LIMESTONES OF MICHIGAN.

R. A. SMITH.

CONTENTS.

Limestones of Michigan.

Introduction.

CHAPTER I.

Origin of Limestone.

CHAPTER II.

Classification and Varieties of Limestones.

CHAPTER III.

Uses of Limestone.

CHAPTER IV.

Geology of Limestone Formations.

LIST OF ILLUSTRATIONS.

PLATES.

FIGURES.

INTRODUCTION.

That Michigan possesses enormous limestone resources has been known for more than a half century yet little was known of the specific or even the general character of many of the beds until recently. A. Winchell,* and C. Rominger,** incidentally have described in various early publications of the Michigan Geological Survey the limestone formations in different localities in connection with the discussion of other geological problems. A. C. Lane† described in detail the limestones of Huron county, W. H. Sherzer†† the limestones of Monroe and Wayne counties, W. H. Sherzer and A. W. Grabau‡ the limestones of the Monroe Formation, A. W. Grabau‡‡ the limestones of the Traverse Formation, and W. M. Gregory§ those of Arenac county. Lane studied in more or less detail the limestone deposits in a number of other localities, and in the Annual Report of the Geological Survey for 1901 published a brief report upon the limestones of the whole state. Brief notes by Lane,§§ Russell,*** and others on limestone were published in some of the other reports. All of the above contributions to the subject, with the exception of the reports on Arenac, Huron, Monroe, and Wayne counties, and on the Monroe formation are out of print and largely out of date.

This report brings together the important facts of the previous reports and adds to these the information afforded by more recent developments, particularly the results of an investigation made by the writer during 1913-14. The economic possibilities of the several limestone formations are presented rather than their geologic relations. The report embraces (1) a discussion of the character origin and classification of limestones, (2) an outline of the geology of the limestone formations of Michigan, (3) their uses, and (4) descriptions of the occurrence, character, development and economic possibilities of the limestone beds of the different counties.

*First Biennial Rept., Mich. Geol. Survey, 1860.
**Geology of Lower Peninsula, Vol. III, Pt. 1, Mich. Geol. Surv., 1869-1873; and Geology of Lower Peninsula, Vol. III, Pt. 1, 1873-1876.
†Geology of Huron County, vol. VII, p. 11, Mich. Geol. Surv., 1896-1900.
††Geology of Monroe County, vol. VII, p. II, 1896-1900.
‡The Monroe Formation, Pub. 2, Geol. Ser. 1, Mich. Geol. and Biol. Surv. 1909.
‡‡The Stratigraphy of the Traverse Formation, Ann. Report, Mich. Geol. Surv. for 1901.
§Geology of Arenac County, Pub. 11, Geol. Ser. 8, Mich. Geol. and Biol. Surv., 1911.
§§Ann Repts., Mich. Geol. Surv. for 1903, 1905, 1907 and 1908.
***A Geological reconnaissance along the north shore of Lakes Huron and Michigan, Ann. Rept., Mich. Geol. Surv. 1904.

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The various bulletins and publications of the United States Geological Survey and some of the state geological surveys have been freely drawn upon for material. The writings of F. W. Clarke; E. F. Burchard; W. E. Emley, and E. C. Eckel of the U. S. Geological Survey; and E. Orton, Jr., and S. V. Peppel of the Ohio Geological Survey and H. A. Buehler of the Missouri Geological Survey have been especially valuable. Acknowledgment will be made elsewhere to many other investigators whose writings have contributed to this report.

CHAPTER I.

ORIGIN OF LIMESTONE.

DEFINITION.

According to commercial usage limestone is a rock varying in composition when free from impurities, from pure calcium carbonate to a mixture of 56.35 per cent of calcium carbonate, 45.65 per cent of magnesium carbonate.* In a general sense it is used to denote a rock in which calcium carbonate is the chief ingredient.† In this report, commercial usage has been followed, but the term dolomite is applied to limestones in which the molecular proportions of calcium carbonate to magnesium carbonate approach the ratio of one to one. Descriptive terms are used to distinguish limestones of intermediate composition.

All limestones contain more or less impurities, chemically combined with the lime or magnesia or as separate minerals. The common impurities are iron carbonate, iron oxides and sulphides, silica, alumina, clay, carbonaceous matter, sulphur, and phosphorous. Under the second definition magnesium carbonate is an impurity and generally it is the most abundant.

Calcium carbonate ($CaCO_3$) is usually present as the mineral calcite, magnesium carbonate as dolomite ($CaCO_3$, $MgCO_3$), silica (SiO_2) as sand, chert, quartz, or in combination with clay, ferrous carbonate ($FeCO_3$) as siderite, iron oxides (Fe_2O_3, (Fe_2O_3, $2H_2O$) as hematite and limonite, iron sulphides (FeS_2, FeS) as pyrite or marcasite, alumina (Al_2O_3) as clay or shale. The impurities vary from a mere trace to more than half, when the rock properly is no longer limestone. The color of limestone is largely governed by the impurities. The light blue, buff, yellow, pink, red, and brown tones are due largely to iron oxides and the gray and black to carbonaceous material. Manganese carbonate generally gives a pink or red tinge to limestone.

*According to definition of the National Lime Manufacturers Association. W. E. Emley, Manufacture of Lime, Technologic Papers, U. S. Bur. of Stand., No. 16, 1913, p. 7.
†F. W. Clark, Data of Geochemistry, Bull. 616, U. S. G. S., 1914, p. 548.
†W. G. Miller, Limestones of Ontario, Bur. Mines, 1903, pt. 2, p. 19.
H. A. Buehler, Lime and Cement Resources of Missouri, Vol. VI, 2nd ser., Mo. Geol. Surv. 1907, p. 4.

ORIGINAL SOURCES.

The original source* of limestone is the igneous rocks. Carbon dioxide (CO_2) which is constantly being given off by decaying vegetable and animal matter is readily absorbed by percolating waters and forms a solution of carbonic acid which accelerates the decomposition of the rocks. The carbon dioxide unites with the calcium of the minerals, particularly the lime feldspars and calcium carbonate ($CaCO_3$), the chief constituent of limestone, is formed. Calcium carbonate is slightly soluble in pure water but is much more so in water charged with carbon dioxide. It combines with water forming calcium bi-carbonate ($CaH_2(CO_3)$) which is much more soluble than the normal carbonate.

Upon exposure to the air some of the excess carbon dioxide in the ground water escapes or is removed by various agencies and part of the calcium carbonate is deposited in springs and lakes as travertine, calcareous sinter, marl, tufa, and öolite. All streams, however, carry in solution more or less calcium carbonate and other mineral substances to the sea. Evaporation through the geological ages has tended to concentrate these substances in sea water and owing to the relative insolubility of calcium carbonate, the sea water long ago would have become overcharged with this salt were it not for the fact that various agencies of deposition, chiefly organic, are constantly removing large quantities.

ORGANIC AND INORGANIC DEPOSITS.

Deposits of limestone may be formed through the agency of organisms or directly by precipitation from solutions. The former are termed organic, the latter, chemical deposits. Many of the Michigan limestones are composed of the calcareous remains of animals but others show little or no trace of organic remains. No sharp distinction, however, can be made between limestones of organic and those of purely chemical origin. In the broadest sense all limestones are of chemical origin because the extraction of lime from sea water by living organisms is an organo-chemical process.

Most limestones are formed by accumulation on the sea bottom of the calcareous shells or hard parts of corals, stromatopora, bryozoa, crinoids, and molluscs, which abound in the shallow places of the ocean.

Small or microscopic organisms, chiefly foraminifera, and many other animals and certain plants have also played a smaller though important part in building up calcareous accumulations. Some strata are composed almost wholly of coral, shells, tests of foraminifera, of the hard parts of crinoids or bryozoa, or a mixture of these. The absence of fossils of lime secreting forms in some limestones is not a proof of inorganic origin. Deformation and thorough recrystallization have obliterated all traces of fossils in most of the pre-Cambrian limestones and in some of later age in areas of extreme metamorphism. The absence of fossils in many limestones is due to the breaking up by the waves, particularly in time of storm, of coral reefs. The detached fragments of the reefs as well as rocks and pebbles on shores, dashed about by the waves, become millstones in grinding up the coral rock, shells, crinoids, etc., into sand and powder or rock flour. The resulting lime-sand and lime-mud are washed and sorted by the waves. The coarser particles are deposited on the slopes of the coral reefs or shores but the finer material may be carried in suspension for long distances before it sinks to the bottom of the ocean as lime-mud. Around modern reefs the water for many miles is milky from this lime-flour, after severe storms. Deposits of lime-sand and lime-mud are now being formed over large areas of sea bottom, especially around coral reefs growing in the open sea. The same process may be observed along the lake shores of Michigan where limestone is exposed to the attacks of the waves. After severe storms the lake waters in the vicinity of Petoskey, Charlevoix, and also of Garden Peninsula are milky white for miles from the rock flour produced through the grinding by boulders and beach shingle along the shore.

*F. W. Clarke, Data of Geochemistry, Bull. 616, U. S. G. S., 1916, p. 548.

Coral reefs with the flanking strata of lime-sand and lime-mud, now compacted and crystallized into hard limestone, are characteristic of several of the limestone formations of Michigan and adjacent states, particularly of the Niagara and the Traverse formations. In the vicinity of Alpena and Petoskey the reefs generally form isolated mounds and more or less continuous and connecting ridges of corals which in places form very complex systems. These coral reefs are more resistant to erosion than associated strata, which explains their elevation above the general level of the rock surface. In some localities they can be traced for considerable distances. Some of them are 100 feet or more wide and 50 to 80 feet high. The lime-sand strata slope away from the reefs at rather steep angles but at relatively short distances the beds become nearly horizontal, and at greater distances gradually give place to the horizontal beds of lime mud.

On the Paleozoic* reefs the grinding tools were largely the colonies of certain corals and stromatopora which were weakly attached and therefore readily broken loose by the waves. In storms these colonies, some of them two or three feet or more in diameter, were rolled about by the waves, grinding the other corals and especially the shells and

*A. W. Grabau. The Devonic Formations of Michigan, unpublished Mss.

crinoids to powder. The frequent occurrence of overturned masses of coral and stromatopora in these reefs and the worn and broken character of all of these fragments near the margins of the reefs testify to the nature of the grinding tools and their work.

Small pelagic organisms, largely foraminifera, flourish on the surface of the ocean, and their tests, sinking to the bottom are forming in clear water seas, deposits of calcareous ooze. Many of the chalk deposits are composed largely of the small or microscopic tests of foraminiferal organisms, similar to those in modern oozes. Various acquatic plants* are locally important in building up deposits of calcium carbonate. The formation of marl is largely due to various species of *Chara*, mosses and algae. These plants extract carbon dioxide from water, and the soluble calcium bicarbonate, being thus robbed of its extra molecule of carbon dioxide becomes the insoluble normal carbonate and is thrown down. The plants growing on marl beds are generally white from the precipitated calcium carbonate. Shelled animals flourish in such waters and their shells locally form a considerable percentage of the marl deposit.

Deposits of travertine are formed in a similar manner around springs by algae and other water loving plants. Some marine limestones may have been formed by plant agencies but definite proof is lacking. When carbonated water enters the sea, calcium carbonate may be precipitated directly. This requires exceptional conditions of temperature and evaporation and the deposition of calcium carbonate in this way is unusual. At present calcareous deposits are being formed in this manner in the everglades of Florida. According to G. H. Drew† bacteria are responsible for much of the marine precipitation of calcium carbonate.

Great masses of tufa are formed in some of the shallow lakes of semi-arid regions where evaporation is rapid and the water is agitated by the winds. Under such conditions the excess carbon dioxide in the water is readily driven off and calcium carbonate is precipitated. The deposition may take place around grains of sand on the lake shores and deposits of öolite sand are thus formed. Evaporation, agitation of the water, and loss of pressure which aid in the escape of carbon dioxide from spring waters are effective agencies in the formation of travertine and sinter around springs, though plants usually play a more or less important role in the process.

*F. W. Clarke, Data of Geochemistry, Bull. 616, U. S. G. S., 1916, p. 550.
†Carnegie Institute, Washington, Pub. 182, 1914.

CHAPTER II.

CLASSIFICATION AND VARIETIES OF LIMESTONES.

As noted on a previous page, on the basis of origin, limestones are classed as organic and inorganic. They may also be divided into two general classes on the bases of (1) texture and (2) composition.* The chief varieties of each class according to texture and composition are given below. Many limestones are mixtures of some of these several varieties.

Varieties based upon Texture.

1. Compact, dense, fine grained, or lithographic limestone.
2. Crystalline limestone (non-metamorphosed).
3. Crystalline limestone or marble (metamorphosed).
4. Oolite and pisolitic limestone.
5. Fossiliferous limestone.
6. Shell limestone (fragmental).
7. Chalky limestone.
8. Conglomeratic limestone (including limestone breccia).
9. Cherty limestone.
10. Fresh water marl.
11. Travertine or calc sinter.
12. Stalactitic and stalagmitic limestone and onyx marble.

Since limestones vary in chemical composition from nearly pure calcium carbonate to a mixture or compound containing theoretically 54.35 calcium carbonate and 45.65 per cent of magnesium carbonate, any classification based strictly upon chemical composition must be largely arbitrary. The combined chemical and physical qualities of limes made from different kinds of stone, however, furnish a good basis for classification. The following are important varieties based upon chemical composition. Other varieties based upon conspicuous impurities such as iron oxides and sulphides, bitumen, and carbonaceous matter may be distinguished but these are of minor importance:

*E. F. Burchard and W. E. Emley, Min. Res. U. S. for 1913, pt. 2, pp. 1515-1520.

Varieties based upon composition.

1. High calcium limestone.
2. Magnesian limestone.
   (a) Low magnesian.
   (b) High magnesian.
3. Dolomite.
4. Argillaceous limestone.
5. Arenaceous and siliceous limestone.

Most of these varieties grade into each other or may show characteristics belonging to two or more varieties.

VARIETIES BASED ON TEXTURE.

Dense fine grained limestone. Many of the limestone strata in Michigan are of very fine grain or of lithographic texture, and apparently represent the lime-mud or rock-flour produced on limestone shores or reefs by the waves. Currents carried the mud in suspension into quiet water where it was slowly deposited. Such limestones, however, may have been the result of direct chemical precipitation in shallow water. The Fiborn limestone is a conspicuous example of the fine grained variety. It has a fine lithographic texture but unfortunately it is very brittle and generally contains numerous small disseminated crystals of calcite rendering it unsuitable for lithographic purposes.

Crystalline limestone (non-metamorphosed). Simple crystallization may in many places more or less obliterate all traces of fossils. Crystallization is brought about through the agencies of pressure, heat, and water. However, some very crystalline limestones, are exceptionally fossiliferous. A very coarsely crystalline but extremely fossiliferous limestone occurs near Bolton, Alpena County, in the Traverse formation. Many of the strata in the "Niagara" formation in Michigan are highly crystalline. The other limestone formations also contain thoroughly crystalline beds.

Metamorphosed crystalline limestone (marble). Commercially the term marble is applied rather loosely to almost any granular crystalline limestone or dolomite, or other rocks susceptible of taking a high polish. Technically, marble is a rock which consists mainly of completely crystalline particles of calcite or dolomite, or of both. Recrystallization results from the metamorphic action of pressure, heat, and liquid and gaseous solutions. Though pressure or heat alone is

sufficient to bring about the complete recrystallization of limestone, generally two or all three agencies appear to have played an important role in the transformation.

Marbles are found in regions which have been subjected to mountain making forces, or igneous intrusions.

Metamorphism usually results in the destruction of fossils, bedding planes, fractures, and other secondary characters of the limestone, and in formation of new minerals from the impurities. Microscopically, marble is composed of crystalline plates of calcite or dolomite, many of which show numerous twinning planes. Granular limestone, so-called marble, on the contrary, usually consists of an aggregation of irregular crystalline plates of calcite in which twinning is absent. This is a marked difference* between marble and crystalline limestone.

Deposits of marble generally occur in lenticular masses interbedded with other metamorphosed rocks, and also as metamorphosed zones along the contact of a limestone with an igneous rock. The Paleozoic strata in Michigan are undisturbed, and contain no marble.

The original limestone beds of the pre-Cambrian rocks of Michigan have been greatly metamorphosed and are now largely marble.

Oolitic limestone. Oolitic limestone is composed wholly or partially of small rounded concretionary grains, resembling fish eggs. Oolites are formed by the deposition of successive concentric coats of calcium carbonate about nuclei, such as grains of sand, in shallow water near shore. Large concretionary grains are called pisolites. The well known Bedford limestone of Indiana is a typical öolitic limestone.

Fossiliferous limestone. Fossiliferous limestone contains noticeable quantities of shells and hard parts of organisms. In some strata certain fossils are present almost to the complete exclusion of others, hence the terms "crinoidal," "coralline," etc.

Shell limestone. Shell limestone is a variety of fossiliferous limestone in which shells, shell fragments, and shell sand form an important part of the rock.

Chalky limestone or chalk. Chalky limestone or chalk is a soft fine grained light colored or white limestone composed chiefly of minute shells of foraminifera. No chalk beds occur in Michigan.

Conglomeratic limestone and limestone breccia. Conglomeratic limestone consists of fragments rounded by wave action held together by

*T. Nelson Dale. The Commercial Marbles of Western Vermont, Bull. 521, U. S. G. S., 1912, p 11.

calcium carbonate cement. Limestone breccia consists of angular fragments similarly cemented. Conglomeratic limestone is comparatively rare but, in Michigan, limestone breccias are characteristic of the Monroe formation.

Cherty limestone. Cherty limestone contains nodules and bands of chert or flint. Chert is a general term applied to impure flint, or jasper. It is composed chiefly of silica (SiO_2). From the fact that chert nodules frequently show the presence of organic remains such as radiolarian tests and sponge spicules it is probable that these in many cases were the nuclei around which precipitation of silica took place.

Marl. Fresh water marl or bog lime is a loose earthy material largely composed of amorphous calcium carbonate. Marl, in a loose sense, also includes deposits of mixed amorphous calcium carbonate, clay, and sand. The term has also been applied to the ''green'' or glauconitic sands of New Jersey which contain no carbonate. In some fresh water lakes marl is precipitated from the lake waters by plants, mosses and algae. In some deposits shells form a considerable portion of the marl. Many of the lake beds in Michigan contain marl and in some of them marl is being formed at the present time. In the Southern Peninsula alone the total area of known marl beds having an average thickness of ten feet or over, is over 26,000 acres.

Travertine and onyx marble. Travertine or calc sinter, often called calcareous tufa, is a massive porous to compact limestone deposited by water around springs or along streams. It occurs on the faces of limestone bluffs and also in crevices in limestone. Travertine deposited in water much agitated is generally porous and spongy and is called tufa. This form usually contains traces of leaves, twigs, and other organic material upon which it was deposited. Though usually white, the color is often some shade of brown, yellow, green, or red due to various impurities such as iron oxide, manganese, mud, etc. In onyx marble, a more compact variety of travertine, the coloring matters have been deposited in alternating bands producing a beautiful effect. Onyx marble is considered to have been formed generally by precipitation from hot spring waters from deep seated sources. Travertine deposits are generally of small extent and importance.

Stalactitic and stalagmitic limestone. Stalactites are icicle-like forms of calcium carbonate suspended from the roofs of caves. They are deposited from dripping water. Stalagmites are the more or less conical masses of calcium carbonate on the floors of caves. Each

stalagmite has a corresponding stalactite above it, and are similarly formed.

Waters, especially those containing much carbon dioxide in percolating down through fractures or joints in limestone strata, take lime carbonate into solution and in this way tend to widen the openings and form cavities. When lime bearings waters enter such cavities the pressure on the water becomes less and carbon dioxide escapes. More or less evaporation takes place and the operation of both of these factors causes the precipitation of calcium carbonate. Part of it is deposited on the roof of the cavern, forming stalactites. The drip from each stalactite carries some of the precipitated calcium carbonate to the floor and this builds up the stalagmite beneath. The splashing of the drops of water probably drives off more of the carbon dioxide and further precipitation of calcium carbonate takes place on the surface of the stalagmite.

Travertine, stalactitic and stalagmitic limestone are closely related deposits since their formation depends upon the same principles.

VARIETIES BASED ON COMPOSITION.

High calcium limestone. High calcium limestone is distinguished by a low content of magnesium carbonate and relative freedom from other impurities such as silica, alumina, and oxides and sulphides of iron. According to Burchard and Emley* high calcium limestone contains from 93 to more than 99 per cent of calcium carbonate From the viewpoint of the lime manufacturer Peppel† classes limestones containing as low as 85 per cent of calcium carbonate as high calcium. Buehler‡ places the minimum content of calcium carbonate at 90 per cent, which is more nearly in harmony with the general usage and the specifications demanded in Michigan.

Magnesian limestone. From the standpoint of the lime burner, Peppel§ classes all limestone containing from 10 to 30 per cent of magnesium carbonate as magnesian limestone, and limestone containing more than 30 per cent as dolomitic limestone. According to Burchard and Emley§§ limestones carrying magnesian carbonate in any quantity up to 45.65 per cent are classed as magnesian limestones, thus including normal dolomite.

Dolomite. Dolomite is a mineral or rock composed of the double carbonate of calcium and magnesium, $CaMg(CO_3)_2$. When pure it

*E. F. Burchard and W. E. Emley, Min. Res. U. S. for 1913, Pt. II, p. 1518.
†S. V. Peppel, Technology of the Lime Industry, Bull. 4, Ohio Geol. Surv. 1906, pp. 252-253.
‡H. A. Buehler, Lime and Cement Resources of Missouri, Vol. VI, 2nd Ser., 1907, p. 17.
§Cit. loc. p. 253.
§§Loc. cit. p. 1519.

contains 54.35 per cent of calcium carbonate and 45.65 per cent of magnesium carbonate. The term "dolomite" is sometimes loosely used by geologists to include limestones containing considerable amounts of magnesium carbonate. In common practice limestones carrying 20 per cent or more of magnesium carbonate are called dolomites. Magnesian limestones are generally mixtures of calcite ($CaCO_3$) and dolomite ($CaMg(CO_3)_2$) with more or less impurities and the term dolomite should be restricted to the double carbonate which occurs both as a well crystallized mineral and as a massive rock. Owing to impurities it does not generally contain over 44 per cent, and usually somewhat less of magnesium carbonate. In this report limestones containing 40 per cent or over of magnesium carbonate are called dolomites.

The dolomitization of limestones has long been a subject of inquiry and many elaborate experiments have been carried out in order to discover the principles and conditions which might give a plausible explanation of the widespread occurrence of magnesian limestones.

Experimentally dolomite has been formed in a variety of ways but since the conditions under which most of the experiments were conducted cannot reasonably be assumed to have had widespread occurrence in nature, many of the artificial methods of formation are not to be seriously considered in seeking the true explanation. From various experiments and from geological evidence it appears that the formation of dolomite from limestone has been largely through the replacement of calcium carbonate by magnesian carbonate. T. Sterry Hunt* held that dolomite is generally a chemical precipitate. This view is not widely held today. His experiments, however, those of F. Hoppe-Seyler† and others, and the deposition of natural magnesian travertine around warm or hot springs indicate that temperature‡ is an important factor in the formation of dolomite. In general, mixtures of the various chemical substances used in the experiments yielded no dolomite at ordinary temperature but when moderate temperature was employed dolomite was formed.

The character of the original substance‡‡ is apparently another important factor. Aragonite is the less stable form of calcium carbonate and is abundant in coral reefs. Concentrated magnesium sulphate alone or with other solutions even at ordinary temperatures produces mixtures of magnesium and calcium carbonates but not dolomite. If such mixed products are formed in nature the double salt in time would probably be formed through recrystallization.

*Am. Jour. of Sci., 2nd Se., Vol. 28, 1859, pp. 170, 365; Vol. 42, 1866, p. 49.
†Zeitschr. Deutsch. geol. Gesell., Vol. 27, 1875, p. 509.
‡F. W. Clarke, Data of Geochemistry, Bull. 616, U. S. G. S., 1916, p. 561.
‡‡F. W. Clarke, loc. cit., p. 562. C. Klement, Bull. Soc. Belge. geol., Vol. 9, Min. 3, 1895. Min. pet. Mitt. Vol. 14, 1894, p. 526.

The products of organic decomposition—carbon dioxide, ammonium carbonate, and ammonium and hydrogen sulphides, probably play a more or less important part in the process of dolomitization, as shown by Pfaff.* It must be remembered, however, that the tests, shells, and hard parts† of marine organisms contain small, though in some cases relatively large quantities of magnesium carbonates. G. Forchhammer,‡ Gümbel,‡‡ A. G. Högbom‡‡‡, H. W. Nichols,‡‡‡‡ and F. W. Clarke and W. C. Wheeler in investigating the composition of recent shells, corals, and algae found that the content of magnesium carbonate in recent coral, shells, crinoids and the hard parts of sea urchins, starfish, and cuttle stars, ranges from a fraction of one per cent to over 13 per cent. Cold water crinoids, sea urchins, and cuttle stars uniformly contain only small quantities of magnesium carbonate, but in the tropical forms the content is high. Högbom found no such temperature relations in the calcareous algae analyzed by him.

The foregoing data shows that the original sediments must contain very considerable quantities of magnesium carbonate. As a general rule the calcareous deposits as we now find them contain proportionately more of it than the original organic remains. As might be expected the fossil forms show no regularity in composition as do living forms. Leaching§ and the deposition of foreign substances by infiltrating waters have altered the original ratio of lime to magnesia in the organic forms and have brought about a general relative enrichment of the rock in magnesia. Leaching alone either by sea water or surface water is sufficient to bring about the complete dolomitization of a calcareous deposit through the removal of more soluble calcium carbonate, particularly when in the form of aragonite, which is abundant in coral.

Undoubtedly some dolomites have been formed chiefly through leaching but experimental and geologic evidence indicates that replacement of the calcium carbonate by magnesium carbonate is a much more general process than leaching. Geologic evidence in favor of the replacement process is so strong that it has been commonly accepted as the dominant process in dolomitization. A deep boring in the coral deposits of the island of Funafuti indicates dolomitization near the surface, probably through enrichment by leaching, and shows strikingly gradual dolomitization downward from a depth of about 700 feet. The process was nearly complete at 1114 feet. Judd§§ doubtfully ascribes the surface dolomitization to the leaching out of

*F. W. Pfaff, Neus. Yahrb. Beil. Band 9, 1894, p. 485; also Vol. 23, 1907, p. 529.
†F. W. Clarke, Data of Geochemistry, Bull. 616, U. S. G. S., 1916, p. 565.
‡Neus. Yahrb. 1852, p. 854.
‡‡Abhandl. K. Akad. Wiss. Munchen, Vol. II, 1871, p. 26.
‡‡‡Neus. Yahrb. 1894, Band 1, p. 262.
‡‡‡‡Field Columbian Museum, Pub. III, p. 31, 1906.
§F. W. Clarke, Data of Geochemistry, Bull. 616, U. S. G. S., 1916, pp. 566-569.
§§The atoll of Funafuti, published by the Royal Soc., London, 1904. For Judd's report on the chemical examination see pp. 362-389.

the calcium carbonate. In a deep boring at Key West, Florida, there is a gradual enrichment down to about 775 feet but the dolomitization is slight as compared with that at Funafuti. Below this depth, however, the rock is only slightly and irregularly dolomitized. Dolomitization can be accomplished by replacement of calcium by magnesium in spring waters, but this process is unimportant as compared with the action of sea water on coral reefs.

Argillaceous limestone. Limestone containing a considerable amount of clay is termed argillaceous limestone. Clay is chiefly the silicate of alumina. If present in the proper proportions it forms hydraulic limestone. Mortar produced by burning hydraulic limestone will set under water. ''Natural cements'' are made from such limestone, hence the term ''cement rock.''

Arenaceous and siliceous limestone. Arenaceous limestone contains a noticeable amount of sand, usually silica sand of fine grain. Some limestones contain silica in the form of quartz, deposited by infiltrating water in cavities and seams such as geodes, vugs, and veins. The silica may also be deposited as a cement but more often it is concentrated in fossils. In general, arenaceous and siliceous limestones containing 4 per cent or more of silica are of little commercial importance, though sandy limestone of good texture, makes a satisfactory building stone, or if sufficiently hard it may be crushed for road material and concrete.

GRADATIONS* IN LIMESTONES.

From the foregoing descriptions of classes, varieties, and origin of limestone it is obvious that the criteria for distinguishing different varieties are definite, although there are physical and chemical gradations between them. In any formation, uniformity of composition and texture is not generally to be expected.

From these facts the development of a limestone quarry should not be undertaken until the character of the beds have been carefully ascertained both vertically and horizontally. Generally this can be done best by the core drill.

*E. F. Burchard and W. E. Emley. Min. Res. U. S. 1913, Pt. II, p. 1520.

CHAPTER III.

USES OF LIMESTONE.

A generation ago the uses of limestone were few and simple. The chief uses were for lime, flux, building stone, and road making. The progress of industrial chemistry in the last thirty years has developed a large number of new uses. The more important uses* of limestone in its raw and burned condition are as follows:

- Acetate of lime.
- Acetic acid.
- Agricultural limestone.
- Ammonia.
- Ammonium sulphate.
- Basic steel.
- Blast furnace flux.
- Bleaching powder.
- Bone ash.
- Building stone.
- Calcium carbide, calcium cyanimide and calcium nitrate.
- Carbon dioxide.
- Chloride of lime.
- Concrete aggregates.
- Disinfectant and deodorizer.
- Dyeing.
- Fertilizers.
- Finishing lime.
- Gas manufacture.
- Glass making.
- Insecticides.
- Lime burning.
- Lithographing.
- Milk of lime.
- Mortar.
- Oil, fat, glycerine and soap manufacture.
- Paints and varnishes.
- Paper making.
- Portland cement.
- Potassium and sodium dichromates.
- Pottery glazes.
- Refractory bricks.
- Road material and railway ballast.
- Sand-lime brick.
- Soda-ash products, soda, potash and ammonia.
- Sugar manufacture.
- Tanning.
- Wood distillation—wood alcohol, acetate of lime.
- Water softening and purifying.

BUILDING STONE.

Stone satisfactory for building purposes must be homogeneous in texture, relatively hard, free from parting planes, of pleasing color and texture, and resistant to weathering.

*E. F. Burchard and W. E. Emley. Min. Res. U. S. 1913, U. S. G. S., Pt. II, pp. 1592-1593.

ROAD MATERIAL, CONCRETE, AND RAILROAD BALLAST.

Limestone is widely used in the crushed state for road making, for railroad ballast, and as the aggregate material in concrete mixtures. Limestone for such purposes should be hard and resistant to weathering. A high cementing power is desirable in limestone for road material.

LIME.

No other substance can take the place of lime in the building and chemical industries. It is the cheapest and most easily obtainable of the strongly basic oxides, therefore it is the most widely used in manufacturing chemistry.

Definition of Lime.

In a strict chemical sense lime* is the oxide of calcium. It is made by heating limestone ($CaCO_3$) to a temperature sufficient to drive off the carbon dioxide (CO_2). Inasmuch as limestones are composed of varying proportions of calcium and magnesium carbonates with minor amounts of impurities, commercial lime is a mixture of calcium and magnesium oxides.

For practical purposes lime may be defined† as the material obtained from the calcination of a stone in which calcium carbonate is the chief constituent.

Classification of Limes.

Limestone burns to approximately 44 per cent of its original weight, but the impurities, such as sand, clay, and iron lose very little weight in burning, therefore the percentage of these impurities in the lime is nearly double that in the original limestone.

The chemical and physical qualities of limes vary with the amount of magnesia and impurities. Calcium oxide combines energetically with water to form calcium hydroxide or slaked lime. Magnesium oxide in lime burned at the temperatures usually employed in kilns combines very slowly with water. Magnesium oxide burned at temperatures‡ below 1100°C, lower than usually employed in ordinary kilns, combines with water more rapidly than it does when burned at temperatures above 1100°C. In general the higher the content of magnesia in limes, the slower and cooler is the slaking process. The high calcium limes are known to the trade as "hot," "quick," "fat"

*W. E. Emley. Technologic Paper No. 16, Manufacture of Lime, U. S. Bur. Stand., 1913, p. 14; also Min. Res. U. S. 1913, Pt. II, p. 1556.
†S. V. Peppel. Technology of the Lime Industry. Ohio Geol. Surv., Bulls. 4 and 5, 4th Ser., 1906, p. 249.
‡W. E. Emley. Technologic Paper No. 16, U. S. Bur. Stand., 1913, p. 15.

or "rich" limes and the magnesian as "cool," "mild," or "slow" limes.

If the impurities,—clay, sand, and iron exceed about 5 per cent, they interfere with slaking and generally give a gray or yellow color to the lime.

Many widely different classifications of limes have been made on the basis of differences in composition and in the chemical and physical properties. Some are very simple, others very elaborate. Most of them do not meet the requirements of the trade and only two or three are used in specifications or in technical works. To meet the needs of lime manufacturers, the National Lime Manufacturers' Association adopted the following classification based upon composition:

1. High-calcium lime, 0 to 5 per cent magnesia.
2. Magnesian lime, 5 to 25 per cent magnesia.
3. Dolomitic lime, 25 to 45 per cent magnesia.
4. Super-dolomitic lime, over 45 per cent magnesia.

This classification does not harmonize well with the classification given by Burchard* which conforms closely to the more generally accepted uses of the terms,† viz., high calcium lime, made from limestone containing 93 per cent or more of calcium carbonate; magnesium lime from limestone containing 7 per cent or more of magnesium carbonate; and dolomitic lime, a special grade of magnesian lime, in which the ratio of calcium oxide to magnesium oxide is very nearly 8 to 5. If magnesian limestones are distinguished as "low" and "high" magnesian and the term dolomite is reserved for limestone containing calcium and magnesium carbonates nearly in the ratio of 1 to 1, the limes and the limestones approximately corresponding are as follows:

High calcium lime (0 to 5% MgO) = High calcium limestone (93% or over of $CaCO_3$).

Low magnesian lime (5 to 30% MgO) = Low magnesian limestone (7 to 30% $MgCO_3$).

High magnesian or dolomitic lime (30% or over MgO) = High magnesian limestone (30 to 40% $MgCO_3$) and dolomite (over 40% $MgCO_3$).

Since all classifications are based upon more or less arbitrary distinctions, uniformity of opinion or practice is not to be expected.

Hydraulic limes. The above classifications do not take into account limes containing relatively large amounts of impurities. Limes burned

*E. F. Burchard. Min. Res. U. S. 1913, U. S. G. S., Pt. II, p. 1519.
†W. E. Emley. Min. Res. U. S. 1913, U. S. G. S., Pt. II, p. 1556.

from limestone containing 5 to 10 per cent of sandy and clayey matter,* slake readily without further treatment and harden under water. Limes containing under about 5% of impurities are generally white, but those containing more than about 5 per cent of impurities are usually gray. On the basis of this physical difference Peppel classifies limes as "white" and "gray." This is not a satisfactory classification because any limestone with 3 to 5 per cent of iron will produce a gray or yellow lime.† Limes made from limestone containing from 10 to 30 per cent of sandy and clayey matter and which will not slack until finely ground are called natural or Roman cements. Such limes solidify under water much more quickly than hydraulic limes and are much harder.

USES OF LIME.‡

The main uses of lime are classified as follows:

1. Building lime, for use in plastering and stone work.
2. Finishing lime, for the white coat of plaster.
3. Agricultural lime, for use as a soil amendment or rectifier.
4. Chemical lime, used in various chemical industries.

Building Lime.

Mortar. Lime mortar is composed of mixtures of sand and lime varying usually from three to one, to five to one. Pure lime mortar will not harden under water and should be used only where exposed to the air. Used alone, slaked lime shrinks and cracks on drying, but when mixed with a large volume of sand to form mortar it will not crack and is the most valuable material for wall plaster and brick work. Cement mortars are much stronger than lime mortars but they are rather unsatisfactory substitutes for lime mortar, because they lack plasticity and do not work easily.

The kind of lime best suited for making mortar depends upon the cost of labor, the experience of the workmen available, the volume of mortar which a given lime produces, the ease with which the mortar can be worked, and the strength of the mortar when set. High calcium or "hot" lime sets quickly, magnesian or "cool" lime slowly. The first is unsuitable where much time is required for finishing and the latter in cases where the longer time of setting interferes with building operations. In general high calcium lime is preferred for all rough or heavy work and high magnesian lime for finishing, though many contractors prefer magnesian lime for the first coat in plastering, because it sets slowly and permits the covering and finishing of large surfaces in one operation. Magnesian lime is generally whiter than high calcium lime, a reason for its preference for final as well as rough coats. Dry hydrate of magnesian lime is much used by the manufacturers of hard wall plasters. Mortar made from hot lime is at first more plastic and easier to work than that from magnesian lime, and is usually preferred for stone and rough brick work. In laying front brick, where much care must be exercised, magnesian lime is generally preferred.

*S. V. Peppel. Technology of the Lime Industry, Bulls. 4 and 5, Ohio Geol. Surv. 1906, p. 253.

†H. A. Buehler. Lime and Cement Resources of Missouri, Vol. VI, 2nd ser., Mo. Bur. Geol. and Mines, p. 17.

‡W. E. Emley. Min. Res. U. S. 1913, U. S. G. S., Pt. II, p. 1581.
S. V. Peppel. Limestones and Lime Industry of Ohio, Bulls. 4 and 5, Ohio Geol. Surv., pp. 254-260.
H. A. Buehler. Lime and Cement Resources of Missouri, Mo. Bur. Geol. and Mines, Vol. VI, 2nd ser., p. 20.

High calcium lime when properly slaked yields a greater amount of putty or paste than magnesian lime, and the paste will carry a greater amount or "load" of sand, therefore the yield of mortar from hot lime is materially greater than from cool lime. The proper slaking of hot limes, however, requires more care and intelligence, and results are often unsatisfactory. The higher the percentage of calcium oxide, the hotter the lime and the greater is the danger of burning in slaking, especially with unskilled labor. Burning decreases the yield of paste, makes it lumpy and decreases its sand holding capacity. Correspondingly the yield of mortar is less and of poorer quality. These two factors are important cost items and form two reasons why hydrated lime is rapidly coming into general use.

It has been found that addition of hot lime to magnesian lime improves the working qualities of the latter and the addition of magnesian lime to hot lime gives a mortar much slower in setting. From this it follows that mixtures of magnesian and high calcium limes would be the most satisfactory for general purposes. For small amounts of mortar this is not practicable but it is commonly done with large amounts of mortar, particularly when mixing machines are used. In such cases the mixtures can be easily varied to produce a mortar suited to the purpose for which it is to be used.

Finishing Lime.

The putty produced when lime is slaked is used directly as a finishing coat on plaster. The putty must work easily under the trowel, must not pop or pit in the wall, and must be nearly white. According to Emley* putty from magnesian limes works better under the trowel and most of them are whiter than high calcium limes. The magnesian limes, therefore, are to be preferred to the high calcium even though the latter give a greater amount of putty. When hot lime is "burned" through

*W. E. Emley. Tests of Commercial Limes, Nat. Lime Mnf. Assoc. Trans., 1913.

improper slaking the lumps contain fine particles of unslaked lime. If used in a finishing coat these particles slowly take up water, expand and fall out, leaving pin holes in the wall. This is called popping* or pitting. On account of the lack of skilled labor for slaking lime it is safer to use commercially prepared hydrated lime.

Agricultural Lime.

Liming of soils. The application of calcium in the form of calcium carbonate, calcium oxide, or calcium hydroxide to soils is termed "liming."

Apparently the Romans two thousand years ago practiced liming† of soils. Long before the value of lime in agriculture was generally known in America the liming of soils was practiced in European countries. Marl has been and still is extensively used in certain parts of Germany in maintaining the productivity of soils. Schultz of Lupitz demonstrated the value of marl as a fertilizer of the sand soils of northern Germany. Ruffin as early as 1818 called attention to the use of lime as a fertilizer and in 1832 published his well known work on "Calcareous manures."

The subject has been and still is being widely investigated by the U. S. Department of Agriculture, the various agricultural colleges and experiment stations. The experimental work has included all forms of lime and almost every variety of soil, soil conditions, and plants. The investigations show that the productivity of most soils is increased by the judicious use of some form of lime. Large areas of lean soils can be made productive with proper application of lime and other fertilizers.

CHEMICAL USES OF LIMESTONE AND LIME.

Soda Ash and Caustic Soda.

Limestone is used for the production of calcium oxide and carbon dioxide in the manufacture of soda ash and related products. The process may be described as follows: Brine is first saturated with ammonia and then carbon dioxide is passed into the resulting solution. Two substances are formed: sodium hydrogen carbonate ($NaHCO_3$) or bicarbonate of soda, and ammonium chloride (NH_4Cl). The bicarbonate of soda is but sparingly soluble and is thrown down. This is common baking soda. When heated in a retort this compound breaks up into sodium carbonate or sal soda, carbon dioxide, and water. Sal soda is used extensively for softening water and in the manufacture

*S. E. Young. On the popping of lime. Amer. Ceramic Soc. Trans., 1913.
†H. J. Wheeler. The Liming of Soils. Farmers' Bull. No. 77, U. S. Dept. Agriculture, 1915.

of glass, and many chemicals. Since ammonia is expensive the mother liquor containing ammonium chloride is treated with lime which replaces ammonia in its compounds and sets free the gas. The ammonia is then distilled off and recovered for further use. Calcium chloride is the end product. When heated under certain temperature conditions it becomes a valuable drying agent because of its great attraction for water.

Magnesium oxide apparently should be as effective in breaking up the compounds of ammonia as calcium oxide but according to Lunge,* magnesian limestone is not suitable for use in soda ash manufacture.

When sodium carbonate is dissolved in water and treated with calcium hydrate, sodium hydroxide or caustic soda and calcium carbonate is formed. The latter being insoluble settles, leaving a clear solution of caustic soda, which is largely used for the manufacture of soap. Magnesia takes no part in the reaction. The impurities form a gelatinous precipitate which does not settle clear, and are therefore undesirable. Quick lime is preferable to hydrated lime since the heat generated in slaking hastens the reaction.

Bleaching Powder.

When moist slaked lime is treated with chlorine, an oxychloride of lime, the bleaching powder of commerce is formed. The bleaching agent is chlorine and since magnesia and impurities in the powder lower the amount of chlorine per unit of weight they are objectionable. Magnesia is especially objectionable because it forms magnesium chloride which absorbs moisture from the air and makes the powder sticky and hard to handle. In this process hydrated lime is preferable to quick lime on account of its greater freedom from impurities and the ease of manipulation.

Soda ash, caustic soda, bleaching powder, and calcium chloride are produced on a large scale in the vicinity of Detroit. The value of these products is more than five-sixths of the total value of the chemical products of the state.

Calcium Carbide.

Calcium carbide (CaC_2), the source of acetylene, is made by fusing a finely ground mixture of lime and coke in an electric furnace. Calcium oxide is the only substance in lime used, therefore all other impurities are objectionable on account of the heat wasted in their fusion. Limestone or hydrated lime could be used but since these must be

*Geo. Lunge, Manufacture of Sulphuric Acid and Alkali. 2nd ed., Vol. III, p. 37, 1891-1896.

reduced to the oxide before fusion and electric power is expensive, lime is preferable.

Calcium Cyanamide and Calcium Nitrate.

The discoveries of the commercial processes for the manufacture of calcium cyanamide and calcium nitrate were made only a few years ago. These substances owe their importance to the fact that they represent two methods of obtaining a commercial supply of nitrogen for plant food from the air. This is of the utmost importance in view of the facts that the commercial supply of combined nitrate will soon be exhausted and that the demand for nitrogen in farm practice and for explosives will then be greater than the means of supply, without resource to these or other new sources.

Calcium cyanamide was first prepared in Europe as a commercial fertilizer. One kind manufactured in Italy was called lime-nitrogen and another kind made in Saxony, Germany, was called nitrogen lime. Calcium cyanamide contains from about 15 to 23 per cent of nitrogen. It is made by heating finely powdered calcium carbide, or lime and coke in an electric furnace at a temperature of about 1100°C and treating the mixture in closed retorts with nitrogen. The product is calcium cyanamide and free carbon, the latter being disseminated throughout the cyanamide and giving it a black color. The nitrogen for the process may be obtained by passing air over heated copper or by the fractional distillation of liquid air.

As in the manufacture of calcium carbide only the calcium oxide is used, hence lime containing the highest percentage of calcium oxide is the most economical. The manufacture and reduction of limestone or hydrated lime to the oxide simply entail unnecessary expense.

Nitric oxide is made by passing air through an electric arc. The nitric oxide (NO) is passed through milk of lime to produce calcium nitrate. This substance, yellowish white in color, is easily soluble in water but deliquesces rapidly in air. This trouble can be avoided if an excess of lime is used in the manufacture or by melting the product, then grinding it fine and packing in sealed containers. The commercial product contains from about 9 to 13 per cent of nitrogen in form a available for plants.

The heat required varies between 2500° and 3000°C. This is much higher than that necessary for calcium cyanamide and the cost is governed directly by the cost of the electricity. With the great possibilities for the production of electricity in this country from water power the manufacture of calcium nitrate may become an industry of the greatest importance.

In this process the actions of the oxides of calcium and magnesium are similar, hence either high calcium or magnesian lime can be used, but, because the continued use of a fertilizer high in magnesia may result in an excess of magnesia in the soil, high calcium or low magnesian lime on the whole is preferable. The impurities are of little importance. Since milk of lime is required, quick lime or hydrated lime is the most economical form for use.

Sugar.

Sugar, like soda-ash products, requires in its manufacture, both calcium oxide and carbon dioxide.

The juice from sugar beets and sugar cane contains various impurities. Some of these discolor the sugar and some change it to glucose. When the juice is heated almost to the boiling point and treated* with an excess of milk of lime, the lime neutralizes the organic acids, breaks up organic compounds, and coagulates the albumen and mucus. In addition it forms an insoluble compound with the sugar, hence carbon dioxide is forced into the liquid to break up this combination. All of the lime is precipitated as calcium carbonate which settles, carrying with it all of the matter in suspension and leaving a clear solution of sugar.

Only calcium oxide is useful in sugar making and the impurities, especially magnesia, are liable to cause mechanical difficulties. Magnesium carbonate, being more soluble in sugar solutions than calcium carbonate, remains in the solution to be deposited later on the tubes in the evaporating pans. Silica forms a gelatinous precipitate which clogs the cloth in the filter presses. Sugar manufacturers usually specify that the content of magnesium carbonate in limestone shall not exceed 2 per cent and the silica 1 per cent.

Michigan is a large producer of beet sugar and demands considerable stone suitable for sugar manufacture. Some quarry companies find it worth while to produce sugar stone by sorting exceptionally high calcium rock from the quarry run. However, the purest calcium stone cannot be economically used for sugar manufacture if it has unsatisfactory burning qualities.

Distillation of Wood.

The primary products† produced from the destructive distillation of wood are wood gas, pyroligneous acid, tars and oils, and charcoal,

*Manufacture of sugar. Internat. Lib. of Technology, sec. 50, p. 36, Internat. Textbook Co., Scranton, Pa., 1902.

†J. R. Withrow. The Chemical Engineering of the Hardwood Distillation Industry. Chem. Engr., Jan. 1916. S. F. Acru, Chem. Engr., Jan. 1916.

W. E. Emley, Manufacture and Use of Lime, Min. Res. U. S., 1913, Pt. II, p. 1590.

of which charcoal is of least commercial importance. Pyroligneous acid is of chief importance to the lime manufacturer because wood or methyl alcohol, acetic, acid and acetone are derived from it. The manufacture of these products requires the use of lime.

Paper.

Wood pulp used for the manufacture of paper is prepared by three different processes,—mechanical, soda, and sulphate. Lime or limestone is used only in the last two. In the soda process,* or alkali process, lime is used to causticise sodium carbonate, thus recovering the caustic soda used in cooking the wood. Calcium oxide is the only useful substance in lime in the soda pulp industry, hence the purest high calcium lime is most desirable. The magnesia and impurities are merely inert substances. Lump lime is preferred to hydrated lime on account of the heat generated in slacking which hastens the chemical reaction with the soda.

In the sulphite or acid process, ''bisulphite liquor'' is used for dissolving the cementing substances of wood. The liquor may be prepared by subjecting limestone to the solvent action of sulphur dioxide and water or milk of lime may be treated by sulphur dioxide. Since magnesium sulphite is much more soluble than calcium sulphite, a much stronger liquor, fundamental to the economic success of the process, can be prepared. In addition a high magnesian liquor gives a better color to the pulp, makes it softer, and this results in better felting qualities when it is made into paper. Impurities are not injurious.

Sand-Lime Brick.

Sand-lime brick are manufactured from a mixture of fine grained sand and hydrated high calcium lime. The brick are pressed into form and then subjected to high pressure steam. The lime combines with a part of the sand, forming a calcium silicate which acts as a cement to bind the sand grains together. Complete hydration of the lime is necessary or the subsequent hydration and expansion will cause the brick to swell or crack. For most purposes the complete hydration of lime is not necessary, hence most of the commercial hydrated lime contains small amounts of unslaked lime. For this reason sand-lime brick manufacturers buy quick-lime and do their own hydrating or have it hydrated according to certain specifications.

Magnesian lime is not well adapted for use in this industry because of the difficulty of completely hydrating† the magnesia and also because the magnesia reduces the strength of the resulting product. The impurities, especially silica or clay owing to their fluxing qualities, are beneficial if they are not present in excessive amounts.

*W. E. Emley, Min. Res. U. S., 1913, Pt. II, p. 1590.
†S. V. Peppel, Sand-Lime Brick, Bull. 5, p. 38, Ohio Geol. Surv., 1906.

Glass Making.

The essential raw materials* of the common varieties of glass are lime, sand (silica), soda ash (sodium carbonate), and salt cake (sodium sulphate). Red lead (lead oxide) may be used instead of lime and potassium carbonate may replace soda ash. Small amounts of other substances such as carbon, arsenic, etc., are also used to secure certain physical and optical properties. Sand composes from 52 to 65 per cent of the mixture of raw materials. In mixtures for plate glass, limestone equals by weight about one-fourth of the sand, for window glass about two-fifths, and for green bottle glass about one-third. Calcium oxide† is a necessary constituent of these varieties of glass and also of much of the pressed and blown glass. It acts as a flux. Magnesia, on the contrary, makes the mixture of raw materials more difficult to melt, thus more heat is consumed than would otherwise be necessary. It is used, however, when certain optical properties are desired.

For bottle and window glass‡ ground limestone is used but for plate and flint glass ground lime is much more preferable. When ground limestone is used the bubbling or foaming of the viscous half fused mixture, due to the evolution of the carbon dioxide, necessitates the use of much larger glass pots, which are very expensive. The manufacturer of window and bottle glass uses large tank furnaces in which the evolution of gases gives rise to no physical difficulties.

For the manufacture of common bottle and window glass the impurities commonly present in limestone are of little importance, but for white glass the iron oxide in the stone should be less than 0.3 per cent. When present in amounts much above one-half per cent it detracts markedly from the brilliancy, clearness, and transparency of the finished product.

Water Softening.

In many parts of the state, particularly in limestone regions, well waters are very hard, being unfit for boiler or laundry purposes. In many cases most of the hardness is only ''temporary.'' This ''temporary hardness'' is due to calcium carbonate which, though only

*E. B. Mathews and J. S. Grasty. The limestones of Maryland, p. 234, Md. Geol. Surv., 1910.
W. G. Miller, The limestones of Ontario, XIIIth Rept. Bur. Mines, 1904, Pt. II, p. 5.
E. F. Burchard, The requirements of sand and limestone for glass making, Bull. 285n, p. 452, U. S. G. S., 1906.
†W. E. Emley. Manufacture and use of lime. Min. Res. U. S., 1913, Pt. II, p. 1586, U. S. G. S.
‡S. V. Peppel, Bull. 4, Limestones and lime industry of Ohio, p. 242, Ohio Geol. Surv., 1906.

slightly soluble in pure water, is held in solution by carbon dioxide in the form of calcium bicarbonate. When the carbon dioxide is removed, this becomes insoluble calcium carbonate, which is precipitated. Carbon dioxide may be driven out by boiling but neutralization with lime is more practicable and cheaper. Lime combines with the carbon dioxide to form calcium carbonate which, together with the original calcium carbonate in the water, is precipitated. Since magnesium oxide and impurities are inert substances, the purest high calcium lime is preferred. The lime is usually carefully slaked* to a cream and fed into the main body of the water in an automatically regulated stream. From the fact that well burned high calcium lime produces not only the greatest quantity but also the best quality of cream, it is the most satisfactory and economical.

Gas Purification.

Gas manufactured by the distillation of coal contains a number of objectionable substances such as carbon dioxide and hydrogen sulphide. These may be removed by passing the gas through layers of moist slaked lime. Calcium oxide is the only useful constituent† in lime but magnesium oxide and the impurities are not injurious.‡ For this reason the purest high calcium lime is the most economical. Hydrated lime is the most convenient form because it is already prepared and easier to handle.

By-Products of Coal Distillation.

The chief supply of ammonia is obtained from crude coal gas. The ammonia is removed by washing the crude gas before it reaches the lime purifiers. The resulting solution contains free and combined ammonia. The free gas is distilled off and collected. The addition of lime breaks up the ammonia compounds thus liberating free ammonia, which similarly can be recovered by distillation. According to Peppel§ both high calcium or magnesian lime may be used but Lunge asserts that magnesian lime is not suitable for this purpose. Hydrated and quick lime appear to give equally satisfactory results.

Paints.

Ground lime, air slaked lime, levigated chalk (natural whiting) and chemically precipitated calcium carbonate are extensively used in

*W. E. Emley, Manufacture and use of lime. Min. Res. U. S. 1913, Pt. II, p. 1587.
S. V. Peppel, Uses of limestone in Ohio. Bull. 4, p. 244, Ohio Geol. Surv. 1906.
†W. E. Emley, Manufacture and use of lime. Min. Res. U. S. 1913, Pt. II, p. 1588.
‡Chas. Hunt, Gas Lighting, p. 136, 1900.
§S. V. Peppel. Manufacture and Use of Lime. Bull. 4, p. 244, Ohio Geol. Surv., 1906.

paint and pigment industries. One of the most essential qualities is fineness of grain, though color or chemical composition may be equally important. Because limestone is rarely white and is difficult to grind sufficiently fine to meet the requirements of the paint manufacturer, air slaked lime and hydrated lime are the more preferable materials.

Cold water paints* consist essentially of mixed hydrated lime and casein. Obviously, quick lime cannot be used with such substances. Magnesian hydrate is probably preferable to high calcium hydrate on account of its superior spreading qualities.

Glycerine, Lubricants, and Soaps.

Soap and glycerine manufacturers use considerable quantities of lime. Most common fats are compounds of glycerine with various organic acids. When fats are heated with lime and water under pressure lime replaces the glycerine in the compounds, thus liberating the glycerine. Most of the glycerine produced in the United States is made from fats and oils extracted from garbage. When the ''lime soaps'' formed in this process are mixed with heavy petroleum oils they make valuable lubricants or greases, especially for heavy machinery and for use at high temperatures. Much of the ''lime soap,'' however, is treated with sulphuric acid to liberate the fatty acids for use in the manufacture of soap and related products. For the manufacture of these products lime is again needed to convert sodium or potassium carbonate into the caustic or hydroxide form. For these purposes calcium oxide is the only useful constituent in the lime, therefore pure high calcium lime gives the most satisfactory results. Magnesia and the impurities, however, are not injurious. Either slaked lime or quicklime can be used, though quicklime may be preferable because the additional heat of slaking tends to hasten the reactions.

Tanning.

In the process of tanning leather† lime softens and loosens the hair and adhering particles of fat and flesh so that they can be readily removed by scraping. It also causes an expansion of the pores, called ''plumping,'' which permits of a larger absorption of oil and tallow. This gives greater weight and solidity to the leather. High calcium limes are desired for most tanning operations, though for some varieties of leather such as morocco the presence of magnesia is desirable. Magnesia and clay are injurious‡ because they not only diminish the amount

*W. E. Emley, Manufacture and Use of Lime, Min. Res. U. S. 1913, Pt. II, p. 1591.
†S. V. Peppel. The Uses of Limestone in Ohio. Bull. 4, p. 245, Ohio Geol. Surv. 1906.
‡H. R. Proctor. Principles of Leather Manufacture, p. 121, Spon & Chamberlain, New York, 1903.

of calcium oxide but make the lime more difficult to slake. Iron oxides, becoming mechanically fixed in the grain of the leather, may cause stains. The trouble incident to the slaking of magnesian lime may be avoided through the use of hydrated lime. Since hydrated lime needs no preparation and is easier to handle it is the more preferable form.

Insecticides.

Lime is an important ingredient in many insecticides. Calcium oxide is the only useful constituent, though magnesia and the impurities are not injurious. The material is usually applied in liquid form by some form of atomizer. Either slaked or hydrated lime can be used with water or other liquid. It is very difficult to slake lump lime to a cream free from coarse particles. These are apt to clog the spraying apparatus, therefore hydrated lime screened to the desired fineness should be much more satisfactory.

Furnace Linings.

Pure lime is a most refractory substance.* It fuses only at the high temperatures of the electric furnace.

Theoretically high calcium lime should be a satisfactory material† for lining open hearth furnaces, but the rapidity with which it slakes upon exposure to air makes this substance valueless for this purpose. Upon reheating, the driving off of the moisture reduces the lime to powder, therefore it has little durability. Calcined dolomite ($CaCO_3$, $MgCO_3$) slakes very slowly upon exposure to air and is much less liable to crack with changes of temperature but calcined magnesite ($MgCO_3$) is far superior to the purest dolomite in these respects and is now always used for the original bottoms in openhearth furnaces. Its high first cost, however, has until recently prevented its general use. As a consequence dolomite, on account of its cheapness, has been commonly used for the working linings and the repairing of basic furnaces and in some cases for the whole lining. It is impossible to set a dolomite bottom as dense and vitreous as magnesite, hence portions of the bottom from time to time will break loose and float even with the most watchful care.

The permanent lining of the furnace is usually built of basic brick, generally magnesite brick, chromite, etc. A working lining of crushed basic material, dolomite or a mixture of dolomite and magnesite with a binding material such as tar or molasses to hold it in place, is then

*E. B. Mathews and J. S. Grasty. The Limestones of Maryland, Vol. VIII, Pt. III, p. 234 Md. Geol. Surv. 1910.
†Harbison-Walker Refractories Co. A Study of the Open Hearth, p. 22, Pittsburg, 1912.

tamped upon the permanent lining to the depth of two or three feet. Formerly it was thought necessary to use lime but at present crushed limestone is found to give just as satisfactory results since the stone is calcined to lime during the operation of the furnace.

The stone must be low in silica and alumina because these materials fuse readily with lime, thus tending to destroy the lining. A stone suitable for openhearth lining should contain less than 1 per cent of silica and 1.5 per cent of alumina and iron, and not less than 35 per cent of magnesium carbonate, though in practice stone considerably short of these specifications is often used.

Blast Furnace Flux.

Iron ores generally carry considerable impurities or gangue material such as silica, alumina, etc. The gangue material is generally acid* in nature and not readily fusible. To remove this relatively infusible material its composition must be so changed that fusibility will be increased. This may be brought about by supplying a suitable base to unite with the acid material. Limestone furnishes the cheapest and most active of the bases, namely calcium oxide, hence its universal use as a flux in the smelting of iron ores or other metallic ores containing acid gangue material.

The quantity of limestone necessary for smelting iron ore depends upon the amount of acid material present to be neutralized,—in general, the greater the acid impurities the greater the amount of base required. In some iron ores the gangue includes a considerable percentage of basic material which will neutralize an equivalent amount of the acid material. In such cases only enough limestone is added to flux the excess acid material in the ore and in the ash of the fuel. In 1914 approximately 15,300,000 tons of limestone were used in smelting approximately 40,600,000 tons of iron ore or about three-eighths tons of limestone to one ton of ore.

It follows that the value of a limestone for fluxing purposes depends upon the amount of available bases present. This consists of that portion of the stone remaining after the carbon dioxide, the silica, alumina, and other acid impurities, and the portion of the base required to flux the acid impurities have been deducted.

High calcium limestone is generally preferred for blast furnace work yet practical tests indicate that dolomite or magnesian limestone can be used for flux in part or whole with satisfactory results.† Small quantities of magnesia do not appreciably affect the behavior of the

*R. Forsythe. The Blast Furnace and the Manufacture of Pig Iron, p. 86, D. Williams & Co., New York, 1913.
†R. Forsyth. The Blast Furnace and the Manufacture of Pig Iron, p. 88, D. Williams Co., New York, 1913.

flux but when present with calcium in considerable amount it makes the slag more fusible. According to Mathews and Grasty* magnesia has less affinity for sulphur and phosphorus than calcium oxide, hence its presence is undesirable.

In openhearth work,† however, high calcium, low silica-alumina limestone is demanded. The specifications usually required are that the silica must be under 1 per cent, the alumina under 1.50, and the magnesia under 5 per cent.

Hydraulic Limes and Cements.

Hydraulic limes. Lime burned from limestone, either high calcium or magnesian, containing 5 to 10 per cent‡ of sand and clayey material are termed hydraulic lime. Hydraulic limes will slake as they come from the kilns without further treatment. If the sandy and clayey material in the limestone exceeds about 10 per cent, the resulting lime fails to slake without first being finely ground and is a hydraulic cement.

No hydraulic limes are produced in Michigan, though many strata in the Traverse formation and the Trenton limestone apparently have the desired composition.

Hydraulic Cements. There are three principal classes§ of hydraulic cements, viz., (1) Portland cement, (2) natural, or Roman, and (3) Puzzolan.

Natural Cements. Natural cement is made by grinding finely the calcined product from burning at a temperature below 1000-1100°C to incipient vitrification an argillaceous limestone containing over 10 per cent of siliceous and argillaceous matter. The limestones from which the commercial natural cements in the United States are made contain from 13 to 35 per cent§§ of clayey material of which 10 to 22 per cent is silica. Natural cement is usually yellow or brown. It sets more rapidly than Portland cement and has lower specific gravity and tensile strength.

Portland Cement. Portland cement is made by finely pulverizing the clinker produced by burning to incipient fusion an intimate mixture§§§ of finely pulverized and properly proportioned argillaceous and calcareous materials with the addition of such other substances, not to

*Mathews and Grasty, loc. cit.
†E. B. Mathews and J. S. Grasty. The Limestones of Maryland, Vol. VIII, Pt. III, p. 249, Md. Geol. Surv., 1910.
‡S. V. Peppel. The Uses of Limestone in Ohio, Bull. 4, p. 252, Ohio Geol. Surv. 1906.
§H. A. Buehler. The Lime and Cement Resources of Missouri, Vol. VI, 2nd ser., p. 18, Mo. Bur. Geol. & Mines, 1907.
§§E. C. Eckel. Cement, Limes and Plasters, Chapter XVII.
§§§E. F. Burchard. Cement, Min. Res. U. S. 1914, Pt. II, p. 222, U. S. G. S.

exceed 3 per cent, as may be necessary to control certain properties. The proportions of the mixture are approximately three parts of calcium carbonate to one part of silica, alumina, and iron oxide. Portland cement is made from carefully proportioned mixtures and is burned at a temperature (approaching 3000°F) sufficient to fuse or clinker.

The raw calcareous ingredients are limestone, marl, and chalk, and the argillaceous and siliceous ingredients, clay, shale, and slate. Blast furnace slag, which is mainly fused lime, alumina, and silica, contains all of the ingredients of Portland cement, though not in the prescribed proportions.

Formerly 4 per cent of magnesia was considered the maximum permissible in Portland cement. To secure such a product only pure high calcium limestone may be used. Incomplete results of an important investigation carried on by the U. S. Bureau of Standards* indicate that satisfactory cement can be made with a magnesia content in the finished cement of about 7.5 per cent. If more thorough tests substantiate the preliminary tests the range of raw materials will be greatly extended and many quarries containing beds relatively high in magnesia may be operated without sorting necessary under the present specifications for raw materials.

Puzzolan Cement. Puzzolan cement is a finely ground mechanical mixture of siliceous and aluminous materials such as blast furnace slag or volcanic ash, and slaked lime. Slag cement is made extensively at a number of the larger blast furnaces in the United States. The hot slag is granulated in cold water, dried, and then ground with slaked lime. Puzzolan cements are generally light bluish in color and of lower specific gravity and less tensile strength† than Portland cement, and are considered better adapted for use under water than in air.

Miscellaneous Uses of Limestone and Lime.

Limestone and lime are used for many other purposes,‡ among which may be mentioned the manufacture of dichromates, magnesia, bone ash, glue, and varnish; as the refining and purifying agent in the distillation of mercury; in the clarification of grain, in refining fats, greases, butter, linseed oil, and petroleum; in preserving eggs, and as a general disinfectant and deodorizing agent; as a filter in the paper,

*P. H. Bates. Progress Report. The properties of Portland cement having a high magnesia content: Concrete-Cement Age, Cement Mill section, Mar. 1914, pp. 29-33, 38. See also extract, E. F. Burchard, Min. Res. U. S. 1914, Pt. II, pp. 245, 246, U. S. G. S.
†E. C. Eckel. Portland cement materials and industry of the United States, U. S. Geol. Surv. Bull. 22, p. 18, 1913.
‡E. F. Burchard, Production of Lime in 1911, Min. Res. of U. S. for 1911, U. S. Geol. Surv., Pt. II, pp. 645-718.
See also W. E. Emley, Manufacture and Use of Limestone, Min. Res. U. S. for 1913, U. S. G. S., p. 1592.

textile, linoleum, and rubber industries; as a mordant in dyeing; as an abrasive in polishing; in the manufacture of calcium light pencils, and of magnesium for flash-light powders; as lime water in medicine; for the recovery of potassium cyanide used in extracting gold and silver from ores; to neutralize the sulphuric acid used in pickling steel, and for a great variety of minor purposes.

CHAPTER IV.

GEOLOGY OF LIMESTONE FORMATIONS.

GEOLOGIC DISTRIBUTION.

Limestone occurs in rocks of all ages from the Archean to the Recent. In Michigan it occurs in Algonkian and Paleozoic rocks. Marl or bog lime occurs in the inland lakes.

ALGONKIAN LIMESTONES.

Algonkian limestones occur only in the Lower Huronian group of the iron bearing districts of the Northern Peninsula. In the Marquette iron bearing district the limestone formation is called Kona dolomite; in the Crystal Falls, Menominee, Sturgeon River, and Felch Mountain districts, the Randville dolomite; in the Iron River district, the Saunders formation; and in the Gogebic district, the Bad River limestone. They are heavily magnesian, generally approaching normal dolomite in composition. Locally there are thick pure beds but generally these formations contain interbedded slate or quartzite, and in most places abundant cherty and argillaceous impurities and silicate minerals. These impurities occur in bands parallel to the bedding,

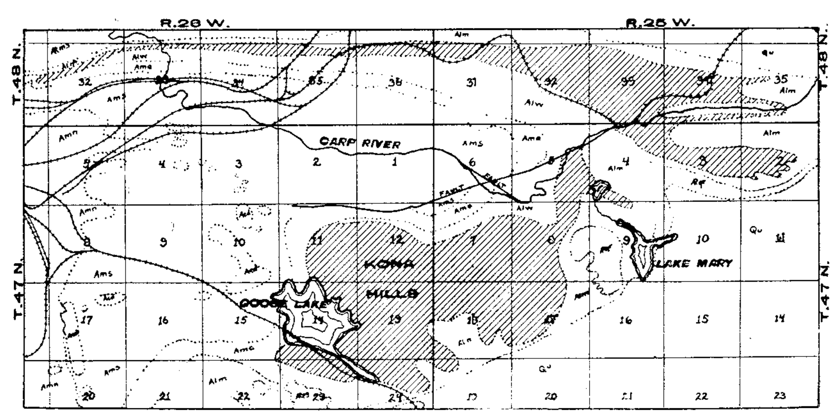

Figure 1. Map showing distribution of Kona dolomite. (After Van Hise, Bayley and Smyth, Monograph 28, U. S. Geological Survey).

in irregular seams and masses, and intimately intermingled with the dolomite. In some places the color is white, in others it varies from white to pink, red, buff and brown, and even light and deep blue. The generally siliceous character (see analyses) of the Lower Huronian dolomites makes them unsuitable for most purposes, except for crushed stone, hence they are of little economic importance.

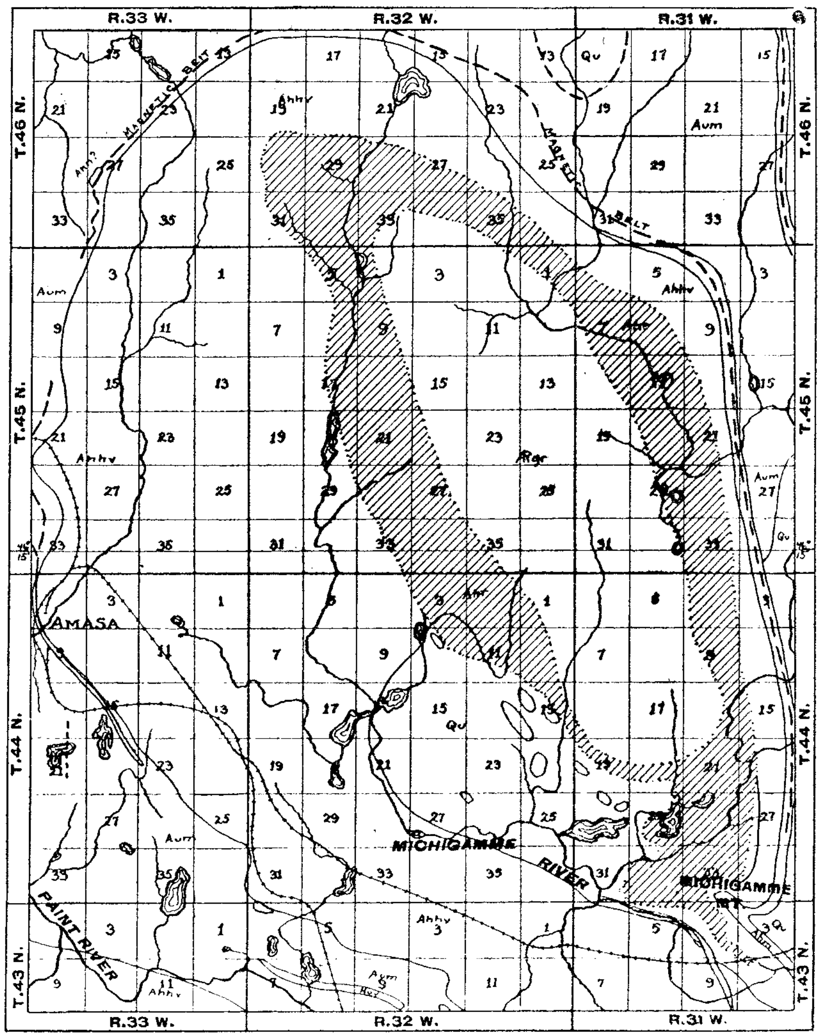

Figure 2. Map showing distribution of Randville dolomite northeast of Crystal Falls. (After Clements and Smyth, Monograph 36, U. S. Geological Survey).

Kona dolomite. The Kona* dolomite (fig. 1) forms a westward facing-U in the eastern part of the Marquette iron district, the arms of which terminate near Teal Lake on the north and Goose Lake on the south. The exposures are usually in the form of sharp and abrupt cliffs cut by ravines or separated by drift filled valleys. The Kona formation is dominantly dolomite with interstratified layers of shale,

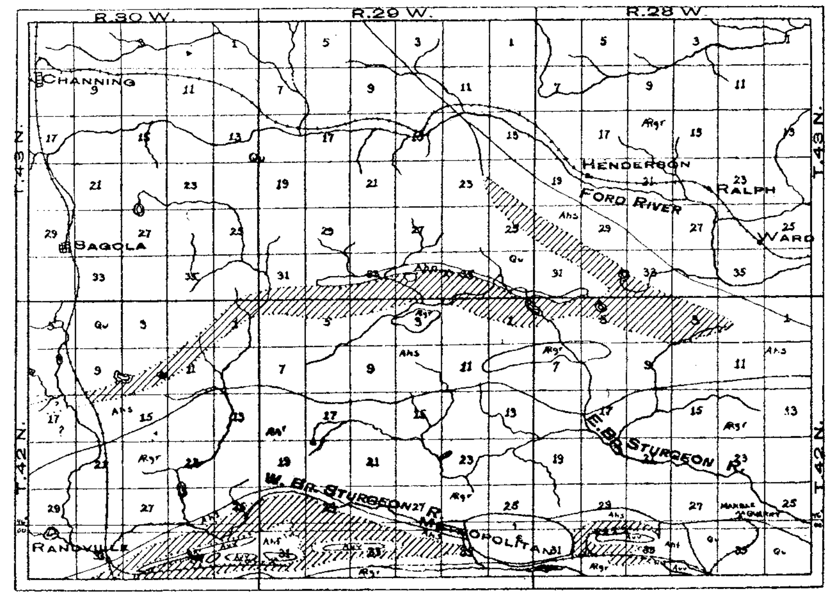

Figure 3. Map showing distribution of Randville dolomite in the Felch Mountain and Sturgeon River district. (After Smyth and Clements, Monograph 36, U. S. Geological Survey).

graywacke and quartzite. The dolomite beds are from a few inches to many feet thick, but even the purest beds contain thin cherty layers and clastic material. The color varies from pink and red to dark brown. The total thickness of the Kona formation ranges from about 200 or 250 feet to apparently 600 or 700 feet.

Owing to folding and consequent metamorphism the dolomite is finely shattered and the siliceous and argillaceous impurities are altered to quartzite, schist, and slate. Locally the graywacke, quartz, and cherty quartz layers are brecciated. The Kona formation grades upward into the Wewe slate and downward into the Mesnard quartzite.

Randville dolomite. The Randville dolomite† occurs in the Crystal Falls, Menominee, Felch Mountain, Calumet and Sturgeon River districts.

*C. R. VanHise and C. K. Leith. The Geology of the Lake Superior District, Mon. LII, U. S. Geol. Surv. 1911, p. 258.
†C. R. VanHise and C. K. Leith. Geology of the Lake Superior District, Mon. LII, U. S. Geol. Surv. 1911, pp. 293, 300, 302, 333.

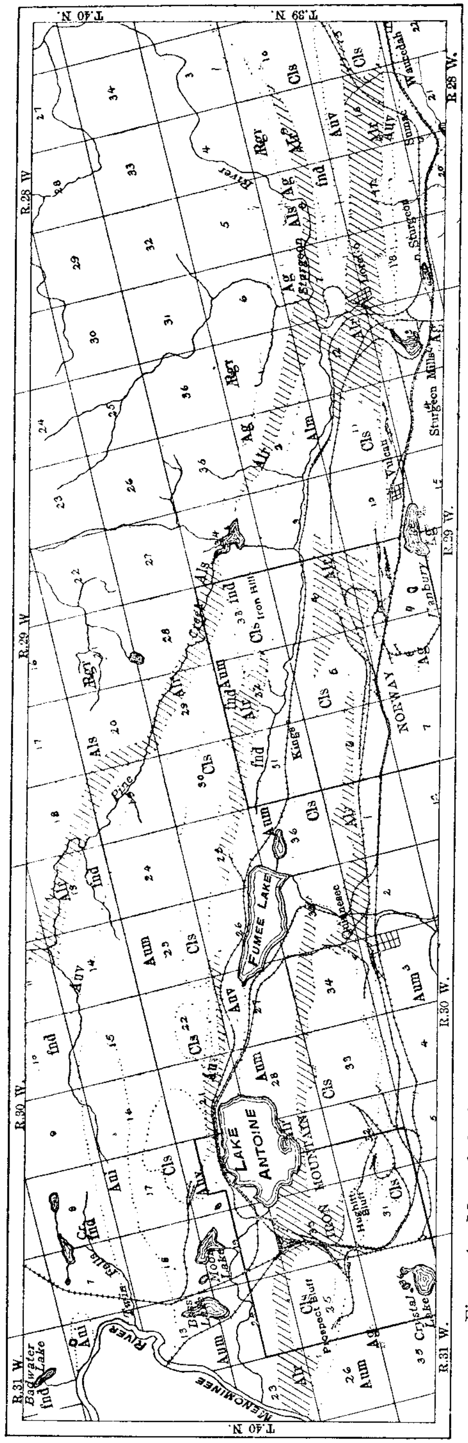

Figure 4. Map of the Randville dolomite in the Menominee district. (After W. S. Bayley, Monograph 46, U.S. Geological Survey).

In the Crystal Falls district (fig. 2) it has a maximum thickness of about 1500 feet. It varies from coarselycrystalline marble, in places very pure, but usually filled with silicate minerals, to fine grained, little altered limestone, locally grading into dolomitic sandstone and shale. The color is generally white, but various shades of pink, light and deep blue, and pale green are not uncommon.

The Randville dolomite underlies a large part of the Felch Mountain district (fig. 3) and is very thick.

In the Menominee district (fig. 4) it occupies three separate belts extending in a more or less east and west direction. The formation, though dominantly dolomite, is composed of heterogeneous beds including siliceous dolomite, calcareous quartzite, argillaceous and cherty

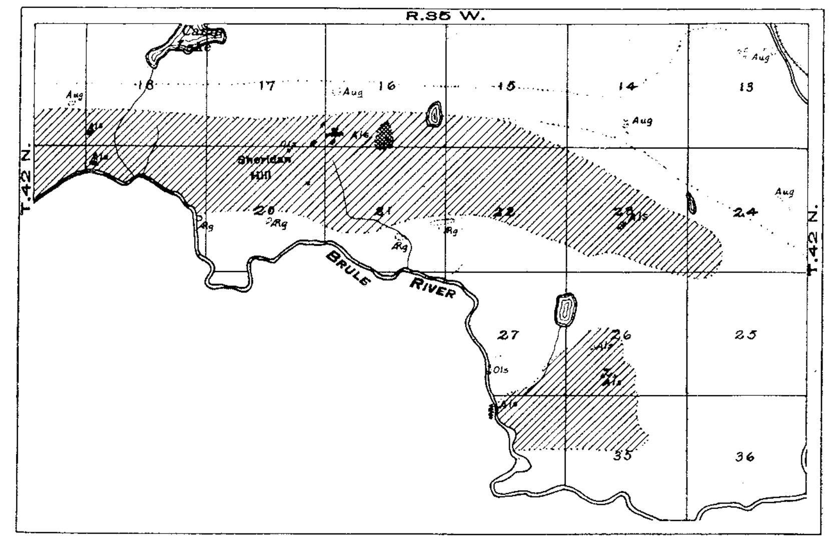

Figure 5. Map of the Saunders formation in the Iron River iron bearing district. (After R. C. Allen, Michigan Geological Survey, Publication 3).

quartz rocks. It grades downward into the Sturgeon River quartzite. The predominant phase is homogeneous, fine grained white, pink, blue, or buff dolomite. The beds vary in thickness from a few inches up to many feet. Thin veins of quartz running parallel to the bedding, anastomosing, or running irregularly through the rock mass are characteristic. The argillaceous material is in the form of light or dark gray slate and to a small extent, black slate.

Saunders formation. The Saunders* formation (fig. 5) extends across

*R. C. Allen. The Iron River District, Mon. LII, U. S. Geol. Surv. 1911, pp. 310, 311.

the southern part of the Iron River district. It is composed mainly of cherty dolomite and quartzite. Associated with these are massive white and pink dolomite, impure calcareous and talcose slates. The formation is locally much brecciated. The thickness is believed to be great but owing to folding it cannot be closely determined.

Bad River limestone. The Bad River limestone* occurs in limited areas on the Gogebic iron range (fig. 6). It is heavily magnesian and

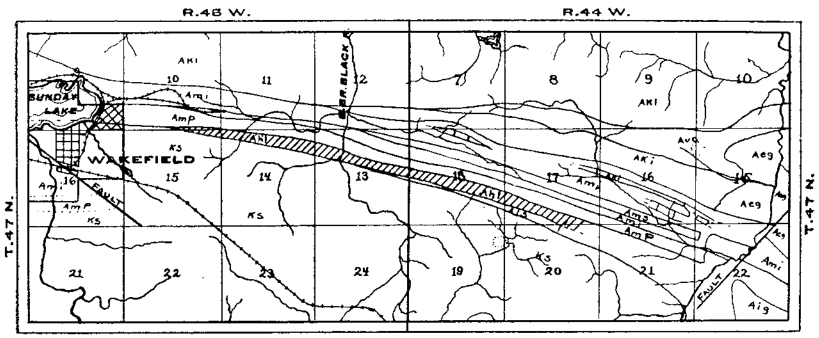

Figure 6. Map showing distribution of Bad River limestone in the east end of the Gogebic iron range. (After Van Hise and Irving, Monograph 19, U. S. Geological Survey).

locally it is nearly normal dolomite. Generally it is very siliceous, the siliceous content being in the form of chert and quartz, and to less extent silicate minerals. In places the free silica is intermingled with the dolomite and at other points it is in bands varying from a fraction of an inch in thickness to many feet.

PALEOZOIC LIMESTONES.

Geologic Occurrence.

Limestone formations occur in all of the Paleozoic systems of Michigan, except the Cambrian and Pennsylvanian. The chief limestone formations are the Beekmantown (Calciferous) including the Hermansville limestone, and the Trenton limestone of the Ordovician; the "Niagara" or Guelph and Lockport limestones, and the Monroe and Salina formations of the Silurian, the Dundee limestone, and the Traverse formation of the Devonian, and the Bayport limestone at the top of the Mississippian. Limestone horizons of minor importance occur at other points in the geological column as the Manitoulin limestone in the Cincinnati series of the upper Ordovician and the

*C. R. VanHise and C. K. Leith. The Geology of the Lake Superior District, Mon. LII, U. S. Geol. Surv. 1911, p. 228.

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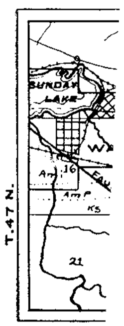

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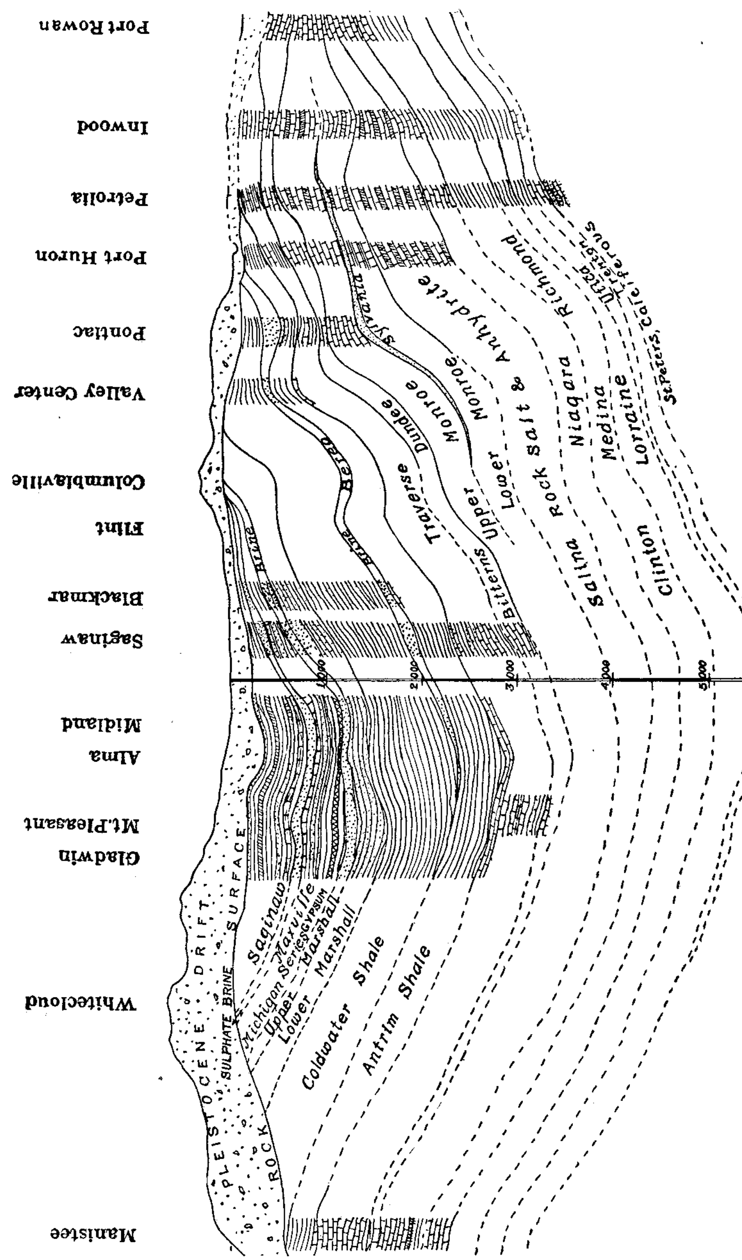

Figure 8. Geologic section across the Michigan Basin from Port Rowan, Ontario, northwest to Manistee, Michigan.

Clinton of the lower Silurian. Lenses of limestone also occur in the Michigan series in the upper portion of the Mississippian and locally in the Coal Measures of the Pennsylvanian, but these are of little or no importance.

As may be seen from the following geologic column (fig. 7) the great bulk of the limestone occurs in the lower two-thirds of the Paleozoic.

RELATION OF GEOLOGIC STRUCTURE TO AREAL DISTRIBUTION.

The Paleozoic formations in Michigan form a gigantic nest of very broad, shallow, warped basins, whose diameters decrease regularly from the bottom upward (fig. 8). Were the rocks uncovered by removing the loose surface deposits and draining the Great Lakes the rims of these basins would form concentric belts around the Coal Measures (fig. 9).

The *Michigan Basin* is a geologic province including the Southern Peninsula, the eastern part of the Northern Peninsula, the western part of Ontario, the eastern part of Wisconsin, and northern parts of Illinois, Indiana, and Ohio. The average diameter of the Basin is about 500 miles. The deepest part appears to be in Midland and Isabella counties near the geographical center of the Southern Peninsula. The total depression or depth apparently is over 7000 feet, but this is so small in comparison with the diameter that the inclination of the formations toward the center of the Basin is usually between 25 and 50 feet per mile, and rarely exceeds 60 feet.

The basin-like structure and the occurrence of the bulk of the limestone in the lower part of the rock column determine the areal distribution of the limestone formations in concentric belts near the margin of the Basin. The only extensive limestone regions in the Southern Peninsula are in the extreme northern and southeastern portions.

MARL OR BOG LIME DEPOSITS.

Many of the glacial lakes in Michigan, northern Indiana and western New York contain marl deposits. Many swamps, formerly the sites of glacial lakes, also contain marl. In some of the lakes marl formation is still being formed. Marl deposits vary in extent from a few acres up to several hundred, and in thickness from a few feet to 50 feet or more.

Marl is known to occur in 22 different counties in the Southern Peninsula, and the total area of proven deposits of workable size is over 26,000 acres.

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THE PALAEOZOIC LIMESTONES.

Areal Distribution and General Description.

Beekmantown. (Calciferous, Lower Magnesian), Hermansville limestone. The Beekmantown formation (fig. 9), which apparently includes the Hermansville limestone, forms the rock surface throughout a belt in the Northern Peninsula, extending north-northeast from Menominee River through the central part of Menominee County into the southeastern part of Marquette County where it veers toward the east and extends through Alger County, the northern part of Schoolcraft, and the central portions of Luce and Chippewa counties, crossing St. Marys River near the north end of Neebish Island. It is exposed in the bed of Menominee River, at several places in Alger county and on Neebish Island.

In Michigan the Beckmantown is composed of white dolomite generally sandy, white sandstone and gradational phases from one to the other. Much of the sandstone has an abundance of dolomitic cement, but some is a true glass sand composed of small rounded colorless quartz grains with little cement. The Hermansville limestone of the Menominee iron district represents some part of the Beekmantown. It is described by Rominger* as a ''coarse grained sandstone with an abundance of calcareous cement in alternation with pure dolomite, or sometimes oolitic beds.'' The dolomite, however, is in many places very sandy. The thickness of the Beekmantown is variable, due to erosion, but generally it is between 180 and 250 feet. The Hermansville has been heavily eroded and exists chiefly as remnants on the tops of the hills in the Menominee district.

The generally siliceous character (see analyses) of the dolomite in the Beekmantown makes it unfit for most purposes. It is of little economic value except possibly for building stone.

Trenton (Galena and Platteville) limestone. The Trenton limestone is exposed only in the Northern Peninsula where it underlies a broad belt extending northeast along the west side of Green Bay and Little Bay de Noc, through the eastern part of Menominee county and the western half of Delta county, becoming much narrower through Schoolcraft, Luce, and Chippewa counties to St. Marys River. The formation is well exposed near Menominee along the lower courses of the Ford, Escanaba, Rapid, and White Fish rivers and on St. Marys River.

The formation is composed of both low magnesian and high magnesian limestone, blue to buff and brown in color and generally argil-

*Paleozoic rocks, Geol. Surv. Mich., Vol. I, Pt. III, 1873, p. 81.

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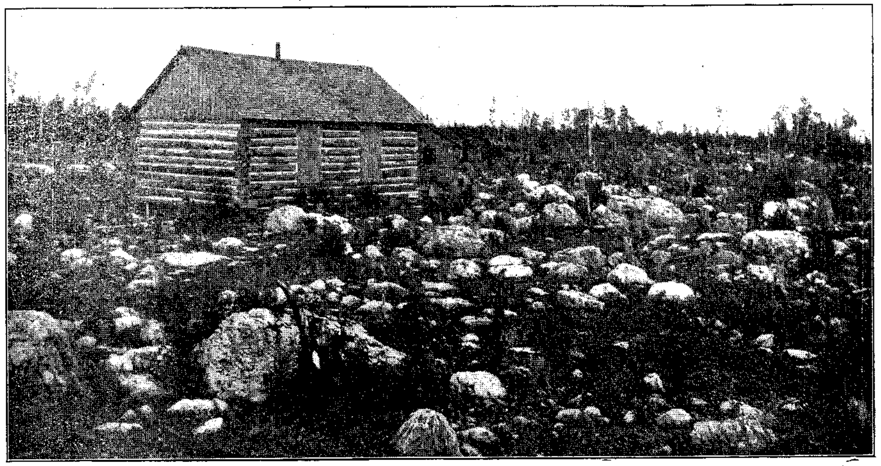
onlaceous. Locally it is very argillaceous and bituminous. Thin seams of shale are common and fine wavy laminae of shaly or bituminous matter are characteristic. In the Northern Peninsula the Trenton has three phases,* viz., (1) an upper granular, crystalline, high magnesian limestone with alternating blue and buff or brown layers terminating at the base in a dark or black bituminous limestone, (2) a middle portion of sandy or cherty layers, and (3) a basal member of blue shale and limestone, the latter being locally dark or black. In the southern part of the state where it has been penetrated in deep wells it has four well marked divisions, viz., (1) an upper, thin, dark grayish, buff and brown, high magnesian portion, (2) a thick, white to light buff, low magnesian limestone series, (3) a thick, dark, buff and brown argillaceous and bituminous series of limestones, and (4) a lower, very thick, dark gray and brown, argillaceous and bituminous series. The generally shaly and argillaceous character of the Trenton formation makes most of it unsuitable for most purposes except rough building block and crushed stone.

The thickness in the Northern Peninsula ranges from about 250 feet along Green Bay to 100 feet or less on St. Marys River. In southeastern Michigan the formation is much thicker, averaging about 850 feet.

''Niagara'' Limestone.—Guelph and Lockport. The ''Niagara'' limestone is composed of an upper whiter and more crystalline portion called the Guelph dolomite, and a lower darker and generally less crystalline portion called the Lockport limestone, which is the Niagara proper. Since the two formations have not yet been certainly differentiated in Michigan and since quarrymen, lime burners, and lime users are habituated to the use of the term ''Niagara'', the name is retained in this report to include both the Guelph and the Lockport.

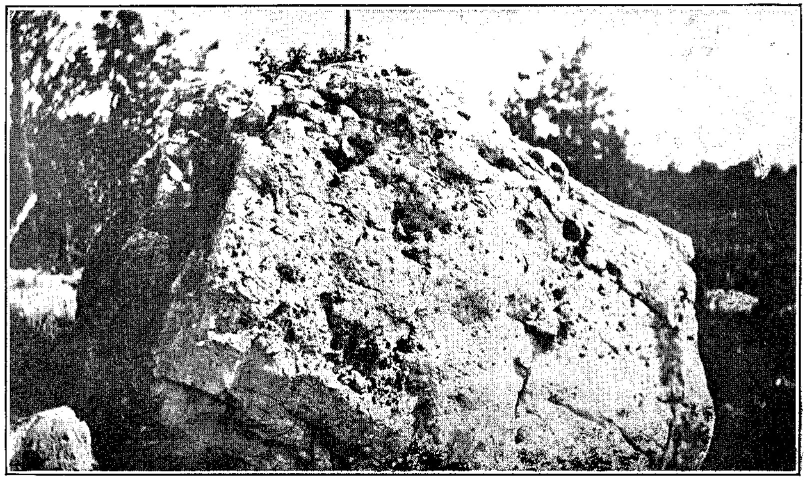
The Niagara limestone comes to the surface only in the Northern Peninsula. It underlies a broad belt skirting the northern shores of Lake Michigan and Lake Huron from the southern end of Garden Peninsula, Delta County, to the eastern side of Drummond Island, Lake Huron. Throughout large areas it is at or near the surface. The exposures are numerous, and owing to the hard and massive character of many of the rock layers and the gentle inclination of the strata they are usually in the form of escarpments or cuestas with steep or precipitous slopes toward the north and gentle slopes toward the south. Swamps occupy most of the depressions between the escarpments. The escarpments afford unusually favorable conditions for quarrying. The long slopes in many cases correspond to the in-

*A. C. Lane, Geological Section of Michigan, Ann. Rept. 1908, Mich. Geol. Surv., p. 48.



A. BOULDER TRACT OF ENGADINE DOLOMITE NEAR HESSEL, MACKINAC COUNTY.

These massive boulders are of characteristic occurrence in regions underlain by the Engadine dolomite.



B. A LARGE WEATHERED BOULDER OF ENGADINE DOLOMITE NEAR THE RAILROAD ONE MILE WEST OF ENGADINE, MACKINAC COUNTY.

The massive character of the boulders and the numerous drusy cavities with the peculiar concentric structures about them are characteristic of the Engadine dolomite.

clination of the beds which varies from about 40 to 60 feet per mile. The gentle lakeward dip of the strata results in shallow water for long distances off shore and an absence of good harbors. This forms a serious obstacle in the development of the numerous high grade limestone beds of the Niagara which occur some miles back from the shore

The whole formation, excepting near the base, is characterized by an absence of shaly or argillaceous material. The content of both iron and alumina is generally below one per cent, and in many beds less than one-half of one per cent. Silica, in the form of quartz sand, seams and nodules of chert, and silicified fossils, is much more abundant. Some beds are extremely cherty and siliceous, though in most of them the silica does not exceed $1\frac{1}{2}$ or 2 per cent. In the Engadine dolomite at the top of the formation the total impurities are in many places less than one per cent.

The Niagara limestone is composed of at least four distinct and easily recognized members which the writer has provisionally named and defined as (1) *Engadine dolomite,* (2) *Manistique series,* (3) *Fiborn limestone* and (4) *Hendricks series.*

Engadine dolomite. The Engadine dolomite is the name proposed for the upper member of the Niagara. It is best exposed in the vicinity of Ozark, Mackinac County, but because this name was already pre-occupied in geologic literature the member was named from the village of Engadine, where it is exposed over a large area about one mile west of the village. The Engadine dolomite is an extremely massive, hard, and very crystalline dolomite, distinctly bluish or mottled and streaked with blue. It is also characterized by numerous druse cavities more or less completely filled with crystals of dolomite or pearl spar. The stone is very poorly and massively bedded, and except where greatly weathered shows very few distinct bedding planes. The joint systems are generally poorly developed and very irregular. It forms a strong, though broken, northward facing escarpment nearly the entire distance from Seoul Choix Pt., Schoolcraft County, to St. Marys River. Areas where this formation is exposed or near the surface are covered with great boulders as at Ozark, Engadine, Hessel and Garnet. (Pl. I, A and B).

Owing to its highly crystalline character and bluish colorations the Engadine dolomite is known locally as marble. This resemblance to marble resulted in considerable core drilling near the mouth of Bulldog River, Schoolcraft County, in an attempt to prove up a marble deposit. The color, however, is not permanent. Upon exposure to the weather for a year or two the bluish color changes to a light buff or brown. The writer has seen stone in which the color had been completely altered to the depth of more than an inch, though the stone had been quarried but two years. Those parts of the stone which are free from druse cavities undoubtedly would make good building block, but it would be an unsatisfactory substitute for marble.

The Engadine beds are uniformly normal dolomite, almost free from impurities. The exceptional purity of the dolomite makes it especially adapted for basic linings in open hearth furnaces and for paper manufacture with the sulphite process.

The dark argillaceous dolomites of the Monroe-Salina apparently overlie the Engadine dolomite but nowhere have the two been seen in contact. The contact with fossiliferous beds of the underlying Manistique series is sharp and well exposed along a high bluff about two miles north of Ozark. At this point the thickness, which is the maximum observed anywhere, is about 54 feet. The surface of the bluff has suffered severe glacial erosion, therefore the normal thickness of the formation is presumably considerably more than this.

In southeastern Michigan and southwestern Ontario the same bluish, highly crystalline dolomite occurs directly beneath very dark argillaceous dolomite apparently belonging to the base of the Salina. The thickness of the bluish crystalline dolomite in the H. R. Ford well at Dearborn, Wayne County, is about 95 feet.

Manistique series. The Manistique series is a thick succession of dolomite and high magnesian limestones extending from the base of the Engadine dolomite downward to the top of the Fiborn limestone.

It comprises a great variety of dolomites and generally high magnesian limestones, differing greatly in color, texture, and structure. The color varies from pure white, light gray and buff to blue, dark gray, and buff or brown, the texture from earthy or finely crystalline to coarsely crystalline. Some of the strata are massive but others are thin bedded. The jointing varies from regular to very irregular. Many of the beds are very fossiliferous but some contain no fossils. Favosites, Halysites, and Syringopora are conspicuous among the corals, though many other forms are abundant. *Pentamerus oblongus* is a most conspicuous form among the brachiopods. Two to three miles north of Engadine the beds are extremely fossiliferous. Some are a mass of corals and bryozoa and others a mass of brachiopods. Apparently this region was the site of extensive reef building in Niagaran time.

Many of the beds are very dense, finely banded or laminated, and break with a pronounced conchoidal fracture. The fine banding is beautifully brought out through weathering and the term "ribbon limestone" is often given to such rock. Some beds are very granular and resemble sandstone.

The percentage of iron and alumina, though generally higher than in the Engadine dolomite, is usually low. The silica, however, is apt to be high and some of the beds are extremely cherty and siliceous.

Formerly the limestones of this series were much used for burning lime, but now they are utilized for lime only at Manistique. Some of the stone is burned only with great difficulty. The great difference in chemical composition and physical qualities between the different beds in most quarries generally necessitate hand sorting. The hardness and toughness of much of the stone, combined with ease of access, lend value to this formation for road making and concrete.

The series is widely exposed, particularly in the vicinity of Manistique and along the west side of Garden Peninsula where there are bluffs rising nearly vertically from 100 to over 230 feet above Big Bay de Noc, also near Gould City, north of Engadine, southeast of Trout Lake, at Rockview, and at many places on Drummond Island. From Manistique northwest to Indian Lake and beyond there is an almost continuous succession of small roughly parallel and nearly E-W escarpments facing north with gentle back slopes toward the south. The northern limit of the exposures of this series, like that of the Engadine dolomite, is generally marked by a pronounced though much broken escarpment. In places the escarpment rises 100 to 150 feet or more above the level of the swamps to the north.

The thickness of the series is uncertain but it is over 250 feet as shown by the section at Burnt Bluff, Garden Peninsula. The contact with the Engadine dolomite above is well exposed at several places but the contact with the Fiborn limestone below was observed only in the Hendricks quarry where in places five or six feet of light colored magnesian limestone rests directly on the Fiborn.

Fiborn limestone. In practically all of the geological literature the Niagara limestone is described as a dolomite formation. Rominger* who made an early study of the Niagara found only very thin and insignificant beds of high calcium stone. Some time prior to 1901, Dr. A. C. Lane† visited some caves in limestone on sections 15, 16, 21 and 22, T. 44 N., R. 7 W. This limestone proved to be low in magnesia and some years later quarrying operations were begun at the site of the present Fiborn quarry. Deposits of high calcium limestone were discovered at other places to the west and two other quarries, now known as the Blaney and Hendricks were opened.

In 1913 the writer found that the Fiborn limestone is exposed at many places in several areas of considerable size in an arcuate belt (fig. 9) which extends from a point (cen. S. line of sec. 2, T. 42 N., R. 14 W.)

*C. Rominger, Paleozoic rocks, Vol. I, Pt. III, p. 37, Mich. Geol. Surv., 1869.
†Ann. Rept. Mich. Geol. Surv. 1905, Limestone, p. 20.

four miles north of Whitedale, Schoolcraft County, eastward to Gould City, Mackinac County, thence northeast to Hendricks quarry (sec. 1, T. 44 N., R. 9 W.) and thence southeast through Fiborn quarry (secs. 16 and 21, T. 44 N., R. 7 W.) to within two or three miles of Trout Lake. Westward from section 11, T. 42 N., R. 14 W., the bed disappears beneath the swamps north of the prominent escarpment of the Manistique series, along the Manistique River and its branches, and the streams running into Indian Lake. Eastward from Trout Lake the bed disappears beneath the lake clays of Mackinac and Chippewa counties. On Lime Island, St. Marys River, the drift is filled with angular fragments of the Fiborn stone, indicating its presence in that immediate vicinity. Apparently the bed crosses Drummond Island from the vicinity of Maxton southeast toward Marblehead. It is possible that a three foot bed of fine grained, ash colored, high calcium* limestone in the lower portion of the Marblehead section is the diminished representative of the Fiborn bed.

The largest area of exposures is in the vicinity of Blaney quarry, Gould City, and the Hendricks and Fiborn quarries. Blaney quarry is located near the west end of an area of almost continuous exposures over a mile in width extending from about the middle of section 4, T. 42 N., R. 13 W., eastward about five miles nearly to Lake Ella. About a mile west of Gould City the area in which Fiborn stone is exposed, or near the surface, is apparently more than a square mile in extent. In the vicinity of Hendricks and Fiborn quarries exposures are said to extend over an area of two to three square miles. The Fiborn bed is exposed, or is at shallow depths, at several other places, notably four miles north of Whitedale, five miles north of Engadine, two or three miles northwest of Trout Lake, and between Fiborn and Hendricks quarries.

The Fiborn limestone beds are buff to grayish buff dense grained to lithographic limestone generally containing small disseminated crystals of calcite. The lithographic texture is very marked in some beds but small crystals of calcite apparently render nearly all of the stone of no value for lithographic purposes. It is possible that certain thin strata may be found sufficiently free from crystals to yield moderate sized slabs suitable for lithographic work.

The stone is mainly massive though locally it is markedly laminated and well bedded. The joint systems are very irregular and poorly developed. The stone is brittle and breaks with a perfect conchoidal fracture, forming fragments with sharp points and edges. The lithographic texture, numerous small calcite crystals, and perfect conchoidal fracture are features which make field identification of the Fiborn

*C. Rominger, Vol. I, Pt. III, p. 35, Mich. Geol. Surv. 1873.

beds easy and unmistakable. Moreover, the stone calcines easily and, wherever forest fires have passed over it, the surfaces of the exposures and field boulders are pure white in contrast to the grayish or yellowish white of partially burned stone from other beds.

The Fiborn bed is very uniform in composition and generally the content of calcium carbonate is between 94 and 97 per cent. The silica varies usually from 0.75 to 1.50 per cent, and the iron and alumina from 0.25 to 0.75 per cent. Magnesium carbonate, except near the bottom of the bed, is usually below 2 per cent, though locally it may exceed 3 or 4 per cent. The bottom portion in most places contains from about 2 per cent to 5 per cent, or even more of magnesium carbonate. Owing to its purity and freedom from magnesia the Fiborn limestone is quarried extensively for blast furnace flux, carbide, sugar manufacture, and hot lime. Though very brittle the stone makes very satisfactory road material on account of its high cementing power.

The thickness of the member varies from 18 to about 30 feet. The maximum thickness developed in the Blaney quarry is about 26 feet. Eastward this decreases to only about 18 feet at the Hendricks quarry but still farther east the bed thickens to nearly 30 feet in the Fiborn quarry. If the thin bed of high calcium acicular stone in the Marblehead section, Drummond Island, is the representative of the Fiborn bed it has shrunk to only about three feet in thickness. In one of the Manistique wells 27 feet of "white limestone" was penetrated between 80 and 107 feet in depth and this may be the Fiborn bed. It is a significant fact that although the lower portion (Lockport) of the Niagara is well exposed on Manitoulin Island in Ontario no trace of a high calcium bed has been observed. The same may be said for the western extension of the Niagara in Wisconsin. In the H. R. Ford well at Dearborn which completely penetrated the Niagara, no trace of high calcium stone was found though samples were taken every five feet. This would indicate that the Fiborn bed is a lens in the Niagara and largely confined to the limits of the Northern Peninsula.

Hendricks series. In the floor of the Hendricks quarry of the Union Carbide Company a test pit has been sunk to the depth of about 20 feet and test holes have been drilled in the vicinity of the quarry to the depth of over 145 feet. The beds in the test pit range in composition from high calcium limestone to normal dolomite, and according to the analyses of the drill cores the strata down to 145 feet and perhaps deeper are composed of the same alternating series of high calcium, and low to high magnesian limestones. As far as known none of these strata are exposed anywhere else except in the vicinity of the Manistique lakes and apparently at Marblehead, Drummond Island. The writer, however, has not visited these localities, hence must rely upon the older descriptions given by Rominger. Other exposures probably occur on some of the islands in St. Marys River and Potagannissing Bay.

The bed immediately underlying the Fiborn limestone at Hendricks quarry is a very white crystalline limestone containing from 2 to 5 per cent of magnesia. In the Blaney quarry of the White Marble Lime Co. this bed is said to contain only about 85 per cent of calcium carbonate. At Fiborn also it contains considerable magnesia. At Hendricks quarry the white limestone is directly underlain by one foot of dark lithographic limestone containing only about one per cent of magnesia. The next lower bed, 2 feet thick, is higher in magnesia and the next two, together 8 feet thick, are practically normal dolomite. Next follows one foot of high calcium stone which gives place to heavy magnesian limestone which forms the floor of the pit. According to the analyses of two drill cores from the vicinity of Hendricks quarry the magnesian zone below the Fiborn bed is between 13 and 14 feet thick, therefore the floor of the test pit must be near the bottom of the zone. The magnesian zone is followed by a series of high calcium limestones 30 to 50 feet in thickness. Below this there are low magnesian limestones down to 145 feet, the bottom of the deeper hole.

According to Rominger the exposures on Manistique lakes are highly magnesian and also most of the strata at Marblehead, Drummond Island.

The writer has provisionally termed the series of limestones and dolomites from the base of the Fiborn limestone down to the Rochester shale, the *Hendricks series*. Further field work and faunistic studies, however, may show that the Fiborn limestone should be included in this series. The belt underlain by the Hendricks series lies directly north of the belt of Fiborn exposures and almost wholly in a heavily drift covered area, hence the conditions for detailed study are very unfavorable.

The thickness of the Hendricks series is uncertain but it is certainly over 100 feet as shown by the drill holes near Hendricks quarry.

Salina formation. The Salina formation has not been definitely recognized in outcrops in Michigan. In St. Ignace peninsula it may be some part of what is now mapped and described as the Monroe formation.

Monroe formation. The Monroe formation is exposed in southeastern Michigan and in St. Ignace peninsula and adjacent islands. In Monroe county the following subdivisions are now recognized*:

*W. H. Sherzer and A. W. Grabau. The Monroe Formation, Pub. 2, Geol. Ser. 1, Mich. Geol. and Biol. Surv. 1909, pp. 27-54.

1. Upper Monroe or Detroit River series.	Lucas dolomite	200 ft.+
	Amherstburg dolomite	20 ft.
	Anderdon limestone	40 ft.
	Flatrock dolomite	60 ft.
2. Sylvania sandstone and dolomite.		
3. Lower Monroe or Bass Island series.	Raisin River dolomite	200 ft.
	Put-in-Bay dolomite	100 ft.
	Tymochtee shale	90 ft.
	Greenfield dolomite	100 ft.

These subdivisions, however, have not been recognized in the Monroe formation in St. Ignace peninsula and adjacent islands and apparently the three primary divisions are clearly developed only in southeastern Michigan in Monroe County and along Detroit River. North and northwest from this region the Sylvania sandstone grades into dolomite, though here and there in the state borings show the presence of a sandstone at about the horizon of the Sylvania.

Lower Monroe or *Bass Island series.* The Lower Monroe series is composed chiefly of gray argillaceous dolomite with some shale, gypsum, and celestite. Only the upper member, the Raisin River dolomite, is exposed in Monroe County. It is composed of gray, fine grained argillaceous dolomite and subordinate amounts of öolite. The dolomites are generally thin bedded, in places bituminous and more or less shattered and brecciated. There are several öolitic beds, each being underlain by a peculiar bed of fine grained, blotched, mottled, and streaked dolomite. The markings are of a distinct bluish cast, but where weathered they are rusty brown, indicative of the presence of iron. The more massive blue portions near the bottom of this bed are very shaly.

The brecciation of the Monroe dolomite is a very general characteristic. The most conspicuous occurrences are in St. Ignace peninsula, on Mackinac Island, and in the vicinity of Monroe, Monroe County. Brecciated horizons have been struck in many wells penetrating the Monroe in different parts of the state.

The brecciation is of two types.* The first is a complete shattering of the formation, producing a breccia, the fragments of which are firmly held in a matrix of finer materials completely cemented. The second is more local and affects individual beds only. The blocks in this type are locally more or less disturbed but only slightly displaced, where in the first type the breccia is composed of a mixture of fragments of several different beds showing considerable displacement.

*W. H. Sherzer and A. W. Grabau. The Monroe Formation, Pub. 2, Geol. Ser. 1, Mich. Geol. and Biol. Surv. 1909, p. 29.

The cause of the brecciation is a mooted question. Lane* ascribes the regional type to the inrush of great tides across shallow flats, but Grabau† argues that it represents the talus breccia produced on an extensive land surface of post Monroe time and that this talus was incorporated into the lower Onondaga on the resubmergence of this region by the sea, or that it was produced by solar fluxion. The local brecciation is apparently due to buckling produced by some expansional force such as might arise when anhydrite by chemically combining with water is transformed into gypsum.

The Raisin River dolomite is exposed at many places in eastern Monroe County, particularly in the vicinity of the river from which the member takes its name. In the early days the stone was extensively burned for lime but owing to its argillaceous character, the exhaustion of suitable fuel, and competition of limes of better quality, the industry in this region ceased many years ago. Many small quarries were formerly operated, supplying Detroit with crushed stone chiefly for concrete and macadam, but now only two or three quarries are in operation. The stone is too impure and highly magnesian for chemical purposes and the argillaceous content or its brecciated character makes it locally unfit even for concrete, macadam or ballast.

Upper Monroe or *Detroit River series.* The Upper Monroe or Detroit River series is exposed along Detroit River and at several places in the western part of Monroe County.

The Flat Rock, Amherstburg, and Lucas members are high magnesian limestones or dolomites, but the Anderdon is a very pure high calcium limestone. The dolomites are gray to brown, argillaceous or bituminous, and locally brecciated. Formerly several quarries were operated in the Upper Monroe dolomites, but during the past few years only two or three have been in operation and these but intermittently. The argillaceous and highly magnesian character of much of the stone makes it unsuitable for most purposes. The Anderdon limestone is exposed in the Anderdon quarry on the Ontario side of Detroit River and also in the lower part of Sibley quarry where, due to erosion of the Lucas and Amherstburg dolomites, it directly underlies the Dundee and is quarried with it. The Anderdon is present only in patches, having been largely removed by erosion.

In places the Anderdon limestone is practically pure calcium carbonate and its generally low content of magnesium carbonate makes it particularly suitable for chemical purposes.

In the St. Ignace peninsula and adjacent islands the Monroe formation is characterized by much brecciation and contains beds of gypsum. The argillaceous and magnesian character of the breccias and their tendency to disintegrate under weathering, make them valueless. Formerly they were utilized locally for burning lime.

*A. C. Lane, Vol. V, Mich. Geol. Survey 1895, pt. 2, p. 27.
†A. W. Grabau. The Monroe Formation, Pub. 2, Geol. Ser. 1, Mich. Geol. and Biol. Surv. 1909, p. 29.

Dundee (Onondaga) limestone. The Dundee limestone is a widespread formation and underlies nearly all of the Southern Peninsula, but it comes to the surface only in a narrow belt in the southeastern part of the Peninsula and along the shore of Lake Huron from Mackinac City, Cheboygan County, to Presque Isle, Presque Isle County. Its outcrop elsewhere is buried under surface deposits or lies beneath the waters of Lake Michigan and Lake Huron.

The Dundee is chiefly high calcium limestone with some magnesian beds near the base of the formation where it rests directly on the Monroe dolomites. It is generally gray to buff or brown, crystalline, bituminous, and locally very fossiliferous. Locally some of the beds average over 98 per cent of calcium carbonate. Its purity and freedom from magnesia renders the Dundee limestone especially valuable for chemical purposes, soda ash products, flux, carbide, etc. It is quarried very extensively near Detroit and Rogers City. The bituminous content renders much of the stone unsuitable for lime burning.

The Dundee formation averages about 100 feet thick in the southeastern portion of the Southern Peninsula and over 200 feet in the northern part. In the central part where penetrated by borings it is over 250 feet thick, but on the western side of the state it is very thin and in places, as at Muskegon, perhaps absent.

Though the areal extent of the exposures of the Dundee is small in comparison with most of the other limestone formations, it is one of the most economically important and furnishes nearly half of the annual output of limestone.

Traverse (Hamilton and Marcellus) formation. The Traverse formation is widely exposed throughout a curving belt extending from Little Traverse Bay, Lake Michigan, to Thunder Bay, Lake Huron. Southwest from Little Traverse Bay to Benzie County the formation is generally deeply drift covered. It occupies a narrow belt in southeastern Michigan but it is not exposed there. Generally speaking, it is a series of limestones and shales with a heavy shale (Bell or Marcellus) at the base. In the southern part of the state the formation is dominantly shale. In the Alpena district, however, limestone is dominant and in the Little Traverse Bay region the formation is almost wholly limestone, containing only a few relatively thin beds of shale, excepting the Bell shale at the base. The limestone varies greatly in color, texture, and composition. The color varies from pure white to gray, buff, brown, and black, and the texture from very fine grained or lithographic to coarsely crystalline. Some of the strata are very thin bedded, others massive. In general the jointing is very regular. The formation as a whole is richly fossiliferous, many strata being composed of a mass of brachiopods, corals or bryozoans. In the Alpena district large reefs of corals, many of them chiefly of Acervularia, are characteristic. The limestone varies in composition from practically pure calcium carbonate to heavy magnesian limestone or normal dolomite. There are also all gradational phases between limestone and shale. Most of the shale is very calcareous and generally very soft. Under the drill it churns up into a ''soapy'' mass, hence it is generally reported by drillers as ''soapstone.'' The gray color is generally due to the argillaceous content and the black color to a large amount of bituminous matter. Some of the shaly limestone is also extremely cherty. Along Little Traverse Bay much of the limestone is yellow, buff, or brown, which is due to the oxidation of the iron content. The limestone here is generally much more magnesian than elsewhere.

In the Alpena district the Traverse has been subdivided by Grabau* into the following members:

1. Thunder Bay series.
2. Alpena limestone.
3. Long Lake series.
4. Bell shale.

The Long Lake series is chiefly shale and thin bedded limestone, some of the limestone being very argillaceous. This series forms a belt extending from Stony and Partridge points northwest along Thunder Bay river. Owing to its generally shaly or argillaceous character the series apparently is of little value except for manufacture of cement.

The Alpena limestone is chiefly high calcium limestone and is characterized by the presence of an extensive system of coral reefs. The reefs, being more resistant to erosion than associated strata, form a network of low ridges on the surface in the vicinity of Alpena. The Alpena limestone as a whole is more massive and resistant than the Thunder Bay series above or the Long Lake series below and forms an elevated tract several miles wide extending northwest from the head of Thunder Bay between Long Lake and the North Fork of Thunder Bay river into Presque Isle county. Apparently the elevated tract extending through Metz and Larocque toward

*A. W. Grabau. The Stratigraphy of the Traverse Formation, Ann. Rept. 1901, Mich. Geol. Surv., pp. 163-196.

Onaway is also due to this hard limestone series. The reef limestone is generally very free from magnesia and impurities. In some places the calcium carbonate averages over 99 per cent. Locally, however, the reefs have been heavily dolomitized. These areas are known as dolomite or magnesian ''chimneys.'' The beds dip away from the reefs at rather steep angles but at a relatively short distance they become practically horizontal. The beds extending horizontally between the reefs are chiefly high calcium limestone with some magnesian limestone, shale, and shaly chert, and very bituminous limestone. In large quarrying operations the presence of these undesirable beds generally results in a large percentage of waste in the quarry product. At Alpena the Huron Portland Cement Company utilize this waste product in the manufacture of Portland cement.

According to Grabau* the Alpena Limestone is only 35 feet thick, but in the quarry of the Michigan Alkali Company, Alpena, the high calcium strata and coral reefs have been quarried to the depth of 80 feet or more. Several drill holes northwest of Alpena also show that the thickness of the high calcium strata is much greater than that given by Grabau. Since by definition the name refers to the ''Middle Limestone'' lying between the shales and limestones of the Thunder Bay series above and of the Long Lake series below, the term should include the entire limestone series exposed in the Michigan Alkali quarry down to the argillaceous limestone beneath. This would give a thickness of about 80 feet for the Alpena or ''Middle'' limestone. Due to its generally high calcium content and its numerous exposures the Alpena limestone is of much more economic importance than the other members of the Traverse formation in northeastern Michigan. The many large exposures with favorable quarrying conditions form an immense reserve of high calcium limestone. Only those in the vicinity of Alpena near cheap water transportation have been developed successfully.

In the Little Traverse Bay region exposures are largely confined to a double line of bluffs along the south shore of the bay. The first line of bluffs is close to the shore and varies in height from 10 to 40 feet or more. The second line is generally from a few hundred feet to a half mile from the shore and varies from a few feet to about 50 feet in height.

Quarrying operations and well borings show that in this region the Traverse formation is almost wholly limestone down to depths of 350 to 475 feet. An upper bed of shale 6 to 10 feet thick has been encountered in some of the quarries and another bed has been struck in wells at about 250 feet. Thin partings of shale from a fraction of an inch up to 6 inches, however, are characteristic of much of the lime-

*A. W. Grabau, Ann. Rept. 1901, Mich. Geol. Surv., p. 174.

stone exposed in the quarries. Thus the formation changes from an alternating series of limestone and shale in the Alpena district to almost solid limestone in the Little Traverse Bay region. As exposed along the shore of the bay the series consists of an upper, yellow to brown, friable, high calcium limestone 15 feet or more thick, a middle, yellow to brown, friable and more or less completely dolomitized limestone about 40 feet thick, and a lower, gray, dense grained or lithographic to crystalline, high calcium limestone, apparently more than 40 feet thick.

The Traverse formation is widely exposed in Presque Isle county and exposures are also numerous in the central portion of Cheboygan county. The limestone is generally high calcium though there are some highly magnesian beds. Many of the strata are shaly, bituminous, and fossiliferous. The texture varies from dense grained or lithographic to very crystalline. The subdivisions of the Traverse easily recognizable in the Alpena district do not appear to be clearly defined in Cheboygan county and the western part of Presque Isle county. Apparently these limestones represent the transition from the limestones and shales of the Alpena district to the solid limestone of the Little Traverse Bay region.

In the northern and central parts of the state the Traverse averages from 600 to 650 feet thick, including 50 to 80 feet of shale at the base. Along St. Clair River it is only about 300 feet thick and in the extreme southern and southwestern portions of the state it is generally less than 100 feet thick.

The Traverse probably contains a larger amount of high calcium limestone than any of the other formations within the state and, owing to the number of and extent of its exposures, it also contains a larger amount of available high calcium limestone. Unfortunately the exposures are all in the northern part of the state and largely inland. Only in the vicinity of Thunder and Little Traverse bays are deposits of the higher grade limestone near cheap water transportation. Moreover, the limestone contains interbedded shales or shaly limestones and magnesian strata, which make development difficult and uncertain. Notwithstanding these unfavorable factors the Traverse formation is second only to the Dundee in economic importance and the inland deposits of high calcium stone form an enormous reserve for future use.

Bayport (Maxville) limestone. The Bayport limestone is the upper member of the Grand Rapids group of the Mississippian system. It underlies a belt around the central Coal Basin excepting on the southeast where it has been largely removed by erosion. The chief areas of exposures are in the vicinity of Bayport in Huron county, in Arenac

County, and near Bellevue, Eaton county. In Jackson county the Bayport limestone forms a capping on many of the pre-Coal Measure hills.

The formation consists of white to light gray and bluish limestone, locally very cherty and sandy, very calcareous sandstone and pure sandstone. The limestone varies from high calcium to high magnesian. Owing to its cherty or sandy character much of the limestone is suitable only for concrete or road metal. The high calcium beds are thin and only locally are sufficiently thick and pure to warrant development. At Bellevue, Eaton county, a high calcium bed from 12 to 15 feet thick, is utilized with the underlying shale for the manufacture of Portland cement.

CHAPTER V.

DISTRIBUTION, CHARACTER, AND DEVELOPMENT OF LIMESTONE DEPOSITS BY COUNTIES.

PRE-CAMBRIAN LIMESTONES,

Dickinson County.

Distribution. The Menominee Iron District of Michigan extends across the southern portion of Dickinson county. The Randville dolomite (Fig. 4) forms three distinct* belts roughly parallel with the longer axis of the district. The northern belt extends from section 11, T. 40 N., R. 30 W., southeast into section 10, T. 39 N., R. 28 W., where it is buried under Cambrian sandstone,—a distance of about 12 miles. The dolomite is exposed at only a few places. The middle belt begins just north of Lake Antoine in section 20, T. 40 N., R. 30 W., and extends east-southeast between Indiana and Cuff mines to Iron Hill in section 33, T. 40 N., R. 29 W., a distance of nearly seven miles. The exposures in this belt are large and very numerous. The southern belt extends from the Menominee River to Waucedah, at the east end of the district,—a distance of over eighteen miles. From Menominee River east to Sturgeon River the dolomite forms a range of high hills broken only at a few points. The tops of the higher hills are capped with Cambrian sandstone. Some of the exposures in the belt are very large. East of Waucedah the Randville dolomite is covered by Paleozoic rocks.

The Felch Mountain range† (fig. 3) is a belt, usually less than a mile wide, which extends in an E-W direction through the southern portion of T. 42 N., Rs. 28, 29, and 30 west, a distance of over 13 miles. The Randville dolomite underlies a large part of the range. The formation is well exposed in the vicinity of Randville, from which it takes its name and also in the vicinity of Felch Mountain.

In section 26, T. 42 N., R. 28 W., at the extreme eastern end of the range, the Northern Michigan Marble Company made an unsuccessful

*C. R. VanHise and C. K. Leith. Geology of the Lake Superior Region. Mon. LII, Geol. Surv. 1911, pp. 333-334.
†Mon. LII, U. S. Geol. Surv. 1911, p. 302; also H. L. Smyth, The Felch Mountain Range Mon. 36, U. S. Geol. Surv., 1899, pp. 374-426.

attempt to quarry marble. The Commissioner of Mineral Statistics of Michigan describes the deposit as follows: "Some of it is pure white, some variegated, shading from white to pink, green, gray, and purple, making beautiful slabs for wainscoting and interior work. It is somewhat granitic in nature; sufficiently so that the tests given foreign and New England marbles will not tarnish the highest polish. It is susceptible of a polish almost equal to onyx."

The Sturgeon River district* (fig. 3) occupies the western portion of T. 42 N., R. 27 W., and the central and northern portions of T. 42 N., Rs. 28, 29, and 30 W. The area of Randville dolomite occurs on the opposite limbs of a syncline which pitches to the northwest. The north arm extends from the western part of section 2, T. 42 N., R. 28 W., northwest into sec. 23, T. 43 N., R. 29 W., a distance of over six miles. The south arm extends slightly south of west into sections 9 and 16, T. 42 N., R. 30 W., a distance of over 14 miles. Exposures are few in number and both limbs of this fold disappear beneath a thick drift cover.

Character. The Randville formation is dominantly dolomite but contains a variety of other beds, including quartzite, slate, cherty quartz rocks, and corresponding gradational phases. The Randville grades downward into the underlying Sturgeon River quartzite. It is also cut by veins of quartz.

The dominant phase of the Randville dolomite is massive, homogeneous, fine grained, white, pink, blue, and buff dolomite, but even the purest beds contain interstratified siliceous quartzite and vein quartz. The abundance of vein quartz indicates extensive fracturing and crushing, followed by cementation resulting in many places in a breccia of dolomite fragments with a siliceous matrix. Owing to its generally siliceous and argillaceous character the dolomite is unsuitable for most purposes excepting crushed stone and building stone.

Locally the dolomite has been more or less completely altered to marble and attempts have been made to exploit it for this purpose but apparently the impurities and the unfavorable jointing renders it unsatisfactory.

An analysis by Geo. Steiger† of the ferruginous phase of the Randville dolomite from Hamburg Hill in Dickinson County is given below:

*Mon. LII, U. S. Geol. Surv. 1911, p. 300.
†Bull. 591, U. S. Geol. Surv. Analysis of Rocks and Minerals from the Laboratory of the U. S. Geol. Surv. 1880 to 1914, p. 236.

Analysis of Randville dolomite.

	No. 1.
SiO_2	36.71
Al_2O_3	5.34
Fe_2O_3	.35
FeO	3.37
CaO	15.11
MgO	10.78
Na_2O	.12
K_2O	2.40
H_2O −	.55
N_2O +	1.61
TiO_2	.27
CO_2	23.22
P_2O_5	.05
MnO	.23

The following test made by the Office of Public Roads, Department of Agriculture, Washington, D. C., shows that it is considerably harder than the average limestone but lower in toughness and cementing value:

Locality.	Weight lbs. per cu. ft.	Absorption lbs. per cu. ft.	Per cent of wear.	French coefficient of wear.	Hardness.	Toughness.	Cementing value.
Iron Mountain..........	178	0.40	4.06	8.6	19	8	25

Gogebic County.

Distribution. The Gogebic Iron Range extends from the Wisconsin line eastward to Gogebic Lake. The Bad River limestone* (fig. 6) is present only in a narrow belt from the northeastern corner of section 15, T. 47 N., R. 45 W., about one mile east of Sunday Lake, E-SE to section 22, T. 47 N., R. 44 W., a distance of about six miles.

Character. The Bad River limestone is heavily magnesian and locally approaches normal dolomite. It contains impurities in the form of silicate minerals such as tremolite, chlorite, and sericite, and free silica, in the form of quartz and chert. The free silica is partly intermingled with the dolomite and partly occurs in bands varying in thickness from a fraction of an inch up to many feet. The siliceous bands stand out in relief on weathered surfaces. The entire formation has been metamorphosed and thoroughly recrystallized. The texture ranges from fine† to coarse, and the color, from white to gray. The dolomite has no present industrial value. The following analysis by W. F. Hildebrand of the U. S. Geological Survey shows the siliceous and heavy magnesian character of the limestone.

*C. R. VanHise and C. K. Leith. Geology of the Lake Superior District, Mon. LII, U. S. Geol. Surv. 1911, p. 228.
†R. D. Irving and C. R. VanHise. The Penokee Iron Bearing Series of Michigan and Wisconsin, U. S. Geol. Surv. 1892, p. 130.

Analysis of Bad River Limestone.

Analysis No.	Location.	SiO_2.	Fe_2O_3.	FeO.	$CaCO_3$.	CaO.	$MgCO_3$.
2	Sunday Lake S. E. ¼, Sec. 18, T. 47 N., R. 44 W..........	3.07	.09	.86	....	29.72	....

Analysis No.	Location.	MgO.	H_2O.	CO_2.	Cl.	Total.
2	Sunday Lake, S. E. ¼, Sec. 18, T. 47 N., R. 44 W.........	19.95	.30	45.31	trace	99.45

Iron County.

Distribution. In the Iron River Iron District the limestone formation is known as the Saunders formation and in the Crystal Falls Iron District, the Randville dolomite.

In the Iron River District the Saunders formation* (fig. 5) occurs in a belt of varying width across the southern part of the district in a general direction a little north of west. It is well exposed at Sheridan Hill in sec. 20, T. 42 N., R. 35 W. and vicinity. The belt owes its altitude to the more resistant character of the Saunders formation.

Character. Cherty dolomite is dominant but the formation also includes beds of massive white and pink dolomite, quartzose dolomite, impure carbonate slates, quartzites, and talcose slates. The rock is exceedingly brecciated in the vicinity of Sheridan Hill and crushed and fractured cherty fragments are imbedded in the greatest confusion in secondary infiltrated silica and carbonate, silica being dominant. In the Saunders ridge masses of almost pure quartz are associated with pure massive white dolomite and banded chert and cherty dolomite. Due to their more resistant character, the chert bands stand out prominently on weathered surfaces and give a ribbed appearance to the rock. Every gradation from dolomite to pure silica may be observed but generally when the chert content becomes important it shows a tendency to segregate from the dolomite in bands.

Analysis No. 3 by Prof. A. C. Clark of the Michigan Agricultural College is of the purer phase of the dolomite and No. 4 is of a typical specimen from the ferruginous dolomitic slate phase.

*R. C. Allen, The Iron River District. Monograph LII, U. S. Geol. Surv. 1911, p. 310; also Publication 3, Geol. Ser. 2, Michigan Geol. Surv. 1910, The Iron River Iron Bearing District of Michigan, pp. 36-44.

Analyses of Saunders Dolomite.

	3.	4.
SiO_2	6.10	25.3
Fe_2O_3	.49	3.25
Al_2O_3		13.78
FeO	....	2.93
CaO	29.33	17.28
MgO	19.98	7.86
MnO	....	trace
CO_2	43.90	24.50
Na_2O	....	.42
K_2O	....	2.68
N_2O	.07 (at 105°)	2.04
H_2O	.05 (at 115°)	

Distribution. In the Crystal Falls district the Randville dolomite (fig. 2) completely surrounds a large oval or dome like anticline of Archean rocks northeast of the city of Crystal Falls. The longer diameter of the oval has a general N-NW direction. The formation is exposed on the east side of this fold in the vicinity of Michigamme Mountain, sec. 10, T. 43 N., R. 31 W., and northwest into sec. 19, T. 46 N., R. 32 W., a distance of nearly 18 miles. On the west side of the fold the dolomite is not well exposed. On the east the belt is about a half mile wide and the thickness of the dolomite is about 1500 feet.

Character. The formation ranges from coarse "sugary" marbles, in places very pure, but usually filled with secondary silicate minerals, to fine grained, little altered limestones, which locally grade into dolomitic sandstones and shales. The usual colors are white but various shades of pink, light and deep blue, and pale green are not uncommon. Some of the varieties are oolitic.

Analyses No. 5, 6, and 7, by R. J. Forsyth, are of Randville dolomite from the Michigamme Mountain region. Nos. 8, 9, and 10, by G. B. Richardson are of samples from localities unknown. No. 8 represents the pure dolomite, Nos. 5 and 6 the slaty phases, and No. 10 siliceous dolomite.

Analyses of Randville dolomite.

	5.	6.	7.	8.	9.	10.
Insoluble in HCl	14.25	9.34	....	2.0	9.7	29.1
Fe_2O_3	11.15	12.57	5.38	1.2	2.1	2.1
Al_2O_3						
$CaCO_3$	47.18	45.98	36.60	53.2	48.9	39.3
$MgCO_3$	18.48	19.22	16.36	42.3	38.0	27.7
Total	....	....	....	98.7	98.7	98.3

This formation is suitable only for road metal and ballast.

Marquette County.

Distribution. The Kona dolomite* of the Marquette Iron District takes its name from the Kona hills east of Goose Lake. It forms a westward facing U (fig. 1) in the eastern part of the district with the northern arm ending near Teal Lake and the southern arm on the south side of Goose Lake. The northern very narrow arm extends from Mt. Mesnard, in section 35, T. 48 N., R. 25 W., about three miles south of the city of Marquette nearly due west for a distance of about 10 miles. The southern arm, due to transverse folding, is much wider and very irregular in outline and extends southwest to the foot of Wewe hills, a distance of over seven miles. The exposures are usually in the form of sharp and abrupt cliffs, cut by ravines and drift filled valleys, and are abundant in the vicinity of Kona Hills in sections 15, 17, 23, T. 47 N., R. 25 W.

Character. The formation is cherty dolomite containing interstratified layers of slate, graywacke, and quartzite, and gradational phases between the various mechanical sediments and the pure dolomite. The dolomite beds vary in thickness from a few inches to many feet thick and locally form only a third to a half of the formation. The purest of the dolomite beds contain thin cherty layers mingled with mechanical sediments. The texture of the dolomite varies from very dense grained to very coarsely crystalline, approaching marble. The color varies from nearly pure white to pink and red or dark brown. The layers of siliceous and argillaceous material also show a wide variation in color, hence the rock ledges differ greatly in appearance.

The dolomite has been greatly fractured and brecciated, though in most cases the fracturing is so minute as not to be recognizable except under the microscope. The brecciation in the layers of quartz, slate, and graywacke is much coarser. After brecciation the fragments were cemented together by coarsely crystalline quartz or dolomite, or both together. The bands and fragments of siliceous material stand out as ridges or nodules on weathered surfaces giving a very rough and jagged appearance.

Composition. The purer phases of the rock are heavily magnesian, generally approaching normal dolomite. The abundance of siliceous, argillaceous, and ferruginous impurities renders it of little value except for road metal, ballast, and rough building stone.

Trap rock, owing to its superior hardness, toughness, and high cementing value makes the best known road material. Because of

*C. R. VanHise and C. K. Leith. The Marquette Iron District, Mon. LII, U. S. Geol. Surv. 1911, p. 258; also C. R. VanHise, The Marquette Iron Bearing District, Mon. XXVIII, U. S. Geol. Surv. 1897, p. 240-256.

its fire resisting qualities, it is also much superior to limestone as an aggregate in concrete mixtures. Marquette county has an abundance of trap rock, hence the beds of dolomite probably will never be of much economic value as a source of crushed stone.

Numerous projects have been started for developing the marble-like phases of the Kona and Randville dolomites, but thus far nothing has come of them. The vari-colored crystalline portions when polished are said to be very beautiful, but it is probable that the impurities would result in a large amount of waste in quarrying. Moreover, many of the layers of argillaceous and siliceous material are schistose or slaty, thus tending to produce parting planes. For these reasons it is doubtful that the pre-Cambrian dolomites are susceptible of development for marble or building stone.

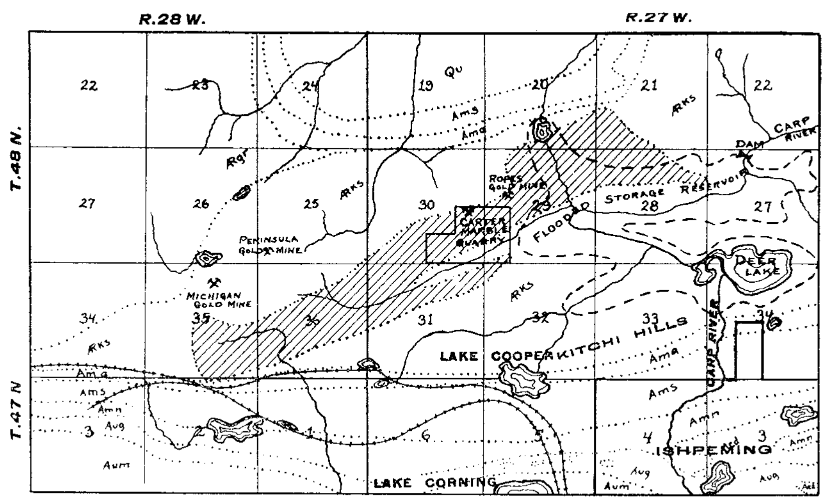


Figure 10. Map showing the distribution of the peridotites northwest of Ishpeming, Marquette county. (After Van Hise, Bayley and Smyth, Monograph 28, U. S. Geological Survey).

Verde antique marble. There are, however, in Marquette county certain peridotite rocks,* composed chiefly of olivine, now largely altered to serpentine and dolomite, to which the name *verde antique* marble has been applied. Northwest of Ishpeming a belt of altered peridotite (fig. 10) about 4½ miles in length extends from the southern part of sec. 21, T. 48 N., R. 27 W., southwest into the southeastern part of sec. 35, T. 48 N., R. 28 W. There are a number of separate exposures, the larger ones being from 1 to 3 miles long.

In some places the rock is almost wholly dolomite, in others it is a calcareous or dolomitic serpentine. The serpentine phase predominates.

*C. R. VanHise. The Marquette Iron Bearing District, Mon. XXVIII, U. S. Geol. Surv. 1897, pp. 183-186.

The dolomite generally occurs as veins cutting the serpentine and in ill-defined bands bordering cracks and joint planes. The serpentine varies in color from light to dark green with shades of olive but the dolomite is generally white. The rock takes a high polish and the intricate veining of dolomite produces very beautiful effects.

The rock is said to be very massive and the numerous cliffs and knob-like exposures afford very favorable quarrying conditions. The Michigan Verde Antique Company, Ishpeming, Michigan, is opening a quarry in sec. 30, T. 48 N., R. 27 W., about five miles northwest of Ishpeming. Polished slabs of stone from this quarry are beautifully veined and colored, equal or superior in polish or coloration to much of the *verde antique marble* now on the market.

Analyses Nos. 15 to 17, made by Whitney* in 1859, are partial analyses of serpentine from Presque Isle and No. 18 of peridotite† from the vicinity of Opin Lake, 1220 paces north, 500 paces west of the southeast corner, section 27, T. 48 N., R. 27 W.

Analyses of Serpentine and Peridotite.

	No. 15.	No. 16.	No. 17.	No. 18.
SiO_2	36.95	37.25	....	39.37
Al_2O_3	....	....	....	4.47
Fe_2O_3	16.50	6.75	12.90	4.96
FeO	....	14.14	19.52	9.13
CaO	....	....	....	3.70
MgO	33.07	28.67	14.82	26.53
MnO	....	....	....	.12
TiO	....	....	....	.66
Cr_2O_3	....	....	....	.68
NiO	....	....	....	.21
SrO	....	....	....	trace
BaO	....	....	....	trace
K_2O	....	....	....	.26
Na_2O	.97	1.16	....	.50
H_2O, below 110°	10.40	10.89	....	.87
H_2O, above 110°	....	....	....	7.08
P_2O_5	....	....	....	.17
CO_2	....	....	....	1.23

PALEOZOIC LIMESTONES.

Alger County.

Distribution and Character. The Beekmantown (Calciferous) sandstone forms a sinuous belt across the central portion of Alger county from the southwest to the northeast. It is well exposed in the vicinity of Chatham, Alger county, especially along the upper course of Au Train River. It is also exposed south of Munising. Analyses Nos.

*J. D. Whitney, Notice of new localities and interesting varieties of minerals in the Lake Superior region, Am. Jour. Sci., Vol. XXVIII, 1859, p. 18.

†C. R. VanHise. The Marquette Iron Bearing District, Mon. XXVIII, U. S. Geol. Surv. 1897, p. 186.

19 to 23 show that locally it is a very sandy dolomite. In places the sand content is low and quite possibly in some places it is sufficiently pure for use as a basic lining of furnaces. The stone is sufficiently massive and durable for use as building stone, but its distance from markets and the abundance of other stone equally suitable for building purposes nearer good markets make it of no present importance for such purposes.

Alpena County.

Distribution. The Traverse* formation (figs. 9 and 11) occupies the northeastern half of Alpena county and the Antrim shale, the slightly smaller southwestern half. Rock is at or near the surface over most of the northeastern half except near the western margin. The Long Lake, or Lower Traverse series, the Alpena, or ''Middle'' limestone, and the Thunder Bay or Upper Traverse series form three roughly parallel belts extending in a general northwest-southeast direction across the eastern half of the county. The limestones and shales of the Long Lake series cross the northeastern corner from the vicinity of Misery or Little Thunder Bay into Presque Isle county and they can be definitely traced as far northwest as Rogers City and Black Lake. The Alpena series forms a belt between 4 and 5 miles wide extending from North Point, Thunder Bay peninsula, into Presque Isle county and across the central part of Presque Isle county in the vicinity of Onaway into the central portion of Cheboygan county. The Upper Traverse shales and limestones occupy the southwestern belt, apparently 6 miles or more in width, which extends from Partridge Point northwest into Presque Isle county.

Long Lake Series. The Long Lake group consists of alternating beds of limestone and shale. Most of the limestone is more or less argillaceous, and some of it is more nearly shale than limestone.

The shale is generally very calcareous and almost every variety of rock from pure limestone to pure shale may be found. Many of the beds of limestone are also very bituminous and fossiliferous. Most of the black limestones are locally extremely fossiliferous. The most notable of these fossiliferous beds occurs at the base of the series and lies directly over the Bell shale. At Rockport (see Rockport quarry) this bed is 25 to 30 feet thick.

Some of the limestones are very massive and resistant to erosion and give rise to roughly parallel lines of prominent escarpments facing northeast with long gentle slopes on the southwest.

The shales and more argillaceous and thin bedded limestones occupy the valleys between the lines of escarpments. The bottoms of some of

*See previous chapter for general description of the formation.

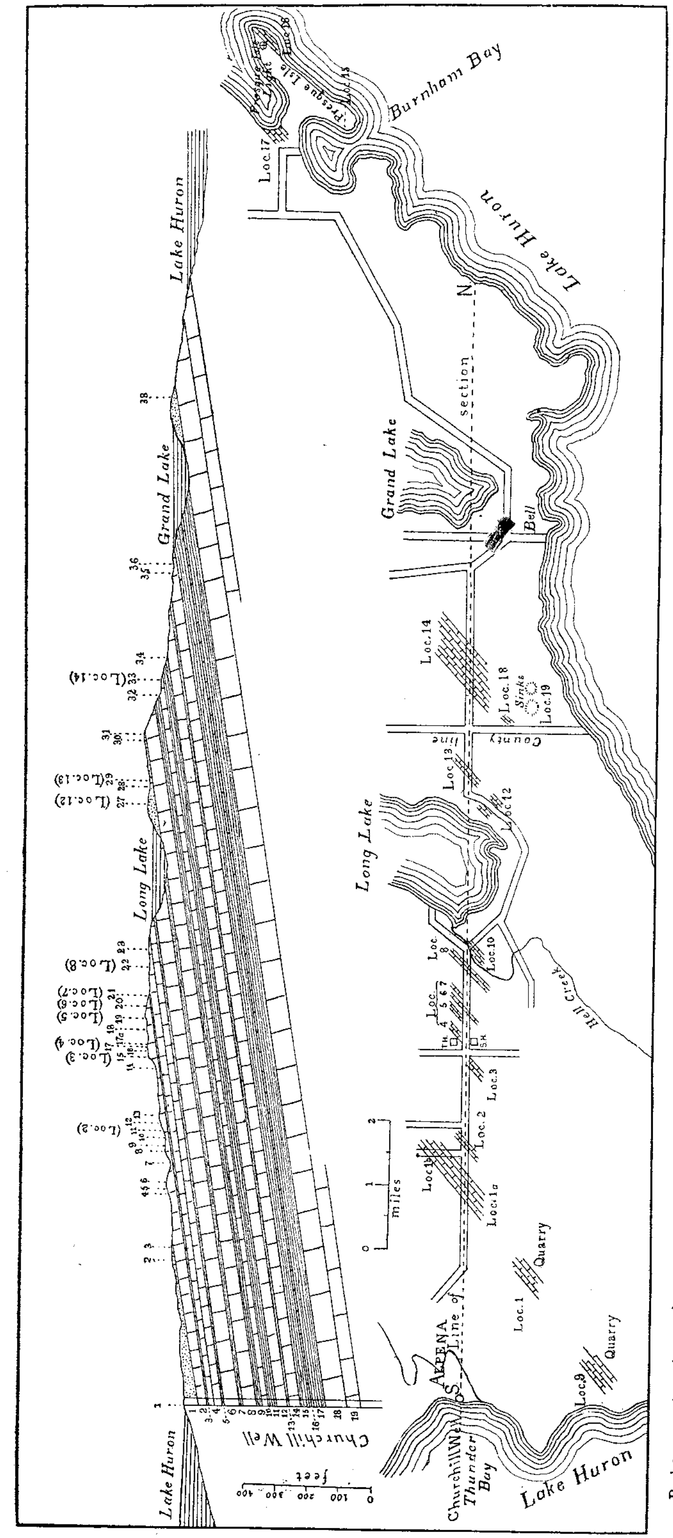


Figure 11. Geologic section from Alpena, Alpena county, north to Lake Huron. (After A. W. Grabau).

Bed 1 = sand and gravel.
Bed 3 - thin shale bed.
Bed 5 - " " "
Bed 13 - " " "
Bed 16 - thin limestone bed.

the valleys are occupied by lakes and swamps. The numerous escarpments afford very favorable opportunities for quarrying but unfortunately the argillaceous character of much of the limestone and the occurrence of seams and beds of shale make most of the beds of little economic value. It is possible, however, that some of the argillaceous limestones may be found suitable for the manufacture of natural cement.

The Alpena Portland Cement Co. obtained their supply of shale from an exposure in section 18, T. 32 N., R. 9 E. Several shale beds from a few inches to 18 feet thick and considerable argillaceous limestone was struck in test holes in the western part of sections 20, 30, 31, and 32 of the same township. Shale and argillaceous limestone was also encountered in test holes just across the line in southeastern Presque Isle County. Very argillaceous limestones are exposed at Beck's Mill at the falls of Hell Creek in section 23, T. 32 N., R. 8 E., and along the highways to the south and east of Long Lake, on Thunder Bay Island, at El Cajon Beach (sec. 10, T. 31 N., R. 9 E.), and Misery or Little Thunder Bay, and at many other places. It must not be inferred, however, that none of the exposures contain pure limestone. On the contrary in many of the exposures there are massive beds of high calcium limestone under very favorable conditions for quarrying, but the relatively thin sections of marketable limestone in most of these exposures do not permit of quarrying operations on a large scale. There are numerous deposits of pure limestone sufficiently large to supply the needs of lime burners or the local demands for crushed stone, etc. The day of the small operator and crude methods, however, is past and it is only under favorable local conditions that small operators can compete with the many limestone products companies now operating on a large scale with the most efficient methods and equipment.

Quarries and Localities.

Rockport. At Rockport, the Great Lakes Stone & Lime Company have recently opened a large quarry in the thick, massive and extremely fossiliferous bed at the base of the Long Lake series. The bed is from 25 to 30 feet or even more thick and forms an almost continuous bluff extending from the north line of section 6, T. 32 N., R. 9 E., southeast along the shore of Lake Huron for more than a mile. The bed rests directly on the soft blue Bell shale, the bench between the lake and the bluff being formed largely of the shale. From the top of the bluff the surface rises gently to the west for about a third of a mile where there is a second terrace. Farther inland there are other terraces.

These upper terraces are composed of higher lying beds of the Long Lake series and undoubtedly include beds of shale and argillaceous limestone.

The Rockport Limestone is essentially stromatopora, coral, etc., with a matrix of dark or black crystalline and very bituminous limestone. The stone contains from about 94 to nearly 98 per cent of calcium carbonate. Analyses Nos. 24 to 29 show the general character of the stone. It is said to be especially well adapted for flux. Owing to its very bituminous character, however, it does not burn well. The bituminous pieces are apt to have a dark carbonaceous core but the white masses of stromatopora, coral, etc., burn well and make excellent chemical lime.

A natural escarpment parallel to the lake shore and relatively thin overburden afford exceptional advantages for development. Due to the presence of a transverse drift filled ravine the quarry face has been developed only along the northern portion of the bluff. Later it is planned to extend the workings to the southeast beyond the ravine. A harbor has been dredged, docks erected, and a modern crushing plant has just been completed with a rated capacity of over 1000 tons per hour.

The floor of the quarry is formed of the soft blue shales of the Bell member. At the top of this there is a thin, very fossiliferous bed. Below this the shale is apparently non-fossiliferous and homogeneous and probably will be found suitable for various brick and tile products. With the progress of quarrying operations a large supply of shale will become available under exceptionally favorable quarrying conditions.

El Cajon Beach. At El Cajon Beach (sec. 10, T. 31 N., R. 9 E.) dark argillaceous limestones form a prominent flat topped bluff along the Lake Huron shore 40 to 50 feet above the water. There is practically no overburden on the top of the bluff, which faces a beautiful bay about a half mile wide. The bay is almost land locked by a barrier beach. About 15 years ago the El Cajon Portland Cement Company planned to build a plant for the manufacture of cement from the argillaceous limestones. A quarry was opened and hydraulic lime or cement was burned for making the foundations of a large plant. The company failed and the project was abandoned. The foundations are now crumbling to decay.

The favorable quarrying conditions here and a good harbor afford exceptional advantages for development.

The lower beds are covered with talus from the bluff. The visible beds are dark and argillaceous, containing over 6 per cent of alumina and iron and nearly 33 per cent of silica. The magnesia, however, is low. Analysis No. 42 was made from a composite sample and shows the argillaceous character of the beds.

Misery (*Little Thunder*) *Bay*. At the head of this inlet there is a large sink hole known as the "bottomless hole," from which strong springs arise. The western wall of this sink is a vertical cliff composed of thin bedded limestones separated by shale partings. Large masses are continually breaking off and falling into the bay. At present there is a large crevice from a few feet to 10 feet wide extending roughly parallel to and at a short distance from the shore for several hundred yards. In this crevice alternating beds of pure limestone and argillaceous limestone, typical of the Long Lake series, are exposed. Were the stone of commercial grade the favorable quarrying conditions and the deep natural harbor would invite development.

Exposures of the Long Lake series are very numerous throughout much of the belt and are characteristically shaly and argillaceous. Analysis 90 is of a compact gray limestone* near the top of the series, exposed on the Long Lake road along the east line of sec. 27, T. 31 N., R. 8 E.

So far as known the Rockport limestone at the base of the series is the thickest bed, free from shale and argillaceous matter. It is probable that exposures of this bed in Alpena county are confined to the vicinity of Rockport. Northwest in Presque Isle county the bed apparently comes to the surface some distance west of Grand Lake.

Alpena Limestone. The Alpena limestone is a group of very massively bedded gray and buff crystalline high calcium strata characterized in the Alpena region by reefs of white coral. The group includes some interbedded shale and shaly limestone, locally very cherty and bituminous. Some of the upper beds contain more or less magnesia and locally the reef limestone contains magnesian or dolomite "chimneys."

Michigan Alkali Company quarry. The Alpena limestone is best exposed in the vicinity of Alpena, particularly in the large quarry (Pl. II A) of the Michigan Alkali Company in the eastern part of the city. This quarry consists of a roughly circular opening, the area of which is said to be between 60 and 70 acres. Quarrying is conducted on two levels. The face on the upper level varies from about 40 to nearly 50 feet. The lower level was just being developed in 1914 and the working face was then only about 30 feet and wholly below lake level. A sump, however, had been excavated below the floor of the

*A. W. Grabau. Stratigraphy of the Traverse formation, Ann. Rept. 1901, Mich. Geol. Surv., p. 179.

lower quarry so that the height of the exposure was between 80 and 90 feet. The great size and depth of the quarry affords exceptional opportunity for study of the reefs and intervening beds. The reefs are mounds and ridges of very white coral limestone. Some of the mounds are more or less connected, others are isolated. More commonly they are united and form more or less continuous and anastomosing system of ridges. The mounds and ridges can be traced for considerable distances in the vicinity of Alpena.

The beds dip away from the reefs at rather steep angles but at short distances they flatten out and become nearly horizontal. Many of the beds are continuous from one reef to the next. The fossil materials of the reefs interfinger with the beds and locally masses of reef material occur between the beds at some distance from the parent reef.

The following is a section of the southeastern side of the upper quarry midway between two coral reefs and represents only the massive crystalline and less fossiliferous beds:

Section in Upper Quarry.

No. of Bed.		Thickness, ft.	Depth, ft.
1.	Hard buff crystalline limestone. ($CaCO_3$ 90.43%, $MgCO_3$ 8.31%, Anal. No. 30.)	4+	4+
2.	Grayish buff crystalline limestone. Similar to No. 1. ($CaCO_3$ 90.43%, $MgCO_3$ 8.31%, Anal. No. 30.)	2	6
3.	Hard grayish buff crystalline limestone with some bituminous streaks. ($CaCO_3$ 94.54%, $MgCO_3$ 2.61, Anal. No. 31.)	9	15
4.	Shaly and cherty limestone.	2	17
5.	Dark gray crystalline limestone with bituminous streaks. ($CaCO_3$ 92.38%, SiO_2 4.03, Anal. No. 32.)	4	21
6.	Shaly, fossiliferous, and cherty limestone. Much soft shale.	3+	24
7.	Light buff crystalline limestone. ($CaCO_3$ 95.58%, Anal. No. 33.)	3	27
8.	Dark gray crystalline limestone with shaly streaks and chert nodules.	4	31
9.	Buff crystalline limestone.	2	33
10.	Grayish buff crystalline limestone similar to No. 2. ($CaCO_3$ 94.78%, Anal. No. 34.)	6+	39+

The following is a continuation of the section in the lower quarry. There is a gap between the two sections of 6 to 10 feet.

No. of Bed.		Thickness, ft.	Depth, ft.
	Missing	10+	49
11.	Dark crystalline and crinoidal limestone	3	52
12.	Dark bituminous limestone with interbedded coral masses	7	59
13.	Dark gray massive limestone with scattered heads of coral	8	67
14.	Crystalline limestone, with stylolitic structure ($CaCO_3$ 96.40% Anal. No. 35.)	5	72
15.	Dark fine grained bituminous limestone	4	76
16.	Argillaceous (?) limestone or limestone of inferior quality	....	....

The reefs vary from about 50 to nearly 100 feet wide, though measured from the extremities of some of the interfingering masses of coral which extend outward from the reefs the width is much greater.

The reef rock is generally very pure, in places, containing over 99 per cent of calcium carbonate. (Anal. No. 49). Locally there are heavily magnesian areas in the reefs, called magnesian or dolomite ''chimneys.'' Generally the stone in such areas is more or less stained yellow by iron and is extremely porous or sponge-like. Owing to its extreme porosity the magnesian stone is in great demand by paper manufacturers using the sulphite method.

The composition of the beds between the reefs varies vertically from bed to bed and horizontally in the individual beds. The upper beds in the Michigan Alkali quarry contain considerable percentages of magnesia (Anal. No. 30) and some of the middle ones are very siliceous or argillaceous. The interbedded shale and argillaceous limestone ordinarily would result in much waste material but this, together with the ''fines'' or limestone screenings is utilized for the manufacture of Portland cement by the Huron Portland Cement Company, whose plant is located on Thunder Bay a short distance from the quarry. Excepting the upper beds, the Alpena limestone is dominantly high calcium. The magnesian stone causes little trouble because in the process of quarrying it is mixed with so much of the exceptionally high calcium stone that its effect is barely noticeable in the quarry product.

Analyses Nos. 30 to 34 show the general character of the crystalline limestones on the southeast side of the upper quarry and No. 35 the limestone in the lower quarry. No analyses were made of the beds of shale and argillaceous and cherty limestone. Analyses Nos. 36 to 41 are of hand specimens from different beds in the quarry.

A large part of the select stone is shipped by boat to Wyandotte and Ford City for the manufacture of soda ash, bleach, caustic, etc. A

large amount of stone, including the ''fines'' or argillaceous screenings is also used in the manufacture of Portland cement. The remainder of the quarry product is disposed of for a variety of purposes.

Alpena Portland Cement quarry. The abandoned plant and quarries of the Alpena Portland Cement Company are near the shore of Thunder Bay about three-fourths of a mile east of the quarry of the Michigan Alkali Company, but at a lower level. On the occasion of the writer's visit the quarries were full of water and only the upper beds were accessible. Probably these beds are to be correlated with those in the lower quarry of the Michigan Alkali Company. The south face of the quarry is composed of reef limestone and other beds dipping away from it.

The prevailingly high calcium character of the stone is shown by analyses Nos. 43 to 62.

Richard Collins quarry. This is a small quarry operated for lime burning about two miles north of the Michigan Alkali Company's quarry. The opening is in dense, light gray, fragmental reef-limestone, in every way similar to the fragmental portions of reefs in or about the quarries of the Alpena Portland Cement Company and the Michigan Alkali Company. The high quality of the stone is indicated by analyses Nos. 63 to 65.

Owen Fox's quarry. This quarry is located about two miles north and slightly west of the Michigan Alkali Company quarry. The general dip* of the strata is 4 degrees to the south. In the eastern end the dip increases from 8 to 18 degrees, the steepest dip being in the easternmost portion where the abundance of corals indicate the neighborhood of a reef. On the southwest these beds are overlain by dark shaly limestones and bituminous shales with a rich coral and brachiopod fauna. Analyses Nos. 66 and 69 show the great purity of the unaltered Acervularia and Stromatopora limestone. The upper beds contain only 1.33 per cent of magnesia, but the lower ones 4.20 per cent.

*A. W. Grabau, The Stratigraphy of the Traverse Formation, Ann. Rept. Mich. Geol. Surv. for 1901, p. 176.

Analysis of Drill Core, Hole No. 38, Alpena.

On the East ½ of section 12, T. 31 N., R. 8 E.

B. H. Taylor, Carnegie Steel Co., Pittsburgh, Pa., 1909.

No. Anal.	Depth.	SiO_2.	Al_2O_3.	Fe.	$CaCO_3$.	CaO.	$MgCO_3$.	MgO.	Sul.	Phos.
93	6-11 ft..	5.72	2.97	.36	87.6	49.11	**2.40*	1.15	.193	.019
94	11-16 ft..	3.88	1.96	.56	89.4	50.63	*2.26*	1.08	.187	.018
95	16-21 ft..	2.90	1.45	.30	93.0	52.11	*1.96*	.94	.123	.017
96	21-26 ft..	3.72	2.30	.32	90.8	50.94	*2.11*	1.01	.183	.019
97	26-31 ft..	1.80	1.45	.22	93.6	52.58	*1.80*	.86	.217	.016
98	31-36 ft..	.50	.54	.46	90.0	50.51	*7.82*	3.74	.143	.005
99	36-41 ft..	.48	.65	.40	92.0	51.55	*6.02*	2.88	.207	.006
100	41-46 ft..	1.28	1.07	.32	94.4	52.95	*2.24*	1.07	.250	.019
101	46-51 ft..	6.10	3.54	.45	87.6	49.04	*2.21*	1.06	.385	.041
102	51-56 ft..	1.96	1.62	.38	93.4	52.34	*3.18*	1.52	.188	.020
103	56-61 ft..	6.16	3.44	.57	85.7	48.13	*3.80*	1.82	.484	.033
104	61-66 ft..	4.42	4.37	.36	86.6	48.56	*1.98*	.95	.876	.030
105	66-71 ft..	2.36	2.81	.35	90.0	50.33	*1.88*	.90	.320	.010
106	71-76 ft..	.58	.90	.24	96.0	53.86	*1.96*	.94	.259	.009
107	76-81 ft..	.34	.50	.23	97.0	54.41	*1.80*	.86	.155	.007
	Average Anal....	2.81	1.98	.37	91.2	51.14	....	1.37	.278	.018
108	81-86 ft..	1.58	.78	.66	91.8	51.48	*4.70*	2.25	.242	.006
109	86-91 ft..	3.18	1.91	.57	90.3	50.51	*3.43*	1.64	.242	.010
110	91-96 ft..	12.78	7.91	.72	73.7	41.30	*3.01*	1.44	.488	.021
111	96-98½ ft..	12.28	7.39	.74	74.8	41.91	*3.43*	1.64	.426	.018

*Figures in italics are calculated from original analyses.

Analysis of Drill Core, Hole No. 1, Alpena.

N. ½ of sec. 13, T. 31 N., R. 8 E.

B. H. Taylor, Carnegie Steel Co., Pittsburgh, Pa., 1909.

No. Anal.	Depth.	SiO_2.	Al_2O_3.	Fe.	$CaCO_3$.	CaO.	$MgCO_3$.	MgO.	Sul.	Phos.
112	2- 7 ft..	.42	.46	.42	96.5	54.05	1.84	.88	.015	.020
113	7- 12 ft..	1.00	.46	.66	96.2	53.93	1.50	.72	.075	.022
114	12- 17 ft..	2.94	1.49	.44	93.2	52.24	1.13	.54	.091	.013
115	17- 22 ft..	2.68	2.27	.38	93.5	52.47	.84	.40	.067	.014
116	22- 27 ft..	2.12	1.84	.38	93.5	52.47	1.96	.94	.072	.015
117	27- 32 ft..	.68	.52	.32	95.7	53.57	1.90	.91	.042	.018
118	32- 37 ft..	.86	.49	.34	95.7	53.57	1.96	.94	.071	.019
119	37- 42 ft..	1.66	1.37	.36	94.1	52.78	1.73	.83	.097	.018
120	42- 47 ft..	3.42	2.07	.30	91.3	51.26	1.65	.79	.150	.017
121	47- 52 ft..	3.42	2.55	.36	90.8	50.95	1.50	.72	.150	.020
122	52- 57 ft..	2.36	1.58	.24	93.5	52.47	1.50	.72	.110	.017
123	57- 62 ft..	3.12	1.81	.34	93.8	52.49	1.50	.72	.158	.015
124	62- 67 ft..	.84	.79	.26	94.6	53.00	1.50	.72	.150	.020
125	67- 72 ft..	.76	.21	.40	94.4	52.96	3.62	1.73	.116	.012
126	72- 77 ft..	.94	.58	.34	96.8	54.24	1.50	.72	.116	.008
127	77- 82 ft..	2.72	1.17	.34	96.8	54.24	1.96	.94	.166	.005
128	82- 87 ft..	3.74	2.28	.32	91.2	51.03	1.50	.72	.232	.040
129	87- 92 ft..	2.00	2.29	.36	93.5	52.36	1.50	.72	.197	.022
130	92- 97 ft..	1.98	1.45	.44	92.0	51.51	2.88	1.38	.280	.025
131	97-102 ft..	2.28	1.99	.40	93.4	52.29	1.69	.81	.333	.015
132	102-107 ft..	.44	.04	.28	97.6	54.72	1.61	.77	.100	.006
133	107-112 ft..	.36	.19	.26	96.0	54.36	1.61	.77	.167	.005
134	112-117 ft..	.68	.22	.24	96.4	54.00	1.71	.82	.146	.005
135	117-122 ft..	1.50	1.01	.36	94.0	52.60	1.96	.94	.247	.008
137	122-125 ft..	.54	.21	.22	97.6	54.72	1.50	.72	.107	.005
	Average	1.74	1.17	.35	94.4	52.95	....	.83	.138	.015
138	117-125 ft. Cuttings.	1.54	1.96	.52	....	52.36	....	.72	.240	.016

Gilbert Olson's quarry. This is a very small opening in S. E. ¼ S. W. ¼ sec. 18, T. 31 N., R. 9 E., formerly operated for lime burning. The stone is a light gray, dense grained, fragmental reef limestone similar to that in the Collins and Alpena Portland Cement quarries. The exposure forms a low mound adjacent to a swamp. Across the road the surface is much higher and limestone is exposed at many places in the S. W. ¼ sec. 18.

Other localities. The Alpena limestone is at the surface or under very light cover over large areas north and northeast of Alpena in sections 6, 7, and 18, T. 31 N., R. 9 E., and sections 1, 2, 11, and 12, T. 31 N., R. 8 E. Analyses Nos. 70 to 75 are from various exposures in this vicinity, the exact location of which are not known. Analyses 93 to 138 are of cores from two test holes in sections 12 and 13, T. 31 N., R. 8 E. In hole No. 1, which is in the vicinity of the Michigan Alkali quarry the limestone, to the depth of 125 feet, averages 94.4 per cent calcium carbonate. In hole No. 38 many of the beds are siliceous, argillaceous and comparatively low in calcium carbonate, though the magnesia exceeds 2 per cent in but three analyses. From 91 to 98 feet the silica and alumina form nearly 20 per cent of the rock.

The high average purity of the rock in the first hole may be due to its nearness to reef limestone and the relative impurity of the stone in the other to its greater distance from reef limestone. The bottom beds in hole No. 38 apparently belong to the Long Lake series. The depth of the pure limestone in hole No. 1 indicates that the Alpena stone is thicker than apparent in the Michigan Alkali quarry. It is obvious, however, that in the vicinity of Alpena, due to the great horizontal variation in the composition of many of the beds, drill holes do not always furnish conclusive evidence of the precise character of the limestone beds. Exposures are abundant north and northwest of Alpena along the elevated tract to the Presque Isle County line. Two miles north of Alpena on the Long Lake road near the southwest corner of sec. 35, T. 31 N., R. 8 E., there is an exposure of a highly fossiliferous limestone consisting chiefly of stems and joints of crinoids and of various bryozoa. Analysis No. 89 shows that it contains considerable silica. One mile north in a well drilled by E. S. Beal in the S. E. corner section 26, T. 31 N., R. 8 E., over 54 feet of solid limestone was penetrated.

Reef limestone is exposed in the N. E. corner of section 4, T. 31 N., R. 8 E., but, one-half mile east, light blue argillaceous limestone was encountered in a shallow well on the Chas. Allen farm near the S. ¼ post of sec. 33, T. 32 N., R. 8 E. On the Leon Mainville farm S ½ S. E. ¼ sec. 29, T. 32 N., R. 8 E., reef limestone is exposed over a large area and according to Mr. E. S. Beal, a man of wide experience in drilling, 154 feet of good limestone was penetrated in a well across the road near the S. W. corner section 28, the hole ending in black shale. The Alpena series is well exposed in numerous sinks in the vicinity of Bolton. The following section is exposed in a sink in the N. W. corner of section 14, T. 32 N., R. 7 E.:

	Feet.
Crinoidal limestone	1
Massive gray limestone	2
Acervularia limestone	4
Dark crystalline limestone	4
Very shaly and bituminous limestone	1
Gray crystalline limestone	2.5
Shale seam	0.5
Gray crystalline limestone	3
Talus	50

A similar series of beds is exposed in another sink about 120 rods east and slightly south. Mr. E. S. Beal drilled a well with a core drill 137 feet in depth near the northwest corner of section 16, T. 32 N., R.

8 E. Four feet of black shale was struck at 54 feet, all the rest of the rock being limestone.

The sections exposed in the sinks and penetrated in the wells indicate that the Alpena limestone series is thicker to the northwest or that the upper portion of the Long Lake series becomes less shaly west of Long Lake. No analyses were made of the cores from the wells, but if the stone is low in magnesia there is a large reserve of high grade limestone in the northern portions of Alpena and Maple Ridge townships.

M. J. Griffin quarries. These quarries, now abandoned, are about one and a half miles northwest of Bolton, near the Detroit and Mackinac railroad in the S. E. ¼ section 5, T. 32 N., R. 7 E. The quarries are small and only about 8 feet of stone is exposed. Near the top the beds are extremely fossiliferous. The top bed is composed of a mass of crinoid stems. At the bottom of this bed there is a 6 inch stratum composed almost entirely of brachiopods. Near the bottom of the section the beds are dark and contain argillaceous and bituminous material. The stone is very pure and well suited for chemical and fluxing purposes as indicated by analyses Nos. 76 to 88.

Numerous exposures of the Alpena series occur in the vicinity of Bolton on the side of the valley of Thunder Bay river. Reef limestone occurs in the N. E. ¼ section 20, T. 32 N., R. 7 E., a mile and a half south of the station. This evidently belongs to the upper portion of the series since the shaly Upper Traverse series occupy the valley of the Thunder Bay river to the southwest.

Summary. The Alpena series in Alpena County is essentially high calcium limestone containing reefs of great purity and beds of massive crystalline gray to buff limestone with some interbedded shale and argillaceous and cherty limestone. The elevated tract extending from Thunder Bay peninsula northwest into Presque Isle County is underlain chiefly by the Alpena series and contains an enormous reserve of easily accessible high calcium limestone under very favorable quarrying conditions. The inland situation, however, of most of the deposits is a factor unfavorable to their immediate development. The extensive beds of high calcium limestone in the vicinity of Alpena located near cheap water transportation are sufficient to last for a great many years.

*Thunder Bay or Upper Traverse Series.** The Upper Traverse series is not so well exposed as the middle and lower series. It consists of shale and limestone, much of the latter very argillaceous.

*A. W. Grabau. Stratigraphy of the Fraverse Formation. Ann. Rept. Mich. Geol. Series for 1901, p. 192.

Quarries and localities.

Dock Street, Alpena. A bed of clay about 6 feet in depth occurs in a test well on Dock street, Alpena, overlying the Alpena limestone. Above the clay is a bed of limestone only a few inches thick.

Fletcher Dam. Limestone is exposed at many places along Thunder Bay river, especially along the upper branches. At Fletcher Dam, section 7, T. 31 N., R. 8 E., formerly the location of Broadwells sawmill and dam, reef limestone occurs in the bed of the river. This is now concealed by the dam. Below the dam 6 feet of limestone and calcareous shale are exposed. Analysis No. 138 of this so called ''hydraulic limestone'' was made by N. H. Winchell about 1870. According to Winchell's unpublished field notes there are numerous exposures chiefly in sinks and cracks in T. 32 N., Rs. 6 and 7 E. In section 2, T. 31 N., R. 7 E. hydraulic cement was burned by a man named Trowbridge. The Boom Company's dam on Thunder Bay river in section 2, T. 31 N., R. 7 E., was formerly the site of Trowbridge's mill. A cliff of shale 15 feet in height occurs along the east bank. The lower part is very calcareous. Above the shale there is about a foot of subcrystalline limestone, apparently identical with the thin limestone above the Dock street clay in Alpena. Below the dam on the right bank of the river 6 feet of very calcareous shale is exposed.

Warner brick yard. Calcareous shales with thin bands of argillaceous limestone are exposed at Warner's old brick yard in the southwestern part of Alpena. The following analysis shows the calcareous nature of the lower blue portion of the exposures:

**Analysis Warner's Brick Yard Clay.*

No. Anal.	SiO_2.	Fe_2O_3.	Al_2O_3.	$CaCO_3$.	CaO.	$MgCO_3$.	MgO.	CO_2, organ., Alk., and loss.
140........	54.46	4.66	17.26	*11.79**	6.60	*5.92**	2.82	14.20

*Calculated from original analysis.

Stony Point. A cliff of limestone and shale 12 feet in height is exposed at this place. The upper 4 or 5 feet is composed of limestone with shaly partings and the lower portion of shale with thin bedded calcareous layers. The top bed of the Upper Traverse series is a brownish granular dolomite.

Summary. The foregoing data indicates that the Upper Traverse series is too shaly and argillaceous to be of much commercial importance

as a source of limestone. It is possible, however, that locally the argillaceous limestones and shales may be adapted for making natural cement.

Arenac County.

Distribution. The Grand Rapids series occupies the northeastern half of the county. The Lower Grand Rapids, or Michigan series, underlies that portion of the county north of a line drawn from the mouth of Au Gres river west-northwest to the point where the river intersects the north county line. The Upper Grand Rapids or Bay Port (Maxville) forms a belt from about 2 to 4 miles wide extending from Point Au Gres on Saginaw Bay to the northwest corner of the county. The western half of the county is heavily drift covered, hence exposures of limestone are confined to the eastern portion.

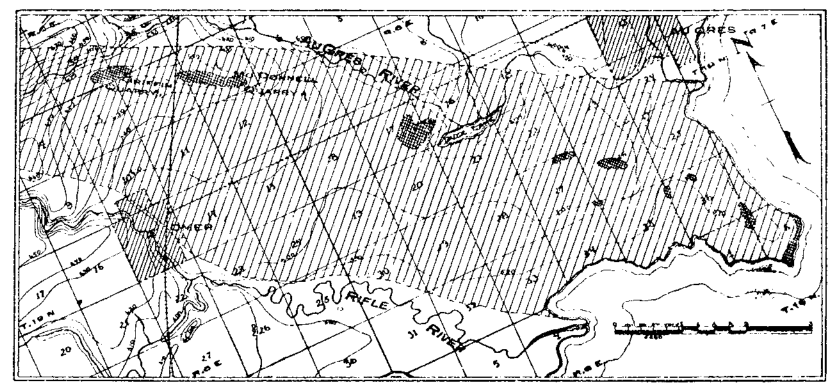


Figure 12. Map showing the distribution and the chief areas of exposures of the Bayport limestone in Arenac county. Black triangles indicate quarries.

The principal exposures of the Bayport limestone are along a low broad ridge (fig. 12) extending from Point Au Gres northwest into the southeast portion of section 34, T. 20 N., R. 5 E. Exposures of the Michigan series are almost entirely confined to a broad low ridge in Ts. 19 and 20 N., R. 20 E., lying between Lake Huron and Au Gres River and extending south-southwest roughly parallel to the lake shore.

The Bayport formation* in Arenac County is composed of limestone, generally very sandy or cherty, thin bedded, and full of fossils, and hard gray or white sandstone. The thickness of the member at Omer is apparently about 45 feet and the high calcium layers form only a small fraction of this.

*W. M. Gregory. Geology of Arenac County. Pub. 11, Geol. Ser. 8, Mich. Geol. and Biol. Surv., 1911, pp. 47-52.

Quarries and Localities.

Pt. Au Gres. An 8 foot bluff of limestone extends along the lake shore at Pt. Au Gres for a half mile. The upper 5 feet is sandy and contains traces of green shale and the lower 3 feet is light gray, very brittle limestone with nodules of chert and fossils. The stone was formerly quarried for building stone and it has proven very resistant to weathering. To the northwest of Point Au Gres limestone is exposed under light overburden in several places in sections 27, 28, 35, and 36, T. 19 N., R. 6 E. In section 27, as shown by the schoolhouse well, the limestone is only 5 inches thick and is underlain by 3 to 4 feet of brown sandstone and 7 feet of dark grayish limestone with sandy streaks.

Duck Lake quarries. Limestone is a'so reported to occur south of Duck Lake and on the west side of the lake. In sections 16 and 17, T. 19 N., R. 6 E., it forms a low flat ridge in which two or three small quarries have been opened for building stone. The Omsted quarries are in the southeast corner of section 17 where there are about 8 acres of limestone under light drift cover. The quarries consist of two small openings. In the one near the road a face of about 4 feet of very cherty limestone is exposed. In the other, located some 20 rods southeast, the upper 3 feet is very cherty. This is underlain by one foot of very shaly limestone, a 4 inch layer of fossils, and an 8 inch layer of dark lithographic limestone. Analysis No. 141 shows that the stone is a siliceous dolomite. The generally sandy, cherty, and magnesian nature of the limestone in this vicinity makes it unsuitable for most purposes excepting building stone or crushed stone for road making, concrete and ballast.

McDonnell quarry. The Jas. McDonnell quarry is located in the southeast corner of section 1, T. 19 N., R. 5 E., about 3 miles northeast of Omer at the southeastern end of a ridge of limestone which extends northwest into section 2. The quarry is operated for burning hot lime. The stone is obtained from a 3 foot layer of high calcium limestone underlain by 6 inches of argillaceous sandstone. The upper bed is a very hard dense grained white to light gray limestone. It is much fractured and disturbed by glacial action and tree roots, and stained by infiltrated clayey matter.

In 1902 Thomas Burt, former owner of the quarry, made a test boring in the bottom of the quarry, penetrating the following strata:

	Feet.	Inches.
Arenaceous limestone	6	....
Sandstone	20	....
Blue limestone	100	....
Dark shale	0	2
Gypsum	10	....

The overburden consists of a thin covering of loam and clay which is removed by shovels. The stone is pried out by bars and picks, loaded by hand on cars and drawn to the top of the kiln by horses. Wood is used for fuel. The lime is of good quality and is sold chiefly for chemical purposes and to supply the local needs.

The area underlain by the high calcium stone is unknown but it appears that it extends northwest across the adjoining property of Geo. Averill. In such case the area of available high calcium stone is between 20 and 25 acres. Analyses Nos. 141 and 142 show that it contains less than 2 per cent of magnesium carbonate. The relatively high silica content of the first analysis is due largely to the infiltrated clay and sand.

M. J. Griffin quarry. This quarry is located about three-fourths of a mile northwest of the McDonnell quarry near the opposite end of the same ridge. The quarry was operated largely for supplying crushed stone for paving and road ballast, but it has been abandoned for many years. The openings cover several acres but are shallow, varying from 4 to 6 feet in depth. The following section shows the general character of the beds:

Section in M. J. Griffin quarry.

	Feet.	Inches.
1. Gray to buff thin bedded limestone with some chert or flint nodules	2	....
2. Buff gray and gray very sandy and very cherty limestone. The bed contains many nodules of chert and flint irregularly distributed and 15 to 20 per cent of fine quartz sand	3	....
3. Black or dark limestone with shaly seams	0	2 to 6
4. Gray limestone	1+	....

Very cherty limestone is also exposed in an old quarry just across the road in section 2 where lime was formerly burned in an old set kiln.

Analysis No. 143 is of the purest stone in the quarry. The abundance of chert and sand in most of the beds and its magnesian character renders this limestone of little value except for building stone, road metal, concrete, and ballast.

Locally the chert or flint nodules are very abundant in some of the beds in the Bayport limestone in Arenac County, and it is possible they may prove satisfactory for use in pebble mills used in grinding Portland cement clinker. Practically the entire supply of flint pebbles is imported at the present time. Flint pebbles are expensive and it is possible that where chert and flint nodules are abundant their recovery may be a source of considerable profit.

Sections 34 and 35, T. 20 N., R. 5 E. The ridge of limestone in which the McDonnell and Griffin quarries are located is interrupted in the eastern part of section 2, T. 19 N., R. 5 E., but it reappears again in the southwestern part of section 35 and southeastern part of sec. 34, T. 20 N., R. 5 E. Hard, light gray thin bedded limestone similar to that in the McDonnell quarry is reported at several places over an area of about 150 acres. Owing to the surface covering the thickness of the stone could not be determined, but according to Gregory* it is thinner than in the McDonnell quarry and is underlain by a ripple marked sandstone. According to Mr. Tyler, part owner, an analysis made by the German Sugar Co. showed an average of about 95 per cent of calcium carbonate. Analysis No. 144, from the northeast corner of section 3, T. 19 N., R. 5 E., according to W. M. Gregory, is apparently from the sections adjoining on the north. This part of section 3 is low and swampy and the ridge of limestone lies wholly in the sections on the north. Though a high calcium stone the silica is also high, which renders it unsatisfactory for the manufacture of sugar.

White Stone Point. At White Stone Point† low ledges of grayish limestone are exposed along the lake shore and extend out under the lake for a short distance. The stone is brittle, fine grained and free from sand.

In sec. 23, T. 20 N., R. 7 E., limestone is exposed over a considerable area, terminating on the north in a low cliff or steep terrace. Formerly Harmon and Crowell operated a small quarry in this deposit for lime burning. The stone contains an abundance of chert nodules and these finally caused the abandonment of the enterprise. The section exposed is as follows:

*W. M. Gregory. Geology of Arenac County. Pub. 11, Geol. Ser. 8, Mich. Geol. & Biol. Surv. 1911, p. 51.
†Loc. Cit. p. 134.

Section in Harmon and Crowell quarry.

	Feet.	Inches.
Boulder clay	6	11
Sandy limestone	....	6
Gray limestone with abundant chert nodules in upper portion 2 to 3 inches in diameter	9	....

Limestone was also obtained for burning from a small exposure in section 24 on the lake shore. The bed is only 1½ feet thick and is covered with shale.

The limestone ridges in which the above quarries were opened begin near the southeast corner of section 13, T. 20 N., R. 7 E., and extend southwest into section 23. Analysis No. 145 said to be from the top layer shows that it is a high calcium limestone.

Many of the limestone strata in T. 20 N., R. 7 E., resemble those of the Bayport, northeast of Omer, and it is possible that they belong to this formation rather than to the Michigan or gypsum bearing series. Due to the extremely flat dip (about 15 feet per mile) of the strata to the southwest in Arenac county, the Bayport limestone may exist in the northeastern part of the county as a thin capping over the higher portions of the rock ridges.

Summary. The limestone resources of Arenac County are relatively small. The beds of high calcium stone are thin and associated with sandy, cherty, or magnesian limestone and shale, hence the greater portion of the quarry products is adapted only for building stone, concrete, road making, and ballast. The beds, however, are situated in a low flat clay region of the Saginaw Valley practically without other sources of suitable material for road making, therefore they are of very considerable local importance. The rapid settlement of the fertile clay lands in the eastern part of the county and the necessity for good roads will undoubtedly cause the early development of many of the deposits. Quite probably the developments will lead to the discovery of beds of high calcium limestone which, due to the scarcity of such stone in the central and larger portion of the Southern Peninsula, will be of importance to some of the sugar, chemical, and other industries dependent upon high calcium limestone. The cherty or flinty limestone may also become valuable as a source of pebbles for use in the manufacture of Portland cement. In brief the limestone resources of Arenac County, due to their isolated position and peculiar local conditions, have an economic importance out of proportion to their relative magnitude.

Charlevoix County.

Distribution. The northwestern portion of Charlevoix county is underlain by the Traverse formation which in the Little Traverse Bay region is chiefly limestone. The strata dip to the southeast and in the southeastern part of the county are overlain by the black shales of the Antrim formation.

The principal exposures are in the vicinity of the lake shore along high terraces cut by the glacial lakes formerly occupying the basin of Lake Michigan and standing at much higher levels than the present lake. The only considerable area of easily accessible limestone is in the vicinity of Charlevoix. The other exposures are chiefly in the form of narrow benches along the lake shore.

The Traverse is composed of alternating beds of high calcium and high magnesian limestones, as in the vicinity of Petoskey (see Emmet county). The thickness and precise character of all of the different beds and their relations, however, are not well determined.

Quarries and Localities.

Charlevoix. The largest and probably the most important area of limestone in the Little Traverse Bay region occurs in sections 28, 29, 32, and 33, T. 34 N., R. 8 W., just west of the city limits of Charlevoix. The area in which limestone is exposed or under light cover totals several hundred acres. On the east, the area is cut off by a deep valley partially occupied by Pine Lake. The limestone forms a table land generally from 20 to 60 feet or more above lake level between this rock valley on the east and Lake Michigan on the west.

The strata are locally very much disturbed. The general inclination of the beds is southward but it varies greatly in amount and direction from place to place. In one place, the dip is over five degrees to the north and an eighth of a mile distant over 22 degrees to the south. The rock series includes an upper horizon of high calcium limestone with a thin shale bed, a middle thick shale bed, and a lower series of limestones, apparently high calcium in composition but with some siliceous and argillaceous beds. Due to the general southward inclination, successively lower beds are exposed in passing from south to north across the area. The strike of the beds is in a general east and west direction but this is considerably modified locally by the sharp variations in dip. The limestone area is divided into two parts. The northern or smaller one includes Pine River Point and is separated from the much larger southern part by a narrow belt underlain by the middle shale.

Charlevoix Rock Products Company quarry. The Charlevoix Rock Products Company's quarry (Pl. II B) and limekilns are located a short distance northwest of the City of Charlevoix in the SE. $\frac{1}{4}$ SE. $\frac{1}{4}$ of section 28, T. 34 N., R. 8 W. At the time of the writer's visit in 1914, Quarry No. 1, located at the plant, was an irregular opening about 400 feet in greatest diameter and about 23 feet in greatest depth. The following section was exposed in the workings:

Section in Charlevoix Rock Products Co. quarry.

		Feet.	Inches.
Surface or overburden about		1	....
Light buff, friable, and sandy appearing limestone. Top portion much fractured and disturbed	Average Anal. 97.46 per cent. $CaCO_3$	18	....
Light buff fine grained earthy limestone		1	6
Banded buff to dark gray earthy limestone		2	6
Fine grained buff limestone, the floor of the quarry		0	8 to 10
Blue shale very soft and said to be very uniform in character and composition		10	6

The beds dip gently southward. Toward the west, however, the dip of the beds locally becomes discordant and much steeper as shown in a small quarry located about a quarter of a mile west-southwest of the plant.

The beds of limestone, though rather massively bedded toward the top of the quarry, are so completely traversed by an irregular system of joint planes that the stone is won by steam shovel without blasting. The shale beneath the quarry is so soft that a 10 inch layer of limestone is left above the shale as a floor to support the tracks and steam shovel.

The beds in the quarry average over 97 per cent of calcium carbonate, less than 1.5 per cent of magnesium carbonate and 1 per cent of silica. Analysis No. 146 is fairly representative of the average composition of the stone in the quarry excluding the top broken portion. Analyses No. 147 and 148 are apparently from this quarry, although the exact location is not given.

Due to its low percentage of silica, magnesia, or other objectionable impurities the stone is especially adapted for use in the manufacturing of special steels, sugar, and paper, as well as for general fluxing and chemical purposes.

Quarry No. 2 of the Charlevoix Rock Products Company is situated about one-fourth of a mile slightly south of west from Quarry No. 1. It consists of a narrow arcuate opening about 200 feet long extending in a general east-northeasterly direction and varying from a few feet up to 9 feet in depth. In this quarry the dip of the beds is abnormal in amount and direction. At the east end the dip is 18 degrees in a direction S. 65° E., at the center 22 degrees S. 37° E., and at the west end 5 degrees S. 15° W. On the north the floor of the quarry begins at the surface and extends downward parallel to the beds, hence the face is wholly on the south side of the opening and parallel to the strike of the beds. Due to the steep southward inclination and a gentle northward slope of the surface the edges of underlying beds are exposed on the north side of the quarry. The following section is exposed:

Section in Quarry No. 2, Charlevoix Rock Products Co.

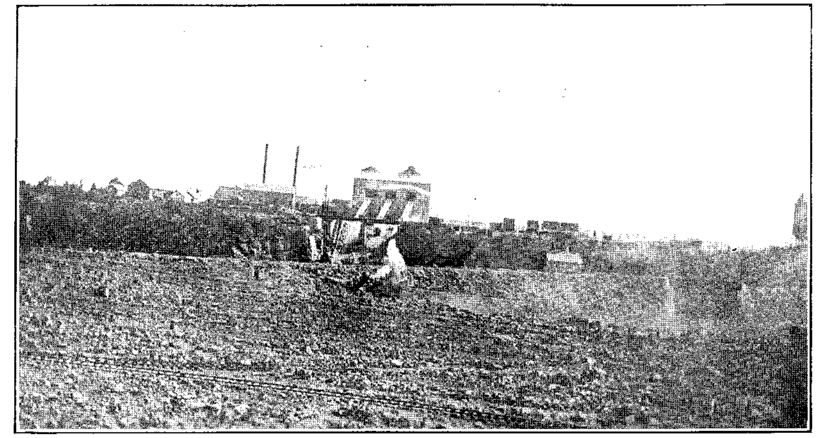
		Thickness, feet.
	Surface	0 to 1
1.	Yellow friable, earthy and fossiliferous limestone, much weathered, $CaCO_3$, 89 per cent	3 +
2.	Shale, very fossiliferous, and yellow where weathered	1 +
3.	Hard gray to buff gray very crystalline limestone. $CaCO_3$, 95.94 per cent. Said to be especially adapted for sugar manufacture	4
4.	Dense white laminated limestone, the floor of the quarry	1 ±
5.	Extremely fossiliferous limestone. This bed is a mass of coral and stromatopora. Bed said to contain over 95 per cent of calcium carbonate	14

Bed No. 5 is said to be directly underlain by the yellow friable limestones exposed in quarry No. 1 at the plant, hence at this point there is about 45 feet of limestone above the heavy shale bed exposed in the bottom of quarry No. 1.

Analysis No. 149 indicates that the top bed, where fresh and unweathered is probably a high calcium limestone. The sample was taken from the exposed margin of the bed and probably farther south in the direction of the dip the stone is less weathered and of better quality. Analysis No. 150 is of a representative set of samples from the crystalline bed below the shale seam. No analyses are available showing the character of beds Nos. 4 and 5, but according to R. F. Sloan, general manager of the company, they contain over 95 per cent of calcium carbonate.

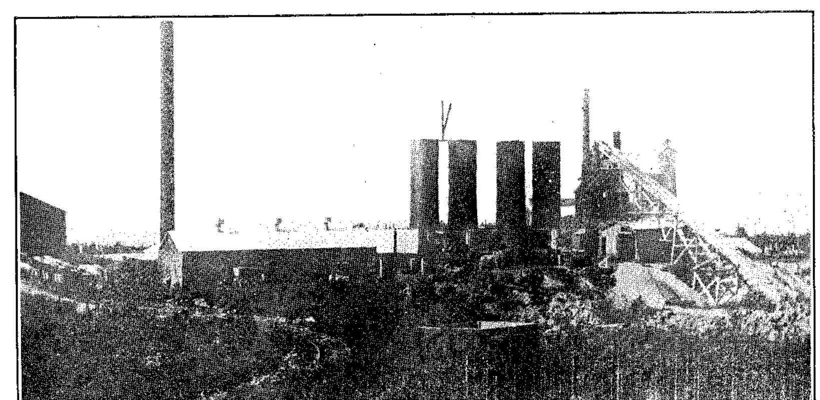
City quarry. Formerly the city of Charlevoix operated a small quarry near the northwest corner NW. ¼ NE. ¼ section 33, T. 34 N., R. 8 E., about one-eighth of a mile south of quarry No. 2 of the Charlevoix Rock Products Company. The section is apparently the same in both quarries with the exception that bed No. 3 is much thicker than in quarry No. 2. The stone was used for paving and road making.

A similar abnormal inclination of the beds occurs in this quarry. Apparently a small plunging anticline extends into the quarry from the southwest. The dip varies from 2 or 3 degrees to the northwest to about 7 degrees slightly east of north and directly toward quarry No. 1 of the Charlevoix Rock Products Company. Almost directly south the dip decreases to only 2 or 3 degrees. The dip is about 11 degrees south from quarry No. 1 and 7 degrees north from the city quarry, hence there must be a very pronounced trough or syncline in the strata



A. QUARRY AND CRUSHING PLANT OF THE MICHIGAN ALKALI COMPANY AT ALPENA, ALPENA COUNTY.

The lower quarry is shown at the right center and a portion of the new steel crushing plant at the extreme right.



B. KILNS AND CRUSHING PLANT OF THE CHARLEVOIX ROCK PRODUCTS COMPANY AT CHARLEVOIX, CHARLEVOIX COUNTY.

A portion of the quarry is faintly shown at the lower right.

between the two quarries. Since the southeastward dip in quarry No. 2 is about 20 degrees, the syncline apparently plunges to the east. South of quarry No. 1, the dip of the beds is said to be very gentle, therefore the abnormal dips noted above must flatten out quickly to the eastward.

Wolverine Lime Co. quarry. A small quarry has been opened in the S. $\frac{1}{2}$ SE. $\frac{1}{4}$ sec. 29, T. 34 N., R. 8 W., in the western part of the Charlevoix limestone area. The Wolverine Lime Company owns or controls this and adjacent limestone properties and proposed to erect a modern lime plant. According to reports the enterprise did not materialize.

The quarry was about 7 feet in depth and the stone is apparently similar in character to that in the city quarry and quarry No. 2 of the Charlevoix Rock Products Company.

Analysis No. 150 is of a representative set of samples from the quarry. Analyses Nos. 152-154 were furnished by E. S. Stacks, a member of the company. These analyses show that the stone averages nearly 97 per cent calcium carbonate and less than 1 per cent of magnesium carbonate.

Lake shore. Due to the southward inclination of the beds in the Charlevoix area and the very considerable elevation of much of the area above lake level, a number of beds below the heavy shale bed of quarry No. 2 of the Charlevoix Rock Products Company are exposed at the surface northward from the quarries and along the lake shore to Pine River Point. Some of the beds are dark fine grained or lithographic in texture, others crystalline and fossiliferous. Apparently the lower series is in general low in magnesia, as indicated by analyses Nos. 155 to 159, which are supposed to be of stone from the vicinity of Pine River Point. Possibly analyses Nos. 147 and 148 are also from the lower series. The striking feature of the first set of analyses is the high silica, alumina, and iron which together average about 8 per cent. The evidence, though of doubtful nature, indicates that the character of the limestone deposits in the immediate vicinity of Pine River Point should be carefully investigated before developments are attempted.

Along the lake shore on the west, limestone is exposed at various places near water level from Pine River Point to Norwood. Close to the shore sand dunes conceal the rock. Farther inland and south of Charlevoix it is drift covered, exposures being few and small. South of Charlevoix near the west shore of Pine Lake there is an exposure of dolomite but no analyses are available. This lies above the high calcium series of the Charlevoix area but its exact position has not been determined.

From the foregoing data a generalized section of the strata exposed in the vicinity of Charlevoix is as follows:

	Feet.
Heavy magnesian limestone exposed south of the Charlevoix limestone area near Pine Lake	?
Series of high calcium limestones with a thin shale bed. Exposed in the various quarries and at many places from the Charlevoix Rock Products Co. quarry westward to the lake shore	45
Soft blue shale. Exposed in the bottom of the Charlevoix Rock Products Co. quarry No. 1	10
Series of high calcium limestones with some very siliceous and argillaceous beds. Exposed north of Charlevoix Rock Products Co. quarries along lake shore and on Pine River Pt	40+

Norwood. North of Norwood, limestone is exposed along the shore on old terraces 40 to 60 feet or more above the water. The exposures or areas of easily accessible limestone are relatively small, being confined to the narrow terraces. Inland the overburden becomes excessive. Immediately south of Norwood the limestone is overlain by the black shales of the Antrim formation.

One mile north of the dock at Norwood, sec. 34, T. 33 N., R. 9 W., heavy magnesian limestone is exposed in a low bluff near the lake shore. Analysis No. 160, made by Rominger in 1869, shows that it is practically dolomite.

About $1\frac{1}{2}$ miles northeast of Norwood, NE. $\frac{1}{4}$ section 26, T. 33 N., R. 9 W., high calcium limestone is exposed in a number of places along the top of one of the upper terraces and at the base of a series of ancient sand dunes. The area of the terrace at this point is considerable but the area of accessible limestone could not be determined. Apparently it is at least several acres. About 5 feet of light gray dense grained to lithographic limestone was exposed in two small openings formerly operated for lime burning. Other openings are reported in this vicinity but these were not discovered. Nothing could be learned as to the probable thickness of this bed. Analysis No. 161 from a composite of several representative samples is indicative of its high average purity. It is possible that a considerable acreage of this high calcium stone could be developed in this locality.

Bay Shore. A double line of terraces or old lake beaches extends along the south shore of Little Traverse Bay. The lower terrace ranging from a few feet up to 40 feet or more in height is generally very close to shore. The upper terrace of equal height is usually from a few hundred feet to a half mile distant. Due to wave cutting by the present lake, limestone cliffs occur at many places in the lower terrace from Bay View, Emmet county, westward to Charlevoix and beyond. The upper terrace has but few exposures, being largely drift covered.

At Bay Shore cliffs of friable or sugary yellow brown limestone varying from a few feet to 40 feet or more in height extend continuously along the shore for a considerable distance. Here the lower terrace is several hundred feet wide but the overburden is relatively thick in most places.

Northern Lime Co. quarry. Bay Shore or Standard Plant. The Northern Lime Co. of Petoskey operates a number of quarries along Little Traverse Bay for lime burning. Their plant at Bay Shore is called the Bay Shore or Standard Plant. The quarry is double, consisting of an eastern and western portion with a battery of four kilns midway between. At the time of the writer's visit the western opening was the smaller and shallower but plans were then under way for cutting through the neck separating the quarries. The developed face in the smaller quarry ranges in height from 15 to 25 feet but in the other it is 35 to 40 feet. The overburden is relatively thick, varying from 3 to about 10 feet, the thickness increasing away from the shore.

Locally the strata show very discordant dips. The general dip is slight and almost due south yet in the smaller quarry it averaged 5 degrees N. 45° W., resulting in a pronounced inclination of the quarry floor. Larger dips were observed but these were not maintained throughout the quarry. In the eastern quarry the dip, though not measured, was strongly to the northwest as in the smaller quarry. A quarter of a mile west of the quarry the dip is about 10° in the same direction. At Kawgachewing Point two miles farther west apparently corresponding strata are higher than at Bay Shore, therefore a marked syncline is indicated between these two places.

The following section was exposed in the western quarry:

Section in Bay Shore quarry, west end.

		Feet.
	Surface	3 to 6+
1.	Light gray to white dense grained limestone, harder than the strata below	3+
2.	Very yellow and ferruginous limestone, worthless and rejected for lime burning	1
3.	Yellow to brown laminated limestone	2
4.	Massive yellow limestone, very soft in upper portion	3
5.	Banded yellow limestone with bituminous bands	2+

In the eastern quarry bed No. 1 is overlain by 2 to 3 feet of gray crystalline magnesian and siliceous limestone, resembling at a little distance, gray granite and so termed by the quarrymen. The bed is rejected for burning. The remainder of the section is similar to that in the western quarry, but a much greater thickness of the lower, yellow, sugary limestones is exposed, the working face of the quarry being from 35 to 40 feet.

On the northeastern side of the quarry the strata down to and into the yellow limestone is cut out by a "horse of sandstone." It is a massively bedded yellow sandy appearing lime-sandstone said to contain only about 56 per cent of calcium carbonate and to be worthless for lime. This so-called ''horse of sandstone'' apparently represents an eroded channel in the limestone filled with lime-sand. The presence of this stone has stopped further quarrying on that side of the quarry.

Bed No. 1 is said to be ''good'' limestone, but No. 2, the ferruginous bed, is worthless. The yellow, ''sugary'' limestones below this bed are largely magnesian but are said to burn well and make very satisfactory commercial lime, containing from about 75 to 85 per cent of calcium oxide. Analysis No. 162 is of a representative set of samples from the usable stone in the quarry and indicates the general magnesian character of the beds. As at Petoskey and Superior (2 mi. west of Bay Shore) the percentage of calcium carbonate increases downward though irregularly.

Determinations of calcium carbonate were made for eight strata from top to bottom with the following results:

Analyses of limestone beds at Bay Shore.

No. analysis.	No. of bed.	$CaCO_3$.
166	1. (top)	63.03
167	2.	82.45
168	3.	79.77
169	4.	92.44
170	5.	88.34
171	6.	97.97
172	7.	93.33
173	8.	63.71

Analysis No. 163 is said to be from a high calcium bed near the base of the quarry. Analyses 164 and 165 are of commercial lump lime. The low content of silica, alumina, and iron in the stone as quarried is noteworthy. Analysis No. 174 is by Rominger from dark lithographic limestone about one mile east of Bay Shore and presumably from near the water edge. Very probably these lithographic beds are but a short distance below the bottom of the Bay Shore quarry as they are exposed on either side along the shore.

Owing to the soft friab e nature of the stone it is not adapted for concrete, roadmaking, or ballast.

Superior. At Superior, about 2 miles west of Bay Shore, the yellow sugary limestones form the upper terrace, the base of which is between 30 and 40 feet above the lake. The general character of the beds in the lower terrace is not known, but near the top there is a bed of blue shale and shaly limestone, and at the bottom slightly above and also below water level, there is a light gray lithographic bed overlain

by gray, dense grained to crystalline and fossiliferous limestone. These lower beds are high calcium limestones according to the local lime burners and apparently they belong to the series of high calcium lithographic limestones exposed at a number of places along the lake shore near water level from Petoskey westward nearly to Bay Shore.

Northern Lime Company, Superior Plant. The Northern Lime Company operates a quarry in the upper terrace of sugary limestones for burning lime. The quarry has been developed parallel to the face of the terrace or bluff and is about 600 feet long. The working face varies from 30 to 35 feet in height. The overburden is largely sand and stony gravel and varies from 2 to 10 feet thick. Apparently it is relatively thin over a considerable area back from the lake. The quarry supplies stone for a battery of three continuous kilns. Owing to its soft friable nature the stone is not suitable for concrete, road making, and ballast.

The section exposed in the quarry is as follows:

Section in Superior quarry.

		Feet.
	Surface sand and gravel	2 to 10
1.	Yellowish white dense grained to earthy limestone	6+
2.	Clayey or shaly light yellow limestone disintegrated and ''rotten''	2
3.	Earthy limestone with light yellow and gray mottlings and streaks. More crystalline toward the bottom	10
4.	Massive earthy yellow limestone	7
5.	Banded brownish ''sugary'' limestone with bituminous bands. Bottom of this bed forms the floor of the quarry	2+
6.	Blue very shaly limestone weathering yellow	1+

The beds, though magnesian, are much less so than at Bay Shore as shown by analysis No. 175. According to Mr. Zipp, superintendent of the Superior and Bay Shore plants, lime averaging 85 per cent calcium oxide can be obtained by sorting the stone. Analysis No. 176 by Rominger in 1869 is from one of the dark lithographic beds near the bottom of the lower terrace and indicates that they are exceptionally high in calcium carbonate. The stone, however, is not adapted for lime burning on account of its tendency to ''pop'' or break to pieces in the kiln, thus choking the draft.

West of Superior and Kawgachewing Point cliffs of limestone similar in character to that at Superior occur at one or more points along the lake shore but the extent of the accessible limestone is uncertain. Generally ancient sand dunes and glacial deposits limit the quarryable areas to small narrow benches near the shore.

Summary. The limestone resources of Charlevoix county are chiefly confined to relatively small areas along the lake shore in the form of narrow benches, the inland portions of the county generally being heavily drift covered. The largest and most important area occurs between the city of Charlevoix and Lake Michigan. The limestone in this area is high calcium but that eastward along the lake shore from Charlevoix is largely low to high magnesian. An area of high calcium stone occurs north of Norwood but its extent and importance is uncertain.

Cheboygan County.

Distribution. Three limestone formations underlie Cheboygan county. The Monroe formation skirts the lake shore on the north, the Dundee limestone forms a narrow parallel belt immediately south, and the Traverse formation occupies the whole central portion of the county. The Antrim and the Coldwater shales underlie the southern portion.

The rock surface is cut by a system of deep valleys partly drift filled and partly occupied by lakes. The deepest and largest extends from Cheboygan southwest to Little Traverse Bay and is occupied by Mullet, Burt, and other lakes. Black Lake occupies a branch of this valley extending southeast from Cheboygan. Due to the deep valleys and the irregular deposition of the drift, the exposures of limestone are chiefly on the sides of river valleys or along old glacial lake beaches and are usually of limited extent. The numerous drift filled channels locally makes the development of limestone deposits uncertain and hazardous.

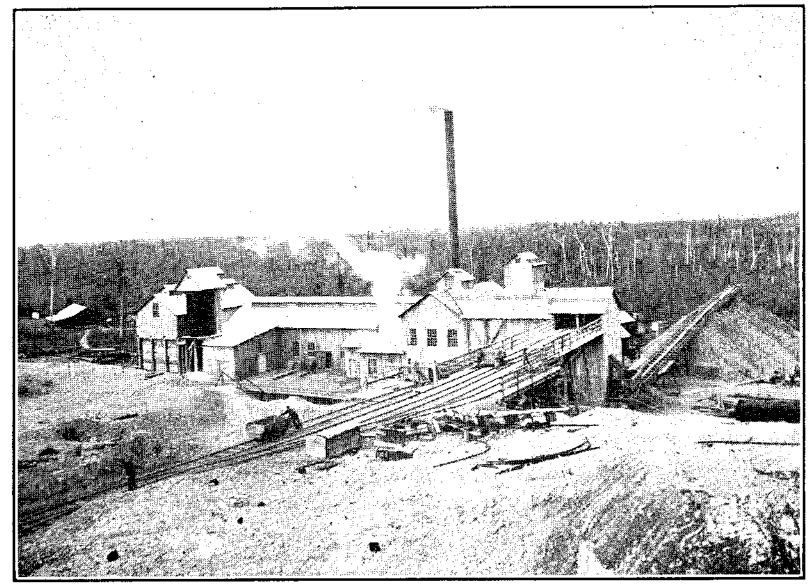
The Monroe formation is doubtfully exposed near the water's edge on the lake shore east of Mackinaw City. The Dundee limestone forms the upper terrace along the lake shore from section 30, T. 39 N., R. 3 W., eastward across Private Claim No. 334, a distance of about three miles. Exposures occur along the lower course of Mill Creek which flows across the claim. The Traverse formation is exposed in numerous bluffs along river valleys in the vicinity of Afton, Legrand, and Tower.

The Dundee limestone as exposed in Cheboygan county is essentially a high calcium formation with a magnesian base. The Traverse formation is less shaly than in Alpena county but more so than in the vicinity of Little Traverse Bay.

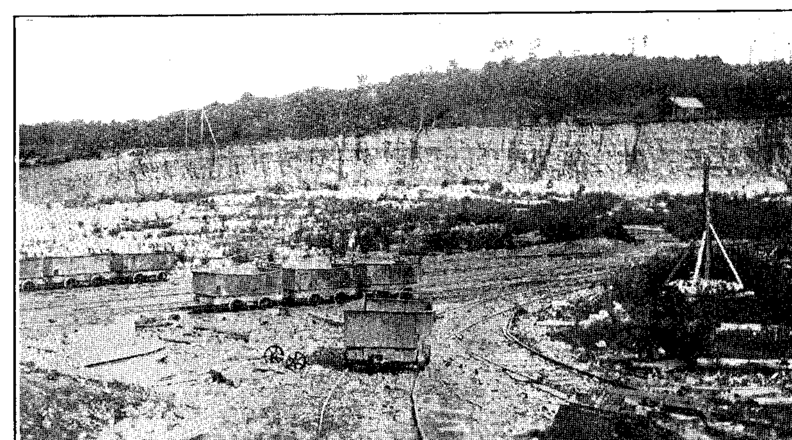
Quarries and Localities.

Afton quarry. At Afton in NW. ¼ NE. ¼ section 36, T. 35 N., R. 2 W., the Campbell Stone Company operates a quarry (Pl. III A) both for lime burning and for crushed stone products. The quarry has been opened in the upper part of a high bluff on the east side of Pigeon River valley. The quarry is a more or less oval opening several hundred feet long and 30 to over 40 feet in depth.

The area of easily accessible stone was not determined but it is large



A. PLANT OF THE CAMPBELL STONE COMPANY AT AFTON, CHEBOYGAN COUNTY.



B. QUARRY OF THE PETOSKEY CRUSHED STONE COMPANY FOUR MILES WEST OF PETOSKEY, EMMET COUNTY.

Pronounced undulations of the beds as shown at the left are characteristic of the Traverse formation along Little Traverse Bay.

since a half mile to the north limestone is at or near the surface. The ridge, which forms a bluff along the river valley, extends eastward past the village of Afton for a considerable distance.

The section exposed in the quarry is as follows:

Section in Afton quarry.

			Feet.
	Glacial drift		0 to 2 +
1.	Light gray dense grained to crystalline limestone. $CaCO_3$, 97.32%		5
2.	Black bituminous limestone with masses of cup corals. Much of the stone rejected though high in calcium carbonate. $CaCO_3$, 92.6%. Organic matter 2.61%		6
3.	Light gray crystalline limestone. Very pure and burns easily. Used chiefly for paper manufacture by the soda process, $CaCO_3$, 96.97%		4 +
4.	Disintegrated limestone. Falls to pieces in quarrying	$CaCO_3$, 98.04% (Nos. 4–6)	1 −
5.	Very bituminous, banded, thin bedded limestone with bituminous bands. Parts readily along bituminous bands.		2½
6.	Similar to No. 5, but less bituminous. More bituminous near top.		5½
7.	Badly disintegrated or "vesicular" bed; belongs to bed below. Stone breaks into fine pieces in quarrying		2 −
8.	Very porous vesicular limestone. Openings due to solution. Stone breaks up badly, resulting in much waste.	$CaCO_3$, 95.75% (Nos. 8–10)	4
9.	Light gray to buff fine grained limestone; main quarry beds. Stone used for lime obtained largely from this bed.		10
10.	Light gray to grayish buff limestone with thin shale parting at top		2
11.	Vesicular limestone, the floor in part of the quarry		1 +

A core drilling* near the quarry gave the following section:

Core Drilling, Afton Quarry.

	Thickness, feet.	Depth, feet.
Clay, sand and broken rock	4	4
Light colored rock (This forms the quarry beds. Near the lower south side of the quarry the black limestone (No. 2) is not present and the fact that this conspicuous bed was not noted in the record indicates that the hole was near the south edge of the bluff, hence the 38 feet of light colored limestone probably does not include beds No. 1 and No. 2).	38	42
Brown rock, soft. (This is probably the soft vesicular limestone which forms the bottom of the quarry)	6	48
Light limestone, hard	6	54
Dark limestone, soft	1	55
Dark limestone, hard	1	56
Blue shale, soft	5	61
Black limestone, hard	1	62
Light limestone, soft	2	64
Black limestone, hard	1	65
Light limestone, soft	1	66
Mixed dark and light limestone, hard	13	79
Light limestone, hard	4	83
Gray limestone, hard	5	88
Mixed dark and light limestone, hard	7	95
Black limestone	5	100

Several other holes drilled in the vicinity of the quarry show practically the same section. Undoubtedly the holes located farthest north show the presence of beds No. 1 and No. 2, which were encountered farther up the bluff during the progress of quarrying in this direction.

*A. C. Lane, Appendix Annual Report, 1908, Michigan Geological Survey, p. 91.