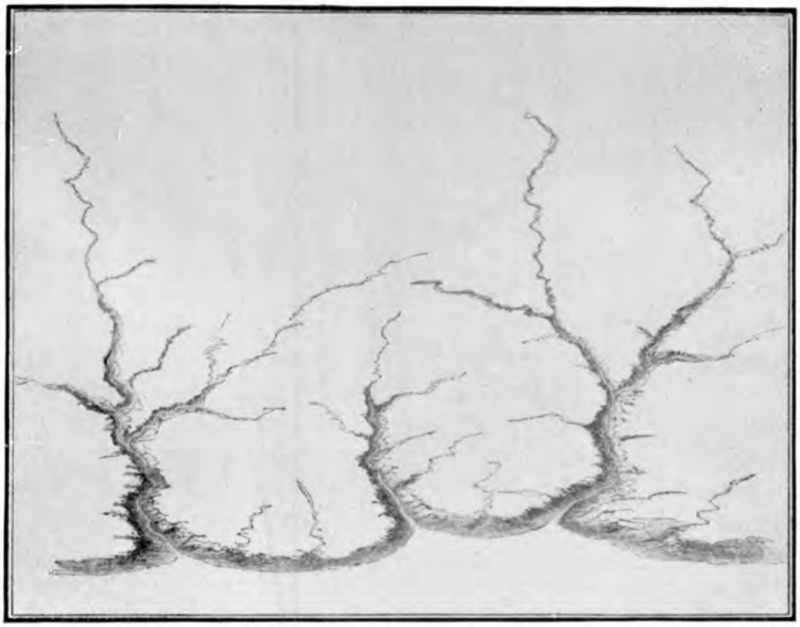


Fig. 1. YOUNG VALLEYS. (From Bull. V., Wis. Sur.)

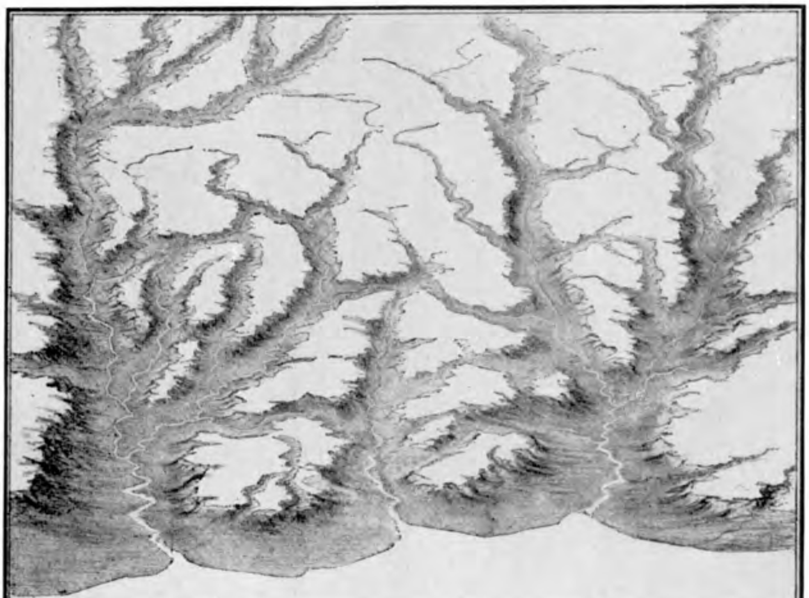


Fig. 2. SAME VALLEYS AS SHOWN IN FIG. 1, IN A STILL LATER STAGE OF DEVELOPMENT.

rocks are filled with water, the water from the sides seep into it in the same manner that water seeps into a well. The tendency is for the ground water to fill the valley to the same level as the ground water in the adjacent land. Instead of the water accumulating in the valley as in a well it tends to flow off, and thus lower the level of the ground water. At the same time the bottom of the valley is sunk deeper by constant flow thus tending to retain the permanent stream. There is usually a stage in the development of valleys, however between the periods of possessing temporary and permanent streams, called the *intermittent stage,* when the valleys possess streams only during wet seasons of the year.

As soon as a valley acquires a permanent stream its development goes on without interruption. No stream however can cut below a certain gentle gradient from source to mouth. When a stream has reached a gradient below which it cannot cut, it may be said to be *at grade* and the valley has reached *base level.*

Weathering, wash, and lateral erosion tend to widen a valley long after its channel has reached base level. The final result of the widening of valleys is to reduce all the area which they drain to a broad base level.

Relation of Tributary to Main.

In the development of tributaries along main streams a characteristic feature is the angle at which the tributaries join the main. The main stream follows down the main slope of the land to the sea because it is up this main slope that the greatest lengthening headward takes place. If a tributary gully were to start at right angles from the main most water would come from the side sloping upward. There would also be a tendency for the gully to lengthen upward from the seaward side and thus the head would be brought toward parallelism with the main valley. In general therefore tributary streams under normal conditions join their main at an obtuse angle down stream. Where this is not the case some factor has interfered with the normal development. While most of the tributaries of North Central Wisconsin join their main at an obtuse angle down stream there are several which do not namely, those of the Black River, whose abnormal relations are fully described later.

The Relation of Underground Water to Streams.

It has already been stated that a valley acquires a permanent stream when it is cut down to the level of the ground water table. But the level of ground water fluctuates from season to season. It is depressed when the season is dry, and raised when the season is wet. A valley has only an intermittent stream when it has been cut down to the higher level of ground water during the wet seasons of the year. Figure 35 illustrates the relations

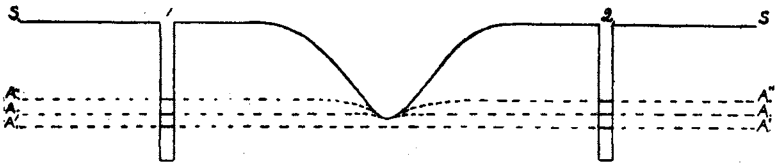


FIG. 35. Diagram illustrating relations of groundwater to streams and wells. The dotted line A A represents the usual groundwater level which rises to A" A" in wet seasons and sinks to A' A' in dry seasons.

of ground water to streams. The upper dotted line represents the highest level of ground water when the valley has a stream and the water in the adjacent wells stands high. The lowest line represents the ground water level in a dry season when no water flows into the valley, and the latter then possesses only a dry stream bed. Permanent lakes like permanent streams lie just below the level of the ground water table of the adjacent land, and, fed from the ground water, they are kept at an approximate uniform level. The levels of lakes change, therefore, with the level of ground water and streams.

While the ground water level fluctuates from season to season it also gradually changes from year to year, and in certain porous land formations permanent changes in the ground water level are often wrought which exert a profound effect upon the smaller tributaries and lakes of the locality.

On account of permanent changes in the level of the ground water in the area of the porous alluvial formations of North Central Wisconsin, once permanent streams have become intermittent streams or wholly extinct, and certain lakes have greatly diminished in size and some have been wholly obliterated. The process of the extinction of lakes is described on page 612.

A striking illustration of the effect of changes in the level of underground water upon permanent streams as illustrated by Spring Brook Creek in the porous alluvial plain about Antigo. When lumbering began in this region a dam was built across the upper portion of the creek for the purpose of impounding water

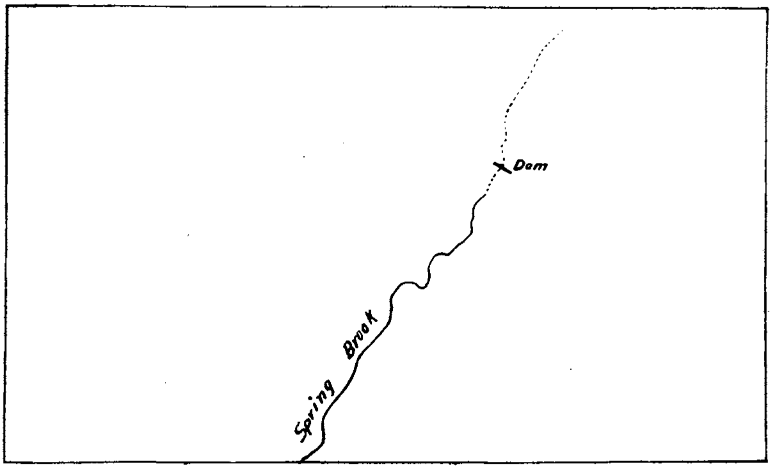


FIG. 36. Map of upper portion of Spring Brook near Antigo. On account of the permanent lowering of the groundwater the dam is now located upon a dry stream.

for driving logs down the stream to the saw mills below. At present however this dam stands high and dry far above the living stream. The position of the dam with respect to the living and dry stream is illustrated in Fig. 36.

A Cycle of Erosion.

When a land area is just elevated above the sea and a system of valleys with permanent streams is acquired like that above outlined the valleys would at first constitute but small and narrow depressions separated by broad elevations representing the original land surface. Such a condition of young valleys in a new land area is represented in Fig. 1, Plate LXIII.

By constant erosion the valleys lengthen and broaden out and the intervalley areas gradually become narrower and narrower. By processes of weathering and wash down the valley sides and the developing of side tributaries the broad highland areas between the valleys finally become cut up into small uplands, short ridges, and hills, as shown in Fig. 2, Plate LXIII. By the development of side tributaries the original surface is lowered much more rapidly than by merely widening the principal valleys.

The successive stages in lowering the land surface is shown in Fig. 37 which represents a series of cross sections of a land

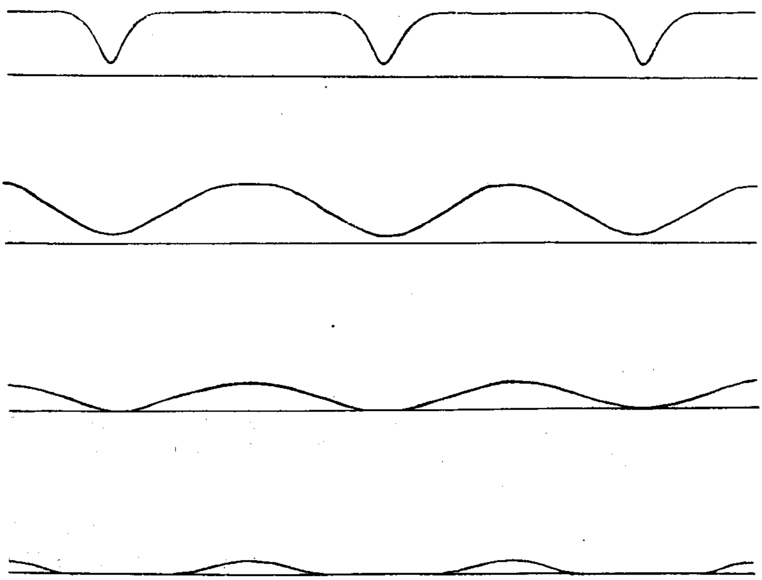


FIG. 37. Cross sections showing various stages of erosion in a cycle. The upper section represents young and narrow valleys, the lower sections older and broader valleys.

mass in process of degradation. The uppermost section represents a level surface crossed by young valleys. The next represents the same surface at a later stage, when the valleys are grown larger and broader, while the third and lowest section represents still later stages in the process of degradation.

In this manner a series of rivers under favorable conditions of erosion and weathering finally reduce great land masses to a very low level, approximately to the level of the sea. The new level would be developed earliest near the sea and the areas farthest from the sea would be the last to be reduced. The time necessary for the development of such a surface is known as a *cycle of erosion* and the resulting surface is a *base level plain.* A *peneplain* is a surface of erosion brought near to base level. Valleys and land surfaces are spoken of as old or young in their erosion history according to the stage of advancement in the process of base leveling. The pre-Cambrian land of Northern Wisconsin, as later described, is an excellent illustration of a peneplain of erosion.

During the general processs of the degradation of a land mass by rain and stream erosion, the softest rocks are the first to be worn away, and the hardest ones remain the longest, and finally constitute mere ridges in the partly degraded plain. Such hard rocks as the Rib Hill quartzite constitute the remains of a very old land area in the region about Wausau. The quartzite rocks on account of their extreme resistance to weathering and erosion were not worn to the level of the surrounding softer rocks, and now remain as prominent elevations standing above the old peneplain of the crystalline land mass.

Falls and Rapids.

Falls and rapids are a common feature of the rivers and streams of Northern Wisconsin. These are developed in the valleys where the streams cross from a more resistant rock to a less resistant one. Where the rocks are relatively easy to erode a low stream gradient is soon acquired, but where the rocks are hard erosion is slow, and hence a series of steps or rapids are formed as the streams alternately flow over the hard and soft formations. In course of time however the streams will succeed in cutting down the hard rocks of the rapids to grade with the stream above and below. They belong therefore to the youthful stage of a valley history rather than to that of old age. Views of rapids are illustrated in Plates LXII, LXIII and LXVI.

Waterfalls and rapids are an important natural resource of this area, and many of them have already become sites for the development of valuable water powers. The location of all the cities on the Wisconsin River, and also on the Black, has been determined by the presence of rapids.

Narrows and Gorges.

Where a stream crosses a hard rock formation a much narrower channel is carved than where it crosses the softer rocks. As a general rule the harder the rock the narrower the valley, and the softer the rock the wider the valley. In the area of Northern Wisconsin the narrow channels and gorges in the rocks are quite generally called dells. Nearly all the streams of this area are characterized by one or more dells. They constitute one of the most picturesque features of the region. A partial view of the dells of the Pine River is shown in Plate LXXIV.

Relation of Erosion Forms to Rock Structure.

The rocks of Northern Wisconsin fall into three groups: the folded crystalline formations; the horizontally bedded sandstone; and the glacial drift and alluvium. While the processes of river erosion are essentially the same, whatever the character and structure of the land mass upon which the erosion operates, yet the various slopes of the valleys and hills developed by erosion in a folded crystalline area differs essentially from the forms developed in horizontally bedded rock like the Potsdam sandstone. Once developed, the rivers widen their valleys and lengthen their courses and finally bring the area drained to nearly sea level, without regard to the character and structure of the land mass. But in the intermediate stages of the degradation of a land mass, the forms of the valleys and the hills vary in accordance with the structure of the rocks.

The erosion of a formation like the sandstone tends to develop forms which are largely determined by the characteristic vertical joints and horizontal bedding of the formation. As a result the upland areas in the sandstone are generally carved into huge blocks or *buttes* with nearly vertical escarpments along the sides and flat lying beds on the tops. These forms are most easily attained, because the plains of easiest erosion and weathering are the plains of horizontal bedding on the one hand and the planes of the vertical jointing on the other. See the illustrations of sandstone mound shown in Plate XLIX.

VIEW OF THE DISSECTED PRE-CAMBRIAN PENEPLAIN, NORTHWEST OF WAUSAU.
Looking west across the valley of the Little Rib River.

THE DISSECTED PRE-CAMBRIAN PENEPLAIN, NINE MILES NORTHWEST OF WAUSAU.

The folded schists and strata of the crystalline area however possess no well defined and regular system of planes of easiest erosion on account of their great variation in structure and hard ness. The jointing planes of the crystallines not only extend vertically but they also extend in various other directions. As a result of great variation in the character and structure of the folded crystalline rocks the valleys and hills developed in them are carved into gentle contours, as a rule, and gently rising slopes from valley bottoms to the upland summits prevail. See Plates LXIV and LXV.

The drift formations on account of their lack of stratification and bedding planes and jointing, and the great variation in the character of the material, also possess no well defined planes of easiest erosion, and as a result, erosion forms are developed quite similar to those in the folded crystalline rocks. Compare Plate LXIV with Plate LXVIII.

Topographic Forms of Stream Deposits.

The rock material eroded by the streams is carried down the slopes of the valleys in their course to the sea. While the final goal of the weathered detritus is the sea bottom, much of the material is deposited along the way for longer or shorter periods. The forms which the material assumes where deposited in the valleys are various. A common form is known as *alluvial cones,* forms which are deposited at the foot of steep slopes by temporary streams after showers.

A common form which streams and river deposits assume in valleys are the broad alluvial plains developed by rivers upon their flood plains. A river carrying sediment towards the sea will drop its load wherever the slope of the valley becomes so low as to check the current. The alluvial deposits in the valleys of Northern Wisconsin are very extensive and their general origin have already been described in Chap. X.

The Rejuvenation of Streams.

After the degradation of a land area to a base-level plain, the plain may be elevated by uplift, and the streams on account of the increased elevation will again deepen their valleys and will assume the characteristics of youth. In like manner on account of uplift the streams and rivers occupied in filling their valleys may be rejuvenated by uplift. After uplift they will cease depositing material and begin to cut new channels in the old flood plain. The rejuvenation of the rivers in the filled valleys of this area have caused the extensive development of terraces in many of the valleys, as already described. See Figures 24 to 27.

Disturbances of Stream Development.

A river system once developed upon a land mass remains as one of the most persistent features of nature. It is very seldom, however, that a river is permitted to pass through all stages of development from youth to old age in a regular and normal manner. The most important interruptions are due to conditions arising from elevation or subsidence and glaciation. Some of the effects of changes of elevation in filling the valleys with alluvial deposits, and later the eroding of the river terraces have already been described, pages 522–3. The effects of glaciation in filling the rivers and turning aside the rivers into new and narrow channels has also been referred to, pages 414–418.

The Adjustment of River Systems to the Land.

A stream developed upon a new land area in consequence of uplift, like those already described, is called a *consequent* stream. A consequent stream is one whose course is determined by the conditions of slope and structure of the land mass in which it occurs. The rivers developed upon the Paleozoic rocks of Wisconsin, as illustrated in the driftless area, are consequent streams developed upon uplift of the Paleozoic formations. The development of their courses and of their valley features has been determined by the slope and structure of the Paleozoic land.

A *subsequent* stream is one developed after the youthful stage of this system, usually along a line of softer rocks. Subsequent streams are common in glacial areas. An *antecedent* stream is one which has maintained its original consequent course without regard to the upheavals within the basin in which the stream flows.

THE WISCONSIN RIVER ON THE UNDISSECTED PENEPLAIN.
The Upper Paper Mill Dam, Conants Rapids.

A *superimposed* stream is one whose course has been determined by the structure and slope of a previously existing surface which has been partly or wholly removed by erosion. The course of a superimposed river system is not determined by the character and structure of the land in which it is now located, but by that of the land surface which once lay above it, but is now removed by erosion. The river systems of Wisconsin as

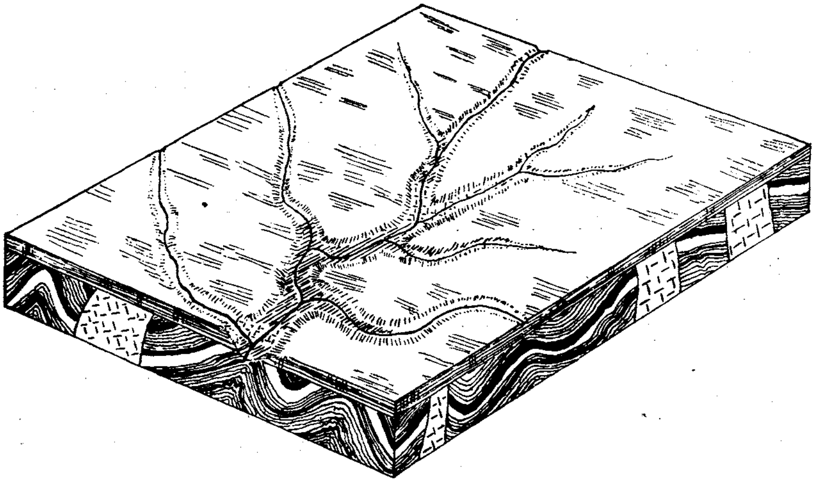


FIG. 38. Diagram illustrating the development of a superimposed stream.

later described (p. 617-620) are consequent upon the Paleozoic formations, and superimposed upon the underlying pre-Cambrian.

The development of a superimposed river is illustrated in Fig. 38. The river, after carving its valley through the overlying nearly horizontal strata, comes in contact with the underlying folded metamorphic rocks The structure and character of the underlying rocks upon which the river system now begins to erode is quite different from that of the overlying sediments through which it has just cut its valleys. Nevertheless, unable to change its course, it continues to sink its valleys into the underlying formations, though wholly out of harmony with the rock structure there existing. Instead of developing a system of valleys, therefore, in the lower and older land mass in harmony with the structure of the older land, there is superimposed upon it a system whose courses have been wholly determined by the structure of the overlying formations.

SECTION III. THE ORIGIN OF THE TOPOGRAPHIC FEATURES.

The principal topographic feature of the area is the plain of the pre-Cambrian rocks. The subordinate features are due to formations depositd upon the pre-Cambrian plain, or to their subsequent erosion. The subordinate features fall into several groups: those relating to the Potsdam sandstone; those relating to the glacial drift and alluvium; and those relating to the lakes and rivers.

THE PLAIN OF THE PRE-CAMBRIAN ROCKS.

If one should stand upon one of the flat-topped hills immediately northwest of Wausau, where neither the sandstone nor glacial drift obscures the topography of the pre-Cambrian, and should look eastward across the narrow valley of the Wisconsin and its tributaries, he would see that the uplands rise approximately to his own elevation and form an even crest line along the horizon. To the northward the even crest line would seem to rise gently but persistently, while to the southward the even sky line formed by the flat-topped uplands is seen to descend, and not only fall below his own elevation but also far below the summits of Rib Hill and Mosinee Hill, which lie a few miles to the south. The even summit surface of the main upland is the most striking feature of the landscape and at once suggests an ancient plain, radiating to all points of the compass, below which the Wisconsin River and its tributaries have eroded their valleys, and above which project a few isolated hills and ridges, like Rib Hill and the Mosinee Hills.

At Wausau the elevation of the plain, represented by the summits of the even crested uplands, is approximately 1420 feet above the sea; 20 miles north of Wausau in the vicinity of Merrill it is 1550 and 1600 feet above sea level. Going south of

Wausau about 20 miles, in the vicinity of the boundary of Marathon and Portage counties, the plain of the pre-Cambrian descends to an elevation of about 1200 feet; and 20 miles still farther south, in the vicinity of Grand Rapids, it is 1000 feet above the sea.

As the plain gradually descends to the southward and the border of the Potsdam sandstone district is approached, the pre-Cambrian is seen to be covered with isolated outliers of the sandstone formation. The valley of the Wisconsin and its tributaries grows shallower and shallower, the valley bottoms of the river ever rising nearer and nearer to the level of the pre-Cambrian plain. Forty miles south of Wausau, in the vicinity of Grand Rapids, at the approximate border of the sandstone district, where the plain is 1000 feet above the sea, the valley bottom of the Wisconsin practically coincides with the level of the pre-Cambrian plain, as illustrated by the numerous crystalline rock rapids of the Wisconsin, capped on either river bank by the thin beds of nearly horizontal sandstone.

To the westward in the region of the Yellow and Black rivers, there is an abundance of drift obscuring the general surface of the pre-Cambrian, but in these parts of the area, also, the surface of the pre-Cambrian is seen to slope gradually downward to the south and the thin edges of the sandstone are seen to lap upon it.

Origin of the Plain.

Wherever the various kinds of pre-Cambrian rocks are exposed, their schistosity and bedding are seen to be dipping at various angles, and along the valley bottoms the streams flow over the upturned rock edges. Hand specimens chipped from ledges show rock crumplings on a minute scale; and the dipping beds are the remnants of rock folds that once were evidently continuous and roofed over broad spaces from a few hundred to a thousand feet across. Everywhere the rocks stand on edge and are folded and crumpled, having a structure similar to those of the Alps, the Alleghanies or the Rockies.

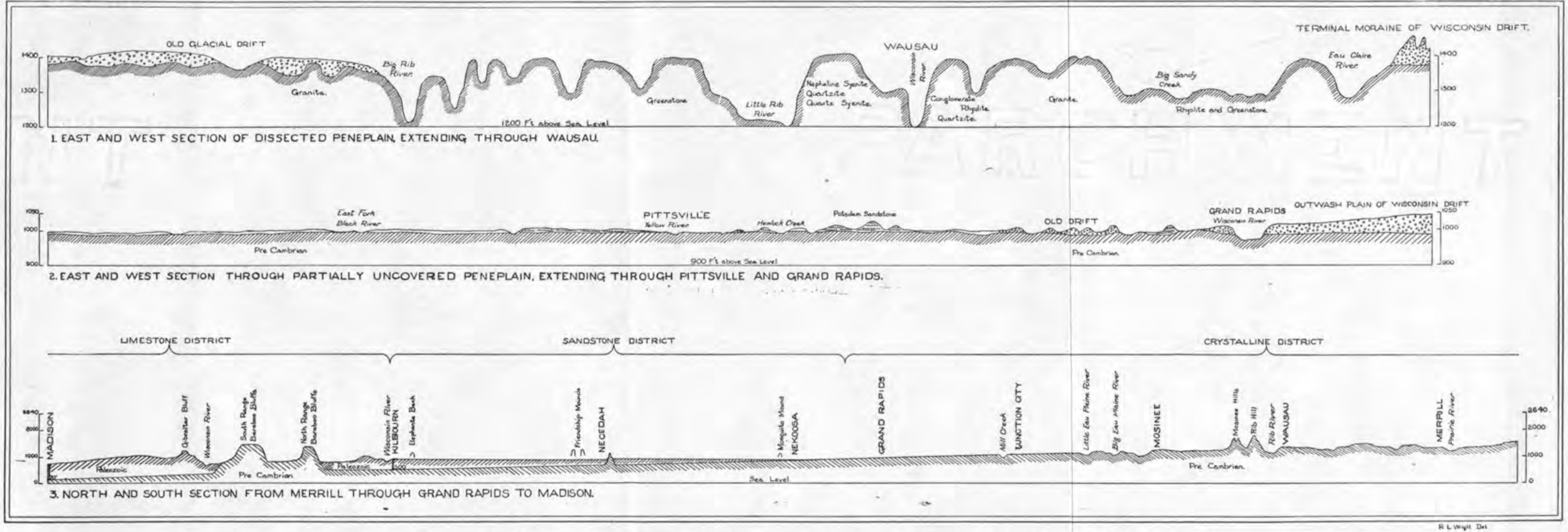
While the rocks of the pre-Cambrian plain have typical mountain structures, there is nothing in the present gently sloping land surface to suggest mountain topography. The dipping beds and schists everywhere stop abruptly at the even plain formed by the summits of the flat-topped hills. There is thus an entire lack of sympathy, a striking incongruity, between the gently sloping surface of the pre-Cambrian area and the internal structure of the rocks.

It is a well established fact of geology that approximate level tracts of land, or plains, are formed in only two ways, either by the formation of new land areas by sedimentation, or by the leveling of the old land areas by degradation and erosion. If formed by sedimentation, the general slope of the land necessarily closely coincides with the stratification of the sediments. Plains formed by erosion, however, need have no regard for the folded or otherwise complicated structure of the underlying rocks. The pre-Cambrian land with its plain-like surface and its internal mountain structures must therefore have been developed by the process of degradation and erosion of a pre-existing mountainous region.

The development of a plain out of folded rock formations with its marked discordance of land surface and rock structure, like that of this pre-Cambrian area, has been so adequately explained and so generally accepted by geologists as the resultant of long continued erosion, that it seems reasonable to conclude at once that the sloping, flat-topped uplands about Wausau represent a nearly level land surface produced by the wearing down of a mountainous region to an approximate plain. The mountain folds of the pre-Cambrian have been cut off by erosion at the even sky-line of the area, just as the fibres of a great tree are cut across at the even surface of its sawed stump. The complete degradation of the mountains was not accomplished, as is evidenced by such isolated hills as Rib Hill and the Mosinee Hills, which project above the flat-topped uplands, and hence the region must have been, not a plain, but a peneplain of degradation.

A view of the pre-Cambrian peneplain before the Paleozoic transgression is illustrated in Plate LXVIII.

In retrospect, the pre-Cambrian area was once a mountainous region. Subsequently the mountainous area was worn down by erosion to a peneplain. At a later period the peneplain was uplifted and again subjected to erosion, which is continued into the present time. Out of this ancient plain of erosion the pres-



SECTIONS SHOWING THE CHARACTER AND RELATIONS OF THE PRE-CAMBRIAN PENEPLAIN.

Scale of Figs. 1 and 2: horizontal, 1 in. = 4 miles; vertical, 1 in. = 400 feet.
Scale of Fig. 3: horizontal, 1 in. = 15 miles; vertical, 1 in. = 5,280 feet.

EXPLANATION OF PLATES

LXVIII, LXIX, LXX AND LXXXI.

Plate LXVIII. Topographic Features of the Area at the Close of the Pre-Cambrian.

Diagram illustrating the structure of the Pre-Cambrian rocks, and the surface features of the area at the close of the pre-Cambrian erosion, the final stage in the production of the peneplain of erosion. The broken lines represent the boundaries of the several counties of the area. See maps, Plate I and II. In central Marathon County are the quartzite monadmocks of Rib Hill and the Mosinee Hills, and in Wood County are Powers Bluff and South Mound which were not reduced by erosion to the general level of the plain.

Plate LXIX. Topographic Features at Close of the Paleozoic Sedimentation.

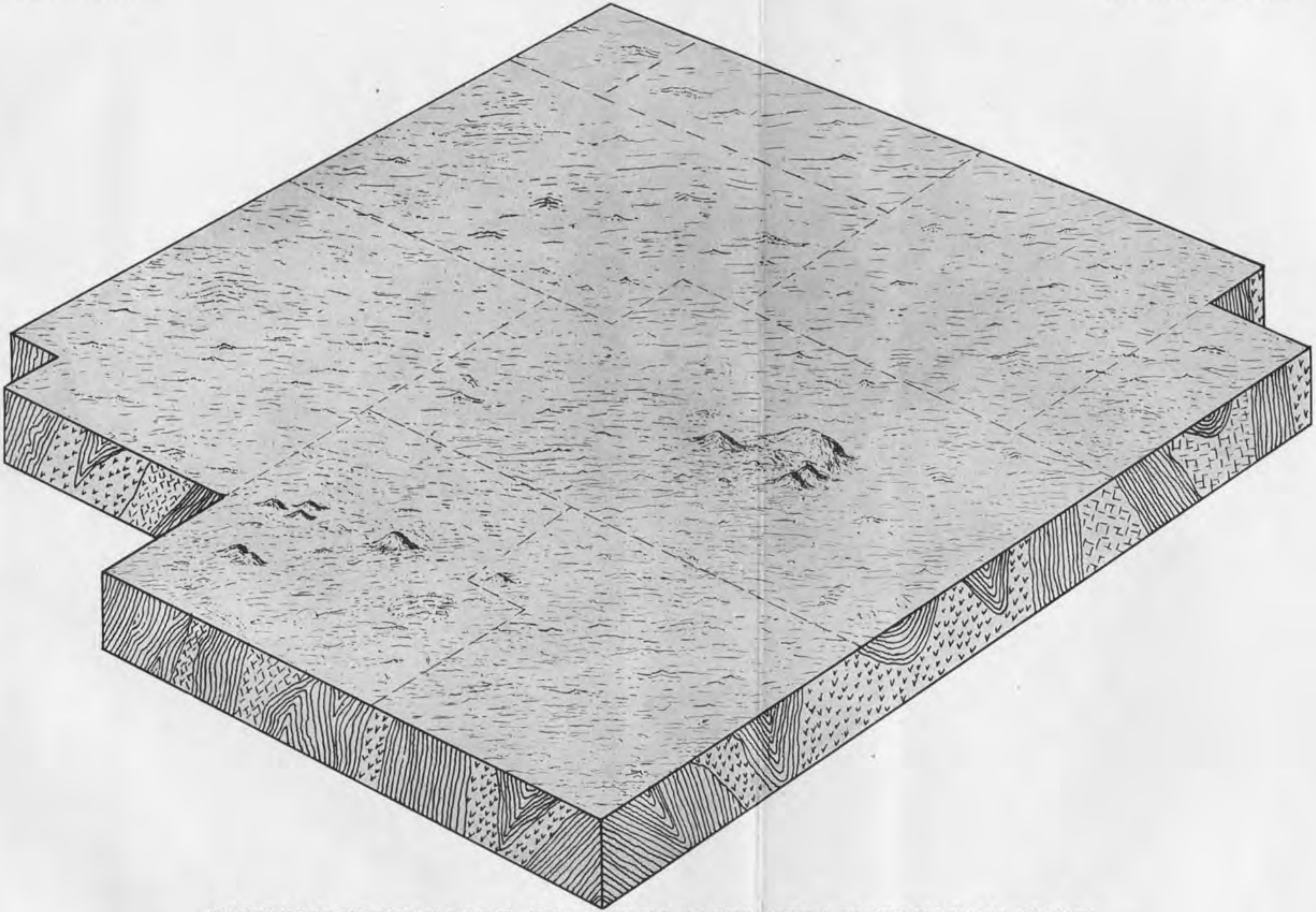
Same as above, after the transgression of the Paleozoic sea and the deposition of the Paleozoic formations. The Paleozoic formations up to the Niagaran may have been deposited over the area.

Plate LXX. Topography and Drainage at Close of the Pre-Pleistocene.

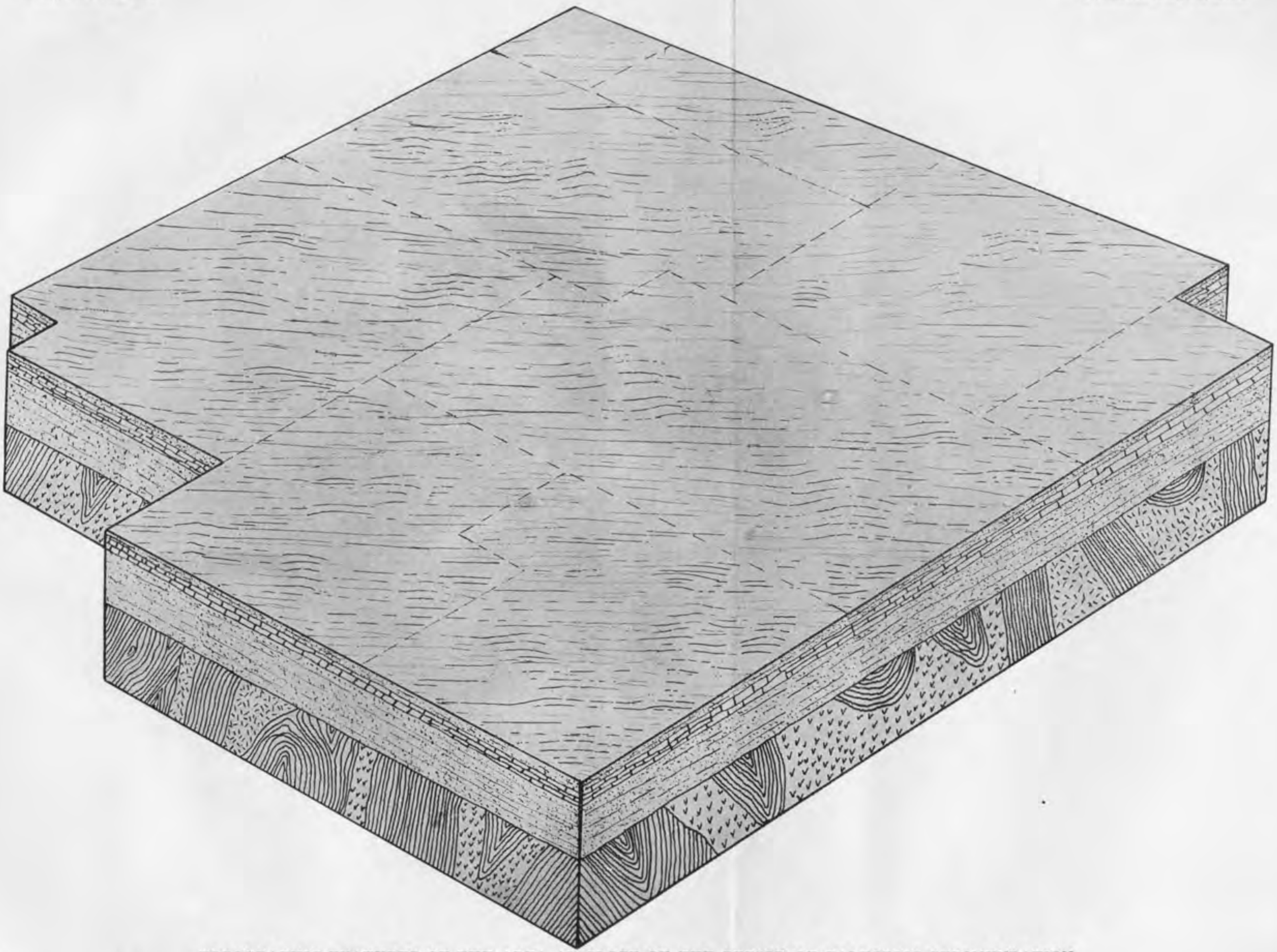
This plate represents the area after the long erosion of the Paleozoic formations which extended up to the beginning of the Pleistocene period. Only a small portion of the Paleozoic, namely the Potsdam sandstone, is left in the southern and southwestern parts of the area. Compare with map, Plate I. The drainage developed on the Paleozoic in consequence of uplift is now superimposed in all its details upon the resurrected pre-Cambrian peneplain. The quartzite monadmocks of Rib Hill and Powers Bluff appear as before. The depth of erosion and dissection of the pre-Cambrian probably uniformly decreased from north to south where the sandstone yet remains. The Wisconsin River probably continued directly south of Stevens Point. The Black River probably extended only a short distance north into Clark County.

Plate LXXI. Topography and Drainage at the Present Time.

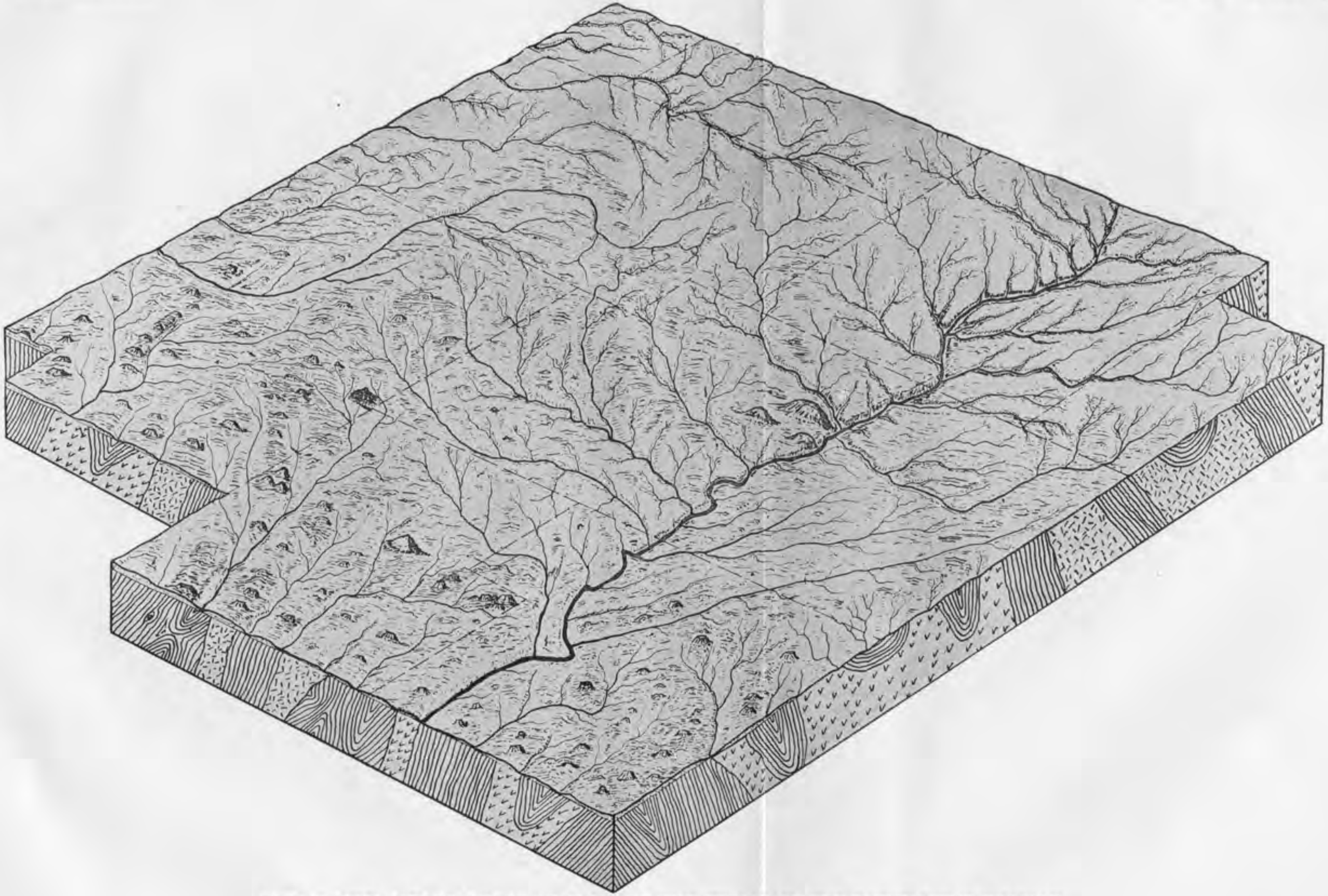
This plate represents the area at the present time, after the transgression of the Pleistocene ice sheets, and the filling of the valleys with alluvium and drift. Compare with map, Plate II.



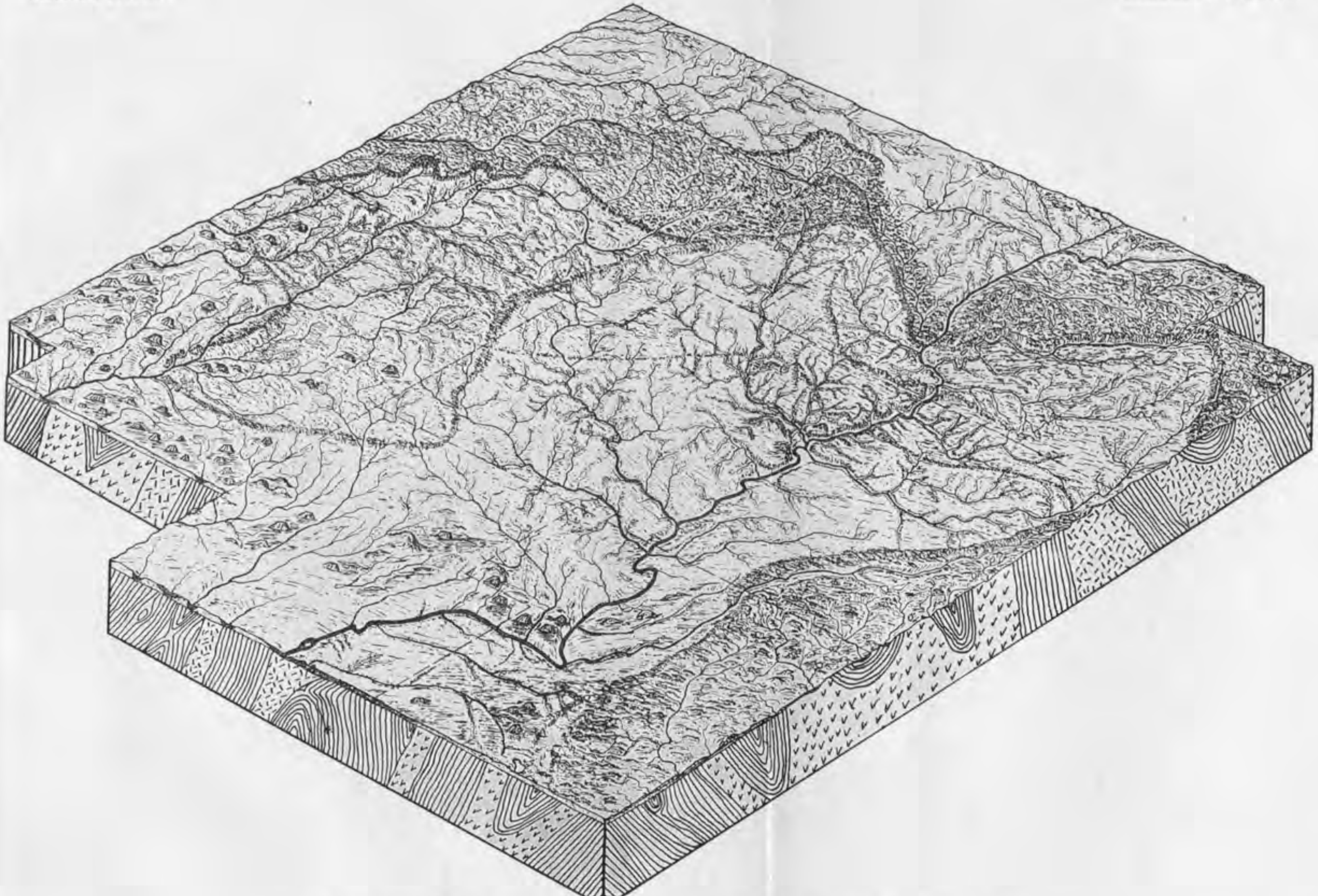
TOPOGRAPHIC FEATURES OF THE AREA AT CLOSE OF THE PERIOD OF PRE-CAMBRIAN EROSION.



TOPOGRAPHIC FEATURES OF THE AREA AT CLOSE OF THE PERIOD OF PALEOZOIC SEDIMENTATION.



TOPOGRAPHY AND DRAINAGE AT CLOSE OF THE PERIOD OF PRE-PLEISTOCENE EROSION.



TOPOGRAPHY AND DRAINAGE AT THE PRESENT TIME, AFTER GLACIATION.

ent valleys about Wausau are seen to be in process of construction and hence this part of the area may be described as a dissected peneplain.

The Age of the Peneplain.

Going south of the crystalline area about Wausau and approaching the region of the Potsdam sandstone in northern Wood and Portage counties, as previously stated, the valleys in the pre-Cambrian become appreciably shallower, the dissection of the peneplain is seen to grow gradually less, and the surface of the pre-Cambrian becomes dotted with outliers of the Potsdam. Still farther south, along the numerous rapids of the Wisconsin in southern Wood and Portage counties, the pre-Cambrian is seen to occur only in the valley bottoms with the cappings of sandstone lying upon it along the river banks, and in this vicinity the pre-Cambrian plain is practically intact and untrenched by valleys.

Going still farther south below Nekoosa, the crystalline rocks are no longer seen even in the river bottom, and the overlying sandstone or the alluvium becomes the only surface rock.

The deeply dissected peneplain about Wausau thus passes into the slightly dissected peneplain in northern Wood and Portage counties, and at Grand Rapids and Nekoosa it is seen to slip under the Potsdam sandstone and becomes a buried peneplain. Hence we must conclude that this peneplain was made in pre-Potsdam time and was later submerged by the early Paleozoic sea and covered by the Potsdam formation.

A view of the pre-Cambrian peneplain after the Paleozoic transgression, after it was covered with the Potsdam sandstone and later formations, is shown in Plate LXIX.

The evidence upon which the pre-Potsdam age of the peneplain is based is the continuity in slope and the uniformity in character of the dissected and uncovered portions of the pre-Cambrian plain with that sloping beneath and buried under the Potsdam formation. Ordinarily such evidence as this would be deemed conclusive and it may be so considered in this instance, but attention is called to the evidence, previously described (see pages 388–392), in certain portions of the pre-Cambrian area, consisting of an abundance of residual clays lying beneath the sandstone, the occurrence and relation of which, it is believed, furnish additional proof of the pre-Potsdam age of the peneplain.

The Peneplain made by Sub-aerial Erosion.

Peneplains are formed by sub-aerial erosion—the work of rains and streams; by marine erosion—the work of sea-waves beating against a coast line; and by a combination of these processes. It was formerly believed that only sea-waves could accomplish the work of reducing land areas to the near level of the sea. But the presence of the residual clay formations beneath the sandstone, indicating widespread weathering and decomposition of the pre-Cambrian surface before the Potsdam formation was deposited upon it, and also the fact of the occurrence of Potsdam conglomerate only about the isolated pre-Cambrian monadnocks, obviously indicate that the region must have been flat-lying and very near to sea-level a long time before the encroachment of the Potsdam sea. Hence the sea waves could have had little to do with the leveling of the pre-Cambrian to a peneplain, for the degradation was evidently accomplished long before the sea was present.

Monadnocks in the Dissected Peneplain.

In our view of the region surrounding Wausau it was noted that certain hills and ridges project above the flat-topped uplands of the pre-Cambrian plain. These are the conical Mosinee Hills and Hardwood Hill, and the sharp ridge, Rib Hill. The above named hills consist for the most part of very coarse quartzite, undoubtedly the most resistant rock in nature, and for this reason they were not worn down during the general degradation of the surrounding area in pre-Cambrian time. These monadnocks, with their pointed crests, are in marked contrast with the flat tops of the uplands forming the peneplain. They are the remnants of a land surface older than the even-crested hills, and are typical monadnocks like Mount Monadnock of New Hampshire, which bears a similar relation to the peneplain of erosion of southern New England. Rib Hill, the most prominent of these monadnocks, has an elevation of 1,942 feet above the sea and of 500 feet above the surrounding dissected peneplain. Its summit reaches over 700 feet above the plain of the Rib and Wisconsin rivers lying at its base, and it has the distinction of being probably the highest hill in the state. Upper Mosinee Hill reaches about 200 feet above the peneplain, Lower Mosinee Hill about 100 feet, and Hardwood Hill about 180 feet.

Monadnocks in the Slightly Dissected Peneplain.

About 35 miles southwest of Wausau in central Wood County is Powers Bluff, consisting of fine-grained quartzite and chert, whose elevation is not known, but which apparently reaches about 300 feet above the surrounding area of the slightly dissected peneplain. This bluff stands in the midst of isolated thin sandstone remnants lying upon the surrounding crystalline plain, and wrapped about its base are patches of Potsdam conglomerate. Powers Bluff bears the same relation to the surrounding slightly dissected peneplain that Rib Hill bears to the deeply dissected peneplain about Wausau. In adjacent parts of Wood County, farther south, there are other monadnocks of resistant quartzite and granite, some of which rise from 50 to 100 feet above the general slope of the pre-Cambrian plain.

Valleys in the Dissected Peneplain.

Since the pre-Cambrian and overlying formations have been elevated, as previously described, the rivers and streams have not only uncovered large portions of the pre-Cambrian but have deeply dissected it, while other portions are still largely covered with sandstone and have been but slightly or not at all trenched by streams. The Wisconsin River meandering across the pre-Cambrian from Merrill to Stevens Point has carved a prominent winding valley with steep sides and variable width in the peneplain. North of Merrill in the region of thick drift, the valley is much modified by glacial deposition. That part of the valley between Merrill and Wauasu in the area of old thin drift and driftless has a depth of 200 to 300 feet (see Plate LXVII). The Wisconsin valley gradually grows shallower toward the south, and twenty miles south of Wausau the valley bottom is only about 100 feet below the peneplain, and about twenty miles still farther south, at Grand Rapids, the valley bottom is on a level with the descending slope of the peneplain. The branch rivers of the Wisconsin, such as the Big Rib, Big Eau Pleine, and Little Eau Pleine on the west, and the Pine, Trap and Eau Claire on the east, are U-shaped for about one-quarter to one-third of their distance from the Wisconsin, and then pass into narrow V-shaped valleys, and finally into broad V-shaped valleys near the flat-topped uplands. North of the branch rivers just named the drift is very thick, and the side valleys, like the Wisconsin, are either wholly post-glacial or much modified by glacial action. South of these branch rivers, in the region of the sandstone outliers, the side valleys, like the valley of the Wisconsin, gradually grow shallower until their floors coincide with the level of the peneplain.

In the western part of the area in the drainage of the Black River, the surface features are largely due to the secondary features of eroded sandstone and old drift superimposed upon the plain of the pre-Cambrian. In this part of the area it is only here and there that the old crystalline plain is to be seen through the overlying surface formations.

Throughout the entire extent of the region, however, the plain of the crystalline rocks, whether appearing at the surface, as in the driftless area about Wausau, or a few feet below, as in those parts covered with drift or sandstone, pre-eminently forms the dominating topographic feature of the region. The pre-Cambrian peneplain of erosion, made in comparatively early geologic time, furnishes the platform upon which, the subordinate features of the landscape are imposed.

THE MOUNDS OF SANDSTONE.

In Portage, Wood and Clark counties numerous isolated mounds, hills and ridges of the Potsdam sandstone occur lying in nearly horizontal beds upon the plain of the pre-Cambrian rocks. The sandstone was deposited in early Paleozoic time (Upper Cambrian) upon the weathered crystalline peneplain, and was clearly, at an earlier date, a much more widespread formation than at present. It is extremely probable that the sandstone once extended over the entire pre-Cambrian of this district of north central Wisconsin, and later investigation may show its probable continuation over the whole of northern Wisconsin.

The position of the sandstone overlying the crystalline rocks indicates, as previously briefly pointed out, that the pre-Cambrian land, after having been reduced to approximately base level by sub-aerial erosion, and having remained near sea-level for a time sufficiently long for the deep weathering and decomposition of its surface, finally sank below the sea. And in the succeeding sea bottoms a great thickness of sandstone and perhaps still later formations accumulated. The depth which this sandstone reached is not known, but it may have reached 500 or 700 feet over most parts of the area, for remnants, probably 300 feet in thickness, still remain in the southern and southwestern parts of the area. From the amount of accumulated Paleozoic sediment in adjacent parts of the state, it seems very probable that the ancient plain of the pre-Cambrian remained a very long time beneath the Paleozoic sea.

Finally the region was slowly elevated above the sea, and immediately the forces of weathering and erosion, the streams and rains, attacked the uplifted ocean sediments, carrying the fine debris of sand and silt down the slopes to the adjoining seas. The streams assumed a position dependent upon the slope of the elevated region, ever growing larger and larger as the area of land surface increased, and ever eroding deeper and deeper into the sediments as the region was lifted higher above the sea-level, until finally the region became covered with a network of meandering rivers and streams, trenching the ancient ocean beds into hundreds of valleys, ravines and gorges.

At last through the overlying strata the truncated edges of the pre-Cambrian rocks began to appear again at the surface. The streams cutting down through the softer Paleozoic rocks reached the hard rocks of the underlying crystalline peneplain, denuding large portions of the pre-Cambrian plain of its overlying sediment. The streams, settling down upon the underlying platform of crystalline rocks could not cease their work but continued their erosion, trenching numerous winding valleys into the once deeply buried peneplain.

A view of the pre-Cambrian peneplain after the partial removal of the overlying Paleozoic formations is illustrated in Plate LXX. The drawing is designed to illustrate the general features of the area just previous to the first glacial transgression.

The various processes bringing about the changes involved in the erosion of the sandstone and the uncovering of the buried peneplain and its dissection are still continuing throughout the area. In some parts, as in southwestern Clark and southern Wood and Portage counties, the sandstone is still the predominating rock at the surface; in other parts, as in the vicinity of Stevens Point, Grand Rapids, Pittsville and Neillsville, it is largely removed from the pre-Cambrian; and in still other parts, as in the region about Wausau, the sandstone has been almost entirely removed, and deep valleys have been trenched into the underlying peneplain. The process of removing the sandstone from the ancient plain of erosion was begun a long time ago, and is still continuing, as clearly illustrated in various parts of the area.

It is only in Portage, Wood and Clark counties that the sandstone formation still remains to furnish features of topography to the area.

The various processes above depicted for the general erosion of the mantle of sandstone overlying the pre-Cambrian is fully exemplified in the erosion of the mounds, ridges and plains of sandstone where these still remain and constitute prominent features of the land surface. The general distribution of the sandstone in the various counties of the area has already been described. (See pages 400–405.)

The prominent and picturesque topographic features of the sandstone lands are the irregular shaped ridges and mounds, especially the latter. All the hilly features are formed in the same manner, by processes of erosion, and represent but the remnants of vast beds of sandstone which once extended continuously across from mound to mound. The mounds occurring in the area of the old thin drift (First Drift) and in the old thick drift (Second Drift) have clearly acquired their subaerial erosion features subsequent to the early ice invasions.

The mounds are capped with resistant beds of sandstone, beneath which lie less coherent and resistant beds. This is shown by the fact that in many of the mounds it is only the stone at the summit that is strong enough to be quarried for building purposes, as illusrated by the quarries opened upon the summit of Mosquito Mound in southern Portage County, and upon

Saddle Mound in northern Jackson County. The mounds, therefore, in many instances, probably owe their existence to locally protecting beds of hard sandstone. While the distribution of streams and rivers may have determined the location of some as ridges and mounds along divides, the general unstable character of the formation seems to indicate that many of them owe their existence to differential erosion and to the removal of surrounding less resistant beds.

Two types of mounds may be differentiated, those with nearly vertical escarpments, and those with gentle talus slopes. Between these two extreme types there are all gradations.

In the former, relatively resistant beds lie beneath the protecting caps and hence the entire succession of beds weather more slowly into mounds with approximately vertical walls, the erosion proceeding chiefly along the vertical joints and along horizontal layers of softer sediments, dividing the mass into fluted and corrugated escarpments of great beauty. The latter have relatively soft beds beneath the overlying hard strata at the summit, and these develop into mounds with gentle talus slopes of loose sand. Compare Plates XLIX and XLV.

In certain parts of the area, mainly in northern Wood and northeastern Clark counties, the sandstone lies beneath a thick mantle of drift through which in only a few places it protrudes. Beneath the drift it probably constituted land forms similar to those outside the thick drift areas.

The sandstone over large parts of its area of distribution forms only thin sheets a few feet thick, extending over broad level tracts of the pre-Cambrian plain. This is especially true immediately north of the alluvial plain region of southern Wood and Portage counties. It is not unlikely that the sandstone is very thick underneath the principal portions of the sand plain of Portage, Wood and adjoining parts of Jackson county. Farther south the sandstone undoubtedly grows very thick and appears as buried hills and ridges beneath the thick mantle of alluvium of northern Juneau and northern Adams counties (see page 519), presumably similar in relief to the broken ridges, hills and mounds of sandstone in southwestern Clark county.

THE GLACIAL DRIFT HILLS AND VALLEY PLAINS.

In certain parts of the area there is an abundance of glacial drift, while in other parts there is much alluvium. The drift forms hills and rolling surface features upon the uplands, and the alluvium forms level stretches in many of the valley bottoms. Both glacial and alluvial features are superimposed upon the older topography of the crystalline peneplain and the sandstone formation, and very often these older land features show through the later drift and alluvium. The latest topographic features are therefore but modifications of the ancient peneplain, here deeply dissected, and there but partially uncovered of its mantle of sandstone.

A view of the area showing the superficial features of drift and alluvium upon the older features of eroded sandstone and crystalline peneplain is given in the diagram Plate LXXI.

The features of the Pleistocene and Recent topography fall into three groups, dependent either upon the structural character or the age of the deposits, and relate to the topography of the old drift formations; of the young drift formations; and of the alluvial or valley plains.

THE OLD DRIFT.

The older drifts (that of the First and Second formations) were deposited by ice sheets that invaded this district from the east and northwest. These drift sheets were deposited in the earlier part of the Glacial Age and subsequently have been subjected to a considerable period of stream erosion. The drift, therefore, no longer possesses the characteristic features of glacial topography but everywhere presents forms of sub-aerial erosion wrought in the relatively soft, incoherent drift. The streams have usually trenched entirely through the drift mantle to the sandstone or crystalline formation beneath, and the entire area of the old drift, with a very few exceptions, is well drained, with gentle slopes leading up from the rock-bound streams to the thick drift-covered upland above. Its topography is therefore in marked contrast with the abrupt topography of steep slopes and deep undrained areas characterizing the regions occupied by the later drift sheets.

The Marshfield Moraine.

Chief among the topographic features due to the old drift is the drift ridge extending in a broad curve through Marshfield, Lynn, Granton and Neillsville, (see Plates XLVI and XLVII). This ridge, standing from 100 to 150 feet above the flat-lying land to the southeast, south and southwest, is the terminal moraine of the Second drift sheet and can be seen for many miles from the southward. The continuation of this ridge northwest of Marshfield, is not prominent except in the vicinity of Medford, but north of Neillsville it has been followed across Clark County and for some distance into Chippewa County, and constitutes an important surface feature throughout its course. It is generally from one to two miles wide and from 75 to 150 feet high, with gentle slopes leading up to a broad indulating summit. Such a ridge would hardly be observable in a hilly or broken country, but in this area of plains it constitutes an important feature of the landscape.

The Arnott Moraine.—In the eastern part of Portage County is a prominent ridge of old drift, named the *Arnott Moraine,* representing the eroded terminal moraine of the Second drift, and thus is of the same age as the Marshfield moraine. Views of the Arnott moraine are shown in Plate LI.

Other features are the short drift ridges and hills from 20 to 40 feet high, which occur here and there over the area of old drift. A belt of these lies west of Grand Rapids along the terminus of the First drift sheet. Other ridges occur scattered over various parts of the area. These hills were built up at the margin of the ice sheets, and while greatly modified by erosion, they are characteristic forms of hills and are quite different in origin from the erosion hills of Potsdam sandstone.

The prevailing surface of the area of old drift is largely but the modification of the hard rock topography beneath, the general tendency being to superimpose upon the more rugged topography of the older land, a series of more gentle contours and broad curving slopes, while upon the undissected portion of the older land a slightly more uneven surface has undoubtedly been developed through the unequal deposition of the drift deposits. Thus the old land forms of the pre-Cambrian peneplain or the later mounds of sandstone superimposed upon it ever reflect through surface of the old drift veneer. The relief of southwestern Clark County, partakes mainly of the erosion topography of the sandstone, while upon the broad crystalline uplands of western Marathon and northern Wood, the mantle of old drift and its erosion contours modify appreciably the older land features.

THE NEW DRIFT.

Over a small portion of the southeastern part of the area and over a large portion of the northern part occur deposits of late drift of the Third and the Wisconsin glacial epochs. As shown upon the map (see Plate II) the area in the northern part has a widely curving boundary extending east and west, while in the southeastern part the border continues in a fairly straight line northwestward.

The surface features of the new drift are not due to stream erosion but partake largely of the constructional forms of glacial deposition. The topographic features of the new drift, therefore, are due to the manner in which the various characteristic deposits, such as the terminal moraine, the ground moraine, and the outwash plains, were formed by the invading ice sheet.

Terminal Moraines.

The terminal moraine is the most prominent feature of the new drift and constitutes a belt or zone characterized by abrupt hills and ridges associated with depressions and undrained areas, the hills and ridges generally reaching from 50 to 150 feet above the surrounding lower land. The terminal moraines extend across the district in broad curves and were formed beneath the lobate margins of great ice lobes that projected into the area. The whole or parts of the terminal moraines of four distinct ice lobes of the Wisconsin ice sheet are evidently present in the district. The location of these terminal moraines has already been described in some detail, and also the ice lobes producing them (pages 490–493).

Green Bay Moraine. In the southeastern part of the area in eastern Portage and eastern Marathon counties is the terminal moraine formed at the margin of the Green Bay lobe which extends as far north as 10 or 12 miles northeast of Antigo. Outside of this district this lobe extends as far south as Walworth county. In the southern part of Portage county the terminal moraine of this lobe stands up prominently above the alluvial plain bordering it on the west. In this locality is the old drift ridge, designated the Arnott moraine. The entire area of the Wisconsin drift in the eastern portion of Marathon county consists of the characteristic hill and sag topography of terminal moraine.

Langlade Moraine. In Langlade county, beginning about 10 miles northeast of Antigo and extending northwest across the county, is a comparatively short terminal moraine belt curving outward toward the southwest, and evidently built up by an ice lobe that entered this area from the northeast. This terminal moraine has been named the Langlade Moraine and its steep drift hills and deep basins constitute the prevailing surface features of northeastern Langlade county. In the vicinity northeast of Antigo, where the Langlade and Green Bay moraines meet, is a considerable area of nearly level land bordering the front of the terminal moraine, consisting of alluvial plains overriden by the Third drift.

Wisconsin Valley Moraine. In northwestern Langlade county there branches off from the Langlade moraine a terminal moraine which extends in a broad southward sweeping curve directly across the drainage of the Wisconsin river. This terminal moraine has been named the Wisconsin Valley moraine and was evidently formed by an ice lobe advancing southward into this area down the Wisconsin valley. East of the Wisconsin river in Lincoln county this terminal moraine covers most of the northeastern part of the county, but on the west side of the river it forms but a narrow belt extending to the northwest a short distance into Taylor and Price counties.

Chippewa Valley Moraine. In northeastern Taylor county, at the divide between the Wisconsin river drainage and the Chippewa drainage there branches off a prominent belt of terminal moraine forming a broad sweeping curve convex toward the southwest and extending across the entire drainage basin of the Chippewa river. This is called the Chippewa valley moraine, and in that part of it occurring in this district it forms a belt from 6 to 12 miles wide extending from northeastern Taylor county in a southwesterly direction into central Chippewa county.

In the area of new drift the terminal moraines, as already stated, constitute the prominent surface features, and in this region of broad plains they can be seen for many miles distant The hills of the moraine belts generally vary in height from 50 to 100 feet, although in many places they reach an elevation of over 200 feet above the surrounding lower land. Where the hilly terminal moraine occurs, it constitutes the predominating relief, but back of the terminal moraine belts, in the region of the ground moraine, the topography is that of the pre-Cambrian plain modified by the over-lying mantle of drift.

Terminal moraine of the Third drift. The lobes of terminal moraine just described mark the border of the late Wisconsin drift sheet, the latest of the drift formations. In southern Lincoln county extending across the Wisconsin river at Merrill is an older belt of less prominent drift hills which is the recessional moraine of an ice sheet earlier than the Wisconsin. The usual height of the drift hills of this moraine is from 20 to 40 feet.

In the northwestern part of the area in northwestern Lincoln county and in southern Price and adjacent parts of Gates and Taylor counties is a broad belt of gentle rolling land which represents ground moraine of the Wisconsin drift sheet. This area does not differ greatly in topography from that of the region of the older drift lying to the south of the border of the Wisconsin drift sheet; however, streams have trenched but little in the ground moraine and the area as a whole possesses the broad swelling contours common to recently glaciated areas.

Relation of Terminal Moraines to the Drainage.

The terminal moraine of the Green Bay lobe in the eastern part of the area is the divide between the drainage of the Wisconsin river, a branch of the Mississippi, and the drainage of the Wolf and Fox rivers, which lead into the Great Lakes and the St. Lawrence river system. The moraine itself appears to be superimposed upon a divide previously formed by these river systems, although there may have been some minor shifting of the drainage by the deposition of the terminal moraine. The Langlade moraine appears to lie upon a continuation of this divide between the Mississippi and the St. Lawrence systems.

The Wisconsin valley moraine which lies across the drainage of the Wisconsin river forms minor divides between the tributary branches of the Wisconsin, while the interlobate moraine formed at the junction of the Langlade lobe on the east and the Chippewa lobe on the west, forms major divides between the drainage of the Fox and Wisconsin on the east and the Chippewa and Wisconsin on the west. Like the Wisconsin valley moraine the Chippewa moraine forms minor divides between its side streams, while its interlobate moraine adjacent to the Wisconsin moraine, as above stated, marks the bounds of its drainage area on the east.

THE ALLUVIAL PLAINS.

Bordering certain portions of the Wisconsin river and many of its side streams and also the lower course of the Black river is a broad area of flat-lying alluvial plains of variable width. The plain covers a large part of Portage and Wood counties and the adjacent area farther to the southwest. It narrows northward along the Wisconsin river and along the side streams as these are followed to their sources.

The material of these plains consists of stratified sand and gravel and was evidently deposited by the rivers and streams which flow through them. The probable origin of the alluvial plain has already been discussed. Briefly stated, at an earlier date, the larger rivers of the area, such as the Wisconsin and its main tributaries, flowed in valleys much deeper than at present. In the southern part of the area the valley bottoms were probably over 200 feet below their present elevations, while farther north they were probably between 100 and 200 feet below. Subsequently the area, with the outlying regions, was depressed, the streams and rivers became sluggish and began to deposit sediments in their valley bottoms where at an earlier date they were swiftly flowing and constantly eroding. As the region slowly sank, the river bottoms became filled with successive layers of sediment until finally broad valley plains were formed, where before were the sloping sides of deeps valleys. Where the valleys were originally wide, the alluvial plains are broad and where they were originally narrow the alluvial plains are but narrow strips along the rivers.

Not all parts of the rivers of the area are bordered by alluvial plains. They are mainly confined to the lower courses of the streams outside the areas of the latest drift deposits. The alluvial plain of the Wisconsin river does not extend farther north than the immediate vicinity of Merrill. The latest drift deposits appear to be of later age and to overlie the extensive filled valleys of the area. The alluvial plains are broad and extensive, forming the main land surface in those parts of the area where the pre-Cambrian plain has been but partially uncovered or little dissected, namely, in southern Portage and Wood counties. They are narrow, forming the valley bottoms where the plain of the crystalline rocks has been trenched into deep valleys, as in Marathon county.

Since the alluvium was deposited in the valley bottoms, the region as a whole has been uplifted, the rivers have become more active, and, as a result, they are now busily eroding and entrenching their courses in the filled valleys. In consequence, new channels are sunk into the built-up flood plain, and terraces or benches are developed along the rivers. . The former level of the flood plain is generally referred to as the upper terrace and the present flood plain of the river, the lower terrace. Usually two or three intermediate terraces are developed between the oldest and the present flood plains.

CHARACTER OF THE DRAINAGE.

Perhaps attention should be called, in this place, to the character of the drainage in the driftless area, in the old drift area, in the new drift area, and in the alluvial plains area. The

Pleistocene map, Plate II, shows the distribution of the several areas referred to. A glance at the map shows the driftless area well drained. The areas of the old drifts, the First and Second formations, are also well drained and covered with a network of interlocking streams like the driftless area.

On the other hand, the area of the later drift, the Third and Wisconsin formations, is characterized by imperfect drainage. Marshes, ponds and lakes are a common accurrence. The area of the alluvial tracts is also characterized by poor surface drainage as indicated by the accurrence of broad marshes in southern Wood and Portage counties.

The drainage of the old drift areas, like that of the driftless is essentially complete and perfect, while that of the new drift area and the alluvial plains is incomplete and imperfect. This marked contrast in the development of the drainage is due to the fact that the driftless and old drift areas have been subjected to the processes of sub-aerial erosion long enough to establish perfect drainage upon them, while the newer drift and the alluvial deposits were so recently formed in the history of the area that complete and perfect drainage has not yet been established upon them.

THE LAKES.

Lakes are important features of the scenery, mainly in the region of the newer drift in the southeastern and northern parts of the district. The lakes of the area are of two kinds, the most important occurring in the glacial drift, the less important in the alluvial tracts. The existence of any hollow which is capable of holding water may give rise to a lake and hence many of the sags and depressions in the terminal moraines are occupied by lakes and ponds.

Many lakes in glacial regions are due to the depressions of drift in pre-existing valleys. All the lakes in the drift of this area, however, appear to be shallow and their bottoms do not extend appreciably below the general level of the surrounding land upon which the drift was deposited. Furthermore they are confined to the areas of terminal moraine where the unequal distribution of drift into billowy drift hills has developed numerous sags and depressions in which water readily accumulates to form lakes and ponds.

The lakes of the area are comparatively recent in origin and do not date back beyond the formation of the last two drift sheets. They are mainly confined to the terminal moraine of the Wisconsin ice sheet, but some small lakes in southern Lincoln county, such as Lake View at Merrill and those near Bloomville, were formed by the Third ice sheet. The few lakes in the area which have not been formed by the ice sheets during the later glacial invasions owe their development to the work of rivers. Reference may be made to Rice Lake in southern Marathon county, formed by the enlargement of the Little Eau Pleine river. Other lakes are those formed in the abandoned meanders along the Wisconsin river, namely, the Ox Bow Lake immediately north of Mosinee, and a few small lakes in an abandoned course of the Wisconsin river 5 or 6 miles north of Stevens Point.

Lakes probably once existed in the area of the older drift in eastern Clark, western Marathon and different parts of the adjoining counties, but have become extinct, for lakes are relatively but fleeting features of the landscape and sooner or later become obliterated by constant changes wrought in the land surface.

The Extinction of Lakes.

The usually recognized processes operating to destroy lakes are three: the down cutting of the outlet, thereby draining the lake; the filling of the lake basin by detritus eroded from the lake-shore or brought in by streams; and the accumulation of organic matter, both vegetable and animal, such as peat and marl, and sometimes chemical precipitation, formed in the lake itself. The relative importance of these processes varies greatly in different lakes, owing to the local conditions, for some lakes have no outlet, others have little debris which can be eroded from the lake shore, and others do not appear to possess the physical conditions congenial to the life of organisms, or for chemical precipitation.

There are other processes operating to extinguish lakes which do not appear to have been generally recognized by those who have studied lake phenomena, namely, the processes operating to lower the level of ground water in the area in which the lakes occur.

The level of lakes coincides with that of the ground water in the adjacent land and any change in the ground water level is soon reflected in the lake levels. The various causes, therefore which tend to permanently lower the ground water will operate to destroy lakes. One of the principal causes of permanent lowering of ground water is the opening of the land to agriculture, with its accompanying clearing of the forest growth and the cultivation of the soil. These changes due to cultivation appreciably increase the amount of run-off after rains and hence much of the rain-fall does not sink into the ground and reach the table of underground water. These processes of lowering the level of ground water vary greatly in different areas, depending upon local conditions, mainly the character of the underlying rock. In land areas underlian by dense crystalline rock but little change in the level of ground water appears to take place. But in porous formations of gravel and sand where the upper surface of the ground water is nearly level over large areas, the changes wrought by agricultural settlement appreciably affect the level of ground water and quite generally lowers it permanently.

The effect of the lowering of ground water level upon the extinction of lakes is especially well shown in southeastern Portage county where the surface formations consist largely of gravel and sand and are therefore quite porous throughout. In the broad level areas of alluvial plains bordering the Green Bay Moraine in this part of the area, the level of ground water has been lowered to depths varying from a few feet up to 40 feet since the region was opened to agriculture. It is a noteworthy fact also that in this area where the ground water has been appreciably lowered the lakes have become greatly contracted and many of them are entirely extinct. Most, if not all, of these contracted lakes, long ago lost their outlets and their bottoms do not contain an appreciable amount of filling due to wash or to organic agencies. The natural inference, therefore, is that these lakes are being destroyed by the same causes which have operated to lower the level of ground water of the area. In those parts of the area where the underlying formation consists of an abundance of clay or other impervious rock, where little change in the level of ground water has been wrought by cultivation, this process of lake extinction is relatively unimportant.

The uplift of a region, through crustal warping, causing a lowering of groundwater level, also exerts a powerful influence on the life of lakes. The various causes operating to lower the level of groundwater are regional in extent, and probably exert as strong an influence on the life of lakes as the local changes wrought within the lakes themselves or their outlets.

These processes, like the others, therefore operate in different degrees in the lakes of the area. While the various changes are slight when observed from year to year, yet these processes of lake extinction are certainly operating, and it is only a question of time when the lakes of this area will be destroyed.

THE RIVERS AND STREAMS.

The drainage of this area consists principally of the Wisconsin River and its tributaries, and the Black River and its tributaries. In the northwestern part of the area are branches of the Chippewa River, and in the southeastern part rise some of the head streams of the Fox River.

THE WISCONSIN RIVER.

The Wisconsin is the most important of the rivers, and the history of this principal stream and its tributaries will furnish in outline the principal features of development of the drainage system of the area.

The Wisconsin flows in a southward course through the middle of the eastern half of the area. Its main tributaries on the east are the Prairie, Pine, Trapp, Big Eau Claire and Little Eau Claire, and Plover rivers and the Buena Vista, Duck and Ten Mile creeks. Its main branches on the west are the Somo, Spirit, New Wood, Copper, Big Rib, Big Eau Pleine, Little Eau Pleine and Yellow rivers, and Mill Creek.

The Features of the Wisconsin River Drainage.

If we turn our attention to the courses of the Wisconsin River and its principal tributaries it will be found that all the tributaries from the west side pursue a similar course, in approximately parallel directions, toward the southeast to join the Wisconsin, while those from the east have likewise similar parallel courses running towards the southwest. All these stream valleys, moreover, are meandering and winding throughout, a feature no less true of the tributaries than of the Wisconsin, whose course is in a meandering valley throughout the area.

Another feature of the Wisconsin and its tributaries is the lack of confinement of their courses to one kind of rock, for everywhere the drainage courses lie indiscriminately through rocks of varying hardness and resistance. This is especially true with regard to the drift, sandstone and crystallines, but attention is called, for the present, only to the distribution of the streams in crystalline rocks.

The Wisconsin itself shows this feature the most strikingly. Through Lincoln County and farther south in Marathon County its course lies through crystalline rocks, which vary greatly in their hardness and resistance to erosion. Usually the valley is narrower in the harder rocks than it is in those of a softer nature, but throughout its winding course it lies indiscriminately across the various crystalline formations. The tributaries, especially those in Marathon County, where the valleys are rock-bound in crystalline formations, likewise flow indiscriminately from hard to soft rocks, now running parallel to the rock cleavage and now directly across the cleavage, with a total disregard for rock structure of every sort.

The branch valleys farther north in Lincoln County lie in drift and crystalline rock, and those in Portage and Wood in sandstone, alluvium, and crystalline rock. There is, therefore, throughout, an utter disregard shown by the rivers for the character of the rock over which they flow in their course towards the sea.

Attention may now be called to another characteristic feature of the drainage system of the area, namely, the lack of harmony between the size of streams and their corresponding valleys. In the lower courses of ordinary streams, whether they are large or small, the valleys are correspondingly larger than in their upper courses, where the streams are smaller. Yet this is quite the contrary with the valleys of the Wisconsin and those of its tributaries in this area, for, as previously observed in noting the topographic features of this area, the valleys of the Wisconsin in southern Lincoln and Marathon counties, are much deeper and more prominent than farther down stream in Portage and Wood counties. Between Merrill and Wausau the valley is 300 feet deep, at Mosinee less than 200 feet, and at Stevens Point and Grand Rapids but a few feet deep. The valley of the Big Rib in northern Marathon is much deeper and more prominent than that of the Big Eau Pleine in southern Marathon, although these two streams are comparatively the same size. Likewise the valley of the Little Eau Pleine is much deeper than that of Mill Creek farther south, though these two streams are of similar size.

The features common to the Wisconsin River and its tributaries are their meandering courses and their complete disregard for the varying character of hard and soft rock over which they flow. The most striking feature of the drainage is the lack of harmony between the size of streams and their valleys in different parts of the area.

Origin of the Wisconsin River Drainage.

Now it has been shown by numerous observations on the development of rivers in other parts of the world that under normal conditions, streams, when they have the usual steep grade and current, tend, not only to flow in nearly direct courses, but also to avoid the harder rocks, thus seeking to establish their courses upon the softer formations and to move along lines of least resistance. Rivers and streams of all land areas flow through valleys of their own shaping and it has been shown by countless observations that under normal conditions the larger the streams the deeper and wider are their respective valleys. In the lower course of the normal streams, therefore, whether they be large or small, the valleys are correspondingly much larger and deeper than in their upper courses where the streams are correspondingly smaller.

The Wisconsin and its branches, therefore, do not appear to be normal, but the contrary, and since all possess these abnormal features there seems to be some cause which has acted upon all alike which has modified the entire drainage in a similar manner. The cause which has produced the abnormal features of the drainage is to be sought for in the geological history of the area.

It has already been shown that the oldest land of the area is the pre-Cambrian plain, the mountain structure of its various rock formations indicating that they have been compressed and elevated into mountain ranges. Throughout the entire period when the land existed as a montainous region, it was subjected to the forces of weathering and erosion. Finally the region was worn down by erosion, to approximate sea level, and only a few isolated mounds of the most resistant rocks, mainly quartzite, remained as manadnocks standing in the plains as remnants of the pre-existing mountain land. This erosion interval probably began far back in pre-Cambrian time and certainly did not end until the Upper Cambrian epoch of early Paleozoic time. Throughout this great period, extending doubtless over millions of years, the pre-Cambrian is believed to have been above sea level. If at any time it was below sea level no record of its submergence now remains. During this long interval, the pre-Cambrian was not only worn down to approximate sea level, but during the closing stages of its period of degradation its surface rocks became deeply weathered into residual clays and soils. The transformation of the mountains of the pre-Cambrian to a plain required a vast amount of time, but when it was completed, the rivers and streams which brought about the change had fixed their courses in the softer rocks and had avoided the more resistant ones, as shown by the existence of such quartzite hills as Rib Hill, Mosinee Hills, Hardwood Hill, Powers Bluff and some granite knobs which stand as monadnocks in the ancient peneplain.

During upper Cambrian time the plain of the pre-Cambrian land sank beneath the Paleozoic sea, the then existing sluggish drainage was obliterated and buried beneath beds of sand, the Potsdam sandstone, laid down in horizontal strata upon the truncated and deeply weathered rocks of the peneplain. After a long period of submergence and sedimentateion the region was elevated and appeared again above the sea, covered with the sandstone and perhaps later formations as well. The region was evidently elevated by simple vertical uplift, as indicated by the very gentle dip of the sandstone formation.

Drainage Consequent Upon the Paleozoic and Superimposed Upon the pre-Cambrian.

It has been shown by observation in other parts of the world that when the bedded deposits of the sea bottoms are elevated by simple uplift above the sea, the streams that gather upon the land surface produce a set of primary streams running in a general direction at right angles to the axis of uplift, and therefore along the direction of the dip of the beds, and a set of secondary streams whose courses are directed along the strike of the strata and approximately at right angles to the primary. The strata also break into vertical joints along the dip and strike of the beds which tend to guide respectively the courses of the primary and secondary streams. River systems that have been initiated as the result of emergence of an area composed of stratified rocks which were originally horizontal have been described by Gilbert[1] as consequent upon the structure and hence consequent streams would, if conditions were uniform, run in straight lines, and the main direction of these streams is usually nearly straight, but in actual emergence of rocks many minor inequalities are developed which tend to divert the streams from side to side, giving them sinuous courses. The secondary tributary stream will only be approximately at right angles to its primary stream because the main slope of the region is along the dip of the beds and hence the tributaries generally run obliquely to the strike joints of the beds to join the trunk streams, as well as to develop sinuous courses from side to side.

It has already been shown that the Wisconsin River has a meandering course southward down the main slope of the area and that its tributaries are meandering streams flowing nearly at right angles to it. Hence these streams have the position and meandering courses of primary and secondary consequent streams developed upon an uplift of gently sloping strata such as we know this region must have been, when, with its covering of Potsdam sandstone, it was elevated above sea level. Compare Fig. 38 with Plates LXIX and LXX.

[1]Geology of the Henry Mountains. G. K. Gilbert, U. S. Geol. Survey, pp. 137-8, 1880.

CHARACTERISTIC EROSION OF COARSE GRANITE, THREE ROLL FALLS, EAU CLAIRE RIVER.
Illustrates a superimposed river on the pre-Cambrian peneplain.

This view of the origin of these streams is strengthened by the distribution which the primary trunk streams have assumed in radiating from the pre-Cambrian Highlands of northern Wisconsin. All the streams flow down the slope of the pre-Cambrian and down the dip of the surrounding Paleozoic beds to the Mississippi and Great Lakes on the outer borders of the state.

But the distribution and meandering courses of the streams flowing from the pre-Cambrian highlands across the Paleozoic strata to the outer borders of the state is not all the evidence available, for if one should visit the streams along the border of the Paleozoic and pre-Cambrian districts in Portage, Wood and Clark counties, today the meandering consequent streams, developed upon the Paleozoic sediments, can be observed in the very process of sinking their channels through the overlying strata into the crystalline rocks beneath.

Perhaps one of the best streams in which to observe the process of drainage superposition is the Wisconsin River itself. In Wood and Portage counties, this river, while everywhere apparently bottomed in crystalline rock, shows in many places, just above the water's edge, the low escarpments of sandstone, while upon the surrounding low plain below which the river has sunk but a few feet there are numerous remnants of the sandstone dotting the partially uncovered pre-Cambrian plain. Here the Wisconsin, therefore, is seen to have just penetrated through the sandstone and to have just begun the process of sinking its channel into the crystalline rocks beneath.

Attention has already been called to a prominent characteristic feature of the drainage of the area, namely, the lack of harmony between size of streams and their corresponding valleys. We now have the explanation of this abnormal feature. This apparent lack of adjustment of valley to stream finds its explanation mainly in the relative case of erosion of the sediments overlying the pre-Cambrian, as compared with that of the hard and more resistant pre-Cambrian. Portage and Wood counties lie at the border of the Paleozoic and pre-Cambrian districts, where the streams have been able to remove most of the soft incoherent sandstone, and have not yet had time to carve valleys in the underlying resistant crystalline rocks. As time goes on, the valleys in the southern part of the area will become deeper and more prominent in the crystalline rocks, like those farther north in Marathon County, where a sufficient time has already elapsed for deep channels to be sunk into the pre-Cambrian since its denudation of overlying sandstone. This lack of harmony between stream and valley in the area is therefore in consequence of the initiation of the older consequent drainage pattern upon a rock structure with which it is wholly out of harmony, and, is the natural result of the superposition upon the pre-Cambrian, of a drainage system, which had been previously developed upon the overlying Paleozoic strata.

Résumé of Development.

We may therefore conceive the initial course of the Wisconsin and its tributaries and other main streams to have begun as soon as the Palezoic sediments emerged above the sea and became dry land. Upon this new land surface the streams flowed and established their courses in harmony with the conditions there existing. They were uninfluenced by the buried topography of the pre-Cambrian and pursued their courses on the slowly rising land surface as consequent streams. Gradually they sank their valleys deeper and deeper into the Paleozoic sediments until finally, one by one, they reached the underlying crystalline peneplain. The highest land was the first to rise above the sea and therefore, being subjected longest to erosion, was earliest denuded of the overlying sediments.

The primary streams first reached the crystalline rocks and then the secondary tributaries. The structure and character of the crystalline rocks upon which the streams now began to flow was extremely complex and entirely different from that of the overlying sediments through which they had just cut their valleys. On reaching the buried pre-Cambrian the drainage was immediately out of adjustment with the conditions there existing, for in place of the soft, gently sloping, strata of sandstone there was met the steeply dipping schists and beds of various formations of great hardness trending and dipping in various directions. Nevertheless the streams unable to alter their courses continued to sink their channels into the crystalline rock below with the same meandering courses which they had acquired upon the sloping beds of overlying sediment. Thus it came about that these streams cutting into the various rocks which they

CHARACTERISTIC EROSION OF THE RHYOLITE SCHIST, DELLS OF THE EAU CLAIRE RIVER.
Illustrates a superimposed river on the pre-Cambrian peneplain.

happened to uncover would here erode a hard rock and there a softer one, as each chanced to appear in their courses. In this manner, therefore, a drainage system which had been developed in harmony with the condition of slope and structure existing in the overlying Paleozoic sediment became fixed in the underlying pre-Cambrian, although out of adjustment with the conditions of structure and character of rock there existing. Thus the consequent streams developed upon the Paleozoic with their meandering course along dip and strike of the gently sloping strata continued their meandering habit as superimposed streams upon the underlying pre-Cambrian peneplain.

The Wisconsin and its tributaries, in this district at least, very evidently developed their initial courses far back in time, even as geological chronology is reckoned. The extreme probability that they had their inception in strata overlying the pre-Cambrian is not only shown by their distribution and meandering courses in this district, but all the streams of the state, as already stated, are seen to radiate to all parts of the compass from the crystalline highlands, crossing, without any break or unconformity at the contact, to the outer zone of gently dipping Paleozoic formations over which they continue their courses along the dip and strike of the strata in the manner of consequent streams developed by symmetrical uplift of horizontal strata.

At the border of the pre-Cambrian and overlying Paleozoic the streams have largely removed the soft sandstone, and the recently superimposed streams are just beginning to sink their valleys into the underlying crystallines. Farther north, where the pre-Cambrian has long been denuded, the superimposed streams have carved deep valleys into the crystalline plain. Farther south, where the sandstone and other Paleozoic strata still lie in great thickness upon the pre-Cambrian, the Wisconsin and its tributaries have likewise sculptured deep valleys in the Paleozoic plain.

The Modifications Wrought during the Pleistocene Period.

But while the Wisconsin river drainage of the area is consequent upon the Potsdam sandstone and superimposed upon the pre-Cambrian crystalline rock as a whole, it is not consequent or superimposed in all its details. It remains now to describe some of the local modifications of the drainage and the causes which have produced them.

In Lincoln County the Wisconsin and its tributaries flow in shallow valleys somewhat similar to those in Wood and Portage counties, although this part of the area would ordinarily be supposed to have deeper valleys than Marathon County, because of its higher elevation, and under normal conditions its crystalline rocks would be subjected to longer erosion since its denudation, and in consequence there would be development of deeper valleys. It has already been shown, however, that most of Lincoln County is covered with abundant glacial drift of comparatively recent deposition, and very probably the accumulation of the drift in pre-existing valleys has greatly modified the pre-glacial drainage lines of this part of the area. In other parts of the area, especially in the southern part, there is an abundance of alluvium in the valleys through which the drainage lines now have their courses. In the broad tracts of alluvium some minor streams appear to have been recently modified and others may have been entirely developed.

In this connection, therefore, it may be well to call attention to some general changes in the area due to subsidance and re-elevation, and to the glacial invasions, during the Pleistocene period. Before doing so, however, the probable development of the drainage at the beginning of the Pleistocene period will be pointed out. See, also, Plate LXX.

It has already been shown that previous to the time of the valley filling and the deposition of the wide areas of alluvium in southern Wood and Portage counties, the streams of that part of the area flowed from 100 to 200 feet below their present elevations. In order that the stream could flow at this lower elevation the area as a whole must have been correspondingly higher above sea level. This period of greater elevation of the area appears to have been in the early part of Pleistocene time, although it may have been somewhat earlier or even later than this. But whatever the date, there evidently was a time when the region stood higher above the sea than at present, when neither alluvium nor glacial drift covered the sandstone and crystalline rocks of the area. This period, on account of the greater elevation also, was one during which the streams flowed more swiftly than at present and when erosion of the land was

THE NARROW GORGE OF THE DELLS OF THE PINE RIVER AND THE BROAD VALLEY BEYOND.

correspondingly more rapid. At that time the streams had uncovered the pre-Cambrian plain as far south at least as Necedah in central Juneau County, and this part of the state was deeply furrowed with valleys in the sandstone. Farther north in Portage, Marathon and Lincoln counties, the valley of the Wisconsin was much deeper than at present and the side streams for certain distances up their courses were correspondingly deeper. The entire area at this time, with other parts of the state, was trenched by deep rock-bound valleys in which the rivers and streams flowed to the sea. At this time the drainage in all its minor as well as major details was consequent upon the Paleozoic or superimposed upon the pre-Cambrian rocks.

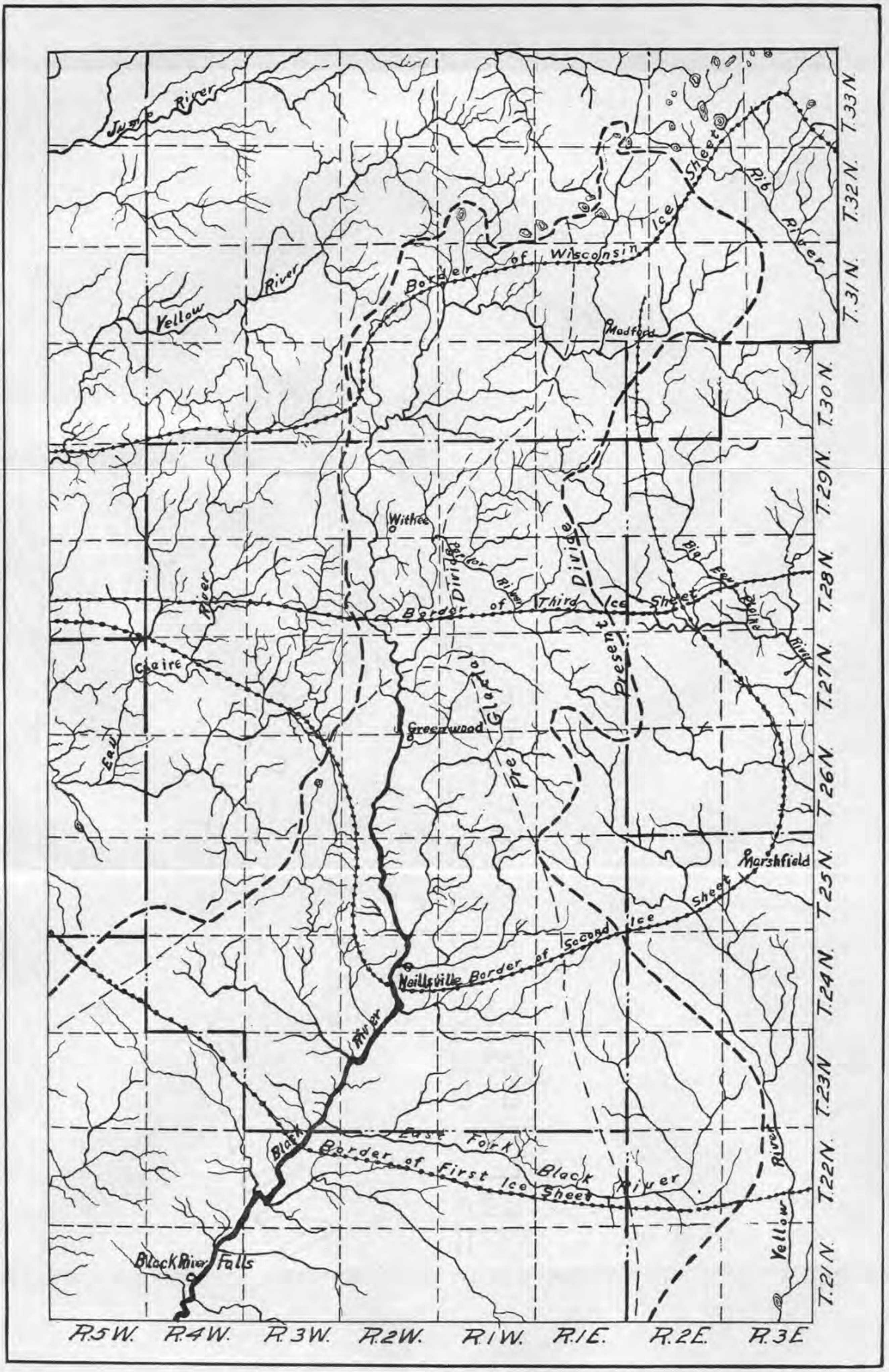
This condition of deep valleys marked the close of what appears to have been a very long period of almost continuous erosion of the land succeeding the emergence of the Paleozoic sediments. During this long period the rate of uplift and consequent erosion may have greatly varied from time to time but there is no record in this area that stream work entirely ceased on account of submergence of the region below sea level.

Finally the changes wrought during the Pleistocene period were brought about. In the glacial drift of various parts of the area are the records of four successive glacial invasions, and in the valley alluvium are records of subsidence and re-elevation. The sinking of the land and its re-elevation may not have been a single continuous movement and the land may have been raised and sunk more than once, but the sum total of the movements as recorded in the valley deposits is that which might have been brought about by a single movement of considerable subsidence followed later by a slight uplift. Through the deposition of drift by the successive ice sheets in different parts of the area and the filling of valleys by the rivers, the valleys through which the rivers and streams flowed were greatly modified.

In the area occupied by the earlier ice sheets the streams have re-opened many of their former valleys, while in the northern and southeastern parts of the area where the extensive deposits of the Wisconsin drift occur, but little change has been wrought by the streams since the disappearance of the ice. Through subsidence of the land, the valleys of the southern three-fourths of the area in Marathon, Portage, Wood and Cark counties were filled with much alluvium, the broad sloping valleys of the southern part of the area being replaced by nearly level tracts of valley deposits. After the larger valleys of most of the area were filled to a certain extent, the region was uplifted and the rivers and streams began to intrench new channels in the alluvial bottoms, where formerly when at lower elevations they were depositing material.

The Wisconsin River has very probably been shifted to some extent to the west in southern Portage and Wood counties where extensive filling of its former valley has occurred. From Stevens Point to Merrill the Wisconsin has persisted in its present course since its initial development consequent upon the emergence of the Paleozoic strata. North of Merrill the course of the Wisconsin, just previous to the Wisconsin stage of glaciation, may have been along the Little Hay Meadow creek and the small stream flowing to the north, the present location of the C., M. & St. P. railroad, as this valley is much more pronounced than the one in which the Wisconsin River is located. The Pine River, which at an earlier date joined the Wisconsin north of the present junction, has a very prominent valley throughout its course, so prominent indeed as to strongly suggest its former occupation by a more important stream, in pre-glacial times, as this valley may be continuous with the valley of the Pelican River, which joins the Wisconsin at Rhinelander. Minor changes in the course of the Wisconsin between Wausau and Stevens Point, caused by meandering from side to side in its alluvial plain, are especially noticeable north of Stevens Point and above the rapids at Mosinee. A slight change has been noted in the course of the Wisconsin at Merrill. The changes in the channels of some of its tributaries, such as the lower courses of the Pine, Eau Claire and Big Rib, have been referred to. That of the Pine is due to the filling of its lower valley with glacial drift (see p. 480) while changes in the Big Rib and Eau Claire near Wausau are due to the work (see p. 541) of these respective streams in their endeavor to adjust themselves in their filled valleys.

In southern Portage County, in the outwash plain and alluvial flat bordering the terminal moraine, Buena Vista, Duck and Ten Mile creeks evidently originated upon the alluvial plains. These streams may or may not have been larger during the presence of the Wisconsin ice sheet to the east. A stream



THE UPPER PART OF THE BLACK RIVER DRAINAGE, SHOWING ITS RELATION TO THE SEVERAL DRIFTS, AND ITS PROBABLE PRE-GLACIAL EXTENT.

at one time flowed from Clauds Lake northwest to join Ten Mile Creek, but became extinct long ago, probably soon after the retreat of the Wisconsin ice sheet. See the abandoned river and stream courses shown on the Pleistocene map, Plate II.

THE BLACK RIVER.

The Black River, which drains a large portion of Clark and eastern Taylor counties, lies between the Wisconsin drainage on the east and the Chippewa drainage on the west. This river has the source of many of its head branches in the terminal moraine of the late Wisconsin drift, and flows southward across the older drift series of the district. The sandstone is the prevailing bed rock beneath the drift in Clark County, but farther north, in Taylor County, the crystalline rocks of the pre-Cambrian peneplain prevail. In the area of the crystalline peneplain the land is quite flat and covered with much drift of both the earlier and later stages. In the area of the sandstone, however, the relief is more broken, the valley of the main river is comparatively narrow, and many crystalline rock rapids occur in the river.

General Features of the Black River.

The profile of the Black River shows it to have by far the steepest grade, and therefore the swiftest current, of any river of its size within the state. The rivers flowing north to Lake Superior, while having quite generally swifter currents than those flowing to the south, are much smaller than the Black. The profile of the Black from Withee to Black River Falls, as far south as crystalline rapids extend, is shown in the profile, page 543.

The elevation of the river immediately below the rapids at Black River Falls is 749 feet above sea level, and at the Wis. Cent. R. R. bridge 1½ miles west of Withee it is 1,187 feet, a difference in elevation of 436 feet within a distance approximating 70.1 miles, thus possessing an average gradient of 6.2 feet per mile, the maximum gradient reaching nearly 20 feet per mile.

The drainage district of the Black River, above Black River Falls, has an approximate area of 1,600 square miles. Much more than one-half of this drainage area, namely 1,100 square miles, lies east of the main stream, the two principal tributaries from the east being the East Fork and the Poplar River.

The Black River drainage system presents a number of interesting physiographic features, only the briefest account of which can be given in this report. The Wisconsin River and its tributaries in this district has already been described as a drainage system developed consequent upon emergence of the Paleozoic strata, and later superimposed upon the underlying crystalline peneplain. The abnormal features of the Wisconsin drainage are readily explained as the necessary resultant of this process of superposition, with some minor changes due to subsequent glaciation and valley filling.

The Black River likewise illustrates a drainage system developed upon the gently sloping sandstone which is now in process of becoming fixed in the underlying crystalline peneplain. The Black, however, and its tributaries, have become but slightly intrenched within the crystalline formations, for it lies mainly in a region where the sandstone is yet the principal surface rock. The abnormal features, due to superposition, therefore, will become more pronounced as the drainage sinks deeper into the underlying crystalline formations.

Abnormal Features.

The abnormal features of the Black River, to which attention is directed, are the lack of harmony in the courses and in the location and distribution of its various tributaries with respect to one another, and to the adjacent drainage lines of the Wisconsin and of the Chippewa rivers. The abnormal features, therefore, are due to the inharmonious courses of the streams rather than an incongruity due to the relative size of the valleys.

The location of the Black River and its tributaries and adjacent drainage lines of the Wisconsin on the east and the Chippewa on the west is shown in the accompanying map. (Plate LXXV).

Examples of Stream Piracy.

Attention may first be called to the largest tributary of the Black, the East Fork, which joins the main stream about 10 miles below Neillsville. It may be observed that the main branches of the East Fork, located about 25 miles up stream, have a southeasterly course, whereas the main stream below these branches flows in the direction nearly opposite, namely, northwest.

One of the most striking characteristics of the courses of streams is, that, as a rule, the tributaries join their mains with an obtuse angle down stream, for under normal conditions a main and its tributaries are developed upon the same slope, and hence all would flow in the same direction. Local irregularities sometimes interfere with these normal relations, but the uniformity in character of the sandstone upon which these streams were developed very probably does not furnish the necessary irregularities of rock or surface features for the development of such abnormal features. A glance at the course of the Wisconsin River and its principal and secondary tributaries, or of other streams of the state, shows them invariably joining their mains at an obtuse angle down stream. The fact, therefore, that the head tributaries of the East Fork have an opposite course from their main, joining the latter at an acute angle instead of an obtuse angle down stream, is a striking abnormal feature. Now a comparison of the courses of the head streams of the East Fork with those of the Yellow River, a tributary of the Wisconsin, shows the former to be parallel with the adjacent tributaries of the latter and clearly directed toward the main valley of the Yellow. The head streams of the East Fork of the Black River, therefore, have the course and location of streams originally developed as tributaries of the Yellow River. Some time after their development as a part of the Yellow River drainage, they were evidently deflected to the Black River system. This change was brought about by the capture of these head streams from the Yellow by the East Fork, favorable conditions for their capture being caused in part perhaps by the changes due to glacial or alluvial deposition in this part of the district. The capture by a stream of the tributaries of another is often referred to as river or stream piracy and is not an unusual proceeding in the life-like behavior of streams.

The course of the Poplar River, the next largest tributary of the Black, which joins its main 4 miles north of Greenwood, is also unusual, for its main branches, the South and North Forks, after their junction, continuing in the course of the South Fork, have the abnormal feature of joining the main Poplar at an acute angle down stream. The course of the South Fork is northwest, while that of the main is but slightly southwest. The south branch of Rock Creek, which joins the Black at Greenwood, runs parallel with the abnormal course of the South Fork of the Poplar. The course of the South Fork of the Poplar, strongly suggests its original development as a part of the Wisconsin River drainage either as a tributary of the Yellow or of the Little Eau Pleine. The courses of the small branches flowing into the South Fork in the towns of Unity and Green Grove, strongly suggest a southeast flow of the main branch in harmony with the Wisconsin drainage system when these minor tributaries were developed.

An unusual feature of the course of the Black River itself is the bend two miles south of Medford, where it changes its course from the southwest to the northwest, and, after flowing to the northwest for 10 or 12 miles, turns to the south again. Normally, it should continue its course down the prevailing southwest slope of the region in general parallelism with its southwestward flowing tributaries in this vicinity. That the course of the Black at the bend should be to the southwest rather than the northwest is shown by the fact that in times of high water there is an overflow in this vicinity from the main channel of the Black through a southwestward flowing tributary which reaches up to it. The course of the overflow is shown in the map Pl. LXXV, in the S. W. corner of T. 31, R. 1 E. There is a line of gravel ridges extending southward from the bend in Black River, through a slight depression, and approaching very near or up to the drainage of the North Fork of the Poplar, which may represent the course of a pre-Pleistocene or early Pleistocene stream. The tendency for the overflow of the Black River to pass through its tributary southwest of the bend instead of the round-about way occupied by the main stream is in harmony with the law that the drainage of an area normally takes its course down the main slope of the land. In this part of the district, the dip of the sandstone beds, as well as the land slope, is to the southwest, and normally, therefore, the main river and its tributaries should flow to the southwest. The local channel of the main and its overflow tributary have not been studied in detail, but it seems likely that, if left to itself, the tributary will, in time, sap its trunk, capture the head waters of the main, and become finally the main channel of the river.

The tendency illustrated in this particular locality, where the actual process of stream capture can be observed, very likely furnishes the explanation of most, if not all, the abnormal features of the courses of the east tributaries of the Black River system. The conformity in slope of the land to the dip of the strata is the necessary accompaniment of the evolution of the land sculpture of a region in accordance with the law of structure. It has already been shown that the general slope and dip of the sandstone in the western part of this district is to the southwest. Normally, therefore, the drainage of this part of the district should assume a southwesterly course, such as that required by the Chippewa tributaries farther northwest.

The capture of the East Fork of the Black of some of the tributaries of the Yellow River is very probably mainly due, therefore, to the strong tendency of the Black River drainage to follow the law of structure. The tributaries of the Black flowing down the slope of the land in conformity with the dip of the sandstone have been enabled to erode faster than the tributaries of the Wisconsin in this locality, whose courses lie across the land slope. The former, therefore, eroding through the dividing ridges which separated them from the latter, were enabled to capture some of the upper branches of the Wisconsin system.

All of the above described diversions are by east tributaries of the Black, whose positons and courses are in full accord with the land structure.

In sharp contrast with the larger east branches of the Black are the smaller west branches, the latter being relatively very weak. The west branches not only show no captures of adjacent tributaries, but appear themselves to be in danger of capture by the southwestward flowing tributaries of the Eau Claire, a principal branch of the Chippewa system. The tributaries of the Eau Claire are vigorous because their positions and courses are in harmony with the land structure, and for this reason, therefore, they have extended their courses remarkably close up to the Black River itself. In sections 8 and 17, of T. 28, R. 2 W., branches of the Eau Claire are within one-half mile of the main channel of the Black.

Thus there is clearly aparent a very strong tendency, shown in the drainage of the Black River and of the Chippewa on the west, for the drainage lines of each to develop according to the law of structure, and for this reason, since in this part of the district the prevailing surface rock, the sandstone, dips to the southwest, the drainage of the Black has been extended to the northeast into the territory of the Wisconsin system, while the drainage of the Chippewa, in the same manner, and for the same causes, holds sway in the apparently legitimate territory of the Black.

Theory concerning the pre-glacial extent of the Black River drainage.

While the Eau Claire tributaries are dangerously near to the channel of the Black River, there is, however, no obvious instance of the capture by the Eau Claire of a branch of the Black. And this fact, combined with others, strongly suggests the possibility that the entire upper portion of the Black River drainage as a part of the latter's system may be comparatively new. Another feature of the Black River drianage which strongly suggests its youthful age is the very narrow valley possessed by its main channel north of Neillsville as compared with the valleys of rivers of similar size of this part of the state.

It is not the purpose, however, of the writer to go into details concerning the most probable course of development of the Black River drainage system, and only suggestions are here offered which may be fruitful of further research and a more complete later investigation when the necessary data, such as abundant well records and topographic maps, are available.

It is suggested, therefore, that the upper head waters of the Black River may at one time have belonged to the Eau Claire River, and was originally joined to it somewhere in the vicinity where the tributaries of the latter at present encroach close to the Black, and if this were true the drainage would have been entirely in harmony with other parts of the Chippewa drainage, in harmony with the law that land drainage devlopes in accordance with the structure, and also in harmony with the tendency to be observed at the present time, for the drainage to flow to the southwest. It is suggested that the Black River system extended originally only some distance above Neillsville, and included only those tributaries that have southwest courses in harmony with that portion of the system below Neillsville. And it is further suggested that the causes which may have brought about the diversion of the main branch of the original Eau Claire to a branch of the original Black was the work of the ice sheets which deposited the very old drift in this part of the district.

The probable pre-glacial divide between the Black and the outlying drainage is indicated on the map, Plate LXXV. The glaciation producing the First drift sheet may not have been adequate to bring about the change suggested, but that of the Second, with its terminal moraine generally from 50 to 150 feet thick, and often over 200 feet thick, was evidently sufficiently vigorous to bring about considerable changes in the pre-existing drainage of a region with such slight relief as this. The capture of the Wisconsin tributaries, as already suggested, was very likely due, wholly or partly, to changes wrought by the deposition of the old drift or to alluvial filling.

The various changes suggested in the Black River system are supposed to have been brought about in the early part of the Pleistocene period, and hence a comparatively long time has since elapsed, during which the present drainage has carved deeply into the old drift formations, developing a perfect drainage upon them, and in many places eroding deeply into the underlying sandstone and crystalline rock. The Black River drainage, therefore, at the time of the Wisconsin stage, and also at the preceding stage of glaciation, was in most, if not all, its details, the same as at present, and its upper tributarics gathered into its main channel the glacial waters of the adjacent borders of these ice sheets. In pre-glacial time, however, as above suggested, the Black River may not have extended far above Neillsville, the territory now drained by the upper Black then being drained by tributaries of the Wisconsin and the Chippewa jointly, but mainly by those of the Chippewa, the entire drainage then being consequent upon uplift of the sandstone and in harmony with the law of structure.

PART III.

ECONOMIC GEOLOGY.

OUTLINE.

Under economic geology is described the various geological formations of the area which have or may have a commercial value. The economic geology is described in one chapter, Chapter XIII divided into three sections:

Section I. The Mineral Resources.
Section II. The Water Supplies and Water Powers.
Section III. The Soils.

CHAPTER XIII.

ECONOMIC GEOLOGY.

The geological resources of the area are: the mineral resources, consisting of various rock and mineral supplies; water supplies, and water powers; and soils.

SECTION I. MINERAL RESOURCES.

The mineral resources include various kinds of stone, such as granite, used for building and monumental purposes; sandstone, used for building purposes; boulders, used for building; sand and gravel, used in the manufacture of cement and concrete; granite and other igneous rocks used for macadam and road material; clays used in the manufacture of brick; crushed quartz, used mainly for abrasive purposes; and carbonaceous schists, and iron-bearing rock, used for mineral paint.

MONUMENTAL AND BUILDING STONE.

The stone of this area used for monuments is granite. For building stone, granite, glacial boulders and sandstone are used.

GRANITE.

One of the earliest granite quarries operated in Wisconsin is located at Granite Heights, ten miles north of Wausau. The granite quarried is generally a bright red variety, a phase of the widespread granite formation of this area (see pp. 179–187), and is quite generally known as the Wausau granite, or the Wausau red granite.

In the vicinity of Granite Heights station the granite forms the steep valley sides of the Wisconsin River. the valley at this place being about half a mile wide and between 200 and 300 feet below the surounding upland area. Granite is obtained from both sides of the river. Formerly it was largely quarried from the steep slopes of the east side of the valley near the station, but at present it is largely obtained from separated blocks of granite, or granite boulders, from the west side of the river.

Granite of similar red color and texture is also quarried from large blocks and boulders about seven miles southeast of Granite Heights in Sections 34 and 35 of T. 30, R. 8 E.

Character of Granite.

The color of the granite in the vicinity of Granite Heights is red, reddish brown, and gray. At present, however, the only granite quarried and placed upon the market is the bright red variety from the west side of the river. The granite consists of quartz and feldspar of medium and fairly uniform size, with very little mica and hornblende. The feldspar generally forms about 60 per cent of the rock and is of a reddish color. The quartzes are clear and transparent, which, combined with the red feldspar, gives the rock, when polished, a bright red pleasing color.

The chemical composition of samples from Anderson Brothers and Johnson's quarry, west of the river, analyzed by Prof. W. W. Daniells is as follows:

Analysis of granite.

SiO_2	76.54
Al_2O_3	13.82
Fe_2O_3	1.62
FeO	....
CaO	0.85
MgO	0.01
K_2O	2.31
Na_2O	4.32
H_2O	.20
	99.67

The physicial tests of Wausau granite made by Dr. E. R. Buckley[1] shows the granite to be adapted to the usual contstructions for which granite is used. The compressive strength as determined by crushing two-inch cubes varies from 22,507 pounds to 27,200 pounds per square inch. Transverse tests, made upon small rectangular pieces, gave an average modulus of rupture of 2,518.5 pounds per square inch.

The Wausau granite was originally largely used for building stone and paving blocks. At present the stone is used almost entirely for monumental purposes.

INDIVIDUAL OPERATORS.

Anderson Bros. and Johnson.

The quarry operated by this firm is located on the west side of the river at Granite Heights, the cutting sheds and polishing mills being located at the railroad station on the east side of the river. The stone is quarried from large blocks covering the side of the hill near the natural outcrop. The supply of stone of ordinary dimensions is very abundant. A large block, without a detectable seam, measured 15 feet by 19 feet by 4 feet. The stone is the bright red variety. The blocks are usually not weathered deeper than two inches, and are essentially free from veins or discolorations. The plant of this firm is well provided with engines, derricks and polishing machines.

[1] Bulletin IV, Wis. Geol. and Nat. Hist. Survey, pp. 137–7.

Marathon Granite Co.

The quarry operated by this company is located in Sec. 34 and 35, Town of Texas, T. 30, R. 8 E. The cutting sheds and polishing mill are located in Wausau. The stone is hauled by team from the quarries to the mill. The stone is quarried from large blocks covering a solid ledge, the supply of the ordinary dimensions, being sufficiently abundant to last for years. The stone is the bright red variety and is at present used exclusively for monumental purposes, being identical with that obtained by Anderson Brothers and Johnson. The cutting and polishing plant of this firm is well supplied with modern machinery.

A new quarry was recenty opened by this company in the western part of Sec. 13, T. 29, R. 6 E. The rock (a phase of quartz-syenite) has a greenish tone of very pleasing color.

Small Quarries.

Numerous small quarries in the granite and related igneous rock are operated on a small scale for building stone throughout the area. In the northwestern part of Wausau the red quartz syenite is quarried for building stone, and about three miles northwest of Mosinee, granite is quarried.

Boulders.

Most of the stone used for building in Marathon, Lincoln, and parts of Portage and Wood counties is the ordinary field stone, either glacial boulders or the loose blocks weathered in place from outcrops. Over the area of the First drift sheet, (see map, Plate II), the loose stone and blocks, weathered in place, are largely used. In the region of the thick drift deposits, suitable boulders for building basements can readily be obtained from the glacial deposits, as well as from the loose blocks weathered in place.

UNDEVELOPED GRANITE LOCALITIES.

Granite suitable for monumental and building stone occurs at various localities throughout the area. Outcrops of granite suitable for quarrying and the market should not only be of the right quality in regard to durability, ease of quarrying, and of suitable color and texture, but should also be conveniently located for transporting to the market.

In the few localities cited below are granite outcrops that are worthy of investigation for quarrying purposes. In the vicinity of Granite Heights is an abundance of granite on both sides of the river, in which various openings have been made. This granite is mainly the red variety, but brownish red and gray granite also occur in places. In some of the openings the stone is mainly suited for building stone and in others it is well adapted for monuments. In this vicinity on both sides of the river, for several miles along the river the granite forms the valley sides, either as steep escarpments or gentle slopes. Much of this granite is the bright red variety, such as that being quarried at present.

A gray granite of fine to medium grain occurs in abundance at the dells of the Prairie River in Lincoln County, where the water power is now being developed. The granite at this place appears to be of an excellent grayish color, of good quality, and in sufficient abundance for quarrying. It has weathered into rectangular blocks of various dimensions and has the appearance of an outcrop easily worked. Lack of transportation facilities is perhaps the chief obstacle in the way of operating at this place.

At Irma in the central part of Lincoln County, an opening has been made by O. J. Jenks in a granite outcrop, of schistose or laminated structure, which, from tests made by E. R. Buckley,[1] appears to be suited either for building or monumental work.

At Cherokee in western Marathon County is a vertical wall of granite exposed for some distance along the east bank of the Big Eau Pleine River. This granite appears to be of good quality and color and readily workable. This locality, however, is not favorably located for transportation by rail.

In Wood County at several localities on the Yellow river, north of Pittsville, are outcrops of granite which appear to be of good quality but are not favorably situated for transportation. Among these may be mentioned the granite forming the rapids

[1] Wis. Geol. and Nat. Hist. Surv., Bull. IV, pp. 158–159.

in Sec. 10 and 14 of T. 23, R. 3 E., and Sec. 21 and 28, of T. 24, R. 3 E. Prominent knobs of granite occur in Sec. 1 and 2, of T. 23, R. 2 E., and in Sec. 25, T. 24, R. 2 E.

SANDSTONE.

The Potsdam sandstone formation of the area is quarried in a number of places for building stone. This stone is used in Clark, Wood, and Portage counties. In most places the stone is quarried only for local uses within 3 or 4 miles of the quarry. The sandstone is quarried for use in the city of Neillsville in the sandstone mounds about 4 miles northwest of the city in sections 3 and 4. For use in the city of Marshfield the sandstone is quarried about 5 miles miles northwest of the city in sections 33 and 34. At Stevens Point the low sandstone mounds on the west side of the river furnish abundant good building stone for local use and also for shipment by rail. About 5 miles northwest of Grand Rapids sandstone has been quarried for a number of years both for local use and shipment by rail. About 6 miles southeast of Grand Rapids quarries have been opened in the NE. ¼ of Sec. 24, T. 22, R. 6 E., and in the SW ¼ of Sec. 19, T. 22, R. 7 E. In the vicinity of Bancroft several quarries have been opened on Mosquito Mound and the adjacent sandstone hills. Near Ellis Post Office in Portage County in section 6, T. 24, R. 9 E. are several quarries in sandstone hills in this vicinity.

MACADAM AND ROAD MATERIAL.

Besides the macadam used in the cities and made from quarried granite and syenite, and from field boulders, there is an abundance of road material in various parts of the area, such as disintegrated granite, gravel, sand and clay, which could be readily applied to the country roads and which would greatly improve them.

Macadam.

Granite and various kinds of basic igneous rocks, generally called trap rocks, are used quite extensively by the cities of the area for street macadam. Formerly cedar blocks were used in some of the cities for street pavements but they are being largely replaced by macadam. The source of the stone for macadam in most of the cities has been glacial boulders and field stone, disintegrated in place, which have been hauled by farmers to the city crushing plant. Merrill, Wausau, Stevens Point, Grand Rapids, Marshfield, Antigo and Medford have used partly, or wholly, macadam made from field stone, for which a price of $2.00 to $2.50 has been usually paid to the farmers. In some of these cities a better stone could be derived from outcrops within the city limits, where the crusher could be installed, and thereby not only reduce the cost of raw material but also reduce the cost of crushing the stone, for the fresh quarry rock can be crushed with greater ease than the field boulders.

A reference to the geological map and to some of the outcrop maps shows the kind of rock at and within the vicinities of the various cities of the area. Below is given a brief statement concerning rock suitable for macadam in the cities.

Tomahawk.

There are no outcrops of rock in the immediate vicinity of Tomahawk and hence the best source of stone for macadam is probably boulders from the glacial drift of the vicinity.

Merrill.

This city is at present using field boulders brought in by farmers. A good supply of rock, either granite or trap rock, could be obtained within the city limits, on the south side of the Wisconsin River near the bridge in section 13.

Wausau.

Wausau formerly used field stone for macadam but is now crushing the rock from outcrops near the C. & N. W. depot. If the supply at this place should become exhausted, there is a number of places where good stone can be obtained within the city limits on both sides of the river.

Stevens Point.

This city has used only field boulders for macadamizing its streets. An abundance of good stone, both granite and trap, could be derived from the outcrops along the river.

Grand Rapids.

Grand Rapids, like Stevens Point, is situated on the rapids of the Wisconsin River, and an abundance of suitable granite and trap rock for macadam is present. In the southern part of the city is an abundance of trap rock.

Antigo.

This city is not located near any extensive exposures of rock, and its most available supply of stone for macadam is probably field boulders.

Marshfield.

The nearest outcrop to Marshfield suitable for macadam is of granite exposed in numerous large ledges about 2 miles east of the city, in Secs. 2 and 3 T. 25, R. 3, E. Field boulders have been used for macadam and probably are the best source of macadam for this place.

Neillsville.

Neillsville has used macadam and gravel to improve its streets. An abundance of good rock for macadam, both granite and trap rock, occurs along the Black River and O'Neill Creek in this city. Recenty a quarry was opened and a rock crusher installed at one of the outcrops on O'Neil Creek.

Medford.

This city has used only field boulders for macadamizing its streets. There are no outcrops within 2 or 3 miles of Medford and boulders are probably the best material to use.

Many of the smaller cities and villages have used gravel to improve their streets. Gravel can be conveniently obtained within a short distance of most villages either from alluvial deposits along the streams, or from the glacial drift deposits. A number of the small cities and villages of this area are located near outcrops of rock suitable for macadam. Among these may be mentioned Athens, Mosinee, Marathon, Edgar, and Greenwood and Pittsville.

COUNTRY ROAD MATERIAL.

Disintegrated Granite.

In a number of places in the area are considerable deposits of disintegrated or partly rotted granite which has been used with very good results to improve some of the country roads and village streets. The source of this material is either very coarse granite or very coarse quartz syenite. The rock phases consist of large quartz and feldspar crystals, ½ inch or so in diameter, which have disintegrated in places to considerable depths. About 3 miles west of Wausau in the NW. ¼ of NW. ¼ of Sec. 33, T. 29, R. 7 E., disintegrated granite is dug from a pit along the road and used quite extensively on the sandy roads of the vicinity. About 3 miles northwest of Mosinee in section 24, similar rotted granite has been used considerably for improving the streets in Mosinee, and the sandy roads in the vicinity. About one mile north of Edgar is an abundance of disintegrated granite which has been used to improve the streets of Edgar. In the area of coarse granite and coarse syenite northwest of Mosinee, over a large part of T. 27, R. 6 E., and adjoining portions of adjacent townships, there is an abundance of this disintegrated granite which has been used to some extent for improving the roads of the immediate vicinity. This disintegrated granite, consisting of angular crystals and fragments of quartz and feldspar, can be pressed into a compact mass when placed on the roads, and forms a hard stratum shedding rain well and bearing the ordinary traffic with ease. This material could be used to good advantage to improve many of the side streets of the cities where the more durable macadam streets would not be necessary. This material is excellent for improving both sandy and clayey roads and its cheapness should recommend it very strongly for a much greater use than is at present applied.

The value of disintegrated granite or feldspar for use as macadam and country road material can not be too highly emphasized. An abundance of this material is present in a large portion of this area and its use should be greatly increased.

Disintegrated Sandstone Formation.

Near the base of the Potsdam sandstone in many places of the southwestern part of the area is an abundance of clay which may be either a part of the sandstone or a part of the residual clay derived from the underlying pre-Cambrian crystalline rock. In places the angular fragments of sandstone are thickly strewn through this clay and the combination of the two makes an excellent covering for roads. This material packs into a compact mass and on sandy roads or heavy clay roads the use of this material renders great improvement.

Gravel, Sand and Clay.

Gravel and sand for surfacing clayey roads, and gravel and clay for surfacing sandy roads, occur in abundance in the various parts of the area. The judicious use of road material of this sort where the roads are especially clayey or especially sandy would greatly improve the general character of the highways. Usually suitable material is close at hand and would have to be hauled but short distances.

The question of improving the country highways is an important one and is receiving considerable attention at present by the American people. One of the most objectionable features to life in rural communities is the unimproved condition of the country highways. Recent improvement in country life has been the extensive use of the rural telephone, established by private enterprise, and the rural mail routes, established by the National Government, both of which reach throughout the more densely settled parts of the country. The next step in improving general conditions of country life should be the demand for, and the inauguration of, an improved public road system. In all parts of this area there is an abundance of raw material of excellent and suitable character close at hand, which could be used to permanently improve the roads.

Already the cities and many villages of this country have adopted the system of permanently improving their streets by some sort of pavement. The higher valuation of city property makes the burden of constructing pavements in cities less proportionately to the property holders in cities than that of less expensive pavements in the country to those living in the country. For this reason, therefore, state aid for constructing rural highways should be invoked and the legislature appealed to. This aid in constructing public roads would require only the further application of the principle involved in state and county aid now applied in the maintenance of the public school system, and in the construction of iron bridges on the country highways.

CLAY.

The clay[1] deposits of this area constitute valuable natural resources and will undoubtedly increase in importance in the future. The clays of the area from the standpoint of their structure or geological occurrence fall into two groups, residual clays and sedimentary clays.

RESIDUAL CLAYS.

The residual clays are formed by the weathering and decomposition of the pre-Cambrian crystalline rocks of the area and are found overlying the solid rock from which they have been derived. The crystalline rocks consits of various kinds of granite and basic rocks and hence the residual clays vary considerably in compositon and texture. The clay deposits vary in thickness from a few feet up to 30 or 40 feet and occur irregularly distributed over certain portion of Marathon, Portage, Wood, Clark,

[1]For a detailed account of the clays of Wisconsin, see Bull. XV, Wis. Survey, by H. Ries or the earlier report, Bul. VII Wis. Survey, by E. R. Buckley.

and Taylor counties. Outside of this area they occur in Jackson, Eau Claire and probably other counties farther northwest.

The general distribution and age of these residual clays have already been described (pp. 388–392). They occur at the border of the sandstone and the crystalline districts, in the region of isolated sandstone outliers. They were evidently formed previous to the deposition of the sandstone, for they occur beneath thick ledges of this rock as well as beneath thin cappings along the rivers and streams

SEDIMENTARY CLAYS.

Clays of sedimentary character are more or less distinctively stratified and usually represent sediments that have accumulated under water. Sedimentary clays occur in all the counties of the area and are associated with either the glacial or the alluvial deposits.

CHARACTER OF CLAY PRODUCTS.

The clay deposits at present only produce common brick of red or brown color. Certain clays of residual deposits, as indicated in the following account of undeveloped deposits, are suited for the manufacture of paving brick, and certain others appear to be good slip clays for glazing earthenware. No fire brick clays are known in the the area, although a thorough investigation may reveal the presence of fire clays among the residual deposits.

Langlade County.

In the vicinity of Antigo in Langlade County are several brick-yards deriving their clay from glacial deposits. The thickness of clay in these various deposits does not exceed 8 or 10 feet and in most there is a thickness of only 3 or 4 feet. Four brick-yards operate in the immediate vicinity of Antigo, the entire annual output of the yards probably not exceeding 700,000 or 800,000 brick. The clays in this vicinity occur as thin deposits underlain with sand and gravel and at times overlain by a few inches of gravel and sand.

Lincoln County.

In Lincoln County brick are manufactured in the vicintiy of Tomahawk, Shultz Siding and Merrill. At Tomahawk the yard is located about one mile east of the city and the clay is derived from a deposit exposed on the south bank of the Wisconsin River. The clay is finely stratified and has a thickness of 8 or 10 feet down to the level of the river. The yard at Shultz Siding is located at the station. The clay bank has a depth of four feet and is a mixture of bluish and yellowish clay. In the vicinity of Merrill, brick-yards are operated 1½ miles east of the city. The clay bank has an average thickness of 3 or 4 feet.

Marathon County.

Brick-yards are located in Marathon County in the vicinity of Wausau, Ringle, Norrie, Edgar, and Athens.

About 3 miles northwest of Wausau in sections 13 and 21 are located brick-yards which operate in clay deposits varying from 2 to 5 feet thick. Some stone is associated with the clay. At Ringle is located a brick-yard deriving its clay from a residual deposit overlying granite and diorite-schist. The clay at this bank is of a varying character depending upon the nature of the crystalline rock beneath. It varies from a grayish clay to a bluish variety. The clay contains some undecomposed rock and is passed through a crusher before being mixed in the pug mills. The average annual output of the yard at Ringle is about 1,000,000 brick. At Edgar are large deposits of good clays, two brick-yards formerly operating at this place, but at present there is only one working. The clay deposits occur along Scott Creek and are of fluvio-glacial origin. In the town of Hamburg, section 28, T. 30, R. 5 E., is a small brick-yard operating in the thin deposit of clay of glacial origin. About a mile north of Athens is a brick-yard operating in a deposit of clay from 4 to 10 feet thick. About a mile north of Norrie is a brick-yard operating in a clay bank about 5 feet thick. This clay is of a greyish color and is associated in origin with the glacial moraines of this vicinity.

Portage County.

In Portage County there are two brick-yards in the immediate vicinity of Stevens Point. Both of these yards obtain their clay from residual deposits derived from decomposition of crystalline schist. The yard of the Langenberg Brick Manufacturing Company is located about 1½ miles north of the city limits and has been operated for a number of years. The factory of the Stevens Point Brick Company is located about ½ mile north of the city, having been organized and operated only since 1904. In both of these deposits the clay is in part fine-grained and in part only partially decomposed, and therefore contains more or less crystalline rock material. The clay is passed through crushers before going to the pug mill.

Wood County.

In the vicinity of Grand Rapids there are two brick-yards northwest of the city, both operating in residual clay deposits. One of the yards, that owned by J. G. Hamilton, is located in the NE. ¼ of Sec. 30, T. 23 R. 6 E., and the other, owned by Lassig Bros., in the SW. ¼ of Sec. 36, T. 23, R. 5 E. In both of these deposits a thin covering of sedimentary clay overlies the residual deposits, the whole being worked together to make common brick. At Vesper a residual clay deposit is being worked for brick. At Pittsville on the farm of Nash Mitchell are residual clays suitable for the manufacture of brick and some grades of devitrified ware. About 2 miles northeast of Marshfield is located a brick-yard owned by the Central Wisconsin Brick Co., using sedimentary clay of glacial origin.

Clark County.

In Clark County the brick-yards are located in Neillsville, near Loyal, and near Withee, about 2 miles north of Dorchester, and 9 miles northeast of Neillsville. In all of these yards the clay is of glacial origin and burns to red brick, as is usual with all the clays of this area.

Taylor County.

In Taylor County brick-yards are operated about 4 miles north of Medford and at Whittlesey 6 miles north of Medford. The former yard derives its clay from a thin deposit 3 or 4 feet thick and the latter from a deposit 10 to 12 feet thick, which occurs in thin layers having reddish-brown color, and is fairly uniform throughout.

UNDEVELOPED CLAY RESOURCES.

The statement has already been made that only common brick clays are at present worked within the area. It seems reasonable to believe, however, that higher grade clays of both sedimentary and residnal origin may be found and developed. The sedimentary clays are distributed over those parts of the area where the glacial drift is abundant. They are of rare occurrence in suitable locations in the broad area of thick deposits of sandstone covered only with thin drift.

The residual clays are the most promising for investigation for the manufacture of paving brick, fire brick and pottery. It is possible also that kaolin may be found in quantity in the residual deposits. As already pointed out, of the several brickyards operating in the residual clays, those at Stevens Point, Ringle, and Grand Rapids are producing only common brick. The investigation of Dr. H. Ries[1] during the years 1904 and 1905, shows that common brick only can be made from the clays now worked at these yards. Residual clay deposits were found in the area, however, the preliminary tests and chemical analyses of which indicate them to be of value for paving brick and as slip clays for the manufacture of pottery.

At Pittsville is a deposit of dense-burning clay found to approach a paving brick body. The fire shrinkage and absorption of the Pittsville clay at different cones was found to be as follows:

	Fire Shrinkage.	Absorption.
Cone 010	2.3	11.32
Cone 05	4.7	6.22
Cone 1	7.0	2.27

[1] Bulletin No. XV, Wis. Geol. Nat. Hist. Survey.

Some of the clays found in the residual area are not only fine-grained, but also easily fusible on account of the high percentage of fluxing elements which they contain, and the possibility therefore suggests itself of using such clays for slips. One sample of this sort tested was from a deposit outcropping along the Black River, about 4 miles due southwest of Medford in the NE. 1/4 of Sec. 8, T. 30, R. 1 E. It was found that if this clay be ground up and mixed with water and applied as a thin slip to a terra cotta body it burns to a reddish and somewhat glossy coat at cone 1. Kaolin and fire-brick clays probably occur in the residual clay area. A kaolin deposit at Grand Rapids was worked a number of years ago but this deposit has been exhausted.

Prospecting for Residual Clays.

The residual clays always occur immediately upon the crystalline rock, and may or may not occur beneath a capping of sandstone. Originally the residual clays were everywhere covered with the sandstone, but in many places this covering of the sandstone has been removed by erosion, and in many places the clays have also been eroded.

The region to prospect for residual clays, therefore, is in the vicinity of cappings of sandstone overlying the pre-Cambrian crystalline rocks. As shown on the general geological map of the area, the region lies in the southern part of Marathon County, central and northern parts of Portage and Wood, and a large portion of Clark and western Taylor counties. The most favorable localities are in those parts of the area where but a thin drift covering overlies the older deposits of crystalline rocks, of residual clays and of sandstone. The residual clays appear most abundantly at the surface in a belt extending westward from Stevens Point and Grand Rapids, through Pittsville to Neillsville and Halycon in Jackson County. The occurrence of residual clays at Ringle and near Medford much farther north indicate the wide distribution of these clays.

Around the bases of the sandstone mounds in the area where the crystalline rocks abundantly outcrop, are favorably situated localities for prospecting. Along the streams, where the crystalline rocks and the sandstone are abundant are also favorable places. It was formerly thought by Irving that these residual clays were mainly confined to the stream beds, but their widespread occurrence beneath the sandstone away from the streams, indicating that they were formed before the sandstone was deposited, shows that they occur without regard to the present location of streams, although the erosion of the overlying strata by the streams has produced localities favorable for the search of outcrops of the residual clay.

In regard to the occurrence of deposits of economic value, the prospector should, of course, keep in mind quantity and quality of the clays and various factors determining the facilities for mining, such as the occurrence of loose material overlying the deposits and facilities for transporting either the clay or clay product. Careful prospecting is necessary because the residual clays vary widely in their character from point to point, and adjoining fields may be underlain with clays possessing quite different properties. The clays can perhaps only be worked where a thin stripping of a few feet is necessary. Underground mining, beneath the sandstone, on account of the loose unstable character of this formation, is probably too costly to be practical.

QUARTZ.

Quartz from the massive white quartzite formation of Rib Hill has been mined since 1893. This rock, as already described, (pp. 43–52) consists of close-fitting coarse grains which, under the microscope, are seen (see Plate VII) to interlock and dovetail with one another in a manner identical with that of vein quartz or granitic quartz. As previously stated, the Rib Hill formation is completely recrystallized quartzite, no traces of the original clastic grains being left. Practically an inexhaustible supply of quartz of character suitable for mining and crushing for abrasive purpose occurs in Rib Hill.

This quartz rock, while of appropriate texture and sufficient hardness for abrasive purposes, does not appear to be of sufficient purity for the various purposes for which "flint" is used, namely, as a constituent of pottery ware. Chemical analysis of the Rib Hill quartz product is as follows:

Analysis of Rib Hill quartz.

Silica	(SiO_2)	99.07
Alumina	(Al_2O_3)	0.52
Iron	(Fe_2O_3)	0.17
Lime	(CaO)	none
Magnesia	(MgO)	none
Water	(H_2O)	0.06
Total		99.82

Two companies operate in Wausau, The Wausau Quartz Company and the Wausau Sandpaper Company, the quartz being hauled by team from Rib Hill. A sandpaper factory is operated by the latter company. The former company produces only the crushed quartz, a ball mill being installed. All grades from the finest powder up to sizes one-fourth inch in diameter are made. Crushed quartz from these mills is sold in all parts of the Union. The various abrasive purposes for which the quartz is used are mainly flint sandpaper, sand blasts, sand belts, pumice stone, marble cutting, and match sand. Besides being used for abrasive purposes, it is also used for filters, bird grit, wood fillers, artificial stone facing, etc. In 1906 about 7,000 tons of crushed quartz were produced, valued at $40,000.

Quartz occurring in veins or dikes like that mined in some of the eastern states and used as "flint" in the manufacture of pottery occurs in a few places in the area but has never been mined. The crystalline rocks of this region are similar in all respects to those in the east where deposits of vein quartz of economic value occur. Quartz veins having a thickness of 5 or 10 feet, and perhaps more, are known to occur at a number of places in northern Wood and Portage counties. Whether these veins are large enough or are favorably situated for quarrying economically is not known.

FELDSPAR.

Feldspar is not mined in this area, although deposits well worthy of investigation are known to occur in sufficient abundance 8 miles northwest of Wausau.

These feldspar deposits occur in an area five or six miles in extent near the central part of the town of Stettin. They are found principally in sections 10, 11, 14, 15, 16, 22 and 23, of T. 29, R. 6 E. The feldspar forms large irregular masses and veins in quartz syenite, popularly known as granite, usually occurring in these masses in large crystals associated with a subordinate amount of quartz and in some places with hornblende and mica. The veins vary from a foot to ten or twenty feet in thickness and occur at numerous places in the above designated area.

Three analyses of the feldspar from different places in the area have been made, showing the feldspar to be quite uniform in composition. Number one was made by Prof. Lenher and numbers two and three by Prof. Daniells, of the University of Wisconsin.

Analyses of Feldspar.

	1	2	3
Silica (SiO_2)	66.42	65.50	66.07
Alumina (Al_2O_3)	20.23	19.24	19.82
Ferric oxide (Fe_2O_3)	0.95	0.46	0.44
Lime (CaO)	trace	0.42	0.11
Magnesia (MgO)	none	0.26	none
Sodium oxide (Na_2O)	5.59	5.29	5.63
Potassium oxide (K_2O)	6.62	8.35	7.27
Moisture (H_2O)	0.14	0.14	0.24
	99.95	99.66	100.58

Feldspar is used extensively in the manufacture of china and porcelain ware, in glazed tile, and in certain kinds of glass. It is used to a lesser extent in the manufacture of certain kinds of soap, polishing materials, and in wood fillers.

The essential quality of commercial pottery feldspar is its capacity to fuse to a white mass when used as flux in the ware. In order to test this quality fusion trials were made upon small and large quantities of the feldspar. Small particles of the feldspar, a few ounces in weight, were fused by the writer and of ten trials made several showed fairly white, while others showed a gray discoloration. Larger quantities of the feldspar were sent to Mr. Karl Langenbeck of Zanesville, Ohio, who made fusion trials upon portions of the feldspar weighing from twelve to fifteen pounds.

In all of the trials thus far made, however, weathered feldspar has been used which was picked up from the surface of the ground, showing more or less discoloration caused by the infiltration of extraneous material.

If it is true that the discoloration is not due to the feldspars themselves, but to the extraneous matter filtered into them, the deposits are of value and are well worthy of exploration. In order to determine definitely the commercial value of the feldspar, excavations in the feldspar veins should be made, from five to twenty feet deep, at a number of favorable localities, and sufficient portions of perfectly fresh mineral should be selected and fusion trials made upon them.

It seems probable that the above deposits of feldspar occur in sufficient quantity for commercial purposes, and it can be readily mined and transported.

MARL.

Only one deposit of marl is known to occur in this area, that of Lime Lake, 5 miles southwest of Amherst, Portage County. Impure marl is known to occur in several other lakes of the area and a systematic search may reveal workable deposits in other lakes of the district.

The Lime Lake deposit, owned by John Een, has a thickness of 10 to 30 feet and an area of 40 to 50 acres. This marl was formerly used for the manufacture of quick lime. The fresh marl is either white or greenish grey. Samples collected by M. L. Nelson and analyzed by W. S. Ferris for the Survey have the following composition:

Analyses of Lime Lake marl.

Calcium carbonate ($Ca\ Co_3$)	89.50	80.83
Calcium sulphate ($Ca\ So_4$)	0.61	0.88
Magnesium carbonate ($Mg\ Co_3$)	2.52	2.50
Alumina and Iron oxide ($Al_2O_3\ Fe_2\ O_3$)	0.39	0.94
Organic matter	5.48	12.58
Insoluble residue	1.33	2.37
Total	99.83	100.10

Marl is used extensively in the manufacture of Portland cement. The rapid increase in the use of Portland cement for constructional purposes and the increase of cement factories throughout the country has led to a large demand for marl deposits, located conveniently with regard to suitable clay deposits and transportation facilities. The recent investigation of the clay deposits of the state by Dr. H. Ries shows the presence of a number of clays suitable for Portland cements in northern Wisconsin, hence it seems likely that some of the Wisconsin marl deposits may be utilized in the near future for the manufacture of cement. Marl deposits to be of economic value should not only be of proper quality, but should also be of considerable quantity, on account of the large scale upon which Portland cement is now made.

MINERAL PAINT.

The mineral substances mined and prepared for pigments in the area are carbonaceous shale, "graphite," and iron-bearing schists.

CARBONACEOUS SHALE (GRAPHITE).

The quartzite formation outcropping about a mile north of Junction City in northwestern Portage County is associated with much shale or slate, phases of which contain a variable amount of carbonaceous material. A description of the character of these deposits have already been given (pp. 91–94).

Since this carbonaceous material has been advertised and placed upon the market as graphite it is of interest to refer briefly to it again in this place.

Graphite, like diamond, is a crystallized form of carbon. In the trade, two forms of graphite are recognized: "Crystalline graphite" and "amorphous graphite," the former generally crystallized in a columnar or foliated form, and the latter as fine grains usually mixed with clay, quartz, and various minerals. The crystallized carbon of graphite has the capacity to withstand high temperatures without oxidation, whereas the uncrystallized carbon of ordinary coal or anthracite is burned at low temperatures. There is a vast difference, therefore, in the value of graphite and ordinary carbon in commerce. In order to ascertain the nature of the carbon of these deposits a sample of the refined carbon product prepared for the trade was submitted to Prof. V. Lenher of the Department of Chemistry, University of Wisconsin. Inasmuch as the conclusion reached by Prof. Lenher concerning the form of the carbon is quite different from that which is popularly held by people interested in developing the deposits, the result of his examination is stated in full in the following report:

"The distinguishing test for graphite is oxidation by means of potassium chlorite and anhydrous nitric acid. Amorphous carbon is completely destroyed by one treatment with the above reagents while graphite by successive treatments is oxidized to graphitic acid, a characteristic compound.

"This black carbonaceous shale on one treatment with these reagents lost all its carbon, behaving precisely like amorphous carbon.

"Graphite burns at 660 degrees in oxygen. In order to get the most direct comparison of graphite and this carbonaceous shale with regard to burning in air, a good quality of graphite was heated in the air in a platinum crucible at a red heat for different lengths of time. In three hours the good graphite lost 68 per cent, in six hours 91 per cent was lost, nearly all the graphite in six hours being consumed. The black carbonaceous shale showed a total consumption of carbon in less than one hour.

"Analysis of the shale (partially refined carbon product) is as follows:

Carbon	32.24 per cent.
Ash (red shale)	67.76 per cent.

The carbonaceous shale from the above can be said to contain no graphite."

It is quite evident, therefore, that the carbon in this shale does not occur in the form of graphite and the name "graphite" from the mineralogic standpoint is erroneously applied to it.

Especial attention is called to the form of the carbon in these deposits in view of the fact that companies have been organized and stock sold for the purpose of mining graphite from them.

The richer portions of the carbonaceous shale, bearing from 10 to 15 per cent carbon, are put through crushers and rollers and separated by flotation in air. The product has been used mainly as a pigment for mineral paint, and in the manufacture of a paste for pipe joint connections. For these purposes the product has been used with success. The product is similar to that of the so-called Baraga graphite of Michigan and the so-called graphitic anthracite of Rhode Island.

It is an evil practice, however, to apply the name "graphite" to the ordinary form of carbon like that occurring in the carbonaceous schists at Junction City, and hoist upon the public the sale of mining shares in so-called graphite mines. The carbon in these deposits has a legitimate use in certain manufactured products and the writer has no wish to criticise the legitimate exploitation of these deposits or the product manufactured. By the use of the name "graphite paint" little deception can be worked upon the purchaser of paints. The principal evil lies in the sale to the unsuspecting public of stock in so-called graphite mines, and claiming for the carbon of these deposits all the virtues of true graphite.

True graphite occurs in small particles in the pegmatite veins in the region about Wausau, as already described, page 307–8, in a geological formation quite different from that in which the carbon occurs at Junction City. The graphite in the pegmatite veins does not occur in paying quantity in the localities observed, although it may be found in the veins of other localities in paying quantity.

IRON OXIDE.

A few miles southwest of Junction City, iron-bearing schist has been mined and crushed for mineral paint by the company operating in the carbonaceous pigment. Mixture of the carbon product and iron oxide are used to produce various colored paints.

PEAT.

Peat fuel, though a novelty in this country, has been used for centuries in Europe. Peat bogs occur in many of the swampy and marshy tracts of this area, in the flats overlying alluvial tracts of southwestern Portage County, southern Wood County, and in the swamps of the Wisconsin drift sheet in the eastern and northern part of the area. Crude peat, cut in blocks out of the bog and dried in the air, after which it is burned without further treatment, has been observed by the writer in southeastern Portage County. Machine peat or peat briquettes are not known to have ever been made in this area.

A considerable variety exists in the composition of all peat bogs. The greater number of peat bogs appear to be made up of several varieties of sphagnum moss; some consist of the compact growths of other species of moss, and others of a mixture of aquatic plants with or without moss or with common marsh grasses and sedges. The peat bogs not only vary in the character of plant growth, but also in the character and amount of mineral matter, such as clay and sand, associated with the peat, and also in the state of the decomposition of the peat plants.

No statement can be made concerning the thickness and extent of the peat bogs of this area, as no special investigation of them has been made. The use of peat as fuel has been investigated at various times in this country. Recently, renewed interest has arisen on account of the increase in the price of coal. If peat fuel is ever placed upon the market in successful competition with coal or other fuel the many peat bogs of this area will become an important mineral resource.

Beside the use of peat for fuel, attention should also be given to certain phases of peat for other purposes, such as a fertilizer of soils and as an absorbent.

IRON ORE.

Iron ore in paying quantities is not known to occur in this area. It may, however, be present either in the pre-Cambrian formations of slate or as bog ore of recent origin in the marshes. Iron ore has never been mined in this part of the state, although considerable exploration has been carried on at various intervals in different parts of the area.

About twenty years ago at the time the Gogebic and Menominie Iron ranges were opened to mining, considerable exploration was made in the crystalline rocks in Marathon County. Perhaps $75,000 was spent exploring for ore within a radius of twenty miles of Wausau. These explorations were carried on by sinking shafts and test pits in various rock formations such as diorite, rhyolite and slate. The usual incentive for exploring these formations was the occurrence of small veins of hematite which were believed to be connected with large pockets of iron ore. Invariably, however, the veins were not more numerous nor larger with increasing depth of surface. Explorations were carried on in Sec. 13, T. 29, R. 7 E.; Secs. 5, 7, 11, T. 29, R. 8 E.; Secs. 31 and 36, T. 30, R. 7 E.; Sec. 31, T. 30, R. 8 E.; Secs. 25, 30, 31, and 32, T. 30, R. 6 E.; and Secs. 32 and 34, T. 27, R. 7 E. Various other localities in Marathon County, in Wood, Portage, Taylor, and Clark counties, have been explored for iron ore.

Without exception, however, in the various localities where explorations have been carried on, there is nothing in the character of the rock to warrant the belief that hematite in more than mere traces would be found. In a majority of instances the explorations were carried on in igneous rocks, either in fine-grained diorite, or in rhyolite, and in some instances schistose granite. These formations where explored contained either small veins of hematite or were colored red by slight infiltration of iron oxide.

The dark colored slates of this area occurring in the towns of Hamburg and Berlin (see general map, Plate I) contain phases of rock such as banded jaspery slates and carbonaceous slates which are often found associated with the iron ores of the Lake Superior iron districts. Among the field fragments found scattered over the area of slate, boulders of iron ore, however, were not observed. While it is possible that iron ores may yet be found associated with the slate formations of the area, it does not appear probable. There are certainly no surface indications in the nature of outcrops or in the character of the scattered boulders of the area which would lead one to believe that ore in quantity occurs in the area. At the same time it should be remembered that the occurrence of jasper and carbonaceous phases of the slate are favorable indications that iron ore may be present.

At Rudolph in Wood County is an occurrence of ferruginous quartzite which has been explored for iron ore. This iron formation is apparently identical with the ferruginous schist at Black River Falls, which was mined some years ago. The formation at Rudolph appears to be of small extent and at the locality where the explorations were carried on no ore in workable quantity was found. This ferruginous schist or ferruginous quartzite is not like the usual iron-bearing rock closely associated with the pre-Cambrian iron ores. While it is not impossible that ores in workable quantity may occur in this kind of iron-bearing rock, the formation, from present knowledge, does not appear to be a favorable one.

Bog iron ore in thin beds and seams is known to occur in the marshy tracts of Portage and Wood counties closely associated with peat bogs. In the village of Nekoosa near the center of Sec. 10, T. 21, R. 5 E., a porous bedded limonite ore is exposed in the river bank 15 feet above the water. As described by Irving[1] this exposure extended along the bank for some 50 feet and appears to be some 8 feet in thickness, the upper 3 feet being a porous but not pure ore containing 50 per cent of metallic iron. Two hundred feet down stream the river bank shows that the ore does not continue in that direction. At several points on the east bank of the Wisconsin River north

[1] Geol. of Wis., Vol. II, p. 636.

of Grand Rapids in Sec. 4, T. 22, R. 6 E., and Sec. 34, T. 23, R. 6 E., small openings show ore like that above described. The average compositions of some of the samples show a content of 51.26 per cent of metallic iron. The writer has observed bog ore in many of the low tracts of Wood, Portage and Clark counties, although nowhere was seen a deposit thick enough or rich enough to warrant investigation. It is within the possibilities, however, that bog ores may occur in the marshes of the area in sufficient quantity to be of commercial value.

GOLD, SILVER AND COPPER.

Neither gold, silver nor copper is known to occur within the area except in very small quantity or mere traces. The pre-Cambrian igneous rocks of the area are very similar to those in other regions in which gold and silver-bearing veins occur, but the lack of discovery of appreciable quantities in the veins or in the stream sands and gravels of the area would seem to indicate that these metals occur only in very slight quantity. Gold and silver have often been reported from various localities of the area and some prospecting and exploration work has been done. Most of the reported finds of gold and silver are not reliable. Prof. R. D. Irving[1] in some samples of quartz carrying pyrite and arsenopyrite, brought to him from northern Clark County, found minute quantities of both gold and silver.

Copper has been picked up in fragments in the glacial drift of the area, evidently being derived from the copper-bearing rocks of northern Michigan. It is not likely that copper in more than very small quantity occurs in the rocks of this area.

While in a general way it is true that the igneous rocks of this region are similar to those of other regions in which gold and silver bearing veins occur, it seems very likely, in fact almost certain that there are slight differences in the chemical composition of the igneous rocks of this region, as compared

[1] Wis. Acad. Sci., Arts and Letters, Vol. I, p. —.

with those of other regions in which these metals occur in paying quantity.

It has been shown for instance that the igneous rocks of North Central Wisconsin are relatively high in alumina lime and soda and relatively low in magnesia, and potash. And these characteristic features of composition are not only true of one kind or group of igneous rocks, but is true of all of them. There is a difference then in the composition of these igneous rocks, inherent in the original magma, which, while measured in small percentage of the whole is nevertheless of sufficient importance to characterize these rocks from all others. This difference in original composition of the igneous magmas of the region may therefore furnish the explanation of the absence of certain rare metals like gold and silver in the mineral veins of the region, and likewise the presence here of such rare elements as columbium, tantalum, cerium, etc., which are known to occur. It seems possible then that the inherent difference in composition of the igneous veins and rocks of one region as compared with those of another may furnish the true explanation of the absence of certain elements like gold and silver in one region and their presence in another.

The absence of the precious metals in the mineral veins of a region is often explained on the theory that the physical conditions under which such veins were developed were not favorable for the precipitation of such metals. The writer wishes to call attention to the possibility, or probability, that the absence of certain metals in the mineral veins may be wholly due to the absence of such metals in the original rock magmas of the region in which such veins occur. The writer is inclined to the belief, therefore, that the essential absence of gold and silver in the veins of the pre-Cambrian igneous rocks of this area may not be due to any accident of physical development of the mineral veins, but may be due to the meager quantity or absence of these metals in the igneous magmas of the region.

THE RARE METALS AND MINERALS.

The occurrence of lithia-bearing mica, corundum, chromite, tourmaline, garnet zircon, fluorite, pyrochlore, and rutile, etc. is of interest from the economic standpoint, as well as the purely scientific, for the fact that these minerals occur in small quantity may lead to the discovery of some of them in sufficient quantity to be of commercial value. Some of these minerals such as tourmaline, garnet, zircon and fluorite probably occur only in such small quantity as to be of value as gem material. Corundum and chromite might be found in workable quantity in the basic rocks (troctolite, periodotite) at the mouth of the Copper River as these minerals are mined in a similar rock in North Carolina. The lithia-bearing mica, and the pyrochlore, and other species of mineral bearing the rare elements, all occurring in the coarse pegmatite northwest of Wausau, may prove to be a commercial source of these rare metals. As to whether these minerals occur in sufficient quantity to be of value, the writer can not at present render any opinion. Their occurrence has not been investigated with this object in mind. All these rare earth minerals, however, as well as the fluorite and zircon occur in very coarse rock, coarse pegmatite, and hence may be present in quantity in certain localities in this rock. This coarse pegmatite rock occurs in considerable quantity and on account of its unusual mineral character is well worthy of much further investigation from the scientific point of view and may also be equally worthy from a commercial view.

SECTION II. WATER SUPPLIES AND WATER POWERS.

WATER SUPPLIES.

The numerous streams of the area afford abundant supplies of water for stock. For most domestic purposes, however, wells are the main reliance.

THE GROUND WATER.

Well water is found at various depths below the surface depending upon the slope of the land surface and the rock formation beneath. At certain depths below the surface all the pores and fissures of the rock formations are filled with ground water and it is into this water-filled portion of the ground that wells must be sunk in order to obtain an abundant and constant supply. The upper surface of the ground water generally called the water level, is usually very near the level of the streams and lakes of the vicinity. The level of the ground water is not horizontal, but is undulating, the undulations approaching, in a general way, the contours of the land surface, standing at greater depths below the surface in the hills than in the valleys.

CHANGES IN THE LEVEL OF THE GROUND WATER.

The position of the ground water level changes from season to season, standing lower in the winter, when precipitation is slight, and higher in summer, when the rainfall is more abundant. It gradually sinks also from year to year as the lands come under cultivation. Some parts of the area show a much greater change in the ground water level than other parts of the area. In the rolling lands of Marathon County where the crystalline rock is at and near the surface but little if any change has taken place. In the area where the wells are in the thick drift, as in Clark County, the ground water has sunk from 10 to 15 feet. In the porous alluvial subsoil of the Bancroft gravelly loam about Almond in southeastern Portage County the water table has sunk from 20 to 40 feet.

CHARACTER OF THE WELL WATER.

The well water throughout the area is that kind known in domestic economy as "soft water." This is due to the absence of limestone in the area.

Abundant well water is obtained in each of the four groups of geological formations, and will be only briefly discussed here as the conditions of the soil water and ground water are more fully described for each of the soil formations in a preliminary report.

Wells in the Alluvial Sand and Gravel.

The securing of well water in the alluvial formation bordering the Wisconsin River, over a large part of southern Wood, in southwestern Portage and the vicinity of Antigo in Langlade, is a very simple matter, for this formation consisting of much gravel and sand, is very porous and the level of ground water is generally 10 to 20 feet from the surface, and very often even less than 10 feet As a rule, however, in order to secure good pure water wells should obtain their supply at least more than 20 feet below the surface and where the ground water is higher than this either "drive wells" or drilled wells should be made. In the vicinity of Almond and farther north in Portage County many of the wells are from 60 to 100 feet deep.

Wells in the Glacial Drift.

Water is found at various depths in the sand and gravel of the glacial drift. In the region of the thick terminal moraines where the drift forms ridges the wells generally penetrate nearly to the level of the surrounding lower lands. Where the drift is les than 50 feet thick, unless the land is very gently sloping, the supply of water is usually obtained at the junction with, or a few feet into, the underlying formation, which may be either the crystalline rock or the sandstone. It is very common to find an abundant supply at the junction of the drift with the underlying cystalline formation. However, if water is not struck at the junction it is only necessary to go down into the information beneath, whether it be the sandstone or the crystalline formation, to find a sufficient supply.

Wells in the Potsdam Sandstone.

Wherever the sandstone has a depth of 10 to 20 feet and the land is gently sloping it usually furnishes an ample supply of water. The wells in the sandstone ridges usually reach near to the level of the surrounding lower lands. The wells in the sandstone are almost entirely in Portage, Wood and Clark counties.

Wells in the Crystalline Rock.

Wells bottomed in the hard crystalline formation and receiving the whole or a large part of their water supply from the various crystalline rocks are found in all portions of this area. They are especially abundant in the rolling uplands of southern Lincoln, in Marathon, and in northern Portage and Wood counties. The wells generally vary in depth from 20 to 40 feet, depending much as to their location in the hills or in the valleys. The level of the ground water in the crystalline formation seems to closely follow the contours of the land surface, standing high in the hills and near the surface in the valleys. In the crystalline rocks the water passages are confined to the fractures, seams or fissures which are, as a rule, abundant near the surface in the crystalline formations of this state. The statement has been made that it is generally useless to attempt to get a sufficient flow of well water from the crystalline rock, but this statement was based on the erroneous belief that the crystalline formation was generally a massive solid formation and not much fractured or fissured. The crystalline rocks are everywhere quite generally fractured within 50 to 100 feet of the surface and contain an abundance of water and it is only necessary, therefore, to go down into this formation below the level of ground water and open up a number of seams and fissures. The required depth to obtain a sufficient supply of water in the crystalline rock is generally from 20 to 40 feet, as above stated, and only in rare cases is a greater depth than 50 feet necessary. In the thickly settled rolling area about Wausau where the crystalline rock is within a few feet of the surface it is believed that more than one-half the wells are less than 30 feet deep. The much fractured and fissured condition of the crystalline formation holds equally well for those portions of the area covered with the glacial drift and the sandstone, for the fracturing was quite general and took place long before either the glacial drift or the sandstone was deposited. In drilling wells in the hard crystalline rock, like granite, the combined weight of bit and stem should equal 1,200 to 1,400 pounds. The light weight drills usually make slow progress. The possible clogging of the water passages in the process of drilling crystalline rock should be taken into account. In the area where the granite and other crystalline rocks are near the surface, however, most of the wells are dug wells and wisely so for such wells being of large diameter open up a correspondingly greater number of the large, generally nearly vertical, fissures ramifying throughout the formation. The dug wells being of larger diameter have a larger storage capacity and on this account, need not be so deep as the drilled wells.

Absence of Artesian Wells

The question is often asked as to the possibility of finding artesian wells in this part of the state. In answer to this it may be stated with a considerable degree of certainty that there is very slight possibility of obtaining flowing wells in this area, because the necessary geological conditions are wanting. The widespread occurrence of the granite and other crystalline rocks usually very near to the surface, and generally within striking distance by wells has already been pointed out. It is a well known fact that the crystalline group of rocks does not furnish artesian conditions and no flowing wells have ever been struck in this formation in this state though repeatedly attempted. The structure of the crystalline group, the character of its water passages and source of water is such as to entirely preclude the possibility of obtaining a flowing well from it, no matter how deep the well is sunk.

The sandstone formation lying upon the crystalline formation, is a principal source of flowing wells in other portions of the state. But where it is the source of flow it lies at a considerable depth below the surface and beneath other thick formations of limestone associated with impervious shales; whereas in this area it either lies at the surface or beneath a variable covering of loose pervious drift. The sandstone of this area, on account of its nearness to the surface, serves as a catchment basin and fountain head for the lower portions of the state, and consequently there is an entire absence of conditions here of fountain flow.

The alluvial formation along the Wisconsin River is porous throughout, and the other conditions for the securing of fountains are wanting. There is a slight possibility of finding an occasional small flow in the hilly portions of the thick drift, but so far as known none such occur in this area.

It may be stated, therfore, with considerable certainty, that the probilities of securing artesian wells in this area are so small as to make the search for them wholly unjustifiable. The conditions controlling the distribution of the artesian wells in this state are fully and clearly described by Prof. Chamberlin in Chapter VI., Vol II, Geology of Wisconsin.

PUBLIC WATER SUPPLIES.

Within the area here described, 8 cities, having a total population, in 1905, of 56,275, are provided with public water supply systems. Five of these cities are on the Wisconsin River, having populations and sources of supply as indicated in the table:

Source of water supply and population of cities on the Wisconsin river.

City.	Population.	Source of Supply.
Tomahawk	2,626	Large spring near bank of river.
Merrill	9,197	Open wells in sand and gravel.
Wausau	14,458	System of 30 six-inch wells, 134 feet deep, in the river gravel.
Stevens Point	9,022	Large open shallow wells on river bank
Grand Rapids	6,157	Springs.

Neillsville has a population of 2.117. Its source of supply are large open wells on bank of Black River, 35 feet deep, 20 feet in drift, 15 feet in granite.

Marshfield, with a population of 6,035, is located upon the divide between the Yellow and Little Eau Pleine rivers and Mill Creek. Its source of supply is a system of wells 30 feet deep, connected by galleries, in a sandy glacial formation.

Antigo, with a population of 6,663 is located upon Spring Brook and obtains its supply from a large open well about 25 feet deep in a sandy gravel glacial deposit.

NEAR THE FOOT OF GRANDFATHER FALLS, WISCONSIN RIVER.
The river has a fall of 90 feet in 1½ miles.

WATER POWER.

The water powers are a prominent and valuable natural resource of the area. No complete systematic measurement of the water powers of the area has been made but fairly accurate estimates have been furnished. Along the Wisconsin River from Tomahawk to Nekoosa, no less than 26 rapids occur. each having a fall of from 5 to 10 feet up to 90 feet.

The amount of available water power in this stretch of river probably exceeds 100,000 horse power, less than one-half of which is at present used. The water powers of the branches of the Wisconsin and other rivers of the area probably exceeds 25,000 horse power. Throughout the area the water powers are readily accessible by rail.

In the following table the data for which has been kindly furnished by Prof. L. S. Smith[1] the amount of the various water powers of the area is summarized.

*Water Powers of Northern Wisconsin, by L. S. Smith. Water Supply and Irrigation Paper No. 156. U. S. Geol. Survey, 1905.

Water powers of the Wisconsin river.[1]

Location.	Head.	Rated horse power of turbine installed.	Theoretical horse power.	Remarks.
	Ft.			
Nekoosa	20	5,700	7,400	Developed.
Port Edwards	18	3,860	6,660	Developed.
Centralia Pulp Co.	14	1,460	5,000	Developed.
Grand Rapids	26	6,500	9,600	Developed, consolidated.
Biron Dam	12	3,060	4,300	G. R. P. & P. Co.
S. 17, T. 23, R. 8, Stevens Point	9	1,370	3,150	Developed.
Stevens Point	16	4,660	5,600	Developed.
Stevens Point	7	....	2,450	Undeveloped.
Jackson Mill Co., Stevens Point	12	140	4,200	Partly developed (7 ft.)
Battle Island	20	....	6,200	Undeveloped.
Mosinee	20	....	6,100	Partly developed.
S. 24, T. 29, R. 7 E., Rothschild	20	....	6,000	Undeveloped.
Wausau	23	5,200	4,900	Partly developed only.
Brokau	12	3,960	2,500	Developed.
Trap Rapids	18	....	3,600	Undeveloped.
S. 12, T. 31, R. 6 E., Merrill	14	2,220	2,520	Developed.
S. 10, T. 31, R. 6, E., Merrill	8	Log dam.	1,300	Undeveloped except dam.
S. 8 and 9, T. 31, R. 6, Merrill	8	Log dam.	1,300	Undeveloped except dam.
Merrill	8	....	1,300	Dam not built.
S. 13, T. 32, R. 5, Bill Cross Rapids	20	....	3,060	Undeveloped.
S. 30, T. 33, R. 6, E., Grandfather Rapids	90	....	13,770	Undeveloped.
Grandmother Rapids	39	....	5,970	Undeveloped.
Tomahawk	13.2	1,200	2,000	Developed.
Pine Creek Power	20	....	1,740	Undeveloped.
Whirlpool Rapids	28	....	2,430	Undeveloped.
Hat Rapids	20	....	1,660	Being built.

[1] Estimate is based on a discharge of 6.10 cu. ft. per second per sq. mile of drainage area.—L. S. Smith.

Water power on the upper tributaries of the Wisconsin river.

Location.	River.	Head.	H. P.	Remarks.
Sec. 31, T. 41, R. 8 E.	Big St. Germain..	15	....	Not used.
Sec. 32, T. 40, R. 8 E.	.... do	20	....	.... do.
Sec. 18, T. 39, R. 8 E.	.... do	26	....	.... do.
Near Tomahawk ...	Tomahawk	18	300	Developed.
Sec. 21, T. 36, R. 6 E.	.... do	20	....	Undeveloped.
Sec. 17, T. 37, R. 6 E.	.... do	8	....	.... do.
Sec. 27, T. 38, R. 5 E.	.... do	12	....	.... do.
Sec. 4, T. 36, R. 10, E	Pelican	8	....	.... do.
Sec. 17, T. 36, R.10 E	.... do	6	....	.... do.
Sec. 26, T. 36, R. 9 E.	.... do	10	....	.... do.
Sec. 21, T. 36, R. 9 E.	.... do	12	....	.... do.
Merrill	Prairie	21	....	Developed.
Sec. 13, T. 32, R. 7 E.	.... do	72	....	.. do.
Sec. 14. T. 33, R. 8 E.	.... do	20	....	Undeveloped(
Marathon	Rib	18	....	Developed.
Rib Falls..........	.... do	20	215	.... do.
Sec. 24, T. 30, R. 4 E	.... do	18	....	Undeveloped.
Schofield...........	Eau Claire	12	....	Developed.
Mansur's......	.... do	25	....	.... do.
Old Kelley..........	.... do	25	....	... do.
Barnards Rapids ...	.... do	22	....	Undeveloped.
The Dalles	.... do	50	800	.... do.
Three Rolls	.... do	12	....	.... do.
Little Rapids.......	... do	12	....	.... do.
Sec. 18, T. 26, R. 6 E	Eau Plaine......	15	....	.... do.
Sec. 24, T. 26; R. 6 E.	.... do	15	....	.... do.
Sec. 13, T. 27, R. 3 E.	.... do	15	....	.... do.
Sec. 4, T. 27, R. 3 E.	.... do	10	....	Developed.
Sec. 24, T. 28, R. 2 E.	.... do	10	....	.... do.
Jordan	Plover	24	580	.... do.
Sec. 29, T. 29, R. 7 E.	Little Rib.......	12	....	
Sec. 5, T. 31, R. 6 E.	Copper..........	30	....	
Sec. 16, T. 34, R. 6 E.	Spirit	13	....	

Water powers on the Black river.

Location.	Owner.	Head.	Horse Power	
			Developed.	Undeveloped.
Black River Falls	City[1]	13	350	650
Black River Falls	J. J. McGillivary[2]	16		
1 mile below city Black River Falls		7		‡500
S. 2, T. 21, R. 4 W.	Black River Imp. Co.	30+		2,000
Halycon-S. 16, T. 22, R. 3.	Black River Imp. Co.	30		2,000
Hadfield	Black River Imp. Co.	90		6-8,000
Ross Eddy Power		42		3,000
S. 2, T. 24, R. 2 W.	V. Huntzecker	24		1,500
Hemlock Dam	Black River Imp. Co.	12	175	500

[1]El. Light.

[2]Sash, Door Mill, etc.

There is in progress at the present time a survey of the water powers of the state by L. S. Smith, and the results of this survey will soon be published as a bulletin of the State Survey. A more detailed account of the water power of this area is to be included in that report.

SECTION II. SOILS.

The soils of the area, though widely variable in composition and texture, readily fall into several well defined kinds or classes. In the 7200 square miles of the area 14 kinds or phases of soils have been discriminated and the area occupied by each shown upon a suitable map.[1]

The soils of the area have been described in a separate report of the Survey, Bulletin XI, accompanied by a soil map, the same size and scale of the two geological maps accompanying

[1] The soil map accompanying Bull. XI, Wis. Geol. & Nat. Hist. Survey.

this report. Since the soils and general agriculture if this area have already been described,[1] it is purposed to present here but a brief general account of the soil conditions of the area.

The various soils of this area, as of other areas, often grade insensibly into one another. Between certain soils, however, like those of the sandy river bottoms and those of the clayey uplands, the boundary lines are sharp and well defined. Some of the soils are very uniform in character over considerable areas, while others are quite variable. The gradation and character of the soils have been pointed out in the report on soils referred to.

ORIGIN OF SOILS.

It is impossible to adequately discuss the nature of any particular soil without describing the history of its origin and development. If it be understood once for all that all the soils were not made and finished at the same moment in some remote period, but that each had a slow development which began at widely different times, and that soils are now actually being formed from day to day, season to season, and year to year, the knowledge of the method of soil growth or origin, is seen at once to be important and valuable to the agriculturist.

Briefily stated, the soils consist of mineral and organic material. The mineral portions of soils originate through the disintegration and weathering of the stony material and rocks forming the surface of the land, and the organic portions through the decay of animal and vegetable matter living upon and within the soil.

The agents most effective in this process of rock weathering which produces the mineral portion of the soil are water in its various forms, change of temperature, and the air. These agents are not only effective at the surface, but they pene-

[1] The report on the soils and agricultural conditions of the area describes the various soils with respect to their area, surface features, general character and origin, ground water conditions, the native forest growth, and the crops now grown upon them. The general conditions of climate, precipitation, and also the history and present conditions of the agriculture are described and illustrated by tables and maps. This report is Bull. No. XI, of the Wisconsin Survey, and can be obtained on application.

trate deeply into the rocks and loose earth. Water in the form of rain acts chemically upon rocks by dissolving them, and mechanically by washing and wearing away the loose material. In temperate climates such as ours the alternate freezing and thawing of the water included in rock pores and crevices, in autumn and spring, tend to loosen and split apart the rocks. Burrowing animals, such as earthworms and the fur bearing animals, aid materially in making soil. The growth of roots of the forest trees and even of the smallest plants split apart the rock particles and assist in soil formation.

As the rocks are being powdered and softened into loose material there is a constant process of wash by rains of this loose soil material from the higher levels on the hill sides to the valley bottoms, and thence by streams to still lower levels on their way to the sea. If the rains are gentle but little loose material is washed away. However, if rains are copious they may transport in a few hours enormous amounts of sand and mud to lower levels. Besides the work of rains and streams in transporting the weathered rocks and soils, wind is also an effective agent in carrying soil particles from place to place.

But perhaps the most important soil transporter in Wisconsin, so far as agriculture is concerned, though now no longer active were the glaciers of the Great Ice Age. While these ancient glaciers were transporting soil and rock debris, they were also very effective in making the rock and soil particles finer and finer by rubbing and grinding them against one another, and thus were soil builders as well as soil carriers.

SURFACE SOIL AND SUBSOIL.

The surface portion of the soil formation containing more or less dark colored organic material brought to it by the decay of plants is generally from four to eight inches thick. The subsoil lies immediately below the darker surface soil and is the medium in which much of the soil moisture and nitrogen are stored and held available for plant life. If the subsoil texture is such as to hold too little or too much water the fertility of the soil is greatly decreased. I has been shown by Professor King that soil moisture may be obtained through capillary movement at depths of 12 feet below the surface and in some cases at depths of 16 feet The roots of corn in search of moisture may penetrate the soil to a depth of four feet and roots of clover often go down 18 inches. Hence it is important for the agriculturist to know the character of the soil for a considerable depth below the surface as well as of that portion which is turned by the plow and the cultivator.

BASIS OF SOIL CLASSIFICATION.

Soils are classified in various ways. A grouping of the soils acording to the native growth of timber is often used and according to this method the area could be divided into hardwood lands, white pine lands, jack pine lands, and cedar or tamarack lands. A classification according to the kind of crops best grown is often applied and in such cases, potato soils, grass soils, wheat soils, and tobacco soils is used. We also have limestone soils and sandstone soils, a classification based upon the nature of the rock from which the soil is derived.

The classification which seems best fitted to answer all purposes is one based on the texture of the soil, mainly due to the relative proportion of sand and clay present. There is no sharp limit in soils between what is called sand and what is called clay, but these grade insensibly into one another through intermediate grains. If there is more than 95 per cent of either sand or clay present the surface is best referred to, not as soil, but as sand or clay. Soils are sandy if from 40 to 65 per cent of their weight is made up of particles so small that from 1,000 to 400,000 of them must be placed in line to span a linear inch, while the balance may be so large that only 20 to 100 of the particles are needed to stretch across the same distance. The heaviest clay soils, on the other hand, may have 80 to 95 per cent of the small sized particles named above and from 5 to 20 per cent of the larger grains. Loam soils are intermediate in grain between the sandy soils and the heavy clay soils; while between this medium loam soil and the coarser sandy soil are sandy loams and loamy sands, and between the loam and the clay soils are loamy clays and clayey loams, there being of course, in all cases, a gradual change between the various kinds. If there is present a considerable amount of stone or gravel the soil is called stony or gravelly. Besides these soils there are the muck, peat or humus soils, containing a high percentage of decaying organic matter or humus and occurring in the undrained areas of the swamps and marshes.

CHEMICAL COMPOSITION OF SOIL.

As already pointed out, the kinds of soil and their classification depend upon the texture of the soil rather than the chemical composition. Chemical analyses of soils as usually made, while important, do not usually furnish the information desired to rightly estimate the character of the soil with respect to fertility or its adaptation to certain crops. In general, most soils contain the necessary constituents for the growth of crops; and hence if soils are infertile it is usually because favorable physical conditions are wanting for the physical development of rich soils, such as the proper conditions of the soil texture, soil moisture, drainage, temperature, rainfall, etc.

The various important chemical elements occurring in soil are oxygen, silicon, carbon, sulphur, hydrogen, chlorine, phosphorous, nitrogen, fluorine, boron, aluminum, calcium, magnesium, potassium, sodium, iron, and manganese. The oxygen, hydrogen, carbon, chlorine, and nitrogen get into the soil from the atmosphere and the rains assisted by vegetation. The other elements are found in abundance in the crystalline rocks of the area as well as in the glacial drift and alluvium made up of crystalline rock debris and in the soils formed by the weathering of these formations. It is believed that the soils of this area contain all the chemical elements necessary for the growth of crops, and that the varying degree of fertility of the different soils is probably due to their texture and the physical conditions surrounding them.

As the soils owe their origin to the slow weathering and decomposition of the rock formations, some of the soil formations are derived from the weathering of the glacial drift, others by the decay and modification of the various crystalline rocks, and others by decay of the sandstone and of the river of glacial gravels and sand.

The names adopted for the various soil formations of the area are local and have been selected from the names of rivers or townships where the soils occur.

SOILS DEVELOPED UPON ALLUVIUM.

The soils formed upon the nearly level alluvial formations are the Wisconsin River sandy soil, the Bancroft gravelly sandy loam, and the Antigo gravelly loam. The common characteristics of these soils are their approximately level surfaces, and the gravel and sand subsoils.

Wisconsin River Sandy Soil.

This soil is a sandy loam or sandy soil occurring upon the nearly level plain bordering the Wisconsin River and extending over the alluvial plain of southwestern Portage and southern Wood counties. The forest growths are, or were originally, mainly Norway and white pine and in places in the southern part of the area a scattering of jack pine. The prevailing crops grown upon this soil are potatoes, corn, rye, hay, and oats; but little wheat and barley are grown, potatoes and rye being the principal export crops.

Bancroft Gravelly Sandy Loam.

This soil formation is wholly within Portage County, where it forms a belt of varying width lying immediately adjacent to the prominent ridge of the terminal moraine. The soil is a sandy loam. The native forest growth is Norway pine and white pine, some hardwoods, and in places scrub oak and jack pine. The crops consist of potatoes, corn, rye, oats and clover, potatoes and rye being the principal export crops.

Antigo Gravelly Loam.

This soil formation is a nearly level plain bordering the terminal moraine in the vicinity of Antigo. The soil is clayey gravelly loam underlain by a subsoil consisting of sand and gravel. The native forest growth consists of an abundant stand of hardwoods, hemlock and white pine. The soil is adapted to grasses, clover, potatoes, barley, oats, rye, peas and corn.

SOILS DEVELOPED UPON GLACIAL DRIFT.

The soils developed upon the glacial drifts of the area are quite variable. The soil of the older drift sheets, the Second and Third, in certain portions of the area, have characters and surface features which distinguish it from the soils of the later drift. The later drifts, the Fourth and the Wisconsin drift, vary in content of sand and clay in different parts of the area, and also in surface features, due to the origin of the drift, as terminal or ground moraine. The soils are not classified in accordance with glacial or pre-glacial stratigraphy, but upon differences in surface features and character of soil, which depend upon a combination of geological factors, such as the method of drift deposition and the character of the underlying rock.

Amherst Sandy Loam.

This soil formation occurs in the two eastern tiers of townships in Portage County, and within the sandy portion of the terminal moraine deposits of the Wisconsin drift sheet. The topography of this area is rolling and hilly and the soil is a sandy loam somewhat stony in places. The forest growth of this soil is usually light, consisting of scrub oak with some hardwoods and pine. It is well adapted to the growth of potatoes, corn, oats, grasses, and clovers. The potato is a most important crop.

Chelsea Clay Loam.

This soil formation lies in the area of the terminal moraine deposits of the fourth and the Wisconsin drift sheets. The soil is a clayey loam somewhat stony in places, the surface feature being hilly like that of the Amherst sandy loam. The forest wrowths are originally dense hardwoods and hemlock, with scattering white pine. The soil is adapted to the growth of barley, oats, corn, potatoes, and grasses and clover.

Harrison Sandy Gravelly Soil.

This is a coarse sandy soil occurring in the northeastern part of Lincoln County within the area of the Wisconsin Terminal Moraine. The surface is therefore generally quite hilly. The forest trees were mainly Norway and white pine with some hardwoods. This region is but little settled, the crops being mainly potatoes, oats, rye and grasses.

Kennan Clay Loam.

This soil formation is in the area of the ground moraine of the Wisconsin drift sheet. The surface is generally sloping and rolling, with here and there broad, nearly level stretches. The soil is a clay loam varying to a lighter loam. The forest growth was usually very dense and consisted mainly of hardwoods and hemlock, with a scattering of white pine. This area is but little settled. The soil is well adapted to the growth of grasses and clovers, corn and potatoes, and oats and barley.

Cary Sandy Loam.

This soil formation forms a belt extending east and west across the central part of Wood County, and the southwestern parts of Clark County. The soil is a sandy loam, the surface being gently sloping and rolling throughout. The soil had its origin in a thin glacial drift covering the sand stone and crystalline rock or its decomposed equivalent of residual clay. The forest growth was pine and hardwoods and the prevailing crops are hay, oats, rye, potatoes and corn.

Colby Loamy Clay.

This soil formation has a wide distribution in the area covering mainly the region of the second and third drift sheets in Marathon, Lincoln, Langlade, Taylor, Clark and Wood Counties. The soil is a rich loamy clay which originally supported a growth of hardwoods with scattering pine. The principal crops are grasses and clover, corn and barley, and oats and potatoes.

SOILS DEVELOPED UPON THE CRYSTALLINE ROCKS.

The soils developed by weathering and decomposition of the pre-Cambrian crystalline rocks are the Marathon loam and the Mosinee gravelly soil. These soils form a veneer overlying the hard crystalline rock and contain a variable amount of crystalline fragments.

Marathon Loam.

The area of this soil is in the central portion of Marathon County and adjoining part of Portage County, and includes the driftless area within the region of the crystalline rocks. The surface is rolling. The soil is clayey loam mainly of residual origin from crystalline rocks, and contains a very small amount of rock fragments. The forest growths were dense hardwoods and hemlock with a scattering of white pine. The crops are grasses and clover, oats, barley, corn and potatoes.

Mosinee Gravelly Soil.

This soil is a gravelly formation of small area covering the disintegrated coarse granite southwest of Rib Hill in Marathon County. The soil has originated from the coarse granite. The forest growth is mainly a dense growth of hardwoods and scattering pine.

SOIL DEVELOPED UPON THE SANDSTONE.

Soil mainly derived from the disintegration of the sandstone occurs in the southwestern part of Clark County. This soil is modified by the presence of some drift.

Mentor Loamy Sand.

The area of this soil is in the southwestern part of Clark County. The surface is gently sloping, and dotted with mounds and hills of sandstone, the soil originating in a disintegration of thin drift overlying the formation. The forest trees were mainly pine and the crops are usually potatoes, corn, rye, and beans.

SWAMP AND MARSH SOIL.

This soil occurs in the various swamps and marshes of the area and is mainly confined to the swampy portions of the Wisconsin drift sheet and the wet alluvial tracts of southwestern Portage and southern Wood counties. The soil is a mixture of clay and humus associated with muck, peat, and sand. The marshes of Portage and Wood counties are utilized for the production of wild hay, and certain portions have been drained and cranberry farms developed upon them.

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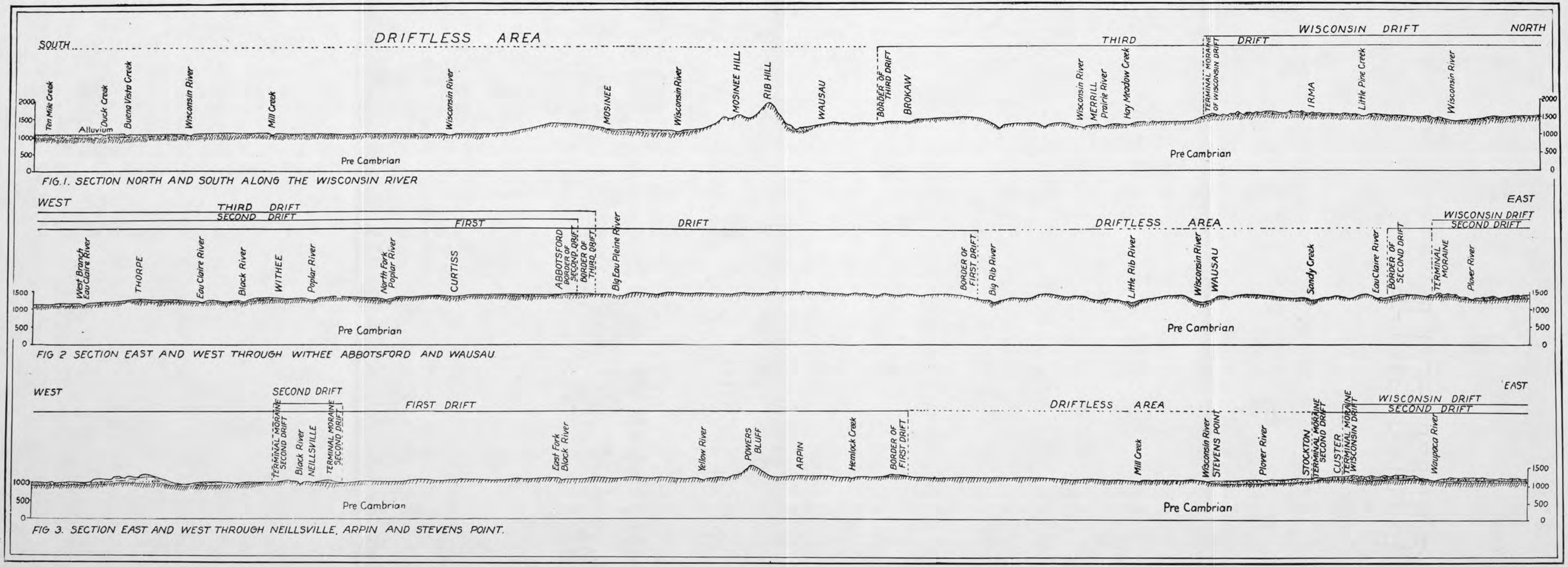

FIG. 1. SECTION NORTH AND SOUTH ALONG THE WISCONSIN RIVER

FIG 2 SECTION EAST AND WEST THROUGH WITHEE ABBOTSFORD AND WAUSAU

FIG 3. SECTION EAST AND WEST THROUGH NEILLSVILLE, ARPIN AND STEVENS POINT.

STRUCTURAL SECTIONS ACROSS THE AREA OF NORTH CENTRAL WISCONSIN TO ACCOMPANY MAP (PL. II.) OF THE PLEISTOCENE FORMATIONS.

Base line of section is the sea level. Horizontal scale 1 in. = 5 miles; vertical scale, 1 in. = 2,250 feet.

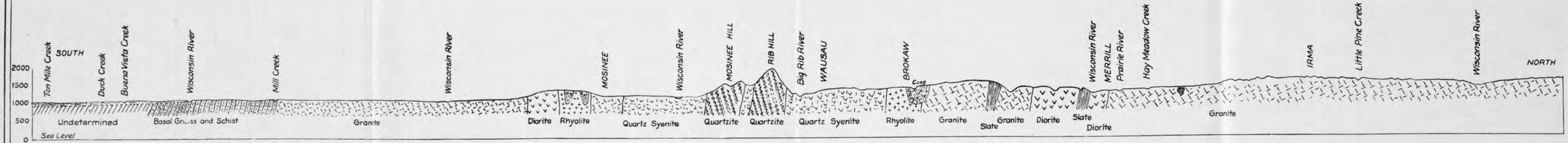

FIG. 1. SECTION NORTH AND SOUTH ALONG THE WISCONSIN RIVER

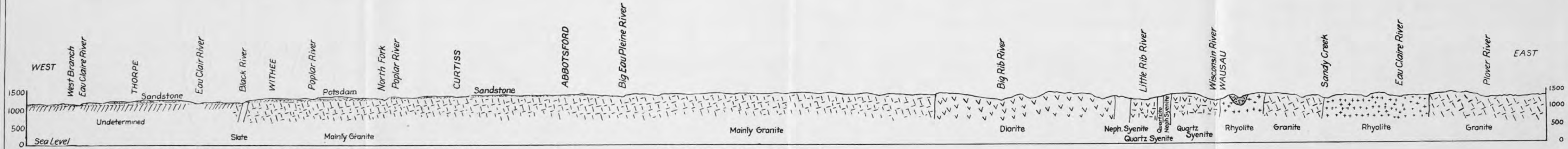

FIG. 2. SECTION EAST AND WEST THROUGH WITHEE, ABBOTSFORD AND WAUSAU

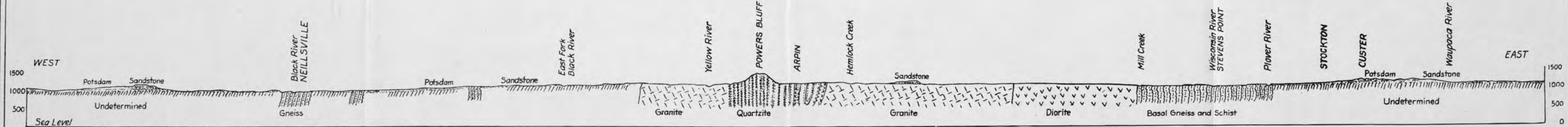

FIG. 3. SECTION EAST AND WEST THROUGH NEILLSVILLE ARPIN AND STEVENS POINT

STRUCTURAL SECTIONS ACROSS THE AREA OF NORTH CENTRAL WISCONSIN TO ACCOMPANY MAP (PL. I.) OF THE CAMBRIAN AND PRE-CAMBRIAN FORMATIONS.

Base line of section is the sea level. Horizontal scale, 1 in. = 5 miles; vertical scale, 1 in. = 2,250 feet.