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A STRUCTURAL STUDY OF THE WAUSAU AREA

by

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The area of this study includes twelve townships, Townships 28 to 30, Ranges 5 to 8E. It is located in Marathon County, Wisconsin, and includes the City of Wausau in the east central part. It is crossed by U.S. Highway No. 51 from north to south, by State Trunk Highway No. 29 from east to west, and in part by State Trunk Highway No. 52 which leads from Wausau northeastward. Elsewhere within the area are several county trunk highways and many secondary roads of good quality. In general, roads are one-half mile to one mile apart.

There is considerable quarrying of granite, quartzite and argillite within the area, which is devoted primarily to farming. Several attempts have been made in the past to exploit the occurrences of nepheline and zircon which have long been known. Nepheline, which is the chief objective of the present work, has not been found in suitable iron free quality nor in sufficient quantity at the surface for quarrying operations.

The purpose of this study has been to learn the conditions under which the nepheline deposits were formed with a view:

(1) To delimiting the area of the nepheline occurrences,
(2) To determining something of the nature of the nepheline reserves,
(3) To learning something about the factors which determine the iron content of the nepheline.

For several years now it has appeared that the nepheline owes its origin and distribution locally to structural factors within the area. With this in mind this structural study was undertaken, and the results of the field work are offered here.

We have had the distinct advantage of two separate pieces of work in the area to help us, that of Weidman, published as Bulletin 16 of the Geological Survey of Wisconsin 1907, and that of the Wisconsin Geological Survey field parties of the early 1920's supplied to us as blue print township plats of the geology. We have modified somewhat these interpretations but have drawn heavily on them, as acknowledged in the accompanying map.

The rocks occurring here are volcanic flows and associated sediments overlain by quartzite, later intruded by granite which differentiated into several types including the nepheline-bearing rocks, as a result largely of the structural control of the overlying roof rocks. With this picture in mind the many rock types found in the area are seen to be in considerable part modifications of the few fundamental types, and the complex picture of the earlier mapping may be simplified greatly by grouping the modifications under general heads. The fundamental rock types and their modifications will therefore be discussed first. Their mutual relationships will then be more easily described.

Rhyolite. The rhyolite is best exposed and occurs in larger bodies in the eastern portion of the area. The mapped rhyolite immediately east of Wausau is well exposed and in considerable part is unaltered. Another excellent locality in which to study the rhyolite is Big Sandy Park where Big Sandy Creek cuts the rhyolite and provides a continuous exposure for 100-200 yards and additional exposures beyond.

In general the rhyolite is a dark reddish or dark gray porphyritic rock, massive in structure and outcropping better than many other rocks of the district. The rhyolite matrix is extremely fine-grained, much too fine-grained for field study. The phenocrysts are feldspar and quartz. The nature of the phenocrysts is not constant over the area, being usually feldspar, sometimes quartz and commonly feldspar with a little quartz. The feldspar is orthoclase at some localities, is usually plagioclase, and locally includes both. The feldspar may be either white or red, but is more commonly white in the darker rhyolite occurrences and is red in the reddish rhyolite.

The Big Sandy Creek exposure gave the best opportunity for study in the area. The rocks appear on both sides of the stream as well as in the bed. Exposures are good. Most of the rock is rhyolite, most of the rhyolite is porphyritic, the remainder (10-20%) is chlorite schist. Virtually all of the rhyolite is at least somewhat sheared. The matrix of the least sheared rhyolite is too fine-grained for the hand lens but the orthoclase phenocrysts are 1-2 mm. long. They show up best on the weathered surface. The thickest beds are inclined to be massive, are 20-25 feet thick; others are as thin as 3 feet. The original lithology of the thinner beds is a question since they have developed schistosity rather consistently and are now chlorite schist. The attitude of the beds and schistosity is uniformly strike N75°E, dip 80°S. Original flow structure in the rhyolite is quite commonly evident and in many beds is very marked.

In the area northeast of Wausau and southeast of Brokaw, the rhyolite was observed mainly in surface float rather than in outcrop. Here much of the rhyolite carries only clear, glassy quartz phenocrysts in euhedral to subhedral form, and having plentiful inclusions of magnetite or chlorite. For the most part, however, the rhyolite here carries plagioclase phenocrysts, well twinned, and white in color. The matrix is very dark. Some of the rhyolite in this section is sheared in which case it is quite light gray in color.

Directly east of Wausau, about one mile from the city limits (NE¼ NE¼ Sec. 29, T 29 N, R 8 E), the rhyolite is well exposed on the crest of a southward facing hill. The matrix is fine-grained, almost glassy, medium gray in color and carries phenocrysts of quartz and plagioclase. The quartz is well rounded, and is by no means abundant, possibly no more than one per cent of the rock. The plagioclase phenocrysts constitute between five and ten per cent of the rock. They are in subhedral to euhedral crystals, 2-3 mm. in diameter, white in color and well twinned on the albite-carlsbad complex law. The rock shows a very massive character at this point. The outcrop does not permit the determination of individual flow thickness.

These descriptions apply to the rhyolite in its most nearly unaltered form. The recognized modifications of the rhyolite are of special interest since the rhyolite is so closely associated with other rocks of critical interest in the area, some of which bear a slight resemblance to modified rhyolite. A few selected modified rhyolites may well be described. A common aspect of the rhyolite where it is close to the intrusive aplite or is cut by aplitic apophyses is a glassy medium gray rock, with or without phenocrysts, in which the matrix is distinctly spotted by chlorite in small grains or in aggregates. Where the aplite apophyses are large and numerous, such as immediately east of the city limits of Wausau on County Trunk Highway "N" and in the environs south of the highway, the rhyolite goes far to blend with the aplite through recrystallization. Apparently this alteration does not extend far from the aplite-rhyolite contact, possibly only a few feet, though the apophyses have been observed to penetrate the rhyolite for two or three hundred feet. This is illustrated on Highway "J" one mile north of Highway "N" in SE$\frac{1}{4}$ SE$\frac{1}{4}$, Sec. 25, T 29 N, R 8 E, and again on Highway "N" just east of Wausau, though less clearly (South border Sec. 31, T 29 N, R 8 E).

Contiguous to the intrusive granite the rhyolite is dark, even becoming dioritic. This peculiarity is not easily explained since the contact selvage is higher in mafic constituents than is either the granite or the rhyolite. Bedrock exposures are so meager in these places that only a suggestion can be offered in explanation. We have observed repeatedly that the rhyolite darkens at intrusive contacts with the granite and locally becomes highly mafic. This process of change leads to a granite hybrid which ranges from granodiorite to mafic diorite. One interpretation of these facts is that the rhyolite passes downward into more vulnerable and mafic rock, such as greywacke or greenstone which yields the hybrid mentioned. The rhyolite itself, being refractory, repels the intrusive which stops progress after digesting the mafic material; hence the hybrid salvage between the intrusive and the rhyolite.

The exposure of rhyolite on the north bank of the Eau Claire River just east of the bridge near Kelly shows both the apophysal penetration of rhyolite by apparent granite and the development of small plagioclase laths through recrystallization, in addition to the spotty accumulation of mafic material already described.

Southeast of Schofield (in Sec. 20, T 28 N, R 8 E) the float indicates the nearest approach to a gradation between aplite and rhyolite of any rock seen in the area. Some of the rhyolite float here shows flow banding which bears a resemblance to the banded aplite seen elsewhere. Also shown here are various degrees of development of the mafic hybrid type from the rhyolite. Since, however, none was found in place, the conclusions must be withheld.

Another type of alteration of the rhyolite is found in SW$\frac{1}{4}$ SE$\frac{1}{4}$ of Sec. 26, T 30 N, R 6 E, where the rhyolite has been sheared to produce a very white, very fine-grained, apparently sericite schist. There are quartz augen, apparently phenocrysts, in the schist. The schist cuts rhyolite which is here exposed in the roadside.

It will be shown below that much of the rhyolite of the map area and most of the smaller rhyolitic bodies are shallow and yield downward to aplite or granite. The reticulating dikes and veinlets which characterize much of the rhyolite are to be interpreted as such contact effects and not as features of the rhyolite itself.

Greenstone. We have chosen to include under this heading the following rock types --- argillite, basalt, agglomerate, chloritic greenstone schist, and hornblendite. We have done so with the thought that all these rock types are closely related, as will be shown. Although the dioritic and gabbroic hybrids could well be included here, we have chosen to classify them with the granite. Actually they are contact phases on a large scale.

The most abundant of the greenstone types is argillite which occurs extensively over the northern part of the map area. It is best exposed for study near the Wisconsin River, where it outcrops in several places boldly and is also revealed in road cuts. It includes both massive and banded types, and both mafic and quartzitic types.

The best exposure of the argillite type is to be found in the Brokaw quarry where the argillite is being used for roofing granules. Outcrops to the south of the quarry for a half mile are also good, especially in highway road cuts. The surface six feet are badly jointed to produce the customary small, angular, hand size blocks so commonly found as float where outcrops are lacking. Below this the rock, though jointed is massive in large part. Some beds are badly jointed as deeply as the cuts reveal them. The argillite may be divided into three main types---banded argillite, massive argillite, and quartzitic argillite.

The banded argillite is perhaps the most common of the three. The banding is not very evident on a freshly broken surface but ordinarily shows well on a weathered surface. In the quarry, however, the banding shows well on fresh surfaces in some parts. The banding consists of color contrasts showing beds ranging in thickness from that of a sheet of paper to 1/4 inch. The bands are by no means parallel but show marked lenticular form. There is no evident contrast in grain size of contiguous beds. Within beds there is further banding, and overall contrasts are evident in stratigraphic units six feet thick. But under the lens all beds are composed of material beyond resolution. In several of the exposures south of the quarry the bedding shows marked folding, even crenulation, without any apparent increase in fracturing of the rock, this despite its hard siliceous nature.

The massive argillite is a dark greenish gray rock for the most part, uniform in color and lacking evident structure. In places it carries small one millimeter spots of chloritic material but in most places is uniformly colored, hard and massive. Specimens from different parts of an outcrop of massive argillite may show distinct color contrast but one is not conscious of the change in the rock at any particular place.

One modification of the massive argillite shows strong development of serpentine. This rock is strikingly massive and uniform and appears to be confined to definite beds. It is not of infrequent occurrence but is much less common than is the siliceous type.

Still another massive type of argillite, apparently of only occasional occurrence, is one which has the appearance of being highly sericitized. It can be scratched by a knife but also scratches the knife. It has an argillaceous odor, its color is quite light gray, and its texture is beyond the reach of the hand lens. It may be an alteration product near an intrusive contact.

The most quartzitic argillite seen is being quarried in the Brokaw quarry. This rock will undoubtedly prove under the microscope to be novaculitic. It is translucent, pale in color, in part massive, in part banded, extremely fine-grained, and breaks with a conchoidal fracture. When struck with a hammer it has a metallic ring.

Another excellent exposure of argillite, most of which is finely banded, is in a road cut on the east side of the Wisconsin River directly north of Wausau on Highway "W" in Sec. 12, T 29 N, R 7 E. This rock is more chloritic than that at the Brokaw quarry but otherwise is quite similar to it. It is well and finely bedded in the southern part of the exposure and quite massive in the northern part. The exposure is about a quarter mile long.

Elsewhere in the area greenstone occurs frequently but usually in small outcrops and masked by typically intense surface fracturing. Also, it is commonly modified by the closely underlying igneous intrusives, and is dissected by their apophyses. This applies especially to the large areas of argillitic greenstone in the north and west of the map area.

In two places, agglomerate was found -- one in the SE$\frac{1}{4}$, Sec. 12, T 29 N, R 7 E, reached on Highway "W" north of Wausau. It occurs on a hillside in a pasture about 100 yards from the road. The other occurs immediately south of the Brokaw quarry in a prominent rock cut on the highway. In both occurrences tuff and agglomerate are found together. Especially in the Brokaw occurrence the larger fragments are rounded, giving the rock the aspect of a conglomerate. The fragments are, however, all volcanic. The tuff and tuffaceous matrix of the agglomerate is composed of volcanic fragments, highly angular in shape, variously colored and textured and dominantly uder 1/4 inch in size. This rock is comparatively soft, especially when compared to the argillite. It appears to be kaolinized or sericitized. Under the hand lens the entire rock appears too fine-grained for resolution. Only by color contrast do the tuffaceous and agglomeratic fragments stand out. Various colors are represented, mostly dark, the fine matrix is mostly a mauve shade. The largest fragment seen in the agglomerate is one foot in diameter. The majority of the fragments are one to four inches.

The hornblendite which is found only at two places in the area (Sec. 33, T 28 N, R 8 E, and Sec. 13, T 28 N, R 8 E) is a rock of unusual interest and significance in its connection with the structural history of the area. It is a metamorphic rock composed of large poikilitic hornblende crystals measuring commonly over one inch across and in the extreme as large as three inches long in a matrix of dominant hornblende and a little feldspar. It is associated with greenstone and granite.

Granite. It is probable that there are two granites in this area but no field method has been found to recognize the older of the two. It is possible that the granite of the rapids at Big Rib Falls is the older granite but we are unable to offer evidence. It is probable that the overwhelming bulk of the granite of the area is younger granite which is intrusive into all the rocks represented on the map. Included under the map designation "granite" are also the hybrid rock types, diorite and gabbro. Most of the granite is red. When contaminated by greenstone, the granite becomes white or gray or even black and gabbroic.

The red granite, the common granite of the district, is by no means uniform even in those parts of the area which are presumably remote from foreign contamination. From place to place there are differences in the orthoclaseplagioclase ratio, in the quartz content and even in the hornblende content. The presence of biotite has been adopted as one indication of contamination by greenstone. Commonly, too, the contaminated granite is gray rather than red, and is higher in mafic constituents than is the common red granite. From place to place the red granite texture shows differences but the most striking differences in texture are to be found near local contamination. Aplite dikes seem to be a common feature of the granite, to be seen in almost any large exposure. Pegmatite and lampophyre dikes are more limited to the vicinity of areas of foreign contact.

There are several quarries in the red granite, in areas where the granite is most "normal" and uniform. The granite at these points is indeed rather uniform. A typical quarry granite of the Wausau area is feldspar 65%, including both orthoclase and plagioclase, quartz 35%, and usually a little chlorite. The texture is coarse granitic, about 5-6 mm. The rock is massive and in the deeper parts of the quarries is very widely jointed. Some of the quarries show a seriously large number of chloritic paulopost veinlets which necessitate the discarding of quantities of otherwise marketable rock. Rarely are inclusions a problem in the granite quarries of the Wausau area.

Areas of hybrid are quite numerous. A typical example is that in the northwest corner of Sec. 34, T 29 N, R 6 E. Here the rock is greenish gray, fine granitic in texture (1-2 mm.) it is dominantly feldspar (80%), and carries about 15% of chlorite and hornblende. The quartz content is about 5%. As is characteristic of the granite hybrids in general, the individual minerals appear to be masked by an alteration such as sericitization which deprives them of the sharp boundaries due to color contrast associated with fresh granite.

Hybrids may be found in the area in all stages of reaction. Some such as that exposed at Big Rib Falls contain quantities of quite undigested greenstone. Some, such as the exposure in the rock cut where County Trunk Highway "O" crosses State Highway No. 29, show the greenstone well recrystallized but by no means granitic in texture except locally. Some, such as the exposures in Sec. 25, T 29 N, R 5 E, show the inclusions as ghosts. This is also shown in a more advanced stage in Sec. 29, T 30 N, R 8 E. A most extreme degree of reaction is illustrated by the granite in SW$\frac{1}{4}$ SE$\frac{1}{4}$ Sec. 16, T 29 N, R 8 E. Here the rock is a biotite granite carrying about 10% of biotite. Other illustrations could be given but these illustrate adequately the principles involved. Usually the hybridization can be traced from greenstone across the greenstone-granite contact almost anywhere within the area, through the stages described out into biotite granite and finally into that which we choose to recognize as "normal" granite.

An attempt was made to learn the depth to which the greenstone influences the granite. Where this could best be learned, in the northwestern part, outcrops are too scattered and we felt that such critical information should not depend on float. In the northeast corner it can be said that one mile from the greenstone the granite shows no recognizable effect of the greenstone. This assumes that the contact is vertical since the measurement is made on the present surface. There will be offered evidence that most of these contacts have a very low angle of dip and doubtless therefore the stated mile can be reduced well below half that distance.

The mutual effects of granite and greenstone may be of the type described above, presumably the normal reaction when greenstone reacts with the main body of the granite where diffusion is most free to operate. Another type of hybridization and one less commonly seen is that which leads to the conversion of greenstone to dioritic and gabbroic rock types. There are two localities within the map area where such rocks have been formed -- the area around Callon and the area around Big Rib Falls.

At Callon, the admixture of greenstone and gabbro in the relationship of an injected gneiss and the transition to hornblendite at one point and to granite to the north leaves little doubt about the origin of the gabbro. This rock is about 50% fine-grained gabbro with occasional pegmatoid areas of small size, the remainder being banded chloritic greenstone considerably recrystallized to coarser feldspar and actinolite. It is composed of an estimated 65% of calcic feldspar and 35% actinolitic amphibole. The feldspar is medium gray in color and the amphibole is green, not basaltic. The rock looks fresh. The texture is fine granitic (2-3 mm.) but pegmatoid phases are coarser (about 6-8 mm.) and show up especially well on the weathered surface. On the fresh break they are marked by an especially strong development of amphibole. Throughout the rock there is a noticeable tendency for the common orientation of amphibole. This amphibole is darker in color than that of the run of the rock. It is the apparent beginning of the formation of poikilitic hornblende porphyroblasts.

The greenstone inclusion phases are marked on a fresh break by more chlorite and by more actinolitic amphibole. The gabbroic phases show a tendency for the amphibole to become hornblendic. The greenstone phases are therefore very evident on a weathered surface, but by no means evident on a fresh break.

The hornblendite in the gabbro area is composed of an estimated 75% hornblende, and 25% calcic feldspar. Much of the hornblende is porphyroblastic and poikilitic. This rock appears to be analagous to the porphyroblastic hornblendite found in Sec. 33 of the same township, differing largely in the smaller size of the hornblende crystals.

In the gabbroic area (mapped as granite) in the vicinity of Big Rib Falls the rock variations include many of the same type but also others. In SW$\frac{1}{4}$ SW$\frac{1}{4}$, Sec.30, T29N, R6E, the rock is a sodic biotite diorite, a mafic hybrid-granite in texture (1-4 mm.), and composed of about 40% biotite and amphibole, 40+% oligoclase and 10+% quartz. The rock is definitely patchy in its mineral distribution, even to slightly pegmatoid groupings. Associated with it is good granite aplite in small dikes. Nearby other rocks are characterized by a dioritic appearance to the naked eye but under the lens reveal a fine-grained matrix carrying lath-shaped plagioclase crystals (near andesine) 2-3 mm. long. The rock appears to be a recrystallized argillite or even a basalt. And again elsewhere in the vicinity are outcrops of granodioritic rock. Good gabbro was found in this area as float but not in outcrop. On the northeast side of Lower Mosinee Hill is some gabbro seen in float only, showing a remarkably coarse, even pegmatoid, texture, carrying calcic plagioclase, coarsely twinned, and actinolitic amphibole.

Aplite. There are three areas of aplite mapped in this study, one in T29N, R8E, one in T28N, R8E, and the third and largest in T29N, R6 and 7E. The second area mentioned is largely granite aplite, the first contains considerable good syenite aplite and the third is very largely syenite aplite. The third area is very probably continuous under the alluvium with the smaller areas of aplite in Little Rib Hill and in the hill to the west of Little Rib across the Little Rib River. Similar good quality syenite aplite is known to us to occur around Rib Mountain though this area has not been remapped by us at this time. There are smaller syenite and granite aplite occurrences but they are believed to lack significance in connection with the present study.

In general the aplite is lithologically a true aplite characterized by the customary fine, sugary texture of crushed and recrystallized minerals. The rock is equigranular, except for a porphyritic variety in the T29N, R8E occurrence. Under the microscope the component minerals commonly show sutured boundaries. Much of the aplite is apparently monomineralic, but most of it carries at least a little amphibole or even biotite and as mentioned some of it carries quartz. The mafic content is especially variable and when high gives the aplite a dark color. The most normal color of the aplite is pink or some light shade of red. Variations include white which is rather rare, brown which is more common, rich red which is also common, and shades of green which become more rare in the darker shades.

An excellent exposure of the aplite where it carries quartz, is that just north of State Highway 29 in NW$\frac{1}{4}$ and NE$\frac{1}{4}$ of the NE$\frac{1}{4}$ of Sec. 31, T29N, R7E. Here the rock shows some range in texture, structure and in composition. It is rather well banded, the bands being both fine (microscopic) and coarse (up to 3"). Some of the banding is quite straight, some is wavy, none is crenulated, much is of variable thickness. It is defined by differences in both texture and composition. The compositional differences are the most evident because of the greater amount of biotite in some bands, giving thereby a color contrast. These differences are typical of the finer bands. The textural differences are also somewhat compositional. They characterize the coarser banding. These differences range from coarse granitic (5 mm.) which is not common, through fine granitic (2-3 mm.) which is common but only 5-10% of the rock, through aplitic (less than 1 mm.) which is the bulk of the rock, to a texture which can be described as truly rhyolitic. Attention is called to this last texture, which is in bands up to 1/2 inch and in places is more than 25% of the rock. Augen-like masses of mafic material from a small fraction of an inch up to 3 inches emphasize the general gneissic structure. The coarser textural portions are also liberally arranged in this same augen-like manner. The attitude of the banding is fairly uniform.

Mineralogically the rock is for the most part a granite aplite. Lesser variations extend to granite at one extreme end to quartz syenite aplite at the other extreme. None of the rock can properly be called a syenite or a syenite aplite at this locality. It is composed of dominantly orthoclase feldspar, with prominent carlsbad twins. There is a little plagioclase feldspar, which is apparently quite sodic. Quartz ranges from 10-40% and averages 15-20%. The mafic mineral is biotite in flakes and aggregates, both quite lineally distributed.

Another excellent exposure of aplite may be found at the north end of the same quartzite-capped hill, in NW$\frac{1}{4}$ SW$\frac{1}{4}$, Sec. 29, T29N, R7E. This is perhaps one of the best available exposures, in that a good section is offered for a depth of at least 60 feet. The rock shows many varieties of the aplite which occurs below the quartzite. The aplite is composed of orthoclase feldspar, black amphibole and in some parts quartz. Some of the rock is composed of pure feldspar. Most contains in addition 10-15% of amphibole. A small part of the rock contains a little quartz, in places reaching at most 20%. The feldspar is present also as occasional phenocrysts in size up to 2 cm. Most of the feldspar is Carlsbad twinned. Grain size of the matrix covers a range from cryptocrystalline to fine trachytic (4 mm. long). Much of the rock shows trachytic texture.

Interest centers on the structure shown by the exposures. In essence the structure shows repeated brecciation, repeated intrusion and welding accompanied by rather strong flowage. The mineral composition of the successive inwellings of igneous material is not constant. Especially does it show variation in mafic content. Similarly the textural differences of the successive inwellings show considerable variation in grain size. The coarsest material seen is also the most quartzose -- essentially a granite.

In NW$\frac{1}{4}$ NW$\frac{1}{4}$, Sec. 28, T29N, R7E, along the east-west road which has been comparatively recently constructed there is a large amount of float material that has been dug up by the construction crews and tossed aside. Outcrops are few here but the float is so plentiful and is so consistently aplite and its phases that the information yielded is of interest. Southward near the Big Rib River, in the lowlands, the rock is coarse enough in texture to be granitic and carries 5% or more of quartz, though it is associated closely with definitely aplitic rock. These lowland occurrences also show more highly mafic syeniteand aplite, being as high as 15% in mafic constituents. Northward the aplite becomes more truly aplitic in texture, the average grain size decreasing northward from 1+ mm. to well below 1 mm. Mafic constituents and quartz are both less prominent and on the east west road (north border of Sec. 28), the quartz is almost entirely missing. The rock is therefore about 95% feldspar and 5% or less mafic material.

The aplite here carries inclusions of quartzite and of modified greenstone-like material. The quartzite inclusions are elongate but appear to be little altered. The mafic inclusions are augen-like in shape and are aligned with the structure of the rock. The rock as a whole is intensely and finely banded, the banding being most commonly evident in the selective alignment of discrete mafic constituents. However, where the rock is essentially pure feldspar and the banding is not at all evident on a fresh break, the weathered surface usually reveals the fine banded structure.

A peculiar feature of the banding is that it is not by any means parallel, except over a distance of a foot or less. Extreme departures from parallelism appear almost like cross bedding.

In places, large (one inch) pegmatoid orthoclase crystals are developed in the aplite. Again, narrow (1/4 inch) indefinitely bounded dikes of syenite cut the aplite with an irregular trend. Since the aplite is here consistently some shade of red or pink and these dikelets are also pink, the blending is emphasized. A few coarse (6 mm.) gray hornblende syenite dikes of 1-4 inches cut the aplite in this vicinity.

In the same locality there is float of nepheline syenite indicating quite surely that at least one nepheline syenite body also cuts the aplite as does the gray hornblende syenite, but none was found doing so in the float.

Distinctly porphyroblastic aplite is a rather common type of the aplite area in T29N, R8E. It is composed of about 20% quartz and 15-20% biotite; the remainder is feldspar. The feldspar is in part present as poikilitic, subhedral porphyroblasts in a matrix of cataclastic, brownish oligoclase, orthoclase and quartz. The biotite is largely in aggregates.

The aplite in places appears to be derived from a hybrid magma. To mention one of these the aplite in SW$\frac{1}{4}$ SW$\frac{1}{4}$, Sec. 26, T29N, R6E, is composed of feldspar 75-90%, quartz 5-10%, and amphibole and chlorite 2-10%. It is not uniform, as the above percentages indicate, but is massive or gneissic, uncontaminated or zenolithic, or cut by pegmatoid dikes. The aplite in general is inclined to be more mafic, some of it much more mafic contiguous to the greenstone which it intrudes.

Syenite. Although the syenites occur only in comparatively narrow dikes, nevertheless they outcrop well and are available for study. The syenites occur in a great many varieties of color and composition and textures. The most common of all the syenites is the gray, the most striking is the pink, and both have very spectacular phases of syenite pegmatite. Where the pink syenite contacts the gray, intrusively, the gray is converted to a brown syenite which should not therefore be regarded as a distinct rock type. The gray syenite is quarried in two places where it is therefore well exposed. Although it is similar wherever found, the following descriptions are quoted from the field notes on the quarries which are in neighboring dikes and are only 1/4 mile apart.

One quarry is in NW¼, Sec. 23, T29N, R6E, and is reached from County Trunk Highway "U." This is dark gray syenite composed of an estimated 85% orthoclase and 15% amphibole. The texture is massive, granitic (4-6 mm.). The quarry rock is cut by two distinct types of pegmatite and a highly mafic aplite. No lamprophyres are seen. The earlier of the pegmatites is dark, the same color as the host, and is composed of an orthoclase, the moonstone variety, in crystals usually under 3 inches long, associated with black amphibole crystals which are usually smaller than the feldspars. The later pegmatite is composed of light-colored orthoclase in crystals up to 18 inches long, associated with black amphibole crystals which are very elongate, up to 12 inches long, and usually under 1 inch wide. These pegmatite dikes are of various thicknesses, commonly 4-6 inches, but range up to 2 feet thick.

The other quarry is in SE¼ Sec. 14, T29N, R6E, and is also reached from County Trunk Highway "U." The syenite here is similar to that of the south quarry. The pegmatites in it are larger and more numerous but are otherwise similar. A special feature of this quarry rock merits description. There are in it areas from 2 feet to 10 feet across of mafic syenite (shonkinite). Its composition is orthoclase 60%, amphibole 30%, and biotite 10%. The biotite is in both small flakes and in 1 inch poikilitic phenocrysts. The orthoclase is dark and with the amphibole occurs in 2-3 mm. crystals. This rock makes rather sharp angular contact with the gray syenite host. Also evident in the gray syenite is a smaller - 6 inch to 1 foot - mottling which shows up as a faint gray color contrast, the effect being that of a ghost igneous breccia. The host is slightly lighter gray in color. The mineral composition is the same so far as can be told.

In NE¼ Sec. 32, T29N, R7E, is a large disintegrated syenite pit. In this pit are exposed several varieties of rock, most of which are syenite. There are several outcrops in the triangular area between Highway 29, the side road and the river. The area is one of syenite mainly.

Although there are several varieties of rock present, most of them are syenitic, and most of them are coarse, granitic in texture. Much of the syenite is massive, but some is gneissic, the gneissosity being of the ortho type rather than of the banded type. At one point there is a dike of fine-grained granite cutting the syenite; it is 6-10 feet thick. The syenite, and the granite too, have strongly aplitic phases, which grade into the coarse granitic phases and have apparently the same mineral composition as the rocks in which they occur. In the syenite the aplitic phases appear as local areas surrounded by the coarse granitic-textured host. In the granite the aplite appears as indefinitely bounded dikes in the host.

The main syenite is composed of perthite estimated at 85% and black amphibole 15%. The texture is coarse, 8-10 mm. for the feldspar, and about half that for the amphibole. The syenite aplite is fine textured (under 1 mm.) and equigranular. It has gradational boundaries with the syenite. In places at these boundaries there are mafic aggregates 1-2 cm. in diameter.

Another phase of the syenite was found at the pit. It is coarse granitic in texture (6-8 mm.) and is composed of feldspar estimated at 80-85% and mafics at 15+%. The feldspar is extremely finely twinned, evident only under 16X magnification. The amphibole is black, and is poikilitic. Inclusions in it are mainly feldspar and a little magnetite. It occurs in grains equivalent in size to those of the feldspar. There is present an occasional grain of quartz. The color of the rock is gray with a faint pink shade.

Still another phase of the syenite here has a strong red color. Its texture is similar to that of the syenite just described but it appears to contain orthoclase instead of plagioclase. It has about 80% feldspar, 15% black amphibole and a small amount, less than 5%, of quartz. The feldspar is very consistently twinned on the carlsbad law.

It will be shown later that the syenite dikes are composite and are mutually independent. The variations therefore are potentially innumerable. The descriptions given above are considered adequate for the present purpose.

Nepheline syenite. There are many dikes of nepheline syenite in the area, almost as many in fact as there are of syenite. Two types of nepheline syenite occur the most frequently. They are quite similar except for the color of the nepheline which they contain. We refer to the one as the gray nepheline syenite and to the other as the pink nepheline syenite.

The best exposure of the gray nepheline syenite is to be found in a hill with good outcrops in SE$\frac{1}{4}$ Sec. 2, T29N, R6E. This rock is very slightly gneissic, so slightly so that a determination of the attitude of the gneissosity is sometimes difficult. It is otherwise massive, medium textured (3-4 mm.) and granitic. It is composed of nepheline and feldspar about 80% and black amphibole 20%. The feldspar and nepheline are present in about equal quantities. The strong pitting of the weathered surface is invariably the best indication of the amount of nepheline present since on the fresh break the nepheline and the feldspar are much alike. The nepheline and the feldspar both are medium to dark gray in color. No white nepheline was seen in this rock anywhere in the area.

The pink nepheline syenite occurs in many places in the area but nowhere in prominent outcrop as does the gray. It is usually gneissic and commonly very strongly so. Its color is some shade of red or reddish brown. The feldspar which is tabular and which by its alignment creates the gneissosity may be white, gray or also pink. These tabular feldspars may be 4-8 mm. long in the typical rock. The texture is intersertal, the nepheline being the last to crystallize. The nepheline in this rock is rather richly colored, a light to dark reddish brown. This rock may be studied best in float along the south border of Sec. 1, T29N, R6E.

Nepheline syenite pegmatite. There are two places, or possibly three, where this rock occurs, though in both it can scarcely be termed a syenite. Pegmatite solutions from the nepheline syenite alone seem able to penetrate the overlying greenstone (argillite), and where they do the reaction produces a very coarse dark green, ptygmatically folded injection gneiss. These two places are (1) from the midpoint of the south border of Sec. 22, T29N, R6E to the west quarter corner on the south border of Sec. 23 contiguous to it; (2) in the SW$\frac{1}{4}$ NW$\frac{1}{4}$ Sec. 18, T29N, R7E, and in the vicinity; (3) the third locality is in NE$\frac{1}{4}$ SE$\frac{1}{4}$ Sec. 21, T28N, R8E. It is apparently similar to the other but is very poorly revealed for study.

At the first locality the nepheline penetrates the greenstone as a gneissic injection. The penetration increases in degree and coarseness to the section corner. The rock is a dark, ptygmatically folded amphibole and chlorite gneiss consisting of a host of feldspar about 40%, mafics 30% and quartz 5%. In this rock the pegmatite both crosses the gneissosity and follows it, giving local pockets and narrow stringers. Single crystals of feldspar and nepheline measure up to 6 inches long and commonly up to 4 inches long. The feldspar is white, the nepheline is brownish.

At the second locality, also penetrating the greenstone, is a large amount of high nepheline syenite and apparent nephelinite. The nepheline is quite distinctly reddish and carries 10-15% of mafics. It appears in gneissic form, some bands being very aplitic nephelinite and nepheline syenite and some being quite pegmatoid. The nepheline-bearing rocks are quite dark greenish despite the reddish cast to the nepheline under the lens. At the western end the float indicates a greenstone breccia penetrated by nepheline syenite pegmatite as host. The fragments are large and small. They are chloritized heavily and well digested by the pegmatite. The pegmatite is composed of dark reddish nepheline 70+% and orthoclase 30-%. No twinning is evident in the feldspar. The crystal size of the pegmatite is up to 2 inches.

White Nepheline Syenite. This rock is separately treated because its color is of marketable quality. It was mistaken for slightly feldspathic nephelinite in the field but is found in the laboratory to be composed of about 20% nepheline only, the remainder being black amphibole 20% and feldspar 60%. The feldspar is plagioclase and perthite, of good white color. The perthite is well crushed though considerably recrystallized, which gives it somewhat the appearance of nepheline in the field.

There are three occurrences of this white nepheline syenite in the area so far as known but there are undoubtedly others not yet discovered. One is mentioned in the last section, though this is the least spectacular of the three. A second occurrence is that of two white nepheline syenite dikes in the floor of a disintegrated nepheline syenite pit in NW$\frac{1}{4}$ Sec. 1, T29N, R6E. These are poorly exposed but the pit contains several residual boulders of the rock. The third and best is in NW$\frac{1}{4}$ SW$\frac{1}{4}$ Sec. 5, T29N, R7E. Here the syenite occurs in a dike 150 feet wide so far as can be seen in the weathered pit. Both the nepheline and feldspar are quite white. The texture is granoblastic.

Structure. Later granitic intrusion has so thoroughly mashed the older formations that the section is and will doubtless remain largely unknown. Among the oldest rocks of the area probably are the rhyolites. Since they are not everywhere intensely folded, and since they predominate among the volcanics of the area--in fact, basaltic greenstone is extremely rare--one develops a feeling in the field that these rocks are not pre-Huronian but younger. On the other hand the rhyolites are rather consistently folded on an axis which trends slightly north of east indicating one time shortening from the north and south, whereas the later regional shortening is from the east and west. Some of the argillite and some of the quartzite is only slightly folded, indicating that folding is not uniform within the area. Some rhyolite, too, shows little evidence of being folded, indicating that the folding is localized within the area. One possibility not to be discarded is that there are both pre-Huronian rhyolites and later rhyolite and argillite. The occurrence of tuff and agglomerate with and in the argillite suggests strongly a rhyolite association. But the occurrence of argillite in very slightly disturbed attitude favors setting it aside from that part of the rhyolite which is so closely and uniformly folded. Although this question is too speculative to answer, it seems most nearly answered by this last suggestion.

As far as is known then, the section consists of rhyolites, folded and intruded or not, overlain by argillite, and possibly rhyolite of later age, and these overlain by quartzite. The area was then folded and intruded by granites which may be of Keweenawan age, though this age too is quite unknown. Toward the close of intrusion by this granite which appears to be the main granite of the area, rotational pressure from the east and west caused mild faulting with associated dike emplacement giving the syenites of various types.

The granite intrusive in this area has a very flat roof which almost coincides with the present erosion surface. Slight irregularities in the roof intersect the present surface, giving alternately areas of granite and roof pendents in the granite. The map area is located within a large group of such roof pendants. Cupolas of the granite have penetrated the roof in many places and have been truncated by erosion. Where penetration and subsequent erosion are deep, the granite is the normal red type of the area, but there are three large dome-shaped cupolas which have been only slightly truncated. These are the three areas of aplite already described.

There is good evidence that the lower surface of the various roof pendants is also quite flat and always close to the present erosion surface. Near to and between any two bodies of greenstone, the granite is charged with inclusions or is contaminated with mafic material or even is a granite hybrid. Using this type of information and applying it in a vertical section we have been able to arrive at an approximate figure of the angle of inclination of the lower surface of the pendant, it is 5 degrees, an average figure. This is well supported by the mapped greenstone capping of the hills in Sections 21, 22, 27, 28 of T29N, R8E, and in Sections 7, 18, 19 of T29N, R7E. With the exception of the granite, therefore, all rock types within the area may be assumed to be shallow, to give way to granite at comparatively shallow depth.

The shortening in the east-west direction is expressed in more than one way. The overlying quartzite was folded along a north-south axis with minor warping in an east-west direction. Along the present course of the Big Rib River the quartzite ruptured, doubtless due to weakening by the subjacent intrusive dome, and a large block of the quartzite, disengaged from the main body, essentially floating on the intrusion, and was rotated, as apparently was the quartzite at Ablemans, Wisconsin, under the influence of displaced material in the trough of the closing north-south fold. This block now stands up on edge to form Rib Mountain, giving the false impression of a fold with a 90° pitch. The limbs are seen in the Mosinee Hills and in Hardwood Hill. However, we are interested in that aspect of the structure here only in its relationship to the local structure. The quartzite of Rib Hill has served as a buttress to the east-west shortening and has given it a strong rotational component in most of the map area. The two shear planes developed as a consequence of this shortening are: (1) the rhyolite bedding faults which strike N 80° E and dip 80° S. Such bedding faults characteristically have dissipated movement through the bedding and though characterized by much movement reveal little of it. The shearing only indicates that movement in this area; (2) the fault planes which strike N 20° E and dip steeply. The elongation bisects the angle and is then N 50° E and the greatest shortening is 90° to it, - N 40° W. This last is the strike too of the consequent tension planes. and this is expressed by the syenite dikes.

Along none of the faults of the area is there any great movement. In fact, the movement is little more than token movement. However, the faulting is very well expressed in the topography of the area and in the stream pattern. Most of the dikes, and doubtless all of them are characterized by some movement between their walls but very few of them show enough movement to cause the elimination, or other modification in mapping, of the exposed formations. Some such evidence of movement is found along the south border of Sec. 22, T29N, R6E, where the aplite which forms a selvage between the greenstone and the syenitic rocks within the aplite at almost all places, is faulted out. But better evidence of movement along the dike-filled faults is to be seen by following the trend of the dike beyond the limits of the dike where there are invariably such signs of faulting as, shearing to produce a schist, or fault gouge and mylonitization or spectacular brecciation. Some of these are described by Weidman. A few occurrences may be mentioned: (1) Fault gouge in the extreme northeast corner of Sec. 17, T29N, R6E; this is developed in greenstone; (2) White sericite schist developed in the aplite in SW$\frac{1}{4}$ SE$\frac{1}{4}$ Sec. 8, T29N, R7E; (3) White sericite schist developed in rhyolite in SW$\frac{1}{4}$ SE$\frac{1}{4}$ Sec. 26, T30N, R6E; (4) Intrusive greenstone breccia in SW$\frac{1}{4}$ SE$\frac{1}{4}$ Sec. 9, T29N, R6E; (5) Another in SW$\frac{1}{4}$ NE$\frac{1}{4}$ Sec. 18, T29N, R7E; (6) Another in SE$\frac{1}{4}$ SE$\frac{1}{4}$ Sec. 26, T29N, R6E; (7) Sheared and shattered quartzitic argillite in a weathered roadside pit in SW$\frac{1}{4}$ SE$\frac{1}{4}$ Sec. 16, T29N, R6E.

There is abundant evidence that many of the dikes are composite. Their emplacement history is therefore one of intermittent opening and filling, with or without displacement along the fractures. The most common of the dike rocks is the gray syenite. Next most common is perhaps the red and pink syenite. And next are the gray nepheline syenite and the red nepheline syenite. There are many other syenitic types. None of the dikes is large; most of them are quite small. All are very local and give evidence not only of having originated locally but definite evidence that the dike magma did not travel far. For instance, the margin of the aplite, near the greenstone is rarely cut and the greenstone is still more rarely cut, though both are sheared and brecciated, and when cut it is by only the more mobile pegmatitic solutions.

Although we have mapped 67 dikes, the correct number is doubtless closer to 200, and if single emplacements are counted as separate dikes, each dike must be regarded as not less than 5 and probably 10 or 20 dikes. This is most convincingly illustrated in the pit and adjacent territory of NW$\frac{1}{4}$ NW$\frac{1}{4}$ Sec. 32, T29N, R7E.

Petrogeny of the aplite and syenites. This will be discussed elsewhere after adequate laboratory study.

Economic geology. (1) Nepheline. Our petrogenic conclusions which are not argued here are that the aplite, the syenite and the nepheline syenite are of strictly local origin, developed from the rocks in which they occur. Only the nepheline syenite pegmatite is sufficiently mobile to penetrate beyond its point of origin and enter the overlying rocks, the greenstone. Therefore the nepheline is to be sought within the aplitic areas, in those parts of the aplitic areas which are faulted and only along the fault lines. Attention has been called to the irregularity of composition of the aplite from which the syenites are derived. The syenites take on the character of the aplites in which they occur. Where the aplite carries free quartz, the syenites also are quartz syenites. But more important, where the aplites are mafic, the syenites are mafic and when the syenite is nepheline bearing some of the iron is found in solution in the nepheline. Since one requirement of commercial nepheline is that it be iron free or low in iron, the search can be very materially aided by more detailed mapping of the aplite. Specifically, the search should be for a truly syenitic aplite and one which is white.

There is one rock in the area which offers real promise of yielding good commercial feldspar and nepheline, that is the white hornblende syenite in NW$\frac{1}{4}$ SW$\frac{1}{4}$ Sec. 5, T29N, R7E. This rock can be studied easily in the laboratory for separation of the amphibole. Magnetic separation should be adequate. The host to the amphibole is quite white. The size of the dike is not known but if the sample proves encouraging, the tonnage can be easily determined by drilling.

Aside from the occurrences of white nepheline syenite described, no white nepheline was seen in this study.

(2) Zircon. Zircon is found in quartz veins in one locality only, Sec. 22, T29N, R6E, but may well occur along any of the northwest faults which we have mapped. This one occurrence is so far unique in the area. Along the fault the underlying granite -- parent of the aplite -- has penetrated more extensively than it is known to have penetrated along the other faults. Even this penetration is mostly by the more mobile granitic pegmatite juices. In other words, this is the uppermost tip of a granitic tongue and must necessarily enlarge downward. It is to be expected that the zircon content of the ore body will also improve with depth despite the fact that the ore is primarily in quartz veins.

It is wholly reasonable to believe that the ultimate parent of all these varied rocks within the aplitic area is the same granite. Therefore it may be suggested that further prospecting for zircon may be guided by the search for coarse feldspathic pegmatite such as that seen in Sec. 22, T29N, R6E. The less prominent quartz veins may then be sought in and around the pegmatite.

(3) Pyrophyllite. A 3 x 4 foot boulder of yellowish pyrophyllite was found in NW$\frac{1}{4}$ Sec. 34, T29N, R6E. The boulder is composed of massive pyrophyllite and quartz in which are grown radial pyrophyllite crystals. A part of the boulder contains about 10% of quartz grains. The mineral is undoubtedly of good commercial quality though not the best quality.

Inquiry revealed that this boulder was dug in SE$\frac{1}{4}$ Sec. 28, T29N, R6E, and hauled away. The area is now a cornfield, without rock exposures. It is highly probable that this mineral is of local occurrence and should be further investigated. The owner of the land is Mr. F. E. Mearek, R.R. 2, Marathon, Wisconsin.

(4) Disintegrated "granite." Throughout the entire area we have observed that disintegration of the rock by weathering is advanced sufficiently for exploitation for road materials only along the fault zones. Not all the faults have been recognized but more can be estimated with fair reliability from the evidence that has been cited and promising areas thereby may be located for road materials.

Another pertinent suggestion may be made for locating faults and therefore disintegrated granite within the granite areas. We have observed that the disintegration of granite along these faults yields as a by-product a profusion of large, glacial appearing boulders. Normal weathering also produces boulders of this type but not in profusion. It is suggested that an examination of aerial photographs may yield useful information of this type.

Recommendations. It appears desirable to obtain more detailed information on this promising area than we have been able to gather in the four weeks at our disposal. It is suggested that a party be sent in for a full summer to map, on a scale of 6 inches to the mile, the area of greatest promise around Stettin. Search should be made for (1) white syenite aplite; (2) granite or syenite pegmatite of the type found in that Radant zircon property; (3) white hornblende syenite; (4) pyrophyllite. This scale will permit the mapping of the syenitic bodies on a true dimension basis rather than on an exaggerated scale, as is done on the accompanying map. Also, there is much information to be obtained by covering the areas within critical sections rather than only the area adjacent to the highways to which we have necessarily been limited. Also, the three townships in southwest corner of the present map area which we have been unable to do in the time at our disposal could be done on a reconnaissance basis, as has been done elsewhere in the area.