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W. O. HOTCHKISS, Director

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Limestones and Marls of Wisconsin

By
EDWARD STEIDTMANN

WITH A CHAPTER ON THE ECONOMIC POSSIBILITIES OF MANUFACTURING CEMENT IN WISCONSIN
By
W. O. HOTCHKISS and E. F. BEAN

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INTRODUCTION

Wisconsin has extensive and valuable deposits of marl and dolomite, but pure limestone in commercial amounts is almost unknown excepting in certain thin beds in parts of southwestern Wisconsin.

The usefulness of the limestones and dolomites of Wisconsin as building and road materials has been discussed in earlier reports of this Survey. This volume has as its central theme the chemical composition of marls, limestones, and dolomites, and the uses for which these rocks are suited by virtue of their composition. Special consideration is given to the possibilities of cement manufacture in this state.

Various industries have called upon the Geological Survey for information on the occurrence of limestone and dolomite of certain qualities. Most of these inquiries have been for pure limestone high in calcium carbonate. Sugar factories want this kind of limestone, so do the sand-lime brick and Portland cement manufacturers. Farmers have frequently asked whether the rock from a certain outcrop is a good agricultural limestone. Up to the present time this information has been in the files of the Survey or in various Survey publications. In this volume all the available facts on this subject are brought together.

This report is based on (1) unpublished notes in possession of the Survey, (2) publications of the Survey and other organizations, and (3) on the writer's field work during the summer of 1912. A part of the results of the writer's field work was embodied in Bulletin 34 of the Survey, entitled "Limestone Road Materials of Wisconsin" by W. O. Hotchkiss and Edward Steidtmann, which was published in 1914.

Many quarries and some outcrops of Wisconsin limestones and dolomites were sampled in the preparation of this report. The samples were selected with the view of approximating the average composition of the beds. Before sampling, the beds were classified on the basis of color, grain, fracturing, compactness, and general appearance. If all the beds of a quarry looked alike, a single sample composed of chips from all the beds in the quarry face was taken. If they varied, each group of like beds was sampled separately. Samples were taken by chipping off pieces across the beds. The ideal was to get equal volumes of rock from equal distances across the beds.

The samples taken were analyzed by W. G. Crawford in the chemical laboratory of the University of Wisconsin. His analyses are included in the tables given in this report. The methods of analysis used were those described by Mr. Hillebrand.[1]

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[1] Hillebrand, W. F., The analysis of silicate and carbonate rocks: U. S. Geol. Survey Bull. 422, 1916.

The dolomites of Wisconsin are the most widely distributed and most available carbonate rocks. They are the only rocks quarried in large quantities for uses in which chemical composition is a factor of fitness. The high calcium limestone beds of southwestern Wisconsin, being far less available, have not been quarried specifically for their high lime content. The marls also have been used very little because they are not as available as the dolomites and because of their high water content.

In this volume special attention is given to the possibility of finding new uses for our carbonate rocks and of extending the uses already known. Their chief chemical uses at present are for lime, agricultural limestone, flux, and for making sulphites in the paper industry. Of these uses, that for agricultural limestone is more likely to see a marked expansion in the future than any other. The College of Agriculture has estimated that approximately three-fourths of the tillable land in Wisconsin needs lime in order to grow the best crops of clover, alfalfa, and other legumes. To remedy the sourness of our soils completely would call for a great development of the dolomite and limestone quarrying industry.

The manufacture of Portland cement from our marls and clays is another important question which merits careful study. For many years it was held impossible to make cement profitably in Wisconsin. Owing to changes in the methods of making cement and to changed economic conditions, the possibility of manufacturing cement from marl in Wisconsin is again worthy of consideration. The facts available, though they do not warrant a final opinion on the subject, indicate that further investigation of our cement resources is highly desirable.

In this volume are given analyses of clays, shales, and marls, some of which are chemically suitable for Portland cement. The facts regarding the location and volume of the materials analyzed are given as fully as known, but in no case are the facts known sufficiently well to warrant definite consideration of a cement plant. Attention is also called to certain unexplored areas in which conditions are favorable for finding marls and clays.

These are the more important phases of the subject discussed in this volume. Dolomites, limestones, and marls have many important uses. They are perhaps the most useful of our common rocks. Their usefulness will no doubt be even greater in the future than at present. New uses may be found for them which as yet are barely foreshadowed or entirely unknown. It is hoped that the analyses and other data in this volume will help in extending the use of these important materials.

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Many data on the composition and characteristics of the limestones and dolomites of Wisconsin which appear in this bulletin were compiled from other publications. The data on clays presented in the discussion of Portland cement materials were taken from other writings, and from work done jointly by this Survey and the State Highway Commission in 1922. The data on marls were taken almost entirely from unpublished notes made for the Survey by Dr. E. R. Buckley, J. Lloyd Nelson, and C. S. Corbett.

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Because of interest in the possibility of establishing a cement plant in Wisconsin the Wisconsin Highway Commission and this Survey cooperated during the summer of 1922 in an investigation of the occurrences of suitable clays in southeastern Wisconsin.

CHAPTER I

NATURE AND ORIGIN OF MARLS, LIMESTONES, AND DOLOMITES

Nature and Origin of Marls

The marls of Wisconsin are soft unconsolidated muds composed largely of calcium carbonate, both calcite and aragonite. Minor constituents are sand, clay, organic matter, and magnesium carbonate. Marls are lake deposits, and are either found in lakes or in swamps which formerly were lakes. Most marl beds lie within the glaciated area and have been deposited in lakes of glacial origin. Through marked changes in climate and drainage, some marls, like those exposed in the Salt Lake basin of Utah, are now dry. Swamp marls are usually covered with several feet of peat and soil. The vegetation on the surface is either of the lowly marsh type or consists of shrubs and trees including alders, cedar, spruce, and tamarack. Wisconsin marl beds vary in thickness but seldom exceed thirty feet.

Marl is usually gray white to brown in color. Darker colors are due to organic matter. In addition to the remains of other fresh water organisms, the shells of snails are usually very abundant. About one-half of the weight of marl in lakes consists of water. Marl can be distinguished from other muds by its abundant shells and by its violent reaction with acids.

Marls develop most favorably in lakes or in portions of lakes in which very little sand and mud is accumulating. The lime carbonate of marls represents in part the accumulation of fresh water shells. The finer grained parts are largely precipitated by chara, a fresh water plant, and as a result of the consumption of carbon dioxide in the surface waters of the lakes by myriads of tiny free swimming plants.

General Characteristics of Limestones and Dolomites

Limestones and dolomites are stratified rocks whose chief mineral constituents are calcite and dolomite, calcite being the chief mineral component of the former, and dolomite of the latter. Calcite is a soft, usually white or grayish mineral which is vigorously decomposed by weak muriatic acid or even by strong vinegar. One of the decomposition products is the colorless, odorless carbon dioxide gas whose escape causes a brisk bubbling or effervescence. This strong discharge of gas when the rock is treated with weak muriatic acid distinguishes calcite from dolomite. Dolomite shows only a very feeble evolution of carbon dioxide gas when treated with muriatic acid.

Limestones, when pure calcite, consist of about 44 per cent carbon dioxide and 56 per cent lime. As a rule they contain admixtures of sandy and earthy matter, such as quartz, opaline silica, flint, clay, and organic matter. Magnesia may also be present in slight amounts either as a constituent of calcite or in the mineral dolomite. If more than 4 per cent of magnesia is present, it usually is possible to find distinct crystals of dolomite. Some recently deposited limestones, however, have as much as 10 per cent magnesia, but show no dolomite. Just how much magnesia a limestone may contain and still be a limestone is a matter of opinion. Limestones containing a few per cent of magnesia are common. Mixtures of calcite and dolomite intermediate between limestone and dolomite are exceptional. Dolomites or dolomites with only a little calcite are also very common, but dolomites with a notably greater amount of magnesia than a normal dolomite are uncommon. Dolomites, when pure, consist of about 47.9 per cent of carbon dioxide, 30.4 per cent lime, and 21.7 per cent magnesia. They have the same impurities as limestone.

METHODS OF DISTINGUISHING LIMESTONE AND DOLOMITE

A simple means of distinguishing limestone from dolomite is by noting the effect of a mixture of one part of muriatic acid, such as any drug store supplies, with ten parts of water on samples of each. Limestone bubbles vigorously, due to the release of carbon dioxide, dolomite either feebly or not at all. If the dolomite is porous, it is more apt to show a slight effervescence than when it is compact. This test is generally sufficient for all practical purposes.

For a more delicate distinction of dolomite and calcite when dealing with intimate mixtures of the two, several methods have been used, of which three will be described. Calcite and dolomite can usually be distinguished by polishing a surface of the rock and etching it with a weak solution of muriatic acid. The proportion of one acid to ten of water previously recommended will do very well. In the course of a few hours, the dolomite grains will stand out in relief above the etched calcite. Those dolomite grains which are completely surrounded by calcite have rhombic outlines, but those bounded by other dolomite grains are generally irregular in outline. A modification of this method consists in adding a little potassium ferricyanide solution to the acid. The calcite will show no change as a rule, but the dolomite, unless very much weathered, will almost invariably turn blue, due to the presence of a minute amount of ferrous iron in combination with the dolomite. Dolomite grains stained in this way retain their blue color for many years. In hundreds of tests made by the writer, the calcite in no case was stained, but the dolomite was stained every time. See Plate II.

Calcite can also be distinguished from dolomite by staining the calcite. In this method the rock is polished and treated with Lemberg solution. The proportions giving best results appear to be 4 grams $AlCl_3$, 6 grams extract of logwood, and 1200 grams of water. The mixture is boiled and stirred for twenty minutes and then filtered. The $AlCl_3$ of the solution interacts with calcite particles and causes a thin film of $Al\ (OH)_3$ to be deposited upon the calcite. The $Al\ (OH)_3$ is gelatinous and absorbs the purple colored extract of logwood dye. Thus the calcite is differentiated from other minerals. The reaction takes place in a few seconds. If left longer than one-half minute in the solution, the calcite will receive too thick a coating of $Al\ (OH)_3$ which is apt to peel off or crack on drying. Dolomite will react the same as calcite if immersed in the solution twenty minutes or more.

ACCESSORY MINERAL CONSTITUENTS OF LIMESTONE

In some recent limestones certain shells or other limy skeletons are composed of aragonite, a mineral having the same composition as calcite but different crystal form. Both calcite and aragonite effervesce strongly when treated with muriatic acid. When powdered, they effervesce more vigorously than large pieces. Aragonite can be distinguished from calcite in two ways. When powdered aragonite is boiled in cobalt nitrate solution, the powder turns violet in about one minute. With calcite powder, boiling in a cobalt nitrate solution produces no change. The other test is with a solution of ferrous sulphate. Aragonite when heated in a ferrous sulphate solution throws down green ferrous hydroxide which rapidly turns brown. A similar treatment of calcite throws out yellow or brown ferric hydroxide. The reliability of the preceding tests has been brought into question by recent investigations. Aragonite flies into pieces when heated, but calcite crumbles into a powder.

Besides the carbonate of calcium (calcite or aragonite) limestones commonly contain a small percentage of sand and mud and very rarely gravel pebbles or larger pieces of foreign rocks. Limestones through increase in amount of sand grains sometimes grade into sandstones. They also grade into shales by increase in mud content. In analyses of limestones these sandy and muddy materials are usually reported as insoluble. The sand grains usually consist of the mineral quartz, but silicates, especially feldspars, and zircon, are nearly always present. Other materials commonly present in limestones are flint, lime phosphate, pyrite, marcasite, hematite, limonite, and oxides of manganese.

Flint is an exceedingly fine grained variety of quartz which usually is a replacement of limestone. It occurs in nodular or spherical bodies varying from microscopic size to masses tons in weight, in irregular lenses which follow the bedding, and as a replacement of shells. Spherical and nodular flints are often concentric in structure. Some flints show an abundance of siliceous sponge spicules. Flints may appear anywhere in a formation. They are commonly more abundant near the surface. Here the largest nodules are found. The silica of flints is at least partly derived from the opaline constituents of certain plants and animals which lived in the sea, such as diatoms, radiolaria, and sponges.

Lime phosphates are present in some shells. In a few cases nodular irregular masses of calcium phosphate of unknown origin were formed at the same time as the limestone. The content of calcium phosphate in a limestone is sometimes greatly increased by the solution of the carbonates by surface waters. Phosphates of this type are quarried in Tennessee.

Marcasite and pyrite are brass colored sulphides of iron, differing only in crystal form and in minor properties. In limestone they are usually present in tiny crystals. Some of the pyrite and marcasite in limestone was formed at about the same time as the calcium carbonate. The sulphides are as a rule more plentiful in dark limestones having considerable organic matter. That pyrite and marcasite have frequently been deposited in their present position by underground water is shown by their common occurrence along fissures, vugs, and other openings. Besides iron sulphides, lead, zinc, and copper sulphides are found sparingly in limestones.

Hematite, the red oxide of iron, and limonite, the brown or yellow hydroxide of iron, are absent or only sparingly present in most limestones. Near the surface some limestones have been partly replaced by hematite and limonite. In some localities, iron oxides were deposited simultaneously with the limestone under exceptional conditions.

Manganese oxides as a rule are sparingly present in limestones. Commonly they form delicate fernlike growths, a few inches in length, usually lying on the bedding planes or in fissures, and evidently formed in their present position after the limestone was solidified.

NATURE AND ORIGIN OF LIMESTONES

Limestones whose origin is known have solidified from materials which were deposited on the bottom of seas or lakes. Originally, they were limy muds or sands, shell beds or coral and algal reefs. Locally such materials before consolidation may be cast upon the shore by waves or tides. From the shore they may be carried inland by the wind and form sand dunes. Such is the case in Porto Rico today. The sand dunes or other wind deposits of these limy materials may be swept away by streams and again deposited in stream channels and on the flood plains of streams, or the streams may carry them back to the sea from whence they came. The limy materials forming on the ocean bottom may in time become land. Thus exposed they may be ground to gravel, sand, or mud by waves, wind, rain, frost, and changing temperatures. These crushed materials may again come to rest on the bottom of seas or lakes, in dunes, or in streams. All limy substances whatever their source, whether formed on the bottom of seas or lakes or whether they have subsequently been transported by various agencies, if coherent and stony in nature, are included under the term limestone.

In the seas of today, lime carbonate muds or oozes are formed by direct chemical precipitation induced mechanically by wave action, by the action of ammonium carbonate formed through organic decay, and by the action of denitrifying bacteria. Bacterial action of this type is very effective in tropical waters. Lime carbonate muds are also formed by the sinking of the dead bodies of tiny lowly forms of lime-secreting organisms, such as foraminifera, pteropods, and globigerina. As previously indicated some lime carbonate muds of the sea represent limestone ledges, coral reefs, and shell beds ground up by waves or contributed by streams. The coarser lime carbonate deposits of the seas are the shell beds chiefly composed of mollusk, gastropod, and coelenterate shells. The coral reefs and coral deposits in general are built up largely by the growth of coral and by the lime carbonate secretions of certain algae. The algae are often more important in their contribution to coral reefs than the corals themselves. At the border of coral reefs waves tear down the stony growth and spread it out on the bottom of the deeper waters about the reef in layers of coral, sand, and mud.

Coral or algal reefs, though porous and cavernous in structure, are composed of coherent rock material. Lime carbonate muds and sands, however, are changed into coherent rocks through consolidation. Consolidation is sometimes due to the introduction of lime carbonate as a cement. Alternate wetting and drying is favorable to this process. As a rule consolidation involves recrystallization of the original grains into a new aggregate of interlocking grains, mostly irregular in outline. It involves the elimination of water and the reduction of pore space. Pressure is favorable to this process. The most compressed limestone formations, marbles for example, are in general the most consolidated. Whether consolidation through recrystallization also takes place without the aid of pressure is an open question. Shell beds usually solidify by the lithification of lime carbonate mud between the shells and not by any change in the size or shape of the shells. In some cases, the shells are replaced by opaline or chalcedonic quartz soon after deposition.

NATURE AND ORIGIN OF DOLOMITES

Nature of Dolomite

Dolomites are sedimentary rocks, usually stratified, which are composed chiefly of the mineral dolomite. They contain besides dolomite the same impurities as limestone.

Dolomite is a double carbonate of magnesium and calcium, $CaCO_3$, $MgCO_3$. A part of the magnesium, always less than 10 per cent, as a rule less than 1 per cent, is replaced by ferrous iron. When exposed to the weather, the ferrous iron oxidizes to limonite, less commonly to hematite; hence dolomites commonly have a buff color on the exposed surface. Limestone outcrops, in contrast with those of dolomite, usually are white or gray, most limestones being low in ferrous iron.

Most dolomite was formed in the sea, but the detail of its formation is still in part an unsolved problem. Two possible ways suggest themselves, (1) direct chemical precipitation and (2)replacement of lime carbonate. Many dolomite formations give no indication as to how they were formed. This is particularly true of the ancient nonfossiliferous dolomites. Such dolomites have furnished no positive evidence of having replaced other substances. Rarely do they show original calcitic bodies which dolomite could have replaced. So far no test has been devised or applied which would determine whether they are a replacement or a chemical precipitate.

Facts Indicating Origin of Dolomite by Replacement

Many dolomites, other than the pre-Cambrian, have characteristics which prove that they are replacements of limestone. Dolomites commonly do not show well preserved fossils. The remains of lime carbonate skeletons in dolomite are often vaguely outlined by a mosaic of dolomite grains which gives no indication of the sharpness of outline and the markings of the original shell. Exceptions to this rule are found when chert replaces the original shell or when the calcitic casts of the original shell are still preserved. In still other cases fair impressions of fossils are preserved when the original cast has been dissolved out and is represented by a cavity. See Plate IA. The dolomitic walls then preserve the markings of the fossil more or less faithfully. In cases where the cast has been removed and the mold remains, the shell evidently was deposited in dolomite mud. After the dolomitic mud had hardened and set, the shell was dissolved. Where the calcitic cast remains, the shell appears to have been deposited in a dolomitic mud but has not been dissolved. The characteristics of fossils in dolomite, such as their vagueness of outline and replacement by dolomite, point to the replacement of calcite by dolomite. That all limestones have well preserved fossils is by no means true although a large number of limestones do show them splendidly preserved. Many fossils in limestones, however, were injured or nearly destroyed by solution in the sea, by the wear from waves and currents, or by the feeding processes of other organisms.

Dolomites which still retain many calcitic casts often give unmistakable evidence of replacement of calcite by dolomite. The dolomite grains which border the calcite have sharp cornered rhomb-shaped crystals which penetrate the walls of the calcitic fossil casts and replace them. The cavities within the fossils are usually filled with dolomite. See Plate I*B*.

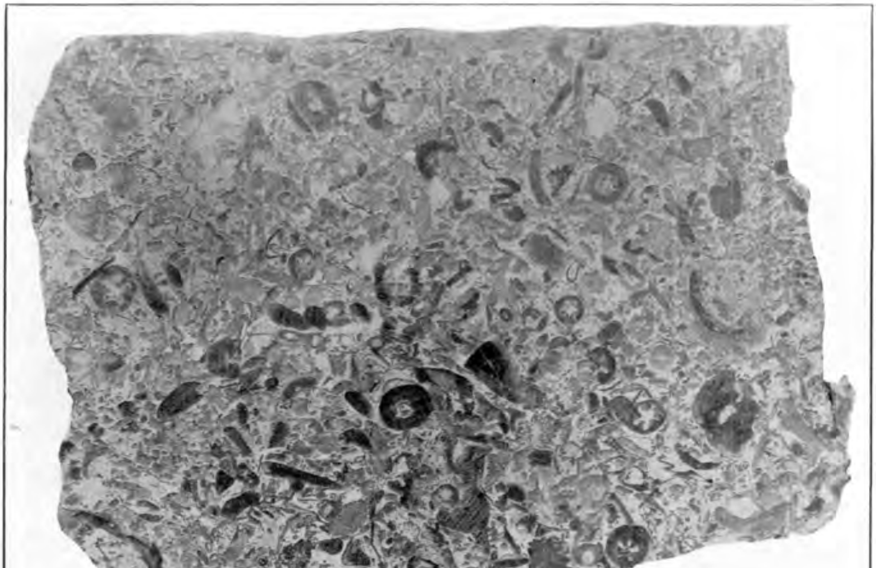
Limestone formations with very little dolomite usually show rhomb-shaped dolomite crystals clustered around shells or in the inner walls of the shells. Worm borings in limestone are often filled with dolomite and the walls adjacent to the borings, including shells which may be present, are more or less replaced by dolomite grains with good crystal outline, where growing singly, or without crystal outline where closely packed. See Plates II, III, and IV.

Beds which consist of mixtures of dolomite and original sedimentary calcite, however compact, do not show a uniform distribution of dolomite. The dolomite occurs in very irregular patches and masses which cut across the bedding. Studied in detail the individual grains of dolomite are seen to replace the original shells if any are present. In such mixed beds of calcite and dolomite, the occurrence of the dolomite is that of a replacement which occurred at or shortly after the time of deposition, when the beds were still permeated by sea water. The replacement by dolomite in such beds is indifferent to the fissures cutting the beds. This type is distinguished from dolomite in fissure veins and replacements of limestone wall rock adjacent to fissures such as can be seen in the Joplin zinc district of Missouri.

Dolomite Deposited by Underground Waters Versus Marine Origin

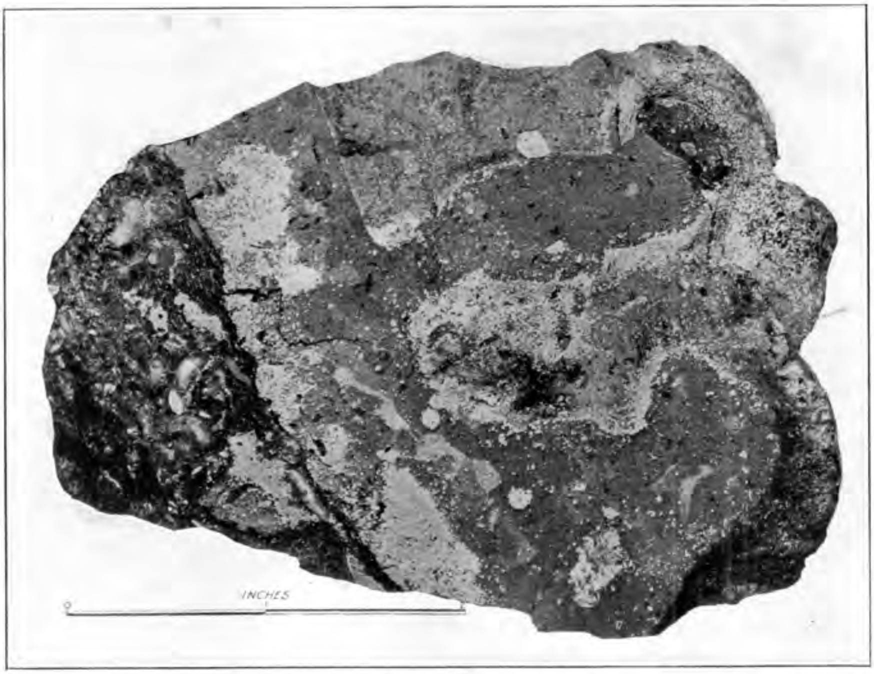
Because of the slight amount of dolomite deposition in the seas of today, it has sometimes been argued that dolomites are formed by the replacement of limestone through the agency of underground waters. That underground waters have deposited some dolomite is true, but it is improbable that they have brought about the formation of most

A. HOLLOW GASTROPOD CAST ENCLOSED BY PERFECT DOLOMITE MOLDS. FROM THE BLACK RIVER NEAR BELOIT, WISCONSIN



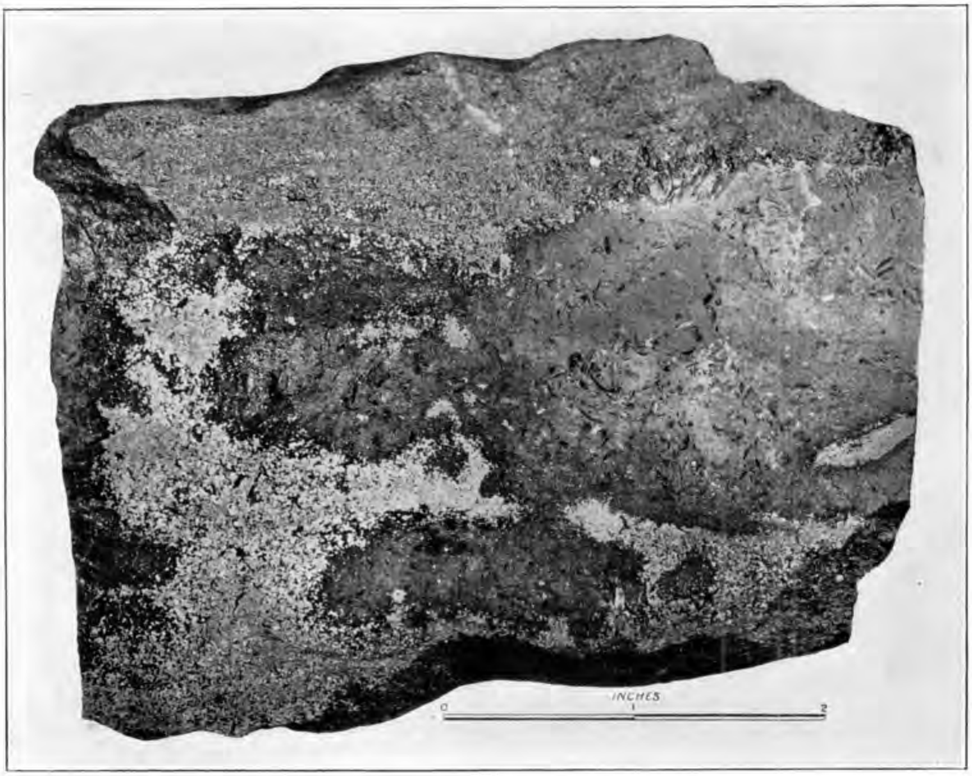
B. PERFECT CALCITIC CASTS. FROM THE BLACK RIVER DOLOMITE OF WISCONSIN, LOCALITY NOT KNOWN

The casts are embedded in fine grained dolomite, the white unstained areas of the picture. Dolomite also fills the shell cavities.



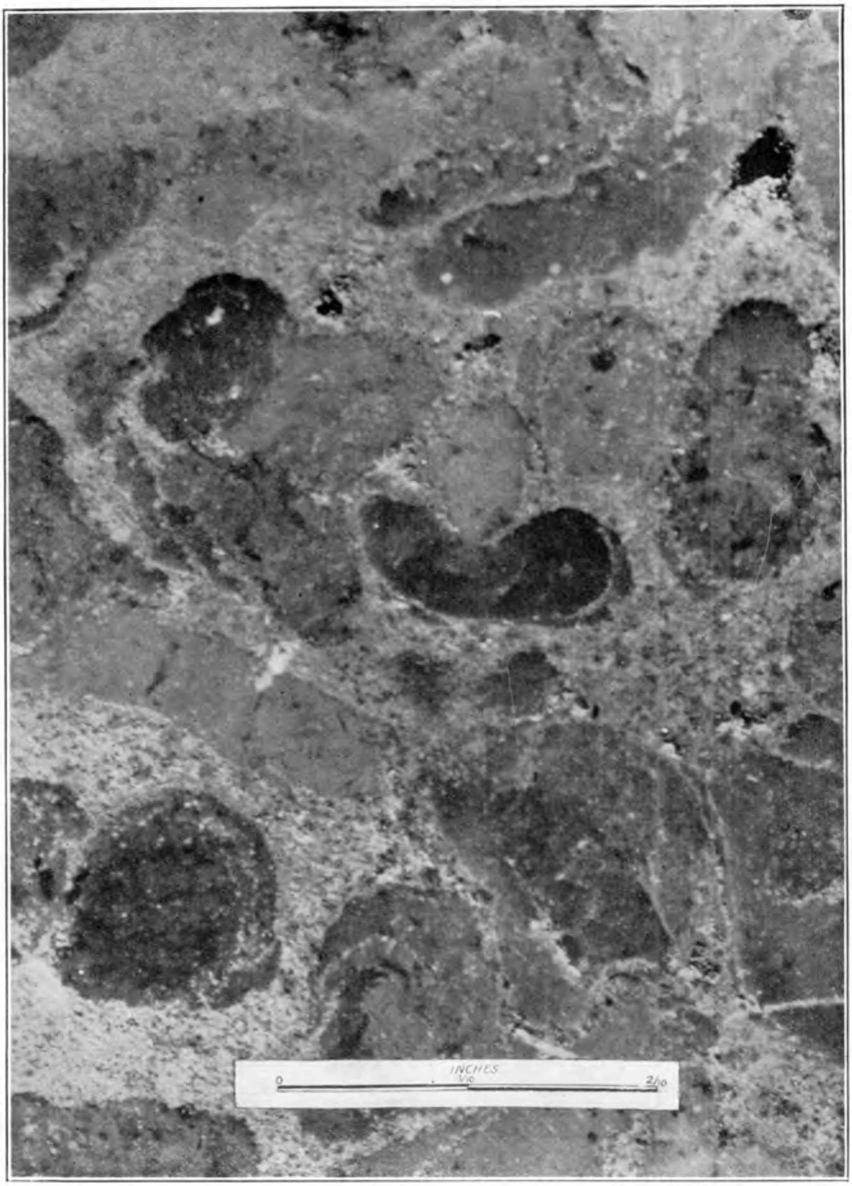
A. SECTION ACROSS BEDDING. FROM LOWER COMPACT BEDS OF THE GALENA FORMATION. WRIGHT'S QUARRY NORTH OF LANCASTER, WISCONSIN

White, unstained irregular patches are dolomite. The calcitic areas are highly fossiliferous. Very few fossils lie within the dolomite, and these show all stages of destruction through invasion of dolomite crystals.



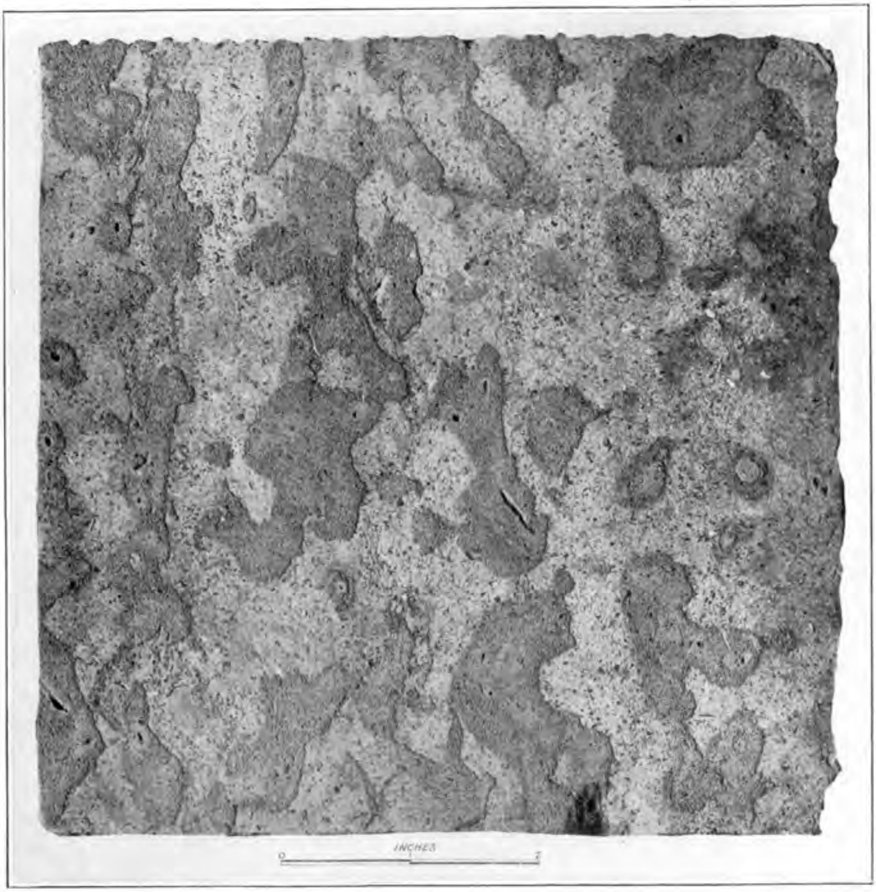
B. BASAL COMPACT BEDS OF GALENA FORMATION. G. WRIGHT'S QUARRY, LANCASTER, WISCONSIN

White areas are dolomite, the darker ones are calcite. Dolomite is irregularly scattered with reference to the bedding. The shape of the dolomitic patch in the lower central portion suggests relationship to an organic structure, possibly algal. The calcitic portion is fossiliferous. Fossils in dolomite are scarce.



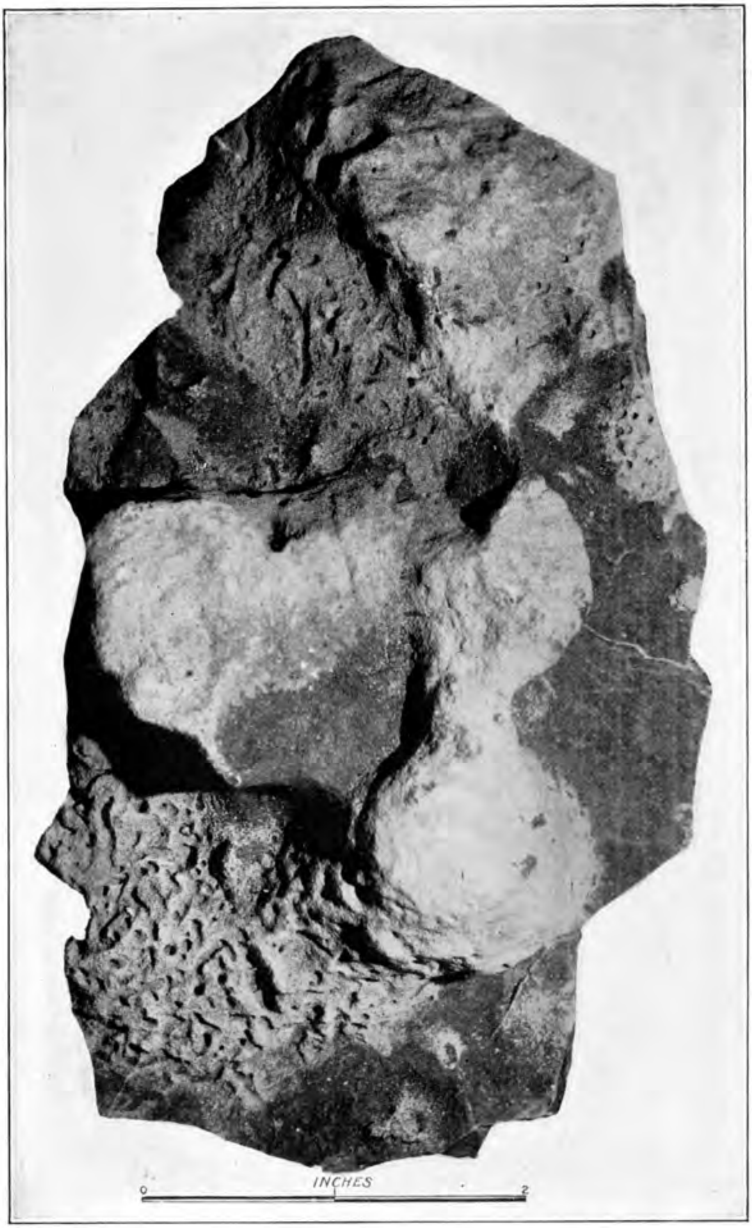
CROSS-SECTIONS OF CALCITE ALGAL SECRETIONS. FROM BASAL BED OF GALENA LIMESTONE NEAR ETNA, WISCONSIN

Dark stained bodies are cross-sections of calcite algal secretions. White granular cement is dolomite. Algal bodies are invaded by dolomite along border and in cracks.



MOTTLED LIMESTONE FROM WINNIPEG

The dark stained areas are nearly pure dolomite with a few partially dolomitized casts. They are traversed by worm borings, the craterlike pits. The calcitic portion is very fossiliferous.



WORM-BORED DOLOMITE. FROM THE BLACK RIVER, ESCANABA, MICHIGAN

The worm-bored areas are dolomite, the compact portions primary calcite.

dolomites. Dolomite which fills fissures or replaces limestones along fissures can be credited to the work of underground water. To this action are also due the dolomite crystals which line various openings formed by the solvent action of underground water. Not all dolomite druses lining minor vugs are with certainty ascribed to this cause. Some vugs of this type may have been lined with dolomite crystals while still in the ocean. The proportion of dolomite due to the work of underground water seems to be insignificant. In point of abundance, dolomite formed by underground waters bears about the same relation to the great dolomite formations that the quartz veins bear to the sandstone and quartzite formations.

Some of the important facts which show that dolomites were formed in the sea follow. The marine origin of dolomites is indicated by the interstratification of limestone and dolomite. Thick formations of dolomite alternate with thick formations of limestone and thin layers of limestone alternate with thin layers of dolomite. Such alternation of formations can not be ascribed to replacement through underground waters.

Variations in the proportions of limestone and dolomite in the same formation are known. Dolomite sometimes occurs in irregular patches scattered through limestone. Such occurrences usually show no relation to openings along which underground waters are active. For example, on the shores of Lake Winnipeg, certain beds of light colored Trenton limestone show dark amoeba-shaped patches rather regularly spaced. See Plates IV and V and figure 1. The dark patches are usually about 1.5 inches long and are about 0.25 inch to 2 inches apart. They are aggregates of dolomite and calcite. Traversing the dark dolomitic patches are marine fossil worm borings about one-sixteenth

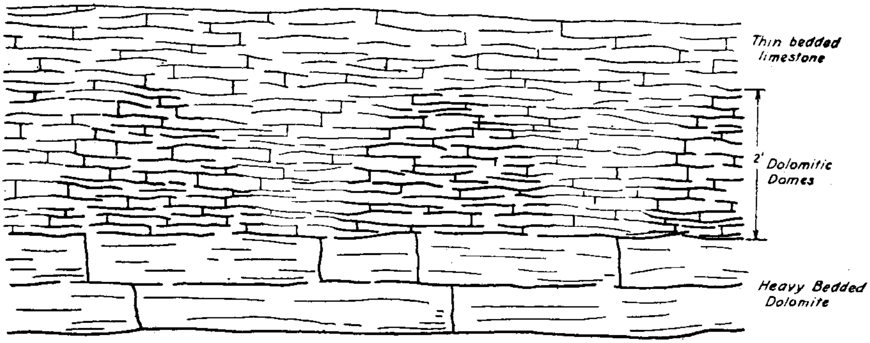


Figure 1.—Diagrammatic view of dolomite domes. The diagram is based on the dolomitic domes in the limestone beds in the Galena and Black River formation northeast of Sun Prairie, Wisconsin. The domes have the same bedding planes as the adjacent limestones and are not related to fissures or shaly seams. They contain numerous dolomitized pelecypods, whereas the limestone parts are rich in bryozoa, brachiopods, and crinoids.

inch in diameter and about one-half inch or more in length. The significant fact in this case is that the dolomite is associated with tiny marine structures and not with the fissures and larger openings along which water circulates most freely.

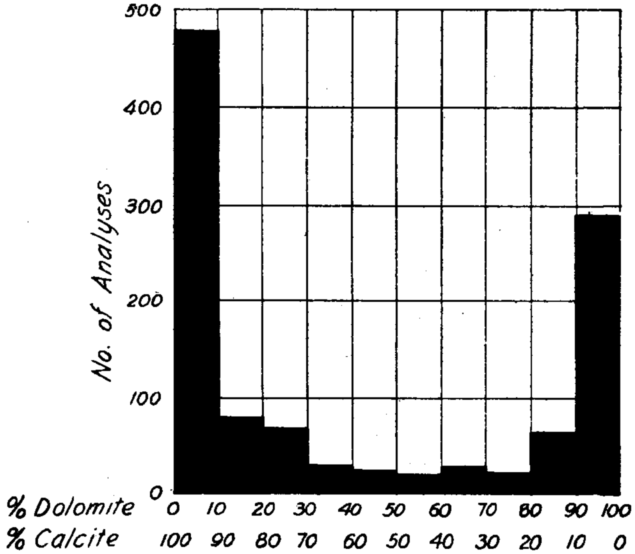


Figure 2.—Graphic representation of dolomite-calcite ratios from 1,148 analyses of specimens from all over the United States. Of these 988 were compiled by Ries in New York Museum Bulletin 44, 1901. It will be noted that about 480 samples were made up of 0 to 10 per cent of dolomite and 90 to 100 per cent of calcite, and that nearly 300 were made up of 0 to 10 per cent of calcite and 90 to 100 per cent of dolomite. The diagram shows that nearly pure limestones and dolomites are much more common than mixtures of the two.

The relative abundance of limestone, dolomite, and mixtures of the two points to the marine origin of dolomite. Limestones with little or no dolomite are very common. Dolomites with very little calcite are also abundant. Mixtures of limestones and dolomites are not common, and appear to be characteristic of certain stratigraphic horizons. See figure 2.

In Wisconsin, mixtures of limestone and dolomite are found in the transition beds between the Black River and Galena limestones of southwestern Wisconsin. If underground waters caused the progressive replacement of limestone by dolomite in any important way, mixtures of limestone and dolomite should be common. The average composition of underground water probably has not changed very much throughout geologic time. Such long continued action by underground waters ought to have left limestones in all stages of change into dolomite.

The average composition of underground water speaks against its effectiveness in causing very extensive replacement of limestone by dolomite. Just what the conditions are under which dolomite can develop have not been fully determined. It is known, however, that solutions high in magnesium salts are more favorable than those which have a low content of these salts. Since the average underground waters contain several times more calcium than magnesium, they are not as likely to bring about the deposition of dolomite as are sea waters. In fact, calcite is very much more common as an underground water deposit than is dolomite. The magnesium content of sea waters is many times greater than that of calcium; hence sea waters are chemically better fitted to bring about the deposition of dolomite than are underground waters.

Relation of Dolomitization to the Geologic Time Scale

Although dolomite beds are common throughout the entire succession of formations exposed on the surface of the earth, dolomite deposits appear to be nearly absent on the bottom of our modern seas and lakes. Direct evidence of present day deposition is very unsatisfactory. Globular masses of calcite found on the bottom of the Mediterranean Sea occasionally have shown rhombs of secondary dolomite. It is claimed that dolomite is less abundant in the deep waters than in shallower depths of this sea. In the Atlantic Ocean, dolomite has been found at a depth of 150 meters on a steep slope of the Seine Bank northeast of the Madeira Islands. The dolomite from this locality was found in fragments of limestone containing a variety of calcium carbonate skeletons including mollusks, snails, echinoderms, foraminifera, corals, and calcareous algae. The cement between the skeletons contains a great many dolomite grains of rhombohedral form, portions of the limy algae are replaced by dolomite. Dolomite is also abundant in the interior of the shells. The shells are found in various stages of decomposition. The cement of the rock is interpreted as a chemical precipitate since it shows no organic structures. Because of the strong currents of the locality it is thought to have been coherent when first formed or else it would have been washed away. The dolomite is either a chemical precipitate or a replacement of calcite. No proof of the replacement of calcite by the dolomite appears to have been found in this case.

As has been stated very little dolomite appears to be forming in the bottom of the seas of today. Less dolomite was formed in the seas of the recent past than in those of the remote past. The oldest sedimentary series commonly contain more dolomite than the sediments of intermediate age or of recent origin.

It is not proven, however, that dolomite deposition has uniformly declined as time went on. Even the oldest formations show some limestones, and the formations of later age show varying proportions of dolomite. A survey of the distribution of dolomite deposition through geologic time over a large area like the United States shows peaks and lows on a curve which, taken as a whole, declines with time. During the same geologic periods, dolomite deposition was marked in some parts of the ocean, less vigorous in others, and only limestone was formed in still other parts. For example, the carbonate formations of Cambrian time were chiefly dolomites in the eastern states and limestones in the western states.

CHAPTER II

GENERAL GEOLOGY OF WISCONSIN

The greater part of the visible portion of the earth is made of rock units or rock substances, each nearly uniform in character and of considerable extent. Each unit is nearly uniform in its constituents, or consists throughout its extent of one or two dominant minerals. The essential materials of each unit were formed by the same processes acting continuously during a certain span of time. It took thousands of years to form some of these rock units. Rock units formed by sedimentary processes, that is by wind, surface waters, or ice, are called sedimentary formations. The common sedimentary formations are sandstones, limestones and dolomites, and shales. The rock units which solidified from a molten state are called igneous rocks. Granites, basalts, and gabbros are common igneous rocks.

The size, shape, and position of rock units varies. Sedimentary rocks are commonly made up of layers. Originally such layers are nearly flat. By movements of the earth's crust the layers may become inclined or vertical, or may even be completely overturned. By compression roughly parallel to the earth's surface, the layers may be buckled into a series of arches and troughs, called folds. The layers may be sliced by fractures along which they slip upward or downward. Such slip displacements, called faults, vary in magnitude from a fraction of an inch to several miles. The fractures vary in dip from vertical to horizontal. Their horizontal length may vary from hundreds of feet to hundreds of miles.

Igneous rocks poured out on the surface of the earth in the form of lava flows have about the same characteristics of size, shape, and position as sedimentary formations. When solidified beneath the surface, igneous rocks vary greatly in form and position. Some are tabular in form, and the position of such ranges from flat to vertical. Others are elliptical, circular, or very irregular in their surface shape and extend downward into the unknown depths of the earth. Below the surface, the shape of these bodies is known but a short distance.

The distribution of rock units on the earth's surface depends on their original shape, size, and position with respect to other units, the displacements from their original position by earth movements, such as faulting, folding, or tilting, and finally the surface wear which they may have received by streams, winds, or glaciers. The distribution of the rock units which underlie Wisconsin is dependent upon all these factors.

The rock materials of Wisconsin from the standpoint of position, age, and unity of character belong to three great classes: namely, (1) the pre-Cambrian rocks, (2) the Paleozoic rocks—horizontal sediments, and (3) the unconsolidated glacial drift and soil—the surface mantle rocks. See figure 4 and Plate VI.

THE PRE-CAMBRIAN ROCKS

The pre-Cambrian rocks are the oldest. Wherever the Paleozoic rocks occur, pre-Cambrian rocks underlie them. The contact between them shows that the pre-Cambrian rocks were worn down by erosion to a nearly level surface dotted by low, widely scattered peaks and ridges before the Paleozoic rocks were deposited upon them.

The pre-Cambrian by no means consists of a single rock unit, the result of a single, unbroken geologic process. It is made up of a great variety of rock units formed at various times. Periods of rock formation were interrupted by periods of erosion when the rocks exposed on the surface were worn away and carried elsewhere. Periods of quiet were interrupted by periods of earth movements and volcanic activity. Thus a great variety of rocks are included.

These rocks fall into two major classes—an older series, the Archean, and a younger group, the Algonkian. The Archean rocks are chiefly igneous, that is, they solidified from a molten state. Extrusives are lava flows poured out on an ancient surface. Intrusives are igneous rocks which were injected while molten into older rocks. Granites and porphyries are the chief rocks of this type. The Archean rocks also include great masses of schists and gneisses. The schists consist of a compact aggregate of platy and fibrous minerals whose long dimensions are parallel. The gneisses, like the schists, are dense compact rocks and are made up of thin alternating layers of minerals. Usually these layers are a fraction of an inch in thickness. Gneisses are generally igneous in origin, but schists are more commonly sedimentary. The schists result from the recrystallization of minerals under intense squeezing at great depths within the earth.

The Archean rocks were subjected to intense lateral pressure generally along roughly north and south directions, thus giving portions of them a vertical foliated structure. They were deeply eroded to a nearly level surface before the Algonkian rocks were deposited upon them. The Algonkian rocks are for the most part very well consolidated sedimentary rocks such as quartzites, slates, iron formations, and marbles, but they also contain important masses of igneous rocks chiefly dark lava flows (basalts) and dark intrusives (gabbros). The youngest rocks of this group are sandstones and shales, very much like those of the Paleozoic.

The Algonkian rocks were not formed by a continuous process. Rock forming processes during the Algonkian were interrupted by several periods of folding and erosion during which the rocks already formed were partly carried away and laid down elsewhere. The major facts regarding the rock succession of the Algonkian are shown in figure 4. The Algonkian rocks were uplifted and their surface eroded to a nearly level plain before the Paleozoic rocks were laid down upon them.

The Paleozoic Rocks

The formation of the Paleozoic rocks began with an invasion of the sea over Wisconsin. For many millions of years this sea covered part or all of Wisconsin. Until the sea finally receded for the last time, there were probably but few times when the whole of the state was dry land, and only one of these times was long enough to leave very marked evidence of erosion before the sea covered the land again.

When the sea first advanced over Wisconsin after the wearing down of the Algonkian rocks, it laid down a series of ripple-marked, cross-bedded sands with some mud and marl beds which were subsequently consolidated. They constitute the Cambrian sandstone. This sandstone includes a pure white sandstone, red shaly sandstones, green glauconitic beds, and a thin dolomitic bed called the St. Lawrence member of the Trempealeau formation. Their deposition was at times interrupted by a withdrawal of the sea during which erosion of the previously deposited sands took place. From 700 to 1,000 feet of Cambrian sandstone was deposited. All of the state with the possible exception of parts of the northern portion was once covered by this sandstone.

Following the Cambrian period came the Ozarkian and Canadian periods (fig. 4), during which some sandstone was deposited. The most important formations, however, are the Oneota and Shakopee dolomites. The early geologists, thinking these two formations were one, gave them the name Lower Magnesian. Owing to the fact that these formations have not yet been mapped separately, the use of the name Lower Magnesian is continued in this report to include the two formations.

The deposition of the Lower Magnesian dolomites was followed by an interval of erosion during which valleys, some of which were more than 200 feet deep, were cut into the surface of the dolomite.

The erosion interval came to a close and the greater part of Wisconsin and possibly all of the state became the site of the deposition of sands. These sands are remarkably pure quartz sands in many places but locally are stained with iron oxides. Dake, who has recently studied this formation in Missouri, thinks that they are marine deposits.[1] These sands formed the St. Peter sandstone formation. It filled the valleys on the surface of the Lower Magnesian dolomite, in places to a thickness of 300 feet. Where it covers the ridges of Lower Magnesian dolomite, it is much thinner or in some places entirely absent.

Following the deposition of the St. Peter sandstone, marine sediments were laid down over a nearly smooth, even surface. The first to be formed were the Black River formation of shale, dolomite, and limestone, and the Galena dolomitic limestones. The total thickness of these formations is about 300 feet.

Deposition of the shale formations of the Richmond group (Maquoketa in southwestern Wisconsin—Richmond in the eastern part of the state) followed. This shale ranges from 40 to 540 feet in thickness. After an erosion interval the Niagara dolomite, over 700 feet thick, was deposited. After the Niagara dolomite was laid down, slight erosion took place, following which a shaly dolomite, the Waubakee formation, was deposited in the vicinity of Milwaukee. The Waubakee formation in turn was raised above the sea and subjected to surface wear, but was soon submerged and the Milwaukee formation was laid down upon its surface.

Erosion of the Paleozoic Formations

After the Milwaukee formation was deposited, all of Wisconsin became land and has remained above sea level to the present time. The formations constituting the Paleozoic system were about 2300 feet thick when the sea withdrew from Wisconsin for the last time. Some time during their formation or after they were formed, the earth's crust over Wisconsin was slightly bowed upward into a broad north to south trending very gentle arch. The highest part of this arch extends roughly through the middle of the state and continues southward into Illinois. East of the crest, the formations are more steeply inclined than west of it.

The upbowed formations were subjected to the wearing action of rains, winds, and streams through millions of years. All parts of the surface were attacked. The crest of the arch was worn more rapidly than the sides. In the north central part of the state, the Paleozoic sediments were stripped away and a large V-shaped pre-Cambrian area, the south edge of which is at Wisconsin Rapids, was

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[1] Dake, C. L., The problem of the St. Peter sandstone: School of Mines and Metallurgy, University of Missouri Bull. vol. 6, No. 1, 1921.

exposed. Farther south hills of the pre-Cambrian in the Baraboo district, at Berlin, Waterloo, and other points were exposed, but they were still surrounded by the sediments.

In this wearing down process, the relative resistance of the Paleozoic sediments varied greatly. The Maquoketa and Richmond shales, nearly all of the St. Peter sandstone, and most of the Cambrian sandstone were easily worn down wherever they became exposed. The Richmond shale underlying the Niagara dolomite was carried off so rapidly wherever the dolomite was removed that only a narrow belt having a maximum width of about 4 miles lies exposed on the inner border of the Niagara dolomite. The St. Peter sandstone bears to the overlying Black River and Galena dolomite about the same relation as the Richmond shale to the Niagara dolomite. A great deal of the Cambrian sandstone along the border adjacent to the pre-Cambrian of central Wisconsin is worn down to a monotonous plain, but along its outer border this plain is broken by numerous hills of the sandstone, many of which are steep sided. Certain hard layers of the sandstone have formed flat benches which are terminated by abrupt slopes.

The dolomite formations, because of their resistance to erosion, have formed more or less plateau-like areas, in general highest at their inner border. The border of each is always marked by a steep slope which faces the interior of the state. These steep slopes or escarpments are irregularly dissected by valleys, and in the area facing the escarpment are outlying isolated hills still capped by dolomite.

GENERAL DISTRIBUTION OF PRE-CAMBRIAN AND PALEOZOIC FORMATIONS

Figure 3 is a general east-west cross-section of Wisconsin through Blue Mounds showing the relative positions of the formations which make up the Paleozoic rocks and their influence on the surface. A glance at this figure and at Plate VI shows the pre-Cambrian rocks outcropping in the central part of the state, enveloped by successive belts of Paleozoic rocks. The oldest of the Paleozoic rocks, the Cambrian sandstone, lies next to the pre-Cambrian and on the outer border of the sandstone is the next younger formation, the Lower Magnesian dolomite. Each formation of the Paleozoic rocks in turn has on its outer border a belt of the next younger formation. The last to be deposited lies along Lake Michigan. It may be emphasized again that this arrangement of outcroppings of the various rock units is the result of the order in which the rock units were laid down one above the other, their slight upfolding along a north-south line through the middle of the state, and their subsequent erosion.

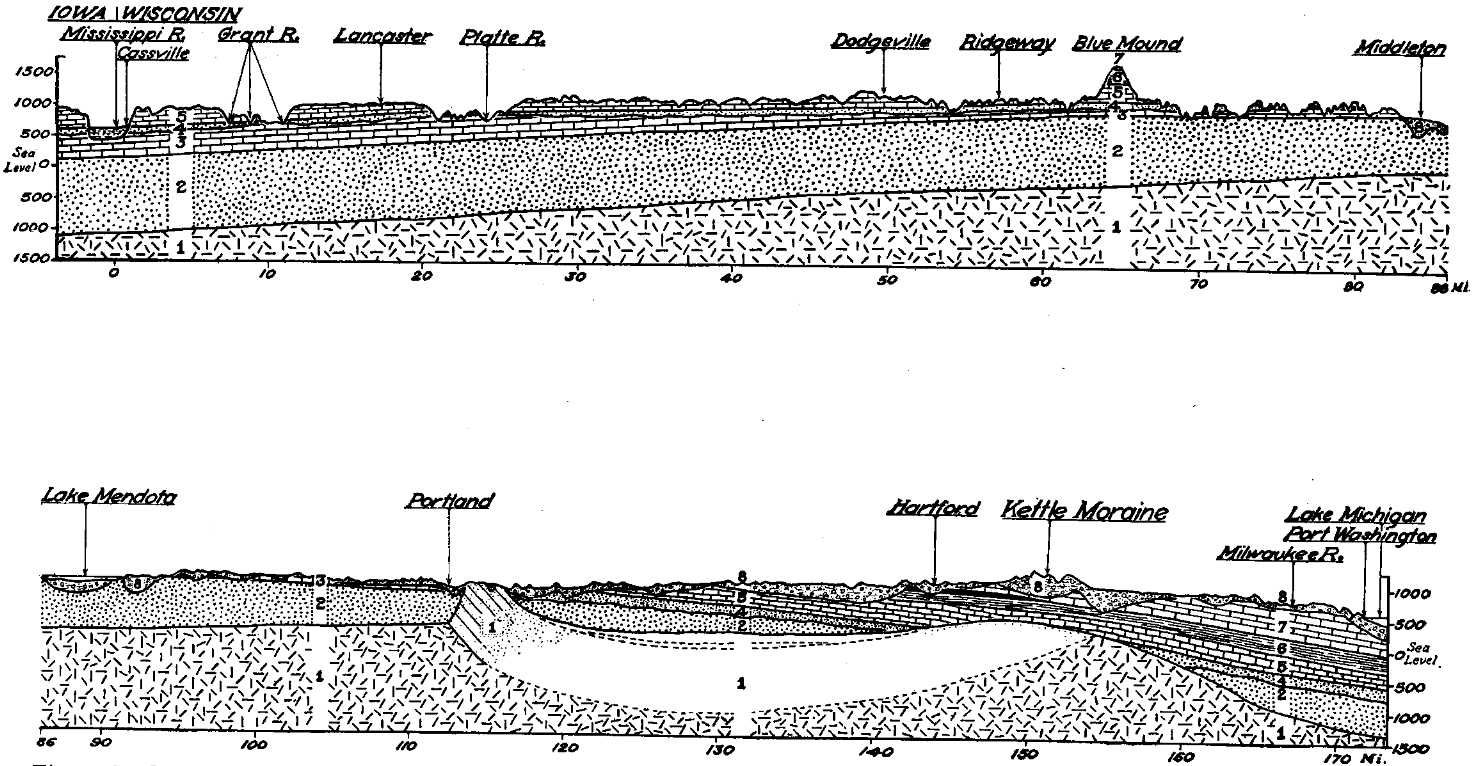

Figure 3.—East and west cross-section of Wisconsin through Blue Mounds, showing (1) the pre-Cambrian rocks, (2) the Cambrian sandstone, (3) the Lower Magnesian dolomite, (4) the St. Peter sandstone, (5) the Galena and Black River dolomite, (6) the Richmond or Maquoketa shale, (7) the Niagara formation, and (8) the glacial drift.

THE MANTLE ROCK

The term mantle rock is applied to all the loose unconsolidated materials which cover the hard rocks of the state. The mantle rocks of Wisconsin are classified as glacial and non-glacial. For distribution of the glaciated area of Wisconsin see Plate VI. In the glaciated area the mantle rock includes stream-laid sands, gravels, and muds; lake deposits, including sands, gravels, muds, peat, and marls; unstratified, unsorted mixtures, called glacial till, consisting of sand, clay, and bowlders of various sizes; and, locally, residual soil formed before glaciation. The mantle rock in the unglaciated or Driftless Area on the uplands is mostly residual soil and slope wash and scattered buff colored unstratified wind deposited silty clays called loess. In a few places quartz stream gravels have also been found on ridge summits. The valley floors are usually covered with stream deposited sands, gravels, and muds. In the large valleys which head beyond the Driftless Area, the stream sediments are largely glacial material.

OUTCROPS OF LIMESTONE AND DOLOMITE IN WISCONSIN

In general, limestone and dolomite and all other hard rocks are covered with a layer of mantle rock. This may be thin or thick. Locally this mantle rock is lacking and the hard rock is exposed.

Rock outcrops are much more abundant in the driftless than in the glaciated area. In the Driftless Area north of the Wisconsin River, the Lower Magnesian dolomite and in a few places the Galena and Black River formations form the cap rock of nearly all the hills. In many places the harder beds of these formations form steep cliffs of bare rock along the tops of the bluffs which border the valleys. These are especially prominent along the Wisconsin and Mississippi rivers, but are also well developed along the branching network of small valleys which dissect this region.

Along the bluffs marking the borders of the Lower Magnesian dolomite formation in the Driftless Area, outcrops also occur, but here the formation is thin as a result of erosion and a considerable mantle of residual soil with flint is generally present. In places this condition prevails for several miles from the border of the formation. Thus along the marginal bluffs of the formation extending through the northwestern part of Sauk County and through Vernon, Monroe, and Buffalo counties, it is usually difficult to find outcrops of sound rock.

The Galena and Black River limestone beds of the Driftless Area north of the Wisconsin River outcrop near the Mississippi on the top of the highest ridge of Crawford County.

South of the Wisconsin River in the Driftless Area lies a strip of closely spaced deep tributary valleys. Near the mouth of the river this strip is only about 2 miles wide. Towards the east it widens, being about 14 miles in width north of Blue Mounds. In this strip the Lower Magnesian dolomite forms almost continuous outcrops along the tops of the ridges near the river, but commonly comes down to the valley bottoms near the southern border of the area. The south side of this dissected belt is marked by the conspicuous elevation known as the Military Ridge. Outcrops of the Galena and Black River are abundant along the northern slopes of this ridge facing the Wisconsin River. South of the ridge all the steep slopes along the stream valleys have numerous outcrops of Galena and Black River limestone and in places other formations are also exposed.[1] The soil mantle of the region is usually less than 10 feet thick and locally the Galena and Black River formations are exposed on the gently undulating uplands of this region. Many large dump piles of Galena and Black River rock are found at the numerous mines of the lead and zinc region, especially along the Chicago & Northwestern Railway between Montfort and the state line.

Along the Grant County bluffs of the Mississippi River, the Galena and Black River formations form almost continuous outcrops which are confined to the upper portions of the bluffs from the mouth of the Wisconsin River to a point about 6 miles north of Cassville. Farther south they commonly extend down to the base of the bluffs.

Outcrops of the Niagara dolomite are especially prominent along the east and west sides of West Platte Mound. On top of West Blue Mound are prominent outcrops of chert which is a part of the Niagara formation. Minor outcrops of Niagara dolomite also occur on the East Platte Mound near Belmont, Sinsinawa Mound and on two mounds south of Shullsburg.

In that part of the glaciated area lying within 15 miles of the Driftless Area, the distribution of outcrops is much the same as in the Driftless Area, only less abundant. Here the preglacial hills are slightly masked with glacial drift. Outcrops of dolomite are common along the tops of the bluffs which border the valleys.

The geological map which accompanies Professional Paper 106[2] shows the rock outcrops and quarries of a large part of the glaciated region. It covers the area from the Illinois state line northward to latitude 44°, a line passing east and west through Oshkosh. From Lake Michigan it extends westward to the 90th meridian, passing through Reedsburg.

South of a line extending from Whitewater to the south side of Milwaukee, outcrops are rare because of the depth of glacial deposits.

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[1] See supplementary maps of Bulletin 14 of the Survey for distribution of outcrops in portions of this region totaling 100 square miles.

[2] Alden, W. C., The quaternary geology of southeastern Wisconsin: U. S. Geol. Survey Prof. Paper 106, 1918.

North of this line, outcrops of dolomite are most abundant along the bluffs which mark the western margin of the Lower Magnesian and Niagara dolomites respectively. The Galena and Black River dolomite in this region has relatively few outcrops. A large part of this formation south of Lake Winnebago underlies a lowland with numerous swamps and lakes and areas of undulating plain covered with fertile soil. Important outcrops occur northwest of Whitewater, northeast of Sun Prairie, northeast of Watertown, and between Waupun and Fox Lake.

Outcrops are abundant along portions of certain rivers. A strip following the Fox River from Waukesha to Germantown has many outcrops and quarries of Niagara dolomite. Quarries and outcrops are also abundant along parts of the Menomonee, Milwaukee, and Sheboygan rivers, along the Fox River between Menasha and Green Bay, and the Oconto and Menominee rivers. The bluffs along Lake Michigan are generally covered with lake clays and other glacial deposits, but in a few places dolomite is exposed. Places where outcrops occur are at Wind Point north of Racine, Port Washington, the town of Belgium, Washington County, and Sheboygan. North of Sturgeon Bay outcrops along the coast are common, especially on the west coast of Door County, where the Niagara dolomite outcrops in bold cliffs. The west coast of Green Bay is generally low and unfavorable for outcrops.

The eastern border of the Lower Magnesian dolomite in the glaciated area of Dunn, Barron, St. Croix, and Polk counties, although marked by a distinct line of bluffs, shows relatively few outcrops. As a rule weathering has made the exposed dolomite soft and earthy. Outcrops are abundant along all the stream valleys which traverse the interior of the area underlain by this formation. They are especially abundant where the streams which flow westward, like the Kinnikinnic, Apple, and Willow rivers, cross the western border of the formation. Here Willow River falls over a prominent precipice of the dolomite onto the Cambrian sandstone. On the nearly level uplands away from streams outcrops are scarce.

In Pierce and St. Croix counties the Galena and Black River dolomite outcrops along the rim of flat topped, mesa-like hills which form the highest eminences of the region. They commonly rise above a nearly flat surface.

EXPLANATION OF THE GEOLOGIC COLUMN

Figure 4, the geologic column of Wisconsin, shows the order in which the visible rock units of Wisconsin were deposited one above the other. The vertical order of their occurrence also represents the time order in which they were formed, the oldest being at the bottom. The four major units—the pre-Cambrian, Paleozoic, Mesozoic, and Cenozoic—

GEOLOGIC COLUMN FOR WISCONSIN

WITH CORRELATION TABLE FOR THE PALEOZOIC ERA

GENERAL TIME SCALE

CENOZOIC	QUATERNARY	RECENT	Marl, peat, and alluvium.
		PLEISTOCENE	Till, sand, clay, gravel, and bowlders of glacial, fluvial, and lacustrine origin (maximum thickness about 600 ft.); and loess of aeolian origin.
	TERTIARY		Absent

							WEST WISCONSIN	EAST WISCONSIN	
MESOZOIC					CRETACEOUS		Windrow formation (?)	(Absent)	
					JURASSIC & TRIASSIC		(Absent)	(Absent)	
PALEOZOIC	NEOPALEOZOIC				PENNSYLVANIAN (Pa. 15,000 ft. ss. sh. & coal.)		(Absent)	(Absent)	
					MISSISSIPPIAN (App. 3000 ft. ls. ss. & sh.		(Absent)	(Absent)	
		DEVONIAN			Neodevonian (N.Y. 7000 ft. sh. & ss.)		(Absent)	(Absent)	
					Mesodevonian (N.Y. 1400 ft. ls. & sh.)		(Absent)	Milwaukee (0-170 ft.)	
					Eodevonian (N.Y. 450 ft. sh. & ss.)		(Absent)	(Absent)	
		SILURIAN			Cayugan (N.Y. & Pa. 1400 ft. ls. sh. & ss.)		(Absent)	Waubakee dol. (0-50 ft.)	
			NIAGARAN	LOCKPORT	Guelph (Ont.)		(Absent)	Guelph dol. (?)	200 ft. to 550 ft.
					Racine (Wis.)		(Absent)	Racine dol. (?)	
					Waukesha (Wis.)		(Absent)	Waukesha dol. (250-300 ft.)	
					Byron (Wis.)		(Absent)	Byron dol. (100 ft.)	
				CLINTON	Upper Clinton (App. 500 ft. ss. sh. & ls.)		(Absent)	(Absent)	
					Middle Clinton (App. 500 ft. ss. & sh.).		Hopkinton dol. (?) (Iowa 50 ft.; age doubtful.)	Mayville dol. (100 ft.)	
					Lower Clinton (App. 600 ft. sh. ss. & ls.)		(Absent)	(Absent)	
			MEDINAN		Upper Medina (App. 350 ft. ss. sh. & ls.)		Burroughs dol. (60 ft.)	(Absent)	
				RICHMOND	(?)	MAQUOKETA GROUP	(Absent)	Neda form (0-55 ft.)	
					Elkhorn (Ind. 75 ft. ls. & sh.)		Brainord sh. (Iowa 30-90 ft.)	Richmond formation, the Brainord shale at the top and the Whitewater suggested beneath this. (50 to 540 ft.) (=Cincinnati shale of older reports.	
					Whitewater (Ind. 75 ft. ls. & sh.)		Probably absent		
					Fort Atkinson (Iowa 60 ft. ls.)		Fort Atkinson ls.		
					Liberty-Waynesville (Ohio 125 ft. sh. & ls.)		Probably absent		
					"Elgin" (Iowa 75 ft. sh. ls.)		"Elgin" sh. ls.		
					Fernvale (Tenn. 30 ft. sh. & ls.)		(Absent)		
					Arnheim (Ohio 75 ft. sh. & ls.)		Probably absent		
					Dubuque (Iowa 40 ft. ls. & sh.		Dubuque ls.	(Absent ?)	

FIGURE 4.

					GENERAL TIME SCALE	WEST WISCONSIN	EAST WISCONSIN
PALEOZOIC		ORDOVICIAN (ULRICH)	CINCINNATIAN App. 1800 ft.		Maysville (Ohio 250 ft. ls. & sh.)	(Absent)	(Absent ?)
					Eden (Ohio 300 ft. sh. & ls.)	(Absent)	(Absent ?)
			MOHAWKIAN App. 1500 ft. ls.		Trenton (N.Y. & Pa. 400-600 ft. ls.)	Galena dol. (250 ft. inc. Prosser ls.)	Galena dol. (100-200 ft.)
				BLACK RIVER	Kimmswick (Mo. 100 ft. ls.)	(Absent)	(Absent)
					Decorah (Iowa 60 ft. sh. & ls.)	Decorah (30+ ft. sh. & ls.)	Upper Blue dol. 15 ft. Upper Buff dol. 52 ft. Lower Blue dol. 25 ft. Lower Buff dol. 28 ft. BELOIT Dol. 120 ft.
					Watertown (N.Y. & Tenn. 8-200 ft. ls.)	Platteville ls. (75 ft.)	
					Lowville (N.Y. & App. 600 ft. ls.)		
			Chazyan (N.Y. & App. 7000 ft.)			(Absent)	(Absent)
			BIG BUFFALO Ark. 500 ft. ss. & ls.		Jochim (Mo. 100 ft. ls.) St. Peter (Minn. 100 ft.)	St. Peter ss. & sh. (0-332 ft.)	St. Peter ss. & sh. (0-300
					Everton (Ark. 120 ft. ls. & ss.) with Kings River ss. and Sneeds ls. members.	(Absent)	(Absent)
	EOPALEOZOIC	CANADIAN			Upper Canadian (App. 2000 ft. ls.)	Shakopee dol. (70 ft.)	Shakopee dol. (0-100 ft.
					Middle Canadian (App. & Okla. 2500 ft.)	(Absent)	(Absent)
					Lower Canadian (Pa. 700 ft. ls.)	(Absent)	(Absent)
		OZARKIAN			Upper Ozarkian (App. 1800 ft. dol.)	Oneota dol. (0-200 ft.)	Oneota dol. (0-100 ft.)
					Middle Ozarkian (App. 2000 ft. dol.)	(Absent)	(Absent)
					Lower Ozarkian (Pa. & Ala. 2500 ft. dol.)	Madison ss. (40 ft.) (Absent)	Madison ss. (30 ft.) Mendota dol. (20 ft.) Devils Lake ss. (100? ft
		CAMBRIAN	UPPER or ST. CROIXAN		Jordan (Minn. 80 ft. ss.)	Jordan ss. (75 ft.)	Jordan ss. (Generally Absent)
					Trempealeau (Wis. 125 ft. sh. & ls.) (= St. Lawrence of Ulrich, 1914)	Norwalk ss. member (50 ft.) Lodi Shale (50 ft.) St. Lawrence ls. (25 ft.) Shale (local 20 ft.)	(Absent) Lodi Shale (0-25 ft.) St. Lawrence (0-20 ft.) Shale (local)
					Mazomanie (Wis. 150 ft. dol. ss.)	(Absent)	Mazomanie ss. (100-165
					Franconia (Minn. 125+ ft. gr. ss. sh. & ls.)	Upper Greensand (54-70) Yellow ss. (40-50) Lower Greensand (40) Micaceous sh. (15) Ironton ss. member (15) 120 to 170	Usually Absent
					Dresbach (Minn.)	Dresbach ss. (40-250 ft.)	Dresbach ss. (40-180 ft.)
					Eau Claire (Wis.)	Eau Claire sh. (200-300 ft.)	Eau Claire sh. (350 ft.)
					Mt. Simon (Wis.)	Mt. Simon ss. (100-200 ft.)	Mt. Simon ss. (700+ ft.)
			Middle & Lower Cambrian (Rocky Mts. 12,000 ft. ss. sh. & ls.)			(Absent)	(Absent)
PRE-CAMBRIAN	ALGONKIAN	KEWEENAWAN	UPPER	BAYFIELD	Chequamegon ss. 1000 ft. Devils Island ss. 300 ft. Orienta ss. 3000 ft.		
				ORONTO	Amnicon Shale and Arkose 5000 ft. Eileen Sandstone 2000 ft. Freda Sandstone 12,000 ft. Nonesuch Shale 120-350 ft. Outer Conglomerate 800-1200 ft.		
			MIDDLE		Basalts; diabase, rhyolite, gabbro, felsites, conglomerates, etc. (17,000 to 30,000 ft.)		
			LOWER		Conglomerates and Quartzites (225-300 ft.)		
		HURONIAN	UPPER		Tyler formation, mica and clay slates, and graywackes (7,000-11,000 ft.) Ironwood formation, ferruginous cherts and cherty iron carbonates (600-1000 ft.) Palms formation (clay slate and quartzite 400-800 ft.)		
			LOWER		Bad River dolomite (200-300 ft.)		
	ARCHEAN				Laurentian — granites, syenites, gabbros, and gneissoid equivalents.		
					Keewatin — greenstones (schistose basalts), and green schists.		

FIGURE 4—(Continued)

are not present everywhere. In many places where hard rocks outcrop, there is no mantle of loose, unconsolidated rock. In north central Wisconsin only the pre-Cambrian with or without mantle rock is represented. Other parts of Wisconsin as a rule have three of the major units. This geologic column is studied to advantage with Plate VI showing the surface distribution of the rock formations underlying Wisconsin. Plate VI does not show mantle rock excepting the glacial drift. It does show the hard rock formations as they would appear if the mantle rock were stripped away.

The age designations of the formations—*Devonian, Silurian, Ordovician, Canadian, Ozarkian,* and *Cambrian*—are standard geologic time units. Though the utilization of dolomites and limestones has nothing to do with their age, the age designations are very useful and convenient in comparing the formations of one region with those of another. In a broad survey of limestone and dolomite formations for materials of a certain composition, the age designations of mapped formations are highly useful since a formation of any given age is likely to exhibit nearly uniform characteristics for long distances. The high calcium limestones used in the Portland cement industry of the Mississippi Valley are scarce in rocks of pre-Cambrian, Cambrian, and Silurian ages. There are some high calcium limestones of Ordovician, Devonian, and Carboniferous ages, but none of these are found in Wisconsin.

CHAPTER III

THE DOLOMITES AND LIMESTONES OF WISCONSIN

THE PRE-CAMBRIAN DOLOMITES

So far as known, the pre-Cambrian carbonate formations in Wisconsin are all dolomites. None have been used for purposes in which chemical composition is a factor of fitness. None of the known exposures are desirable for such uses since they contain considerable silica. In four areas, namely, the Gogebic and Baraboo ranges, near Draper, and near Winegar, dolomites are known. Only those of the Gogebic outcrop. The others are known only in drill holes.

The dolomite of the Gogebic district, which lies in Bayfield, Ashland, and Iron counties, is known as the Bad River formation because of its prominent outcrops on this river near Penokee Gap. It is a member of a series of formations of which one contains important iron ores. The outcrops are scattered along a belt trending a little north of east beginning in T. 44, R. 5 W. and extending northeastward into Michigan. Prominent exposures are found in secs. 15 and 16, T. 44 N., R. 5 W. near the Marengo River, sec. 24, T. 44 N., R. 4 W., and in the SE. ¼ of the NW. ¼, sec. 14, T. 44 N., R. 3 W. The thickness is in most places only a few feet, but near the Marengo River it is about 300 feet.

In most places the formation is very siliceous, the chief silica-bearing minerals being chert and fragmental quartz. Minor minerals are magnetite, tremolite, and chlorite. See analysis 1 (p. 183) for composition of the soluble portion of the dolomite from an outcrop in the NW. ¼ of sec. 22, T. 44 N., R. 5 W.[1]

In Sauk and Columbia counties lies an area of pre-Cambrian rocks in what is known as the Baraboo district. The best exposed of this group of rocks is the great Baraboo quartzite formation which forms two conspicuous ranges of nearly east and west trending hills. The one to the south forms the high bluffs at Devils Lake. The other forms the hills at Ableman, Baraboo, and the Lower Baraboo Narrows.

The Baraboo quartzite is overlain by slates and iron-bearing formation of which a considerable part is dolomite, but neither slate nor iron formation outcrop. They are all covered to a depth of 90 to 600 feet by either Cambrian sandstone, glacial deposits, or non-glacial mantle

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[1] Irving, R. D., and Van Hise, C. R., The Penokee iron-bearing series of Michigan and Wisconsin: U. S. Geol. Survey Mon. 19, p. 131, 1892.

rock. They occur in the Baraboo Valley which lies between the two quartzite ranges and extends from the vicinity of Ableman eastward for more than 20 miles.

Weidman records three analyses of the dolomite in his report on the Baraboo district.[1] Analyses 2 and 3 are from the Illinois Mine at North Freedom and analysis 4 (p. 183) is from a drill hole near this mine. The dolomites of the Baraboo district are ferro-dolomites; that is, in addition to the carbonates of calcium and magnesium, they contain several per cent of iron carbonate. The analyses indicate that dolomites closely associated with the iron-bearing rocks are high in silica. Farther away from the iron-bearing rocks, the dolomite is lower in silica. Because of the depth to which these dolomites are buried it is unlikely that they ever will be used.

In the vicinity of Winegar,[2] Wisconsin, T. 44 N., R. 6 E., eight diamond drill holes have cross-sectioned the Turtle Range. The drillings indicate a syncline of pre-Cambrian rocks. On opposite flanks of this fold which probably trends about N. 80° E. lie quartzite and dolomite. The thickness of the dolomite is estimated to be about 900 feet. The middle of the trough is underlain by slate and iron formation. The minimum drift cover over the dolomite, as shown by the drilling, is about 175 feet.

Diamond drillings disclosed a dolomite of probable pre-Cambrian age near Draper in secs. 6 and 7, T. 39 N., R. 4 W. This is a somewhat mashed siliceous dolomite accompanied by slate and cherty carbonate. The depth of drift is between 50 and 100 feet. From the meager data the thickness of the dolomite is computed to be 300 feet.

The Paleozoic Dolomites and Limestones of Wisconsin

The dolomites of the Paleozoic rocks of Wisconsin will be discussed under county headings. The counties are treated in alphabetic order. Under each county or group of counties for which titles appear, all the dolomite formations occurring in that particular area are taken under consideration. It is believed that this arrangement will be found best for those who may desire to look up the limestones of a particular region.

Brown County

General geology.—The Galena and Black River dolomite belt in the western part of the county is bounded on the east by a narrow strip of Richmond shale, east of which the bed rock is Niagara dolomite. See

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[1] Weidman, Samuel, The Baraboo iron-bearing district of Wisconsin: Wisconsin Geol. and Nat. Hist. Survey Bull. 13, pp. 61, 62, 64, 68, 1904.

[2] Allen, R. C., and Barrett, L. P., Contributions to the pre-Cambrian geology of northern Michigan and Wisconsin: Michigan Geol. and Biol. Survey Pub. 18, p. 99, 1915.

Plate VI for the distribution of the hard rock formations as they would appear if the mantle rock covering them were stripped away. The edge of the Niagara dolomite is marked by a westward facing slope, averaging 250 feet in height. The county is covered by glacial deposits, so that outcrops are most common along streams and along the western edge of the Niagara dolomite.

Galena and Black River dolomite.—Outcrops of this formation are common along Fox River. Exposures of the Galena dolomite are abundant along Duck Creek. The outcrops are similar in nature to those at Kaukauna (p. 71).

The Big Suamico River has likewise laid this formation bare in a number of places along its channel. The largest outcrop of this kind is at Flintville. It is not like those at Kaukauna and Duck Creek. The lower seven feet of the outcrop consists of shale and dolomite beds interlayered. Above them lies a three-foot bed of massive dolomite similar to those at Duck Creek and Kaukauna.

Large quarries in the Galena dolomite are located at Duck Creek and De Pere. A few descriptions of quarries are given below.

Buckley describes the beds of the Chicago & Northwestern Railway Company's quarry at Duck Creek as follows:

Top of section.

15 inches.	Considered one of the best beds of the quarry (for building stone). Below this bed is 1/4 to 1/2 inch of clay.
34 inches.	Sometimes runs solid, while at other times it is split into two or three courses.
16 inches.	Solid bed.
19 inches.	Works into good 18-inch coursing.
28 inches.	This bed is split up into any desired thickness.
11 inches.	This bed is shelly and worthless.
15 inches.	In places shelly and worthless, in others suitable for building stone.

The beds in the other quarries of the Duck Creek district are very similar to those of this quarry. At the M. Brunette quarry about 40 feet of rock is exposed. No great variation of the beds can be noted except that the lower beds are thinner and less suited for dimension stone than the upper. For composition of Duck Creek stone see analysis 62 (p. 186).[1] The thickness of beds represented by this analysis is not given.

Niagara dolomite.—Outcrops of the Niagara dolomite are not common. The escarpment marking the western edge of the formation is most favorable for exposures. The beds outcropping, known as the Mayville beds, belong to the lowest part of the formation. The average thickness is 60 feet, but as a rule only a small part of the beds is exposed in any one place.

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[1] Buckley, E. R., Building and ornamental stones of Wisconsin: Wisconsin Geol. and Nat. Hist. Survey Bull. 4, p. 275, 1898.

The striking characteristics of these beds, in Chamberlin's words[1] are "thick bedding, uneven structure, and the rough, craggy, pitted surface of the weathered ledges." He recognizes the following five distinct types of beds in the lowest part of the Niagara:

Top of section.

I. 0–12 feet.	Same as III.
II. 4–14 feet.	Compact, cherty dolomite, excellent as a building stone.
III. 5–10 feet.	Broken fragments of dolomite cemented with yellowish green marly clay.
IV. 6–12 feet.	Hard, heavy bedded dolomite—(no good for quick lime).
V. 4–10 feet.	Shaly impure dolomite.

Quarries in the Niagara limestone are located at Greenleaf and in the townships of Morrison, Denmark, and Preble.

Lime kilns have been operated for local consumption by Fred Bena, town of Preble, and Wm. C. Trilling, town of Morrison.

Buffalo County

General geology.—Buffalo County has an abundance of Lower Magnesian dolomite which caps nearly all the high ridges and uplands. The lowlands are underlain by the Cambrian sandstone. The loose mantle rock of the county consists of residual soil, wind deposits, slope wash, and stream deposits. Scattered occurrences of glacial debris have been noted in the towns of Maxville and Nelson.

Lower Magnesian dolomite.—The principal exposures of the Lower Magnesian dolomite are found along the tops of the bluffs which face the Mississippi River. Away from the river, the soil mantle becomes deeper, outcrops are less common, and the beds at the surface are usually more decayed.

Following is a partial list of dolomite quarries in Buffalo County:

Alma	Fred Gleiter, John F. Harry, John Dinger, Rudolf Mueller & Sons, and John Eberle
Fountain City	Badger Stone Company, H. F. Murr, and Richard Krause
Cochrane	A. Krause

North of Fountain City the beds exposed are as follows:

Top of section	Feet
I. Soil-covered slope	40
II. Thick-bedded, fine-grained Lower Magnesian dolomite with many small cavities lined with calcite. Flints in lenticular nodules, also in honey-combed forms lining cavities. Analysis 11 (p. 184)	40

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[1] Chamberlin, T. C., Geol. of Wisconsin vol. 2, p. 338, 1877.

III.	A bed of white, fine-grained dolomite from II, 2 feet thick, analyzed separately. Analysis 12 (p. 184).	
IV.	Dolomite, thick bedded without flint. Sandy seams near bottom. Analysis 13 (p. 184)	40
V.	Soil-covered surface	250

The beds of this quarry are higher in carbonate than the average Lower Magnesian dolomite. They would make fair lime and a very good agricultural limestone.

The beds at Cochrane are about the same in thickness and quality as at Fountain City. An excellent quarry site is located about 1½ miles north of Cochrane.

The beds of Lower Magnesian dolomite in the Eberle quarry on the hill just north of Alma are described as follows:

Top of section		Feet
I.	Residual soil and dolomite fragments	4
II.	Fine-grained, compact, thin-bedded dolomite with flint nodules and lenses parallel to bedding. Analysis 14 (p. 184)	10
III.	Massive, compact dolomite—almost without bedding. Analysis 15 (p. 184)	12
IV.	Thick-bedded dolomite, mostly coarse grained. Analysis 16 (p. 184)	12

The upper 22 feet, groups II and III, are pure enough to be a fair lime rock. They would make very good agricultural limestone.

Calumet County

General geology.—The northwest portion of this county is underlain by Galena and Black River dolomite. A strip of Richmond shale lies southeast of this and along the Lake Winnebago shore. All the rest of the county is underlain by the Niagara formation.

Galena and Black River dolomite.—These formations underlie a gently undulating and level area deeply covered by glacial debris and lake clays, and probably do not outcrop.

Niagara dolomite.—The chief outcrops of this formation are along or near the cliffs which border Lake Winnebago.

The largest quarries in the Niagara dolomite are at High Cliff, Hayton, and Brillion. The lower beds along the lake are usually flint bearing, coarse grained, thick, gray, and rough in exterior. The upper beds are generally a very pure dolomite, sandy and porous in grain and well suited for lime. Analysis 141 (p. 188) shows the composition of the lower 20 feet of the formation at High Cliff.[1]

The Western Lime and Cement Company's quarry at High Cliff is located in sec. 36, T. 20, R. 18 E. At High Cliff there is an abrupt rise of 200 feet above the lake. The quarry stone (about 10 feet thick)

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[1] Chamberlin, T. C., op. cit., p. 338.

outcrops in flat layers near the top of the bluff. It is cut by vertical mud seams and fissures. The underlying beds are so full of flint as to be worthless for lime. The stone is a finely crystalline white dolomite. Analysis 144 (p. 188)[1] shows the composition of the quarry beds. The face of the quarry is 600 feet long by 10 feet high.

The foot of clay on top is removed by hand. The stone is drilled by steam and blasted with dynamite. It is then sledged and sorted for size only.

At the Western Lime and Cement Company's quarry at Hayton, the section of Niagara dolomite is as follows:

Top of section		Feet
I.	Soil	Thin
II.	Top layers, shelly, bluish, stained with iron. Not used for lime	5
III.	Hard bluish-gray dolomite	12
IV.	Hard white, coarse crystalline dolomite reported as the best quicklime beds of the quarry	5
V.	Soft white, granular dolomite. Analysis 142 (p. 188)	12

The Western Lime and Cement Company's quarry at Brillion is also located on the Niagara dolomite. Considerable lime has been produced here. The quarry face is over ¼ mile long. The beds are described as follows:

Top of section		Feet
I.	Soil	A few
II.	Top layers, fine grained, slightly earthy. Uniform in quality as a lime maker. Analysis 137 (p. 188)	25
III.	Coarse-grained rock—not strongly coherent. Reported as making a faster slaking lime than II. Analysis 138 (p. 188)	10
IV.	Coarser grained than III. Analysis 139 (p. 188)	4
V.	Reddish, cherty dolomite. Red iron oxide along bedding planes. Chert in bands and nodules parallel to bedding. Used for crushed stone. Analysis 140 (p. 188)	10

Two other analyses of Niagara dolomite have been published before. Analysis 136 (p. 188)[2] from Brillion is of a high-grade dolomite similar to that of the Western Lime and Cement Company's beds. Analysis 143 (p. 188),[3] is from the lower shaly beds of the Niagara dolomite in the NE. ¼ sec. 11, T. 19, R. 18 E.

Columbia County

General geology.—The northwestern part of this county is underlain by the Cambrian sandstone (Pl. VI); the southwestern by Cambrian sandstone and Lower Magnesian dolomite. Along the Wisconsin River,

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[1] Emley, W. E., Manufacture of lime: U. S. Bur. of Standards Tech. Paper 16, p. 123, 1913.

[2] U. S. Geol. Survey Twentieth Ann. Rept., Pt. 6 cont., p. 462, 1899.

[3] Chamberlin, T. C., op. cit., p. 338, 1877.

the Trempealeau dolomite in the upper part of the Cambrian sandstone forms prominent benches. The eastern end of the Baraboo Range is the most striking topographic feature of the town of Caledonia. East of the Cambrian area there is a northwest facing escarpment formed by the Lower Magnesian dolomite, which underlies much of the southeastern part of the county. This escarpment is deeply indented by stream valleys. Numerous hills capped by Lower Magnesian dolomite lie to the northwest of the escarpment. The eastern part of the county is underlain by strips and patches of St. Peter sandstone and Galena and Black River dolomite. The ledge rock is in most places buried by loose glacial debris and soil.

Trempealeau dolomite.—Localities where the Trempealeau appears at the surface are listed because they might in some cases serve as sources for agricultural limestone.

1. In sec. 31, T. 13, R. 12 E., town of Randolph. There are two quarries on the walls of a ravine at the head of Duck Creek. The quarry on the west wall of the ravine shows the following section:

	Top of section	Ft.	In.
I.	Fine-grained, yellow-brown rock, only slightly sandy. Insoluble residue 69.03 per cent	10	0
II.	Fine-grained, compact, yellow and purple blotched—not in distinct layers, but occasionally finely laminated. Insoluble residue 44.53 per cent. Carbonate content about 45 per cent. No good for lime. A local soil neutralizer, if nothing better can be obtained as cheaply	6	0
III.	Fine-grained, milk-white, clayey, sandy rock without carbonate		6
IV.	Similar to II	11	0
V.	Compact, fine crystalline, vugs lined with dolomite. Insoluble residue 41.73 per cent	4	0
VI.	Greensand layers	2	0

2. In the railroad cut at Rio in the northwest corner of the town of Otsego, T. 11, R. 11 E., 4 feet of red and yellow mottled Trempealeau beds are overlain by 18 feet of sandstone.

3. Kingsleys Bluff in the NE. ¼ of sec. 26, and the SE. ¼ of sec. 23, T. 10, R. 8 E., near Lodi, has the following section:

	Top of section	Feet
I.	Drift-covered slope	20
II.	Lower Magnesian dolomite	5
III.	Drift-covered slope without exposure	100
IV.	Sandstone	5
V.	Trempealeau dolomite, yellowish, regular bedded, fine grained. Analysis 5 (p. 183)[1]	10

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[1] Irving, R. D., Geol. of Wisconsin, vol. 2, p. 586, 1877.

VI.	Flat, drift-covered slope. No exposure	40
VII.	Cambrian sandstone	40
VIII.	Sandy slope without exposure	90
	Total	310

Lower Magnesian dolomite.—Most of the outcrops of the Lower Magnesian occur along the escarpment described above.

The J. E. Johnson quarry is located in the SW. ¼, NE. ¼ sec. 36, T. 10, R. 8 E. It is easily accessible and contains a large quantity of stone. The beds consist of 10 feet of thick bedded, compact dolomite, free from flints. Analysis 17 (p. 184).

The Thompson quarry is situated on a bluff in the S. ½ of SW. ¼ of SE. ¼ of sec. 34, T. 10, R. 8 E. The supply here seems to be limited. Its quality is about the same as at the Johnson quarry.

In the high prairie country of southern Columbia County the formation is 120 to 140 feet thick, the uppermost layers being cherty or entirely replaced by chert.

Galena and Black River dolomite.—The principal exposures of the Galena and Black River dolomite occur along its outer or western margin, although some outcrops and quarries are located on nearly level areas away from the border of the formation.

The old city quarry of Columbus, in the NE. ¼, SW. ¼, sec. 22, T. 10, R. 12 E., is in this formation. The beds exposed in the quarry are described as follows:

Top of section		Feet
I.	Soil	2
II.	Thin-bedded dolomite. Analysis 65 (p. 186)	10
III.	Thin-bedded, brittle, fine-grained dolomite similar in appearance to the glass rock of the lead and zinc region. Analysis 64 (p. 186)	4
IV.	Thick-bedded, blue, fine-grained, clayey dolomite. Analysis 63 (p. 186)	4

At the quarry in the SW. ¼ of sec. 27, T. 10, R. 12 E. the section is about the same as at the city quarry. The quarry is easily accessible, although located in a field about ¼ mile from the public road. The quality of the stone is about the same as at the city quarry.

Crawford County

General geology.—The Lower Magnesian dolomite caps the bluffs and uplands along the Kickapoo Valley and throughout the eastern part of Crawford County. Some of the ridges have a thin coating of St. Peter sandstone which as a rule forms unimportant outcrops and has little effect on the soil, being covered in most places by wind-deposited clays. The valleys in this portion of the county are underlain by Cambrian sandstone. In the western part of the county, the ridges are capped with the Galena and Black River dolomite and the St. Peter sandstone. Here the valleys are usually underlain by the Lower Magnesian dolomite. Prominent outcrops of both carbonate formations are found along the Mississippi near Prairie du Chien. The Galena and Black River dolomites are found only on the highest spurs.

Lower Magnesian dolomite.—The bedding of the Lower Magnesian dolomite where well exposed along the Mississippi is very regular and uniform. Certain beds form vertical cliffs, 40 feet or more in height, which the eye can trace for many miles up and down the towering bluffs which follow both sides of the river. A section 207 feet thick on a bluff facing the river in the SE. ¼, sec. 6, T. 7, R. 6 W., was measured by Moses Strong.[1]

Quarries are numerous. At Prairie du Chien the city quarry, located at the mouth of the gully directly east of town, shows 52 feet of dolomite. The section follows:

Top of section		Feet
I.	Porous, coarse crystalline dolomite with flint layers	20
II.	Compact dolomite with flint nodules	7
III.	Banded dolomite	5
IV.	Dolomite with quartz openings parallel to bedding	4
V.	Coarse, porous dolomite known as "lead layer" by local quarrymen	3½
VI.	Compact dolomite	13

At De Soto a quarry owned by O. G. Lewis, cashier of the bank of De Soto, is located about ¼ mile south of the village. Here the Lower Magnesian dolomite appears about 300 feet above the Mississippi River. The lower portions of the bluff are Cambrian sandstone. The thickness of dolomite in the Lewis quarry is 35 feet. The section follows:

Top of section		Feet
I.	Fine-grained, buff, flinty rock. Analysis 20 (p. 184)	12
II.	White, fine-grained dolomite. Analysis 19 (p. 184)	5
III.	Fine-grained, compact dolomite. Upper layers flinty. Analysis 18 (p. 184)	18

The average rock from this quarry is too high in impurities to be suitable for quick lime. As an agricultural limestone, it would be satisfactory for local uses.

The quarry owned by Lawyer and Carrol at Bridgeport shows about 35 feet of Lower Magnesian dolomite. It is an old quarry, having furnished some of the stone used in the old capitol building at Madison. The lower 21 feet consist of coarse, sandy, rotten dolomite and flint and would be undesirable for quick lime or agricultural dolomite. The upper 14 feet are thick bedded, compact, and of fair quality as a soil neutralizer.

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[1] Strong, Moses, Geology of Wisconsin, vol. 4, p. 67, 1882.

In the Kickapoo Valley, Lower Magnesian dolomite can be obtained from the tops of the bluffs which overlook the valley. On the ridges and uplands away from the valleys, outcrops are scarce. The rock is rotten to considerable depths. Residual flint bowlders are almost the only solid rocks near the surface.

About 1½ miles northwest of Wauzeka there is a small roadside quarry in the Lower Magnesian dolomite. The rock is soft and crumbling.

Farther north, around Soldiers Grove, the Lower Magnesian dolomite exposed is soft and decayed. At the Clayson quarry, east of Soldiers Grove in sec. 26, about 10 feet of Lower Magnesian dolomite is exposed about 40 feet above a creek bottom, where the Cambrian sandstone can be seen. The composition of the 10-foot section exposed is shown in analysis 21 (p. 184). This rock is rather high in impurities for quick lime, but would make good agricultural limestone.

On the east side of the road one-half mile north of the Clayson quarry is another quarry in the Lower Magnesian dolomite. The ledge is about 6 feet high by 40 feet long. The composition is shown in analysis 22 (p. 184).

This rock is too impure for quick lime and inferior to the Clayson quarry rock as a soil neutralizer.

Galena and Black River dolomite.—This formation caps the ridge from a point between Bridgeport and Prairie du Chien northward to a point a few miles north of Seneca. An isolated patch also occurs on the uplands in the northwest part of the town of Utica. Outcrops occur along the edges of the high bluffs.

On top of the first bluff north of the road leading east of Prairie du Chien is an outcrop of thin bedded, white, fossiliferous limestone. It is hard to reach, being off the road and about 500 feet above the city. The section is 10 feet thick, fine grained to glassy in texture, and similar to the transition beds found at the base of the Galena south of the Wisconsin River in the lead and zinc district. Analysis 66 (p. 186). Although higher in calcium carbonate than most of our carbonate formations, it is still too high in magnesium carbonate to be used for Portland cement, beet sugar factories, or sand lime brick. It would make a fairly hot quick lime and would be a good agricultural limestone.

Dane County

General geology.—The principal valleys of Dane County, including the Four Lakes region, the Wisconsin Valley, and the Black Earth Valley, are underlain by the Cambrian sandstone. The first hard rock bench which rises above the sandstone areas is underlain by the Mendota dolomite, a sandy dolomite in the upper part of the Cambrian sandstone. Typical outcrops of the Mendota dolomite occur on Lake Mendota at Maple Bluff.

The next bench above the Mendota dolomite is underlain by the Lower Magnesian dolomite. It caps most of the bluffs along the Wisconsin River. It outcrops in many places along the bluffs which border the Black Earth Valley from Mazomanie to Madison. It underlies most of the uplands in the northern part of the county.

The high uplands of the southwestern part of the county and certain ones east and northeast of the Yahara Valley are underlain by the Galena and Black River dolomite. The edge of these uplands is usually marked by a steep slope, the lower part of which is underlain by the St. Peter sandstone. Some of the valleys in the southwestern part of the county are underlain by the St. Peter sandstone.

At Blue Mounds the cap rock is a flint formation, a remnant of the Niagara formation which erosion has failed to remove. The gentle slope of the mound near the top is underlain by the Maquoketa shale.

The edge of the heavy glacial drift sheet extends from the northwest corner of the town of Roxbury southward. It crosses the Chicago, Milwaukee & St. Paul Railway about one mile east of Cross Plains and from there swings southeastward through Brooklyn on the southern border of the county. The region to the west of the glacial drift is mostly covered by residual soil resulting from the decay of the underlying formations.

Mendota dolomite.—The Mendota dolomite extends over a large part of the Yahara Valley. It is absent elsewhere in the county. To the west the Trempealeau formation replaces it at the same level.

The Mendota dolomite averages about 30 feet in thickness, of which the lower 20 feet are heavily bedded, dark yellow in color, and break with a shell-like fracture. In seams and patches it is stained by iron oxides. It contains 3 to 10 per cent of insoluble clayey material. Although not a high grade dolomite and therefore not suitable for commercial lime and other uses in which a nearly pure dolomite is desirable, it has been used as a local agricultural limestone. Cost should determine whether this or the Lower Magnesian dolomite should be used.

On the north shore of Lake Mendota in the NW.¼ of sec. 1 of the town of Madison the Mendota dolomite was quarried for part of the stone used in the construction of the old capitol at Madison. The beds are about 21 feet thick, of a brown color and flinty matrix. On solution they leave about 15 per cent of sandy residue.

The Mendota is also exposed in several railroad cuts on the north side of sec. 22 in the town of Madison. On the SW.¼ of sec. 23 on the point of a low ridge, the lower 10 feet of the Mendota are exposed. The rock is a dark yellow to brownish rough textured, concretionary dolomite with many patches of red iron oxide. Its composition is shown by analysis 6 (p. 183).[1] It is higher in carbonates than the average Mendota.

About 10 feet of Mendota are exposed on the south shore of Lake Monona, near the southeast corner of sec. 25.

On the west shore of Lake Kegonsa near the center of sec. 26, town of Dunn, 12 feet of Mendota dolomite are exposed at the base of an 18 foot section of sandstone.

Lower Magnesian dolomite.—Small quarries are common wherever this formation outcrops. In recent years this rock has been used for crushed stone only. Up to a few decades ago, it was used as a local source of lime.

The composition of the Lower Magnesian dolomite varies greatly. No section of beds 4 feet or more in thickness can be found free from notable amounts of impurities. The chief impurities are clay, flint, and sand. Flint occurs in abundant nodules and irregular layers. Some nodules are a foot or more in diameter. In the deeper layers they are usually 2 or 3 inches across and are arranged parallel to the bedding. A great deal of flint also occurs in tiny spherical globules about ⅛ inch in diameter, which are scattered through the dolomite. Some beds consist chiefly of flint globules rather than of dolomite.

The Lower Magnesian dolomite of Dane County is too impure to serve any of the purposes of a high grade dolomite. It can be used as a local soil neutralizer.

Stone from the old Williams quarry on the south line of the town of Madison in sec. 33 was formerly used for lime. The quarry shows the following section.

Top of section	Ft.	In.
I. Concretionary and irregularly bedded, yellowish dolomite	10	0
II. Flint layer, sometimes forming a continuous nodular-surfaced layer, at others occurring in a row of separate nodules; internally the flint is brown and white banded, and jaspery; externally it has a soft white opaline coating		3
III. Compact, heavily-bedded, flinty-textured gray dolomite containing a few geodic cavities lined with dolomitic crystals. Analysis 23 (p. 184)[2]	4	0
IV. Flint layer like II		2
V. Very heavily bedded dolomite like I	5	0

West of Madison, the Lower Magnesian dolomite has been quarried by the city of Madison, E. F. Paunack, and the David Stephens estate. The beds at the city quarry are about 20 feet thick and have about 3 feet of clayey soil covering them. The layers contain a great

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[1] Irving, R. D., Geol. of Wisconsin, vol. 2, p. 543, 1877.

[2] Idem.

deal of flint in the nodular and concretionary form. Clay and sand are other impurities present. The beds at the other quarries are about the same as at the city quarry.

The Wiesenburg and Dahnke quarry is located about 350 feet west of the station at Middleton. The stone has been used for crushed rock on roads. The dolomite is very impure as shown by the section below.

Top of section	Ft.	In.
I. Soil	Several	
II. Sandy dolomite	6	0
III. Cavernous flinty layer	1	0
IV. Sandy dolomite	3	0
V. Fractured, brecciated dolomite	1	0
VI. Flint	1	6
VII. Loose sand		2
VIII. Flint	1	0
IX. Flint and dolomite	1	0
X. Green clay		1
XI. Dolomite with flint lenses	2	0
XII. Fine-grained dolomite with dome-like structure, ripple marks, and sun cracks	2	0
XIII. Dolomite, flint, and sand grains		6

The O'Malley quarry, SE. ¼ of sec. 10 in the town of Westport, seems to have beds which are somewhat purer than the average Lower Magnesian dolomite. The beds are described as follows:

Top of section	Feet
I. Thin bedded to shaly yellow dolomite	6
II. Three heavier layers of same	2½
III. Broken yellow dolomite with much oolitic flint and calcite in geodes	4
IV. Very heavy layers, interstratified with two or three thin cream-colored layers of dense, granular dolomite	10

The Veerhusen quarry in the NE. ¼ of the SW. ¼ of sec. 25, town of Westport, is on top of a narrow ridge of Lower Magnesian dolomite. The following section was reported from there.[1]

Top of section	Feet
I. Rough, brecciated, yellow, fine-grained dolomite, with 3 per cent impurities	8
II. Very heavy layers, some 4 to 5 feet thick, pale yellow color, close textured, granular dolomite. On solution leaves a large amount of gray sand	15
III. Greenish sandy layer; a specimen left 14.17 per cent of very fine gray sand	1
IV. Thinner-bedded dolomite, like II, but fine grained, of greenish tint, and profusely marked with dendrites of manganese oxide	8½

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[1] Irving, R. D., Geol of Wisconsin, vol. 2, p. 602, 1877.

Heiny's quarries in the Lower Magnesian dolomite, NW. ¼ sec. 35, town of Springfield, show the following section.

Top of section	Feet
I. Concretionary and brecciated yellow dolomite	5
II. Heavily-bedded white layers—much flint—formerly burnt for lime	10
III. Soil-covered slope	25
IV. Irregularly thin bedded, porous white and yellow mottled dolomite with geodic cavities and 6+ per cent of insoluble ingredients	15

Galena and Black River dolomite.—This formation is mostly an impure dolomite with 5 or more per cent of clayey impurities. Certain beds northeast of Sun Prairie in the town of Bristol range from calcitic dolomites to dolomitic limestones. All of them are too high in magnesia to serve as high grade limestones and can not be used for Portland cement.

The Kelly quarry is located on a hill top in the SE. ¼, NE. ¼, sec. 4 of the town of Oregon. The dolomite at this place is 12 feet thick and rests on the St. Peter sandstone. The average composition of the beds is shown by analysis 67 (p. 186).

The O'Brien quarry is located in the SE. ¼ of sec. 7 of the town of Fitchburg. About 27 feet of soft, earthy buff Galena and Black River is exposed.

Top of section	Feet
I. Soil and weathered rock	6
II. Decayed thin-bedded dolomite	10
III. Thin-bedded dolomite	5
IV. Massive-bedded, buff, fine-grained, dense dolomite	12

The average composition of the beds is shown by analysis 68 (p. 186).

The Galena and Black River quarries northeast of Sun Prairie show thick, fairly compact buff colored dolomite beds, capped by thin bedded layers of shaly limestone with dolomitic domes near the base. The domes are of a darker color than the limestone and measure about 2½ feet in height and 3 to 5 feet at the base. The large quarries in the N. ½ of sec. 34 in the town of Bristol have about 10 feet of the lower buff dolomite below 8 feet of dolomitic limestone. The upper dolomitic limestone layers are ½ to ¾ inch thick and are separated by very thin, fragile, dark brown shaly layers. The composition of the limestone layers is shown by analysis 70 (p. 186).[1]

The buff colored dolomite, as shown by analysis 69[2], is a calcitic dolomite (p. 186).

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[1] Irving, R. D., Geol. of Wisconsin, vol. 2, p. 601, 1877.

[2] Idem.

Through the courtesy of the late J. E. Thompson, chemist for the Northwestern Iron Company at Mayville, analyses 71–77 (p. 186)[1] of the Galena and Black River dolomite from the town of Bristol are given. They all appear to be from the lower buff dolomite beds. In composition they are impure calcitic dolomite.

Gravels.—Gravels are not uncommon throughout the glaciated part of Dane County and in the stream valleys leading away from the margin of the glacial drift. The chief stone in the gravel is dolomite. It is possible that on some farms selected dolomite gravel could be used more cheaply as a local soil neutralizer than could rock from more distant dolomite ledges, or commercial limestone hauled from the nearest station.

Dodge County

General geology.—The eastern part of Dodge County is an upland underlain by the Niagara dolomite. Along its western margin are steep bluffs which are very prominent from Iron Ridge northward. Along these bluffs, outcrops are common. Directly west of the bluffs is a narrow belt of Richmond shale which has but few outcrops. A broad strip running north and south through the country is underlain by the Galena and Black River dolomite. Most of this area is gently rolling or level and has many excellent farms. The hill tops of the western part of the county are underlain by Lower Magnesian dolomite, most of the hill sides, valleys, and lowlands by the St. Peter sandstone. In the southwestern part of the county, the pre-Cambrian rocks, at this place known as the Waterloo quartzite, come to the surface in a number of isolated patches.

Lower Magnesian dolomite.—Near the center of the southeast quarter of sec. 19 of the town of Elba about 21 feet of Lower Magnesian dolomite are exposed. The beds are mostly cavernous, flinty, fragmental, and in part sandy. North of this locality the formation outcrops here and there, showing beds of about the same character as shown in the town of Elba. The only use for which their composition fits them is agricultural limestone. The beds containing the least flint should be selected for this purpose.

Galena and Black River dolomite.—The formation is entirely dolomitic. The calcitic layers common at the base of the Galena of southwestern Wisconsin are not represented here. The beds as elsewhere in the state are clayey. They are not used for lime. Good agricultural limestone for local use can be obtained from them.

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[1] Analyses 71 and 72 are from the SE. sec. 26, 73 and 74 from the SW. SW. sec. 26, 75 from the SW. NW. sec. 34, 76 from the NE. NE. sec. 34, and 77 from the SE. NW. sec. 34.

Quarries of the Galena and Black River are located at Beaver Dam; northwest of Juneau in the vicinity of Waupun; between Beaver Dam and Fox Lake; between Fox Lake and Waupun; at Richwood; and in the SE. ¼ sec. 20, NW. ¼ sec. 28, and the SW. ¼ sec. 36, T. 9, R. 15 E.

At the Cowen quarry on the creek in the SW. ¼ of NW. ¼ sec. 28, T. 9, R. 15 E., 6 feet of Galena and Black River dolomite are exposed. The beds are dense and fine grained. The composition of an average sample from these beds is shown by analysis 78 (p. 186).[1]

The Herman Tezloff quarry, in the SE. ¼, sec. 20, T. 9, R. 15 E., shows 27 feet of Galena and Black River dolomite. The upper 15 feet consist of a rotten, buff colored dolomite with small cavities lined with calcite and occasional crystals of zinc sulphide. The lower 12 feet are thick bedded and only slightly decayed. The composition of an average sample from the lower 12 feet is shown in analysis 79 (p. 186). The composition of these beds is about the same as those of the Cowen quarry. They are high in carbonate as compared with most of the Galena and Black River and compare favorably with some Niagara dolomite beds.

Analysis 80 (p. 186)[2] indicates the average composition of 15 feet of dolomite in a quarry in the SE. ¼ of sec. 20, T. 9, R. 15 E.

Two analyses of samples from a quarry near Richwood in the SE. NE. sec. 24, T. 9, R. 14 E. are on file. Details are lacking as to the beds which were sampled. See analyses 81 and 82 (p. 186).[3] A section of this quarry beginning at the top follows:

	Feet
Stripping	2–5
Buff dolomite, much weathered	9
Bluish gray massive bedded dolomite	16

This quarry was operated in 1920 by the Mayville White Lime Works.

Niagara dolomite.—Scattered outlying ledges occur in the town of Ashippun. Those in secs. 6 and 7 outcrop on the steep slope of an escarpment 50 feet high. About 26 feet of typical Niagara dolomite are exposed. Their degree of purity is probably similar to that of the beds at Mayville which are described below.

At Iron Ridge about 35 feet of Niagara dolomite overlie a bed of iron ore. At the quarry of the Northwestern Iron Company at this place, the composition of an average sample of the dolomite is shown by analysis 145 (p. 188).[4] This sample is less pure than the average Niagara dolomite, but is probably typical of the basal beds.

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[1] Wyandotte Portland Cement Company.

[2] Chamberlin, T. C., Geol. of Wisconsin, vol. 2, p. 309, 1877.

[3] Thompson, J. E., personal communication.

[4] Idem.

At the quarry of the Mayville White Lime Company in sec. 1, T. 11, R. 16 E., the following beds are exposed:

Top of section	Feet
I. Buff weathered rock. **Analysis** 154 (p. 188)	20
II. Porous white dolomite, used for lime. Analysis 153 (p. 188)	4
III. Very hard, thick-bedded stone, not used for lime because of its hardness. Analysis 152 (p. 188)	4
IV. Cavernous, buff-colored dolomite full of calcite vugs. Said to make a quick-slaking lime. Only burned in winter. Analysis 156 (p. 188)	10

Groups II and III are nearly pure dolomite and should be very useful for any purpose in which a high grade dolomite is either desirable or satisfactory.

A bed of dense, bluish, fine grained dolomite 1 foot thick near the middle of the quarry face was analyzed separately because it looked different from any other bed in the quarry. It turned out to be more impure than the average quarry sample. See analysis 155 (p. 188). No. 151 (p. 188)[1] is another analysis from this location.

The Western Lime and Cement Company's quarry at Nasbro, 2 miles north of Knowles, shows about 25 feet of Niagara dolomite beds. These are used for lime. The upper 15 feet are soft, broken, and weathered. Analysis 158 (p. 188) shows the composition of an average sample from this upper group. Analysis 157 (p. 188) shows the composition of the lower 10 feet of beds. The lower group is hard and fresh. The analyses indicate that this quarry contains good lime rock and agricultural limestone.

Other analyses of Niagara dolomite from Knowles are numbers 146, 147,[2] 148,[3] 149,[4] and 150[5] (p. 188).

The composition of the lowest shaly layers of the Niagara dolomite, about 10 feet thick in the NW. ¼ of NE. ¼, sec. 27 of the town of Williamstown, is indicated by analysis 159 (p. 188).[6]

Lime has been produced from the Niagara dolomite by the following:

Mayville White Lime Company, Mayville
Western Lime and Cement Company, Knowles and Nasbro
Standard Lime and Stone Company, Knowles.

Gravels.—Dodge County has some gravel deposits. Where farmers who need dolomite as a soil neutralizer are located farther than an easy haul by wagon from a dolomite quarry, they may find it less

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[1] Thompson, J. E., personal communication.

[2] U. S. Geol. Survey, Twentieth Ann. Rept., Pt. 6 cont. p. 462.

[3] Thompson, J. E., personal communication.

[4] Buckley, E. R., Building and ornamental stones of Wisconsin: Wisconsin Geol. and Nat. Hist. Survey Bull. 4, p. 332, 1898.

[5] Personal letter from Northwestern Iron Company, Mayville, Wisconsin.

[6] Chamberlin, T. C., Geol. of Wisconsin, vol. 2, p. 338, 1877.

expensive to crush gravel. Gravels in Dodge County usually contain 75 per cent or more dolomite. It would be necessary, of course, to select limestone gravel. In some gravel pits there is a good deal of oversize gravel, from which limestone cobbles could be selected.

Door County

General geology.—The Niagara dolomite underlies all of the county except the southwestern part where there is a narrow fringe of Richmond shale along Green Bay. Plate VI. Outcrops are common throughout most of the county. North of Little Sturgeon Bay limestone bluffs rise from the waters edge, in some places as precipitous cliffs undercut by waves. The slope on the Lake Michigan side is more gentle and marked by very low bluffs. North of Sturgeon Bay the glacial drift is thin and full of dolomite bowlders.

Niagara dolomite.—This formation along Green Bay as far north as Little Sturgeon Bay is characterized by thick bedding, uneven structure, and a rough craggy pitted surface on the weathered edges. North of Little Sturgeon Bay the beds are mostly white, dense, hard, exceedingly fine grained, and somewhat brittle. Their thickness is about 100 feet. Typical outcrops of these beds occur at the western gateway of Sturgeon Bay and along the coast to the northward. On the north shore of Sturgeon Bay, they are quarried by Louis P. Nebel, Leathem D. Smith Stone Company, and by Jno. M. Laurie; on the south side of the bay, west of Sawyer, by the Sturgeon Bay Stone Company and the Green Stone and Quarrying Company.

Lime has been produced by Chas. Copiskey, Baileys Harbor, and by Louis Nebel, Sturgeon Bay.

About 60 feet of rock is quarried in the Leathem D. Smith quarry northwest of Sturgeon Bay in the NE. ¼ sec. 13, T. 28, R. 25 E. The rock has been used for road material, foundations, concrete, rip rap, and other building purposes. The description and composition of the beds follow:

Top of section	Feet
I. Coarse grained, compact, without openings. Analysis 160 (p. 188)	15
II. Very fine grained, brittle, broken into polygonal blocks. Analysis 161 (p. 188)	15
III. Laminated, blue and gray with pink mottling. Analysis 162 (p. 188)	30

The lower 30 feet of the Leathem D. Smith quarry shows the purest dolomite. The high carbonate content, 97.85, recommends it for any use in which a pure dolomitic rock is desirable.

The east coast is underlain by coral-bearing beds of the Niagara dolomite, 150 feet thick. These are above the beds which outcrop on Sturgeon Bay and from there northward along the west coast. The lower portion of the coral beds is usually rough, heavy bedded, coarse, crystalline, granular, and rather soft. Clay layers and bands of flint nodules or fossils replaced by flint are present in some places. The irregular hardness of the rock gives it a craggy pitted appearance on the weathered surface. In color, it is usually blue, white, yellow, in places marked with red, pink, and purple.

The upper portions of the coral beds are generally of a buff color, thin bedded, fine grained, compact hard, but occasionally earthy. Flints in the form of nodules and as replacements of shells are common. The coral beds are not used much for either construction or lime.

Vertical cliffs of the coral beds are exposed at the entrance of Porte des Morts. Nearly their full thickness is exposed at Baileys Harbor. Other exposures are found south of Jacksonport in secs. 5 and 9, near the city of Sturgeon Bay, and in sec. 17 of the town of Forestville.

Fond du Lac County

General geology.—The eastern part of Fond du Lac County is underlain by the Niagara dolomite, west of which is a narrow strip of Richmond shale. The central portion from Fond du Lac to Ripon is underlain by a broad area of the Galena and Black River dolomite. West of Ripon, narrow belts are underlain by the St. Peter sandstone, Lower Magnesian dolomite, and the Cambrian sandstone. See Plate VI for distribution of formations.

A prominent escarpment, rising about 150 to 200 feet above the region to the west, marks the margin of the Niagara dolomite. The central area of the county underlain by the Galena and Black River dolomite is a level to gently rolling area, in part an old lake plain, the floor of a lake of which Lake Winnebago is a remnant. The Lower Magnesian dolomite underlies hill tops in the northwest corner of the county.

A partial list of quarries in Fond du Lac County follows:

Oakfield, Standard Lime & Stone Company
Hamilton, Western Lime & Cement Company
Marblehead, Western Lime & Cement Company, Eden Independent Lime & Limestone Company
Malone, Lime Rock Crusher Company
Waupun, Stoddart, Boyd & Stoddart
Peebles, Chicago & Northwestern Railway
Ripon, Kroll Quarry.

Lower Magnesian dolomite.—Analysis 24 (p. 184)[1] represents the composition of an outcrop of Lower Magnesian dolomite in the NW. ¼ of NE. ¼ of sec. 20, Ripon. It was formerly used as a local source of quick lime. Beds V and VI (below) in the Kroll quarry at Ripon belong to the Lower Magnesian formation, analysis 25 (p. 184).

Like the Lower Magnesian dolomite throughout the eastern and southern part of the state, that of Fond du Lac County is impure and flinty. It has too high a content of insoluble matter to be a first class agricultural limestone or lime rock. For local use as a soil neutralizer it is said to have given very beneficial results.

Galena and Black River dolomite.—Nearly all of this formation is covered by soil, glacial drift, and lake clays. Small exposures occur along Silver Creek in and near the city of Ripon, on a road 2 miles southeast of Ripon, and about ½ mile to the west of Waupun. It is quarried about 2½ miles west of Brandon, at the Kroll quarry west of Ripon, and a short distance northeast of Waupun.

This formation is in general a clayey dolomite. Locally its fossils are largely replaced by quartz. The carbonate is practically all dolomite and the rock will serve any local purpose for which an impure dolomitic rock can be used.

The Kroll quarry is located on a high hill west of Ripon in the E. ½ of the NW. ¼, sec. 20. The section in descending order follows:

Top of section	Feet
I. Glacial till about	2
II. Thin bedded—buff dolomite. Analysis 83 (p. 186)	6
III. Thick-bedded buff and blue dolomite. Analysis 84 (p. 186)	8
IV. Alternating beds of flint, clay, and dolomite. No analysis	10
V. Fine-grained dolomite. Analysis 25 (p. 184)	2
VI. Alternating bands of clay, sandstone, and dolomite	3

Nos. II to IV inclusive are Black River beds; V and VI belong to the Lower Magnesian formation.

Thwaites studied this quarry section at a later date and reports the following beds:[2]

Top of section	Feet.
I. Glacial till	2–3
II. Gray, thin-bedded dolomite	5.0
III. Bluish thin-bedded dolomite	4.5
IV. Grayish-blue dolomite	.8
V. Glacial sand and gravel, maximum	.2
VI. Hard gray rather thin-bedded dolomite	5.3
VII. Blue, heavier-bedded dolomite with fossils. Sandy base	6.5

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[1] Chamberlin, T. C., Geol. of Wisconsin, vol. 2, p. 284, 1877.

[2] Thwaites, F. T., A glacial gravel seam in limestone at Ripon, Wisconsin: Jour. Geology, vol. 29, pp. 57–65, 1921.

VIII. Sandy buff dolomite, forming a parting	.5
IX. Gray dolomite with layers of gray shale and sandstone. Irregular beds, the bedding in general dipping at low angles to the east	40.0
Total about	63.0

No. IX in the preceding section belongs to the Lower Magnesian dolomite. The dolomites overlying No. IX are a part of the Black River formation.

Rock from this quarry has been used as crushed rock and also as an agricultural limestone.

Niagara dolomite.—Fond du Lac County has some of the largest Niagara dolomite quarries in the state. Most of the quarries are located along the escarpment marking the western margin of the formation.

The beds exposed at Oakfield and Peebles are characterized by thick bedding, uneven, coarse grain, and a rough appearance on the weathered surface. The beds at the Chicago & Northwestern Railway Company's quarry at Peebles are as follows:

Top of section	Feet
I. Soil	Thin
II. Cavernous, flinty dolomite	15
III. Compact dolomite	3
IV. Hard, dense, flinty dolomite	15

The rock in this quarry has a higher content of flinty impurities than most ledges of the Niagara dolomite in this part of the state.

The Western Lime and Cement Company's quarry at Hamilton has the following beds:

Top of section	Feet
I. Soil	Thin
II. Soft, medium-grained rock with irregular billowy bedding. Analysis 165 (p. 188)	25
III. Thin-bedded, fine grained, bluish-colored dolomite with shaly partings. Analysis 164 (p. 188). Also see analysis 163 (p. 188)[1]	20

The beds in the Western Lime and Cement Company's quarry at Marblehead are as follows:

Top of section	Feet
I. Analysis 169 (p. 188)	10
II. Analysis 168 (p. 188)	10
III. Analysis 167 (p. 188)	15
IV. Analysis 166 (p. 188)	25

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[1] Chamberlin, T. C., Geol. of Wisconsin, vol. 2, p. 345, 1877.

For analyses of Niagara dolomite beds at Marblehead, Oakfield, and Taycheedah by W. W. Daniels, see analyses 170,[1] 171,[2] and 172[3] (p. 188) respectively. Details regarding the beds which these analyses represent are lacking. They all show the high carbonate content characteristic of most of the Niagara dolomite quarries in this county.

The Niagara dolomite of Fond du Lac County has been used extensively for quick lime and crushed rock. The beds at Marblehead, Oakfield, and Hamilton have produced a very good dolomitic lime.

Grant County

General geology.—Grant County has a belt of narrow, steep ridges and branching valleys along the Wisconsin River, extending southward to the Military Ridge. This belt is related to the exposure of the soft easily eroded Cambrian sandstone in the river valley and adjacent tributary valleys, and to the even more readily eroded St. Peter sandstone which outcrops some distance south of the river. At the mouth of the river where the Lower Magnesian dolomite covers the Cambrian sandstone, valleys are fewer in number and relatively short.

Along the Wisconsin River valley and its tributaries, the first or lowest rock terrace is generally underlain by the Trempealeau dolomite. The next highest is formed by the Lower Magnesian dolomite. A third terrace is formed by the upland of which Military Ridge is a part. This upland is underlain by the Galena and Black River dolomite.

The Mississippi River flows in a deep trench bordered on the Wisconsin side by an almost unbroken line of bluffs capped by the Galena and Black River dolomite in the northern part of Grant County and farther south entirely composed of this formation. Wind blown deposits of yellowish brown silt called loess sometimes 30 feet or more in thickness and in places standing in vertical cliffs facing the river overlie the top of the Galena and Black River formation in most places along the river.

South of the Military Ridge Grant County has broad uplands with rather gentle undulations due to erosion by the Fever, Platte, and Grant rivers, each with numerous tributaries. The streams have cut through the Galena and Black River formation into the St. Peter sandstone and even into the Lower Magnesian dolomite for short stretches. Farther south these streams have fewer tributary valleys and run in narrow deep valleys with but little bottom land.

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[1] Buckley, E. R., Building and ornamental stones of Wisconsin: Wisconsin Geol. and Nat. Hist. Survey Bull. 4, p. 335, 1898.

[2] Daniels, W. W., personal.

[3] Chamberlin, T. C., Geol. of Wisconsin, vol. 2, p. 338, 1877.

The uplands have but few outcrops of dolomite. Along all the stream valleys they are very abundant. The county has many mine dumps from which dolomite can be obtained. In the southwestern part of the county the uplands are surmounted in one place by a mesa-like hill, namely Sinsinawa Mound. It is capped by Niagara dolomite. The lower gentler slopes are underlain by the Maquoketa shale.

Grant County is in the Driftless Area and has no dolomite gravels. It is probable that bench gravels could be found along the Mississippi and its branches in Grant County. Such gravels would consist largely of hard, non-carbonate bearing rocks. Gravels in the stream beds of Grant County are largely composed of flint from the Lower Magnesian and Galena and Black River dolomites.

Lower Magnesian dolomite.—The thickness of the Lower Magnesian dolomite in Grant County varies between 100 and 250 feet. Flint is common in nearly all beds and usually occurs in nodules parallel to the bedding.

In the valley of Grant River in the NW. ¼ of sec. 22, T. 4 N., R. 4 W., the formation is somewhat shaly. A 3 foot layer of this shaly type of dolomite had the composition given in analysis 26 (p. 184).[1]

The Lower Magnesian dolomite is well exposed on the east side of the valley at the mouth of Green River. The description of the beds follows:

Top of section	Feet
I. Fine grained, sandy; stratification quite regular. No flints. See analysis 27 (p. 184)	12
II. Same as I. Analysis 28 (p. 184)	12
III. Same as above, but with flint nodules. Analysis 29 (p. 184)	16
IV. Mixture of chert and dolomite	3
V. Earth-covered slope	116
VI. Dolomite with chert nodules near top. Analysis 30 (p. 184)	14
VII. Sandy dolomite and oolitic dolomite	16

The upper groups of beds are unusually pure dolomite and compare favorably with the Niagara dolomite in purity. Before any commercial utilization of these based on their purity is undertaken, thorough exploration should be made to determine the extent of beds having this composition. As a rule, the Lower Magnesian dolomite varies greatly in composition.

On the Mississippi River north of Bagley, Wisconsin, the section is as follows:[2]

Top of section	Ft.	In.
I. Sandstone (St. Peter)	30	0
II. Debris concealing contact	30	0

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[1] Strong, Moses, Geol. of Wisconsin, vol. 2, p. 673, 1877.

[2] Grant, U. S., and Burchard, E. F., Lancaster–Mineral Point: U. S. Geol. Survey Folio 145, p. 3, 1907.

III. Lower Magnesian dolomite		
Dolomite—hard porous	1	0
Sandstone, white, very soft	2	0
Dolomite, hard, fine grained, thin bedded, grading into sandy beds	30	0
Siliceous dolomite, hard and quartzitic		4
Sandstone, thin bedded, yellow	8	0
Shale, blue, with 1-inch band of white, siliceous oolite	1	2
Dolomite, very massive, hard, with large concretions	20	0
Shale, blue, with some sand	1	0
Dolomite, white, fine grained, thin bedded	2	0
Chert in irregular, wavy beds	2	0
Shale, sandy	1	0
Dolomite, irregularly bedded, with small concretions. At base is a thin layer of calcareous sandstone	20	0
Shale, blue, with sandstone interbedded, and at bottom a fine-grained, white, conglomeratic dolomite	2	0
Sandstone, pure white. coarse grained, friable	6	0
Siliceous dolomite, very irregularly bedded, weathering rough, and containing a large proportion of chert	20	0

The preceding section has a somewhat high percentage of sandstone. This sand is in lenses rather than in continuous beds. Such sandstone beds were also found along the north and south road about 2 miles southwest of Fennimore. The upper 50 to 60 feet in this vicinity usually contains many sandstone lenses.

Galena and Black River limestone and dolomite.—The lower part, the Black River limestone, is about 50 feet thick. Its upper part is usually a thin bedded impure limestone of which the topmost 2 to 4 feet, the glass rock, is usually a nearly pure limestone, showing no dolomite crystals, but containing about 4 per cent of $MgCO_3$. The Galena is about 250 feet thick. Its lower 20 feet are usually a thin bedded shaly dolomitic limestone with 10 or more per cent magnesia. The balance of the formation is an impure, porous, rough weathering, clayey dolomite with little flint excepting in a few feet of beds usually about 90 feet above the base of the formation.

The following section of the Galena and Black River is derived from exposures along the Boscobel Fennimore road at the place where it descends into the valley of Crooked Creek.[1] It is uncertain whether the term limestone means limestone or dolomite in this section.

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[1] Grant U. S., and Burchard, E. F., Lancaster-Mineral Point: U. S. Geol. Survey Folio 145, p. 5, 1907.

Top of section	Feet
Galena	
9. Limestone, cherty	
8. Limestone, fine grained	15
7. Limestone, somewhat crystalline	20
Black River	
6. Shale and limestone bands	2
5. Limestone—magnesian, in medium beds	12
4. Limestone, thin bedded	25
3. Limestone (magnesian)	10
2. Shale, thin, sandy	1+
1. St. Peter sandstone massive.	

The dolomitic limestones from the transition between the Galena and Black River outcrop on Platte River in the NE. ¼ of sec. 8, T. 3 N., R. 1 W. The beds are as follows:

Top of section	Feet
I. Galena—thin-bedded dolomitic limestone with clay and shale partings. Analysis 87 (p. 186)	12
II. Black River—the main glass rock. Analysis 86 (p. 186)	3
III. Thin-bedded dolomite below glass rock. Analysis 85 (p. 186)	3

The beds at the quarry of the Lancaster Park Association in the NW. ¼ NW. ¼ sec. 3, T. 4, R. 3 W., represent the same transition beds as those of the Platteville quarry. The beds are described as follows:

Top of section		Ft.	In.
Group I. Analysis 90 (p. 186)			
	1. Blue and buff dolomitic limestone with clay seams	8	0
	2. Clay and dolomitic limestone, alternating seams	5	0
Group II Analysis 89 (p. 186)			
	3. Clay		3
	4. Fine-grained limestone		2
	5. Clay		1
	6. Fine-grained limestone		4
	7. Green clay		2
	8. Limestone and brown shale		6
	9. Brown shale		5
	10. Limestone—analysis 91 (p. 186)		8
	11. Brown shale, oil rock, and limestone		6
Group III. Analysis 88 (p. 186)			
	12. Thick-bedded blue dolomitic limestone	6	0

At Cassville the Galena and Black River beds are exposed at the E. Rockefeller quarry. The section includes the transition beds between the Black River and Galena. A description of the beds follows:

Top of section	Ft.	In.
I. Flinty dolomite with calcite-lined openings	30	0
II. Open-weathered buff dolomite	6	0
III. Buff dolomite bed, compact. Openings along bedding	2	6

IV.	Clay bed		3
V.	Buff dolomite with calcite-lined cavities	5	0
	Blue, coarsely crystalline dolomite	2	0
	Analysis 92 (p. 186)		
VI.	Clayey blue dolomite	1	0
VII.	Clay bed		4
VIII.	Oil rock seam		2
IX.	Thin, white, wavy, dolomitic limestone beds interlayered with thin clay partings	16	0
X.	No outcrop	6	0
XI.	Blue medium-grained dolomite outcropping in creek bed	2	0

The transition between the Black River and Galena probably comes at VII and VIII of the preceding group of beds.

Other quarries in the vicinity of Cassville are owned by Bernhart Bros., Henry Johnson, and J. Rush Okey.

The Schumacher quarry is located east of Potosi station on the north side of the Potosi road. The beds belong to the upper part of the Black River. Descriptions follow:

Top of section		Feet
I.	Alternate layers of coarse and fine-grained dolomitic limestone	7
II.	Thin-bedded dolomitic limestone, analysis 94 (p. 186)	20
III.	Blue and buff thick-bedded dolomitic limestone, analysis 93 (p. 186)	20

Use of mine tailings for correcting soil acidity.—At the lead and zinc mines in the southwestern part of the state large quantities of dolomite waste are produced which have been suggested as a source of lime for correcting soil acidity. W. W. Weir of the Wisconsin College of Agriculture studied this problem several years ago, making greenhouse and cooperative tests in the field. All of these experiments indicate that there is no danger from the possible poisonous effect of the lead or zinc, or the development of sulphuric acid through the oxidation of the sulphide. Quantities as large as four or five tons per acre have been used without injurious results and in fact with marked benefit to the clover and alfalfa.

Mr. Weir, however, was not able to make tests of material from all of the tailing piles, so there is still a possibility that there might be a limited amount of this material that would be injurious to soils. It would be wise for farmers to try out the material on a small plot before covering a large acreage. There is no better way to determine the value of this material than by field trials.

There are, however, some disadvantages associated with the use of this material. It is usually too wet to distribute well and is ordinarily so coarse that an unusually heavy application would be necessary, making its shipment to any distance very expensive. Moreover, much of the limestone is of a low grade, being mixed with ore and shale, which reduces the carbonate content. But this material can be used to advantage in the immediate neighborhood of the mine where farmers can haul it directly to their fields and apply heavier applications than would be necessary if the material were more finely ground. The piles of better grade, if dried and ground, would furnish excellent material for shipment.

Green County

General geology.—The eastern part of Green County lies within the area of old glacial drift. The western part is in the Driftless Area. Here the only loose materials covering the rocks are residual soils, wind deposits, slope wash, and stream deposits. The margin of the glaciated area is shown by a red dashed line on Plate VI of this report.

Galena and Black River dolomite.—This formation underlies all the uplands and ridges of Green County. Many outcrops are found along the tops of the bluffs which flank the valleys. Wherever examined the Galena and Black River formation of Green County is an impure clayey dolomite. Limestone beds or dolomitic limestones are probably lacking. No analyses are available, but it seems likely that the dolomite is all too impure to be used for purposes for which a high grade dolomite is desirable.

Numerous quarries in the Galena and Black River formation are located near Brodhead. Near Monroe, the rock is much weathered and outcrops are scarce. Quarries are located near Martintown, Attica, and Brooklyn.

Green Lake County

General geology.—Nearly all of the western portion of this county is underlain by Cambrian sandstone. The eastern portion is underlain by strips of Lower Magnesian dolomite, St. Peter sandstone, and Galena and Black River dolomite trending northeast, and by outlying patches of Lower Magnesian dolomite. In the vicinity of Berlin, Utley, Marquette, and in the northwestern part of the town of Seneca, knobs of old volcanic rocks project through the sedimentary rocks. See Plate VI for distribution of formations.

Lower Magnesian dolomite.—Most of the outcrops of this formation occur along the escarpment which marks the western boundary of the formation. It is known to outcrop in the following places:

The southeastern part of the town of Kingston
The southwestern and eastern parts of the town of Manchester
The western part of the town of Mackford

The western and northern parts of the town of Green Lake
North of Green Lake in the town of Princeton
The town of Brooklyn
The southeastern half of the town of Berlin.

Quarries of the Lower Magnesian dolomite are located at Markesan, about ½ mile north of the village of Green Lake, southeast of Green Lake, and about 2 miles southeast of the village of Princeton.

The composition of the Lower Magnesian dolomite varies greatly. In most places it is flinty. In many places it consists of alternate layers of sandy and clayey dolomite, or of horizontal gradation of one into the other. Analyses are not available, but it is certain that it does not contain lime rock of good quality in large enough amounts to open up a commercial quarry. By selecting the better beds a good supply of agricultural limestone for local purposes can be obtained.

Galena and Black River dolomite.—Outcrops of this formation occur in the towns of Mackford and Green Lake and in the southeastern part of the town of Brooklyn. The beds are thin and the dolomite is gray to buff in color. No analyses are available.

Iowa County

General geology.—All of this county is in the Driftless Area. The residual soil and wind deposits which cover the hard rocks in most places are generally less than 15 feet in thickness except in the Wisconsin River valley where the stream deposits reach a thickness of 300 feet. The broad upland south of Military Ridge, which is followed by the Chicago & Northwestern Railway, is underlain by the Galena and Black River dolomite. This upland is deeply dissected by narrow valleys along whose margins outcrops are common. The steep sided cap of Blue Mounds is composed of flint which has replaced the Niagara dolomite. The gentle slope below this is underlain by Maquoketa shale.

The Wisconsin River valley and its tributaries for some distance south are underlain by the Cambrian sandstone. The first hard rock escarpment is generally formed by the Trempealeau dolomite, a group of beds about 30 feet thick in the upper part of the Cambrian sandstone. The next higher escarpment is formed by the Lower Magnesian dolomite, which in turn disappears under a narrow belt of St. Peter sandstone farther south. The plane of contact between the St. Peter sandstone and the Lower Magnesian dolomite has undulations sometimes of more than 200 feet and in places the dolomite appears on a hill top and the St. Peter sandstone in a nearby valley. The beds of the two dip at a low angle to the south. The St. Peter sandstone is also exposed in some of the deep valleys south of the Military Ridge.

Trempealeau dolomite.—Sliters quarry south of Spring Green is in the NW. ¼ sec. 30, T. 8, R. 4 E. The Trempealeau dolomite exposed here is an earthy buff colored rock about 14 feet thick, which has been used locally as a building stone. Analysis 7 (p. 183) shows the composition of the dolomite at this place.

Lower Magnesian dolomite.—No analyses of Lower Magnesian dolomite from this county are on file. Here as elsewhere in the southern part of the state it is an impure sandy to clayey dolomite, containing a great deal of flint. Outcrops are abundant along the high bluff facing the Wisconsin River and for some distance south along the valleys tributary to the Wisconsin River.

Extensive outcrops of the Lower Magnesian dolomite occur along the streams in secs. 2, 3, and 10, T. 4 N., R. 2 E. near Mineral Point. About 30 feet can be seen in one cliff. The upper 10 feet consist of rough weathering, hard, more or less broken beds; the lower part is more regular, less rough weathering, and in heavy beds; some flints occur in both parts of the cliff. Near the northeast corner of sec. 24, T. 5 N., R. 2 E., on the east bank of the creek and 2½ miles north of Mineral Point is the following section of the upper part of the Lower Magnesian.[1] It is notably sandy.

Section of the Lower Magnesian dolomite north of Mineral Point:

Top of section		Ft.	In.
I.	Sandstone, crumbling, not clearly in place; regarded as base of St. Peter sandstone	5	0
II.	Fine-grained dolomite		6
III.	Sandstone	4	0
IV.	Fine-grained dolomite in undulating beds 1 to 3 inches thick	1	8
V.	Sandstone		1
VI.	Fine-grained dolomite		1
VII.	Sandstone, commonly pure, but in places with blue clay cement	2	0
VIII.	Soft calcareous shale or shaly dolomite		2
IX.	Sandstone		3
X.	Soft calcareous shale or shaly dolomite		6
XI.	Sandstone	2	0
XII.	Coarse dolomite		6

Along the road which runs through sec. 14 and into sec. 10, T. 6 N., R. 2 E., the following section occurs:[2]

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[1] Grant, U. S., Report on lead and zinc deposits of Wisconsin: Wisconsin Geol. and Nat. Hist. Survey Bull. 14, p. 27, 1906.

[2] Idem, p. 28.

Top of section	Feet
I. Sandstone—St. Peter	70
II. Sandstone and dolomite apparently interbedded; at top is siliceous oolite; regarded as Shakopee (upper part of Lower Magnesian dolomite)	40
III. Sandstone	60
IV. Dolomite with some greenish shale and a few thin seams of black shale	104

Galena and Black River dolomite.—The total thickness of the Galena and Black River dolomite is approximately 300 feet, of which in the neighborhood of 50 feet belong to the Black River, the lower beds of the formation. In places the Black River seems to be entirely dolomite, or nearly all dolomite. The upper 10 or 12 feet are quite generally either a dolomitic limestone or a nearly pure limstone with some shaly admixture. The so-called "glass rock" beds, from 2 to 4 feet in thickness, commonly a limestone with little or no dolomite, occur in the uppermost layers of the Black River. The typical glass rock is to the eye grainless, of a hornlike consistency, very brittle, of a light gray brown color on a fresh surface, and has but few fossils. The basal beds of the Galena, including approximately the lower 15 to 20 feet, are about 2 or 3 inches thick, of a wavy form, and separated by thin partings of clay and brown oily shale. They are very fossiliferous. The fossils are well preserved, and most of them are either calcite casts or are flint replacements of the original shells. In composition these beds are a dolomitic limestone. The dolomite content is variable and is clearly a replacement of the original calcite. Above these basal beds of the Galena is a clayey dolomite. Between the Black River and Galena there is in many places an oily brown shale several feet thick, known as "oil rock."

Flint, excepting as a replacement of fossils, is not visibly important in the Galena and Black River. Scattered flint nodules are quite common about 90 feet above the base of the Galena and have also been seen occasionally at other levels.

The purer beds of dolomite are a potential source of agricultural limestone, as are the tailings piles. See page 54.

The city quarry of Mineral Point exposes about 46 feet of beds, as follows:

Top of section	Feet
Soil	about 5
I. Rotten, buff dolomite	5
II. Thick-bedded buff and blue beds	12
III. Blue, thin-bedded, hard, brittle, compact beds high in calcite	14
IV. Buff and blue thick-bedded dolomite	15

Analysis 95 (p. 186)[1] is representative of the glass rock beds in sec. 36, T. 5, R. 2 E., which are similar to Group III above. It is doubtful

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[1] Strong, Moses, Geol. of Wisconsin, vol. 2, pp. 561, 681, 1877.

whether these beds would uniformly show this low content (3.98 per cent) of magnesium carbonate.

At the W. B. Huxtable quarry in the NW. ¼, NW. ¼ of sec. 5, T. 4, R. 3 E. there is a 50 to 60 foot face of dolomite similar to that at the city quarry.

Jefferson County

General geology.—The eastern part of this county is all underlain by the Galena and Black River dolomite. The western edge of this formation forms a fairly distinct escarpment east of the Rock River valley. The lowlands along the Rock River and its tributaries extending north and south through the central part of the county are underlain by the St. Peter sandstone, which is nearly all covered by glacial drift. Some of the isolated uplands along this central belt are capped by the Galena and Black River dolomite. In the western part of the county the underlying rocks are the St. Peter sandstone, Lower Magnesian dolomite, and the Cambrian sandstone.

Lower Magnesian dolomite.—Along the stream below the lower bridge in the village of Waterloo are weathered outcrops of the Lower Magnesian dolomite. It consists of a coarse, cherty, buff, sandy dolomite in medium beds of rough, uneven texture, owing to irregular cavities and granular porous spots and to the presence of flint nodules. The beds belong to the upper part of the formation.

Galena and Black River dolomite.—Most of the outcrops of this dolomite are along the terraces which border the Rock River. Many small quarries in this formation dot the low bluff of the towns of Sumner and Oakland. It has been quarried about 2 miles southeast of Fort Atkinson, in the city of Jefferson, along the Rock River in the town of Aztalan, in the southeastern part of the town of Waterloo, and in the vicinity of Lake Mills. Most of these quarries are small and only a few are being worked from time to time.

At the John Luneck quarry west of the Crawfish River in the NE. ¼ sec. 20, T. 7, R. 14 E. about 11 feet of dolomite are exposed. The glacial drift is only a few feet thick. The lower 5 feet of beds are of a bluish color and rest on the St. Peter sandstone. Their composition is indicated by analysis 97 (p. 186). These beds are separated from those overlying them by a thin seam of oily shale. The upper 6 feet of beds are fine-grained, fossiliferous, brittle layers. The composition of an average sample is shown by analysis 98 (p. 186).

On a hill about 1 mile northeast of Lake Mills, on the road to Milford, there is a small outcrop of much-weathered dolomite.

In the SE. ¼ sec. 35, T. 8, R. 13 E. there is an extensive quarry in the Galena and Black River dolomite on the farm of Wilbur Stiles. The quarry face is about 1,000 feet long and 13 feet high. The glacial drift on top is only a few feet thick. The lower 4 feet of beds consists of dense, fine-grained dolomite above which there is a bed of shaly dolomite with oily seams. Analysis 99 (p. 186) indicates the composition of the lower beds. The upper 8 feet of the quarry consists of thin-bedded, brittle, fine-grained, compact dolomite. The composition is shown by analysis 100 (p. 186).

The Sam Fease quarry is located in the NE. SE. sec. 10, T. 5 N., R. 14 E. The quarry face is about 200 feet long and 20 feet high. The drift cover is about 4 feet in thickness. The lower 10 feet of the quarry face consists of 10 feet of porous, coarsely crystalline, stratified dolomite. The upper 10 feet is composed of the same material with flint nodules and lenses. See analysis 96 (p. 186).

Gravels.—Jefferson County has extensive gravel deposits. Their chief constituent is dolomite. In some cases it may be good economy to grind selected dolomite gravel for soil neutralizer. This may be cheaper than to haul ground dolomite from distant ledges, or to haul commercial agricultural limestone from the nearest station.

Kenosha County

See page 78 for discussion of Racine and Kenosha counties.

Kewaunee County

General geology.—The Niagara dolomite underlies all of this county except a narrow fringe along Green Bay, which is underlain by Richmond shale. See Plate VI. Outcrops are not plentiful except on Green Bay and along stream valleys. In the kettle moraine area through the central part of the county, the chances of finding outcrops are poor. Here the glacial drift is thick and the surface is pitted with kettle-like depressions.

Niagara dolomite.—Coral-bearing beds (see p. 10 for general description) are exposed on Scarboro Creek in the town of Casco, in sec. 28 of the town of Pierce, in sec. 14 at the mill on the Kewaunee River. In the southern part of the county the coral beds are overlain by the Racine beds, which have been used for lime, road making, and other purposes. The name, Racine beds, is applied to them because of their characteristic development near Racine. Their chief outcrop is in sec. 14 of the town of Kewaunee. Here they have been quarried for quick lime, road material, and other purposes.

The Western Lime and Cement Company's quarry, in the SW. ¼ sec. 14, T. 23, R. 24 E., shows about 10 feet of coarse, crystalline, marble-like dolomite, having the composition shown in analysis 173 (p. 188). The composition indicates that this is a good rock for lime, agricultural limestone, or other purposes for which a rock of high dolomite content can be used.

La Crosse County

General geology.—The northern part of this county is underlain by the Cambrian sandstone on which there are outliers of Lower Magnesian dolomite. In the southern part the high ridges with steep or precipitous sides are capped by Lower Magnesian dolomite. See Plate VI. In places these ridges widen out into table lands covering many square miles of farm lands. The hills and ridges of Cambrian sandstone are generally low and gently rounded. Escarpments are usually formed by the Lower Magnesian dolomite or by the Trempealeau dolomite beds in the upper portion of the Cambrian sandstone. The Trempealeau beds are sandy, with about 30 per cent of impurities, but in the sandstone region they may serve as a valuable source of soil neutralizer. The valleys and low-lying areas are all covered with slope wash. The sands and gravels which fill the valley of the Mississippi River are of glacial origin.

Lower Magnesian dolomite.—The largest exposures of the Lower Magnesian dolomite are along the tops of the bluffs east and south of La Crosse. On Grandfather Bluff east of La Crosse about 150 feet of Lower Magnesian dolomite overlies the Cambrian sandstone. The lower 100 feet of the dolomite has been quarried by the La Crosse Stone Company.

The beds from the top down are as follows:

		Feet
I.	Soil and unexposed rock	
II.	A weathered, porous, soft, flint-bearing dolomite. Has been used for crushed rock	30
III.	A very compact, dense, white dolomite quarried for building stone. Analysis 35 (p. 184)	20
IV.	Bed with green spots 1 inch in diameter. Analysis 34 (p. 184)	2
V.	Dolomite, flint nodules arranged parallel to the bedding near top of bed. Analysis 33 (p. 184)	10
VI.	Light-colored, dense dolomite with wavy structure parallel to bedding. Analysis 32 (p. 184)	2
VII.	Dense dolomite	4
	Soil-covered slope	10
	Dolomite. Analysis 31 (p. 184)	10
VIII.	Soil-covered slope	12
	Dolomite	10
	Cambrian sandstone	20

In the vicinity of La Crosse quarries have been operated by Wm. Hass, La Crosse Stone Company, Geo. Holtzhammer, Peter and John Dagendesh, N. Kaiser, H. Stransch, Ole Wold, and L. Kriebach.

At Onalaska, north of La Crosse, dolomite quarries have been opened, but most of them have been idle in recent years. Owners of quarries in Onalaska are Wm. Kenyon and J. W. Ranney. Dolomite quarries have been operated at Holmen, West Salem, Midway, and Mindoro. Lime is reported to have been burned in the SE. ¼ of sec 26 of the town of Greenfield.

Lafayette County

General geology.—All of this county is in the Driftless Area. The residual soil and wind deposits which cover the hard rocks in most places are generally less than 15 feet in thickness. A very large part of the county is underlain by Galena and Black River dolomite (Pl. VI). In the southern part this formation is covered in places by the Maquoketa shale. This shale also appears on several hills northwest of Belmont. West Platte Mound is capped by Niagara dolomite, about 100 feet of which is exposed in nearly vertical cliffs. Near the Illinois boundary in the town of White Oak Springs is a small mound capped with the Niagara. The St. Peter sandstone more commonly constitutes the floor of the valleys, but also forms a low cliff along the sides of the valley.

Galena and Black River dolomite and limestone.—J. D. Whitney's report on the lead region of Wisconsin, published in 1862, contains a description of the upper beds of the Black River dolomite, the so-called blue beds at Quimley's mill on the Shullsburg branch of the Fever River near Benton. Whitney's[1] description follows:

	Feet
A. Very fossiliferous, thin bedded and sometimes rather shaly and argillaceous layers of dolomite; color bluish gray, but bleaching to a dirty white on exposure. Thickness not entirely exposed, but about	12
B. Gray and light yellowish gray, somewhat magnesian layers, with a finely crystalline texture; in rather irregular layers, about 2 inches thick; not valuable as a building stone, but preferred for burning lime. (See analysis 108, p. 187)	5
C. (a) Pure limestone, very compact, brittle, breaking with a conchoidal fracture; color dark gray; very uniform both in texture and color; rather heavy bedded, but not so much so as the division next below (C. b); layers from 6 to 8 inches thick, but not very regular; fossils few in number, comparatively, and confined to the partings between the beds. (See analysis 107, p. 187)	5
Between C. (a) and C. (b) is a thin layer of shale crowded with fragments of fossils, trilobites, brachiopods, Bryozoa, etc.	
C. (b) Very heavy bedded and regularly stratified layers of rock, of the same color and texture as the division next above (C. a); layers 18 to 24 inches thick; numerous specimens of Strophomena Alternata between the layers; the lower portion graduates by a succession of shaly beds, 6 or 8 inches in thickness, into the buff limestone "*(dolomite)*" below	5

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[1] Report on the geological survey of the State of Wisconsin 1862 vol. 1, p. 163.

D.	Buff "limestone," a blue and buff dolomite, somewhat argillaceous, in layers 12 to 13 inches in thickness, with numerous fucoidal markings, otherwise unfossiliferous; extensively quarried as a building stone	8
	Buff and blue dolomite, more shaly and less thickly bedded than the division above, hence of much less value as a quarry stone, gradually sloping down to the branch and not well exposed	9

Analysis 107 represents a high grade limestone which might be of interest to Portland cement manufacturers and other users of high grade limestones. The fact that the bed is only 5 feet thick and under cover of dolomitic limestone would probably make quarrying too expensive to make its use as a high grade limestone a paying proposition.

The Galena and Black River formation at Darlington is an impure dolomite, which has been used for lime. The J. H. Wall quarry at Darlington exposes the following section:

Top of section		Feet
	Soil about	2
I.	Porous, cavernous, fine grained rotten dolomite	15
II.	Medium grained, buff fossiliferous dolomite. Analysis 101 (p. 186)	2
III.	Buff, coarser grained dolomite. Analysis 102, (p. 186)	4
IIIa.	Same as III. Analysis 103 (p. 186)	2
IV.	Alternating layers of dolomite and brown oily shale. Analysis 104 (p. 187)	6
V.	Brittle dense, fine grained, thin bedded dolomite. Analysis 105 (p. 187)	15
VI.	Buff and blue, fine-grained, compact, but slightly earthy dolomite. Analysis 106 (p. 187)	50

The purer beds of dolomite throughout the county as well as the tailings piles (p. 54) should be considered as a source of agricultural limestone.

Manitowoc County

General geology.—All of this county is underlain by the Niagara dolomite. Most of the surface of the eastern part of Manitowoc County is a level monotonous plain. Here the Niagara dolomite is mostly buried under lake clays. Hummocky ridges of coarse glacial debris cover most of the Niagara dolomite beds of the towns of Schleswig, Eaton, Rockland, and Maple Grove.

Niagara dolomite.—Large quarries are operated by the Western Lime and Cement Company at Grimms and Quarry; the Allwood Lime Company, north of Manitowoc, in the NW. ¼ NW. ¼ sec. 36, T. 20, R. 23 E.; the Rockwell Lime Company in the NE. ¼ NE. ¼ sec. 35, T. 20, R. 23 E.; the Standard Lime & Stone Company at Quarry; and the Valders Lime and Stone Company near the center of sec. 32, T. 19, R. 22 E.

The lower 20 feet of the Western Lime and Cement Company's quarry at Grimms is full of cavities lined with calcite. The beds are massive, 12 or more feet thick, and contain many corals. Lime from these beds is said to slake more rapidly than that from the upper 6 feet of the quarry. The composition of the upper 6 feet is given in analysis 174 (p. 189), that of the lower 20 feet in analysis 175 (p. 189).

At Quarry the Western Lime and Cement Company has used the upper 6 feet of broken beds for quick lime only and the lower 12 to 15 feet for crushed rock. The composition of the dolomite in the Standard Lime & Stone Company's quarry at Quarry is given in analysis 176 (p. 189).

Numerous outcrops of Niagara dolomite occur at Cooperstown, about 15 miles northwest of Manitowoc. The dolomite has been used for local building purposes and for quick lime. Analysis 177 (p. 189) is from the Maribel Springs Company property at Cooperstown.

At Cato Falls on the Manitowoc River outcrops of thin, wavy bedded, uniform Niagara dolomite appear. Two miles down the river from this locality similar, thin broken ledges form a wall along the bank of the stream 15 feet high. A short distance farther down stream, there are several outcrops, one of a flinty dolomite, the other consisting of 20 to 25 feet of fragmental dolomite overlain by 12 feet of flinty rock, the hardness of the latter giving rise to rapids. South of the Manitowoc River outcrops are scarce, the formation being covered in most places by glacial drift.

Marinette and Oconto Counties

General geology.—The northwestern part of Marinette and Oconto counties is underlain by granite, quartzite, and trap rocks belonging to the pre-Cambrian. Southeast of this area of hard rocks are four roughly parallel strips of Paleozoic rocks, trending northeast. Beginning with the one farthest northwest, they are the Cambrian sandstone, Lower Magnesian dolomite, St. Peter sandstone, and Galena and Black River dolomite respectively. For distribution of these formations see Plate VI. The soil and glacial drift are deep in these counties and most of the rock outcrops are found along the streams which flow across the formations into Green Bay, and along the low bluffs which mark the western margins of the two dolomite formations.

Lower Magnesian dolomite.—Outcrops of Lower Magnesian dolomite occur at Oconto Falls, on Jones Creek a few miles north of Stiles, about 5 miles north of Stiles, on the south side of the Peshtigo River, from the mouth of Little River to the vicinity of Potato Rapids, and at Grand Rapids on the Menominee River.

A thickness of about 25 feet of Lower Magnesian dolomite outcrops at Oconto Falls. Excepting for 2 feet of shale, the beds offer vigorous resistance to the wear of the stream. A description of the beds taken from Chamberlin[1] follows:

Top of section		Feet
I.	Gray, buff, cherty dolomite, in part granular crystalline and in part earthy, cavities from size of pea to walnut lined with quartz crystals. Beds up to 2 feet thick. Weathered surface is granular and sandy	5.1
II.	Beds same as I but studded with quartz lined cavities	11.7
III.	Thick bed of impure, conglomeratic dolomite having an almost flinty hardness and fracture. Fragments of siliceous dolomite embedded in dolomitic sand and mud. Breaks off in large sections 20 feet in length, which tumble down into the channel	4.7
IV.	Hard, impure dolomite, dark gray mottled, with lighter hues—in places studded with quartz crystals. Regular beds. Many vertical fissures	9.7
V.	Softer than IV, fine, uniform, crystalline grain—in thin layers—bluish cast on fresh, slightly shell-shaped fracture. Stained with purplish brown spots, but weathers gray. Analysis 36 (p. 184)	4.7
VI.	Green and purple shale and sandy, clayey dolomite	2
VII.	Yellow, or gray dolomite—rough, irregular granular and earthy texture with crystal lined openings. Almost no bedding	6
VIII.	Two thin layers composed of small green spherules embedded in gray earthy and crystalline dolomite	.5
IX.	Nodules of chert and dolomite up to 2 feet to 3 feet across	2.2
X.	Dolomite with small chert spherules	1.3
XI.	Dolomite with tiny chert spherules and abundant green spots	.25
XII.	Dark gray, very impure dolomite, with scattered chert spherules. Small cavities lined with quartz or calcite	5

From the Lower Magnesian, lime in small quantities has been burned at a quarry in the SW. ¼ SW. ¼, sec. 34, T. 29, R. 18 E. Quarries are also located about 1 mile southeast of Coleman, and in outlying patches of this formation in the town of Beaver.

Galena and Black River dolomite.—Outcrops of this dolomite are known in the SW. NW. sec. 3, T. 26 N., R. 20 E.; SW. SW. 5, T. 27, R. 21 E.; at the lower, and the second series of rapids of the Menominee River; on the Little Suamico River; and along Green Bay south of Pensaukee. The exposures at the last two localities are similar to those on the Big Suamico River near Flintville in Brown County.[2] They consist of massive dolomite and of alternating beds of shale and dolomite. At the second series[3] of rapids of the Menominee River

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[1] Chamberlin, T C., Geology of Wisconsin, vol. 2, pp. 281–283, 1877.

[2] Idem, pp. 281-284.

[3] Idem, p. 313.

a portion of the rock exposed is a deep blue, thick bedded, crystalline dolomite, wearing smooth and breaking into rectangular blocks. Other portions are quite irregular in texture, being composed of combined earthy, crystalline, and shaly material.

In Oconto County, the Galena and Black River dolomite has been quarried for lime by L. Drews west of Sobieski, and by John Grosse at Little Suamico. Several quarries are located about 1½ miles south of Porterfield, in Marinette County, south of the Peshtigo River.

No analyses of the Galena and Black River dolomite of these counties are on record. Descriptions indicate that it is similar to the dolomite of Duck Creek, a rock which is too high in clayey material to make good commercial lime, although it may be satisfactory for local use. The best beds would make a very satisfactory soil neutralizer.

Milwaukee County

General geology.—The greater part of this county is underlain by the Niagara dolomite. North of the city of Milwaukee there is a small area underlain by the Milwaukee formation. See Plate VI.

Niagara dolomite.—This formation is the only source of high grade dolomite low in impurities. The principal exposures of the Niagara dolomite are along the Menomonee and Milwaukee rivers.[1]

Three distinct phases of the Niagara dolomite are common in this part of the state. The commonest phase is hard, well bedded, compact, and fine grained. The other phases consist of (1) massive coarse or fragmental moundlike masses without stratification or with obscure stratification which grades into (2) well defined beds of soft porous, granular dolomite.

The largest outcrops of Niagara dolomite are along the bluffs of the Menomonee River between Milwaukee and Wauwatosa. Here also are some large quarries. Going westward from the mouth of the Milwaukee River, the first outcrop is on the north side of the Menomonee River at the foot of Washington Avenue in the city of Milwaukee. This was formerly Moody's quarry. The rock face is about 20 feet by 60 feet long. Here the rock is of the massive type; only a slight trace of bedding is visible at the west end. In places it is slightly broken, perhaps by blasting, but as a whole it is hard, massive, coarse grained, pure dolomite.

The next exposure up the river is about 1¼ miles to the west of Moody's quarry on the west side of the river at the National Soldiers Home. Here a drift covered slope about 80 feet high rises above the valley floor. On its northeast side the lower 35 to 40 feet outcrop

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[1] For a map showing the distribution of dolomite outcrops see U. S. Geol. Survey Folio 140, by W. C. Alden.

on a vertical face. It is a section of a dolomite coral mound, uneven, gray in color, and massive without stratification.

Story Bros. quarry is on the south side of the river about ⅔ mile northeast of the exposure at National Soldiers Home. Here the dolomite exposed is even-bedded, coarse-grained beds alternating with fine-grained ones. At the quarries of Manegold Bros., and the Monarch Stone Company about ⅔ of a mile to the northwest, the stone exposed is of a similar quality.

To the east of Wauwatosa are the old Busack and Schoonmaker quarries. At the Busack quarry to the west, the beds are mostly heavy, well defined, and somewhat clayey. The rock is rather fine and even grained and has a shell-like fracture.

At the east end the upper layer becomes irregular in bedding, and rather soft and granular in texture. In the Schoonmaker quarry the bedding is mostly obscure or lacking. The rock is generally a massive, coarse grained, hard, bluish gray dolomite. In places it consists of dolomite fragments cemented by dolomite. In the eastern part of the quarry the upper part of the section is clayey, porous, and weak.

The Wauwatosa Stone and Coal Company's quarry is located in Wauwatosa. Here the core of a coral reef is exposed. It is surrounded by beds which dip away from it at angles as steep as 45°. The rock is Niagara dolomite, cavernous, and porous with numerous calcite crystal aggregates up to 2 inches in diameter. The west face of the quarry, 26 feet high, was sampled. Its composition is shown by analysis 178 (p. 189).

Zimmerman's quarry is located in the valley of the Menomonee River about 3 miles northwest of Wauwatosa. The dolomite at this place is buff colored, thin bedded, only slightly fractured, even grained, and shows minute pores filled with a pitchy asphalt. It is said that the rock in sight is 70 feet deep, 1500 feet long, and 300 feet wide. The thickness of the loose soil and glacial drift overlying it is uncertain.

The quarries reporting production in 1921 were the G. D. Francey Coal, Stone and Supply Company, Milwaukee; F. Hartung & Son, Wauwatosa; and the Wauwatosa Stone Company.

Waubakee dolomite.—Four miles northwest of the city of Milwaukee, sec. 1 of the town of Wauwatosa, the Waubakee beds are exposed. They rest on top of the Niagara dolomite. The rock is a hard, brittle, light gray dolomite, distinguished by numerous minute, angular cavities that give to it a very peculiar porous structure. It is thin bedded and breaks readily into thin plates parallel to the bedding. In cross section the plates consist of thin laminae of alternating dark and gray color. Analysis 179 (p. 189)[1] gives the composition of an average sample.

Another outcrop of the Waubakee beds is reported on the Milwaukee River a short distance above the Washington Street bridge. It shows the same peculiar porous laminated structures as in sec. 1 described above, but is less shaly and shows more red iron oxide. Its composition is given in analysis 180 (p. 189).[2]

Milwaukee formation.—The Milwaukee formation (Hamilton cement rock of older reports) occupies a limited area adjacent to the lake and north of the city of Milwaukee. It overlies the Niagara dolomite and is the youngest of the stratified sedimentary rocks of the state. It was laid down as a marine deposit during the Devonian period.

It is a bluish gray, or ash colored clay bearing dolomite which weathers to yellow and buff colors owing to its iron content. The rock in places has many angular cavities, in which occur crystals of iron sulphide, calcite, and rarely zinc blende. Sometimes the fossil forms are more or less replaced by iron sulphide. Some layers are uniform in texture, others are irregular and lumpy. The composition varies but slightly. The beds are generally thick but in places somewhat shaly.

The most extensive outcrops are on the Milwaukee River in the vicinity of Washington Street bridge, extending above and below in secs. 4 and 5, T. 7, R. 22 E. The rock nowhere rises to more than 30 feet above the river and in most places about 15 feet. The beds are gently folded.

A few feet of the Milwaukee formation are exposed in sec. 11, town of Granville in a railroad cut just south of the station of Brown Deer. It is also said to occur in the bed of the Milwaukee River opposite this place. The beds are about the same as near the Washington bridge although more weathered.

The most northwesterly exposure occurs in secs. 9 and 10 of the town of Granville. It lies in the brow of a hill, the remainder of which is underlain by Niagara dolomite. The Milwaukee formation at this place is a soft, granular, buff, impure dolomite.

On the lake shore at Whitefish Bay there is a small outcrop of the Milwaukee formation a little above the water level. The layers are compact, but uneven. Angular cavities about an inch in diameter are common, some of which contain black tar.

The composition is shown by analyses 216 to 225 inclusive (p. 190).[3] The first nine are from stone collected on the Milwaukee River near the Washington Street bridge. The last one is from the outcrop on

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[1] Chamberlin, T. C., Geol. of Wisconsin, vol. 2, p. 390, 1877.
[2] Idem, p. 390.
[3] Idem, pp. 396, 399.

Whitefish Bay. The rock averages about 21 per cent impurities of which silica and alumina are the most important. Iron, most of it in the form of iron sulphide, is nearly as important as alumina. Silica is the most abundant, averaging about 17 per cent. The rock is a limy dolomite, the calcite averaging about 12 per cent. The calcite lines and fills small cavities.

The Milwaukee formation was used as a natural hydraulic cement until it was displaced by the superior qualities of Portland cement. The average tensile strength of cement made from this rock at the end of seven days is said to have been about 64 pounds to the square inch.[1] The Milwaukee formation is too impure for lime or for any purpose in which a nearly pure carbonate rock is desirable. Its local use for agricultural limestone ought to be practical unless the content of iron sulphide might have an injurious effect.

Monroe County

General geology.—Except for outliers of Lower Magnesian dolomite, the northern part of the county is underlain by Cambrian sandstone. The high ridges and broad uplands of the southern part are capped by Lower Magnesian dolomite. Escarpments are formed by the Lower Magnesian dolomite and by the Trempealeau dolomite bed in the upper portion of the Cambrian sandstone. The Trempealeau bed is sandy with about 30 per cent of impurities, but in the sandstone region it might serve as a valuable source of agricultural limestone. The valleys and low lying areas are all covered with slope wash.

Lower Magnesian dolomite.—Dolomite quarries have been operated near Sparta by August Schmeichel, John Nichols, A. E. Smith, and J. J. Ewers. Dolomite quarries have also been worked at Tomah and Rockland.

The J. J. Ewers quarry is located in the NE. ¼ NE. ¼ sec. 19, T. 18, R. 4 W., on a high steep sided hill. The rock quarried was rolled to the bottom of the hill and hauled to Sparta for road building.

The beds of the quarry are described as follows:

Top of section	Ft.	In.
I. Soil and dolomite fragments	4	0
II. Porous, weathered dolomite with flints	2	0
III. Compact dolomite	3	0
IV. Shaly, crumbly, sandy layers	3	0
V. Flint bed		4
VI. Thick bedded dolomite	3	0

Lime has been burned for local uses at the following places in Monroe County. Quarries of Lower Magnesian dolomite are probably located at each kiln.

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[1] Chamberlin, T. C., op. cit., p. 405.

1. About 7 miles southeast of Tomah on the northern line of outcrop of the Lower Magnesian dolomite on the SW. ¼ of sec. 31, T. 17, R. 1 E.
2. On an isolated outlier of dolomite about 6 miles southwest of Tomah in the SW. ¼ of sec. 22, T. 17, R. 2 W.
3. In the NW. ¼ of sec. 12, T. 16, R. 3 W.
4. At the foot of a high isolated, outlying bluff capped with Lower Magnesian dolomite in the SW ¼ of sec. 28, T. 18, R. 4 W.

Oconto County

See description of Marinette and Oconto counties (p. 64).

Outagamie County

General geology.—This county is underlain by roughly parallel belts of Cambrian sandstone, Lower Magnesian dolomite, St. Peter sandstone, and Galena and Black River dolomite. These belts trend northeast and occur in the order named going from northwest to southeast. See Plate VI. The western margin of each of the dolomite belts is marked by a northwest facing escarpment. The greater part of this county is covered by glacial deposits. Excepting for the escarpments, the surface is nearly level.

Lower Magnesian dolomite.—The most conspicuous outcrops of Lower Magnesian dolomite are along the steep slopes marking its western limit. Chamberlin measured 60 feet of these beds from scattered outcrops in the town of Hortonia.[1] The lower 10 feet of the section are sandy and cherty. The beds overlying them are mostly dolomite with minor amounts of clayey and siliceous materials.

To the south of the small stream running from east to west through the town of Ellington, outcrops of Lower Magnesian dolomite become less abundant as one follows the bluff eastward.

A few feet of Lower Magnesian dolomite are found on top of North and South Mosquito Hills near New London. They are weak, sandy beds, and unlike the Lower Magnesian beds on the opposite side of Wolf River.

The Outagamie Limestone Company operates a quarry in the SW. ¼ SW. ¼ sec. 33, T. 24, R. 17 E., on a spur of the Soo Railway. The quarry face is 22 feet in height. The dolomite is yellowish-gray in color and except for the upper 4 feet is free from weathering. Analysis 37 (p. 184) was made from a general sample.

Many of the beds are undoubtedly suitable for local agricultural limestone. Quick lime was formerly produced by the following:

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[1] Chamberlin, T. C., Geology of Wisconsin, vol. 2, p. 277, 1877.

Drephal Bros. & Litzkow Company, Shiocton
Frank Fuller, Hortonville
G. L. Maas, Black Creek.
No production has been reported in recent years.

Galena and Black River dolomite.—Outcrops of this formation are common in the stream channel of the Fox River below Appleton. Before dams were built across the river, it formed a number of rapids over the heavier and more resistant beds. The outcrops at Kaukauna, Chamberlin states are typical of the Galena dolomite along the Lower Fox River. His description of them is in part as follows: "The layers vary from 6 to 30 inches in thickness. The rock is of a dull bluish green or gray hue and is characterized by very thin shaly partings between some of the layers, and by thin irregular clayey laminae through the body of the rock, not sufficient however to impair its strength or power of resisting atmospheric influences as bowlders which have been exposed since the drift are still sound. Aside from these laminae the rock has a crystalline character, impervious and compact in general, though it contains a few cavities, some of which are lined with calcite and occasionally pyrite."[1]

Quarries in this formation are located at Appleton and Kaukauna. The Lindauer quarry is located on the north side of the Fox River at the northeast end of Kaukauna. About 10 feet of Galena and Black River dolomite are exposed. Where fresh, it is a coarsely crystalline, bluish rock. Analysis 109 (p. 187) gives the average composition of these beds.

The rock is too impure for quick lime but would make a fair agricultural limestone for local purposes.

Ozaukee County

General geology.—The Niagara dolomite underlies all of the county. The Milwaukee formation underlies a few square miles in the southeast corner and a narrow strip along the lake shore extending from Port Washington several miles to the northward. See Plate VI. Outcrops are scarce because of the covering of glacial drift.

Niagara dolomite.—Quarries in this formation are located along Stoney Creek in the town of Fredonia, at Druecker, a few miles north of Port Washington, at Grafton, Cedarburg, and on the lake shore near Belgium. The following firms have produced lime or stone:

Auschuetz & Company, Cedarburg
John F. Groth & Son, Cedarburg
Independent Lime & Stone Company, Druecker
Milwaukee Falls Lime & Stone Company, Grafton
Lake Shore Stone Company, Belgium.

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[1] Op. cit., p. 312.

About 30 feet of Niagara dolomite are exposed in the Milwaukee Falls Lime Company's quarry at Grafton. The rock is used for lime. The upper 20 feet are soft and fine grained. Their composition is shown by analysis 182 (p. 189). Analysis 181 (p. 189)[1] probably represents a picked sample.

Analysis 183 (p. 189)[2] represents the composition of six layers of the Independent Lime and Stone Company's quarry at Druecker, known as the Druecker quarry. As is true of most Niagara dolomite in Wisconsin, this rock is low in impurities, a high grade dolomite useful for any purpose in which a pure dolomite is either desirable or satisfactory.

Waubakee dolomite.—Beds of the Waubakee formation are exposed about 1 mile above the village of Waubakee in the town of Fredonia in the bed of the Milwaukee River. North of the river a quarry shows the following section:

Top of section	Ft.	In.
I. Light gray thin bedded, shaly dolomite, analysis 184 (p. 189)[3]	2	0
II. A layer of hard dolomite containing calcite lined cavities 5 to 6 inches in diameter. Analysis 185 (p. 189)[4]		10
III. Alternating thin and thick layers similar to No. I. Some layers marked with a dark rusty coating	2	2
IV. Similar to No. II	1	2½
V. Moderately thick beds somewhat shaly	1	0

In the bed of the river a little above this locality is an outcrop of dark, carbonaceous, soft dolomite. An average sample from this outcrop had the composition indicated by analysis 186 (p. 189).[5]

The Waubakee rock is not as pure as most of the Niagara dolomite; hence it is not desirable as a commercial lime. As a local agricultural limestone it would serve very well.

Pepin and Pierce Counties

General geology.—The lowlands of Pepin and Pierce counties are underlain by the Cambrian sandstone. See Plate VI. These lowlands include the deep narrow valleys of Pepin County and a broader belt of lowland which extends northward through the eastern part of Pepin and Pierce counties, thence through Dunn and St. Croix County. West of this belt rises an escarpment about two hundred and fifty feet high whose front is cut by many valleys. This escarpment is capped by the Lower Magnesian dolomite which extends westward

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[1] U. S. Geol. Survey Twentieth Ann. Rept., Pt. 6 con., p. 463, 1899.
[2] Chamberlin, T. C., Geol. of Wisconsin, vol. 2, p. 381.
[3] Idem, p. 393.
[4] Idem, p. 393.
[5] Idem, p. 393.

as a broad undulating table land through St. Croix and Pierce counties. Only a few deep valleys like that of the St. Croix cut through the dolomite and into the Cambrian sandstone below. This tableland area has a rich clayey soil and is a good farming region.

The Lower Magnesian uplands in the western part of Pierce County are the base of another escarpment whose lower slopes are underlain by the St. Peter sandstone and whose top cap rock is the Galena and Black River dolomite. This escarpment is very prominent about 3 miles northeast of Prescott.

Lower Magnesian dolomite.—The outcrops of this formation are most numerous along the Mississippi River and for a few miles up its tributaries. On the tablelands away from the river outcrops are scarce. The cover of soil and glacial debris is quite general. Along the bluffs which mark its eastern front, outcrops are also quite scarce. The dolomite along this front is generally deeply decayed, and quarries which have been opened usually show a clayey, soft buff colored rock.

Along the bluffs flanking the Eau Galle River at Spring Valley outcrops of Lower Magnesian dolomite are common. A large quarry south of Spring Valley in sec. 27 formerly supplied flux for the iron furnace which was operated there about 15 years ago. The quarry is now operated as a source of agricultural limestone and crushed stone by the Wissota Sand and Gravel Company. About 72 feet of very thick bedded, flint bearing, slightly cavernous dolomite beds are exposed in the quarry. About 50 feet below the quarry floor is the top of the Cambrian sandstone. Two analyses of these beds are on record, analyses 38[1] and 39 (p. 184).

Analysis 38 was from selected material used for flux. The run of the quarry is shown better by analysis 39. The dolomite has a considerable content of flint and would not do where a high grade carbonate rock is wanted. As an agricultural limestone for local use it serves very well.

This formation has been quarried on the hills overlooking Lake St. Croix between Prescott and the Kinnikinnic River. In one of the gorges on the south bank of the Kinnikinnic River north of Prescott in the SW. ¼ of sec. 13 of the town of Clifton about 68 feet of this dolomite is exposed. The description of beds follows:

Top of section	Feet
I. At head of gorge. Compact hard dolomite. Analysis 42 (p. 184)	40
II. Thick bedded dolomite, wavy contact with overlying beds, marked by occasional round bowlders of dolomite from 1 inch to 1 foot in diameter. Analysis 41 (p. 184)	20

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[1] Lewiston, A., personal communication.

III.	Thin bedded, dense, fine grained dolomite with flint nodules. Analysis 40 (p. 184)	8

The lowest beds of the quarry are purer than the average Lower Magnesian dolomite. In view of the variability in the composition so common in beds of the Lower Magnesian dolomite, it is uncertain whether this degree of purity would hold for any distance beyond the outcrop.

Galena and Black River dolomite and limestone.—This formation has been quarried in many localities in the vicinity of River Falls, Ellsworth, Beldenville, and Prescott.

Dill's quarry, about 3 miles northeast of Prescott, exposes 15 feet of Galena and Black River dolomite on top of a flat topped hill which rises about 100 feet above the surrounding country. The beds are the lowest in the formation and rest on the St. Peter sandstone. They are clayey and probably contain about 10 per cent of impurities, but would furnish a very good supply of local agricultural limestone.

The Thomas Walker quarry is in the Galena and Black River dolomite which caps the bluffs east of River Falls. The section exposed is as follows:

	Top of section	Feet
	Soil	
I.	Thin bedded, brittle frost broken limestone, analyses 112 and 113 (p. 187)	6
II.	Thin bedded cream colored dolomite, analysis 111 (p. 187)	4
III.	Thick bedded, buff dolomite, analysis 110 (p. 187) about	4

The facts of ownership, location, thickness of beds of quarries in the Galena and Black River dolomite near Ellsworth follow:

Owner or name of quarry	Location	Thickness of beds
Campbell Quarry	¼ mile north of railway station on east side of track	12 feet
J. Holman	½ mile north of Campbell Quarry	12 feet
City Quarry, Ellsworth	¼ mile west of railway station	11 feet
Jasper Miller	½ mile west of Ellsworth	12 feet

The beds at the city quarry near Ellsworth are as follows:

	Top of section	Feet
	Soil	
I.	Thin bedded, bluish dolomitic limestone. Beds have about the same appearance as the glass rock beds of southwestern Wisconsin	4
II.	A shaly bed	1
III.	Thick bedded dense fine grained, bluish dolomitic limestone. Analysis 114 (p. 187)	6

The only unusual feature of this analysis is the high content of calcite. The rock, however, has too much magnesia to be a Portland cement limestone, and it is not suitable for any other uses of a nearly pure calcite rock. The 4 feet of glass-rock-like beds, Group I, which overlie Group III are probably lower in magnesia than Group III. The slight thickness of these beds and the small area over which they are laid bare on the surface make it improbable that they could be used profitably as a source of high calcite rock. Furthermore it is unlikely that they average low enough in magnesia. In southwestern Wisconsin where similar glass rock beds are exposed they vary greatly in their magnesia content and are not a reliable source of low magnesia limestone.

Notes on dolomites of Pierce County by W. J. Geib.—The notes below on limestone and dolomite outcrops located in Pierce County were contributed by W. J. Geib of the Soil Survey Division of this Survey. The percentages of equivalent calcium carbonate which he reports for various samples represent the pounds of dry calcium carbonate which would have the same neutralizing effect on soils as 100 pounds of the sample under consideration. Since the samples collected by Geib contain considerable magnesium carbonate in the form of dolomite which neutralizes more acid than the equivalent weight of calcium carbonate, the calcium carbonate equivalents which he reports are all high. Many of them run over 100 per cent, that is 100 pounds of the rock analyzed has more neutralizing value than 100 pounds of dry calcium carbonate. In a pure dolomite the carbon dioxide content is 47.9 per cent. If this amount of carbon dioxide were combined with lime, 108.8 parts of lime carbonate would result. In other words 100 pounds of dolomite have as much neutralizing effect as 108.8 pounds of pure calcium carbonate. The calcium carbonate equivalent in this case is 108.8 per cent. Geib's notes follow:

1 and 2. On farm of Olaf Neyaggen. Location of outcrop in SE. ¼ of SE. ¼, sec. 7, town of Spring Lake. This is in the bed of a dry run and on an adjoining slope about one-eighth of a mile from a public road. There is no road to this outcrop at present, but one could be made without difficulty. The rock is quite accessible although there is a covering of about 3 feet of soil immediately above the top of the rock in the stream bank. Quarry tests were taken, one in the bed of the stream and the other on the adjoining bank. Both tests were 96 per cent plus—calcium carbonate equivalent.

3. Quarry from which limestone was taken for use in the iron furnace at Spring Valley. It is located in the NE. ¼ of sec. 27, town of Spring Lake. The quarry is located at the top of the hill which is about 150 feet above the valley bottom. There is a spur of the railroad running into the base of this quarry and the rock has been blasted along the hillside for fully one-quarter mile. By constructing a chute

this rock can be very easily lowered to the railroad or to the wagon road. There is an unlimited supply of rock available here. Calcium carbonate equivalent—97.55 per cent.

4. Quarry known as the Tuttle Hill Quarry owned by Wm. Brant. It is located in the SE. ¼ of sec. 36, town of Spring Lake, near the top of Tuttle Hill beside the public road. Rock has been taken from this quarry and crushed for road building material and the rock crusher is now installed at this quarry, but no rock for agricultural use has been pulverized. It would be very easy to get large quantities of rock from this quarry as it is on a good public road and comparatively little stripping would be necessary. Calcium carbonate equivalent—100.98 per cent.

5. This is on the farm of Henry Thompson, town of Gilman in the SW. ¼ of the SE. ¼ of sec. 25, adjoining the farm of Albert Hurtgen. It consists of a small hill in which the lime rock is close to the surface. It is about one-eighth of a mile from the public road and quite accessible. Probably no more than one foot of stripping would be necessary. Calcium carbonate equivalent—103.2 per cent.

6. This is located on the public road adjoining the farm of Albert Hurtgen in the SW. ¼, sec. 25, town of Gilman. The outcrop is not at all conspicuous and one must dig in the bank on the south side of the road to find the rock. It would probably be necessary to strip about 3 or 4 feet of soil before much of the rock would be available. Being on a public road, however, the place is easily accessible. Calcium carbonate equivalent—98.9 per cent.

7. Dolomite on the farm of N. Halvorson in the NW. ¼ of the SW. ¼ of sec. 23, town of Rock Elm. This is nearly ¾ of a mile from a public road and it is along a deep gulch which is quite inaccessible altough about eight years ago considerable rock was hauled from this place for building purposes. There is a private road within ¼ mile of the outcrop. There is considerable rock exposed in the bed of this dry run and much more could be uncovered in the bank of the river. Calcium carbonate equivalent—104.2 per cent.

8. Farm of Fred Hague in the NE. ¼, sec. 33, town of Salem. The outcrop is on the top of a hill nearly 200 feet high, overlooking the valley of Rush River in which the soils are mostly acid. In quarrying this rock it would be necessary to convey it down the hill in a chute and grind it at the base of the hill. There is a large exposure and by blasting, no stripping would be necessary. Much of the rock would roll down the hill and at present large quantities of limestone are scattered on the steep slope. The hill borders a public road. Calcium carbonate equivalent—104 per cent.

9. Outcrop on the farm of A. Schraum in the NE. ¼, sec. 6, town of Salem. The rock here is exposed on a steep hillside immediately bordering a public road. There is considerable overburden. The outcrop extends for several rods and is about 15 feet high. It is from 5 to 25 feet above the public road. At the base of the hill there is a strong spring of excellent water. Calcium carbonate equivalent—100 per cent.

10. On the land owned by Nels Madson, located in SE. ¼ of the NE. ¼, sec. 5, town of El Paso. This quarry is located immediately adjoining the public road and also forms one of the banks of the Rush River. It is accessible but there is about 4 or 5 feet of stripping

except where the rock is exposed in the vertical wall. The outcrop is about 60 feet long by 10 to 20 feet high. Calcium carbonate equivalent—98.8 per cent.

11. On the farm of Joe Young on the SE. 1/4, sec. 16, town of El Paso. This is on a good public road immediately adjoining Rush River. It is in the form of a big bluff 100 or more feet high by 1/8 of a mile long. This rock could be easily blasted down the hill where a crusher could be placed on the public road. The one objection to this location is that there is no farm land nearby in the valley of the Rush River where the rock could be used. The rock would therefore have to be hauled up a long hill before it could be delivered to farms where it could be used. Calcium carbonate equivalent—100 per cent.

12. According to the atlas, this is on land owned by Hugh O'Connell in the SE. of the SE. 1/4 of sec. 15, town of El Paso. This is on County Highway C near the top of the long hill east of Rush River. The crusher could be installed in the public road and all the rock taken from the rock wall along the side of the road. A large quantity of rock is available. The road taps considerable farming country which is in need of limestone and which could be easily reached from this point. Calcium carbonate equivalent—102.5 per cent.

13. Land owned by Albert Sperger, located in the S. 1/2 of the NE. 1/4 of sec. 25, town of Rock Elm. This outcrop is on a public road near the top of a long hill. A crusher could be placed in the public road and the rock easily obtained. Only a small amount of stripping would be necessary and the debris could be used in widening the road bed. Calcium carbonate equivalent—102.5 per cent.

14. Land owned by Albert Sperger in the NE. 1/4 of the NW. 1/4, sec. 30, in the town of Eau Galle in Dunn County. This deposit is about one-fourth mile from the public road and is much more difficult to get out than the deposit just above described. It occurs in the bank immediately adjoining a dry run and the rock taken from there has been used for building purposes. There is an old road leading to it, but this has been long neglected. Calcium carbonate equivalent —98.3 per cent.

15. Farm of Charles Fedderby of Elmwood, Wisconsin, located in the SW. 1/4 of the SW. 1/4 of sec. 2, town of Rock Elm. This outcrop is on a public road near the top of a long hill leading out of Elmwood. There is considerable rock exposed here, but there is an overburden of about 3 or 4 feet. Calcium carbonate equivalent—101.2 per cent.

16. Outcrop located on the west side of Cady Creek in the town of Spring Lake, SW. 1/4 of the NW. 1/4 of sec. 14, on a steep hillside, 1/4 mile west of the wagon road. No sample was taken of this rock.

17. Located in the SW. 1/4 of the SW. 1/4 of sec. 24, town of Spring Lake. Outcrop is on a high hill and a chute would be necessary to get the rock down to the public road. The outcrop is within 1/8 of a mile of the road. No sample was taken from this outcrop.

18. SW. 1/4 of SE. 1/4, sec. 26, town of Spring Lake. This outcrop is on a high hill within 1/4 mile of the public road but has not been opened and is too near the large quarry in sec. 27 to need consideration at this time. No sample was taken from this outcrop.

19. SW. 1/4 of the SE. 1/4, sec. 3, town of Spring Lake, immediately adjoining the public road near the top of the hill. This is a large exposure and the crusher could be located at the side of the road and

large quantities of rock can be secured by blasting. The stripping varies from 3 to 5 feet. Calcium carbonate equivalent—97.3 per cent.

20. The N. ½ of sec. 9, town of Spring Lake. Outcrop occurs along the public highway half way up a large hill. It is easy to get at as the rock can be blasted from the road side. Calcium carbonate equivalent—86.5 per cent.

21. Land owned by Charles Tewn, located near the center of sec. 6, town of Spring Lake, ⅛ mile from the railroad and ¼ mile from the depot in Spring Valley. The rock is exposed about half way up the hill and can be gotten out quite easily as some quarrying was done here not very long ago. About 2 to 4 feet of stripping would be necessary. Calcium carbonate equivalent—100.5 per cent.

22. Land owned by Vern Brownlee of Maiden Rock. Quarry is located near the top of the hill on the road leading out of Maiden Rock to Plum City in the town of Maiden Rock about one-fourth mile from the village. This rock forms a high face bordering the public road and considerable rock has been taken out for building purposes. Calcium carbonate equivalent—98.1 per cent.

Polk County

See description of St. Croix and Polk counties (p. 81).

Racine and Kenosha Counties

General geology.—Racine and Kenosha counties are underlain by the Niagara dolomite.

The surface of the eastern part of these counties is level. The western portion is covered with a thick mantle of glacial drift. Its surface is undulating, even hummocky in places, and is dotted by numerous lakes, ponds, and swampy stretches.

Niagara dolomite.—Outcrops of this formation occur along Root River in the vicinity of Racine. The beds consist of a conglomeratic, massive, coarse-grained dolomite grading into even-bedded, compact, hard, fine-grained phases. These characteristics are peculiar to the highest beds of the Niagara dolomite, known as the Racine beds because of their occurrence near Racine.

Two analyses of Niagara dolomite are on record. They are from the old Horlick and Beswick quarries. See analyses 187 and 188 respectively (p. 189).[1] They indicate a high degree of purity, about 98 per cent total carbonates.

The most important quarries are those of the Consumers Company at Ives, and the Racine Crushed Stone Company in sec. 6 on the Root River northwest of Racine.

The beds in quarry No. 2 of the Consumers Company at Ives are fine grained, compact, and even. The quarry face is about 100 feet high. The rock appears to be very pure.

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[1] Chamberlin, T. C., Geol. of Wisconsin, vol. 2, p. 381, 1877.

Gravels.—Gravel beds are common in Kenosha and Racine counties. Dolomite is their chief constituent. Wherever gravel beds are nearer to fields requiring agricultural limestone than dolomite outcrops and quarries, it may be cheaper to crush selected dolomite gravel than to haul the ground stone from greater distances.

Richland County

General geology.—All of this county is in the Driftless Area. The surface is deeply dissected by valleys separated by narrow ridges. In the western and northwestern parts there are some fairly broad uplands. The lowlands are underlain by Cambrian sandstone, the uplands by Lower Magnesian dolomite. Some of the higher portions of the upland still retain a covering of St. Peter sandstone.

Trempealeau dolomite.—Beds of this formation are found 40 feet below the base of the Lower Magnesian limestone where they form benches and projecting ledges. Little data is available regarding the composition of this formation, but it is usually too impure for chemical uses.

Lower Magnesian dolomite.—This formation outcrops along the edges and upper portions of the bluffs flanking the valleys throughout the county. In the past, lime kilns have been operated at the following places: in the NW. ¼ of sec. 19, town of Eagle; in the NW. ¼ of sec. 19, town of Orion; and in several places in the vicinity of Richland Center.

The calcium carbonate equivalent (p. 75) of a sample from the quarry in the NE. ¼ SE. ¼, sec. 15, T. 10, R. 1 W. is 101.25 per cent. This indicates that the rock is chemically very satisfactory for use as agricultural limestone. As the Lower Magnesian dolomite occurs in every town in the county, the problem of securing agricultural limestone should be relatively simple.

Rock County

General geology.—The eastern part of this county is underlain by the Galena and Black River dolomite, which has but few outcrops, being covered by soil and glacial drift in most places. West of the Rock River all the uplands are underlain by the Galena and Black River dolomite. The border of these uplands is dotted by outcrops and quarries. Most of the lowlands west of the Rock River are underlain by the St. Peter sandstone and locally by the Lower Magnesian dolomite. The Cambian sandstone underlies a narrow belt in the Rock River valley from the north county line to a point about 4 miles north of Beloit.

The margin of the last glacial drift sheet extends across the northern part of the county through Johnstown Center. It crosses the Rock River about 2 miles north of Janesville and from there swings northwest along the Chicago & Northwestern Railway. South of this line the glacial drift consists of a level outwash border south of the youngest drift and of a level outwash plain along the Rock River and Turtle Creek. Elsewhere there is a thin covering of older drift.

Galena and Black River dolomite.—This formation is the only dolomite which outcrops. Most of the outcrops are along the west side of the Rock River valley, in the miniature canyon of Turtle Creek in the town of Brandon, and on the edge of the hill tops in the western part of the county.

The Arthur Spencer quarry is in the SW. ¼ NE. ¼ sec. 4, town of Magnolia. The beds are as follows:

Top of section	Feet
I. Weathered broken dolomite, analysis 117 (p. 187)	6
II. Buff and blue beds alternate, analysis 116 (p. 187)	11½
III. Blue and gray dolomite, analysis 115 (p. 187)	8

Peck's quarry is located in the SW. ¼ NW. ¼ sec. 34, T. 1, R. 12 E. The face of the quarry is about 22 feet high.

Top of section	Feet
I. Soil	2
II. Thin bedded, broken dolomite	12
III. Blue beds, analysis 119 (p. 187)	4
IV. Thin bedded, buff colored fossiliferous dolomite, analysis 118 (p. 187)	5
V. Dense and fine grained	2

The Chas. Samp quarry is located in the SW. ¼ NW. ¼ sec. 26, T. 1, R. 12 E. The beds are as follows:

Top of section	Feet
I. Buff thin bedded dolomite	8
II. Buff thick bedded dolomite	10
III. Brittle fine grained dense bed, analysis 120 (p. 187)	2
IV. Buff thick bedded coarser grained dolomite	3

At the quarry on the Chicago & Northwestern Railway about 2½ miles north of Beloit the lowest beds of the Black River dolomite, known as the lower buff, and the group which overlies them, the lower blue beds, are exposed. The lower buff beds are thick bedded, coarse grained, and somewhat shaly at the base with a few feet of sandy beds grading into the St. Peter sandstone. For composition see analysis 121 (p. 187).[1] The blue beds are about 23 feet thick and include thin bedded impure dolomite of varying earthy and crystalline grain inter-

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[1] Chamberlin, T. C., Geol. of Wisconsin, vol. 2, p. 298, 1877.

leaved with shaly partings, the whole having a bluish green or gray color. They are very fossiliferous. For composition see analysis 122 (p. 187).[1]

On the line between secs. 26 and 27 of the town of Beloit at the old Carpenter quarry, the lower portion of the upper buff beds which overlie the lower blue bed are exposed. A ravine below the quarry has gullied into the lower blue beds. The strata in the quarry include 19 feet of fine-grained dolomite of earthy or sub-crystalline texture. For composition see analysis 124 (p. 187).[2] They are overlain by about 3 or 4 feet of uniform earthy dolomite with a shell-like fracture. It sparkles with tiny crystals and is lined and spotted with a peculiar red stain. Analysis 123 (p. 187)[3] gives the composition of this bed.

The Andrew Barren quarry is near the Monroe branch of the Chicago, Milwaukee & St. Paul Railway in the SE. 1/4 34, T. 3, R. 12 E. The beds are described below:

Top of section	Feet
I. Buff thin bedded dolomite, analysis 127 (p. 187)	17
II. Bluish, fossiliferous dolomite with thin clay seam, analysis 126 (p. 187)	12
III. Buff dolomite, analysis 125 (p. 187)	10

A few details regarding other quarries in Rock County are given below:

Name of quarry	Location	Thickness of Galena-Black River dolomite
McGavock	NE. 1/4 NW. 1/4 sec. 34, T. 1, R. 12 E.	35 feet
Stout	NW. 1/4 2, T. 2, R. 12 E.	24 feet
Rieck	1 1/2 miles north of Janesville near Rock River	38 feet
Wille	SE. 1/4 NW. 1/4 16, T. 4, R. 12 E.	20 feet

This county has no high-grade dolomite and no limestone. The dolomite is all earthy and usually has more than 4 per cent of impurities, but is satisfactory for local use as agricultural limestone.

Gravels.—Gravel is abundant along the stream valleys which extend southward from the margin of the last glacial drift sheet. Their chief constituent is dolomite. Most fields are near enough to dolomite ledges to have a good supply of agricultural limestone close at hand. In some cases it may be found cheaper to grind selected dolomite gravel for this purpose.

St. Croix and Polk Counties

General geology.—The greater portion of St. Croix County is underlain by the Lower Magnesian dolomite. This formation also extends

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[1] Chamberlin, T. C., Geol. of Wisconsin, vol. 2, p. 298, 1877.

[2] Idem, p. 298.

[3] Idem, p. 298.

northward into Polk County. The low-lying lands are underlain by Cambrian sandstone. The edge of the Lower Magnesian beds next to the sandstone forms an almost unbroken escarpment, along which outcrops are common. In the southwestern part of St. Croix County certain high, flat-topped hills are capped by the Galena and Black River dolomite. The lower slopes of these hills are underlain by the St. Peter sandstone.

The northwestern part of Polk County is underlain by black trap rocks belonging to the pre-Cambrian. Splendid outcrops of these rocks occur at the Dalles of the St. Croix River. They form uplands as contrasted with the lower-lying area of Cambrian sandstone.

The southern part of St. Croix County is covered by older glacial drift which has been considerably eroded. Much of the drift which remains consists of gravel in which dolomite pebbles are abundant. The northern part of St. Croix County and all of Polk County except the extreme southeastern corner are covered by the most recent glacial drift, called the Wisconsin. The Wisconsin drift is thicker than the older drift, and the surface covered by it has many lakes and swamps. The gravels of this drift within these counties are generally composed of hard pre-Cambrian rocks. Dolomites are generally subordinate.

Lower Magnesian dolomite.—One of the largest outcrops of this formation in St. Croix County is at the falls of the Willow River, west of Burkhardt. About 130 feet of beds are exposed below the falls. The lower 80 feet are described as follows:

Top of section	Feet
I. Dense, thick-bedded, buff-colored dolomite, analysis 51 (p. 185)	50
II. Cream-colored, thin-bedded, fine-grained, dense dolomite, analysis 50 (p. 184)	10
III. Thick-bedded, compact, dense dolomite, analysis 49 (p. 184)	20

The lowest beds are only a few feet above the Cambrian sandstone.

The McDonald quarry is in the NE. ¼, sec. 26, T. 31, R. 18 W. About 5 feet of very tough, compact, thick-bedded Lower Magnesian dolomite are exposed here. Their composition is given in analysis 52 (p. 185).

A quarry on the roadside about 1 mile west of Glenwood shows about 20 feet of flinty, thin-bedded Lower Magnesian dolomite. An average sample gave analysis 46 (p. 184).

For two analyses of a quarry owned by G. W. La Pointe near Wilson in the SW. ¼, SW. ¼, sec. 36, T. 29 N., R. 15 W., see analyses 47 and 48 (p. 184).[1] Details regarding the beds are lacking. The analyses show a higher content of carbonate than is common in the Lower Magnesian dolomite in this area.

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[1] Daniels, W. W., personal communication.

About ½ mile west of Little Falls (Polk County) the Apple River has cut a gorge which is about 40 feet in depth. The dolomite beds outcrop about 35 paces north of the public road. The composition of the lower 8 feet of these beds is given in analysis 43 (p. 184). Analysis 44 (p. 184) gives the composition of the 30 feet of beds above the preceding.

Analysis 45 (p. 184) gives the composition of an average sample from the G. Wall quarry south of Osceola.

Facts regarding other quarries and exposures in St. Croix County are tabulated below:

Owner or name of quarry	Location	Feet of dolomite
	East of Prescott road, NW. ¼, sec. 5, town of Troy	8
Levi Oakes	SE. ¼ sec. 2, T. 30, R. 18 W.	10
	On Apple River near Star Prairie in sec. 1, T. 31, R. 18 W.	70
	Rose Lake, sec. 18, town of Stanton	?
	On railroad at Wilson	95 (flinty)

Galena and Black River dolomite.—This dolomite is quarried on top of a high mound east of Bass Lake in the town of St. Joseph, St. Croix County. The beds are described below:

Top of section	Feet
I. Broken, thin-bedded dolomite, fine-grained, brittle rock	4
II. Shaly dolomitic beds	4
III. Fine-grained, thick-bedded, buff dolomite	4

The composition of an average sample of the above section is given in analysis 130 (p. 187). This rock is classified as a calcitic dolomite. It is far too high in magnesia to serve the purposes of high calcitic rock. The content of insoluble matter is high. About the only use based on composition for which this rock is desirable is as a local agricultural limestone.

A high mound 1 mile southeast of Burkhardt is capped by 10 feet of Galena and Black River dolomite similar to that of the quarry east of Bass Lake.

At the Ryan quarry in the NE. ¼ sec. 30, T. 28, R. 19 W. about 12 feet of Galena and Black River dolomite are exposed on top of a bluff about 100 feet high. The beds are as follows:

Top of section	Feet
Soil ... Less than	3
I. Thick-bedded dolomite, analysis 129 (p. 187)	5
II. Thin-bedded, cream-colored dolomite, analysis 128 (p. 187)	7

Number 129 is calcitic dolomite. Number 128 is dolomitic limestone. Both are high in insoluble matter. The only apparent use of this rock, based on composition, would be for local agricultural limestone.

Sauk County

General geology.—The Baraboo ranges form the most prominent surface feature in Sauk County. They consist of two lines of hills which trend nearly east and west and unite at their western extremity along a roughly half circular loop in the town of Westfield. To the east they join to form a rather sharp wedge beyond the eastern boundary of Sauk County in Columbia County. The Baraboo Valley lies between these two ranges. The ranges themselves are unbroken except in four places: Devils Lake, the Lower and Upper Narrows of the Baraboo River, and on Narrows Creek 2 miles west of Ableman. The Baraboo ranges are underlain by Baraboo quartzite which in places is still capped by the Cambrian sandstone. This quartzite is a highly resistant portion of the pre-Cambrian which was once completely buried under the Cambrian sandstone and other rocks. The portions now exposed have been laid bare by erosion.

All the low-lying portions of Sauk County are underlain by the Cambrian sandstone. It also underlies all the hills north of the Chicago & Northwestern Railway except the quartzite ranges and nearly all of the towns of Honey Creek and Sumpter. Although hilly, these towns have but few heights which reach the level of the Lower Magnesian dolomite.

The eastern part of Sauk County from the mouth of Dell Creek on the Wisconsin River southward to the Prairie du Sac dam 2 miles north of Prairie du Sac is glaciated. Here a deep mantle of loose glacial debris including clays, sands, and bowlders of all kinds is very common. The Driftless Area to the west has many more outcrops. Here the surface mantle is composed chiefly of residual soil, wind deposits, lake beds, and stream-laid sediments. The floor of the Baraboo Valley from about 2 miles west of Baraboo to the Upper Narrows at Ableman is mantled with lake clays. Below the Prairie du Sac dam a deposit of stream-laid sands and gravels over 200 feet at its greatest depth fills the Wisconsin River valley between the high bluffs on each side.

Trempealeau dolomite.—The Trempealeau dolomite consists of a group of sandy and clayey dolomitic beds in the upper part of the Cambrian sandstone, usually 35 to 40 feet below the top of this formation. It is about 60 feet or more in thickness, but of this thickness less than 20 feet is strongly dolomitic. The formation wears away more slowly than the Cambrian sandstone beds directly above and below; therefore, like the Lower Magnesian dolomite, it is the protecting cap of benches and forms prominent vertical cliffs.

The Trempealeau dolomite, being an impure formation, is not a good lime maker, although it has been used locally for that purpose in the past. Where no other lime rock can be had, it can be used locally as an agricultural limestone. In the Cambrian sandstone country of the non-glaciated part of Wisconsin the decayed rock is a valuable source of clay for improving sandy roads.

Ferry Bluff at the mouth of Honey Creek in the SW. ¼ sec. 20, T. 9, R. 6 E., shows about 36 feet of Trempealeau dolomite, beginning 92 feet below the top of the hill. The lower 3 feet contain 26 to 34 per cent of clayey impurities. The remainder of the beds is covered with earth.

North of Spring Green about 2½ miles, in the SE. ¼ of sec. 36, T. 9, R. 3 E., the Trempealeau beds 45 feet thick are exposed 110 feet below the top of the hill.

On Mill Bluff, in the NW. ¼ NE. ¼ sec. 17, T. 9, R. 6 E., about 90 feet of Trempealeau dolomite is exposed. The beds are overlain by 80 feet of sandstone. The cap rock of the hill consists of about 29 feet of Lower Magnesian dolomite. Both the Trempealeau and the Lower Magnesian dolomite form bold vertical cliffs which can be seen for many miles. Analysis 8 (p. 183) gives the composition of the Trempealeau beds.

These beds can be traced along the bluffs of the Wisconsin River to the western boundary of the county. A few of these beds are found on the isolated bluff on Otter Creek in the town of Sumpter near the farm of Ex-Governor Philipp. They appear about 45 feet from the top.

Mendota dolomite.—The Mendota beds are exposed at Cahoon's quarry in sec. 10 of the town of Baraboo and at Eiky's quarry in sec. 25 of the town of Greenfield. At Cahoon's quarry 10 or 15 feet of earthy, porous, finely crystalline, and rough-surfaced dolomite caps a small ridge. The beds of Eiky's quarry are similar to those of Cahoon's quarry. Their thickness is about 25 feet. The individual layers run from 1 to 6 inches in thickness and are rough textured, brown, and slightly earthy. The composition of the dolomite is given in analysis 9 (p. 183).[1]

Lower Magnesian dolomite.—Quarries in the Lower Magnesian dolomite have been opened in the towns of Washington, Bear Creek, Spring Green, Franklin, Westfield, Honey Creek, Troy, Prairie du Sac, and Sumpter.

The beds of Lower Magnesian dolomite capping the precipitous bluff known as Mill Bluff in the NW. ¼ NE. ¼ sec. 17, T. 9, R. 6 E., are as follows:

Top of section	Feet
I. Red residual soil with dolomite fragments, analysis 57 (p. 185)	4
II. Rotten dolomite below I, analysis 58 (p. 185)	2

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[1] Irving, R. D., Geol. of Wisconsin, vol. 2, p. 594, 1877.

III.	Dense, buff dolomite, analysis 59 (p. 185). The carbonate content of these beds is higher than that of the average run of Lower Magnesian dolomite. They make a very good local agricultural limestone	9
IV.	Coarse-grained, rotten dolomite with thin flint seams parallel to bedding. No analysis	29

Ferry Bluff at the mouth of Honey Creek in the SW. ¼, sec. 20, T. 9, R. 6 E., has the thickest section of Lower Magnesian dolomite in this part of the state, about 74 feet. The description follows:

Top of section		Feet
I.	Fine grained dolomite—top about 310 feet above Wisconsin River	3
II.	Soil covered slope	12
III.	Dolomite like I	2
IV.	Soil covered slope	4
V.	Dolomite like I	6
VI.	Fine grained, dense dolomite, analysis 54 (p. 185)	17
VII.	Thin bedded fine grained dolomite, analysis 55 (p. 185)	6
VIII.	Thick bedded dolomite, analysis 56 (p. 185)	24

The composition of beds I, III, and V is given in analysis 53 (p. 185.)

Shawano County

General geology.—This county is underlain by the hard crystalline rocks of the pre-Cambrian in its northwest part. To the southeast of this area are nearly parallel strips of Paleozoic rocks trending northeast. Starting at the boundary of the pre-Cambrian rocks and going southeast, these strips of sedimentary rocks are as follows: the Cambrian sandstone, Lower Magnesian dolomite, St. Peter sandstone, and Galena and Black River dolomite. See Plate VI for the distribution of these formations.

Dolomite outcrops are scarce in Shawano County, for the mantle rock of soil and glacial debris is deep in most places. Most of the outcrops are along the low bluffs marking the western margins of the dolomite formations, and in the stream channels. The escarpment at the western margin of the Lower Magnesian dolomite is more prominent than that of the Galena and Black River formation.

Lower Magnesian dolomite.—Several outcrops occur in the towns of Lessor and Hartland and at several points between Angelica and the Oconto River. In the SE. ¼ sec. 34 of the town of Westcott, this formation caps a bluff whose lower layers are composed of the Cambrian sandstone. About 18 feet of dolomite beds are exposed. Their description follows:[1]

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[1] Chamberlin, T. C., Geol. of Wisconsin, vol. 2, p. 281, 1877.

Top of section	Ft.	In.
I. Soil		
II. Rather thin bedded, shaly, sandy dolomite	4	0
III. Bluish, irregular dolomite containing geodes of quartz	3	0
IV. Compact, flinty dolomite	1	0
V. Grayish, white dolomite		8
VI. Flinty dolomite	1	6
VII. Light gray dolomite		3
VIII. Layer with spherules of flint like fish roe	2	0
IX. Concealed layers	3	0
X. Layer with flint spherules like fish roe	3	0
XI. Light colored dolomite partially exposed		
XII. Slope concealing dolomite		

The Lower Magnesian dolomite has been quarried and burned for lime by Henry Perschbacker near Advance, the Wussow Lime Kiln Company near Bonduel, and by Bert L. Darling near Pulsifer.

No analyses of the Lower Magnesian dolomite of Shawano County are available. The descriptions of certain ledges in the county and the general character of the Lower Magnesian dolomite indicate that without careful selection it would not make a high grade commercial lime, but it would be satisfactory as a local source of agricultural limestone.

Galena and Black River dolomite.—Scattered and meager exposures of the Galena and Black River dolomite are found in the towns of Lessor, Maple Grove, and Angelica. As a source of local building material they have been useful. No analyses of these ledges are available. In general it is inferior to the Niagara dolomite as a source of pure dolomite, dolomitic limes, or agricultural limestone. Certain beds are usually satisfactory for the local production of lime and soil neutralizer. The average ledge has between 5 and 10 per cent impurities.

Sheboygan County

General geology.—All of Sheboygan County is underlain by Niagara dolomite. The mantle rock is of glacial origin. Most of the surface is gently undulating or nearly level. A low wave cut bench follows the Lake Michigan coast. Parts of the towns of Rhine, Greenbush, and Mitchell show the rough kettle type of surface. Hills of glacial debris are also numerous in the town of Sherman. South of Plymouth and east of the Chicago, Milwaukee & St. Paul Railway the surface is quite level, being partly underlain by red lake clays. A large marshy tract, the Sheboygan Marsh about 20 square miles in area, lies to the northwest of Glenbeulah. It is underlain by peat and marl. The Sheboygan River flows in a deep valley with steep sides from the vicinity of Sheboygan Falls to Lake Michigan.

Niagara dolomite.—Sheboygan County is underlain by the upper beds of the Niagara dolomite. They are buff, blue, or gray, thick bedded, rough on weathered surface, and generally low in impurities. They are a good source of rock for any purpose in which a high dolomite content is desirable or satisfactory, such as quick lime, agricultural limestone, flux, and paper mill dolomite.

Outcrops of dolomite are scarce in this county. In the western part, the dolomite is nearly all buried under hummocky ridges of glacial drift. Along Lake Michigan, thick deposits of glacial clays cover the dolomite in most places. The most favorable places for outcrops are in the wave cut bluffs along Lake Michigan and in the stream bottoms. Outcrops of dolomite are known at Lighthouse Point near Sheboygan. Old quarries are located in the NW. ¼ of SE. ¼ of sec. 9, and in the N. ½ sec. 7, T. 15, R. 23 E., and on the rapids of the Sheboygan River at Sheboygan Falls.[1]

The principal lime quarries in Sheboygan County are the Sheboygan Lime Works, the Falls Lime and Stone Company of Sheboygan Falls, and the Garden City Land and Lime Company of Elkhart Lake in sec. 18, T. 16, R. 21 E.

At the Sheboygan Lime Works in the NW. ¼ SE. ¼ sec. 9, T. 15, R. 23 E., over a hundred feet of beds are laid bare. For analyses of these beds see analyses 189,[2] 190,[3] 191, and 192[4] (p. 189). The insoluble matter is exceptionally low, making the total carbonate about 98 per cent. This is a very high grade rock for any purpose in which a nearly pure dolomite is either desirable or satisfactory, such as agricultural limestone, lime, and flux.

The beds at the quarry of the Falls Lime and Stone Company at Sheboygan Falls are described below.

Top of section	Ft.	In.
I. Grayish, sandy dolomite, analysis 197 (p. 189)	6	0
II. Very fine grained dense bluish stone, analysis 196 (p. 189)	1	6
III. Gray dolomite, analysis 195 (p. 189)	5	0
IV. Light colored coarse grained rock, analysis 194 (p. 189)	4	0

An additional analysis of the Niagara at Sheboygan was furnished by the Northwestern Iron Company of Mayville (analysis 193, p. 189).

All of Sheboygan County is glaciated and many of its gravel beds have 75 per cent or more of dolomite. Where local soil neutralizer is needed, it may be found in some cases that the cheapest source is selected dolomite gravel from local pits.

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[1] Chamberlin, T. C., Geol. of Wisconsin, vol. 2, p. 378, 1877.

[2] U. S. Geol. Survey Twentieth Ann. Rept. Pt. 6 cont., p. 464, 1899.

[3] Emley, W. E., The manufacture of lime; U. S. Bur. of Standards Tech. Paper 16, p. 122, 1913.

[4] Fischer, Jacob, personal. Analysis 191 represents the upper 20 feet and 192 the next 48 feet below.

Trempealeau County

General geology.—This county is underlain largely by Cambrian sandstone. Some of the highest hills and ridges are capped with thick bedded, compact Lower Magnesian dolomite. About 90 feet from the top of the Cambrian sandstone occurs a group of shaly dolomitic layers about 80 feet in thickness, called the Trempealeau dolomite. Like the Lower Magnesian dolomite, this formation has buff colored cliffs bordering flat benches and uplands, which are covered with a fertile soil.

Trempealeau dolomite.—North of the village of Trempealeau the Trempealeau formation forms steep slopes and cliffs about 85 feet high. They are covered by 90 feet of sandstone upon which rest 35 feet of Lower Magnesian dolomite. Analysis 10 (p. 183) gives the composition of the Trempealeau beds.

Lower Magnesian dolomite.—The hill north of the village of Trempealeau is capped by 35 feet of Lower Magnesian dolomite of which the lower beds are sandy. Flints appear to be absent. No analysis is available.

Dolomite quarries are owned by the following:

Near Arcadia	George Ziegler, Wenzel Kreibich, Herman Schreiber, John Rohn, Gustav Rube, George Motzko, Christ George, Martin Rebhahn, John Roesch, Frank Katzbahn, Kube Bros.
Near Galesville	Nicholas Perkins, L. S. Keith, Christ Johnson
Near Dodge	C. George
Trempealeau	Trempealeau Lime Products Company, Lehman Bros.

Vernon County

General geology.—All of this county is in the Driftless Area. Deep valleys dissect the surface. The high ridges and gently rolling uplands are mostly underlain by Lower Magnesian dolomite. See Plate VI. Some of the highest ridges still have beds of St. Peter sandstone covering them. On the St. Peter sandstone are a few small remnants of Galena and Black River dolomite. The lowlands are underlain by Cambrian sandstone.

Trempealeau dolomite.—About 40 feet below the base of the Lower Magnesian dolomite are found the Trempealeau dolomite beds, averaging about 60 feet in thickness. Little information regarding them is available. Wherever they have been studied, as in the adjacent portions of Sauk and Iowa counties, they have been found to be very impure, usually containing about 35 per cent of sandy matter. Where the Lower Magnesian dolomite has been stripped away as in the eastern part of this county and in the adjacent parts of Juneau County, they may be of value as agricultural limestone. The Trempealeau beds form flat-topped benches usually covered with good soil. The steep slopes of the benches are sometimes precipitous and often show outcrops of the dolomite.

Lower Magnesian dolomite.—This formation outcrops along the sides and upper portions of the bluffs which flank the valleys. Along the Mississippi River, the Lower Magnesian dolomite consists of two well-defined parts. The lower part is 30 to 40 feet thick and is made up of a soft easily quarried rock which makes good building stone and flagging. Above this is a thick layer of what some quarrymen call "Niggerheads." It is a very dense, resistant stone, which forms the tops of the bluffs along the Mississippi River from a short distance below Lynxville in Crawford County northward to Prescott in Pierce County. These upper layers are generally the purest, although locally they contain thin flint layers and nodules.

Towards the eastern part of the county, outcrops of Lower Magnesian dolomite become less numerous and occur along the edges of the bluffs which overlook the valleys underlain by Cambrian sandstone. The soil covering becomes deeper and weathering extends to considerable depth below the surface.

The following is a list of dolomite quarry owners and of the locations of the quarries. Some of these quarries may be abandoned now:

Viroqua	Isaac Mornson, J. A. Moen
Genoa	Geo. Flick, A. J. Latimer, Chas. Hoover, John McDonald
Near Stoddard	Jac. Strock
Stoddard	Jacob Beans, John Brittlich, H. Seidal, Ludwig Scheuck
La Farge	Village of La Farge

Large outcrops of Lower Magnesian dolomite occur in the village of Springville of the town of Jefferson, and along the banks of the stream below the village. Extensive quarries were formerly operated here. The dolomite beds are 1 to 4 feet thick, of a light yellow color, and are handsome building stone.

Along Coon Creek in the town of Hamburg there are many outcrops of the lower beds of the Lower Magnesian dolomite. As a rule these are not so pure as beds higher up. They may be useful, however, as a local agricultural limestone.

Walworth County

General geology.—The Niagara dolomite underlies the eastern part of Walworth County. The western portion is underlain by Galena and Black River dolomite. Between the two is a narrow strip of Richmond shale, which is entirely covered by soil and glacial drift. Outcrops of the dolomite formations are also scarce because of the deep drift cover.

In the town of Spring Prairie there are a number of quarries of Niagara dolomite. Details regarding them are lacking. They are located in the lower part of the Niagara dolomite. The lowest beds of this formation in the southern part of the state are commonly flint bearing.

Galena and Black River dolomite.—This dolomite is quarried at Whitewater and in the town of Sharon. The quarries in the town of Sharon were not examined.

At the Whitewater city quarry 17 feet of Galena and Black River dolomite are exposed. The lower 2 feet consists of a blue, fine-grained dolomite, having the composition indicated by analysis 131 (p. 187). The composition of the upper 15 feet is shown in analysis 132 (p. 187).

The Galena and Black River dolomite of Walworth County as indicated by the analyses on record has about 8 per cent of impurities. It is too impure to serve the purposes of a high-grade dolomite. It can be used as a local agricultural limestone.

Gravels.—Gravels are found throughout Walworth County, but are especially abundant along the margin of the last drift sheet, which is marked by a belt of undulating drift hills extending across the towns of Richmond, Darien, Sharon, Delavan, Walworth, and Linn. See Plate VI. In some cases for local supplies of agricultural lime it may be cheaper to crush selected dolomite gravels rather than quarried dolomite.

Washington County

General geology.—Portions of the western part are underlain by Galena and Black River dolomite and Richmond shale. The Niagara dolomite underlies the rest of the area. Outcrops of dolomite are scarce due to the thick covering of glacial drift. No outcrops of Galena and Black River are known, and outcrops of the Niagara dolomite are nearly all confined to stream valleys.

Niagara dolomite.—Quarries in this formation are located at South Germantown, Rockfield, Kewaskum, West Bend, and Hartford. The following firms have produced lime:

Rockfield Products Company, Rockfield
Western Lime and Cement Company, South Germantown
Peter Pastors, West Bend.

No analyses are available, but the Niagara dolomite of this county can be used for any purpose requiring a dolomite high in magnesia.

Waukesha County

General geology.—The eastern part of the county is underlain by the Niagara dolomite. See Plate VI. A narrow strip to the west of this is underlain by Richmond shale. The extreme western part is underlain by Galena and Black River dolomite, which is completely covered by glacial drift.

Niagara dolomite.—Outcrops of Niagara dolomite are common in the western part of the county in spite of the thick glacial drift. In the southwest quarter of sec. 10, town of Eagle, the lowest beds of the formation are exposed. Chamberlin says that Hinckley quarry[1] shows 4 feet of thin-bedded, impure dolomite overlain by 9 feet of thicker-bedded, coarse, cavernous dolomite which weathers to a very rough, ragged exterior. He also reports that outcrops of flint-bearing dolomite are found in secs. 11 and 14 of the town of Ottawa. In sec. 11 one outcrop had 3 feet of moderately hard, compact dolomite with some shaly, rotten dolomite layers beneath.

Lee Bros. quarry, opened in 1848, is located in secs. 23 and 26 in the town of Genesee. The depth of the beds averages about 15 feet. Their composition is shown by analysis 200 (p. 189).[2] The total carbonate is low for Niagara dolomite and the beds would not be suitable for high-grade lime or any other purpose in which a pure dolomite is desirable. Analysis 201 (p. 189)[3] of stone from the same quarry shows about the same amount of impurities as analysis 200.

Near the village of Delafield the Niagara dolomite beds are about the same as in the town of Ottawa. In the SE. ¼ of sec. 20 of the town of Delafield a few feet of cherty crystalline dolomite are exposed. These were formerly burned for lime. Analysis 198 (p. 189)[4] is from the upper layer of this outcrop and analysis 199 (p. 189)[5] from the lower layer.

South of Pewaukee Lake in the SW. ¼, sec. 24, town of Delafield, the Niagara dolomite beds are close textured and cherty. The chert is distinctly arranged in layers parallel to the bedding.

At the old Pelton quarry near Pewaukee the lower layer is almost entirely composed of large Pentamerus shells embedded in white dolomite. The composition of this bed is shown by analysis 207 (p. 189).[6]

Weaver's quarry is located in the SE. ¼ NW. ¼, sec. 35 of the town of Lisbon northeast of Pewaukee. About 8 feet of very fine-grained, dense, and brittle Niagara dolomite beds are exposed here. The composition is shown by analysis 208 (p. 189).

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[1] Chamberlin, T. C., Geol. of Wisconsin, vol. 2, p. 342, 1877.

[2] Hunkel, Carl.

[3] Buckley, E. R., Building and ornamental stones of Wisconsin: Wisconsin Geol. and Nat. Hist. Survey Bull. 4, p. 314, 1898.

[4] Chamberlin, T. C., op. cit., p. 338, 1877.

[5] Idem, p. 338.

[6] Idem, p. 381.

About 250 paces northwest of the Weaver quarry there is an outcrop of porous, decayed dolomite, whose composition is indicated by analysis 209 (p. 189).

The Templeton Lime and Stone Company's quarry in the NW. ¼, NE. ¼, sec. 26, T. 8, R. 19 E. exposes about 30 feet of Niagara dolomite. A description of the beds follows:

Top of section	Ft.	In.
I. Buff colored, mostly fine grained. Some porous and cavernous. Analysis 212 (p. 189)	15	0
II. Thick-bedded, fine-grained, dense, bluish dolomite. Analysis 211 (p. 189)	15	0
III. Very fine-grained, light-colored, dense bed. Looks different from other beds. Analysis 210 (p. 189)		4

The Waukesha Lime and Stone Company's quarry is located ½ mile north of Waukesha. About 30 feet of gravel overlies the Niagara dolomite in places. About 20 feet of dense, fine-grained Niagara dolomite is exposed. The lower 15 feet is bluish in color and its composition is indicated by analysis 213 (p. 189). Analysis 214 (p. 189) represents the composition of the upper 5 feet which is bleached and slightly weathered. The beds chosen for analysis 215 (p. 189) are not known.

The section of the R. H. Gumz quarry west of Lannon follows:

Top of section	Feet
I. Buff-colored dolomite—slightly decomposed. Contains small vugs of calcite. Native copper reported from clay seams parallel to bedding. Analysis 205 (p. 189)	25
II. Very compact, hard, bluish dolomite. Analysis 204 (p. 189)	15

See also analyses 202[1] and 203[2] (p. 189) and analysis 206 (p. 189) of samples from other quarries near Lannon.

Following is a partial list of the dolomite producers of Waukesha County:

Lannon	B. Cawley, Davis Bros. Stone Company, Froemming Bros., Schneider Stone Company, Lake Shore Stone Company, H. Harmon & Sons
Menomonee Falls	Albert Droose
Waukesha	Waukesha Lime and Stone Company, John Boeger

Gravels.—Gravel pits are numerous in Waukesha County. The chief constituent of these gravels is dolomite. Where fields requiring agricultural limestone are nearer to gravel pits than to dolomite outcrops, it may be found cheaper to crush selected dolomite gravel for this purpose.

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[1] Thompson, J. E., personal communication.

[2] U. S. Geol. Survey Twentieth Ann. Rept., Pt. 6 cont., p. 463, 1899.

Waupaca County

Lower Magnesian dolomite.—Outcrops of this formation occur in the eastern part of the town of Caledonia and the southeastern part of the town of Mukwa.

The quarry in the NE. ¼ of the SE. ¼ sec. 27, T. 21, R. 14 E. has a 25-foot face in dolomite of good quality either for concrete aggregate or agricultural limestone.

Analysis 60 (p. 185) was furnished by the Independent Lime Company, who operate a quarry near Readfield.

Winnebago County

General geology.—Winnebago County is underlain by four roughly parallel strips of sedimentary rocks, trending northeast. Starting at the northwest, these strips occur in the following order: Cambrian sandstone, Lower Magnesian dolomite, St. Peter sandstone, Galena and Black River dolomite. For distribution of these formations, see Plate VI.

Most of the eastern part of Winnebago County is level, being covered by lake clays. Outcrops are scarce in this part. The remainder of the county is level or gently rolling. The only prominent rise in the surface is the escarpment which marks the western edge of the Lower Magnesian dolomite south of Lake Poygan.

Lower Magnesian dolomite.—Outcrops occur along its western margin. It also crops out in a few places where the surface is nearly level. Outcrops occur at several points west of Rush Lake, in sec. 15 of the town of Nepeuskun, northwest of Winneconne, near the village of Eureka, and in the NW. ¼ of sec. 26, town of Poygan.

The Lower Magnesian dolomite which outcrops west of Rush Lake and to the northwest of Winneconne is exceedingly variable in composition, grain, hardness, and bedding, and would not make good commercial lime, but might, if the best beds were selected, be used as a local agricultural limestone. Near the village of Eureka 32 feet of Lower Magnesian dolomite are exposed. The section is as follows:

Top of section	Feet
I. Thin bedded, even grained dolomite of medium hardness. Contains cavities lined with quartz crystals	10
II. Soft, impure, shaly layers	16
III. Thick bedded compact, even grained dolomite of medium hardness	6

Southwest of Eureka a ledge of Lower Magnesian dolomite shows the following layers according to Chamberlin.[1]

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[1] Chamberlin, T. C., Geol. of Wisconsin, vol. 2, p. 276, 1877.

Top of section	Feet
1. Heavy, irregular beds of impure dolomite containing many quartz geodes; texture varying; bedding, uneven and somewhat undulatory; rock on weathering has rough, rugged surface. Thickness	10
2. Reddish shale, variegated with gray and green, the lower portion mostly soft, breaking and crumbling easily. Some parts sandy. Upper portion more limy and containing many quartz geodes. The layers irregular and somewhat undulating. Thickness	15
3. Very heavy beds, nearly uniform in thickness. Horizontal. Almond sized but irregular cavities common, a few of them geodes. Texture granular, medium hardness, dirty gray or buff on surface, but mottled bluish on the interior. Has been used for construction of locks in Fox River. Thickness exposed	6

At the old lime kiln quarry in the NW. ¼ of sec. 26 in the town of Poygan the beds of Lower Magnesian dolomite are described as follows by Chamberlin:

Top of section	
Thin bedded, wavy bedded dolomite. Layer variable in its characteristics	3 feet
Soft, earthy granular dolomite. Beds below medium in thickness	16 feet
Yellowish gray dolomite	1 foot
Rotten dolomite	8 inches

An analysis of a sample from this ledge showed the constituents indicated by analysis 61 (p. 185).[1]

Galena and Black River dolomite.—The beds of this formation in the Robert Lutz quarry at Oshkosh are about 37 feet thick. They are as follows:

Top of section	Feet
I. Soil	
II. Dimension stone	12
III. Thin bedded frost broken dolomite	a few
IV. Fine grained, bluish colored dolomite with flint nodules and numerous calcite lined cavities	15
V. Shaly, bluish dolomite with fossils	10

An average analysis of this section is given in analysis 133 (p. 187).

West of Neenah and Menasha a series of quarries has been opened of which the most important are the G. H. Salter quarry and the city quarry of Neenah. The former quarry is below the general level of the country and the rock quarried has to be hoisted to the crusher. The section quarried is as follows:

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[1] Chamberlin, T. C., Geol. of Wisconsin, vol. 2, p. 285, 1877.

Top of section	Feet
I. Fine grained buff, thin bedded dolomite with flint nodules. Analysis 134 (p. 187)	6
II. Dense thick bedded, bluish dolomite. Lowest beds are sandy, marking transition into St. Peter sandstone below. The sandy portions have a high content of iron sulphide in concretions and also in fissures. Analysis 135 (p. 187)	12

The upper beds of the quarry show a high carbonate content similar to the Niagara dolomite, but the lower beds have the impurities characteristic of the Galena and Black River dolomite elsewhere.

Following is a partial list of the dolomite producers of Winnebago County:

Menasha, J. C. Jorgensen
Oshkosh, Lutz Stone Company, Last Stone Company
Winneconne, H. E. Gilbert
Poygan, Winnebago County
Omro, G. Ulrich

High Calcium Limestones of Wisconsin

Those interested in high calcium limestones are referred to page 97 for a list of all the analyses of high calcium limestones of Wisconsin now on file. The high calcium limestones occur in the upper part of the Black River and in the lower part of the Galena formation of the lead and zinc district of southwestern Wisconsin including Grant, Iowa, and Lafayette counties. Some are also known at Ellsworth in Pierce and near Sun Prairie in Dane County. About 30 feet of beds in this group range from dolomitic limestones to limestones. The lowest layer of the group is about 40 feet above the bottom of the Black River formation. The purest of these beds is the "glass rock" at the top of the Black River. The entire group of beds is high in clayey matter. Usually 10 per cent or more insoluble matter is present. Only a few feet of the entire group as a rule has little or no dolomite. The composition of the beds varies from place to place as the magnesium carbonate is due to an irregular replacement of the original limestone by dolomite.

The high calcium limestone beds are usually covered by dolomite beds, so quarrying for the limestone beds on a commercial scale would entail mining underground or the expense of stripping.

Two places are known in the lead and zinc region where high calcium limestones occur near the railroad. One is in sec. 36, T. 5, R. 2 E. The description of these beds is given under the discussion of Iowa County of this report (p. 58).

The other locality where high calcium limestone is found near the railroad is about 1 mile west of Buncombe along the road north of the Fever River. Here about 15 feet of thin-bedded limestone of the lower part of the Galena crops out in a steep cliff. The cover of earth and dolomite is considerable here and becomes greater as the beds are followed into the hill. The limestone beds have thin, shaly partings. No analysis is available.

Other localities where high-calcium limestones outcrop in southwestern Wisconsin are listed below. See Supplementary Maps to Bulletin 14 of this Survey. Analyses are not available. The thickness of the high calcium limestone is also uncertain, but probably does not exceed 25 feet in any case.

1. NE. ¼ of NE. ¼, sec. 32, T. 2 N., R. 1 E.
2. NE. ¼ of SE. ¼, sec. 15, T. 2 N., R. 1 E.
3. Along Block House Creek, S. ½ of NW. ¼ and N. ½ of SW. ¼, sec. 34, T. 3 N., R. 1 W.
4. NW. ¼ of NW. ¼, sec. 14, T. 2 N., R. 1 E.
5. NW. ¼ of NE. ¼, sec. 23, T. 2 N., R. 1 E. on Rowe Creek.
6. NW. ¼ of SW. ¼, sec. 24, T. 2 N., R. 1 E.
7. Along creek in SW. ¼, sec. 4, T. 4 N., R. 3 E.
8. On Shullsburg Branch NW. ¼ of NE. ¼, sec. 9, T. 1 N., R. 2 E.

Nine high-calcium limestones have been discussed in the preceding pages: analysis 70 (p. 42), 87 to 91 inclusive (p. 53), 94 (p. 54), 95 (p. 58), and 107 (p. 62).

CHAPTER IV

USES OF MARLS, LIMESTONES, AND DOLOMITES BASED ON THEIR CHEMICAL COMPOSITION

The uses of marls, limestones, and dolomites discussed in this report are based on their composition and are therefore distinct from structural uses which depend only on strength, color, hardness, and other physical properties.[1] The composition of both limestones and dolomites makes it possible to use them in the making of lime, and as agricultural limestone on acid soils. Both are used by paper makers and for fluxing certain ores. As a flux, limestone is commonly preferred. Most so-called natural cements were made from impure dolomites. Natural cements are now used very little in the United States. Only high-grade limestones or marls very low in magnesia are desired for making Portland cement and lime for sand lime brick. Sugar factories also use only very pure limestones. These various uses are taken up in detail farther on. Marl, because of its water content, is used very little excepting for agricultural limestone and for Portland cement.

LIME AND LIME HYDRATE

The Manufacture of Lime and Lime Hydrate

Lime and lime hydrate are made by driving off all or nearly all the carbon dioxide, water, and other volatile constituents from limestone or dolomite by means of heat. The heat applied should be sufficient to do this work, but not high enough to cause a chemical union of the lime and magnesia of the limestone with the impurities such as silica, iron, and kaolin. When this takes place, the lime is said to be overburned, has a yellow color, and does not slake well. The amount of heat which should be applied in order to get the best results varies with the composition, grain, and pore space of the stone. It should be the minimum amount. From experimental evidence it has been assumed to be 722 B. t. u. per pound of calcium carbonate and 464.3 B. t. u. per pound of magnesium carbonate. One B. t. u. represents the amount of heat required to raise the temperature of one pound of water at a temperature of 39° F. one degree Fahrenheit.

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[1] Buckley, E. R., Building and ornamental stones of Wisconsin: Wisconsin Geol. and Nat. Hist. Survey Bull. 4, 1898; also Hotchkiss, W. O., and Steidmann, Edward, The limestone road materials of Wisconsin: Wisconsin Geol. and Nat. Hist. Survey Bull. 34, 1914.

The lime produced by burning limestone or dolomite consists chiefly of the oxides—lime and magnesia. The lime from an impure limestone or dolomite may contain free silica and alumina. The latter in most cases is probably present as a silicate. Iron oxides may also be present. As already stated, overburning may cause the lime and magnesia to combine with the impurities and thus to form a slag. The active constituents of the lime which make it commercially useful are the oxides of lime and magnesia.

Lime is usually burned in vertical kilns built of stone or of steel and stone. Four principal types of lime kilns are in use. The one most commonly used is the flame or patent kiln, which consists of a vertical shaft usually about 30 feet high, and about 5 to 8 feet in diameter, either rectangular, circular, or elliptical in cross-section. It is charged from the top and is continuous in operation. The distinctive feature of this kiln is that only the flame and not the fuel come in direct contact with the lime and rock.

A pot kiln is a vertical shaft which is continuous in operation. Its peculiar feature is that fuel and stone are dropped in it in alternate layers. The field kiln is the only kiln which is intermittent in operation. It is fired until a charge is completely burned, when it is emptied and recharged. In all these kilns wood is the fuel commonly used in Wisconsin. In 1918, 56.4 per cent of the kilns of the United States used coal, 12.4 per cent wood, 9.6 per cent coke, and 4.8 per cent producer gas.

The rotary kiln is a gently inclined hollow cylinder built of steel plates and lined with a refractory material. In all essentials it is like the Portland cement kiln. The stone is finely ground, and the charge fired with ground coal. The temperature used is about 800° C. whereas it is about 1425° C. in the cement kiln. The product is a lime flour and not lump lime. In 1918[1] there was an increase of 42 per cent in the number of rotary kilns in the United States despite the decrease of 20 per cent in the total number of kilns. This increase seems to indicate that the rotary kilns are beginning to be recognized as a very efficient type. They burn the small sizes of stone which choke the draft in upright kilns, and produce a good quality of lime, especially for hydrated lime.

Lime is put on the market either as lump lime or ground lime. Since lump lime falls to a powder when air slaked, the market has been prejudiced against fine lime. When lime is exposed to the air it first absorbs water and forms a lime hydrate and then the water is replaced by the carbon dioxide of the air. In this last step the lime goes back to the composition of limestone or dolomite. When this condition has been attained, the lime is said to be air slaked. A considerable expansion of

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[1] Mineral Resources of the United States: U. S. Geol. Survey, 1918, Pt. 2, p. 854.

volume takes place in this process; hence the lumps fall to pieces. It has been found, however, that finely ground lime keeps better than lump lime, since it does not permit such ready access of air. A thin film of air-slaked lime forms on the surface of a pile of fine lime and protects the interior from the action of the atmosphere.

Hydrated lime is lime which has been mechanically slaked. It is prepared by adding to ordinary lime just sufficient water to assure complete slaking, which leaves the product a fine dry powder. Any lumps which do not slake are removed by screening. In composition it is essentially a hydrate of calcium and magnesium oxides. The water content varies from 24.3 per cent for pure calcium hydrate to 11.3 per cent for impure dolomitic hydrate. If properly screened, it usually contains less impurities than the lime from which it was made.

Qualities of Limestone and Dolomite for Lime Burning

The chief property of limestone and dolomite which determines fitness for lime burning is chemical composition, although size of grains and porosity affect the cost of burning considerably. Experience has shown that a fine-grained, dense stone can be burned at a lower temperature and with less heat than one which is coarse grained and porous. Coarsely crystalline stones, especially if very pure, are apt to fall to pieces in the kiln, thus reducing the production of lump lime. The same is sometimes true of porous stones, but in this case, the falling to powder is thought to be due to the rapid expulsion of water which may fill the voids. Laboratory tests made by the U. S. Bureau of Standards seem to contradict the results of practice. Bleininger and Emley[1] found that "all naturally porous stones lost their carbon dioxide at a lower temperature (about 900° C. or 1652° F.) than the denser materials."

It is suggested by the Bureau[2] that the discord between laboratory and practical results may arise from differences in the size of stone used, the quantity of material, and similar factors.

Every gradation from limestone containing nearly 100 per cent calcium carbonate to dolomite containing 54.35 per cent calcium carbonate and 45.65 per cent magnesium carbonate is believed to exist. In most cases, however, rocks of this type are composed of calcium carbonate with less than 15 per cent of magnesium carbonate or of nearly pure dolomite with less than 10 per cent of calcium carbonate in excess of the calcium carbonate required to satisfy the dolomite ratio. Most of the commercially important limestones used for burning lime have at least 97 per cent of carbonates. The other constituents are chiefly

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[1] Bleininger, A. V., and Emley, W. E., Burning temperatures of limestone: Trans. Nat. Lime Mfgrs. Assoc. 1911, p. 77.

[2] Emley, W. E., Manufacture of Lime: U. S. Bur. of Standards Tech. Paper 16, 1913.

silica, alumina, and iron oxides. These may be regarded as impurities. The silica is usually present as quartz and in combination with the alumina, probably as kaolin. The iron is usually present as the ferrous carbonate and the ferric oxide. All of these accessory constituents may occur in other combinations than those given.

The chemical composition of limestone and dolomite affects the cost of burning and the texture, composition, plasticity, sand-carrying capacity, hardness, strength, spreading quality, time of set, and constancy of volume of lime. Lime has the same constituents as the limestone from which it is made minus the carbon dioxide; hence the chemical composition of the lime depends upon the composition of the limestone from which it is made.

Water, magnesia, and the impurities affect the cost of burning. If for instance the limestone or dolomite contains much water, this water must be evaporated in the kiln. Consequently, some heat which should be active in driving off the carbon dioxide will be spent in evaporating the water. In this way the amount of lime produced per unit of heat is less than it should be. In other words, the efficiency of the kiln is reduced. The greater the proportion of impurities, the more easily is the lime overburned, and therefore too large a proportion of impurities will cause a diminution of kiln capacity. Experience has shown that it generally takes less heat and a lower temperature to burn a magnesian than a high calcium stone.

The texture of the lime is determined chiefly by the water content and impurities of the limestone. The driving out of a large content of water by the heat of the kiln tends to break the lumps of lime into pieces. When the proportion of silica is high enough, lime orthosilicate ($2CaO\ SiO_2$) may form in the kiln.[1] On cooling slowly to 675° C. (1247° F.) this substance increases considerably in volume. This causes the lime to fall to pieces, a phenomenon known as "fire slacking."

The effects of the various constituents of limestone on the physical properties of lime will be considered in order. On the basis of calcium and magnesium content, limes have been classified as:[2]

High calcium limes—containing 0 per cent—5 per cent magnesia
Magnesian lime—containing 5 per cent—25 per cent magnesia
Dolomitic lime—containing 25 per cent—45 per cent magnesia
Super-dolomitic lime—containing more than 45 per cent magnesia

A dolomitic lime will slake more slowly, generate less heat, combine with less water, undergo less increase in volume, set more slowly, and shrink less on setting than a high calcium lime. These are gen-

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[1] Day, A. L., and Shepherd, E. S., The lime silica series of minerals: Jour. Am. Chem. Soc., p. 1089, 1906.

[2] Mineral Resources of the United States: U. S. Geol. Survey, p. 1556, 1913.

eralizations, however. The properties are decidedly influenced by the impurities, the temperature of burning, and many other factors. The high calcium lime will take up more sand and spread more easily than dolomitic lime. In slaking, however, the high calcium limes need more vigorous stirring and closer attention than the cooler dolomitic limes. If not properly handled, the high calcium lime is easily overheated in slaking and then becomes lumpy and hard to work. Very few experiments have been made to give all these properties, such as time of set and spreading quality, a definite meaning. No standard tests have been adopted. Though it can be said that one kind of lime has a certain quality to a greater degree than another, there are almost no quantitative measurements on record which give a precise idea as to the relative qualities of various limes.

One of the fundamental steps to such measurements would be to have the limes burned under standard conditions. If their qualities are to be correlated with their chemical composition, all other factors which affect the physical properties, such as overburning in the kiln and time of burning, must be eliminated. The U. S. Bureau of Standards is now engaged in making such investigations and their results may be expected to furnish buyers and sellers of lime with standard tests which in the future may figure in determining the value of limes.

The impurities of limestones, the sandy, clayey, and iron compounds, are of very little value in lime, and most of them are decidedly injurious. They may interact with the lime during burning and form silicates, thus reducing the output of lime and increasing the percentage of inert materials. Emley[1] states that a limestone should have no more than 2½ per cent of silica and oxides of alumina and iron, and concludes that the presence of a small amount of silica tends to decrease the plasticity, sand carrying capacity, and yield of a lime, but has no apparent effect on hardness or strength. The same is said of iron, except that large amounts of it, 25 per cent, show a marked increase in both strength and hardness. It may be said, however, that it is difficult to find a natural limestone or dolomite with so high an iron content and which at the same time is free from silica and other impurities. Of course iron affects the color, therefore an iron bearing lime can be used only where a white color is not needed. Alumina is said by Emley to increase the strength, hardness, plasticity, and sand-carrying capacity of a lime and to improve the color. This laboratory result probably has little value in practice, since a limestone containing a high percentage of alumina

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[1] Emley, W. E., Manufacture of Lime: U. S. Bur. of Standards Tech. Paper 16, p. 9, 1913.

almost always has a considerable content of silica as well, and the deleterious effect of the silica would probably offset any benefit that might come from the alumina. The alumina is usually present in the form of kaolin which has about the same effect as the oxides of silica and iron. Gypsum is reported to have a bad effect even when only 1 per cent is present.

The Uses of Lime and Hydrated Lime

Mortar and plaster.—The uses of lime and hydrated lime especially in the building trades are nearly identical. As shown on page 109, for certain uses dolomitic and high calcium limes may be used interchangeably. For some other uses one is more desirable than the other. High calcium lime produces more mortar per unit of weight than a magnesian lime.

Actual tests made by the U. S. Bureau of Standards show that dolomitic mortar is stronger than a high calcium mortar. It was found, however, that the most important element in the strength of a mortar was not its composition but its manner of preparation. For instance, the strength of a lime sand mortar was changed 25 to 30 per cent by different methods of adding water or by using different kinds of sand. For most ordinary buildings, however, the relative strength of the mortars need not be considered. Whether a dolomite or high calcium is to be preferred for mortar depends entirely on the relative cost of the two at the particular place where they are to be used, and the experience of the workmen in handling them.

A good plastering lime ought to spread easily, not crack on shrinking, pot or ''pit'' and if used for the finishing coat must have a good color. Pitting is believed to be due to impurities in the lime and to particles of unslaked lime which were ''burned'' in slaking. It is therefore important to get a pure lime and the dolomitic white limes are conceded to be better suited for plastering than the high calcium limes. Hydrated lime is probably more convenient and economical to use than quick lime. It is also purer than the lime from which it was made.

Hydrated lime has the advantage of being already slaked and is ready for use. Lime, especially high calcium lime, may be spoiled in slaking if not properly stirred. Since lime hydrate is stirred mechanically, all elements of carelessness or misjudgment are eliminated in its manufacture and a perfectly correct product is obtained. It does not heat on storing. It will, however, spoil or air slake as easily as quick lime of the same fineness. Being like flour in consistency, a thin outer film of air slaked material will form an impervious covering which prevents air from entering the interior of the pile.

The only disadvantage which hydrated lime has for the consumer is that 15 to 25 per cent of it is water, on which he must pay the freight. To the manufacturer it has the advantage of being an article which can be stored when the market is dull. It also enables him to use some grades of stone which fail to make good lump lime because of their dark color or because they fall to pieces. In 1919 there was in the United States an increase of 25 per cent in the production of hydrated lime, and but 4 per cent increase in total lime produced.

Portland cement.—Hydrated lime is added to Portland cement mortars in order to make them impervious to water. Lazell has shown that (1) hydrated lime up to 15 per cent does not affect the strength of the mortar even when the test specimens are stored under water, (2) this amount of hydrated lime will materially increase the impermeability to water of even a one to five cement-sand mortar, (3) the addition of hydrated lime increases the plasticity of the mortar and makes it easier to work. Quicklime will give the same results but hydrated lime is more convenient to use.

Sand-lime brick.—Sand lime bricks are made by compressing mixtures of sand and hydrated high calcium lime by means of hydraulic pressure. The bricks are then treated with high pressure steam which causes chemical combination between the sand and lime. The magnesian limes make a weaker brick. Impurities in the lime are generally not harmful unless they check the slaking of the lime. Kaolin up to 2½ per cent seems to be beneficial.[1]

Distillation of wood.—The products of the destructive distillation of wood are gas, pyroligneous acid, tar, and charcoal. From the pyroligneous acid are prepared wood alcohol, acetic acid, and acetone. In all of these processes, lime is essential. The crude acid is first distilled with lime. Wood alcohol is distilled off in this process, whereas acetic acid and acetone are held in the still in chemical combination with the lime. Acetone is produced either by dry distillation of the residue in the still, or it may be treated with sulphuric acid and the acetic acid distilled off. The wood alcohol is purified by again treating it with lime and then redistilling it. In this last process, only a high calcium quicklime can be used. For the others either a high calcium quicklime or the hydrated lime may be used. Magnesia and impurities are not harmful but are useless.

Paints.—Finely ground lime, air slaked lime, levigated chalk, and chemically precipitated calcium carbonate are used in the paint industries. In addition to fineness of grain, color and purity are important

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[1] For a thorough presentation of the properties of sand lime brick and their method of manufacture, see S. V. Peppel, The manufacture of artificial sand stone or sand-lime brick: Geo. Survey of Ohio, Bull. 5.

properties. Air slaked and hydrated lime are preferred because of their white color and fine grain.

Cold water paints consist chiefly of hydrated lime, pigments, and casein ground together. The hydrated dolomitic lime is probably to be preferred to the high calcium lime because of the better spreading quality of the magnesia.

Glycerine, lubricants, and candles.—Most of the common fats consist of glycerine with some organic acid. The glycerine is liberated by treating fats with a pure, high calcium quicklime. Quicklime is preferred to hydrated lime because the heat produced by slaking helps the process of breaking up the fats. The calcium takes the place of the glycerine, the glycerine is liberated, and the calcium and the acids form an insoluble soap. This soap is mixed with heavy mineral oils and is sold as a lubricant for heavy machinery, or for use at high temperatures. The calcium soap may be broken up with sulphuric acid. The products are solid calcium sulphate and the liquid organic acids. The organic acids are used in the manufacture of soap and allied products.

Tanning.—Lime water is used for loosening the hair from hides. For this purpose only a very pure calcium quicklime or hydrated lime is used. Iron oxide is objectionable because it may become mechanically fixed in the grain of the hide and cause stains. Magnesia is of no use in this process.[1]

The paper industry.—Grease and some colors are removed from rags used for paper pulp by boiling them with lime. The lime forms an insoluble soap with the grease.

Wood pulp consists of macerated cellulose or wood fiber from which all intercellular, resinous, starchy, or siliceous materials have been removed. These undesirable materials are removed either by boiling the wood with caustic soda or by boiling it with a liquor containing sulphur dioxide gas and calcium bisulphite or calcium and magnesium bisulphite. When the wood is boiled with caustic soda, the latter is converted in part into sodium carbonate. The sodium carbonate is recovered or reconverted into caustic soda by treating the liquor with lime. The reaction is $Na_2CO_3+Ca(OH)_2=CaCO_3+2Na(OH_2)$.

The bisulphites of calcium and magnesium are made by conducting sulphur dioxide gas up through a tower containing limestone or dolomite fragments. A porous stone is preferred. A standard amount of water permitted to trickle downward through the tower takes up the calcium and magnesium bisulphites formed by the interaction of limestone and sulphur dioxide or of dolomite and sulphur dioxide and a certain excess of sulphur dioxide gas.

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[1] Mineral Resources of the United States; U. S. Geol. Survey, 1913, p. 1592.

The reactions between the limestone and the SO_2 may be represented as follows:

(a) $CaCO_3+SO_2=CaSO_3+CO_2$. The CO_2 escapes from the top of the tower.

(b) $MgCO_3+SO_2=MgSO_3+CO_2$.

When the sulphites of calcium and magnesium are dissolved in water containing an excess of SO_2, they are called bisulphites, and are represented as $CaH_2(SO_3)_2$ and $MgH_2(SO_3)_2$.

Another process of making the bisulphites of lime or of calcium and magnesium is to conduct SO_2 into a tank containing water and either a high calcium lime or a dolomite lime.

The magnesium sulphite is not objectionable. In fact it is said to be desirable. It is a more soluble sulphite than calcium sulphite, and hence a more effective liquor can be made with magnesium sulphite than with calcium sulphite. Magnesium sulphite gives pulp a better color, makes it softer to the touch, and causes it to felt together better when made into paper.

Another use of lime in the paper industry is as a carrier of chlorine. In this form it is used for bleaching paper.

Glass making.—Calcium oxide is an important constituent of plate, sheet, and bottle glass. It acts as a flux. Magnesia raises the melting point of the glass, and is not used very much unless special optical properties are desired. The calcium oxide may be introduced in the form of quicklime or hydrated lime, but ground limestone is more commonly used. For white glass the content of oxide of iron must be less than 0.3 of 1 per cent.

Ceramics.—Dolomitic limes are used as fluxes in the manufacture of pottery and porcelain. The natural carbonate is used more than the oxide since it is cheaper. The carbonate is preferred when a porous ware is desired. For wares burned at moderate temperatures, calcium oxide tends to bring the points of vitrification and fusion close together, whereas magnesia tends to separate them, to lower the temperature of vitrification, and to decrease the change of shape due to burning. If the ware is to be burned at a higher temperature, magnesia has little effect on the points of vitrification and fusion, and increases the shrinkage. For glazes, magnesia is generally undesirable. By absorbing SO_3 from the kiln gases, it causes the production of a scum. Only small quantities of carbonate are used; hence a small percentage of impurities is not harmful.

Water softening.—High calcium lime is used in softening water which has "temporary hardness." Temporary hardness is due to the presence of calcium carbonate held in solution by carbon dioxide gas. Hot quicklime reacts with this excess of carbon dioxide and forms the insoluble calcium carbonate. The removal of the carbon dioxide causes the lime and magnesia carbonates in the water to be thrown down. The magnesia in the quicklime has no effect; hence it is desirable to use a high calcium lime.

Soda ash and caustic soda.—Soda ash is the trade name for carbonate of soda. It is made by saturating a solution of common salt with ammonia and the mixture is treated with CO_2. When the solution is evaporated, the soda ash is obtained by crystallization. The ammonia is recovered by treating the mother liquor with lime and then distilling it. The lime replaces the ammonia, and its compounds, and thus the gas is set free to distill off. In this process both the lime and the carbon dioxide of the limestone are used. Dolomitic limestone is believed to be unsuitable for this industry.

Caustic soda is made by dissolving soda ash in water and adding lime. The lime replaces the soda and forms insoluble calcium carbonate; the soda goes into solution as the caustic soda. In this industry, a very pure, high calcium lime is used. Magnesia takes no part in the process, and impurities are apt to interact with the caustic soda to form gelatinous substances which do not settle clear. Quicklime is preferable to hydrated lime because it hastens the reaction.

Bleaching powder.—Bleaching powder is an oxychloride of lime formed by the action of chlorine gas on a hydrated high calcium lime of great purity. Magnesium is very objectionable since it combines with chlorine and forms magnesium chloride, a compound which absorbs water. Bleaching powder containing magnesium chloride is weak, sticky, and hard to handle.

Calcium carbide.—Calcium carbide, the source of acetylene gas, is formed by heating a mixture of coke and very pure, high calcium lime in the electric furnace. The cost of the process makes a very pure lime desirable since only the calcium oxide enters into combination with the coke to form the desired product.

Illuminating gas and ammonia.—Illuminating gas is purified of useless and harmful ingredients, such as carbon dioxide, hydrogen sulphide, and hydrocyanic acid by passing through layers of moist, slaked lime. Only the calcium oxide is effective in this process; hence a pure high calcium lime is preferred.

Before reaching the lime purifiers, the crude gas is forced through water, which takes out ammonia, and some ammonia compounds. The ammonia is driven off or distilled off by heat and is recovered by cooling. The ammonia compounds in the water are broken up with pure, high calcium quicklime and the ammonia set free is distilled off and recovered.

Calcium cyanimide and calcium nitrate.—Calcium cyanimide and calcium nitrate are used as artificial means of converting the nitrogen of the air into plant food. The calcium cyanimide is a compound of calcium, carbon, and nitrogen formed by treating a fused mixture of pure, high calcium lime with nitrogen. The nitrogen is obtained from the fractional distillation of liquid air.

When air is permitted to pass through the heat of an electric arc, the nitrogen and oxygen combine to form the oxide of nitrogen, which, when passed into water, forms nitric acid. In this form, the nitrogen would be a deadly poison to plant life. When the nitric acid is permitted to act on lime, which is the cheapest base obtainable, lime nitrate is obtained. The lime is in itself a fertilizer for certain plants. For this purpose lime, hydrated lime, or limestone could be used. The impurities remain inert but are not harmful. It does not seem to be certain whether or not magnesium nitrate, which would form with dolomitic limes, is injurious to plants.

Agricultural lime.—Lime and hydrated lime can be applied as a plant food to some soils which are very deficient in lime; as a neutralizer of acids which have a very harmful effect on the growth of certain valuable plants such as red clover and alfalfa; as liberators of certain fertilizers in the soil which by their action become available to plants; and as improvers of soil tilth on clayey, sticky soils which are not easily penetrated by air.

The action of lime and hydrated lime is drastic. If their addition to the soil is not followed up by liberal applications of fertilizers, they tend to convert the fertilizers present into ammonia and other easily dissolved products which are removed from the soil by rain water or may escape into the air as gases. Ground limestone or dolomite is used most commonly on soils. Lime is quicker acting and 100 pounds is about equivalent to 200 pounds of limestone. The cheapness and milder action of the limestone make it more desirable. This is discussed at length later.

Spraying.—Finely powdered, hydrated lime is used as an insecticide for spraying vegetation. The impurities and magnesia are not objectionable, but calcium oxide is the only useful constituent.

Sugar making.—In the manufacture of sugar both carbon dioxide and calcium oxide are used; hence sugar manufacturers buy limestone and burn their own lime. A very pure limestone low in magnesia and impurities is used.

The juice extracted from beets and cane contains impurities which if allowed to remain would discolor the sugar. It also contains organic acid which changes sugar into uncrystallizable glucose. Lime is added to the juice. It neutralizes the acids and impurities by forming insoluble compounds with them. It also forms an insoluble compound with the sugar. At this juncture carbon dioxide is forced into the juice. This precipitates the calcium in solution and the calcium combined with the sugar as calcium carbonate and leaves a clear sugar solution which can be filtered off. Magnesium is objectionable since it is more soluble than calcium carbonate in sugar solutions. Some of it remains with the sugar solution until it is precipitated on the tubes of the evaporating pans, thus making it necessary to clean these pans more frequently. When silica is present in the lime, it is thrown out as a gelatinous precipitate, which clogs the filter presses.

Summary of uses of lime.—The following is a tabulation[1] of the uses of lime. The letter c indicates high calcium lime; m indicates magnesian lime. Brief notes on the most important uses are given in the preceding pages.

Chemical Uses of Lime

Agricultural industry—
  as a soil amendment, c.m.
  as an insecticide, c.m.
  as a fungicide, c.m.

Bleaching industry—
  Manufacture of bleaching powder
    Chloride of lime, c.
  Bleaching and renovating rags, jute ramie, and various paper stocks, c.m.

Caustic alkali industry—
  Manufacture of soda, potash, and ammonia, c.

Chemical industries—
  Manufacture of ammonia, c.
  Manufacture of calcium carbide, calcium cyanimide, and calcium nitrate, c.
  Manufacture of potassium dichromate and sodium dichromate, c.
  Manufacture of fertilizers, c.m.
  Manufacture of magnesia, m.
  Manufacture of acetate of lime, c.
  Manufacture of wood alcohol, c.
  Manufacture of bone ash, c.m.
  Manufacture of calcium light pencils, c.
  In refining quicksilver, c.
  In dehydrating alcohol, c.
  In distillation of wood, c.

Gas manufacture—
  Purification of coal and water gas, c.m.

Glass manufacture—
  In most varieties of glass and glazes, c.

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[1] Mineral Resources of the United States: U. S. Geol. Survey, 1911, p. 650.

Milling industry—
    Clarifying grain, c.m.

Miscellaneous manufactures—
    Rubber, c.m.
    Glue, c.m.
    Pottery and porcelain, c.m.
    Dyeing fabrics, c.m.
    Polishing material, c.m.

Oil, fat, and soap manufacture—
    Manufacture of soap, c.
    Manufacture of candles, c.
    Manufacture of glycerine, c.
    Renovating fats, greases, tallow, butter, c.m.
    Removing acidity of oils and petroleum, c.m.
    Lubricating greases, c.m.

Paint and varnish manufacture—
    Cold water paint, c.m.
    Refining linseed oil, c.m.
    Manufacture of linoleum, c.m.
    Manufacture of varnish, c.m.

Paper industry—
    Soda method, c.
    Sulphite method, m.
    For strawboard, c.m.
    As a filler, c.m.

Preserving industry—
    Preserving eggs, c.

Sanitation—
    Disinfectant, deodorizer, c.
    Purification of water for cities, c.
    Purification of sewage, c.

Smelting industry—
    Reduction of iron ores, c.m.

Sugar manufacture—
    Beet root, c.
    Molasses, c.

Tanning industry—
    Tanning cowhides, c.
    Tanning goat and kid hides, c.m.
Water softening and purifying, c.

The Present State of the Lime Industry in Wisconsin

The rise of the Portland cement industry has led to a decline in lime production in Wisconsin. The outlook at present for hydrated lime is more hopeful than for lump lime. This is because hydrated lime is rapidly coming into use in connection with cement because of its advantage for water proofing and increasing plasticity. In 1919 Wisconsin produced 100,120 tons of quicklime and 23,470 tons of hydrated lime, an increase in total production over 1918 of 13 per cent. More than 95 per cent of the production came from one formation in the eastern part of the state, the Niagara dolomite.

Wisconsin probably has over 150 lime kilns, of which perhaps more than half did not produce during the past 5 years. In 1918, the kilns reported as active included 35 flame kilns, 6 pot kilns, and 1 field kiln. The total number reported was 117, which did not include some of the kilns which produce occasionally for local purposes.

Most of the flame kilns in use are about 30 feet high measured from the grates. At the fires they are between 5 to 8 feet square. Nearly all burn wood. The lime output varies from 1.5 to 2.5 tons per cord of wood. A few kilns have been fired with coal gas. The continuous kilns are usually drawn about every 4 hours and yield 16 to 20 barrels per draw. The yield per kiln per day varies from 10 to 20 tons. No technical means of measuring temperatures are in use. Firing is controlled by the judgment of skilled operators.

AGRICULTURAL USE OF MARL, LIMESTONE, AND DOLOMITE

The chief purposes for which limestones and dolomites are applied to soils are (1) to supply plant food, and (2) to neutralize the injurious acids of many soils.

Uses as Plant Food

The chief plant foods which they supply are calcium and magnesium. Some have a small percentage of phosphorus. Both calcium and magnesium are essential to crops, but the amounts required are in most cases small. Clovers use an exceptionally large amount of calcium. Most soils have enough of these elements to supply the demands of growing crops.

There are no published investigations of a comprehensive nature regarding the lime content of Wisconsin soils. That some of our soils need limestone as a plant food is certain. It is true of many sandy soils of the Driftless Area. Phosphorus is a highly important plant food. Unfortunately our Wisconsin limestones and dolomites have a very low content of this desirable element. In over 200 analyses, the content of phosphoric acid (P_2O_5) varied from about 0.01 to 0.2 per cent. None of them can be regarded as having any value as sources of phosphorus. In the decay of limestone to soils, there is a tendency for a large part of the phosphorus to remain in the soil, whereas the carbonates of lime and magnesia are largely removed by solution. Hence soils derived from limestone not infrequently show about the same, or even a higher percentage of phosphorus than the parent material. For information on the amounts of calcium, magnesium, and phosphorus used by various crops see "Soil fertility and permanent agriculture," C. G. Hopkins, Ginn & Co., New York.

The chief dolomite formations of Wisconsin are not alike in their phosphorus content. The Niagara dolomite has the lowest content, the Galena and Black River has the highest, and the Lower Magnesian dolomite holds an intermediate position.

Uses as Neutralizers of Acids in Soils

The application of lime carbonates and dolomite to soils for overcoming a condition known as soil acidity is of great value in growing certain crops. The use of marl, limestone, and dolomite for this purpose in Wisconsin is increasing under the leadership of the College of Agriculture.[1]

Soil acidity is due to acid whose exact nature is not fully known. It is common in new soils rich in decaying vegetation, in peat bogs, in sandy soils, and in soils that have been cropped for a long time. It is usually accompanied by a low content of lime, magnesia, and phosphorus in forms usable by plants. It hinders or even prevents the growth of certain crops, and favors that of others.

The most baneful effect of soil acidity is that it stunts or even inhibits the growth of alfalfa and red clover, the most efficient of the nitrifying plants. Plants which do better in acid soils are radish, flax, blackberry, black raspberry, and cranberry. For carrying out the most profitable methods of crop rotation and for getting the nitrogen content of soils renewed by growing alfalfa and red clover, it is vitally important to overcome soil acidity.

Soil acidity can be detected by means of blue litmus paper which can be purchased from any reliable druggist. Soil which is naturally wet from rain or thaw can be slit open by a knife. The litmus paper is inserted in the slit and the soil is pressed against the paper. The contact of the soil and litmus paper should be maintained for five minutes. If the blue paper turns red in spots or over the whole end, the soil is acid.

The test can also be made by fashioning a ball of wet earth and then breaking it in half. The blue litmus paper is laid on one of the freshly broken surfaces. The other half of the ball is covered over it, and the two halves are pressed together.

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[1] For valuable information on soil acidity and its remedy the reader is referred to Whitson and Weir's "Soil acidity and liming", Bull. 230, and "Testing soils for acidity", Bull. 312, by E. Truog. These bulletins can be obtained on application to the Agricultural Experiment Station, Madison, Wisconsin. Most of the facts in this report dealing with the properties of limestones and dolomites as soil neutralizers are taken from them.

In case dry soil is tested, the soil sample is put in a clean dish and moistened with soft water to a stiff mud. With a clean stick separate the wet soil into two portions. On one portion a piece of blue litmus is placed, which is then covered by the other portion. In all these tests the soil must not be contaminated with materials that might change its reaction with litmus paper, the soil must be damp preferably from rain or thaw, and the paper must be in direct contact with the soil for at least five minutes.

If a soil effervesces when treated with muriatic acid, carbonate of lime may be the cause of the reaction, in which case the soil cannot be acid. The bubbling may be caused, however, by the escape of air. If a soil is first soaked in water until the air is expelled and then treated with muriatic acid, effervescence shows that the soil is not acid. The lack of effervescence does not prove the soil to be acid, since in many of our Wisconsin soils the calcium is not in a form acted upon by muriatic acid.

The growth of certain weeds on soils is a good indicator of soil acidity. Weeds of this character are the sheep sorrel or sour sorrel, horsetail rush, corn spurry, and wood horse tail. These weeds may be found in all kinds of soils, because their seeds are widely scattered. When they take possession of fields, it usually means that the soil is acid and that for this reason other weeds do not thrive. Soils on which red clover and alfalfa no longer thrive should be tested for acidity.

The preceding tests and indications give no clue as to how acid the soil is. Truog has devised an ingenious method by which the amount of acidity can be measured. It is based on the principle that a moist acid soil of known weight when in contact with zinc sulphide generates hydrogen sulphide gas in proportion to the acidity. This gas when brought in contact with lead acetate paper blackens the paper. The darkened paper is compared with the color of standardized paper and the amount of acidity can be read directly. See Truog's Bulletin 312 of the Agricultural Experiment Station of the University of Wisconsin for details of method and results.

Truog states that three-fourths of the soils of Wisconsin are acid. The residual soils of southwestern Wisconsin, despite their origin from the decay of limestones, are frequently acid. Percolating waters have removed most of the lime which would neutralize acids. Nearly all the sandy soils of Wisconsin are likewise acid, because their original content of lime is low. The glacial soils of eastern and southern Wisconsin, although generally quite well supplied with lime when first cultivated, have in many cases, after years of cropping, become acid. Marshes which are underlain by limestones like those of the southeastern part of the state are as a rule not acid. The red clay soils along the coast of Lake Superior and in the Fox River valley as a rule are not acid. These soils are marly clays which were deposited in lakes. Newly broken marsh soils are frequently acid from the decaying vegetation which they contain. This is particularly true of those which are underlain by sandstones or granites, rocks which have a low content of lime in a form which would overcome acidity.

The remedy for soil acidity is to add a neutralizer to the soil. A neuralizer is a substance which will react with the acid, the reaction producing new substances which are not acid. Fresh unleached wood ashes have this property. The cheapest material which can be used is limestone or some of the substances derived from limestone like quicklime, hydrated lime, air-slaked lime, the lime refuse from tanneries, beet sugar and glue factories. Ground shells and marl are also good for this purpose whereas gypsum or land plaster is not.

In 1917 a state law controlling the sale of agricultural limes was adopted. The law reads as follows:

> The term agricultural lime as used herein shall include all quicklime, both lump and ground, ground limestone, ground or pulverized oyster shells, sulphate of lime or land plaster, hydrated lime, gas lime, marl and all similar products, provided that nothing herein shall be construed as prohibiting persons engaged in quarrying and grinding limestone, within the state of Wisconsin, from selling their own products at the place where ground and quarried without complying with sections 1494c, 1494d and 1494e. Every manufacturer, person or firm who shall sell, offer or expose for sale or for distribution in the state of Wisconsin, any agricultural lime to be used as a fertilizer or soil improver, shall furnish with each shipment or lot or shall affix to each package or bulk of agricultural lime a statement clearly and truly certifying the kind of lime, the number of net pounds in each shipment or lot or package, the name of the manufacturer, place of business, and for all quicklime, hydrated lime, gas lime, marl, limestone, clam and oyster shells, the following statement of analysis: (1) The maximum approximate percentage of water. (2) The minimum neutralizing value expressed as the percentage of calcium carbonate. (3) In the case of marl and ground limestone and clam and oyster shells, the additional analyses concerning fineness as follows: (a) Percentage not passing ten-mesh sieve. (b) Percentage passing ten-mesh sieve, but held on sixty-mesh sieve. (c) Percentage passing sixty-mesh sieve.
>
> In the case of sulphate of lime or land plaster the maximum percentage of water and the minimum percentage of sulphur trioxide
>
> Approximate water content as used in this section is to be taken to mean within five per cent. Neutralizing value is to be determined as follows: A determination of the carbon dioxide content is to be made directly on ground limestone, clam and oyster shells and marl.
>
> In the case of quicklime, hydrated lime, gas lime, and other partly slaked and carbonated material, the oxide and hydrate are to be changed to the carbonate and then a determination of the carbon

dioxide content is to be made in the same way as with ground limestone. The carbon dioxide value is then to be calculated over to its chemical equivalent as calcium carbonate and from this value the neutralizing value of the dry material compared to pure dry calcium limestone is to be calculated and expressed in terms of per cent.

Rock sold as limestone may contain as much as 45 per cent magnesium carbonate; that is, it may be a pure dolomite. According to Whitson and Weir dolomite is just as beneficial as limestone. In fact, a pound of pure dolomite has the power of neutralizing a little more acid than a pound of pure limestone. In addition to the carbonates of lime and magnesia, limestones usually contain sand, clay, moisture, and other impurities. In buying limestone, the aim should be to select one with a high content of carbonates. If possible, the carbonates ought to constitute 90 per cent or more of the rock. The earthy or sandy materials which make up the remainder of the rock have no effect on soil acidity. Rock from any of the Niagara limestone quarries of the eastern part of the state is the most uniform in quality of any limestone or dolomite in the state, and averages the best, although locally good limestone or dolomite can be obtained from other formations. The carbonates in the Niagara formation usually exceed 95 per cent. The Lower Magnesian dolomite is exceedingly variable in composition. Usually it has a high percentage of sandy and earthy constituents. The Galena and Black River dolomites are more uniform in composition, but on the average are inferior in quality to the Niagara limestone. Their content of earthy constituents averages about 10 per cent. The glass rock beds of the Black River formation in the lead and zinc region of the southwestern part of the state have a high content of lime carbonate, and are of good quality. Mine tailings from this district have been successfully used (p. 54). Locally the Mendota dolomite and dolomitic phases of the Cambrian sandstone may be used if they are the most available. They are likely to have about 30 per cent of insoluble matter.

As to what kind of limestone to use, no fixed rule can be laid down. The cost per unit of carbonates, not the cost per ton, should be considered. A fairly close estimate of the cost per unit of carbonate can be gotten by dividing the cost per ton by the percentage of carbonates. Thus if the cost per ton is $5.00 and the percentage of carbonates is 95, the cost per carbonate unit is approximately $5.00÷95 or $0.052+. If the cost per ton is $2.00 and the percentage of carbonates is 50, the cost per carbonate unit is about $0.04. In making such calculations, cost per ton should include not only the cost of the raw material, but expense of transportation and application as well.

Marl and ground shells have the same effect as limestone. They usually have a high content of moisture unless artificially dried. In buying these substances, the same rules should be followed as in buying limestone. They should be bought on the basis of carbonate content.

The amount of limestone or similar material to use per acre, Truog says, depends on the acidity of the soil, the kind of soil, the lime requirements of the crops to be grown, and the kind and quality of the lime. He has devised a chart from which the amount of limestone, etc., needed under various conditions can be obtained. The maximum amount recommended by him is 5 tons to the acre. This is on very strong acid soils of good quality and for crops having a high lime requirement. Such crops include alfalfa, sugar beets, tobacco, canning peas, cabbage, and most garden crops. Half the amount of quicklime is used in place of limestone.

According to Whitson and Weir, two tons of damp ground limestone, 20 to 30 per cent of which will pass a 60 mesh sieve, can be applied per acre. Most crops are not injured by an overdose of limestone or dolomite. The U. S. Department of Agriculture claims that the only crops positively injured by liming are radishes, flax, blackberry, black raspberry, and cranberry.

The more caustic forms of lime, such as quicklime, hydrated lime, and some forms of lime refuse should be used cautiously. This is especially true of quicklime. Their action is more drastic than that of the natural carbonates. Quicklime causes rapid decomposition of organic matter and fertilizers in the soil. This at first causes a spurt in the productiveness of the soil, but if it is not followed up by liberal applications of manures or other fertilizers, excess of fertility will be followed by exhaustion. Quicklime and hydrated lime improve the tilth of sticky, clay soils.

LIMESTONE AND DOLOMITE AS FLUXES

Fluxes serve two purposes in smelting operations. When mixed with an ore they lower the melting temperature of the ore, and combine with its impurities to form a slag. The slag being lighter than the metals rises to the surface as a liquid and leaves the metals in a nearly pure state. Limestones are used as fluxes in iron blast furnaces, in the basic Bessemer process of steel-making, and in lead and copper smelting. In all of these operations a pure high calcium limestone is preferred. When this cannot be obtained, magnesian limestones are used in the iron blast furnaces. In copper smelting, the magnesia content of the slag should not exceed 12 per cent and even 4 per cent of magnesia usually has bad effects.

The objection to magnesia is that it makes a very sticky or viscous slag, which requires a great expenditure of heat to maintain in a condition of fluidity sufficient to permit it to flow readily from the furnace. Alumina has a similar effect and the presence of both alumina and magnesia is highly undesirable. Clayey iron ores, therefore, cannot very well be smelted with a magnesian limestone. A small content of silica is not objectionable, but it lowers the effectiveness of the limestone. The chief impurity in iron ore usually is silica and the limestone is generally added to the ore in such proportions as to form the lime meta-silicate, as this has the lowest formation temperature of any compound of lime and silica. If silica is the only impurity in the ore, 1.6 pounds of limestone are necessary to combine with 1 pound of silica to form the lime meta-silicate slag. If the limestone has 2 per cent of silica, a ton of it would contain 40 pounds of silica. To slag this off, 64 pounds of the lime carbonate is necessary—therefore out of every ton of rock 104 pounds are not only useless but consume heat, and as they occupy space in the furnace, they reduce thereby the furnace capacity.

LIMESTONE AND DOLOMITE AS NATURAL CEMENT MATERIAL

Natural cements include all those cements which are obtained by burning impure, clayey limestones at a low temperature, about 900 to 1000° C. Their composition and physical properties are extremely variable. As a rule they set more quickly than Portland cement. Much more sand can be used with Portland cement than with natural cement. They have the property of setting under water but have a lower tensile strength than Portland cement.

The raw material may be either soft or hard, porous or compact, dry or moist. A hard, dry, compact material is preferred. It can be burned with less expenditure of heat and does not tend to check the draft of the kiln. The carbonates in these cements may range from the pure or nearly pure calcium carbonate to one in which the weight of magnesium carbonate is about four-fifths of the weight of the calcium carbonate. The kind which has a high magnesium content is generally less desirable.

Their tensile strength being less than that of Portland cement, they have declined in importance as construction materials since Portland cement has come into vogue. In 1919 natural cements were but 0.6 per cent of the total cement production. They usually are cheaper than Portland cement. Natural cement averages two thirds the price of Portland cement. As to whether Portland or natural cement is to be used depends on the tensile strength required, the cost of each and of sand. Where great ultimate strength is necessary, or where variable strains must be provided for, Portland cement is preferred.

Limestone and Marl in Portland Cement

The uses of limestone and marl in Portland cement are discussed in detail in Chapter V.

Dolomite as a Source of Magnesia

Nearly all magnesia is obtained from the carbonate of magnesia, magnesite. It is a product of great value. Its chief uses are for making magnesia brick for furnace linings; Sorel cements, very desirable for floorings; stucco; and magnesium hydrate. It is also used for making metallic magnesium, magnesium alba, and the sulphates and chlorides of magnesium. Most of the magnesite used in the United States has been imported from Greece. Chewelah, Washington, is now an important producer of magnesite. Some is also produced in California.

Before the war magnesite was laid down on the Atlantic seaboard at $15.00 to $18.00 per ton. During the war the price rose to $100.00 a ton. Dead burned magnesite is now $38.00 a ton at Chewelah, Washington, and $58.00 to $64.00 a ton at Chester, Pennsylvania. Chicago prices are $57.00 a ton. On the Atlantic seaboard it is now $61.00 to $63.00 a ton. In Pennsylvania the value of one ton of dead burned magnesite is 37 to 39 times that of a ton of raw dolomite. In Pennsylvania the manufacture of magnesia alba is an established industry. Magnesia alba is a basic carbonate of magnesia and is used as a fire retarding paint and as a non-conductor of heat in coverings of steam pipes and in other heat insulators. It is also used in face powder and as an absorbent for making dynamite. It is made by the Johns-Manville Company of Milwaukee. In view of the great usefulness of magnesia products, the industry of making them from dolomite seems to have very attractive commercial possibilities.

Schurecht has recently reviewed and studied the processes of making magnesia products from dolomite.[1] For references see his paper. Some of these processes seem to be based on the apparently erroneous conception that the magnesium carbonate of dolomite is dissociated at a lower temperature than the calcium carbonate. Some of the methods outlined by Schurecht are essentially as follows:

1. Add 8750 parts $MgCl_2$ to 1250 parts of caustic dolomite. This forms soluble $CaCl_2$ and a precipitate of $Mg\ (OH)_2$. Remove soluble $CaCl_2$ by filter press and obtain 1000 parts of $Mg\ (OH)_2$ in press.

2. Calcine dolomite between 500° and 600° C. This dissociates $Mg0$ which can be removed either by air or water currents. The idea back of this is probably wrong.

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[1] Schurecht, H. G., Jour. Am. Ceramic Soc., July, 1921.

3. Add a 10 to 15 per cent sugar or molasses solution to milk of dolomite. The $Ca(OH)_2$ goes into solution and the $Mg(OH)_2$ remains solid. The sugar and lime are recovered by passing CO_2 through the solution.

4. Crush calcined dolomite to 8 to 40 mesh size and leach with cold water. This dissolves $Ca0$ but leaves $Mg0$ as a residue. Leach until residue contains 3 to 10 per cent $Ca(OH)_2$.

5. Treat dolomite with H_2SO_4. $MgSO_4$ is filtered from the less soluble $CaSO_4$ precipitate.

6. Hydrated calcined dolomite is treated with H_2SO_4. Forms fine-grained $CaSO_4$ and leaves bulkier $Mg\ (OH)_2$ which can be separated by screening.

7. Dolomite is calcined and hydrated and the hydrate leached until low in $Ca(OH)_2$.

CHAPTER V

LIMESTONE AND MARL IN PORTLAND CEMENT

General Characteristics of Portland Cement

Portland cement is one of the hydraulic cements. All cements of this class set and harden under water. Portland cement is made by heating a finely ground mixture of clayey and limy materials containing definite proportions of lime, alumina, and silica, and minor amounts of magnesia, alkalies, and iron oxides to a temperature of incipient fusion. The clinker thus formed is ground very fine and is usually mixed with about 2 per cent of powdered gypsum to produce the commercial Portland cement.

The setting, hardening, and strength of Portland cement depend on the compounds which it contains, its fineness of grain, and the manner in which it is mixed with water. The water used must be free from strong acids, chlorides, sulphates, alkalies, and tannic acid. The compounds present in Portland cement depend on the composition of the raw materials, their fineness of grinding before they are put in the kiln, the temperature to which they are subjected in the kiln, and the length of time they are kept at high temperatures in the kiln.

The Chemical Constituents of Portland Cement

The composition of a cement, although important, is only one of the factors which determine its quality. A Portland cement may show the same chemical analysis as the best Portland cement made, yet be worthless. The quality depends on the compounds or physical constituents of the cement. The formation of these compounds depends on the composition as shown by the analysis and upon the heat treatment.

The commercial Portland cements of the United States have an approximate composition within the following limits:[1]

	Per cent
Silica	19–25
Alumina	5– 9
Iron oxide	2– 4
Lime	60–65
Magnesia	1– 4

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[1] Burchard, E. F., Cement: U. S. Geol. Survey Mineral Resources of the United States 1911, Pt. 2, Nonmetals, pp. 485-519.

Sulphur trioxide	1- 1.75
Loss on ignition	0.5- 3
Insoluble residue	0.1- 1

Below is an analysis of cement made by the Universal Portland Cement Company at Buffington, Indiana, as reported in a circular of this company:

Silica	23.62
Alumina	8.21
Ferric oxide	2.71
Lime	61.92
Magnesia	1.78
Sulphur trioxide	1.32
Sulphur as sulphides	none
Loss on ignition	.52

The Bureau of Standards of Washington has prepared excellent Portland cement from pure mixtures of lime, alumina, and silica. They differed from commercial varieties only in their much higher clinkering temperature—1650° C. Commercial clinker is usually made at about 1425° C.

The average of seven typical Portland cements tested by the U. S. Geological Survey[1] had the following composition:

SiO_2	21.86
Al_2O_3	7.19
Fe_2O_3	2.99
CaO	62.42
MgO	2.58
SO_3	1.48
Undetermined	1.47

Meade says that the $\frac{\text{per cent silica}}{\text{per cent alumina}}$ should lie between 2.5 to 5. The high alumina cements are apt to be quick setting. They also clinker at a lower temperature than the high lime cements. High lime cements are harder to burn and are slower in setting and hardening. Since the quality of cement depends as much on the best treatment as on composition, only general characteristics due to composition are given here.

Iron in cement materials reduces the clinkering temperature. Iron free cements are white. High iron cements make hard clinker—harder to grind. Eckel says that the ratio $\frac{SiO_2}{Al_2O_3+Fe_2O_3}$ should be less than 3.5 and more than 2.

According to standard specifications magnesia should be lower than 5 per cent in the finished cement. The clinkering temperature is low-

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[1] Humphrey, R., and Jordan, W., Portland cement mortars and their constituent materials: U. S. Geol. Survey Bull. 331, 1908.

ered by magnesia. Studies by the Bureau of Standards discussed farther on show that cement with as much as 7.5 per cent magnesia has essentially the same cementing value as one containing less than 4 per cent.

Alkalies are nearly absent from most Portland cements. Most raw cement materials contain less than 2 per cent alkalies. The potash is volatile and much of it goes up the stack. Soda is less volatile. Alkalies in the form of carbonates and hydroxides when added to cement give it a rapid set. Cements from alkali waste are said to be unsatisfactory in some cases, and the fault seems to be traced to their high alkali content.

The maximum permissible percentage of sulphur trioxide is 2 per cent. Most of the sulphur volatilizes on burning and true Portland cement has been made from gypsum and clay. The resultant cement had only 1.83 per cent sulphur. Just what are the injurious effects, if any, of higher sulphur content does not appear to be clearly stated by cement technologists.

PORTLAND CEMENT MIXTURES

A Portland cement mixture when ready for burning should contain about 75 per cent of lime carbonate, about 20 per cent of silica, alumina, and iron; the remaining 5 per cent or so contains any magnesia, sulphur, and alkalies that may be present. For methods used in calculating the proper mix the reader is referred to Meade[1] and Eckel.[2]

THE RAW MATERIALS OF PORTLAND CEMENT

The raw materials used in the manufacture of Portland cement are (1) cement materials proper, including cement rock, limestone, marl, shells, slag, shale, and clay, (2) fuels for drying the raw materials, burning the cement, and for power, and (3) retarders.

A cement rock is a clayey limestone containing in the proper proportions all the ingredients necessary for the manufacture of Portland cement. Limestone or marl, which supply lime, are mixed with clay or shale, which supply alumina and silica. Some mills use slag from iron furnaces. This material supplies lime, alumina, and silica, but is too low in lime for a perfect cement. Limestone is added to supply the deficiency.

Harmful physical constituents in Portland cement materials are hard, gritty substances, such as flint, quartz, and feldspar, in amounts greater than 1 or 2 per cent. They make fine grinding very costly.

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[1] Meade. R. K., Portland cement, pp. 69–93, Easton, Pa., The Chemical Publishing Co., 1911.

[2] Eckel, E. C., Cements, limes and plasters, pp. 356–372, New York, John Wiley & Sons, 1922.

Flint nodules are commonly present in the chalk deposits which are used very extensively by the English cement industry. They are mechanically separated from the easily pulverized chalk before final grinding. Unless the hard objectionable substances are easily separated, it is too expensive to remove them.

Limestone is preferred to marl as a source of lime for Portland cement. The cost of excavation per barrel of cement is about the same for both. A cubic yard of marl makes 1.5 to 3 barrels of cement; a cubic yard of limestone in the quarry makes 9. This difference is due to the marl being less compact and containing about 50 per cent of water. Besides water, marl usually contains organic matter. Some users of marl complain of the irregularity of the deposits, that silt and sand are sometimes found to be interlayered with marl when least expected. It would seem, however, that the latter difficulty could be avoided by thorough prospecting before using. There is no reason why the composition of a marl deposit should not be known as thoroughly in advance of excavation as a limestone deposit. It has also been found difficult or impossible to dredge marl during the winter months whereas quarrying limestone is not hindered to the same extent.

The slurry from marl contains 42 to 62 per cent or more water and requires about 130 to 220 pounds of kiln coal per barrel. The B. t. u. of the coal used ranges from 9,000 to 14,000. The amount of coal used in the kiln varies with the length of the kiln. The limestone slurry contains 32 to 35 per cent water and burns with about 120 pounds of coal per barrel. The dry process kiln uses 90 to 100 pounds of coal per barrel. Gypsum is commonly added to finished cement in amounts up to 3 per cent for the purpose of retarding the set.

Every barrel of cement requires about 450 pounds of limestone and 150 pounds of clay or shale. A limestone deposit sufficient for a production of 1,000 barrels per day for 50 years should contain 50,000,000 cubic feet. About 12,500,000 cubic feet of shale would be needed. If the marl were used, it would take about 250,000,000 cubic feet, or a deposit 5,000 feet square and 10 feet deep.

Outline of Process of Manufacturing Portland Cement

Two types of processes are used in the manufacture of Portland cement, the dry process and the wet or slurry process. In the dry process the raw materials are dried before grinding preparatory for the kiln. In the slurry process the raw materials are ground wet and then stirred into a thin paste or slurry. The slurry is then pumped into the kiln.

The dry process is generally used at present. Some of the more recently erected mills use the slurry process. The advantage of the dry process for mills using limestone is said to lie in the low total fuel cost despite the fact that the limestone and clay or shale are both dried before grinding. This advantage is particularly great when a short kiln is used for burning the clinker. In the long kiln now in use, heat which was largely wasted with the short kiln is used to dry the wet materials. The advantages claimed for the wet process are (1) elimination of the dust nuisance in grinding, (2) grinding wet material requires ⅓ less power, (3) more thorough mixture of shale and limestone, and (4) better means of maintaining uniformity of composition of the cement mixture.

The process of cement making may be divided as follows: (1) excavating the raw materials and moving them to the mill, (2) grinding and mixing them in the proper proportions and transferring them to the kiln, (3) the kiln treatment involving evaporation of the water, burning the organic matter and sulphur, the removal of carbon dioxide from the carbonates, and the chemical combining of the lime, alumina, silica, etc., into new compounds, (4) the cooling and grinding of the clinker. In the latter process about 3 per cent gypsum is added.

Limestones and shales are quarried. Clay and sometimes shale are taken up by steam shovel without preliminary blasting. In a few cases limestones and shales are mined underground.[1] Most mills are near the limestone, but in some cases the mills are 20 or more miles from the quarries. The way in which the rock is handled depends on the topography and the distance of the mill from the quarry.

Marl is excavated by steam shovel if the deposit is sufficiently dry. Usually a stripping of a few feet of peat has to be removed. If wet, the marl is usually taken out by a dipper dredge mounted on a barge. The marl is loaded on cars or barges and taken to the mill or is delivered directly to a pug mill which mixes the marl with water and forms a thin slurry which is pumped to the mill.

In dry methods of preparation the raw materials are generally dried to remove any natural moisture they may contain. Usually the materials are first crushed and partly reduced separately, then dried, and finally mixed and pulverized. Some mills report that 98 per cent of their ground rock passes a 100-mesh sieve and that about 90 passes 200 mesh. Dry grinding is said to cost 10 to 20 per cent more than wet grinding.[2] In the eastern states the cost of dry grinding the raw material was about 12 cents per barrel in 1921. After grinding the material goes to the rotary kiln where it is burned to clinker. Dried and pulverized coal is blown into the lower end of the kiln by means of compressed air.

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[1] For methods of quarrying see O. Bowles, Rock quarrying for cement manufacture: U. S. Bur. of Mines Bull. 160, 1918.

[2] Meade, B. K., Cost of dry grinding of cement material: Concrete-Mill Section, vol. 18, No. 5, p. 135, 1921.

The rotary kiln is a cylinder constructed of steel sheets, lined with refractory brick, and inclined at a pitch of 0.50 to 0.75 inches to the foot. The length is 60 to 260 feet. In recent years the tendency has been towards building kilns between 150 and 200 feet in length. The diameter of the kilns varies from 6 to 11 feet. The kiln is rotated at such a speed as to require 1.5 to 2 hours for the material to pass through the kiln. The materials are only partially fused. The chemical reactions which the kiln operation tends to bring about are favored by fineness of grinding of the raw material, high temperature, and by the length of time the material is exposed to the high temperatures.

The hot clinker is cooled, crushed, and ground to a fine powder. Either the clinker or the ground cement must be seasoned before using in order to slake any free lime that may be present. Gypsum is usually added to the clinker before crushing as this insures more thorough mixing and pulverizing. After the final grinding and seasoning the cement is ready for use.

THE PHYSICAL CONSTITUENTS OF PORTLAND CEMENT

Portland cement consists essentially of certain silicates and aluminates of lime. Other constituents such as iron oxides and alkalies in the amounts commonly present in Portland cement do not influence the properties of finished cement in any important way; nor do they enter into the constitution of these compounds in any important way. The same compounds are formed when these accessory materials are absent. Iron oxides and alkalies in Portland cement materials do, however, affect considerably the cost of making Portland cement.

Rankin[1] finds that the average gray Portland cement on the market contains about 36 per cent $3CaO.SiO_2$, 33 per cent $2CaO.SiO_2$, 21 per cent $3CaO.Al_2O_3$, and 10 per cent of minor constituents. The maximum amount of $3CaO.SiO_2$ is about 40 per cent.

It has been found that the $3CaO.SiO_2$ is the most important strength-giving compound of cement. Cement experts believe, however, that it is nearly impossible to increase the amount of this constituent in cement.

THE HYDRATION OF PORTLAND CEMENT

The $3CaO.Al_2O_3$ of Portland cement hydrates to a gelatinous form and then crystallizes as a hydrated tricalcium aluminate.[2] It sets and

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[1] Rankin, G. A., Chemistry of Portland cement: Concrete-Mill Section, vol. 8, No. 3, p. 15, 1916. Rankin, G. A., The constituents of Portland cement clinker: Jour. Ind. & Eng. Chem., vol. 7, No. 6, p. 466, 1915. Bleininger, A. V., and Emley, W. E., Burning temperatures of limestone: Trans. Nat. Lime Mfgrs. Assoc., 1911. Day, A. L. and Shepherd, E. S., The lime silica series of minerals: Jour. Am. Chem. Soc., 1906.

[2] Klein, A. A., and Phillips, A. J., Hydration of Portland cement; U. S. Bur. of Standards Tech. Paper 43, 1914.

hydrates almost immediately. Much heat is evolved in the process. Its tensile strength is never beyond 100 pounds to the square inch. It is largely responsible for the early strengths of cement.

The dicalcium silicate ($2CaO.SiO_2$) hydrates to a very porous colloidal hydrated silicate and crystallized lime hydrate. It sets so slowly that test pieces are hard to get. At the end of a year it has a tensile strength of 600 pounds to the square inch and 5.5 per cent water of hydration. Seven-day test pieces crumbled. At 14 days it had a tensile strength of 60 pounds to the square inch.

Tricalcium silicate ($3CaO.SiO_2$) forms a colloidal hydrated silicate and hydrated lime, the latter largely crystalline and scattered through the dense mass of colloidal silicate. Its set and strength are about the same as that of Portland cement as a whole. Hydrated tricalcium silicate is largely a dense, and semivitreous colloid which is poorly adapted to withstand temperature and moisture changes. In this respect it is believed to be improved by the more porous hydrate of dicalcium silicate.

EFFECT OF MAGNESIA IN PORTLAND CEMENT

Bates[1] found that magnesia up to 9.5 per cent in cement did not cause compounds to form other than those ordinarily present. Below this amount it appears to replace lime without any deleterious effect on the cement. With less than 9.5 per cent magnesia, the clinker was black, glistening, and coke-like; with 9.5 per cent magnesia, monticellite ($MgOCaOSiO_2$) formed in small amounts. With 14 per cent or more magnesia, spinel ($MgOAl_2O_3$) forms in addition to monticellite. Both these compounds are non-hydraulic and inert materials in cement. When 9.5 per cent magnesia was reached, the clinker began to "ring up" because of the fusibility of the material. Up to about 9.5 per cent magnesia, the cement formed seemed to be as good as one having less than 4 per cent. Larger amounts were not as desirable.

POTASH FROM CEMENT DUST

Since 1914 the United States has produced some potash from cement dust. The first one to point out the volatilization of potash and soda from cement materials during the clinkering process seems to have been W. F. Hillebrand. In 1920 cement plants in the United States produced 1,141 tons of potash (K_2O), which was 2.4 per cent of the total production.

The average raw cement material of the United States is said to contain about 0.8 per cent K_2O. Few of the materials used run over 2 per cent K_2O. The amount of potash volatilized varies from 25 to 95 per

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[1] Bates, P. H., Properties of Portland cement having a high magnesia content: U. S. Bur. of Standards Tech. Paper 102, 1918.

cent of the total. A high recovery is obtained by making a high lime mix, by hard burning, and by the addition of chlorides or fluorides to the raw mix. The potash in the dust is not all water soluble, which is said to be due in part to recombination with fuel ash. The recombined potash is slowly soluble in water. It is held by some that the slow solubility of the potash in the dust is an advantage to the farmer. The dust usually contains about 10 per cent K_2O and 90 per cent inert material.

It has been estimated that the potash escaping from the kilns varies from 0.35 to 5.14 pounds per barrel of cement produced with an average for the plants of this country of 1.93 pounds. On the basis of 100,000,000 barrels per year, the potash formed amounts to nearly 200,000,000 pounds or nearly 100,000 tons. Fully 90 per cent of this is recoverable.

CHAPTER VI

THE MARLS OF WISCONSIN

INTRODUCTION

The available facts regarding the marls of Wisconsin have been put together in view of the renewal of public interest in the cement manufacturing possibilities in Wisconsin and because of the increased agricultural use of marl. A part of the information given herewith is taken from unpublished notes by E. R. Buckley and J. L. Nelson on marl studies which they made in 1900 for the Geological Survey. Buckley and Nelson began their work when the public was keenly interested in the cement question. It was still incomplete when economic developments made the cement question a dead issue for many years. The facts collected by Buckley and Nelson cover the area and volume of a considerable number of marl deposits located in the northeastern part of the state.

During the summer of 1922 C. S. Corbett sampled a number of marl deposits in the southeastern part of the state. In these investigations a large number of 18-foot auger borings through marl deposits were made and the results carefully recorded. Chemical analyses were made of some of the marl samples. These are included in this report.

Many of the marl deposits studied proved to be small and of insufficient volume to have cement possibilities. Many more deposits are still unstudied and it is possible that some have favorable characteristics. These occur in the glaciated region of the eastern part of the state. The most attractive area seems to lie within a triangle whose corners are at Madison, Fond du Lac, and Racine.

Marls were deposited and are still being deposited in lakes. Through changes in drainage the lakes in which some marls formed are now extinct or are nearing extinction. The best marl deposits from the cement standpoint are those which underlie a thin stripping of muck and which can be drained. Marsh marls in general are usually better than lake marls.

Marl has been excavated for agricultural use in a large number of counties.[1]

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[1] Whitson, A. R., Richards, G., and Ullsperger, H. W., Liming Wisconsin soils: University of Wisconsin Exp. Sta. Bull. 361, 1924.

The following data on marl deposits are arranged by counties in alphabetical order:

COLUMBIA COUNTY

Swan Lake.—About 5 acres of marl are reported in and around Swan Lake, a few miles east of Portage. The depth of marl in the marshes is said to be 8 to 34 feet, and in the lake 17 to 40 feet. An analysis of a sample of this marl is given as number 226 (p. 191).[1]

DANE COUNTY

Lake Mendota.—Where the water is 25 feet or more in depth, the bottom of Lake Mendota is composed of marl. In many tests W. O. Hotchkiss has found the marl to be quite uniformly 40 feet thick. Only one analysis of the marl is now available. See analysis 227 (p. 191.)[2]

Lake Wingra.—Lake Wingra is situated on the southern outskirts of the city of Madison. There are large marl deposits both on the bottom of the lake and along its margins. In some places these deposits reach a thickness of 26 to 30 feet. No estimate of the amount of marl can be given, but it is probably in excess of 5,000,000 cubic yards.

DOOR COUNTY

Clay Banks.—See figure 5 for distribution of marl and location of borings. The log of the borings is given below. The borings indicate that there is at least 40,000 cubic yards of marl.

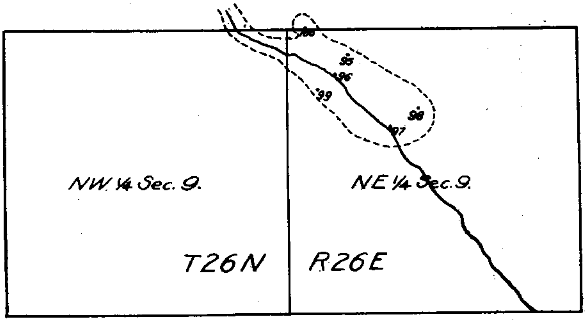

FIGURE 5.—MARL BORINGS IN TOWN OF CLAY BANKS, DOOR COUNTY.

No. 95—6 inches black soil, 4 feet marl, almost wholly decomposed, light gray, resting on gravel bed.

No. 96—Boring in bottom of creek, 4 feet solid light gray marl. See analysis 228 (p. 191).[3]

No. 97—6 inches soil, 4 feet marl. Top 6 inches dry, powdery, and almost white. Wet underneath.

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[1] Reported to Wisconsin Geol. and Nat. Hist. Survey by C. C. Wayland, Portage, Wisconsin. Victor Lenher, analyst.

[2] Birge, E. A., and Juday, C., The inland lakes of Wisconsin: Wisconsin Geol. and Nat. Hist. Survey Bull. 22, p. 171, 1911. Victor Lenher, analyst.

[3] Unpublished notes by E. R. Buckley and J. L. Nelson. W. S. Ferris, analyst.

No. 98—12 inches marl with considerable admixture of soil.

No. 99—Boring near outside boundary, 1 foot marl under 5 feet black soil.

No. 100—Marl taken out of ditch, 3 feet deep.

Clark's Lake.—Marl occurs all over the bottom of Clark's Lake, situated in T. 29 N., R. 27 E. and in the township south. See figure 6 for location. Around the shores a thin deposit of marl covers the rocky and sandy bottom. At the north end around the inlet there are about 100 acres of marl from 10 to 20 feet deep, covered by water from 6 inches to 5 feet deep. The borings indicate that there is at least 1,000,000 cubic yards of marl. The rest of the lake has rocky or sandy shores excepting around the outlet and in East Bay, where there is a large swamp which was not investigated. The deepest part of the lake has 35 to 40 feet of water.

The logs of the borings are given below. The locations of the borings are shown by figure 6. The numbers on the figure correspond to the numbers of the bore holes in the log.

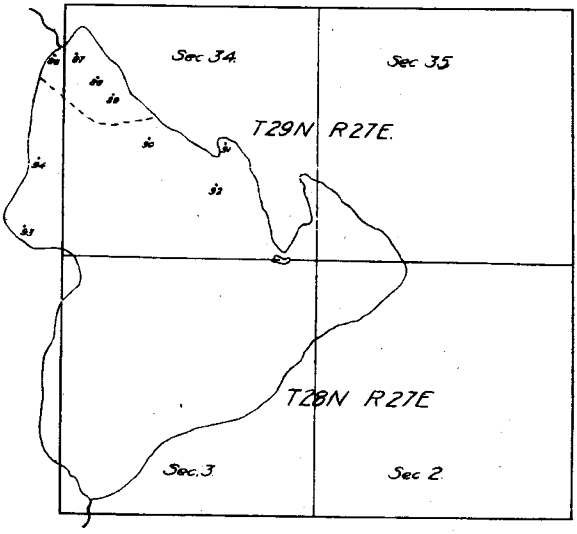

FIGURE 6.—MARL BORINGS ON CLARK'S LAKE, DOOR COUNTY.

No. 86—12 inches water, 3 feet vegetable mold, 8 feet marl of a dark gray, almost blue color. Is wholly decomposed and solid. Rests on hard pan.

No. 87—1 foot water, 17 feet dark gray, decomposed marl with some vegetable matter on top. For composition of marl see analysis 229 (p. 191).[1]

No. 88—5 feet water, 20 feet compact, decomposed marl.

No. 89—5 feet water, 20 feet compact and decomposed marl. 90, 91, 92, 93, and 94, borings in shallow water with rock bottom on which rests a very thin layer of marl.

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[1] Unpublished notes by E. R. Buckley and J. L. Nelson. W. S. Ferris, analyst.

Jacksonport.—Marl underlies 40 acres on the S. ½ of NE. ¼ of sec. 10, T. 29, R. 27 E. It seems to lie at a uniform depth of 10 feet on a bed of gravel. The marl extends northward along the creek valley under the swamp land for over a mile. It seems to be uniform in quality and appearance. The borings indicate that there is at least 400,000 cubic yards of marl.

The log of the borings of this marl area follows:

For location of borings see figure 7.

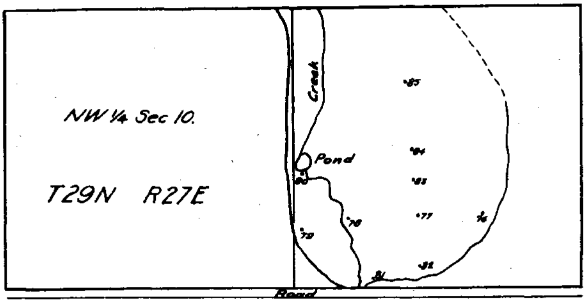

FIGURE 7.—MARL BORINGS NEAR JACKSONPORT, DOOR COUNTY.

No. 76—1 foot black soil, 1 foot clean raw marl, wholly decomposed.
No. 77—1 foot soil on top, 10 feet clean, compact, light gray, decomposed marl. For composition of marl see analysis 230 (p. 191).
No. 78—Boring in creek bottom, 10 feet clean marl.
No. 79—1 foot soil, 10 feet marl, clean, compact. See analysis 231 (p. 191).
No. 80—Boring on edge of lake, 3 feet marl, clean, compact, light gray.
No. 81—18 inches black soil, 6 inches coarse shelly marl on gravel bed, near edge of deposit.
No. 82—6 feet solid marl under 1 foot black soil.
No. 83—10 feet solid marl under 2 feet soil.
No. 84—12 feet marl under 2 feet soil.
No. 85—16 feet marl under 2 feet soil. Marl light gray with brown tinge. Marl in this deposit seems especially uniform in quality and appearance.

Kangaroo Lakes, Baileys Harbor.—For location of the marls of Kangaroo Lakes see figure 8. The borings indicate that there is at least 100,000 cubic yards of marl.

The inlets of the lakes are spring fed and the marl seems deepest near them.

The log of the borings is given below. Where borings occur out in the lake with none on the shore, it indicates that the marl runs out in gravel or mud at the edge of the lake. No marl underlies the lands beyond the limits of the lake shore. For location of borings see figure 8.

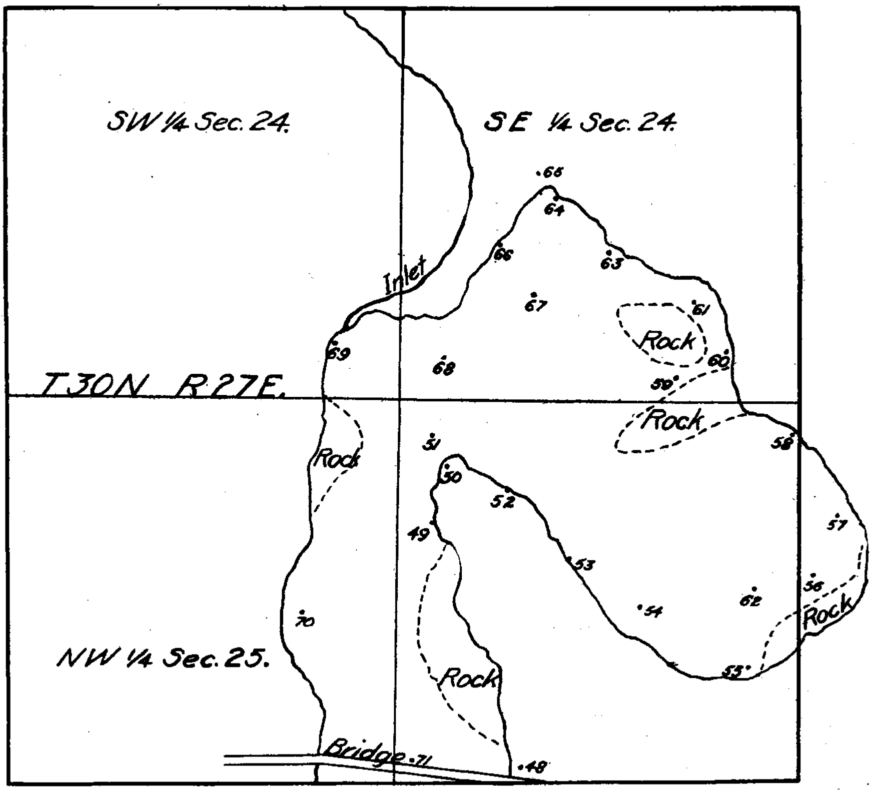

FIGURE 8.—KANGAROO LAKES, BAILEYS HARBOR, DOOR COUNTY.

No. 48—Borings at east end of bridge, at edge of water. 1 foot marly sand, marl very little decomposed. Rock bottom.

No. 49—Rock and sand shore between 48 and 49 with thin spots of marl and sand now and then. No. 49, 18 inches marl on bed of stiff blue clay and gravel. Marl well decomposed but contains some vegetable mold and a few shells, and is gray in color.

No. 50—18 inches marl, 70 per cent decomposed. Marl contains considerable vegetable mold, some shells. Has coarse and gritty appearance. Rests on bed of white sand.

No. 51—4 feet marl. Decomposed, contains some vegetable mold, and some shells. Rests on bed of sand.

No. 52—18 inches marl on rock bottom. Marl 50 per cent decomposed on top, more decomposed at bottom. Apparently extends out to considerable depth. Will not bear weight. Contains lots of vegetable mold.

No. 53—12 inches marl. Little decomposed, 50 per cent mold. Color dark gray.

No. 54—4 feet marl, 50 per cent decomposed, gray in color. Hard bottom. Boring 6 rods from edge of lake in grassy swamp.

No. 55—9 feet vegetable mold with 30 per cent of undecomposed marl. Blue clay at bottom.

No. 56—Between 55 and 56 mostly bowlders and black mold, wet. Some marl. Boring at 56, 5 feet marl, 50 per cent decomposed, 6 inches soil on top, rock bottom. Marl is gray and has some vegetable mold.

No. 57—3 feet marl, 6 inches soil. Marl 70 per cent decomposed. Contains a few shells and a little vegetable mold. Rock bottom. Boring is in wild rice swamp extending out 20 rods from shore.

No. 58—5 feet marl, 50 per cent decomposed. Contains some vegetable mold. Rests on clay bottom.

No. 59—15 rods from shore, 4 feet marl, 50 per cent decomposed. Contains some mold. Rests on rock bottom.

No. 60—4 inches marl on rock bottom. Marl is little decomposed.

No. 61—2 feet marl, 30 per cent decomposed. Contains some vegetable mold.

No. 62—Boring 20 rods from shore. 1 foot marl. Contains some vegetable matter on top. Marl is 60 per cent decomposed.

No. 63—6 feet marl on bed of clay, 60 per cent marl, 40 per cent vegetable mold. Marl partially decomposed, of a dark gray color. 3 inches soil on top.

No. 64—6 feet marl, 70 per cent decomposed. Contains 20 per cent vegetable mold. 6 inches soil on top. Vegetable mold well decomposed.

No. 65—Boring in small creek. 5 feet of marl on bed of mold. Marl well decomposed. Contains a few shells. 10 feet mold. Marl light gray in color.

No. 66—Boring 10 rods from shore and 30 rods south of mouth of small inlet. 8 feet of well-decomposed marl, light gray in color.

No. 67—Boring 40 rods from shore, 8 feet marl, mold on bottom.

No. 68—8 feet marl on rock bottom, 90 per cent decomposed. Light gray color. Compact at bottom.

No. 69—Boring 10 rods from shore, 8 feet marl much decomposed. Rests on mold bottom. Marl light gray.

No. 70—Boring 10 rods from shore, 6 feet marl, 90 per cent decomposed. Rests on rock bottom. Bay all underlain by marl.

No. 71—Boring at middle of bridge. 2½ feet water, 3½ feet marl. Lots of large shells on top. Marl is well decomposed. Rests on mold bottom. Color of marl light gray.

KEWAUNEE COUNTY

Alaska Lakes.—See figure 9 for location of the marls of Alaska Lakes, Kewaunee. The numbers refer to positions of borings.

The marl of these lakes is nearly all under water. The greatest depth of water is about 35 feet. Most parts of the lakes are very shallow with a white marl bottom. The marls seem to be underlain by sand.

The lakes cover 160 acres and 40 acres, respectively. In each there is a small island which is all marl. The level of Lake Alaska No. 1 can be lowered 18 feet at the mill outlet. If the outlet of No. 2 were correspondingly lowered, about two-thirds of the marl deposits of both lakes would be exposed. The borings indicate that these lakes contain at least 1,000,000 cubic yards of marl.

The logs of the borings on Alaska Lakes are given below:

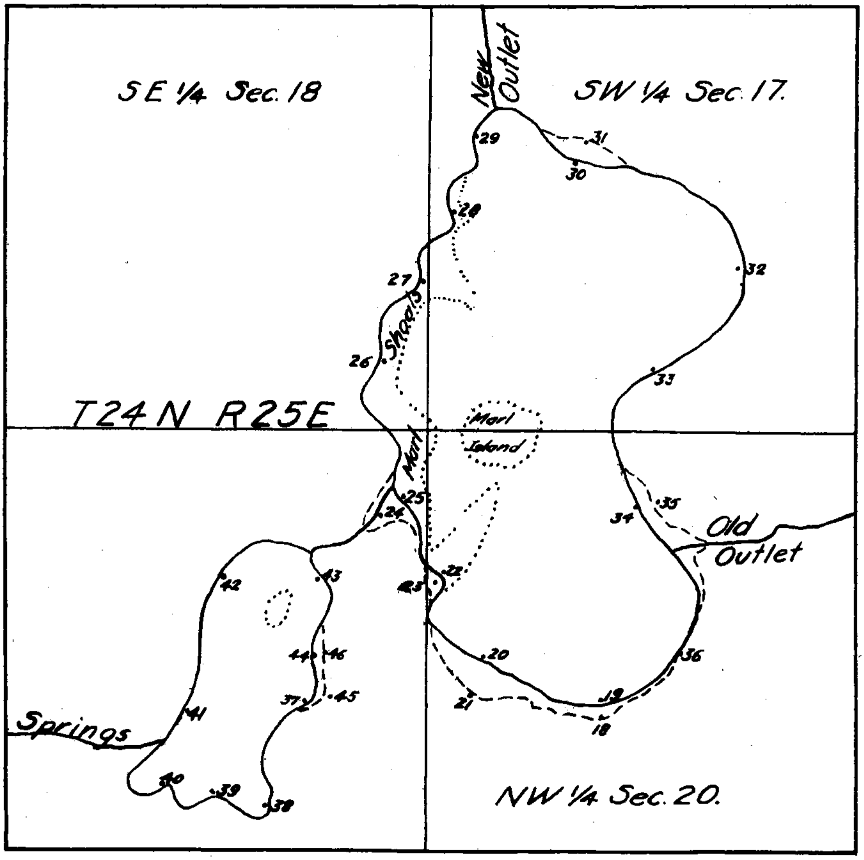

FIGURE 9.—ALASKA LAKES, KEWAUNEE COUNTY.

No. 18—15 paces from edge of water. 6 inches black soil, 12 inches marl mixed with 50 per cent black soil, marl very little decomposed, grayish white.

No. 19—12 feet of solid marl on red sand bed. Marl very much decomposed, uniform throughout except at top where some vegetable matter exists. Some large shells and many small ones, color light gray, boring on edge of lake in swampy soil.

No. 20—17 feet of marl, no bottom. 1 foot of water. Marl same as in boring 19, almost wholly decomposed.

No. 21—1 foot of black soil, 2½ feet of marl on sand bed. Marl partially decomposed, gray, some large shells, many small ones.

No. 22—Outcrop on bank 3 feet, 3 feet below surface of water on bed of sandstone. Deposit runs out under water. Marl compact and well decomposed with very few shells, white, nearly like that in boring 19.

No. 23—Under 1 foot of soil, 2 feet of light gray, compact, partially decomposed marl. Rests on bed of sand.

No. 24—1 foot of soil, 7 feet of compact, light gray marl, 90 per cent decomposed. Deposit extends to outlet of Lake No. 2.

No. 25—1 foot of water, 10 feet of compact, light gray marl, 90 per cent decomposed. Seems to have rock bottom; auger would not penetrate or detach fragments.

No. 26—18 inches of water. 16 feet of gray marl and no bottom found. Marl only partially decomposed. More soil and vegetable material than water. No marl on shore. Shore steep and rocky.

No. 27—Sample taken. 6 inches of water, 11 feet of marl on red sand bed. Marl 90 per cent decomposed. Few large shells, many small ones. Point 3 rods by 3 rods running out into lake all marl. Analysis 232 (p. 191).

No. 28—5 feet of marl in 1 foot of water. Marl compact, 90 per cent decomposed, and light gray in color. Strip 1 rod wide along shore by 10 rods long.

No. 29—1 foot of water, 12 feet of marl, sand bottom.

No. 30—1 foot of water, 6 feet of marl on sand bed. 80 per cent decomposed, light gray in color.

No. 31—12 paces from lake. 6 inches black soil, 1 foot marl, 50 per cent soil, very little decomposed.

No. 32—10 feet of marl, 80 per cent decomposed. 1 foot of water. Hard bottom, sand and gravel. Marl has light gray color and contains many shells. Strip on shore very narrow.

No. 33—Boring in 10 inches of water. 1 foot of marl, well decomposed. Marl runs out on gravel bed at edge of lake. Marl is light gray in color.

No. 34—1 foot of water, 10 feet of marl, well decomposed. Some soil, few shells.

No. 35—18 paces back from water. 12 inches of soil on top. 18 inches of marl, undecomposed at top, but decomposed on bottom. Gravel bottom.

No. 36—1 rod from shore in swamp. 1 foot of water, 17 feet of compact marl, no bottom found.

No. 37—Over 18 feet of solid marl in island. All of island is solid marl, pure and almost wholly decomposed. Shoal all around island. About 3 acres in island.

No. 38—1 foot of water, 17 feet of light gray marl, no bottom.

No. 39—1 foot of water, 17 feet of marl, light brown in color and rather shelly. No bottom.

No. 40—1 foot of water, 17 feet of marl which is light brown in color and contains some sand. Marl is well decomposed. No bottom.

No. 41—1 foot of water, 17 feet of light brown marl which contains some soil and is well decomposed. No bottom.

No. 42—2 feet of water, 16 feet of marl which is well decomposed and has a light brown color due to a slight admixture of vegetable matter. No bottom.

No. 43—2 feet of water, 16 feet of marl, decomposed, and light gray-brown in color. No bottom.

No. 44—2 feet of water, 16 feet of light brown marl. Marl contains few large shells and is very stiff at bottom of boring. No bottom.

No. 45—Boring 100 feet back from lake in wooded swamp. 2 feet of black soil, 1 foot of marl, little decomposed.

No. 46—100 feet back from lake. 4 inches of marl mixed with stiff yellow clay, 1 foot of clay, then gravel and clay. Marl is poor and undecomposed.

No. 47—10 feet back from water on little point 10 rods long and 10 rods wide. Point is all marl. This sample apparently same as the marl in all parts of lake. Very little marl out of water. The marl is over 16 feet deep. Analysis 233 (p. 191).

Chamberlin reported that a sample taken from the shell marl of Alaska Lakes had the composition shown by analysis 234 (p. 191).[1]

Ahnapee River near Algoma.—For a distance of four miles up the Ahnapee River from Algoma only slight traces of marl were found in the deep black soil along the banks of the river. Farther up the borings began to show a little more marl, but only in the surface strata. In the bottom of the river a thin layer of marl also occurred in many places.

The only place marl occurred in any quantity was just south of the railroad bridge on the east bank of the river. Here about 18 inches of marl were found under 1 foot of soil. Marl well decomposed, white, and compact. Dolomite outcrops along the river for about 80 rods. The soil is rocky.

In the city of Algoma, north of the river and road between two bridges, occurs a limited amount of marl around a large spring. About 3 acres of well-decomposed and compact marl from 1 to 5 feet deep underlies about 1 foot of soil.

On the N. $\frac{1}{2}$ of N. $\frac{1}{2}$ sec. 7, T. 24, R. 25 E., a small bed of marl about 18 inches thick at its greatest depth lies under 1 foot of soil. White and powdery outcrops of marl occur on the roadside.

Algoma.—Marls near Algoma underlie parts of sec. 5, T. 24 N., R. 25 E.

The lake covers about 25 acres and is said to reach a depth of 60 feet. The marl covers anywhere from 50 to 70 acres. The soil on top averages about 6 inches in depth. In most places the marl is more than 17 feet in depth, its bottom not having been found. The borings indicate that there is at least 1,000,000 cubic yards of marl.

For $\frac{1}{2}$ mile the outlet of the lake flows without a considerable fall. Lowering the lake level 10 feet would expose a strip of marl around the lake about 20 feet wide, but not any more in most places.

The logs of 17 borings are given below. For location see figure 10.

No. 1—6 inches black soil, 2 feet marl lying on bed of red clay and gravel. Marl a little sandy near top with some small shells. Grows purer and more decomposed at bottom. Of a light gray color.

No. 2—6 inches soil, 18 feet and more of marl. No bottom. A little shelly on top. Almost wholly decomposed at bottom, very wet, light gray in color. For composition see analysis 235 (p. 191).

No. 3—10 inches soil, 10 inches marl. Shelly, 50 per cent clay and soil. Very wet.

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[1] Chamberlin, T. C., Geology of Wisconsin, vol. 2, p. 239, 1877.

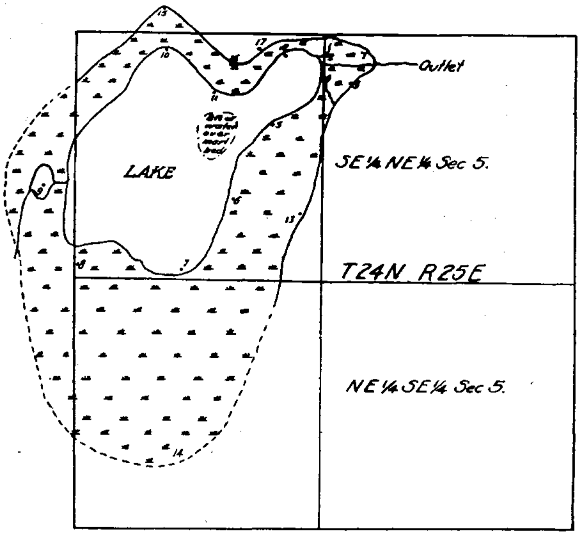

FIGURE 10.—MARL LAKE NEAR ALGOMA, KEWAUNEE COUNTY.

No. 4—6 inches soil, 18 feet and more of marl. No bottom found. Marl ¾ decomposed on top. After first few feet marl almost free from undecomposed marl. Marl of a light grayish color. Boring in water.

No. 5—4 inches soil, 17 feet of marl. No bottom found. Marl much decomposed, wet and slimy, light gray in color.

No. 6—6 inches soil, 17 feet marl. No bottom found. Some shells throughout. Marl is light gray in color. For composition see analysis 236 (p. 191).

No. 7—Boring in 1 foot of water, 17 feet of marl. A few shells. Marl light gray in color, free from foreign material. No bottom. Boring in swamp.

No. 8—Taken in 1 foot of water, 17 feet. No bottom. Marl contains moderate number of shells and some vegetable matter. Color light gray.

No. 9—14 inches soil, 16 feet marl, gravel at bottom. Marl with shells, considerable soil and vegetable matter, very wet. Boring on land. For composition see analysis 237 (191).

No. 10—1 foot in water, 17 feet marl. No bottom found. Some vegetable matter near top. Marl well decomposed at bottom and light gray in color.

No. 11—1 foot in water, 17 feet marl, vegetable matter in small quantity toward top. Clear marl at bottom and of a light gray. Some large shells, many small ones. No bottom found.

No. 12—1 foot in water, 17 feet marl. No bottom found. Much vegetable matter, particularly decayed wood. Marl nearly all decomposed, gray in color.

No. 13—Boring taken in woods at edge of hill. 8 inches of black soil, then 1 foot of marl mingled in large percentage of sand. Between this point and lake marl becomes very pure and completely decomposed and of a very light gray color. Marl under 6 to 8 inches black soil.

No. 14—Almost no marl. Marl of a gray color, mostly decomposed, under 1 foot black soil. Seems to run out into bed of white lake sand.
No. 15—6 inches black soil, 3 feet solid marl, resting on bed of red clay. Marl well decomposed, has moderate number of small shells, light gray color, quite stiff.
No. 16—1 foot black soil, 1 foot of marl resting on bed of red clay. Marl gray, compact, mostly decomposed.
No. 17—6 inches soil, 3 inches marl, 50 per cent sand and clay. Rests on a bed of red clay. Marl very little decomposed.

Kewaunee River.—Marls underlie parts of the following lands along the Kewaunee River. The borings indicate that there is about 5,000 cubic yards of marl:

N. ½ of NE. ¼, sec. 13.
NE. ¼ of SW. ¼, sec. 13.
Also E. ½ of NW. ¼, sec. 13, east of river.
S. ½ of SE. ¼, sec. 2.

Marl occurs in bottom of the river all along its course. A narrow strip of land running parallel with the railroad for 400 paces, 30 paces wide at the widest, has a bed of marl under 18 inches to 3 feet of black soil. The marl is from 6 inches to 2 feet in thickness and is compact, clear, well decomposed, of a yellowish white color. This, as far as is known, is the largest deposit along the river, black vegetable mold and soil being the chief constituent of the low land along the river.

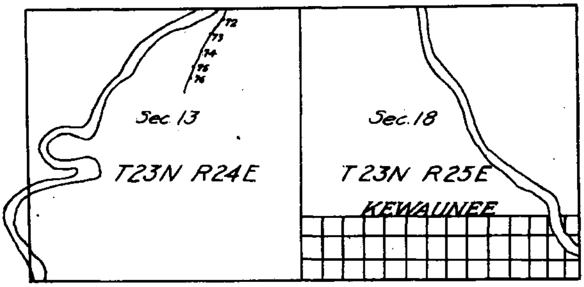

FIGURE 11.—MARL BORINGS ON KEWAUNEE RIVER, KEWAUNEE COUNTY.

Borings 72, 73, 74, and 75, figure 11, verify the above statements as to position and extent of the marl.

Where dredging has been done at the mouth of the river, the marl and clay from the bottom of the river has been used in many instances in the town for lawns and has produced a fine growth of grass where it was well watered. On drying it has a tendency to bake and crack.

Marquette County

Lake Ennis.—This lake lies about three quarters of a mile northeast of the Fox River in sec. 14, T. 14 N., R. 9 E. A sample of marl was taken from a hole about 50 feet from the shore of the marsh at the south side of the lake near the foot of a steep hill. In this boring the marl was struck at a depth of 6 inches and continued to 18 feet without reaching the bottom of the deposit. A little sand appeared with the marl at one level and again in the portion from 15 to 18 feet. The marl was compact enough to bore easily and to remain on the auger, especially in the deeper portion. The marl from this hole was taken as sample No. 36A. This analysis, No. 238 (p. 191), shows that it is suitable for cement if added to the proper clay or shale. See Table 5 (p. 194) for combinations of this marl with clays and shale. See page 165 for description of clays found in this vicinity.

In 1905 the Wisconsin Portland Cement Company was organized for the purpose of manufacturing cement at Lake Ennis. The company failed to raise sufficient capital for the erection of a plant. The prospectus of the company states that the plant is to be erected on a point of land running out into the marl deposit on the north shore of Lake Ennis; that the plant will be bordered on three sides by marl, and will have clay at a distance of 300 feet on the fourth side; and that the quantity of marl and clay has been tested and found to be sufficient for the production of 20,000,000 barrels of cement. Reports from S. B. Newberry and R. C. Carpenter show that the clay and marl are chemically suited to the manufacture of cement, and that good cement was made in the laboratory from these materials. No records of the details of the marl and clay explorations of this company are available.

MILWAUKEE COUNTY

Cudahy.—Sample No. 2 was taken from a bore hole two miles west southwest of Cudahy near the southwest corner of sec. 27, T. 6 N., R. 22 E. in a marshy tract about ½ mile wide which extends through parts of secs. 18, 19, 20, 27, 28, and 34. The bore hole showed the following section.

		Feet
I.	Black peat almost entirely organic	3½
II.	Gray marl, no coarse material excepting small snail shells, no sand	3
III.	Brown marl with streaks of green changing to reddish brown	3
IV.	Greenish marl	5½

All the material from II, III, and IV was taken as a sample. Water was struck at 2½ feet. The material was soft enough to run into the hole. This tendency may have affected the record slightly. For analysis see No. 239 (p. 191). This material has in nearly the right proportions all the ingredients necessary for Portland cement. Note combinations 1 and 6, Table 5 (p. 194). Further investigation of this tract is desirable in order to determine how much of the marsh is underlain by marl, as but a single boring was made in this vicinity.

The Northwestern line passes north and south through sec. 27 about one-quarter mile east of the west line on a fifteen to twenty foot embankment. West of this section line the swamp is farmed for the most part excepting in the southeastern part of sec. 28, the northeast quarter of 33, and the northwest quarter of 34. Truck farms lie east of the railroad. The southeastern 80 acres of sec. 28 are unimproved. The unimproved acreage in secs. 27, 28, 33, and 34 is estimated at 1,000 acres. Improved land in this vicinity is held at about $1,000 per acre.

OUTAGAMIE COUNTY

Shaking Lake.—The marls of Shaking Lake underlie parts of sec. 7, T. 21 N., R. 15 E., mainly in the N. ½ of the section. See figure 12 for location. The numbers on this sketch indicate the position of borings whose log is given below.

The marl underlies about 130 acres, nearly all of which lies in an open swamp and extends an average distance of 250 feet back into a tamarack bog all around the marsh. The borings indicate that there is at least 1,500,000 cubic yards of marl. The open swamp is a floating bog of vegetable mold covered with wild hay. About 15 acres are open water which is about 6 inches deep.

The marl is exceedingly uniform in color and grain. It is a bluish marl, very well decomposed, and very compact. In the north and south line of borings, a stiff red clay was found lying under the marl. In other borings the marl was found to rest on white sand. No springs occur around the shores of the lake.

The log of the borings follows. Note analyses of boring numbers 282, 296, and 299.

No. 273—2 feet muck, 3 feet marl colored dark by muck.
No. 274—3 feet muck, 6 feet marl. Sand bottom.
No. 275—1 foot muck, 8 feet marl. Purer and lighter colored than 273.
No. 276—10 inches muck, 10 feet marl.
No. 277—10 inches muck, 15 feet marl.
No. 278—8 inches muck, 23 feet marl.
No. 279—8 inches muck, 28 feet marl. Red clay bottom.
No. 280—8 inches muck, 29 feet marl.
No. 281—8 inches muck, 19 feet marl.
No. 282—1 foot muck, 15 feet marl. For composition see analysis 240 p. 191).
No. 283—6 inches muck, 12 feet marl. A little darker than 282.
No. 284—6 inches muck, 10 feet marl.
No. 285—6 feet muck.
No. 286—1 foot muck, 9 feet marl, dark.
No. 287—1 foot muck, 9 feet marl.
No. 288—1 foot muck, 12 feet marl, light gray, pure.
No. 289—3 feet muck, 11 feet marl, dark gray.

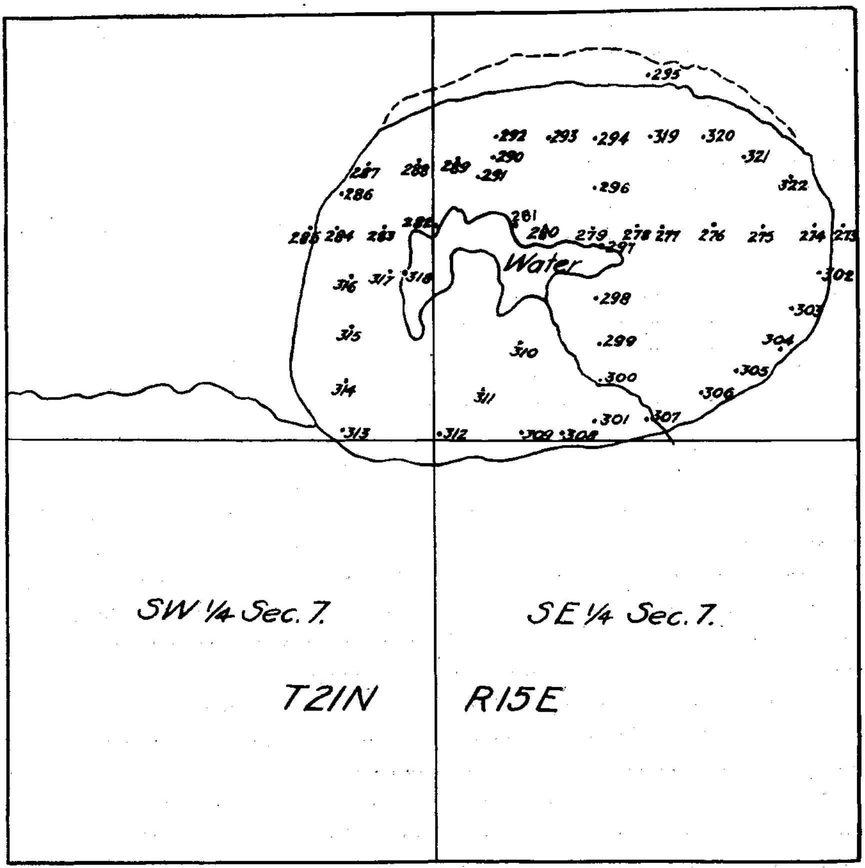

FIGURE 12.—SHAKING LAKE, OUTAGAMIE COUNTY.

No. 290—4 feet muck, 10 feet marl, dark.
No. 291—4 feet muck, 10 feet marl, dark.
No. 292—6 feet muck, 6 feet marl, 20 per cent muck.
No. 293—18 inches muck, 14 feet marl.
No. 294—18 inches muck, 15 feet marl. } Red clay bottom.
No. 295—18 inches muck, 1 inch marl.
No. 296—18 inches muck, 13 feet marl, light gray. For composition see analysis 241 (p. 191).
No. 297—18 inches muck, 35 feet marl. Red clay bottom.
No. 298—18 inches muck, 21 feet marl, sand.
No. 299—18 inches muck, 14 feet marl. For composition see analysis 242 (p. 191).
No. 300—12 inches muck, 8 feet marl.
No. 301—12 inches muck, 4 feet marl.
No. 302— 3 inches muck, 5 feet marl.
No. 303— 3 inches muck, 11 feet marl.
No. 304— 6 inches muck, 4 inches marl.
No. 305—2½ inches muck, 4½ feet marl.
No. 306—2½ inches muck, 3½ feet marl.
No. 307—2½ inches muck, 4 feet marl. Clay bottom.

No. 308—2½ inches muck, 3½ feet marl.
No. 309—2½ inches muck, 1 foot marl.
No. 310—2 inches muck, 12 feet marl.
No. 311—1 inch muck, 8 feet marl.
No. 312—1 foot muck, 1 foot marl.
No. 313—3 feet muck, 7 feet marl, a little shelly.
No. 314— 8 feet muck, 9 feet marl.
No. 315— 5 feet muck, 6 feet marl.
No. 316— 5 feet muck, 8 feet marl.
No. 317— 8 feet muck, 13 feet marl.
No. 318— 6 feet muck, 20 feet marl.
No. 319—15 feet muck, 8½ feet marl.
No. 320—15 feet muck, 5 feet marl.
No. 321—15 feet muck, 8 feet marl.
No. 322—15 feet muck, 7 inches marl.

Portage County

Lime Lake.—Lime Lake is located in the W. ½ of SW. ¼, sec. 31, T. 23 N., R. 10 E. and in the E. ½ of SE. ¼, sec. 36, T. 23 N., R. 9 E. Figure 13 shows the location of the lake and of the borings for marl.

About 60 to 70 acres of marl in Lime Lake lies under water, and perhaps 3 acres is above water. The borings indicate that this deposit contains at least 1,500,000 cubic yards of marl.

The shores on the north and west sides of the lake are steep. On the north side a long low bar of sand cuts off a long neck of the original lake from the rest of the lake. The lake has no outlet.

From 1850 to 1870 the marl from the lake was burned for lime and many thousand barrels were taken out. The quality of the marl is uniform. It is wholly decomposed in the bottom of the bed and has a small proportion of shelly fragments towards the top.

The lake has a depth of 25 feet in a limited area, but the water is shallow for a considerable distance from shore. From the pitch of the marl near shore, the possible depth of marl in the middle of the lake may be 100 feet, but this depth is not proven.

The log of the borings is given below:

No. 110—Boring 80 feet from shore, 30 feet marl.
No. 111—Boring 20 feet from shore, marl over 30 feet thick.
No. 112—Boring 25 feet from shore, marl over 30 feet thick.
No. 113—Boring 25 feet from shore. 12 feet marl on gravel bottom.
No. 114—Boring 30 feet from shore. Marl 12 feet thick.
No. 115—Boring 35 feet from shore. Marl 20 feet thick. For composition see analysis 243 (p. 191).
No. 116—Boring 30 feet from shore. Marl 14 feet thick.
No. 117—Boring 20 feet from shore. Marl 10 feet thick.
No. 118—Boring 70 feet from shore. Marl 25 feet thick. At 22 feet strike a compact white layer of marl.
No. 119—Boring 25 feet from shore. Marl 30 feet thick.
No. 120—Boring 14 feet from shore. Marl 8 feet thick.

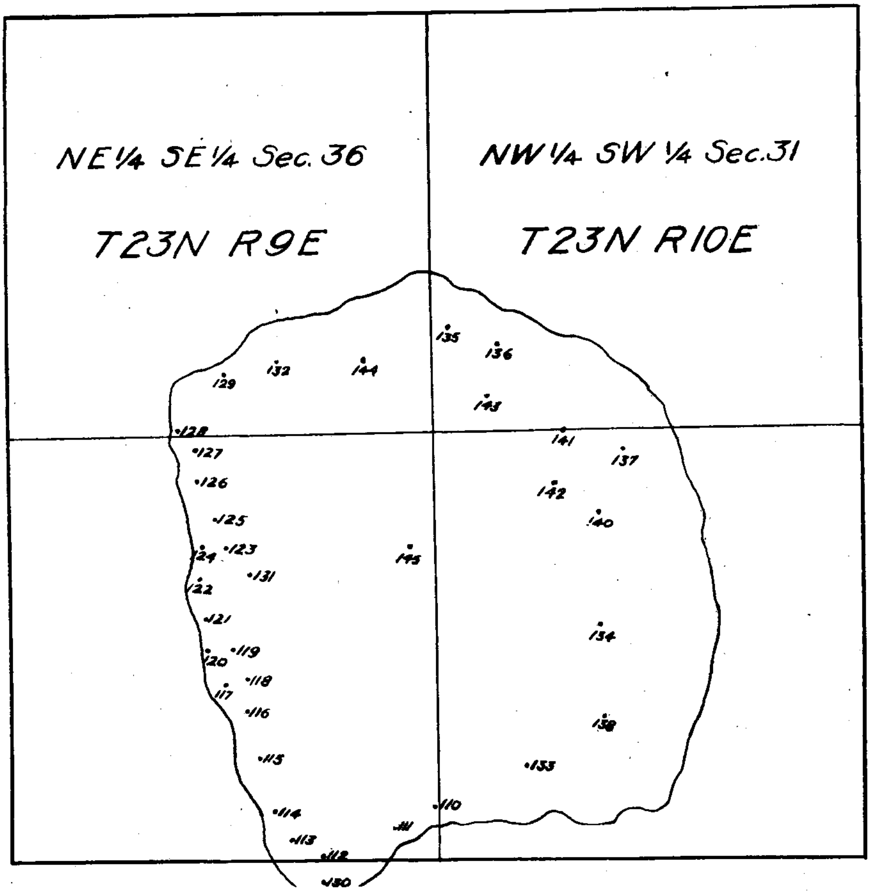

FIGURE 13.—MARL BORINGS ON LIME LAKE. T.23N., R.10E., PORTAGE COUNTY.

No. 121—Boring 16 feet from shore. Marl 10 feet thick.
No. 122—Boring 20 feet from shore. Marl 12 feet thick.
No. 123—Boring 40 feet from shore. Marl 16 feet thick.
No. 124—Boring 20 feet from shore. Marl 8 feet thick.
No. 125—Boring 80 feet from shore. Marl 30 feet thick. No bottom at 30 feet.
No. 126—Boring 50 feet from shore. Marl 8 feet thick.
No. 127—Boring 50 feet from shore. Marl 20 feet thick.
No. 128—Boring 10 feet from shore. Marl 15 feet thick. No bottom.
No. 129—Boring 20 feet from shore. Marl 30 feet thick. For composition see analysis 244 (p. 191).
No. 130—Boring 10 feet from shore. Marl 32 feet thick in vicinity of main spring. Sand bottom, 1 foot water. A little vegetable mold and soil on top. Marl slightly dark colored and almost totally decomposed. Shores very steep.
No. 131—Boring 100 feet from shore. 30 feet marl of uniform quality. A few springs along shore. Bank not quite so steep as at 130.
No. 132—Boring 100 feet from shore. 25 feet marl on sand bed. Shoal water at this place.

No. 133—Boring 150 feet from shore. 30 feet marl on sand.
No. 134—Boring 150 feet from shore. 30 feet marl.
No. 135—Boring 25 feet from shore. 22 feet marl.
No. 136—Boring 25 feet from shore. 30 feet marl.
No. 137—Boring 100 feet from shore. More than 10 feet of marl.
No. 138—Boring 50 feet from shore, 8 feet marl.
No. 140—25 feet marl.
No. 141—20 feet marl.
No. 142—20 feet marl.
No. 143—30 feet marl.
No. 144—20 feet marl.
No. 145—20 feet marl. For composition see analysis 245 (p. 191).

Town of New Hope.—The marl in the lake in the town of New Hope underlies parts of secs. 27 and 34. See figure 14 for location of borings.

The marl bed is wholly under water and covers about 50 acres. The reported greatest depth of the lake is 90 feet. The marl ends at the shore, the shore being sandy and gravelly. The lake partially fills one of the typical "kettles" of this region; the shores on the north, northeast, and northwest sides are about 30 feet high and steep. Springs are found along these steep shores. The borings indicate that there is at least 300,000 cubic yards of marl.

The marl is very uniform in quality and lies all over the bottom of the lake to a considerable depth and is deepest at the shore where springs flow into the lake. It is almost wholly decomposed on top and wholly decomposed near the bottom of the bed. It is all of a light bluish gray color.

The log of the borings is given below:

No. 146—Boring 20 feet from shore, 7 feet marl. Sand bottom.
No. 147—Boring 50 feet from shore, 18 inches marl. Sand bottom.
No. 148—Boring 150 feet from shore, 4 feet marl. Sand bottom.
No. 149—Boring 150 feet from shore, 1 foot marl.
No. 150—Boring 20 feet from shore, 7 feet marl.
No. 151—Boring 40 feet from shore, 13 feet marl.
No. 152—Boring 150 feet from shore, 9 feet marl.
No. 153—Boring 190 feet from shore, 10 feet marl.
No. 154—Boring middle of lake in bar, 10 feet marl.
No. 155—Boring 300 feet from shore, 20 feet marl.
No. 156—Boring 100 feet from shore, 7 feet marl.
No. 157—Boring 50 feet from shore, 16 feet marl.
No. 158—Boring 20 feet from shore, 8 feet marl.
No. 159—Boring 60 feet from shore, 10 feet marl.
No. 160—Boring 150 feet from shore, 16 feet marl.

SHAWANO COUNTY

Lake Shawano.—On the north shore of Lake Shawano a bed of marl from 6 inches to 2 feet thick underlies about 15 acres.

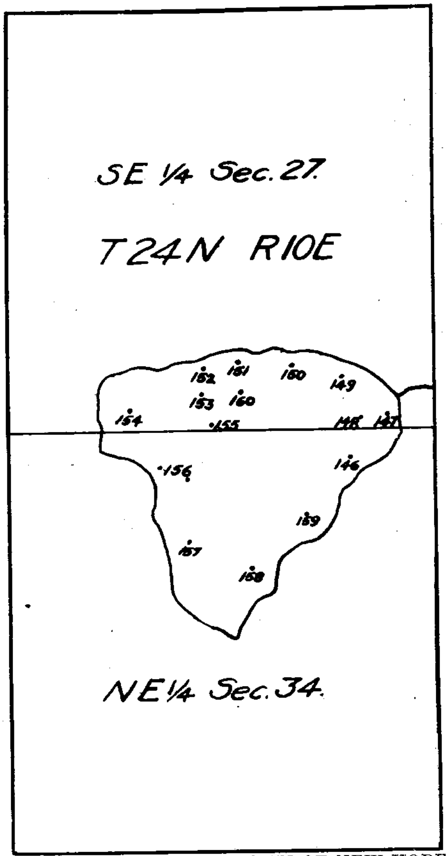

FIGURE 14.—MARL BORINGS IN LAKE IN TOWN OF NEW HOPE, PORTAGE COUNTY.

In the SW. ¼ of the SE. ¼ of sec. 31, T. 26 N., R. 15 E. a small deposit of marl occurs in the bank of a lake. The marl is 4 to 6 feet thick and underlies about 2 acres. The soil on top is 1 to 2 feet thick. The marl is a shelly deposit, partially decomposed. This deposit may contain as much as 15,000 cubic yards of marl.

SHEBOYGAN COUNTY

Sheboygan Marsh.—The Sheboygan Marsh, north of Glenbeulah, has an area of about 15 square miles. The peat cover, about 4 feet in thickness, is underlain by an unknown thickness of marl. About one-third of the marsh is covered by fifteen-year-old spruce and tamarack. For composition of two samples of marl from this marsh see analyses 246 and 247 (p. 191).

WAUKESHA COUNTY

Scuppernong Marsh.—A sample was taken from an auger hole about 150 yards southwest from the center of the SE. ¼ of sec. 34, T. 6 N., R. 17 E., near the plant of the former Lime Products Company. The sample represents the 7 feet of marl found in a 10-foot hole. The section of the bore hole follows:

	Ft.	In.
I. Peat	1	9
II. White coherent marl		9
III. Dark brown peat	1	3
IV. Gray incoherent marl almost no recovery	2	6
V. Coherent marl probably with small amount of clay		3
VI. Unconsolidated gray marl which filled hole like quicksand	3	6

VII. Coarse material either shells or fine gravel below.

Water stood at 1½ feet from surface. For composition see analysis 248 (p. 191). Combinations 2 and 7, Table 5 (p. 194), show the analyses of mixtures of this marl with shale and clay.

A sample was taken from the hopper leading into the kiln at the plant of the Lime Products Company. See analysis 249 (p. 191). In Table 5 (p. 194) are analyses of mixtures of this marl with shale and clays.

The Soil Survey reports marl in secs. 3 and 4 of the town of Eagle. For description of clays from this locality see page 172.

Waupaca County

Bear Lake.—The marls of Bear Lake are entirely under water. See figure 15 for the location of the lake and the position of borings made for marl. The lake covers about 230 acres. The borings indicate that there is at least 1,000,000 cubic yards of marl. The level has fallen somewhat, leaving a narrow edge of swamp and bog around most of the lake. The bottom of the lake is sand and gravel. The banks of the lake are about 30 feet high and very steep.

The thickest and largest quantity of marl lies near the outlet. Its quality here is poorer than in other parts of the lake. Around the inlet the bottom is black muck and vegetable mold to a depth of 20 to 25 feet, underneath which is a sandy bottom. In most lakes the marl is thickest near the inlet. Several springs enter the southwest end of the lake. The marl is mostly decomposed. Near the outlet it contains a small percentage of vegetable mold and black silt.

The log of the borings is given below:

No. 161—At edge of water by the dock. 13 feet marl, 1 foot water Marl is light gray in color with decomposed shells and silt on top.

No. 162—25 feet marl, decomposed, vegetable mold on top. 1 foot water.

No. 163—20 feet marl wholly decomposed.

No. 164—In bed of outlet 300 feet south of bridge. 20 feet marl. Marl is decomposed, clean, and light gray in color.

No. 165—300 feet from shore. 25 feet marl decomposed.

No. 166—Boring 100 feet from shore, opposite steep bank. 20 feet marl. Marl contains some shells. Is decomposed. 6 inches vegetable mold on top. 1 foot water.

No. 167—Boring 50 feet from shore, 18 feet decomposed marl.

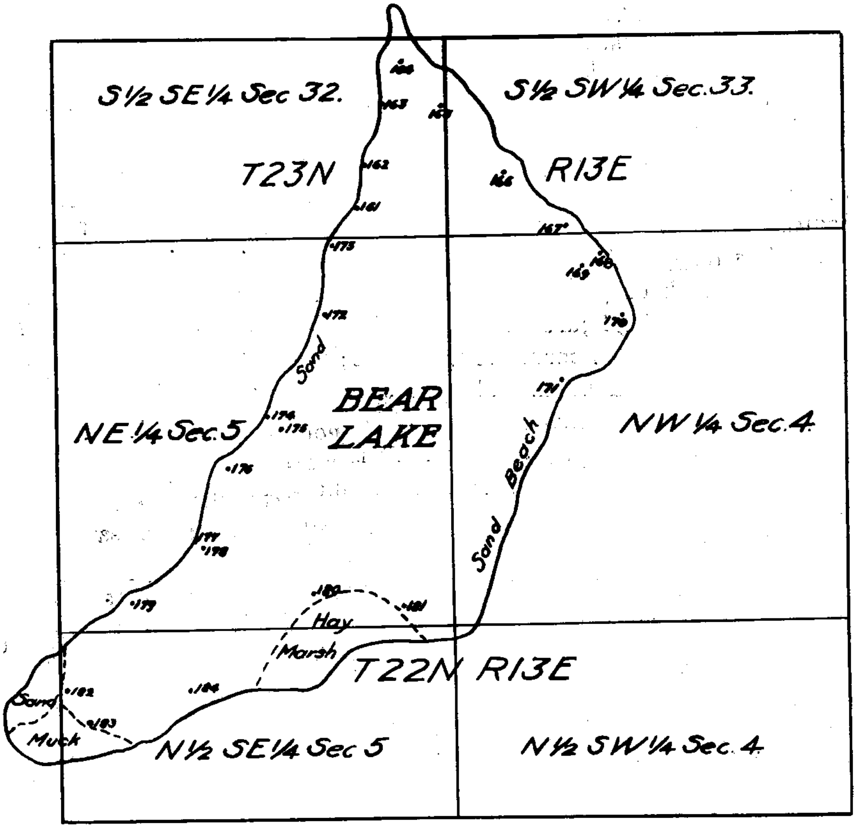

FIGURE 15.—MARL BORINGS ON BEAR LAKE, WAUPACA COUNTY.

No. 168—Boring 10 feet from shore, 3 feet marl partly sand.

No. 169—Boring 40 feet from shore, 22 feet decomposed marl, light gray. 1 foot vegetable matter on top. 1 foot water.

No. 170—Boring 100 feet from shore, 10 feet decomposed marl, 1 foot water.

No. 171—Sand beach begins.

No. 172—Boring 20 feet from shore. 8 feet marl, partially decomposed.

No. 173—Boring 30 feet from shore. 10 feet marl. Contains some vegetable matter on top, also black silt.

No. 174—Boring on shore, 6 inches marl.

No. 175—Boring 125 feet from shore. 2 feet water, 14 feet decomposed marl.

No. 176—Boring 80 feet from shore. 1 foot water, 13 feet decomposed marl.

No. 177—Boring on edge of lake. 1 foot water, 6 feet marl.

No. 178—Boring 50 feet from shore. 20 feet decomposed, light gray marl.

No. 179—Boring 20 feet from shore. 20 feet decomposed, light gray marl.

No. 180—Boring 300 feet from shore. 12 feet decomposed, light gray marl. 1 foot water.

No. 181—Sand beach begins.
No. 182—25 feet black muck and vegetable mold.
No. 183—25 feet black muck and vegetable mold.
No. 184—20 feet black muck and vegetable mold.

Big Falls.—A small lake on the NW. ¼ of NW. ¼ of sec. 17, T. 25 N., R. 12 E., near Big Falls has about 15 to 20 acres of marl around the inlet at the west end of the lake. The marl is of a clear light gray color and is well decomposed. It is 6 to 12 feet deep. The borings indicate that this deposit contains at least 100,000 cubic yards of marl.

Marl factory, north of Waupaca.—The marl bed at the marl factory, 3½ miles north of Waupaca, underlies about 6 acres of open marsh along a creek. See figure 16 for location and for position of borings. Only about 3 acres of marl are accessible; the rest lies under a great depth of muck and mold. The accessible portions contain at least 10,000 cubic yards of marl.

The marl is of a light gray color. It is compact and wholly decomposed. The layer beneath the marl is sand. The depth of marl is greatest around the factory.

The log of the borings in this marl deposit follows:

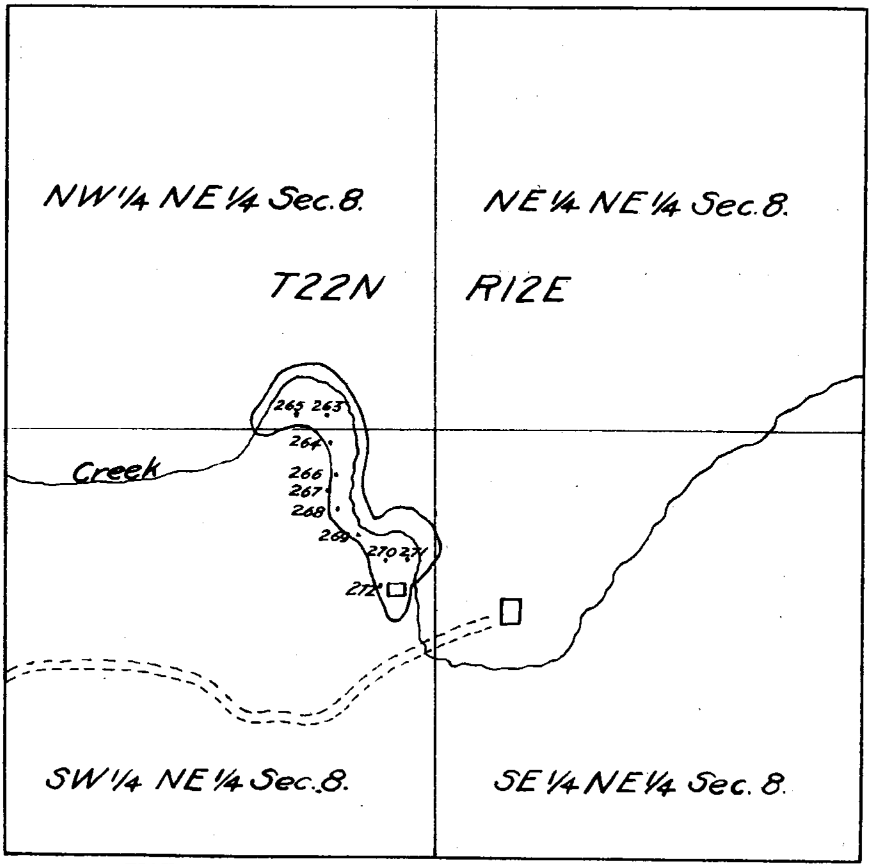

FIGURE 16.—MARL DEPOSIT 3½ MILES NORTH OF WAUPACA.

No. 263—12 feet black muck with traces of gray marl.
No. 264—12 feet black muck, 7 feet light gray marl.
No. 265—12 feet black muck, 9 feet light gray marl.
No. 266—12 feet black muck, 3 feet light gray marl.
No. 267—19 feet black muck, 1 foot light gray marl.
No. 268—6 feet soil, 6 feet soil and marl.
No. 269—4 feet soil, 8 feet marl.
No. 270—4 feet soil and clay, 12 feet marl.
No. 271—4 feet soil and clay, 6 feet marl.
No. 272—2 feet soil and clay, 12 feet marl. For composition see analysis 250 (p. 191).

School Section Lake.—School Section Lake is located in sec. 21, T. 24 N., R. 13 E. The numbers in figure 17 indicate the location of the borings whose logs are given below.

The marl of this locality covers 100 acres of which 75 are under water. Nearly all of the marl on land is covered by 6 inches to 18 feet of soil on which grow tamarack, cedar, and hardwood. The water in the lake reaches a depth of about 80 feet. The marl under the lake is covered by 6 to 20 feet of vegetable mold and muck. As a rule, the marl lies on a bed of sand, but locally on red clay. Much of the marl, though in large quantity, is not practically accessible. The borings indicate that at least 40,000 cubic yards of marl are accessible.

The lake lies in a kettle. The slopes on the north and east sides are steep and rise directly from the shore. The other shores are low and marshy and in places too wet for landing.

The marl appears uniform in quality, of a light gray color, wholly decomposed, and very compact. The marl on land is lighter in color and more compact than that in the lake.

The log of the borings follows:

No. 185—6 feet black muck, 6 feet light gray, decomposed marl and black muck.
No. 186—1 foot soil, 3 inches pure light gray marl.
No. 187—Sand ridge.
No. 188—18 inches black soil, 2½ feet marl.
No. 189—12 feet muck, 10 feet marl, edge of lake.
No. 190—1 foot soil, 4 feet marl, white, dry, and very compact.
No. 191—1 foot soil, 11 feet gray marl.
No. 192—1 foot soil, 17 feet marl.
No. 193—2 feet soil, 10 feet marl.
No. 194—1 foot soil, 3 inches solid white marl.
No. 195—2 feet soil, 11 feet marl.
No. 196—3 feet soil, 9 feet marl.
No. 197—2 feet soil, 5 feet marl. For composition see analysis 251 (p. 191).
No. 198—Sand.
No. 199—2½ feet soil, 10 feet light gray marl.
No. 200—6 inches soil, 7 feet marl.
No. 201—6 inches soil, 6 inches marl mixed with sand.
No. 202—Sand, no marl, 23 feet from lake.

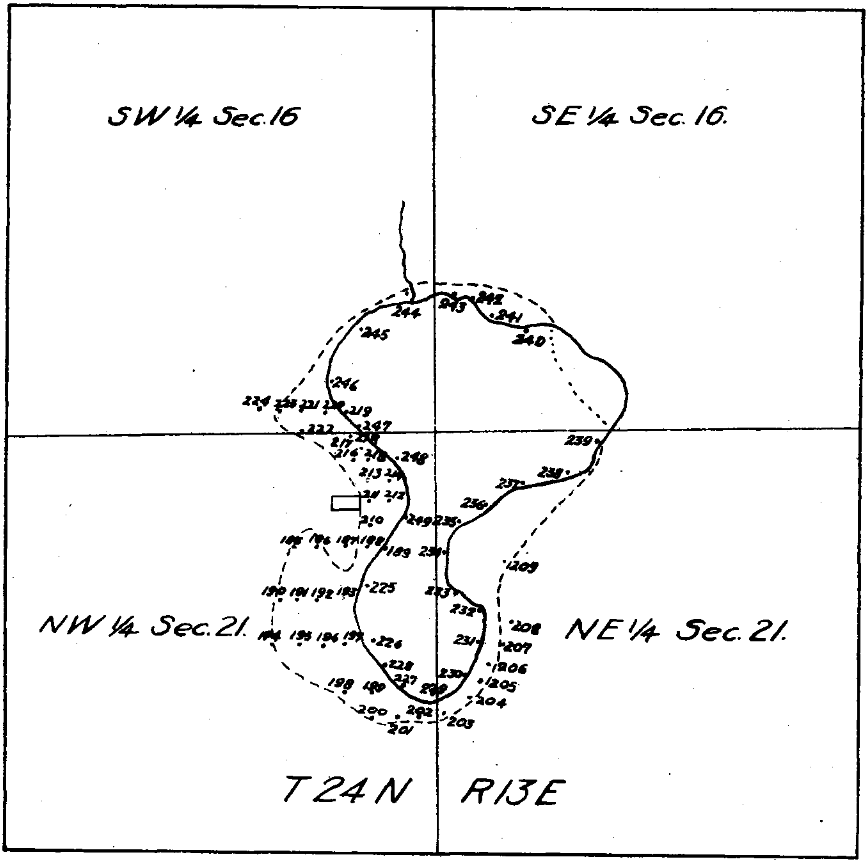

FIGURE 17.—SCHOOL SECTION LAKE, TOWN OF UNION, WAUPACA COUNTY.

No. 203—2 feet soil, 3 feet marl, 50 per cent soil.
No. 204—4 feet soil, 15 feet marl and vegetable mold.
No. 205—13 feet light gray, clean, compact marl.
No. 206—6 feet black soil with traces of marl.
No. 207—All black soil and mold.
No. 208—21 feet black mold, traces of marl down 12 feet.
No. 209—Edge of marl bed.
No. 210—6 inches black soil, 3 feet light gray, pure marl.
No. 211—50 paces north of 210, 6 inches soil, 2½ feet clear light gray marl.
No. 212—50 paces east of 211, 12 inches soil, 10 feet clear light gray marl. For composition see analysis 252 (p. 191).
No. 213—12 inches soil, 3½ feet clear light gray marl.
No. 214—4 inches soil, 7 feet clear light gray marl.
No. 215—12 inches soil, 15 feet clear light gray marl.
No. 216—12 inches sandy soil, 4 feet marl, 50 per cent soil.
No. 217—1 foot soil, 14 feet light gray marl.
No. 218—1 foot soil, 16 feet light gray marl.
No. 219—7 feet mold, 14 feet light gray marl.
No. 220—7 feet mold, 13 feet impure marl, 50 per cent soil.

No. 221—2 inches soil, 3 feet clean light gray marl.
No. 222—Sand.
No. 223—15 feet black muck.
No. 224—Black muck.
Nos. 225–249 were at the edge of lake in water.
No. 225—18 feet marl, 12 feet soil.
No. 226—12 feet marl, 22 feet muck.
No. 227—8 feet marl, 25 feet muck.
No. 228—15 feet marl, 12 feet muck.
No. 229—18 feet muck, 10 feet marl.
No. 230—15 feet muck, 12 feet marl.
No. 231—16 feet muck, 15 feet marl.
No. 232—10 feet muck, 12 feet marl.
No. 233—12 feet muck, 14 feet marl.
No. 234—10 feet muck, 14 feet marl.
No. 235—11 feet muck, 15 feet marl.
No. 236—10 feet muck, 16 feet marl.
No. 237—10 feet muck, 10 feet marl.
No. 238—Muck, no soil.
No. 239—8 feet muck, 12 feet marl.
No. 240—9 feet muck, 6 feet marl.
No. 241—18 feet muck, 16 feet marl.
No. 242—7 feet muck.
No. 243—10 feet muck, 15 feet marl.
No. 244—2 feet muck, 15 feet marl.
No. 245—20 feet muck.
No. 246—16 feet muck, 12 feet marl.
No. 247—16 feet muck, 10 feet marl.
No. 248—18 feet muck, 12 feet marl.
No. 249—8 feet muck, 12 feet marl.

Town of Helvetia.—This marl deposit underlies about 20 acres of lake and about an equal area of marsh (fig. 18). The lake has a maximum depth of 9 feet. The greatest depth of the marl may be about 30 feet. The borings indicate that there is at least 200,000 cubic yards of marl in this deposit. It seems to be uniform in quality and appearance. High ridges come close to shore on the north, northwest, and south sides of the lake. The marsh is a floating bog. The inlet is fed by springs.

The log of the borings follows:
No. 250—4 feet mold, 6 feet light gray marl.
No. 251—4 feet mold, 9 feet light gray marl.
No. 252—4 feet water and mold, 8 feet marl.
No. 253—Soil.
No. 254—3 feet mold and water, 18 feet marl.
No. 255—2 feet mud and marl.
No. 256—2 feet water and mold, 17 feet marl.
No. 257—2 feet water and mold, 17 feet marl.
No. 258—10 feet marl.
No. 259—4 feet marl.
No. 260—6 feet marl.
No. 261—13 feet marl.
No. 262—19 feet marl.

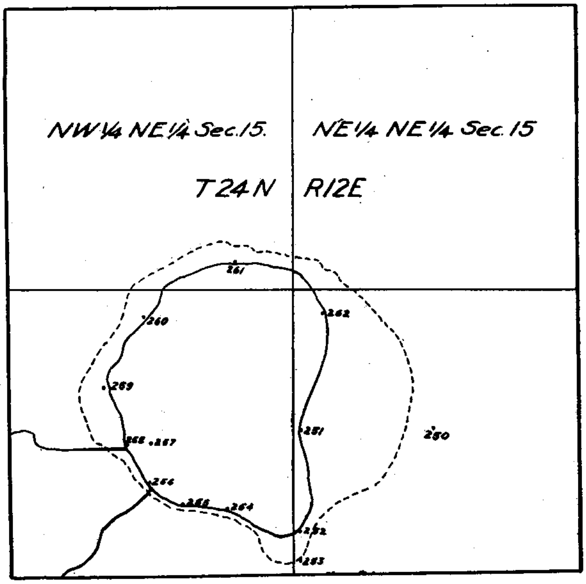

FIGURE 18.—MARL POND ON SECTION 15, TOWN OF HELVETIA, WAUPACA COUNTY.

WINNEBAGO COUNTY

Lake Winnebago.—The marl bed on the SW. ¼ of sec. 26, T. 20 N., R. 17 E., underlies 5 or 6 acres of swampy ground along Lake Winnebago. The soil covering the marl is black and from 1 to 2 feet thick. Layers of soil alternate with layers of marl. The marl itself is uniform in quality, but limited in amount. At high water in the lake, most of the bed is under water.

See figure 19 for distribution of the marl and the location of the bore holes.

The log of the borings follows:

No. 101—18 inches black muck, 4 inches marl. Marl is compact, dark gray, largely decomposed and contains some sand.

No. 102—1 foot black soil, 2 feet marl. Marl is stiff, blue gray in color, and very much resembles blue clay. Is largely decomposed. Contains some shells. Rests on sand bottom.

No. 103—1 foot soil, 1 foot black gritty soil mixed with shells. 1 foot marl like 102. Bottom is sand.

No. 104—1 foot black soil, 10 inches light gray, largely decomposed, compact marl containing 10 per cent shells. 15 inches marl and vegetable mold, mold predominating. Marl contains many small shells. 2 feet light gray, gritty compact marl, 50 per cent decomposed. Marl contains some soil and vegetable mold. Marl rests on sand bottom.

No. 105—2 feet soil. 10 inches light gray compact marl partially decomposed. 6 inches vegetable mold. 4 feet loose marl little decomposed and consisting mainly of small shells with some mold.

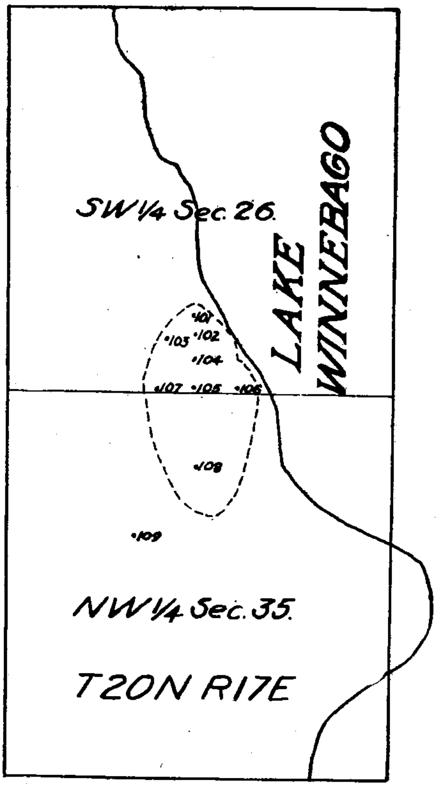

FIGURE 19.—MARL BORINGS ON LAKE WINNEBAGO.

No. 106—4 feet soil, 3 feet loose, partially decomposed marl containing considerable vegetable mold.

No. 107—2 feet soil, 1 foot clay with streaks of marl partially decomposed, 3 feet marl. Rests on bed of sand.

No. 108—2 feet soil, 4 feet partially decomposed, compact marl with some clay on top. Contains many small shells. Color of marl dark gray and blue. Rests on rock bottom.

No. 109—No marl. Stiff black soil.

CHAPTER VII

SOURCES OF ALUMINA AND SILICA FOR PORTLAND CEMENT IN WISCONSIN

INTRODUCTION

Before 1922 the clays and shales of Wisconsin had not been studied from the standpoint of making Portland cement. In 1922 C. S. Corbett, under a joint arrangement between this Survey and the Highway Commission, examined various clay and marl deposits of Wisconsin with the principal purpose of determining whether suitable clays could be found for Portland cement material. The major facts compiled from his field notes are included in this chapter. The records of a large number of unfavorable localities are included in Corbett's field notes. These notes are available for examination at the Survey office.

A large amount of additional data has been compiled from Survey publications, especially those dealings with clays.[1]

Aside from the size and position of clay deposits, the qualities of clay most esteemed by cement makers are uniformity of composition and absence of grit or hard pebbles of quartz, chert, or similar rocks. The silica content should be from 2.5 to 4 times as great as the total of ferric oxide and alumina. The ratio of alumina to ferric oxide should be about 3 to 1 and not less than 1 to 1. The amount of magnesia should be low and depends on the magnesia content of the limestone or marl used. The magnesia in the finished cement should not exceed 5 per cent.

The shales of Wisconsin are of Cambrian, Ordovician, and Devonian age. The Cambrian shales are usually sandy and associated with sandstone. It is unlikely that it would prove feasible to use these shales in cement manufacture. The Ordovician shales (Richmond and Maquoketa) so far as known are chemically of inferior quality for cement manufacture. Further investigation of these formations is desirable. The Richmond shale is about 50 to 540 feet thick and outcrops in a narrow north and south trending belt a few miles wide in eastern Wisconsin. In southwestern Wisconsin the similar Maquoketa shale

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[1] Buckley, E. R., Clays and clay industries of Wisconsin: Wisconsin Geol. and Nat. Hist. Survey Bull. 7, Pt. 1, 1901.

Ries, H., The clays of Wisconsin and their uses: Wisconsin Geol. and Nat. Hist. Survey Bull. 15, 1906.

caps some of the highest uplands and forms the lower slopes of Platte and Belmont mounds in Grant and Lafayette counties. For distribution see Plate VI of this report. For its detailed occurrence in southwestern Wisconsin see the maps of the lead and zinc region accompanying Bulletin 14 of this Survey. Where exposed in southwestern Wisconsin, it usually is a brown sticky clay. In eastern Wisconsin it has been worked for brick clay at Oakfield, Fond du Lac County, and at Stockbridge, Calumet County. There are some thin shale beds in the upper part of the Black River formation in southwestern Wisconsin (p. 53).

The Devonian shale occurs north of Milwaukee, see page 166.

The clays are of glacial and residual origin. Details as to their content of gritty materials are lacking. It is generally true, however, that glacial clays are too high in gritty matter to make very good cement material as are also residual clays derived from granite, shaly sandstone, or other quartz bearing rocks. Residual clays derived from basic schists, syenites, and basic igneous rocks generally have a low content of grit.

Most of the clays of Wisconsin are too high in silica to be good cement material. This is especially true of most glacial and wind deposited clays. The residual clays usually have a desirable proportion of silica and alumina. Some have too much ferric oxide in proportion to alumina.

Table 3 (p. 192) is a compilation of analyses of Wisconsin clays and shales. Not all of the clays listed are chemically suitable for Portland cement. Most Wisconsin clays are high in magnesia and therefore most of them could only be used with low magnesia marls or limestones. It must be remembered that a clay may have proper chemical composition for the manufacture of Portland cement and still not be of proper physical quality. Plate VI shows the localities from which the clays analyzed were taken.

Descriptions of Clays and Shales

The descriptions of clays and shales which follow are listed under county headings, which are in alphabetical order.

Adams County

Sample No. 39 is a glacial lake clay taken from an auger hole about one-quarter mile from the Northwestern line and about 1 mile southeast of the station of Brooks. The hole is located in the center of the NW. ¼ of sec. 2, T. 15 N., R. 7 E., on a hill slope within 30 yards of a stream. The topography is rolling and the surface for the most part is covered with sandy soil. The clay is free from sand and gravel, probably was laid down in ponds, and may cover a considerable area especially in the valley to the south, possibly 300 to 500 acres. The log of the hole follows:

		Feet
I.	Sandy loam	1
II.	Yellow sand	1
III.	Light pinkish brown silty clay, effervesces freely, water at 3½ feet from surface	5¼
IV.	Same clay with medium grained sand	½
V.	Same clay	¾
VI.	Same clay with medium to coarse sand and gravel, clay about 80 per cent of the total	3½

Groups III and V were combined as sample No. 39. Analysis 253 (p. 192) indicates this clay has too high a magnesia content for use with anything except a low magnesia carbonate.

Sample No. 40 was taken from a clay pit on the fair grounds of the village of Friendship, near the center of the SW. ¼ of the NE. ¼ of sec. 6, T. 17 N., R. 6 E. Clay is being excavated here for use on the roads of this vicinity. The pit is made in the valley side and is about 50 by 100 feet in area. The maximum working face of the clay is about 15 feet. The layers exposed from the top downward are as follows:

		Feet
I.	Medium to fine grained yellow sand	3–4
II.	Reddish brown clay with an inch of sandy clay about a foot from the top and two thin partings of silt about 8 inches above the bottom	2½
III.	Reddish brown clay horizontally bedded in thin layers ranging from 1/16 inch or less to 2½ inches or more, these layers separated by partings of light gray silt and silty clay whose maximum thickness is 1 inch. At 4½ to 5 feet above the base occurs a 15 inch bed of massive clay which is dense and breaks with a shell-like fracture	12
IV.	Medium to fine yellow sand which was bored into for 3 feet and bottom not reached.	

The bottom of the clay formation is about 6 or 7 feet above the creek. All the beds are above the level of ground water. The entire thickness of clay exposed in the pit, 14½ feet, was sampled as No. 40 with the soil auger. This clay (analysis 254, p. 192) is chemically suitable for cement although rather high in magnesia.

Clay similar to that of No. 40 is exposed in a small excavation for road material along highway No. 13, ½ mile west and 1½ to 2 miles north of the village of Easton.

Ashland County.

Lake clays near Ashland extend from the lake shore up to an elevation of about 560 feet above the lake. Analyses of these clays are given in Nos. 255 and 256 (p. 192).[1]

Brown County

Sample No. 48 was taken by E. F. Bean of the Geological Survey from a pit in Richmond shale in the SW. ¼ of the NE. ¼ of sec. 22, T. 22 N., R. 20 E. The pit is sunk in the side of a valley and exposes about 9 feet of shale beds containing no dolomite. The maximum quarry face which could be obtained is estimated to be 15 to 20 feet in height with 5 to 10 feet of stripping. The sample was taken from pieces on the dump. Rail haul from here would be possible down the valley to the Chicago, Milwaukee & St. Paul Railroad about ¾ mile distant. The analysis (No. 257, p. 192) shows too high a magnesia content for use in cement manufacture.

The lake clay beds at Green Bay usually have a stripping of 6 inches to 2 feet of gravelly clay. Below the stripping lies 2 to 4 feet of red burning clay, 4 to 12 feet of red clay which burns pink or cream color, and a variable thickness of clay which burns white or cream color. Thin laminae of sand alternate with clay throughout the deposits. An analysis of the red burning clays from Finnegan's brick yard is given in No. 258 (p. 192).[2] This analysis combined with that of "Calcite" limestone produces a cement mixture of satisfactory composition. See Combination 22, Table 5 (p. 194). Analyses compiled by Buckley indicate that high magnesia clays are common in this vicinity and that only the weathered red surface clay is low in magnesia. Further investigation should be made of the clays in this vicinity.

Calumet County

Samples 29, 30, and 31 were taken from a shale pit on the shore of Lake Winnebago at an abandoned brick yard two miles north and one mile west of Stockbridge, formerly operated by the Cook & Brown Lime Company of Oshkosh. About 58 feet of Richmond shale are exposed in this pit. The section is as follows:

	Ft.	In.
I. Shale with two thin seams of dolomite and a few layers of iron oxide, probably representing weathered pyrite. Sample 31 did not include dolomite seams	11	0
II. Dolomite		6
III. Shale, sample 30	11	0
IV. Shale, covered	5	0

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[1] Geology of Wisconsin, vol. 3, p. 213, 1879.

[2] Buckley, E. R., The clays and clay industries of Wisconsin: Wisconsin Geol. and Nat. Hist. Survey Bull. 7, p. 92, 1901.

V.	Dolomite 6 inches to	1	0
VI.	Shale with thin seams of dolomite	4	0
VII.	Dolomite 6 inches to	1	0
VIII.	Soft gray to dark gray shale with only an occasional thin discontinuous seam of dolomite. Sample 29	25	0

Near the top of the pit are 4 or 5 feet of dolomite beds ranging from 1 to 2 inches in thickness. Above the pit the surface rises moderately for about 100 yards to a cap of dolomite 60 to 100 feet higher. The shale dips eastward at an angle of about 1° and the lower shale division could not be mined very far down the dip without making provision for handling water and for preventing the entrance of lake water. The lands in this vicinity are used for farming.

Although sample 29 (analysis 259, p. 192) contains a high percentage of magnesia, the lower 25 feet of shale is chemically suitable for cement if mixed with lime carbonates low in magnesia. Analysis 260 (sample 30) and analysis 261 (sample 31, p. 192) show that the upper beds of shale in this pit have such a high content of magnesia that they cannot be considered for cement manufacture.

Samples 32 and 33 are from another shale pit operated by the Cook & Brown Lime Company located on the east shore of Lake Winnebago in the SW. ¼ of the NE. ¼ of sec. 11, T. 19 N., R. 18 E. The lake shore here is bordered by a high bluff at the base of which the Richmond shale outcrops from 2 to 20 feet or more above the water. The pit is being operated for the third season and is about 110 feet wide along the shore and has a working face of shale about 57 feet high. Sample 32 consists of small fragments of shale chipped off from the side of the pit and represents a thickness of 42 feet of the formation beginning about 3 feet above the water level. One bed of dolomite and that only 6 inches thick was struck in the sampling. It lies about 5 feet above the water. The shale as a whole is gray to dark gray and is fairly soft. It does not break out along the bedding but in irregular blocks showing a shell-like fracture. No pyrite or any rusty seams suggesting oxidized pyrite were seen. Above the pit there is a shelf about 50 yards wide and beyond this the bluff rises more steeply for another 60 feet. The shale is said to extend to the top of the bluff. Sample 33 represents ground shale from this pit taken at the brickyard of the Cook & Brown Lime Company at Oshkosh. It represents more weathered material than No. 32. Sample 32 (analysis 262, p. 192) is high in magnesia but might make a fair cement material if properly proportioned with a low magnesia limestone. Sample 33 (analysis 263, p. 192) is too high in magnesia and too low in silica to make a satisfactory shale for cement.

Dodge County

Sample 15 was taken from an exposure of Richmond shale 10 feet high on a stream bank about 450 paces south and 100 paces west of the NE. corner of sec. 1, T. 9 N., R. 16 E., Dodge County. The small stream referred to is a tributary of the Rock River. The location is about 3 miles north of the Chicago & Northwestern line. Most of this distance is along the marshy flats of the Rock River.

The shale is soft and yellowish gray. It is not distinctly bedded and breaks in irregular fragments. A hard layer 2 or 3 inches thick at the top of the outcrop shows bedding, and one at the bottom slightly harder than the mass of the material outcrops a few inches above the stream bed. The magnesia and silica content (analysis 264, p. 192) indicates that this shale is not suitable for the manufacture of cement.

Fifty paces south-southeast from the outcrop from which sample 15 was taken is another outcrop of Richmond shale in a small watercourse. Sample 16 was taken from this exposure. About 10 feet of beds are exposed above those of sample 16, but satisfactory samples could not be taken from them without test pitting. Hard layers of sandy shale evidently occur in this vicinity, for their debris was abundantly represented along the watercourse. Probably 5 to 10 acres of Richmond shale could be laid bare along these stream valleys with not over 10 feet of stripping. Sample 16 was not analyzed.

A small outcrop of light yellowish gray Richmond shale occurs on a bank of a small stream about 150 paces south and 100 paces east of the road corner near the center of the NW. ¼ of sec. 6, T. 9 N., R. 17 E. A bore hole made here could be pushed only to a depth of 3 feet when it reached a hard layer. The material brought up constitutes sample 17. Although this shale is somewhat leached by weathering, it contains (analysis 265, p. 192) about 17 per cent of magnesia when free from volatile material. It is not suitable for cement.

Samples 22, 23, and 35 are lake clays taken from the large Horicon Marsh which extends northward from Horicon for a distance of about 13 miles. Samples 22 and 23 were taken about 1½ miles east-northeast of Burnett near the western edge of the marsh. Sample 22 is from a bore hole in sec. 14, T. 12 N., R. 15 E., 360 paces west of the center of the section. The layers cut by the hole are as follows:

		Feet
I.	Peat	3
II.	Gray marl	1½
III.	Dark bluish-gray clay, very plastic and moderately compact to about 9½ feet, lower 5 feet is soft and contains a small amount of marl. Sample 22	10
	Hole stopped in clay	

Water level is about 2½ feet below the surface. The 10 feet of bluish gray clay constitutes sample 22. The analysis (No. 266, p. 192) shows that it is suitable for cement if properly proportioned with a low magnesia carbonate. See combinations 12 and 13, Table 5 (p. 194).

Sample 23 is from a bore hole in sec. 14, 550 paces east of the center of the section. The log of the hole follows:

		Feet
I.	Peat. The water level stands at 8 inches	2½
II.	Gray marl	1¼
III.	Dark bluish-gray clay like that found in the hole from which sample 22 was taken. For the most part the material is only slightly compacted	10¼

Sample 23 represents the bluish-gray clay (group III). The analysis (No. 267, p. 192) indicates that this clay could be used for cement if properly proportioned with a low magnesia carbonate. See combinations 14 and 15, Table 5 (p. 194).

Sample 35 was taken from an auger hole near the northeast portion of the Horicon Marsh about 1½ miles southeast of Chester, a station on the Chicago & Northwestern Railway. The hole is located on the west line of sec. 12 about ⅖ of a mile south from the northwest corner of sec. 12, T. 13 N., R. 15 E. The bore hole shows the following log:

		Feet
I.	Peat	4
II.	Blue clay silt	1
III.	Blue-gray compact clay, sample 35	10

The water level stood at a depth of 3 feet, the level having been lowered at this place by ditching. At 15 feet gravel was struck. The lands in this vicinity have been under plow, but are now mostly grown up with grass.

The analysis of this sample (No. 268, p. 192) indicates a clay of only fair quality for cement. It should be mixed with a low magnesia carbonate. See combination 16, Table 5 (p. 194).

Fond du Lac County

Samples 25, 26, and 27 were taken from the strip of flat lands about 3 miles southwest of Fond du Lac, formerly covered by a glacial lake. No. 25 was taken from a bore hole 15 paces south of the northwest corner of sec. 30, T. 15 N., R. 17 E. The lands in this vicinity are planted to ordinary farm crops. The beds cut by this hole starting from the top are:

		Feet
I.	Heavy dark-gray clay soil	1
II.	Heavy brownish-red clay free from sand and gravel. Contains marl. Sample 25	9
III.	Dark gray clayey silt carrying water	1
IV.	Gray clay with pebbles, large pebble at 11¾ feet from surface. Hole stopped by large pebble.	¾

Analysis 269 (p. 192) indicates that this is a clay which could be used for cement, although the magnesia content is rather high. See combination 23, Table 5 (p. 194).

Another bore hole was put down 100 yards north of the center of sec. 31, T. 15 N., R. 17 E. This location is about one mile south-southeast from the place where sample 25 was taken. The log of the hole is as follows:

		Feet
I.	Dark gray, heavy clay soil	1
II.	Heavy gray clay	½
III.	Heavy yellow and greenish-gray clay	1½
IV.	Reddish-brown and brown heavy clay. Contains considerable marl	11½
	Hole stopped in clay	

Water level is at 3 feet below surface. The material of groups II and III constitutes sample 26 (analysis 270, p. 192). That of group IV was taken as sample 27 (analysis 271, p. 192). Sample 26 is a clay chemically suitable for cement. See combinations 17 and 18, Table 5 (p. 194). No. 27 is too low in silica and too high in magnesia.

No. 28 was taken from a belt of glacial lake clays which border Lake Winnebago. The place from which the sample was taken is about one mile west of Fond du Lac at the corner of secs. 8, 9, 17, and 16, T. 15 N., R. 17 E. The land here is used for ordinary farm purposes. The layers cut by the hole are as follows:

		Feet
I.	Gray clay loam	1½
II.	Reddish-brown heavy clay with numerous small pebbles and a small percentage of grit	7

The materials of group II constitute sample 28. The analysis of this sample (No. 272, p. 192) indicates that this clay is not suitable for cement manufacture. The presence of pebbles is decidedly objectionable.

Analysis 273 (p. 192) is representative of the Richmond shale used for tile manufacture at the plant of the Standard Lime & Stone Company near Oakfield in the SE. ¼ of the SW. ¼, sec. 14, T. 14, R. 16 E. The magnesia and silica content indicates that this shale is not suitable for cement manufacture.

Grant County

Eckel[1] gives the following section at Potosi station:

		Ft.	In.
I.	Limestone, fine grained, thin bedded (Galena)	12	0
II.	Shale including 2 feet 4 inches of interbedded limestone	7	10
III.	Limestone, fine grained, thin bedded	3	6

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[1] Eckel, E. C., The Portland cement materials and industry of the United States: U. S. Geol. Survey Bull. 522, pp. 177, 373, 1913.

IV.	Limestone, even grained, medium bedded	3	0
V.	Limestone crystalline, thin bedded	12	0
VI.	Limestone, fine grained, thin, wavy bedded (partly concealed)	18	0

The composition of bed II exclusive of limestone bands is shown in analysis 274 (p. 192).

The section of the Galena and Black River formation near McCartney, Wisconsin, about 6 miles up the river from Potosi is described by Eckel[1] as follows:

		Ft.	In.
I.	Limestone, sub-crystalline with carbonaceous shale partings (Galena)	12	0
II.	Shale, calcareous, including 6 inches of thin limestone partings, total	3	6
III.	Shale, blue	2	0
	Concealed	5	0
IV.	Limestone, bluish crystalline, thin bedded	5	0
	Concealed	10	0
V.	Limestone, fine grained, thin bedded	7	0
	Concealed	13	0
VI.	Limestone, heavy bedded, buff to blue, probably magnesian	6	0

The composition of beds II and III exclusive of limestone bands is shown in analysis 275 (p. 192).

The analyses show that the shales from Potosi and McCartney are too low in silica to be suitable for Portland cement without the addition of a more siliceous clay. Considerable deposits of loess are known along the Mississippi bluffs. These are generally high in silica. Loess on the Mississippi River bluffs of Grant County is in places 60 feet thick. Analyses and measurements of the extent of these deposits are not available.

Iron County

The Tyler slates, from 7,000 to 11,000 feet thick, overlie the iron formation in Iron and Ashland counties. The lower part of the slates includes flinty, fragmental iron bearing slates, iron carbonate slates, and feldspathic and chloritic slates. Other phases include mica slates, clay slates, quartzites, and conglomerates. For distribution see maps in monographs 19 and 52 of the United States Geological Survey.

Two analyses of the clay slates are taken from Monograph 19.[2] See No. 276 (p. 192) for analysis from the NW. 1/4, sec. 6, T. 45 N., R. 2 E., and No. 277 (p. 192) for one from the NE. 1/4, sec. 1, T. 45 N., R. 1 E. The amount of magnetite in both is too high. In both, the alumina and iron cxide content as compared with silica is higher than desirable for

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[1] Op. cit., pp. 177, 373.

[2] Irving, R. D., and Van Hise, C. R., Penokee iron bearing series of Michigan and Wisconsin: U. S. Geol. Survey Mon. 19, p. 306, 1892.

Portland cement. Too little is known of the composition of the various beds of the formation to tell whether any of them are of proper composition for cement manufacture.

Jackson County

Analyses 278 to 283[1] inclusive (p. 192) are of residual clay from the Halcyon Pressed Brick Works at Halcyon northeast of Black River Falls. This clay is a decomposed schist.

Residual clay from Halls Creek near the Halcyon brick plant was sampled and analyzed with the results shown by Nos. 284 and 285 (p. 192).[2]

Near Merrillan clays have been formed from the weathering of shales in the Cambrian formation. The analysis of a sample from the NW. ¼ of NW. ¼, sec. 25, T. 23 N., R. 4 W. is given under No. 286 (p. 192).[3]

Two samples from the farm of Robert Dunlap near Merrillan had the composition shown by Nos. 287 and 288 (p. 192).[4]

Analysis 289 (p. 193) is of Eau Claire shale from the NW. ¼, NW. ¼, sec. 32, T. 19, R. 6 W., near North Bend.

Kenosha County

At the W. J. Craney brick yard near Kenosha the section exposed is as follows:

	Ft.	In.
I. Soil		18
II. Deep red clay	7	0
III. Blue or cream burning clay	6	0

Analysis 290 (p. 193)[5] of the upper red weathered clay indicates that this clay is chemically suitable for cement.

Manitowoc County

The bank of the Manitowoc Clay Products Company shows the following section of lake clays:

	Feet
I. Loam and soil with sandstone pebbles	2
II. Red clay	6
III. Blue clay with sandy streaks	8
IV. Fat blue clay	Depth unknown

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[1] Buckley, E. R., The clays and clay industries of Wisconsin: Wisconsin Geol. and Nat Hist. Survey Bull. 7, p. 222, 1901. Ries, H., The clays of Wisconsin and their uses: Wisconsin Geol. and Nat. Hist. Survey Bull. 15, p. 111, 1906.

[2] Buckley, E. R., op. cit., p. 222.

[3] Ries, H., op. cit., p. 113.

[4] Buckley, E. R., op. cit., p. 240.

[5] Ries, H., op. cit., p. 60.

Analysis No. 291 (p. 193)[1] of the top red clay indicates that this clay is chemically suitable for cement manufacture.

Marathon County

The clay at the brickyard at Ringle, Wisconsin, underlies 1 to 3 feet of sand and gravel. The clay from the top downward includes a dark red plastic clay from 1 to 3 feet thick, 3 to 4 feet of dark blue clay, and an unknown depth of dark blue, partly weathered gneiss. The clay is derived from the weathering of the gneiss. Analyses 292, 293, and 294 (p. 193)[2] are of samples from this deposit. These clays are not suited to cement manufacture.

Marquette County

Samples No. 37 and 38 were taken from auger holes made in old lake deposits which cover about 4 square miles in the vicinity of Oxford. A strip of these deposits about 2 miles wide extends southward to Briggsville, a distance of about 11 miles. A boring was made about 1½ miles southeast of Oxford, 415 paces north and 815 paces west of the SE. corner of sec. 21, T. 15 N., R. 8 E. The beds cut by the hole are as follows:

	Ft.	In.
I. Gray silty loam		8
II. Reddish brown silty, clay effervesces slightly with acid. At 6 feet struck a thin seam of clayey silt of the same color as sample 37	10	10
III. Bluish gray silty clay, effervesces readily with acid. Sample 38	6	6
Water at 6 feet.		

A well at a house not over 100 yards north of this boring is said to have cut through 85 feet of the same kind of clay as appears near the surface. In composition sample 37 (analysis 295 p. 193) would be suitable as clay for cement although rather high in magnesia. Combinations 19 and 20, Table 5 (p. 194) indicate the possibility of manufacturing cement from this clay and marl. The analysis of sample 38 (No. 296 p. 193) shows that this clay could be used only with a very pure carbonate.

A boring made in the SE. ¼ of the SE. ¼ of sec. 21, 450 paces north of the hole from which samples 37 and 38 were taken, went through 7½ feet of reddish brown clayey silt before striking the gray clayey silt. This boring was at an elevation several feet lower than the previous one. A boring made on the west line of sec. 21, 175 paces south of the

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[1] Ries, H., op. cit., p. 89.

[2] Buckley, E. R., op. cit., p. 229.

W. ¼ corner, was stopped in peat at a depth of 9 feet. Another boring made in the marshy tract in the west half of sec. 21 showed from the surface downward:

	Ft.	In.
I. Sandy loam		6
II. Gray sand, very clayey in lower one-half foot	2	0
III. Yellow clayey sand	1	0
IV. Gray silt	2	6
Water at 3 feet.		

These lands are within a mile of the Northwestern Railway which could be reached on a very easy grade.

Samples 41 and 42 were taken from lake clays which lie about 4 miles west of Montello. The boring from which they were taken was made 225 paces west of the S. ¼ corner sec. 10, T. 15 N., R. 9 E. The surface here is gently rolling except for some low hills about ¼ mile to the north. About 50 yards south the land is marshy. The location is on the northern edge of a marshy area about 3 miles long and from ¼ to 1 mile wide. Clay is being taken from a small pit near the road for use on the roads. The pit has a working face of 4 feet and is about 25 feet long and 10 feet wide. The log of the boring is as follows:

	Ft.	In.
I. Mixed yellowish gray clay, sand, and gravel	2	0
II. Brownish yellow clay with a little sand and occasional pebbles	1	6
III. Yellow silty clay		6
IV. Yellow clayey silt	2	0
V. Interlaminated yellow silty clay, silt, and some fine gray sand	6	6
VI. Interlaminated bluish gray clayey silt and silty clay	4	6

Hole was stopped in the last described material. The water level stood at 6½ feet below the surface. The material from groups II, III, IV, and V was taken as sample 41 (analysis 297, p. 193), that from group VI as sample 42 (analysis 298, p. 193). In both samples the magnesia content is rather high and the alumina low.

Samples 43, 44, 45, and 46 were taken in the vicinity of Lake Ennis, a locality which was under consideration for a cement project about 20 years ago (p. 139). Lake Ennis lies about ¾ mile northeast of the Fox River in sec. 14, T. 14 N., R 9. E. The lake and marsh cover about 60 acres and the adjacent land is high. The maximum depth of the lake is said to be 40 feet.

A bore hole just north of the former shore line of Lake Ennis on land 10 feet above the marsh level located 525 paces west and 260 paces south of the E. ¼, sec. 14 gave the following log:

		Ft.	In.
I.	Yellow sandy clay	2	0
II.	Reddish-yellow and yellowish-gray clay	3	3
III.	Yellowish-gray clayey silt and very fine sand		6
IV.	Reddish-yellow and yellowish-gray clay		9
V.	Yellowish-gray silt and very fine sand with water	2	6
VI.	Reddish-yellow clay		6
VII.	Yellowish-gray silt and very fine sand	1	0
VIII.	Bluish-gray clay	1	0
IX.	Yellowish-gray silty clay		6
X.	Interbedded bluish-gray pebbles, gray and yellowish-gray clay with some silt and pebbles	5	9

Sample 43 (analysis 299, p. 193) represents the materials from II, IV, VI, VIII, IX, and X. The materials from III, V, and VII were saved as sample 44 (analysis 300, p. 193). The high magnesia content makes these clays of doubtful value for cement.

Another bore hole about 600 paces south and 260 paces west of the center of sec. 14 gave the following:

		Ft.	In.
I.	Hard-packed, gray, clayey sand overlain by a few inches of sandy loam	1	0
II.	Yellow sand with small amount of clay binder	1	9
III.	Gray and yellow clay		9
IV.	Gray sand		6
V.	Gray and yellow sandy clay		9
VI.	Gray and yellow clay with some silt layers	1	0
VII.	Blue-gray clay with some silt layers	12	0
	Hole stopped in silt layers		

The water level stood at 5½ feet below the surface. The material from III and VI was saved as sample 45 (analysis 301, p. 193); that from VII constitutes sample 46 (analysis 302, p. 193). The magnesia content of these samples is high. Such clays would be suitable for cement if properly proportioned with a low magnesia carbonate.

Milwaukee County

Sample I is from the Milwaukee formation and was a dark shale (of Devonian age) taken from the dump pile at the mouth of the intake tunnel extending out under Lake Michigan from the north end of Lake Park, Milwaukee, in line with Linnwood Avenue, located in the SW. ¼, sec. 14, T. 7 N., R. 22 E. The material was excavated in constructing the tunnel. The analysis (No. 303, p. 193) shows that in composition it is a very satisfactory shale for cement. See combinations 1 to 5, Table 5 (p. 194). It is not known whether any of this material underlies the surface adjacent to the lake at a sufficiently shallow depth to make quarrying feasible.

Sample 3 was taken in the SW. corner of the NE. ¼ of the SW. ¼ of sec. 22, T. 6 N., R. 22 E. The surface materials here have been mapped by Alden as terminal moraine. A sixteen-foot bore hole in this place showed the following log:

		Feet
I.	Soil	1
II.	Yellow clay, occasional pebbles	4½
III.	Fine clayey sand with small pebbles	1½
IV.	Yellow clay, occasional pebbles	1½
V.	Fine clayey sand	1½
VI.	Yellow clay, occasional pebbles	1
VII.	Blue clay, occasional pebbles	5

The materials from layers II, IV, and VI were put together as sample 3. The sample was somewhat contaminated by sand rubbed off the side of the hole in bringing up the auger. The analysis (No. 304, p. 193) shows that this material is probably too high in silica and too low in alumina to make a good clay for cement.

The Milwaukee cream-burning clays are glacial lake clays. See analysis 305 (p. 193)[1] of a sample from the Chase Brick Company's deposit. This indicates a clay chemically suited to the manufacture of cement. This deposit is exhausted and the pit is now surrounded by buildings.

Pierce County

The clay bank at G. H. Smith's brickyard at River Falls is a glacial clay, 36 feet deep, of which the upper 10 feet is a yellow clay and the lower 26 feet a blue clay. See analyses of the clay, Nos. 306 and 307[2] (p. 193). No. 307 is chemically suited for the manufacture of cement.

Portage County

Residual clay is found underlying the Cambrian sandstone at Springvale. The composition of a sample from a deposit 4 miles south of Stevens Point on the Stevens Point and Plover Highway, just north of a railroad bridge is shown by analysis 308 (p. 193).[3]

The clay at the Stevens Point Brick and Construction Company is derived from the decay of a granitic schist and is over 8 feet deep. The composition of a sample is given by analysis 309 (p. 193).[4]

Racine County

Sample 4 represents lake clay lying at a depth of 2 to 11½ feet as determined by an auger hole about 3½ miles north of Racine on the western line of sec. 21, T. 4 N., R. 23 E., about 200 yards north of the southwest corner of the section. The log of the hole follows:

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[1] Ries, H., The clays of Wisconsin and their uses: Wisconsin Geol. and Nat. Hist. Survey Bull. 15, p. 72, 1906.

[2] Buckley, E. R., The clays and clay industries of Wisconsin: Wisconsin Geol. and Nat. Hist. Survey Bull. 7, p. 273, 1901.

[3] Ries, H., op. cit., p. 123.

[4] Idem, p. 125.

	Ft.	In.
I. Gray loamy soil		6
II. Fine yellow sand or silt, slightly clayey	1	6
III. Grayish red to red heavy clay	5	6
IV. Reddish gray to gray clay. At 9 feet from the surface there is a gray silty clay seam 3 or 4 inches thick	4	0
V. Gray pebbly clay	1	6

The material from III and IV was taken as sample 4 (analysis 310, p. 193). It is too high in magnesia to make a desirable clay for cement unless used with a low magnesia carbonate.

The clay deposit is reported to extend 200 or 300 feet to the east. Westward the clay probably extends one-half mile or more. The land in this vicinity is used for ordinary farm crops or is in pasture.

Sample 5 is a lake clay taken from 2 to 8 feet below the surface at the lake bluff exposure near the center of the SE. ¼ of the NE. ¼ of sec. 17, T. 4 N., R. 23 E. about 5 miles north of Racine. The section from the top downward is described as follows:

	Feet
I. Sandy soil	1
II. Yellow clayey sand	1
III. Laminated clay of various colors and fine clayey sand or silt chiefly reddish or gray	4
IV. Dark reddish gray clay	2
V. Dark gray pebbly clay apparently not bedded. Pebbles are mainly dark shale	5

Sample 5 representing the material from III and IV contains occasional pebbles and a sandy silt layer constituting about 8 inches of the section. The silt would probably pass through 100 mesh. See analysis 311 (p. 193). The magnesia content is rather high for cement manufacture. See combinations 6 to 9, Table 5 (p. 194).

Sample 6 is a bluish gray lake clay taken from an auger hole bored on the marshy flats to the southeast of Wind Lake on the north line of sec. 16, T. 4 N., R. 20 E. about 650 paces east of northwest corner of the section. There is a drainage ditch along the line between secs. 15 and 16 and another between secs. 10 and 15. The ditches are 5 to 6 feet deep, but show no good exposures on account of slump. The log of the hole is as follows:

	Ft.	In.
I. Black muck	2	0
II. Yellowish-gray sandy clay		6
III. Sand, medium grained at top, coarse at bottom, carrying water	2	0
IV. Bluish-gray clay entirely free from sand and gravel and smooth and plastic, sample 6	11	6
V. Below 16 feet a bluish-gray clay containing coarse sand particles was struck and was penetrated for an inch or two		

Chemically this clay (sample 6) is not suitable for cement unless properly proportioned with a low magnesia lime carbonate. See analysis 312 (p. 193).

The marsh deposits of this area are diversified by occasional slight elevations consisting of morainal deposits. Land in the south part of sec. 10 and north part of 15 is farmed only to a small extent, mainly for growing hay. Near the southwest corner of sec. 15 the ditch is 10 feet deep and shows some gravel and fine silt with marl on the dump. A bore hole on the north line of sec. 15, 150 paces east of the northwest corner of the section, showed the following layers:

		Feet
I.	Black muck, water at 3 feet	3½
II.	Brown organic matter	2
III.	Light blue-gray marly clay	1½
IV.	Light blue and gray sandy clay	2
V.	At 9 feet gravel	

Sauk County

A clay deposit exposed in a ravine in the NW. ¼, sec. 6, T. 12 N., R. 6 E. gave the following mechanical analysis:[1]

	Size in Millimeters	Per Cent
Fine gravel	2 to 1	0.0
Coarse sand	1 to 0.5	0.1
Medium sand	0.5 to 0.25	0.0
Fine sand	0.25 to 0.1	0.4
Very fine sand	0.1 to 0.05	3.1
Coarse silt	0.05 to ?	13.9
Fine silt	? to 0.005	35.5
Clay	0.005 to 0	46.9

This clay bank is a part of a large clay deposit of unknown extent. Thicknesses of 5 to 15 feet were seen at four places 880 to 920 feet above sea level, within 1½ miles of the head of Mirror Lake. The composition of the clay is shown by analysis 313 (p. 193).[2] The silica alumina ratio is rather low to favor the use of this clay in cement manufacture.

The Seeley slate underlies parts of the Baraboo Valley in Sauk County. It does not outcrop, but has been found at the Illinois iron mine near North Freedom and at the Cahoon mine near Baraboo. In both mines the slate beds lie at a steep angle and are overlain by the iron formation. The Seeley slate has also been found in various diamond drill holes in the Baraboo Valley.[3] At the Cahoon mine it lies under less than 100 feet of overburden. The depth to the slates in the Illinois mine is about 100 feet.

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[1] Alden, W. C., The quaternary geology of southeastern Wisconsin: U. S. Geol. Survey Prof. Paper 106, p. 322, 1908.

[2] Idem, p. 228.

[3] Weidman, Samuel, The Baraboo iron-bearing district of Wisconsin: Wisconsin Geol. and Nat. Hist. Survey Bull. 13, 1904.

Only one analysis of the Seeley slate is on record. It is of a sample from the Illinois mine. The analysis as given by Weidman is No. 314 (p. 193).[1]

From the foregoing analysis, it appears that the Seeley slate would probably make a fair shale for Portland cement. Favorable qualities are its low magnesia and sulphur content, and the almost total absence of alkalies. The silica content as compared with the total alumina and iron oxide content is low.

The cost of mining the Seeley slate and shipping it to a cement mill would need to be given careful consideration.

Sheboygan County

A thin bed of red clay overlying the cream-burning clay at the O. Zimbal Brick Yard at Sheboygan has the composition shown by analysis 315 (p. 193).[2]

Taylor County

A greenstone outcrop on the Black River 4 miles southwest of Medford is changed at the surface into a deep red clay, 16 feet or more in depth. It is covered in most places by glacial drift. The composition of a sample from this deposit is given by analysis 316 (p. 193).[3] The high iron content of this clay renders it useless for cement manufacture.

Walworth County

The composition of a sample of lake clay taken near the southwest corner of the NE. ¼ of the NW. ¼ sec. 4, T. 4, R. 15 E., near Whitewater is given by analysis 317 (p. 193). Owing to the high magnesia content this clay is not chemically suited to cement manufacture.

Washington County

Samples 19, 20, and 21 were taken from the area of level land comprising about 10 square miles northeast of West Bend. These lands, some of which are still marshy, were once covered by a glacial lake. Sample 19 was taken in the northwest corner of the area 450 paces west of the center of sec. 30, T. 12 N., R. 20 E. The auger hole made at this place gave the following record:

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[1] Weidman, Samuel, The Baraboo iron-bearing district of Wisconsin: Wisconsin Geol. and Nat. Hist. Survey Bull. 13, p. 48, 1904.

[2] Ries, H., The clays of Wisconsin and their uses: Wisconsin Geol. and Nat. Hist. Survey Bull. 15, p. 174, 1906.

[3] Idem, p. 132.

	Ft.	In.
I. Dark gray silty loam		8
II. Brown silty clay		10
III. Yellow silt, at a depth of 8 feet struck several pebbles, possibly thin gravel seam	6	6
IV. Yellow clayey silt with a seam of gray silty clay at a depth of 10 feet	3	0
V. Bluish-gray silty clay contains marl	2	0

The material from V constitutes sample 19 which was not analyzed.

Samples 20 and 21 were taken from an auger hole in the southeast corner of sec. 32, T. 12 N., R. 20 E. about 1½ miles southeast of the place where sample 19 was taken. This location is about 3 miles from the Northwestern Railway. To the east, southeast, and south of this corner, the lands are marshy with some standing timber. A few rods to the west and northwest they are cleared and under cultivation. The log of the hole is as follows:

	Ft.	In.
I. Surface		8
II. Yellowish-gray sand	1	4
III. Light yellow silt	1	0
IV. Yellow sand		6
V. Mixed yellow and gray clay. Water at 4 feet from surface	3	0
VI. Bluish-gray clay	4	0
VII. Gray, heavy, clayey silt	4	0
VIII. Bluish-gray clay	2	0

Sample 20 (analysis 318, p. 193) represents the yellow and gray clay from V, VI, and VIII; sample 21 (analysis 319, p. 193) the silt from VII. Both samples are too high in magnesia to be suitable for cement.

Waukesha County

Sample 7 was taken from a boring in marsh deposits between Wind Lake[1] and Muskego Lake in Waukesha County. The location is about 40 yards west of the center of sec. 33, T. 5 N., R. 20 E. The following is the log of the bore hole:

	Ft.	In.
I. Black muck	3	0
II. Brown organic matter becoming somewhat clayey	3	0
III. Greenish-brown clay with much organic matter showing slight effervescence with cold hydrochloric acid. Light bluish-gray color at 8 feet. Sample 7	9	0
IV. Sand		4
V. Gravel		

The material from III, sample 7, was very similar to that of sample 6 southeast of Wind Lake, differing only in compactness. No. 6 was a hard mass containing very little water and difficult to bore through.

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[1] See sample 6, Racine County (p. 168), for logs of borings southeast of Wind Lake.

The material of No. 7 was soft and wet and flowed into the bore hole soon after the auger was removed. No. 7 (analysis 320, p. 193) is chemically suitable for cement, although its content of magnesia is too high except for use with a low magnesia carbonate. See combination 21, Table 5 (p. 194). The Milwaukee Electric Railway passes within a mile of the place where sample 7 was taken.

Sample 8 was taken from a bore hole in the same marshy area as were samples 6 and 7. The boring was made a little to the east of Muskego Lake, 170 paces north and 30 paces west of the E. ¼ corner of sec. 23, T. 5 N., R. 20 E. The sample is a bluish-gray clay and gray silty clay and is a combination of IV, VI, and VIII. The section of the bore hole follows:

	Ft.	In.
I. Gray sand with soil at top	1	6
II. Heavy grayish-green clay with pebbles	3	0
III. Fine gray, clayey sand	3	0
IV. Bluish-gray clay free from sand and pebbles	1	6
V. Fine clay sand like III		6
VI. Gray silty clay	2	6
VII. Very fine gray sand		6
VIII. Gray silty clay	1	3
IX. Fine clay silt		3

The analysis, No. 321 (p. 193), shows that this clay is not suited chemically for cement manufacture. The content of magnesia is too high and alumina is too low.

Sample 9 was taken from a bore hole on the south line of sec. 8, T. 5 N., R. 17 E. about ⅛ mile west of the southeast corner of the section. The section of the hole follows:

	Ft.	In.
I. Black muck	2	6
II. Mottled gray silt, becoming more clayey downward until at 4 feet (from surface) it is a gray clay almost free from silt	9	9
III. Material which felt like sand or fine gravel, but auger came up empty		6
IV. Gray clay with some pebbles probably from just above		3

Sample 9 (analysis 322, p. 193) is representative of all clayey material below 3¼ feet from surface. This clay is chemically unsuited for cement because of the high magnesia content.

Sample 10 was taken from a bore hole on a slight ridge in the marsh in the NW. ¼ sec. 16, T. 5 N., R. 17 E., on diagonal road about 300 feet southeast of its intersection with the west line of sec. 16. The section of the bore hole follows:

	Ft.	In.
I. Black loam	1	6
II. Yellow clay	1	0
III. Medium to fine sand		9

IV. Pinkish-yellow pebbly clay		6
V. Fine sand with water	2	3
VI. Yellow clay free from pebbles	3	0
VII. Gray silty clay		3
VIII. Gray clay		9

Sample 10 represents material from VI. The analysis (No. 323, p. 193) shows a clay too high in magnesia to be used for cement.

Sample 12 represents incoherent gray clay piled up near the receiving end of the Lime Products plant. The source of this is uncertain. Analysis 324 (p. 193) indicates that this clay is of good quality for cement. See combinations 10 and 11, Table 5 (p. 194). See page 146 for a marl analysis from this vicinity.

Wood County

Immediately west of Milladore at the west end of the Hooper property lying south of the Soo Line, there is a clay deposit more than 12 feet thick. See analyses 325[1] and 326[2] (p. 193). No. 325 is high in iron and low in silica; No. 326 is a clay chemically suited for cement.

On the Mitchell property southeast of Pittsville a residual clay deposit from 6 to 8 feet thick underlies about 35 acres. See analysis 327 (p. 193)[3] for composition of this clay which is not suitable for cement.

Analyses 328 and 329 (p. 193)[4] were made from residual clay samples collected near Wisconsin Rapids. No. 328 is too high in iron to be suitable for cement. No 329 is a clay which could probably be used in cement manufacture.

At the Grand Rapids Pressed Brick Yard, 3 miles northwest of Wisconsin Rapids, the following residual clay beds are exposed:

	Feet
I. Surface sand	1–2
II. Blue clay	3–4
III. Decomposed granite schist	6

Analysis 330 (p. 193)[5] shows that this clay is of fair quality for cement.

A residual clay from diorite is located south of Wisconsin Rapids in the southwest corner, sec. 18, T. 22 N., R. 6 E. The clay is about 8 feet deep. The bed rock on which it rests outcrops from 8 to 10 feet above the river. For composition see analysis 331 (p. 193).[6] This clay is not chemically suitable for cement manufacture.

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[1] Ries, H., The clays of Wisconsin and their uses: Wisconsin Geol. and Nat. Hist. Survey Bull. 15, p. 114, 1906.

[2] Idem, p. 116.

[3] Idem, p. 120.

[4] Buckley, E. R., The clays and clay industries of Wisconsin: Wisconsin Geol. and Nat. Hist. Survey Bull. 7, p. 225, 1901.

[5] Ries, H., op. cit., p. 118.

[6] Idem, p. 117.

SUMMARY

The sample of Devonian shale from the intake tunnel at North Park, Milwaukee, is chemically suitable for cement. There is considerable doubt, however, whether any of this material is near enough to the surface on lands adjacent to the lake to permit cheap quarrying operations.

All samples of Richmond shale which were analyzed are high in magnesia, ranging from 9 to 18 per cent when calculated to a non-volatile basis. The weathered shales do not appear to have less magnesia than the less leached portions of the formation. In fact, the reverse seems to be true so far as tested. It is possible that further exploration will lead to the discovery of chemically suitable beds. The Tyler slate near Hurley (p. 162) is clearly not chemically suitable for cement. The cost of mining the Seeley slate at Baraboo might be sufficiently high to make its use uneconomical, but its desirable quality necessitates careful consideration.

With most of the shales and slates tentatively eliminated as sources of silica and alumina and all Wisconsin limestone eliminated as a source of lime, the investigation is largely limited to lake clays and marls as the chief cement materials available in Wisconsin.

In Table 4 (p. 194) a number of analyses are calculated to a non-volatile basis. Table 5 gives the proportions of clay or shale and marl or limestone which would make Portland cement and the analyses of the resulting cements.

Marl analysis 239 was chosen as a type of marly clay. Analyses 238, 248, and 249 were selected as typical marls and suggest the sort of marl that may be found elsewhere in Wisconsin.

''Calcite'' is a very pure limestone from the vicinity of Rogers City, Michigan. As the quarry, the largest in the world, is located on Lake Huron, a water haul is possible. The quarry produces furnace flux and at present wastes a good deal of stone smaller than 4 inches in diameter. If deposits of suitable clay or shale can be found accessible to Lake Michigan, it might be feasible to use ''Calcite'' as a source of lime.

Combinations 1 to 5, Table 5, are all based on Devonian shale. In No. 1 a combination of this shale with marly clay produces a mixture low in lime. A combination with marl (analysis 248) produces a mixture low in alumina and high in magnesia. Combinations 3, 4, and 5 produce mixtures of satisfactory analyses. They show that the manufacture of cement from Devonian shale and marl or a limestone similar to ''Calcite'' is chemically possible.

Combinations 6 to 9 are based on a lake clay. See analysis 311 (p. 193). Combination 6, a mixture with marly clay, is low in lime, but could be made satisfactory by the addition of some low magnesia limestone. Combination 7 is too high in lime and magnesia and too low in iron and alumina. Combination 8 is too high in magnesia. Combination 9 indicates a satisfactory mixture. This clay is chemically suited for mixture with a low magnesia marl or limestone.

Combinations 10 and 11 use clay, analysis 324 (p. 193). These combinations indicate that a clay of this composition is chemically suitable for mixture with marl.

Combinations 12 and 13 use clay, analysis 266 (p. 192). In both mixtures the magnesia content is a little high.

Combinations 14 and 15 use clay, analysis 267 (p. 192), from the Horicon Marsh. In the first the magnesia content is a little high. The second indicates a satisfactory mixture.

Combination 16 uses clay, analysis 268 (p. 192), and a marl. The mixture is too high in magnesia.

Combinations 17 and 18 use clay, analysis 270 (p. 192), with marls and produce satisfactory mixtures.

Combinations 19 and 20 using a clay, analysis 295 (p. 193), and marls produce mixtures which are too high in magnesia.

Combination 21, a mixture of clay, analysis 320 (p. 193), and marl, is too low in alumina and too high in lime and magnesia.

Combination 22 is a mixture of a clay, analysis 258 (p. 192), and "Calcite," and results in a satisfactory cement mixture. See page 194.

Combination 23, a mixture of clay, analysis 269 (p. 192), and "Calcite," is a little high in magnesia.

These studies lead to the following conclusions regarding clay materials for cement manufacture in Wisconsin:

1. The Devonian shales sampled are chemically suited to the manufacture of cement, either with a marl of good quality or with a low magnesia limestone. Whether these shales can be quarried at low enough cost and in sufficient quantity has not been determined.
2. Some glacial lake clays are chemically suited to the manufacture of cement either with marl of good quality or with low magnesia limestone.

Further investigation should be made

1. To determine the accessibility, quantity, and quality of Devonian shales.
2. To locate beds of Richmond shale which are low in magnesia.
3. To locate beds of clay which are of suitable quality and sufficient size to justify the erection of a cement plant.

CHAPTER VIII

THE ECONOMIC POSSIBILITIES OF MANUFACTURING PORTLAND CEMENT IN WISCONSIN

The principal factors governing successful cement manufacture in Wisconsin are (1) raw materials, (2) market, (3) transportation, and (4) labor.

RAW MATERIALS

This is the most important factor. The plant must be located in a place where abundant supplies of raw materials may be cheaply obtained. These raw materials are limestone or marl, and clay or shale. In previous chapters the following facts in regard to raw materials in Wisconsin have been presented:

1. Limestone. Some of the "glass rock" beds in Grant County are chemically suitable for cement manufacture, but the beds are thin and the overburden usually heavy, making the cost of quarrying high. Though the cost of quarrying does not necessarily condemn a deposit properly located with reference to transportation and center of demand the location of the Grant County limestone is very unfavorable. All other limestones in the state have such a high magnesia content that they cannot be used for cement manufacture.
2. Marl. Investigation has shown that there is marl chemically suited to cement manufacture in many localities in Wisconsin.
3. Clays. Investigation during the summer of 1922 has shown that there are chemically satisfactory clays in southeastern Wisconsin.
4. Shale. The analysis indicates that Devonian shale from the intake tunnel north of Milwaukee is chemically suitable for cement. There is considerable doubt whether this shale is near enough to the surface to permit economical exploitation. All samples of Richmond shale which were analyzed are high in magnesia. It is possible that future exploration will lead to the discovery of beds chemically suitable for cement manufacture.
5. Michigan stone at lake ports. There is a possibility of shipping in chemically suitable limestone by water from Michigan.

Before the erection of a cement mill can be seriously considered, investigation must be made to determine whether at a suitable site we have marl and shale or clay of proper quality and in sufficient quantity to justify the erection of a mill. This investigation will involve considerable field work to determine what areas are most encouraging. The geological work should be followed by very careful exploration, sampling, and chemical analyses. Samples from the more favorable sites should be made into cement and the product tested before final decision is made.

Coal is an important factor. We know this must be shipped in. Freight from various mines to certain prospective sites must be considered.

Plant possibilities.—There are two distinct possibilities of plant location as determined by raw materials: first, a plant on the Lake Michigan shore, on Green Bay, or Lake Winnebago utilizing Michigan limestone. Such a plant would have the advantage of water-hauled limestone and coal. This plant could use a local clay or shale, or these could be shipped in. Such a plant would be obliged to stock-pile limestone and coal during the transportation season in sufficient quantities to carry the mill through the four months when navigation is closed. Such a plant would not have absolute control of its raw materials unless it bought and operated a quarry outside the state.

The second possibility is a marl plant. The information at hand indicates that such a plant would be located away from the lake and would be dependent upon rail-hauled coal. A million-barrel plant would need for a 50-year life 1,150 acres of marl averaging ten feet in depth. This means that no small deposit can be considered. The disadvantages of a marl plant are: (1) As excavated the marl contains 50 to 60 per cent of water. This would require a wet process mill involving somewhat higher fuel consumption than would the limestone plant described above. The use of long kilns makes it possible to use the wet process more efficiently than with short kilns, but there seems to be an advantage of about 5 cents per barrel in favor of the dry process. (2) Marl deposits are likely to be erratic in quantity and quality. Very thorough exploration of the deposits will be necessary to insure the plant against much of this uncertainty. (3) It is impossible to excavate marl during the winter months. The plant would be obliged (a) to shut down during the winter, (b) to stock-pile marl during the summer, or (c) to operate during the summer at increased capacity and operate only the clinker-grinding department in the winter.

MARKET

Wisconsin offers a good market for Portland cement. In 1920 its rank as a cement consumer was eighth in the Union. The states which used more cement than Wisconsin in that year include New York, Pennsylvania, Illinois, Ohio, California, Michigan and New Jersey.

According to the U. S. Geological Survey, Wisconsin used 3,484,700 barrels of cement in 1920. Its per capita consumption of cement was

1.31 barrels, that of the United States as a whole was only 0.87 per capita. Of the total cement production of the United States 3.4 per cent was consumed in Wisconsin.

In 1921 the total shipment of cement into Wisconsin was 3,849,000 barrels. Of this total 1,173,550 barrels, or 30.5 per cent, was used in highway construction. This does not include cement for city pavements. In 1922 the total shipments were 3,756,000 barrels. Of this 1,193,800 barrels, or about 32 per cent, was used in highway construction.

We have no statistics on the distribution of cement other than that used for highway purposes. Assuming that the non-highway cement is distributed equally according to population, the center of non-highway cement consumption coincides with the center of population, which in 1920 was 2.5 miles south of Neshkoro in Marquette County. Since 1880 the center of population has been in eastern Marquette County. If it is fair to assume that the center of consumption of non-highway cement is and will continue to be relatively near the center of population, it seems likely that this center of consumption will not move very far during the life of a cement mill.

The center of highway construction cement consumption in 1922 was about five miles southwest of Fond du Lac. This center will change somewhat from year to year as the amount of concrete construction in bond issue counties fluctuates. With an increase in concrete construction in the southwestern part of the state, it is to be expected that the general movement of the center of highway consumption will be westward.

There is a strong demand for cement in Wisconsin. A cement plant located near the center of this demand would find a ready market for cement of proper quality. If other factors permit, the plant should be located near the center of least competition with outside plants.

TRANSPORTATION

The mill should be located on or near two competing main railway lines. The freight rates on cement from Mason City, La Salle, Buffington, Duluth, and Petoskey to Wisconsin points should be determined. With this data it will be possible to construct a freight rate contour map, thus determining the center of least competition.

LABOR

In determining the location of a plant the labor supply and the housing of employees must be considered. If the plant is near a town and transportation can be arranged, labor supply and housing will not present many difficulties. If the plant is at some distance from a town, it will be necessary to establish a village which would contain 500 to

600 people. This would require houses for married men, a boarding house, a church, schools, and a store, as well as sewage, water, and lighting systems. Such an additional expenditure would add materially to the cost of the completed plant. For this reason it would appear advisable to locate a plant near a town.

SIZE AND COST OF MILL

In order to be a real factor in competition and to operate at as low a cost as possible, the mill should have a capacity of 1,000,000 barrels per year.

Hilts estimates (December 9, 1920) that a first-class 1,000,000 barrel mill will cost about $4,500,000.[1] The South Dakota Cement Commission reports (January 23, 1923) that the most recent estimate of the cost of a 600,000 barrel state-owned plant is $1,500,000. It has been stated recently by a well-informed engineer that a 1,000,000 barrel mill would cost about $2,000,000. The average invested capital plus funded indebtedness of seven Lehigh Valley companies[2] having an annual production of about a million barrels is $2,387,000.

COST OF MANUFACTURING CEMENT

In the present state of our knowledge it is futile for the writers to attempt to estimate the cost of manufacturing cement in Wisconsin. A properly located plant with an ample supply of raw materials with proper management would be able to compete successfully with outside mills, since the local plant would have a great advantage in cost of freight on finished cement. This would probably outweigh the increased cost of coal, since the freight on the coal necessary to manufacture a barrel of cement is less than the freight on a barrel of cement. For example, the freight on 200 pounds of northern Illinois coal at Fond du Lac is 26 cents. The freight on a barrel of cement shipped from La Salle, Illinois, to Fond du Lac is 57 cents. If shipped from Buffington, Indiana, the freight is 51 cents per barrel.

The estimated freight advantage in favor of the Fond du Lac plant is 25 cents per barrel. Assuming the fuel consumption at Fond du Lac to be 200 pounds per barrel using the wet process and at La Salle or Buffington 130 pounds per barrel using the dry process, there is a differential of 70 pounds of coal in favor of the outside plant. At $5.00 per ton this is 17.5 cents per barrel, leaving a balance of 7.5 cents in favor of the Fond du Lac plant.

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[1] Hilts, H. E., Shall the state own and operate its own Portland cement plant?: Bur. of Public Roads; Public Roads, vol. 3, No. 33, p. 12, 1921.

[2] United States of America, Plaintiff, v. Cement Manufacturers Protective Association et als, Defendants: In the District Court of the United States, Southern District of New York, Answer of defendant p. 18.

PROFITS OF CEMENT MILLS

There is an impression that the cement mills are making exorbitant profits. The following quotation has reference to nineteen Lehigh District cement manufacturers:[1]

"Beginning with the common 'pre-war standard' year, the following table gives the average cost per barrel and the average price received per barrel by the defendant manufacturers operating each year from 1913 to 1920, inclusive, together with the percentage which the margin between cost and price bears to the selling price—or what would be the percentage of profit on the selling price but for the fact that other items reducing profit are not included in cost:"

Year	Cost per barrel	Price received per barrel	Per cent margin to price
1913	$ .7151	$ .8403	14.9
1914	.7398	.8616	14.1
1915	.6796	.7257	6.3
1916	.8158	.9699	15.9
1917	1.1069	1.2410	10.8
1918	1.3923	1.5426	9.7
1919	1.4496	1.6529	12.3
1920	1.7798	1.9290	7.7

The average profit of these companies figured from net income minus taxes on invested capital was in 1919 7.4 per cent, in 1920 5.0 per cent.[2]

In the following table the first column represents the average costs of a large group of American mills representing about 25 per cent of the total output of Portland cement. The second and third columns represent the range in average cost at all mills as indicated by Eckel's estimate. The fourth column is the average factory price for the United States as given by the U. S. Geological Survey:

Year	Total cost per barrel shipped from 25 per cent of lowest cost production[3]	Eckel's estimate of total cost at all mills		Average factory price in U. S. per barrel[4]
		from	to	
1913	$ .734	$ .8070	$ .8808	$1.005
1914	.7314	.8045	.8776	.927
1915	.696	.7656	.8352	.86
1916	.798	.8778	.9576	1.103
1917	1.129	1.2419	1.3548	1.354
1918	1.454	1.5994	1.7448	1.598
1919	1.467	1.6137	1.7604	1.71
1920	1.812	1.9932	2.1744	2.02
1921	1.625	1.7875	1.9500	1.89

"It should be noted that the large group tabulated above represents about the lowest cost large fraction of the American industry; for the

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[1] United States of America, Plaintiff, v. Cement Manufacturers Protective Association et als, Defendants: In the District Court of the United States, Southern District of New York, Answer of defendant p. 13.

[2] Idem, p. 18.

[3] Eckel, E. C., Cements, limes and plasters, p. 501, New York, John Wiley & Sons, 1922.

[4] Mineral Resources: U. S. Geol. Survey, 1921, p. 223.

American industry taken as a whole the average cost of cement shipped would be 10 per cent to 20 per cent higher than the costs in Table 214, according to the year and to local conditions as regard coal, labor, etc.'"[1]

The difference between the above figures for any year does not accurately measure the average profits since we are not comparing similar data. It does suggest, however, that the profits are not so excessive as has sometimes been stated.

When it is realized that labor and fuel commonly make up about three-fourths of the mill cost, it is readily apparent that the rise in the price of cement from 1916 to 1920 was due in large measure to rapidly increasing wages and fuel costs. We can hope for a reduction in the price of cement only as a reflection of reduced cost of labor and coal.

A study of the relative or true prices of cement is interesting. From this table it will be seen that the relative price of cement from 1915 to 1920 was actually less than the 1914 price and that the nominal price of cement has lagged considerably behind the average of commodity prices. This lag in prices was in part the result of sharp competition between cement mills with productive capacity about 50 per cent in excess of output.

PRICES NOMINAL AND REAL OF PORTLAND CEMENT, 1914–1920[2]

Year	Nominal price per barrel in currency	Index number, average prices	Relative or true price
1914	$0.927	100	$0.927
1915	0.860	101	0.851
1916	1.103	124	0.889
1917	1.354	176	0.770
1918	1.596	196	0.814
1919	1.71	212	0.807
1920	2.01	244	0.829

Summary

Granted that investigation develops the fact that there are several places where raw materials of proper quality exist in sufficient quantity, the final decision regarding the location of a plant will depend upon a proper balancing of the remaining factors (1) location with reference to center of demand, (2) location with reference to center of least outside competition, (3) transportation, (4) labor, and (5) cost of fuel. In order to save time and expense the investigation should be confined to the area defined by the factors mentioned above.

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[1] Eckel, E. C., op. cit., p. 500.

[2] Idem, p. 503.

Table I

ANALYSES OF WISCONSIN DOLOMITES AND LIMESTONES

ANALYSES OF PRE-CAMBRIAN DOLOMITES

Number	County	Insoluble	SiO_2	Al_2O_3	Fe_2O_3	$CaCO_3$	$MgCO_3$	P_2O_5	H_2O	FeO	MnO	Total	Calcite	Dolomite	Magnesite	Analyst	Page
1	Bayfield	....	.63	....	.03	55.00	43.20	....	.27	.75	.08	^{a}99.65	3.60	94.6	....	W F. Hillebrand	29
2	Sauk	....	23.04	2.50	Trace	35.00	29.4	Trace	1.10	8.57	1.44	99.74	....	64.40	....	V. Lenher	30
3	Sauk	....	18.17	4.73	8.37	33.9	26.4	....	....	7.04	.63	100.09	....	^{b}61.00	....	V. Lenher	30
4	Sauk	....	4.28	2.92	Trace	53.40	37.3	....	.38	1.04	....	99.84	....	^{b}92.00	....	V. Lenher	30

ANALYSES OF CAMBRIAN DOLOMITES

Note: Analyses 5, 7, 8, and 10 are from the Trempealeau, 6 and 9 are from the Mendota.

5	Columbia	....	44.57	8.68	1.18	26.69	17.97	....	1.28	.22	....	99.83	5.26	39.4	....	E. T. Sweet	35
6	Dane	....	4.18	2.17	1.45	55.68	36.52	....	.58	....	....	100.58	12.18	80.02	....	E. T. Sweet	40
7	Iowa	34.56	....	.48	1.68	38.20	25.65	.03	....	....	....	100.60	7.60	56.25	....	W. G. Crawford	57
8	Sauk	31.12	....	.76	1.26	38.00	28.75	.06	....	....	....	99.95	3.75	63.00	....	W. G. Crawford	85
9	Sauk	....	5.66	2 26		51.61	38.51	....	.40	....	....	98.44	5.67	84.45	....	W. A. Hover	85
10	Trempealeau	40.16	....	2.04	1.22	32.80	23.60	.04	....	....	....	99.86	4.7	51.7	....	W. G. Crawford	89

a Cl—trace.
b Ferro dolomite.

Table I—Continued

ANALYSES OF LOWER MAGNESIAN DOLOMITES

Number	County	Insoluble	SiO_2	Al_2O_3	Fe_2O_3	$CaCO_3$	$MgCO_3$	P_2O_5	H_2O	FeO	Fe	S	Total	Calcite	Dolomite	Magnesite	Analyst	Page
11	Buffalo	4.86	....	.49	.52	56.10	38.40	.27	....	....	....	....	100.64	10.25	84.25	....	W. G. Crawford	32
12	Buffalo	2.38	....	.38	.33	62.40	34.00	.02	....	....	....	....	99.51	21.90	74.50	....	W. G. Crawford	33
13	Buffalo	5.70	....	.28	.66	51.90	40.79	.02	....	....	....	....	99.25	4.49	88.20	....	W. G. Crawford	33
14	Buffalo	4.53	....	.54	.52	51.94	42.19	.08	....	....	....	....	99.78	1.88	92.25	....	W. G. Crawford	33
15	Buffalo	2.36	....	.54	.25	54.26	42.60	.01	....	....	....	....	100.02	3.37	93.49	....	W. G. Crawford	33
16	Buffalo	13.25	....	23.00	.67	32.00	27.00	.04	....	....	....	....	99.54	....	59.25	.25	W. G. Crawford	33
17	Columbia	13.65	....	.95	.50	48.30	35.58	.04	....	....	....	....	99.02	5.88	78.00	....	W. G. Crawford	36
18	Crawford	10.76	....	.79	.45	49.90	38.10	.02	....	....	....	....	100.02	4.50	83.50	....	W. G. Crawford	37
19	Crawford	11.96	....	.70	.30	48.60	38.50	.01	....	....	....	....	100.17	2.70	84.40	....	W. G. Crawford	37
20	Crawford	3.93	....	.61	.45	54.75	40.85	.02	....	....	....	....	99.71	6.10	89.50	....	W. G. Crawford	37
21	Crawford	7.31	....	.32	.47	51.40	40.60	.02	....	....	....	....	100.21	3.10	88.90	....	W. G. Crawford	38
22	Crawford	14.36	....	.29	.73	47.60	36.80	.04	....	....	....	....	99.82	3.80	80.60	....	W. G. Crawford	38
23	Dane	....	1.09	.44	.43	66.82	30.40	....	.35	.63	....	....	100.16	30.52	66.70	....	....	40
24	Fond du Lac	....	3.16	3.09	.60	51.68	40.93	....	.70	....	....	....	100.16	3.01	89.60	....	....	48
25	Fond du Lac	10.22	....	.38	.38	49.50	36.05	.09	....	....	....	....	99.79	6.65	78.90	....	W. G. Crawford	48
26	Grant	....	17.03	3.56	1.51	42.14	34.56	....	1.28	....	....	....	100.08	1.00	75.70	....	E. T Sweet	51
27	Grant	1.37	....	.02	.46	53.20	45.25	02	....	....	....	....	100.32	....	97.70	.75	W. G. Crawford	51
28	Grant	2.31	....	.47	.66	54.25	42.80	.04	....	....	....	....	100.53	3.15	93.90	....	W. G. Crawford	51
29	Grant	5.38	....	.40	.50	53.35	41.00	.04	....	....	....	....	99.67	4.45	89.90	....	W. G. Crawford	51
30	Grant	7.28	....	.18	.60	51.50	40.75	.12	....	....	....	....	100.53	3.00	89.25	....	W. G. Crawford	51
31	La Crosse	10.56	....	.49	.45	49.45	38.90	.24	....	....	....	....	100.09	3.10	85.25	....	W. G. Crawford	61
32	La Crosse	4.96	....	.18	.43	53.30	40.73	.02	....	....	....	....	99.58	4.93	89.10	....	W. G. Crawford	61
33	La Crosse	11.48	....	.13	.76	49.60	37.50	.09	....	....	....	....	99.56	5.0	82.10	....	W. G. Crawford	61
34	La Crosse	6.02	....	.18	.72	51.10	40.50	.18	....	....	....	....	98.70	2.80	88.80	....	W. G. Crawford	61
35	La Crosse	11.17	....	.00	.70	49.35	39.30	.12	....	....	....	....	100.64	2.55	86.10	....	W. G. Crawford	61
36	Oconto	....	7.64	1.47	1.69	49.41	39.78	....	....	....	....	....	99.99	1.99	87.20	....	G. Bode	65
37	Outagamie	....	1.6	2.00	....	51.8	44.6	....	....	....	....	....	100.00	....	95.72	.68	G. J. Barker	70
38	Pierce	....	3.50	.95	....	53.5	39.7	....	....	....	1.00	.015	98.00	6.20	87.0	....	....	73
39	Pierce	10.45	....	.00	1.14	48.65	39.79	.03	....	....	....	....	100.06	1.24	87.20	....	W. G. Crawford	73
40	Pierce	2.10	....	.35	1.85	55.05	40.00	.02	....	....	....	....	99.37	7.15	87.90	....	W. G. Crawford	74
41	Pierce	6.00	....	.37	.87	52.10	40.55	.05	....	....	....	....	99.94	3.75	88.90	....	W. G. Crawford	73
42	Pierce	10.94	....	.42	1.43	49.70	38.00	.03	....	....	....	....	100.52	4.20	83.5	....	W. G. Crawford	73
43	Polk	20.22	....	.40	.92	43.75	34.80	.08	....	....	....	....	100.17	2.25	76.30	....	W. G. Crawford	83
44	Polk	1.72	....	.34	.59	54.75	42.80	.06	....	.22	....	....	100.26	3.75	93.80	....	W. G. Crawford	83
45	Polk	10.00	....	.20	1.69	49.40	38.50	.06	....	....	....	....	99.85	3.50	84.40	....	W. G. Crawford	83
46	St. Croix	26.26	....	.32	.92	40.00	31.80	.05	....	....	....	....	99.35	2.00	69.80	....	W. G. Crawford	82
47	St. Croix	4.2	....		1.0	52.2	42.6	....	....	....	....	....	100.	1.30	93.50	....	....	82
48	St. Croix	2.6	....		1.4	52.9	42.8	....	....	....	....	....	99.7	1.70	94.00	....	....	82
49	St. Croix	10.46	....	.37	1.10	48.60	37.20	.05	1.65	....	....	....	99.64	4.20	81.60	....	W. G. Crawford	82
50	St. Croix	13.21	....	.42	.56	47.92	34.75	.11	....	....	....	....	96.97	6.47	76.20	....	W. G. Crawford	82
51	St. Croix	11.14	....	1.26	.74	50.50	29.81	....	....	....	....	....	93.45	14.91	65.4	....	W. G. Crawford	82
52	St. Croix	6.20	....	6.10	1.12	51.75	39.40	.04	....	....	....	....	104.61	4.85	86.30	....	W. G. Crawford	82
53	Sauk	3.50	....	.80	.00	49.55	42.25	.02	2.97	....	....	....	100.09	....	91.40	.40	W. G. Crawford	86
54	Sauk	2.02	....	.49	.66	54.55	41.50	.03	....	....	....	....	99.25	5.05	91.00	....	W. G. Crawford	86
55	Sauk	7.75	....	.34	.42	50.75	40.55	.01	....	....	....	....	99.82	2.40	88.90	....	W. G. Crawford	86
56	Sauk	6.65	....	.26	.42	52.60	39.30	.08	....	....	....	....	100.31	4.70	86.20	....	W. G. Crawford	86
57	Sauk	14.08	....	6.35	.32	46.50	25.50	.02	6.69	....	....	....	99.44	16.20	55.80	....	W. G. Crawford	85
58	Sauk	23.00	....	5.79	.34	44.95	18.70	.04	6.27	....	....	....	99.09	22.65	41.00	....	W. G. Crawford	85
59	Sauk	5.72	....	.33	.48	51.85	40.80	.02	....	....	....	....	99.20	3.25	89.40	....	W. G. Crawford	86
60	Waupaca	....	1.62		.58	72.03	23.72	....	....	....	....	....	97.95	43.67	52.18	....	....	94
61	Winnebago	9.44	....	1.00	.59	49.75	38.19	....	1.19	....	....	....	100.16	4.43	83.50	....	....	95

Table I—Continued

ANALYSES OF GALENA–BLACK RIVER DOLOMITES

Number	County	Insoluble	SiO_2	Al_2O_3	Fe_2O_3	$CaCO_3$	$MgCO_3$	P_2O_5	H_2O	Total	Calcite	Dolomite	Magnesite	Analyst	Page
62	Brown	3.17	....	1.95		49.97	44.58	....	....	99.67	....	91.90	2.65	W. W. Daniells.	31
63	Columbia	13.80	....	.58	.92	46.75	37.80	.12	....	99.97	1.65	82.90	....	W. G. Crawford	36
64	Columbia	9.56	....	.00	.40	49.45	40.40	.05	....	99.86	1.25	88.60	....	W. G. Crawford	36
65	Columbia	9.55	....	.48	1.18	51.50	37.10	.05	....	99.86	7.20	81.40	....	W. G. Crawford	36
66	Crawford	5.57	....	.38	.62	80.00	12.55	.26	....	99.38	65.05	27.50	....	W. G. Crawford	38
67	Dane	6.00	....	.68	1.07	52.18	40.08	.09	....	100.10	4.46	87.80	....	W. G. Crawford	42
68	Dane	9.25	....	.39	.66	51.50	38.78	.05	....	100.63	5.28	85.00	....	W. G. Crawford	42
69	Dane	....	4.45	2.08	.69	56.07	35.32	....	.46	[c]99.65	14.14	77.25	....	E. T. Sweet.....	42
70	Dane	....	7.03	2.21	.83	84.02	5.33	....	.61	[d]100.42	77.74	11.61	....	E. T. Sweet.....	42
71	Dane	....	1.26	.45	1.05	58.00	40.10	....	....	100.86	10.10	88.00	....	J. E. Thompson.	43
72	Dane	....	4.24	.35	.70	51.20	39.85	....	....	96.34	3.65	81.40	....	J. E. Thompson.	43
73	Dane	....	3.20	.30	.90	52.20	40.10	....	....	96.70	4.30	88.00	....	J. E. Thompson.	43
74	Dane	....	3.28	.30	.90	51.80	39.85	....	....	96.13	4.25	87.40	....	J. E. Thompson.	43
75	Dane	....	6.80	6.40	1.20	47.80	35.49	....	....	97.67	5.49	77.80	....	J. E. Thompson.	43
76	Dane	....	3.30	5.00	1.30	51.40	38.00	....	....	99.00	6.20	83.20	....	J. E. Thompson.	43
77	Dane	....	6.36	.50	1.88	54.80	33.80	....	....	97.34	14.40	74.20	....	J. E. Thompson.	43
78	Dodge	....	2.84	1.24		55.44	40.40	....	....	98.92	7.34	88.50	....	....	44
79	Dodge	2.50	.20	.22	....	53.00	43.90	.04	....	99.86	.65	96.25	....	W. G. Crawford	44
80	Dodge	....	1.57	.07	.17	54.05	44.14	....	....	100.00	2.49	96.70	....	G. Bode........	44
81	Dodge	....	5.34	.40	1.54	53.80	35.90	....	....	96.98	10.90	78.80	....	J. E. Thompson.	44
82	Dodge	....	5.20	.40	1.90	49.20	39.50	....	....	97.20	2.20	86.50	....	J. E. Thompson.	44
83	Fond du Lac	8.95	....	.30	1.00	49.55	39.30	.03	....	99.73	3.05	85.80	....	W. G. Crawford	48
84	Fond du Lac	16.10	....	.34	1.13	44.70	36.90	.04	....	99.21	2.2	79.4	....	W. G. Crawford	48
85	Grant	17.86	....	.32	1.46	44.60	33.80	.06	1.22	99.32	4.30	74.10	....	W. G. Crawford	53
86	Grant	12.34	....	.88	1.39	50.45	32.50	.03	1.92	99.51	11.70	71.25	....	W. G. Crawford	53
87	Grant	18.37	....	1.36	.50	72.80	4.87	.03	2.13	100.06	67.03	10.64	....	W. G. Crawford	53
88	Grant	10.36	....	.53	.38	79.50	9.06	.05	....	99.88	68.76	19.80	....	W. G. Crawford	53
89	Grant	1.87	....	.00	.15	94.25	2.49	.02	....	98.78	91.28	5.46	....	W. G. Crawford	53
90	Grant	10.64	....	.00	.60	81.30	6.26	.12	.36	99.34	73.86	13.70	....	W. G. Crawford	53
91	Grant	11.57	....	.04	.88	85.00	1.84	.03	....	100.27	82.81	4.03	....	W. G. Crawford	53
92	Grant	9.44	....	1.25	.65	51.40	36.60	.32	....	99.66	7.80	80.20	....	W. G. Crawford	54
93	Grant	10.00	....	.60	.52	55.15	25.60	.06	8.03	99.96	24.55	56.20	....	W. G. Crawford	54
94	Grant	12.02	....	1.37	.30	76.00	4.65	.05	4.89	99.28	70.47	10.18	....	W. G. Crawford	54
95	Iowa	.95	6.16	2.26	.95	85.54	3.98	....	.93	99.87	80.78	8.74	....	E. T. Sweet.....	58
96	Jefferson	3.94	....	.18	.39	51.64	43.00	.13	....	99.28	.39	94.25	....	W. G. Crawford	60
97	Jefferson	8.04	....	.36	1.62	49.95	39.80	.02	....	99.79	2.50	87.25	....	W. G. Crawford	59
98	Jefferson	4.80	....	.36	.75	52.20	42.10	.02	....	100.23	1.90	92.40	....	W. G. Crawford	59
99	Jefferson	2.78	....	.00	1.04	52.75	41.10	.08	.80	98.55	3.75	90.10	....	W. G. Crawford	60
100	Jefferson	9.10	....	.88	.78	51.50	36.10	.04	....	98.40	8.50	79.10	....	W. G. Crawford	60
101	Lafayette	12.36	....	.94	.83	48.00	38.15	.02	....	100.30	2.55	83.60	....	W. G. Crawford	63
102	Lafayette	13.47	....	1.28	.95	47.20	38.00	.02	....	100.92	1.90	83.30	....	W. G. Crawford	63
103	Lafayette	8.36	....	1.22	.77	49.98	39.20	.06	....	99.59	3.28	85.90	....	W. G. Crawford	03
104	Lafayette	7.72	....	.72	.78	52.40	38.35	.35	....	100.32	6.75	84.00	....	W. G. Crawford	63
105	Lafayette	3.30	....	.31	.85	54.40	40.20	.50	....	99.56	6.40	88.20	....	W. G. Crawford	63
106	Lafayette	10.00	....	.49	1.33	49.25	39.00	.06	....	100.13	2.75	85.50	....	W. G. Crawford	63
107	Lafayette	.82	....	.28		97.92	1.60	....	....	100.62	96.02	3.50	....	....	62
108	Lafayette	.98	....	.80		62.58	35.30	....	.34	100.00	20.48	77.40	....	....	62
109	Outagamie	8.76	....	.48	.80	49.50	40.20	.14	....	99.08	1.60	88.10	....	W. G. Crawford	71
110	Pierce	12.40	....	2.76	.69	47.00	37.96	.07	....	100.88	1.71	83.25	....	W. G. Crawford	74
111	Pierce	26.69	....	1.68	3.40	40.55	27.00	.22	....	99.54	8.30	59.25	....	W. G. Crawford	74
112	Pierce	9.47	....	.65	3.34	48.95	36.90	.24	....	99.55	4.95	80.90	....	W. G. Crawford	74
113	Pierce	13.84	....	.89	2.53	47.90	34.18	.10	....	100.44	7.28	74.80	....	W. G. Crawford	74
114	Pierce	17.07	....	.74	1.74	63.60	15.98	.10	....	99.23	44.68	34.90	....	W. G. Crawford	74
115	Rock	14.76	....	.38	.42	46.10	38.30	.07	....	100.03	.40	84.00	....	W. G. Crawford	80
116	Rock	15.10	....	.85	.88	46.50	37.60	.03	....	100.96	1.60	82.50	....	W. G. Crawford	80
117	Rock	6.36	....	1.87	.27	51.15	37.30	.03	3.01	99.99	6.65	81.80	....	W. G. Crawford	80
118	Rock	5.60	....	.83	.20	51.50	37.50	.03	3.51	99.17	6.90	82.10	....	W. G. Crawford	80
119	Rock	11.64	....	.58	.26	48.25	39.00	.03	....	99.76	1.75	85.50	....	W. G. Crawford	80
120	Rock	4.36	....	.60	.33	51.90	42.80	.03	....	100.02	.90	93.80	....	W. G. Crawford	80
121	Rock	5.74	1.96	3.27		52.63	36.40	....	....	100.00	9.23	79.80	....	....	80
122	Rock	10.29	1.75	1.60		47.97	38.39	....	....	100.00	2.26	84.10	....	....	81
123	Rock	12.50	1.87	2.23		48.54	34.86	....	....	100.00	7.00	76.40	....	....	81
124	Rock	3.42	1.99	1.42		49.30	43.87	....	....	100.00	....	90.70	2.47	....	81
125	Rock	4.48	....	.10	.65	52.60	42.80	.02	....	100.65	1.60	93.80	....	W. G. Crawford	81
126	Rock	13.78	....	.82	.88	47.65	36.60	.05	....	99.58	4.05	80.20	....	W. G. Crawford	81
127	Rock	3.16	....	.00	.42	53.00	43.70	.06	....	100.34	1.20	95.50	....	W. G. Crawford	81
128	St. Croix	28.46	....	6.10	3.46	40.45	13.55	.24	7.85	100.11	34.35	29.65	....	W. G. Crawford	83
129	St. Croix	13.90	....	.35	.87	53.50	30.50	.03	....	99.15	17.10	66.90	....	W. G. Crawford	83
130	St. Croix	14.90	....	.00	.69	60.48	21.25	.15	....	97.47	35.13	46.60	....	W. G. Crawford	83
131	Walworth	3.66	....	.51	.60	53.75	42.25	.10	....	100.87	3.40	92.60	....	W. G. Crawford	91
132	Walworth	7.68	....	.00	1.12	51.55	39.75	.04	....	100.14	4.30	87.00	....	W. G. Crawford	91
133	Winnebago	7.64	....	.25	.25	50.75	41.05	.14	....	100.08	1.10	90.70	....	W. G. Crawford	95
134	Winnebago	2.46	....	.10	.95	53.75	42.60	.03	....	99.89	2.95	93.40	....	W. G. Crawford	96
135	Winnebago	9.74	....	.75	.47	49.20	39.10	.04	....	99.30	2.50	85.80	....	W. G. Crawford	96

[c] FeO .58.
[d] FeO .39.

Table I—Continued

Analyses of Niagara Dolomite

Number	County	Insoluble	SiO_2	Al_2O_3	Fe_2O_3	$CaCO_3$	$MgCO_3$	P_2O_5	H_2O	Total	Calcite	Dolomite	Magnesite	Analyst	Page
136	Calumet	....	.59	.36	....	55.09	43.96	....	....	100.00	2.80	96.25	....	G. Bode	34
137	Calumet	.90	....	.00	.30	54.20	44.60	.01	....	100.04	1.10	97.70	....	W. G. Crawford	34
138	Calumet	1.84	....	.13	.13	55.00	42.40	.01	....	99.51	4.00	93.40	....	W. G. Crawford	34
139	Calumet	.73	....	.00	.20	53.90	44.20	.00	....	99.03	1.30	96.80	....	W. G. Crawford	34
140	Calumet	1.40	....	.00	.00	53.25	44.40	.00	....	99.05	.15	97.50	....	W. G. Crawford	34
141	Calumet	1.23	....	.10	.30	53.95	44.28	....	Trace	99.86	1.23	97.00	....	W. W. Daniells	33
142	Calumet	1.12	....	.13	.09	53.80	44.90	.00	....	100.04	.20	98.50	....	W. G. Crawford	34
143	Calumet	....	4.52	2.67	1.02	50.54	40.37	....	.70	99.82	2.51	88.40	....	W. W. Daniells	34
144	Calumet	....	1.12	.06	.40	54.82	43.79	....	....	100.19	2.58	96.03	....	....	34
145	Dodge	....	2.50	.94	1.70	53.20	39.60	.015	....	97.95	5.90	86.60	....	J. E. Thompson	44
146	Dodge	1.22	....	.10	.27	54.30	44.00	.02	....	99.91	1.70	96.60	....	W. G. Crawford	45
147	Dodge	.28	....	.24		54.30	45.32	....	....	100.14	.22	99.40	....	W. W. Daniells	45
148	Dodge	....	.65	.37	.40	55.00	42.83	....	....	99.25	4.03	93.80	....	J. E. Thompson	45
149	Dodge	....	.012	.005		54.74	45.07	....	....	99.83	.81	98.90	....	W. W. Daniells	45
150	Dodge	....	.70	.35	.45	55.10	42.80	....	....	99.40	4.10	93.80	....	....	45
151	Dodge	....	.87	.56	.76	54.80	42.80	.006	....	[e]99.79	3.70	93.90	....	J. E. Thompson	45
152	Dodge	.41	....	.25	.13	51.60	44.75	.01	....	100.14	1.35	98.00	....	W. G. Crawford	45
153	Dodge	.57	....	.00	.36	54.70	44.70	.04	....	100.37	1.40	98.00	....	W. G. Crawford	45
154	Dodge	1.26	....	1.09	.20	53.60	43.80	.02	....	99.97	1.40	96.00	....	W. G. Crawford	45
155	Dodge	5.50	....	.17	.45	51.50	42.30	.02	....	99.94	1.20	92.60	....	W. G. Crawford	45
156	Dodge	.70	....	.00	.24	54.50	43.90	.02	....	99.36	2.40	96.00	....	W. G. Crawford	45
157	Dodge	.63	....	.00	.28	54.90	44.00	.04	....	99.85	2.50	96.40	....	W. G. Crawford	45
158	Dodge	2.52	....	.00	.60	53.55	43.00	.04	....	99.71	2.30	94.25	....	W. G. Crawford	45
159	Dodge	....	3.57	3.49	.77	50.52	40.97	....	.48	99.80	1.59	89.90	....	W. W. Daniells	45
160	Door	3.04	....	.00	.45	52.80	43.70	.05	....	100.04	1.00	95.50	....	W. G. Crawford	46
161	Door	5.27	....	.26	.09	51.95	41.90	.03	....	99.50	2.05	91.80	....	W. G. Crawford	46
162	Door	1.68	....	.00	.40	55.75	42.10	.02	....	99.95	5.55	92.30	....	W. G. Crawford	46
163	Fond du Lac	.67	....	.10	.26	54.25	44.48	....	.11	99.87	1.33	97.40	....	W. W. Daniells	49
164	Fond du Lac	1.48	....	.60	.09	54.00	43.00	.02	....	99.19	2.75	94.25	....	W. G. Crawford	49
165	Fond du Lac	1.06	....	.45	.00	54.45	44.00	.08	....	100.04	2.05	96.40	....	W. G. Crawford	49
166	Fond du Lac	.94	....	.00	.20	54.50	44.25	.02	....	99.91	1.85	96.90	....	W. G. Crawford	49
167	Fond du Lac	.81	....	.49	.08	54.25	44.25	.07	....	99.95	2.60	96.90	....	W. G. Crawford	49
168	Fond du Lac	1.13	....	.00	.40	54.90	43.70	.03	....	100.16	3.10	95.50	....	W. G. Crawford	49
169	Fond du Lac	.66	....	.00	.24	54.90	44.25	.03	....	100.08	2.15	97.00	....	W. G. Crawford	49
170	Fond du Lac	....	2.12	.59		53.51	43.54	....	....	99.76	1.45	95.60	....	W. W. Daniells	50
171	Fond du Lac	....	.69	.48		54.40	44.43	....	....	100.00	1.58	97.25	....	W. W. Daniells	50
172	Fond du Lac	.26	....	....	.31	55.03	44.34	....	.29	100.23	2.27	97.10	....	W. W. Daniells	50
173	Kewaunee	1.34	....	.00	.42	54.65	42.70	.00	....	99.11	3.85	93.50	....	W. G. Crawford	60
174	Manitowoc	.96	....	.13	.14	54.95	43.50	.03	....	99.71	2.95	95.50	....	W. G. Crawford	64
175	Manitowoc	.81	....	.17	.13	54.30	43.80	.03	....	99.24	2.10	96.00	....	W. G. Crawford	64
176	Manitowoc	....	.24	.20	.38	54.38	44.39	....	....	99.59	2.57	97.20	....	A. S. Mitchell	64
177	Manitowoc	....	.86	.62	.31	54.31	43.94	....	....	100.04	2.02	96.23	....	A. S. Mitchell	64
178	Milwaukee	1.50	....	.00	.40	55.00	43.15	.04	....	100.09	3.65	94.50	....	W. G. Crawford	67
179	Milwaukee	....	1.49	.21	.31	54.56	43.41	....	....	99.98	2.72	95.25	....	G. Bode	68
180	Milwaukee	....	1.58	.48	1.43	54.69	41.82	....	....	100.00	4.71	91.80	....	G. Bode	68
181	Ozaukee	.62	.37	.92		52.57	45.34	....	....	[f]100.62	....	97.00	.91	....	72
182	Ozaukee	1.14	....	.12	.16	54.50	43.60	.02	....	99.54	2.60	95.50	....	W. G. Crawford	72
183	Ozaukee	....	.50	.61		55.41	43.48	....	....	100.00	3.49	95.40	....	G. Bode	72
184	Ozaukee	....	2.90	1.46	.82	53.23	41.57	....	....	99.98	3.60	91.20	....	G. Bode	72
185	Ozaukee	....	1.28	.16	.49	56.55	41.50	....	....	99.98	7.05	91.00	....	G. Bode	72
186	Ozaukee	....	3.09	.09	.24	52.78	43.78	....	....	99.99	.66	95.90	....	G. Bode	72
187	Racine	.28	....	.82		52.16	45.50	....	.67	99.43	....	96.10	1.56	W. W. Daniells	78
188	Racine	.40	....	.92		55.23	43.52	....	.25	100.32	3.35	95.40	....	W. W. Daniells	78
189	Sheboygan	....	.46	1.10		52.17	45.65	....	....	[g]100.00	....	96.00	1.83	G. Bode	88
190	Sheboygan	....	.55	.24	.40	55.09	43.91	....	....	100.19	2.82	96.18	....	....	88
191	Sheboygan	....	.78	.56	.37	56.22	40.35	....	....	[h]98.84	8.07	88.50	....	....	88
192	Sheboygan	....	.78	.56	.37	58.26	38.35	....	....	[i]100.04	12.61	84.00	....	....	88
193	Sheboygan	....	.40	.30	.85	55.50	44.10	....	....	101.15	2.80	96.80	....	....	88
194	Sheboygan	.30	....	.42	.06	55.00	42.60	.00	....	98.38	4.10	93.50	....	W. G. Crawford	88
195	Sheboygan	.66	....	.00	.28	54.50	44.75	.06	....	100.25	1.25	98.00	....	W. G. Crawford	88
196	Sheboygan	.92	....	.00	.40	53.25	44.40	.00	....	98.97	.25	97.40	....	W. G. Crawford	88
197	Sheboygan	1.86	....	.00	.55	53.85	43.75	.02	....	100.03	1.60	96.00	....	W. G. Crawford	88
198	Waukesha	1.35	....	.46	.43	54.91	42.77	....	.26	100.18	4.08	93.60	....	W. W. Daniells	92
199	Waukesha	1.73	....	.18	.57	55.18	41.70	....	.45	99.81	5.48	91.40	....	W. W. Daniells	92
200	Waukesha	4.40	....	.35		50.35	42.45	....	....	97.55	....	92.60	.20	....	92
201	Waukesha	....	6.32	1.02		50.96	41.75	....	....	100.05	1.31	91.40	....	W. W. Daniells	92
202	Waukesha	....	3.75	.51	.64	52.30	41.80	....	....	[j]99.03	2.50	91.60	....	J. E. Thompson	93
203	Waukesha	....	3.96	1.68		52.29	42.27	....	....	100.20	1.86	92.70	....	Geo. N. Prentiss	93
204	Waukesha	4.32	....	.48	.30	53.25	41.70	.02	....	100.07	3.55	91.40	....	W. G. Crawford	93
205	Waukesha	5.96	....	.00	.46	52.25	42.50	.03	....	100.20	1.55	93.20	....	W. G. Crawford	93
206	Waukesha	7.70	....	1.48	.00	51.15	39.40	.03	....	99.76	4.05	86.50	....	W. G. Crawford	93
207	Waukesha	3.44	....	.30	.20	52.86	42.98	....	.49	100.09	1.74	94.10	....	W. W. Daniells	92
208	Waukesha	6.16	....	.38	.19	51.50	41.90	.02	....	100.15	1.50	91.90	....	W. G. Crawford	92
209	Waukesha	1.93	....	.55	.60	53.55	42.90	.04	....	99.57	2.45	94.00	....	W. G. Crawford	93
210	Waukesha	4.20	....	.14	.09	55.65	39.70	.02	....	99.80	8.35	87.00	....	W. G. Crawford	93
211	Waukesha	1.76	....	.15	.27	54.25	43.50	.05	....	99.98	2.25	95.50	....	W. G. Crawford	93
212	Waukesha	3.27	....	.77	.00	54.25	40.90	.09	....	99.28	5.55	89.60	....	W. G. Crawford	93
213	Waukesha	8.14	....	.17	.72	51.40	40.00	.18	....	100.61	3.80	87.60	....	W. G. Crawford	93
214	Waukesha	8.20	....	.00	.69	50.75	40.85	.03	....	100.52	2.15	89.50	....	W. G. Crawford	93
215	Waukesha	2.21		.84		53.27	43.63	....	....	99.95	1.30	95.60	....	W. T. Schrenk	93

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[e] Sulphur .002.
[f] Alkalies .80.
[g] CO_2 .64.
[h] Loss 1.56.
[i] Loss 1.72.
[j] Sulphur .038.

Table I—Continued

MILWAUKEE FORMATION

Number	County	SiO_2	Al_2O_3	Fe_2O_3	$CaCO_3$	$MgCO_3$	P_2O_5	$CaSO_4$	S	Total	Calcite	Dolomite	Magnesite	Analyst	Page
216	Milwaukee	17.56	1.41	3.03	45.54	32.46	....	....	....	100.00	6.90	71.10	....	G. Bode	68
217	Milwaukee	17.56	1.40	2.24	48.29	29.19	....	....	....	98.68	13.58	63.90	....	G. Bode	68
218	Milwaukee	13.74	3.95	3.85	47.55	30.91	....	....	....	100.00	10.66	67.80	....	G. Bode	68
219	Milwaukee	18.77	5.14	4.05	47.09	24.95	....	....	....	100.00	17.34	54.70	....	G. Bode	68
220	Milwaukee	15.65	4.60	3.04	45.44	31.27	....	....	....	100.00	8.11	68.60	....	G. Bode	68
221	Milwaukee	15.60	.12	.38	45.57	27.67	....	....	....	99.34	12.64	60.60	....	Doremus	68
222	Milwaukee	16.99	5.00	1.79	41.34	34.88	....	....	....	100.00	....	76.10	.12	G. Bode	68
223	Milwaukee	17.00	5.00	1.80	40.05	35.82	....	....	....	99.67	....	73.70	2.17	G. Bode	68
224	Milwaukee	16.61	4.09	3.25	45.11	30.89	....	....	....	99.95	8.20	67.80	....	G. Bode	68
225	Milwaukee	8.59	3.51		49.12	38.76	Trace	.07	Trace	100.05	2.88	85.00	....	W. W. Daniells	68

TABLE 2

ANALYSES OF WISCONSIN MARLS

Number	County	Insoluble	SiO_2	Al_2O_3	Fe_2O_3	$CaCO_3$	$CaSO_4$	$MgCO_3$	CaO	MgO	H_2O	Loss CO_2, H_2O, organic	Organic matter	Total	MgO recalculated to non-volatile basis	Analyst	Page
226	Co'umbia		2.16	.54		93.89		Trace			(a)			96.59	Trace	V. Lenher	129
227	Dane		15.85	2.51		59.39		4.52				13.45		b99.67	3.82	V. Lenher	129
228	Door	1.68		.94		88.42	.85	2.96					4.93	99.78	2.62	W. S. Ferris	129
229	Door	4.45		1.36		77.40	1.63	3.79					11.24	99.87	3.50	W. S. Ferris	130
230	Door	1.09		.56		88.62	.66	4.49					4.80	100.22	4.05	W. S. Ferris	131
231	Door	1.47		.52		88.00	.63	4.63					5.13	100.38	4.12	W. S. Ferris	131
232	Kewaunee	1.84		.70		82.25	.95	3.84					7.79	100.37	3.60	W. S. Ferris	135
233	Kewaunee	.62		.50		86.35	.70	3.21					8.87	100.25	3.00	W. S. Ferris	136
234	Kewaunee		1.48	.19		86.09		7.18			1.67		2.95	c100.00	6.32	G. Bode	136
235	Kewaunee	1.31		.58		81.68	1.00	3.43					11.90	99.90	3.26	W. S. Ferris	136
236	Kewaunee	.66		.40		79.02	1.82	3.12					15.16	100.18	3.15	W. S. Ferris	137
237	Kewaunee	1.20		1.50		57.82	4.03	2.95					32.58	100.08	3.70	W. S. Ferris	137
d238	Marquette		5.11	.61	.73				44.50	1.89	5.94	45.59	Present	98.43	3.47	W. T. Schrenk	139
d239	Milwaukee		9.44	2.91	1.63				33.68	1.90	11.72	46.41	Present	95.97	3.55	W. T. Schrenk	139
240	Outagamie	5.44		2.58		69.85	1.98	3.55					16.74	100.14	3.42	W. S. Ferris	140
241	Outagamie	4.22		2.03		72.03	2.03	3.67					16.06	100.04	3.50	W. S. Ferris	141
242	Outagamie	9.00		2.95		66.85	2.06	3.63					15.39	99.88	3.35	W. S. Ferris	141
243	Portage	2.37		.94		80.83	.88	2.50					12.58	100.10	2.38	W. S. Ferris	142
244	Portage	1.33		.39		89.50	.61	2.52					5.48	99.83	2.27	W. S. Ferris	143
245	Portage	5.31		.95		74.86	1.21	1.86					15.93	100.12	1.80	W. S. Ferris	144
246	Sheboygan	.87		.36		93.21	.40	3.66					1.70	100.20	3.16	W. S. Ferris	145
247	Sheboygan	.97		.48		89.53	1.22	3.06					.5.01	100.27	2.74	W. S. Ferris	145
d248	Waukesha		9.19	.78	.40				43.18	2.60	3.22	41.46	Present	97.61	4.44	W. T. Schrenk	146
d249	Waukesha		2.95	1.37	.99				48.56	2.14	2.92	43.65	Present	99.66	3.79	W. T. Schrenk	146
250	Waupaca	1.61		.63		88.46	.87	3.37					5.25	100.19	3.00	W. S. Ferris	149
251	Waupaca	1.53		.73		87.51	.64	4.95					4.80	100.16	4.40	W. S. Ferris	149
252	Waupaca	1.64		.70		87.63	.73	4.77					4.57	100.08	4.24	W. S. Ferris	150

a Loss of H_2O at 105° 1.29.

b Na_2O .95, SO_3 1.37, K_2O .34.

c SO_3 .44.

d Sample collected by C. S. Corbett and analyzed by W. T. Schrenk. In the analysis H_2O is water driven off above 110° and under 600° from a sample which had been dried at 110°. Loss on ignition was total loss on igniting after a sample had been dried at 110°. Other determinations are based on weight of sample after drying at 110°.

TABLE 3

ANALYSES OF WISCONSIN CLAYS, SLATES, AND SHALES

Note: Attention is called to the fact that clays may have proper chemical constitution to make cement but still not be of proper physical constitution.

Number	County	SiO_2	Al_2O_3	Fe_2O_3	FeO	CaO	MgO	Na_2O	K_2O	Loss on ignition (CO_2, H_2O, organic)	H_2O	TiO_2	Total	MgO recalculated to non-volatile basis	$\frac{SiO_2}{Al_2O_3+Fe_2O_3}$	$\frac{SiO_2}{Al_2O_3}$	Character of deposit	Suitability for Cement	Analyst	Page
253	Adams......	47.68	7.86	3.88	......	11.63	8.57	......	......	16.70	^{a}1.94	......	96.32	10.28	4.05	6.05	Marly clay....,	Poor...	W. T. Schrenk..	156
254	Adams......	53.13	17.49	5.20	......	7.29	6.39	......	......	11.21	^{a}3.03	......	100.71	7.22	2.34	3.02	Dry lake clay...	Fair...	W. T. Schrenk..	156
255	Ashland.....	58.09	25.32	4.44	......	2.42	1.94	......	......	....	4.09	......	96.41	2.1	1.95	2.29	Glacial lake clay	Poor...	W. W. Daniells..	157
256	Ashland.....	64.56	18.86	4.11	......	3.58	1.66	......	......	....	2.56	......	95.33	1.79	2.81	3.42	Glacial lake clay	Fair...	W. W. Daniells..	157
257	Brown......	32.33	12.83	4.87	......	13.37	10.88	......	......	21.95	^{a}2.93	......	96.23	13.94	1.82	2.55	Richmond shale.	Poor...	W. T. Schrenk..	157
258	Brown......	59.98	16.33	7.10	......	1.02	1.97	1.04	4.22	....	8.15	.58	100.39	2.13	2.55	3.67	Lake clay......	Fair...	....	157
259	Calumet....	39.37	15.65	4.58	......	11.25	9.53	......	......	17.65	^{a}3.22	......	98.03	11.60	1.94	2.55	Richmond shale.	Fair...	W. T. Schrenk..	158
260	Calumet....	31.89	14.59	4.41	......	14.17	11.42	......	......	21.82	^{a}2.82	......	98.30	14.70	1.67	2.18	Richmond shale.	Poor...	W. T. Schrenk..	158
261	Calumet....	26.12	11.54	3.36	......	17.47	13.27	......	......	26.22	^{a}2.51	......	97.98	18.10	1.75	2.26	Richmond shale.	Poor...	W. T. Schrenk..	158
262	Calumet....	40.12	19.47	5.86	......	8.94	7.86	......	......	15.51	^{a}3.09	......	97.78	9.36	1.58	2.06	Richmond shale.	Fair...	W. T. Schrenk..	158
263	Calumet....	38.02	13.53	4.94	......	10.15	10.18	......	......	17.22	^{a}2.83	......	94.04	12.29	2.19	2.86	Richmond shale.	Poor...	W. T. Schrenk..	158
264	Dodge......	27.65	10.26	5.45	......	17.23	12.18	......	......	27.36	^{a}2.20	......	100.43	16.70	1.67	2.72	Richmond shale.	Poor...	W. T. Schrenk..	159
265	Dodge......	28.65	7.66	3.52	......	17.56	12.30	......	......	27.12	^{a}2.01	......	96.81	16.87	2.56	4.12	Richmond shale.	Poor...	W. T. Schrenk..	159
266	Dodge......	55.79	15.71	4.01	......	6.90	5.00	......	......	11.02	^{a}2.81	......	98.43	5.62	2.82	3.54	Marsh clay.....	Good...	W. T. Schrenk..	160
267	Dodge......	56.13	15.45	3.44	......	8.36	4.80	......	......	11.30	^{a}3.00	......	99.48	5.41	2.97	3.63	Marsh clay.....	Fair...	W. T. Schrenk..	160
268	Dodge......	45.66	15.26	5.10	......	9.03	7.33	......	......	14.41	^{a}3.22	......	96.79	8.56	2.24	2.99	Marsh clay.....	Fair...	W. T. Schrenk..	160
269	Fond du Lac	44.83	16.40	6.08	......	9.17	7.70	......	......	13.57	^{a}4.18	......	97.75	8.92	1.98	2.73	Dry lake clay...	Poor...	W. T. Schrenk..	161
270	Fond du Lac	62.72	19.15	5.45	......	3.50	3.15	......	......	6.41	^{a}4.39	......	100.47	3.36	2.54	3.26	Dry lake clay...	Good...	W. T. Schrenk..	161
271	Fond du Lac	45.68	23.01	5.04	......	8.65	6.30	......	......	12.23	^{a}3.75	......	100.47	7.19	1.62	1.98	Wet lake clay...	Poor...	W. T. Schrenk..	161
272	Fond du Lac	42.58	12.02	4.91	......	12.51	7.91	......	......	17.18	^{a}2.81	......	97.11	9.55	2.51	3.54	Dry lake clay...	Poor...	W. T. Schrenk..	161
273	Fond du Lac	46.08	13.85	4.20	......	8.28	8.25	......	......	13.63	^{a}3.26	......	94.29	10.21	2.55	3.32	Richmond shale.	Poor...	W. T. Schrenk..	161
274	Grant......	48.88	12.00	14.54	......	4.8	1.5	......	6.43	11.21	......	......	^{b}100.62	1.67	1.84	4.07	Decorah ? shale.	Poor...	L. G. Michael...	162
275	Grant......	49.10	8.46	17.15	......	6.18	1.35	......	3.62	12.63	......	......	^{c}100.18	1.55	1.91	5.80	Decorah ? shale.	Poor...	L. G. Michael...	162
276	Iron........	53.44	19.62	11.38	5 35	.42	1.58	2.61	1.73	....	4.07	......	100.20	1.65	1.46	2.72	Tyler slate......	Poor...	L. G. Eakins....	162
277	Iron........	52.58	20.76	12.17	4.08	.30	1.33	.37	4.87	....	3.43	......	99.89	1.37	1.42	2.54	Tyler slate.....	Poor...	L. G. Eakins....	162
278	Jackson.....	70.30	18.07	1.65	......	......	.90	.76	2.94	....	^{d}5.26	......	99.88	.95	3.57	3.90	Residual clay...	Good...	....	163
279	Jackson.....	72.30	16.06	.35	......	.26	1.50	.40	5.23	....	^{d}3.68	......	99.78	1.56	4.40	4.50	Residual clay...	Poor...	....	163
280	Jackson.....	55.87	19.60	9.22	......	1.05	3.71	.32	3.93	....	^{d}6.22	......	99.92	3.96	1.93	2.85	Residual clay...	Poor...	....	163
281	Jackson.....	65.52	16.33	4.02	......	1.65	3.09	.33	3.94	....	^{d}4.38	......	99.86	3.15	3.22	4.00	Residual clay...	Fair...	....	163
282	Jackson.....	67.96	17.25	2.27	......	.67	2.07	.38	5.81	....	^{d}3.86	......	100.27	2.08	3.31	3.93	Residual clay...	Good...	....	163
283	Jackson.....	60.44	19.74	6.23	......	.40	2.22	4.03	1.89	....	5.60	.06	100.61	2.33	2.33	3.06	Residual clay...	Fair...	V. Lenher......	163
284	Jackson.....	59.88	18.10	10.04	......	.31	3.13	.52	3.72	....	4.40	......	100.10	3.23	2.11	3.30	Residual clay...	Fair...	....	163
285	Jackson.....	50.17	17.90	12.29	......	.55	6.86	.58	3.06	....	7.16	......	99.93	7.40	1.66	2.82	Residual clay...	Poor...	....	163
286	Jackson.....	63.21	18.00	4.62	......	.18	1.12	9.11	.57	3.61	......	.05	100.47	1.16	2.79	3.50	Residual clay...	Good...	V. Lenher......	163
287	Jackson.....	40.09	11.87	4.00	......	10.29	7.15	.86	2.74	....	18.03	.75	99.78	8.75	2.52	3.37	Blue clay (Cambrian)...	Poor...	....	163
288	Jackson.....	62.59	17.42	5.88	......	......	1.24	.52	8.08	....	^{d}4.15	.30	100.18	1.29	2.68	3.59	Blue clay (Cambrian)...	Good...	....	163
289	Jackson.....	55.90	22.90	4.66	......	.90	2.21	......	......	3.53	^{a}2.78	......	92.88	2.29	2.02	2.43	Eau Claire shale	Fair...	W. T. Schrenk..	163
290	Kenosha....	55.41	18.10	5.91	......	6.28	.14	1.54	.49	12.34	......	.25	100.46	.16	2.26	3.00	Glacial lake clay	Fair...	V. Lenher......	163
291	Manitowoc..	41.70	11.29	2.77	......	15.40	3.32	1.27	3.05	19.84	......	.38	99.02	4.19	2.97	3.70	Glacial lake clay	Fair...	V. Lenher......	164
292	Marathon...	52.60	14.42	16.00	......	.65	3.15	.36	4.90	....	^{d}6.86	.80	99.74	3.37	1.73	3.64	Residual clay...	Poor...	....	164
293	Marathon...	54.47	13.68	15.96	......	.55	3.17	.40	4.60	....	^{d}6.00	1.10	99.93	3.37	1.83	3.98	Residual clay...	Poor...	....	164
294	Marathon...	49.92	13.03	20.20	......	.31	4.15	.40	5.72	....	^{d}6.14	.85	100.09	4.46	1.50	3.83	Residual clay...	Poor...	....	164
295	Marquette...	54.51	13.73	4.27	......	8.70	6.08	......	......	12.20	^{a}2.23	......	99.49	6.92	3.02	3.97	Marsh clay.....	Fair...	W. T. Schrenk..	164
296	Marquette...	43.86	12.61	4.22	......	12.66	8.24	......	......	17.32	^{a}2.25	......	98.91	9.96	2.34	3.86	Marsh clay.....	Poor...	W. T. Schrenk..	164
297	Marquette...	49.35	8.34	3.58	......	11.48	7.24	......	......	15.57	^{a}1.72	......	95.56	8.57	4.12	5.92	Lake clay......	Poor...	W. T. Schrenk..	165
298	Marquette...	46.90	7.83	3.06	......	13.52	8.07	......	......	17.93	^{a}1.70	......	97.31	9.83	4.30	5.99	Lake clay......	Poor...	W. T. Schrenk..	165
299	Marquette...	44.23	13.14	3.26	......	13.39	8.11	......	......	17.93	^{a}1.61	......	100.06	9.88	2.69	3.36	Marsh clay.....	Poor...	W. T. Schrenk..	166
300	Marquette...	51.64	10.25	2.38	......	12.05	7.78	......	......	16.64	^{a}8.36	......	100.74	9.33	4.09	5.04	Marsh silt......	Poor...	W. T. Schrenk..	166
301	Marquette...	49.32	15.63	4.16	......	9.92	6.90	......	......	14.18	^{a}1.91	......	100.10	8.05	2.49	3.15	Marsh clay.....	Poor...	W. T. Schrenk..	166
302	Marquette...	50.73	9.03	3.71	......	11.59	7.44	......	......	15.41	^{a}1.74	......	97.91	8.79	3.98	5.60	Marsh clay.....	Poor...	W. T. Schrenk..	166
303	Milwaukee..	54.16	16.52	9.29	......	2.97	2.57	......	......	11.13	^{a}7.34	......	96.64	2.87	2.10	3.27	Devonian shale..	Fair...	W. T. Schrenk..	166
304	Milwaukee..	42.61	8.11	5.18	......	17.68	7.33	......	......	18.83	^{a}2.78	......	99.74	9.03	3.21	5.25	Dry lake clay...	Poor...	W. T. Schrenk..	167
305	Milwaukee..	37.76	9.07	3.60	......	22.48	2.84	.54	2.07	21.52	......	.38	100.26	3.61	2.99	4.15	Glacial lake clay	Fair...	V. Lenher......	167
306	Pierce......	62.74	17.01	5.60	......	2.38	1.84	.34	3.18	....	^{d}6.72	......	99.81	1.96	2.77	3.69	Glacial lake clay	Fair...	....	167
307	Pierce......	70.02	14.77	5.00	......	1.02	1.03	.60	2.73	....	^{d}4.50	......	99.67	1.07	3.55	4.76	Glacial lake clay	Poor...	....	167
308	Portage.....	63.04	21.60	3.50	......	.85	1.00	......	......	5.95	......	......	95.94	1.11	2.50	2.92	Residual clay...	Fair...	A. S. Mitchell...	167
309	Portage.....	59.94	16.74	7.64	......	.43	1.69	......	......	3.91	......	......	90.35	1.77	2.45	3.58	Residual clay...	Fair...	A. S. Mitchell...	167
310	Racine......	39.68	9.27	5.70	......	19.12	7.41	......	......	19.62	^{a}2.44	......	100.80	9.22	2.54	4.28	Dry lake clay...	Fair...	W. T. Schrenk..	168
311	Racine......	42.26	9.84	5.77	......	18.38	5.32	......	......	18.63	^{a}2.96	......	100.20	6.53	2.70	4.30	Dry lake clay...	Fair...	W. T. Schrenk..	168
312	Racine......	43.99	11.89	4.66	......	11.00	6.67	......	......	16.26	^{a}3.28	......	99.47	7.96	2.65	3.69	Marsh clay.....	Fair...	W. T. Schrenk..	169
313	Sauk.......	40.56	14.91	4.32	......	12.11	2.63	1.59	2.57	....	18.30	.57	97.56	3.23	2.10	2.72	Glacial lake clay	Fair...	W. T. Schaller..	169
314	Sauk.......	62.03	29.34	Trace	5.09	.16	.29	Trace	Trace	....	2.25	......	99.16	.30	1.80	2.12	Seeley slate.....	Fair...	V. Lenher......	170
315	Sheboygan..	59.22	16.65	7.72	......	.96	.52	1.94	2.78	10.23	......	.03	100.05	.58	2.45	3.55	Glacial lake clay	Fair...	V. Lenher......	170
316	Taylor......	45.65	18.90	18.00	......	.86	.29	7.66	1.70	6.55	......	.03	99.64	.31	1.26	2.46	Residual clay...	Poor...	V. Lenher......	170
317	Walworth...	34.82	10.62	3.35	......	16.45	10.40	......	......	23.08	^{a}2.87	......	98.75	13.52	2.49	3.27	Lake clay......	Poor...	W. T. Schrenk..	170
318	Washington.	28.27	7.82	2.63	......	19.10	12.22	......	......	28.10	1.61	......	98.16	17.10	2.70	3.62	Dry lake clay...	Poor...	W. T. Schrenk..	171
319	Washington.	26.54	6.06	1.68	......	21.10	13.48	......	......	29.27	^{a}1.00	......	98.13	19.20	3.42	4.24	Dry lake clay...	Poor...	W. T Schrenk..	171
320	Waukesha...	42.94	9.71	3.69	......	12.79	5.93	......	......	21.19	^{a}4.98	......	96.25	7.53	3.20	4.42	Marsh clay.....	Fair...	W. T. Schrenk..	172
321	Waukesha...	37.08	6.93	7.21	......	14.87	8.08	......	......	20.06	^{a}2.08	......	94.23	10.10	2.62	5.36	Marsh clay.....	Poor...	W. T. Schrenk..	172
322	Waukesha...	28.33	7.12	3.15	......	19.04	11.23	......	......	26.80	^{a}1.84	......	95.67	15.30	2.76	3.98	Marsh clay.....	Poor...	W. T. Schrenk..	172
323	Waukesha...	29.02	6.58	4.37	......	19.03	11.43	......	......	26.46	^{a}2.00	......	96.89	15.50	2.65	4.84	Marsh clay.....	Poor...	W. T. Schrenk..	173
324	Waukesha...	54.59	21.19	5.81	......	1.75	1.04	......	......	8.16	^{a}6.42	......	92.54	1.13	2.00	2.56	Clay..........	Good...	W. T. Schrenk..	173
325	Wood.......	53.18	14.92	14.64	......	1.09	2.53	......	......	8.07	......	......	94.91	2.91	1.80	3.56	Residual clay...	Poor...	A. S. Mitchell ..	173
326	Wood.......	64.88	17.90	5.40	......	.60	1.40	......	......	5.64	......	......	95.87	1.55	2.78	3.62	Residual clay...	Good...	S. B. Newberry..	173
327	Wood.......	46.34	16.20	17.75	......	2.62	.80	.58	4.83	10.51	......	.05	99.68	.89	1.36	2.88	Residual clay...	Poor...	V. Lenher......	173
328	Wood.......	52.52	14.65	18.07	......	.94	2.40	.34	5.52	....	^{d}4.69	1.35	100.48	2.51	1.60	3.58	Residual clay...	Poor...	....	173
329	Wood.......	67.50	19.48	2.66	......	......	.83	.48	2.50	....	^{d}6.47	......	100.18	.83	3.05	3.47	Residual clay...	Good...	....	173
330	Wood.......	54.74	16.62	10.27	......	.36	1.73	1.72	6.26	7.87	......	.05	99.62	1.87	2.03	3.28	Residual clay...	Fair...	V. Lenher......	173
331	Wood.......	52.33	17.61	15.94	......	2.25	.25	.23	.93	10.38	......	.04	99.96	.28	1.56	2.97	Residual clay...	Poor...	V. Lenher......	173

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a Collected by C. S. Corbett. In the analysis H_2O is water driven off above 110° and under 600° from a sample which had been dried at 110°. Loss on ignition was total loss on igniting after a sample had been dried at 110°. Other determinations are based on weight of sample after drying at 110°.

b SO_3 1.26.

c SO_3 1.69.

d Includes H_2O and C.

TABLE 4

ANALYSES OF CEMENT MATERIALS CALCULATED TO A NON-VOLATILE BASIS

Analysis number	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO
303	60.94	18.59	10.41	3.35	2.87
239	17.61	5.43	3.04	62.84	3.55
311	51.93	12.09	7.09	22.59	6.53
320	54.48	12.32	4.68	16.23	7.53
248	15.69	1.33	.68	73.76	4.44
324	59.44	23.07	6.33	1.90	1.13
249	5.23	2.43	1.75	86.17	3.79
266	62.69	17.65	4.51	7.75	5.62
267	63.28	17.42	3.87	9.43	5.41
269	51.97	19.01	7.05	10.63	8.92
270	67.01	20.46	5.82	3.74	3.36
271	52.04	26.21	5.74	9.86	7.19
268	53.35	17.84	5.96	10.55	8.56
238	9.39	1.12	1.34	81.79	3.47
295	62.08	15.64	4.87	9.91	6.92
258	65.30	17.78	7.73	1.11	2.14
"Calcite"	.61	....	....	98.31	1.07

TABLE 5

PROPORTIONS OF SHALE, CLAY, MARL, AND LIMESTONE SAMPLES AND THE ANALYSES OF THE RESULTING CEMENTS

Combination	Shales and clays		Marls and limestone		Analysis of resulting cement				
	Analysis number	Proportion	Proportion	Analysis number	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO
1	303	1	9	239	21.94	6.74	3.78	56.89	3.48
2	303	1	6	248	22.16	3.79	2.07	63.70	4.21
3	303	2	5	249	21.14	7.04	4.22	62.50	3.52
4	303	1	3	238	22.28	5.49	3.60	62.18	3.32
5	303	1	1.8	"Calcite"	22.16	6.64	3.72	64.39	1.71
6	311	1	9	239	21.04	6.10	3.44	58.81	3.85
7	311	1	5	248	21.73	3.12	1.74	65.23	4.78
8	311	1	2	249	20.79	5.65	3.53	64.98	4.70
9	311	1	1.2	"Calcite"	23.92	5.49	3.22	63.89	3.55
10	324	2	5	249	20.72	8.33	3.06	62.09	3.03
11	324	1	3	238	21.90	6.61	2.59	61.82	2.88
12	266	2	5	249	21.65	6.78	2.54	63.76	4.31
13	266	1	3	238	22.72	5.25	2.13	63.28	4.01
14	267	2	5	249	21.81	6.71	2.35	64.24	4.25
15	267	1	3	238	22.86	5.19	1.97	63.70	3.96
16	268	1	3	238	20.38	5.30	2.49	63.98	4.74
17	270	2	5	249	22.88	7.58	2.94	62.62	3.67
18	270	1	3	238	23.80	5.95	2.46	62.28	3.44
19	295	3	8	249	20.73	6.03	2.60	65.37	4.64
20	295	1	3	238	22.56	4.75	2.22	63.82	4.33
21	320	1	3	238	20.66	3.92	2.18	65.40	4.48
22	258	1	1.8	"Calcite"	23.71	6.35	2.77	63.69	1.44
23	269	1	1.5	"Calcite"	21.15	7.65	2.82	63.24	4.20

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