University of Minnesota

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WILLIAM H. EMMONS, DIRECTOR

THE LIMESTONES AND MARLS OF MINNESOTA

BY
CLINTON R. STAUFFER
AND
GEOREGE A. THIEL

MINNEAPOLIS • 1933
THE UNIVERSITY OF MINNESOTA PRESS

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PREFACE

Minnesota has extensive deposits of calcium carbonate in the form of limestones, dolomites, and marls. This report deals primarily with the distribution and chemical composition of these carbonate deposits and the uses for which they are suited. The dolomites are the most widely distributed and the most readily available carbonate rocks in Minnesota. They are quarried in large quantities in the southeastern part of the state, where the lower Ordovician rocks are predominantly dolomitic limestones. Limestones high in calcium are far less abundant, being confined to several strata that are more limited in their distribution. Locally they have been quarried for their high lime content. The marls have been but very recently recognized as one of the valuable mineral resources of the state. These light, grayish muds underlie marshes, bogs, and lakes; they are not often visible at the surface. Most persons, therefore, are unfamiliar with the name, appearance, and distribution of marl. It can be distinguished from other muds by its light color, its abundant shell fragments, and its violent reaction with acid. The marl beds of Minnesota vary in thickness, but they are seldom more than thirty feet thick.

The authors are indebted to a large number of persons who kindly furnished information and in other ways assisted in the collection of data for this report. Special acknowledgment is due the men named below, whose services are gratefully recognized.

Much of the field work on marl was done with the able assistance of Mr. Melburne H. Heins, whose untimely death in Africa is deeply regretted by all his associates. During one field season Mr. Lee Armstrong served as an assistant. He later conducted the experiments to determine the relation of marl deposits to different types of glacial drift. In the measuring of sections and in the sampling of limestones and dolomites, Messrs. William Strunk, John A. Brown, and Richard E. Gile served as field assistants. Certain maps and diagrams were made by Messrs. Adolph Sandberg, Maynard Stephens, L. J. Snell, and W. I. Gardner. The chemical analyses tabulated in this report were made by Dr. R. J. Leonard of the Department of Geology and by Mr. Wallace Cornell of the School of Chemistry of the University of Minnesota.

The work both in the field and in the laboratory was in charge of Dr. W. H. Emmons, director of the Minnesota Geological Survey. His editorial work in preparing the manuscript for publication is gratefully acknowledged.

C. R. S.
G. A. T.

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INTRODUCTION

THE USES OF LIMESTONE, DOLOMITE, AND MARL

The uses of calcium carbonate are so many and varied that only a few of them can be discussed in detail within the limited space available. Some require large quantities of material or are likely to do so in the near future. It is, in general, these that have been given most consideration in the description that follows. A more extensive table enumerating a wider range of common uses of limestone is given on page 2. A very complete chart of limestone uses has been prepared by the National Lime Association.[1] In the following paragraphs some of the more common uses are described.

Manufacture of Lime

Marls, limestones, and dolomites are used in the manufacture of lime. The process consists in the application of sufficient heat to drive off virtually all the volatile constituents, such as carbon dioxide and water, from the limestone or dolomite. This involves the decomposition of the carbonates and requires a temperature of about 800° C. Higher temperatures are avoided, since they may cause a chemical union of the calcium and magnesium with the impurities of the limestone or dolomite, which is undesirable. The process is one of burning and requires the use of a kiln, of which three or four types are in common use. The construction and operation of these may be found in standard treatises on lime and cement manufacture.[2]

Dolomitic limestones have some advantages over those of the purer varieties. They "burn" at a lower temperature (600° to 700° C.), and they produce a lime that will slake more slowly, set more slowly, shrink less on setting, and produce a stronger bond than a lime made from a limestone of high calcium content. The dolomitic lime is also easier to handle, since it requires less water for slaking, increases less in volume, and generates less heat during this process. The lime made from the purer limestones will take up more sand, however, and will spread more readily. It therefore produces more mortar per unit of weight and requires less material for a given job than the dolomitic lime. The high-calcium lime produces a whiter material and on this account is better suited to use in plastering. The magnesian or dolomitic limes are likely to contain larger quantities of iron and thus may produce a yellowish plaster. The easy spread of the high-calcium lime also favors its use in

[1] B. L. Miller, *Limestones of Pennsylvania* (Pennsylvania Geological Survey Bulletin M 7, 4th series, 1925), Figure 2, opposite page 52.

[2] Edwin C. Eckel, *Cements, Limes and Plasters* (New York, 1922), 655 pages.

plastering, but its tendency to crack on shrinking is against its use as a finishing coat. For this last purpose especially the dolomitic limes that are relatively free from iron are preferred.

Commercial Uses of Limestones and Marls

Common Commercial Uses of Naturally Occurring Calcium Carbonate, and Manufactured Products in the Preparation of Which Limestones or Marls Are Utilized

Absorbent of gases	Insecticides
Acetate of lime	Insulating
Acid neutralizer in various industries	Lime burning
Agricultural limestone	Lithographing
Ammonia	Milk of lime
Ammonium sulphate	Mortar
Basic steel	Oil, fat, glycerine, and soap
Blast furnace flux	Oil refining
Bleaching powder	Ore flotation
Bone ash	Paints and varnishes
Building stone	Paper-making
Calcimine	Plaster
Calcium carbide	Portland cement
Calcium cyanide	Potassium and sodium dichromates
Calcium light pencils	Pottery glazes
Calcium nitrate	Preservative
Carbon dioxide	Purification of sewage
Ceramics	Railway ballast
Chicken grit	Refining of quicksilver
Chloride of lime	Refractory lime
Clarifying grain (milling industry)	Rip-rap
Coagulator	Road metal
Concrete aggregate	Rubber manufacture
Dehydrating agent	Sand-lime brick
Deodorizer	Sanitation
Disinfectant	Salt refining
Drugs	Silica brick
Dyeing	Soda-ash products
Electrolytic work	Stock feed
Fertilizers	Stucco
Finishing lime	Sugar manufacture
Fungicide	Tanning
Gas manufacture	Textiles
Glass-making	Water softener
Glue	Wood distillation

Neutralizer of Acid Soil

Marls, limestones, and dolomites are used on acid soils as neutralizers. It is difficult to grow alfalfa and clovers on acid soils. These nitrifying forage crops are stunted or even inhibited in their growth by an acid soil condition. Liming of the soil, therefore, produces immediate results in the growth of clovers and alfalfa. The growth of clovers renews the nitrogen content of the soil, thereby enriching it for other crops. A soil that is suspected of acidity may be tested by using a strip of blue litmus paper (obtainable at any drug store). When the soil is moist from rains or melting snows, a stiff mud brickette may be made or a ball rolled in the hands. This may then be slit open with a knife and the blue litmus paper laid in the cut so that the flat sides are brought into contact with the sides of the gash when the two parts are squeezed together. The blue litmus paper should remain thus in contact with the damp soil for about five minutes. If the litmus paper turns red over portions of the strip or over the whole end that has been pressed between the halves of the brickette, the soil is acid. Such weeds as sheep sorrel, corn spurry, and horsetail rushes or wood horsetail flourish on an acid soil, and when these are present and other types of vegetation are not, acidity is indicated. Even the fact that alfalfa and red clover do not thrive on a soil is a fair indication of acidity. The Agricultural Experiment Station of the University of Minnesota puts out much helpful literature on soils, and the United States Department of Agriculture also furnishes useful information.

As neutralizers of acid soils the limestones and marls are usually preferred, but the dolomitic limestones are just as serviceable. In fact, pound for pound, the dolomite will go a little further and neutralize a little more acid than the pure limestone. Which should be used is therefore a matter of cost and convenience. Usually two and a half tons an acre are used, but five tons have been applied without any harmful effects being noted. Lime and hydrated lime, however, are rather drastic in their effects. They attack the fertilizers present in the soil, converting them into ammonia and other products that easily escape from the soil as gas or that may go into solution and be carried away by percolating waters. Although such treatment may be beneficial in some cases, more fertilizer is required, and the end results are not so satisfactory as the use of ground limestone or dolomite.

Crushed limestone and marl are used also for chicken feed, supplanting the usual oyster shell, and both pulverized limestone and marl form part of the base in manufactured stock foods of various kinds.

Paper-Making

Both limestone and dolomite are used by paper-makers, who show no very strong preference for one over the other. The lime removes the grease and some of the color from rags intended for paper pulp. The rags are boiled in a solution of lime, and the grease forms an insoluble soap with the lime. Wood pulp also may be treated with calcium or magnesium bisulphite to remove the intercellular starchy rosinous or silicious materials. This is accomplished by boiling, the bisulphite having been made from limestone or dolomite by passing sulphur dioxide fumes through it.

Sugar-Refining

In the refining of sugar only the highest grade of lime is used. The sugar manufacturers buy a very pure limestone, therefore, and burn their own lime. The lime is used to neutralize certain organic acids that prevent the crystallization of the sugar. The lime forms insoluble compounds with these acids, and the excess of calcium is removed by treating the liquid with carbon dioxide and filtering off the precipitates thus formed. Magnesium is more soluble in the sugar solutions and is much more difficult to remove than the calcium.

Limestone Fluxes

Ground limestone is used as a flux in the manufacture of glass. Dolomite or dolomitic limestones are objectionable because of their iron content, which discolors the glass; moreover, the magnesium raises the melting point of the glass.

In the blast furnace limestone is used almost exclusively. Marl briquettes have been used experimentally for the same purpose, but not on a commercial scale. Since the limestone fuses at a lower temperature than does dolomite and requires less heat to keep it fluid, it is preferred. Mixed with the ore, the limestone lowers the melting temperature, combines with its impurities to form a slag, and thus floats them to the top of the furnace where they can be drawn off, leaving the metals at the bottom in a nearly pure state. Limestones are also used in the smelting of lead and copper ores.

Natural Cements

Impure clayey limestones are burned at 900° to 1000° C. to form what is known as natural cement. The rocks free from magnesium, or nearly so, are more desirable for the making of natural cement, but the composition of the materials used and of the finished product varies greatly. In some of the limestones thus used, the proportion of magnesium carbonate to calcium carbonate is as great as 4 to 5 by weight. Natural cement production has declined rapidly with the increase in importance of Portland cement. However, the natural cement has some favorable points, especially for certain classes of work. It sets more quickly and is cheaper, the average price being only about two-thirds that of a high-grade Portland cement.

Portland Cement

Only limestones of very low magnesium content are used in the manufacture of Portland cement. Six or 7 per cent of magnesium oxide in the rock is considered the maximum amount that can be tolerated, and many manufacturers regard that as too high. One of the great objections to the presence of the magnesium in cement is that it combines chemically with water and swells, thus causing disintegration of the finished work in which such cement has been used. In the manufacture of Portland cement shale or clay is added before the burning process begins. Hence the argillaceous limestones, such as some of those used in the Lehigh district of Pennsylvania, are often very satisfactory. They require the addition of a smaller quantity of clay or shale and are less difficult to grind than the hard pure limestones. The great objection to these argillaceous limestones, however, is the variability of the non-calcareous compounds. In the high-grade limestones the troublesome magnesium is absent, and it is always much easier to control the important silica-alumina ratio in the mixture. For this reason, if for no other, the pure limestones are preferred.

At the present time the demand for a high-grade limestone in the manufacture of Portland cement exceeds all other demands for this grade of rock. Pennsylvania is the leading state in Portland cement production, with California second and Michigan third. The industry has been growing rapidly throughout the country but is still relatively undeveloped in the Central Northwest. In Michigan and Indiana a number of cement plants use marl instead of limestone.

The quality and quantity of marl necessary for the erection of a modern Portland cement plant are discussed in detail by Raymond E. Kirk in Bulletin 4 of the Engineering Experiment Station of the University of Minnesota. The marl must carry a relatively high percentage of calcium carbonate. The higher this percentage the more desirable the marl becomes. Above 90 per cent dry basis is desirable, although plants have operated on marl with a calcium carbonate content as low as 80 per cent. The lowest limit that can be used will depend on the character of the impurities present.

The amount of organic matter present in the marl is of vital importance. When organic matter is present, the amount of water needed to give a slurry that can be handled by the machinery of a cement plant is greatly increased. As a consequence the kiln capacity is reduced and the fuel cost raised. The amount of water needed to form a workable slurry will vary greatly in different marls that contain about the same amount of organic matter. It seems that the character and state of division of the organic matter are of as great importance as the amount.

A wet marl as it rests in the lake may contain as high as 60 per cent water. A cubic yard of such marl may weigh about 2,000 pounds and contain only about 800 pounds of dry marl. A dry marl in a well-drained swamp or marsh may have as low as 20 per cent of water. A cubic yard weighs about 2,600 pounds and contains about a ton of dry marl. Plant operations on wet lake marls in Michigan justify a figure of 1.7 barrels as a conservative estimate of the amount of Portland cement that could be made from a cubic yard of marl. The smallest mill that could possibly be built with modern equipment and operated economically would have a capacity of at least 2,000 barrels daily. Such a mill, operating 300 days a year for 30 years, would produce 18,000,000 barrels of cement, for which 10,600,000 cubic yards of marl would be required. Each acre of marl 20 feet deep would yield 32,266 cubic yards of marl, and approximately 320 acres of marl of this depth would be needed to supply the mill for the 30-year period. Most cement plants are either worn out or obsolete in 20 years, so the figures above could be revised for that length of time if desired. Approximately 240 acres of marl would be required for successful operation for 20 years.

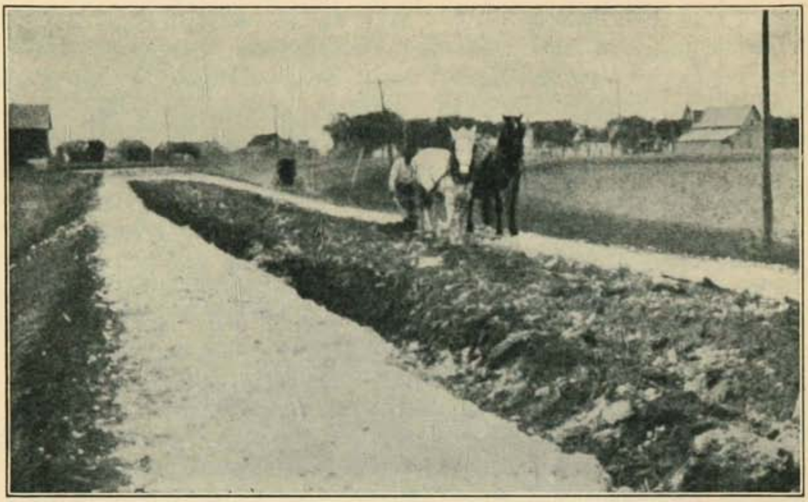

FIG. 1. — Marl being plowed into a sandy road bed, near Rice. (After Dow.)

USE OF MARL IN ROAD CONSTRUCTION

The use of marl in road construction has been investigated by C. H. Dow of the Engineering Experiment Station of the University of Minnesota.[1]

Minnesota has many sandy regions where the roads become deeply rutted because of the absence of binding material in the sand. The common method of improving such roads is to spread clay upon them and by plowing and harrowing to mix the clay with the sand. The road then becomes surfaced with a sand-clay mixture. Because of the similarity in many respects between marl and clay, the use of marl instead of clay was suggested as a binder on sandy roads. (See Figures 1 and 2.) A marl-sand surface has proved entirely satisfactory as a slab to bear up the weight of traffic against breaking through into the subgrade. Such a surface withstands heavy rains without noticeable injury and beyond a certain amount of absorption is also impervious to water. In fact, a marl-sand road is at its best during periods of frequent rains. Under moderate traffic such a road will require surface treatment on account of dust. A blanket of fine gravel, not over an inch thick, spread over about two-thirds of the width of the roadway has been entirely satisfactory for this purpose. Calcium chloride serves the same purpose. Because marl holds moisture well, the applications are effective for a long time.

Under heavy traffic, disintegration by dusting in dry weather is rapid without surface protection. Under such conditions the gravel blanket must be thicker. There are indications that this combination is almost ideal because of the freedom of the marl-sand from waves and surface

[1] University of Minnesota Engineering Experiment Station Bulletin 7, February, 1923.

pockets. Gravel of moderate thickness and width is sufficient, since it does not need to contribute structural strength.

Comparison was made of marl with clay. Where clay is available and can be combined in accurate proportions with sand as a surface mixture, it is probably superior to marl-sand. Pit clay varies greatly in its sand content and is difficult to manipulate in surfacing. Clay is at its worst in wet weather and at its best in dry weather. In comparing the qualities of clay with those of marl, it has been shown that marl compares very favorably with clay as a surfacing material for roads and is superior in some respects.

Rip-Rap, Rubble, and Crushed Stone

Broken limestone in various sizes is much used in all parts of the country where it is available. Large blocks, called rip-rap, are used to protect concrete and masonry work, such as breakwaters, piers, abutments, etc., against strong currents and wave action. Great quantities of the same material are used also to prevent excessive erosion of stream banks or railroad and highway grades that are built adjacent to streams. Smaller angular fragments, known as rubble, a term originally applied to the quarry waste, may be used to fill in between large blocks or with cement to make a coarse concrete. Crushed limestone is much used in concrete, especially where gravel is scarce. It is used also as road metal for highways or as ballast for railroad grades.

Building Stone

Limestone and dolomites furnish some of the finest moderate-priced building and construction stones in the state. They are easily quarried and easily cut, and many have attractive colors. Moreover, they are suf-

Fig. 2. — Excavating marl with slips near Rice. (After Dow.)

ficiently durable to meet the needs of several generations. Massive layers are used for foundations and for heavy construction. Thinner layers find a ready use in walls of buildings or even for interior finish.

Minor Uses

The whiting used as an adulterant of paint is merely a pulverized limestone. The same material is used to mix with linseed oil to form putty, or as a filler for asphalt. Certain limestones are used successfully as a substitute for chalk in the manufacture of crayon. A small amount of high-grade limestone is used in the drug trade, and the various minor uses of limestone, after it has been converted into lime, make a long list. The supply for such purposes must come from regions supported by more insistent demand, for the whole minor list would hardly justify the opening of a quarry for such purposes alone. High-grade marl may serve the same uses.

PART I

THE LIMESTONES AND DOLOMITES OF MINNESOTA

CLINTON R. STAUFFER

CHAPTER I

THE NATURE AND ORIGIN OF LIMESTONE AND DOLOMITE

Physical and Chemical Characters

Generally speaking, limestone is a sedimentary rock composed of calcium carbonate ($CaCO_3$). Its materials have been derived from other rocks through weathering and solution; then later by deposition, either through organic or other agencies, laid down in beds and bound together or cemented into a solid mass. The particles or fragments composing the sediment may be small or comparatively large, the finest fragments making a compact rock in which the pore space is very small. So compact are some limestones that they break with a conchoidal fracture like flint or glass, and the curved fracture surfaces thus left are smooth. The sediment composing the limestones is accumulated in bodies of standing water. The great region of accumulation is the sea bottom.

Although most limestones are of marine origin, some are formed as shell deposits in fresh-water lakes, and the shell marls may be considered the first stages in that process. Such lake deposits, however, are seldom of great extent, and probably none in Minnesota have reached the limestone stage. Other limestones are probably chemical precipitates formed in enclosed basins where excessive evaporation is taking place and where concentration proceeds to and beyond the saturation point. Or limestones may have been formed by biochemical means, the active agency of precipitation being bacteria. Still other limestones may be formed by ground water where it escapes from the rocks as a spring or a seepage. On reaching the surface this ground water may lose some of its dissolved carbon dioxide. This reduces the ability of the water to hold calcium carbonate in solution, and if it was saturated with this substance before, some of it is now precipitated, leaving a film over the floor of the outlet. Layer after layer is thus deposited and in time a very important accumulation may form. Examples are travertine and Mexican onyx. In general, however, these processes are not very important as limestone builders, and such an origin may be assigned to few rocks in Minnesota.

Limestone is normally white to light gray in color; however, it usually contains various impurities that affect its composition and change the color to yellow buff or brown and nearly black. Other colors occur also, such as pink, red, blue, and drab, but many of these tints are indefinite, and the color descriptions are not very consistently applied. Color is usually due to the presence of iron in various stages of oxidation, but organic matter also may be the cause of color variation. Mingled with the sediments that give rise to limestone are such other materials as clay and grains of sand; hence these are among the impurities shown when a chemical analysis is made. With an increase in the amount of clay the limestone passes into a calcareous shale, and with an increase in the sand content it becomes a calcareous sandstone. The finely divided or the amorphous silica present in the original calcareous sediment may be carried in solution and replace portions of the limestone as nodules of flint or chert. Iron sulphide in like manner may form nodules of pyrite or marcasite. These latter may oxidize to hematite or limonite. Calcium phosphate sometimes occurs, but it is usually rare in the limestones of this state, although from .03 to .05 per cent may sometimes be found in the less pure varieties, and small pebbles or black nodules of calcium phosphate may occur at various horizons, chiefly in the Platteville. Manganese oxides are more common, but they are always a very minor constituent, forming thin dendritic films in the cracks or joint planes of the rock. The most common and most persistent impurity in limestone is magnesium. It varies in amount from a trace to a large percentage of the rock and often forms a double carbonate with calcium. When calcium and magnesium are in equal molecular proportion the formula is $CaCO_3 \cdot MgCO_3$, which is the true dolomite.

Origin of Limestone

Limestones have been formed in two ways, one organic, the other inorganic. By far the majority of those limestones of which the history can be definitely determined are of organic origin. The shells or hard parts of marine organisms, chiefly of the simpler forms of life (invertebrates and calcareous algae), have as their principal constituent calcium carbonate. These shells, together with the broken fragments and finer particles resulting from wave action, form a lime mud or marl on the sea bottom that is eventually consolidated into a solid mass to form the limestone. The shells, corals, algae, bones, teeth, etc., incorporated into the limestone are called fossils. They give us some idea of the kinds of organisms that have contributed to the formation of the particular limestone, and since these fossils are usually different in the limestones of different ages, they make possible the correlation of such rocks over wide areas, even when other similar rocks are lacking or deeply buried over the intervening areas. It is also easy to determine from the fossils the conditions under which the limestones were formed, and one may say, with much confidence, that certain limestones are marine. The table on pages 14 and 15 shows the composition of the hard parts of a number of marine forms now living and their suitability for limestone formation.[1]

The shell fragments and calcareous muds are pressed more closely together and squeezed in between the shells by the weight of additional layers formed as the accumulation continues. Calcium carbonate is

[1] See F. W. Clarke and W. C. Wheeler, *The Inorganic Constituents of Marine Invertebrates* (United States Geological Survey Professional Paper 102, 1917, 56 pages, and Paper 124, revised edition, 1922, 62 pages).

introduced by waters circulating through the pore spaces, and this fills up the interspaces binding the fragments together into a solid mass of rock. In some cases the whole mass may be more or less recrystallized, producing a rock that approaches a marble. Heat and pressure are very favorable to this process and when long enough continued may produce a true marble.

The inorganic formation of limestone is limited chiefly to the chemical precipitation of calcium carbonate from solution in sea water or in salt lakes through the process of evaporation, or perhaps induced by the agitation of the waves in water that is at or near saturation in calcium carbonate. Some of the oolitic limestones may have had such an origin.[1] It is also possible that the escape of carbon dioxide from sea water due to rise in temperature[2] may have been responsible for the formation of some limestones, in cases where the sea water was at the saturation point in calcium carbonate when the temperature change took place. Some of the pre-Cambrian limestones are believed to have had such an origin, but positive proof is lacking. Important beds of travertine are formed as spring deposits. Such beds may form on the surface where water charged with calcium carbonate escapes through openings in the native rock or as a stalactite and stalagmite filling of caves. In either case the cause of precipitation or deposition is usually partial evaporation or the escape of CO_2 from the heavily charged solution. No important deposits of travertine are known in Minnesota.

Weathering and Erosion of Limestones

Weathering affects all rocks. It is the sum of all those processes by which rocks are broken up, disintegrated, or decomposed. It is obvious that some rocks will be more readily attacked by certain weathering processes than others. A sandstone is a hard, durable rock, and for many purposes it is preferred to limestone. But if the sand grains are bound together by a calcareous cement, it is obvious that a very little solution may convert the whole into a bed of loose sand that may easily be carried away by running water. Limestone also is soluble (see Figure 3), but it would require solution of all except the insoluble residue to remove a formation composed entirely of this material. Solution, therefore, is a slow process in the distintegration of limestone, but frost action, exfoliation, and corrasion may produce effects on it similar to those produced on other rocks. The bedding planes and joints are sources of weakness in any rock. They serve as avenues through which the disintegrating processes may work. If the rock is jointed, blocks may be plucked or quarried out by streams flowing over a bed of such limestone; thus it is gradually removed, while at the same time the usual corrasion process is going on.

[1] G. F. Loughlin, E. W. Berry, and J. A. Cushman, *Limestones and Marls of North Carolina* (North Carolina Geological and Economic Survey Bulletin 28, 1921), p. 16.
[2] William H. Twenhofel, *Treatise on Sedimentation* (2d ed., Baltimore, 1932), p. 289.

COMPOSITIONS OF THE SHELLS OF MARINE INVERTEBRATES AND THE CALCAREOUS ALGAE *

Organism		SiO_2	$(Al,Fe)_2O_3$	$MgCO_3$	$CaCO_3$	$CaSO_4$	$Ca_3P_2O_8$
Foraminifera	*Pulvinulina menardii d' Orbigny*	15.33	3.98	3.67	77.02	None	?
Foraminifera	*Orbitolites marginalis Lamarck*	.31	.13	10.55	89.01	None	tr.†
Porifera	*Euplectella speciosa Q. and G.*	98.68	.35	None	.43	None	None
Porifera	*Hircinia campana turrita Hyatt*	1.36	4.45	8.00	81.64	?	3.55
Anthozoa	*Madrepora prolifera Linné*	.20	.07	.14	99.38	.21	tr.
Anthozoa	*Heliopora cerulea Pellas*	.15	.07	.35	98.93	.50	tr.
Anthozoa	*Gorgonia acerosa Pellas*	.22	.22	12.52	81.45	1.95	3.64
Hydrozoa	*Millepora alcicornis Linné*	.24	.11	.95	98.22	.48	tr.
Hydrozoa	*Distichopora sulcata Pourtalis*	.07	.05	.26	98.56	1.06	tr.
Annelida	*Protula tabularia (Montagu)*	None	None	.32	99.55	.13	tr.
Annelida	*Hydroides dianthus Verrill*	None	None	9.72	89.66	tr.	.62
Crinoidea	*Ptilocrinus pinnatus Clark*	2.01	1.31	7.91	88.48	None	.29
Crinoidea	*Isocrinus decorus Thomson*	.03	.08	11.69	88.20	None	tr.
Echinoidea	*Strongylocentrotus fragilis Jackson*	.32	.81	6.95	88.44	2.42	1.06
Echinoidea	*Tetrapygus niger Molina*	.33	.32	6.27	90.52	2.56	tr.
Asteroidea	*Asterias vulgaris Packard*	.64	.30	7.79	91.06	?	.21
Asteroidea	*Asterias tanneri Verrill*	1.01	.70	10.28	87.44	?	.40
Ophiuroidea	*Ophioglypha sarsii Lütken*	1.15	.62	9.84	87.65	?	.74
Ophiuroidea	*Ophioderma cinercum M. and T.*	.24	.11	14.08	85.09	.30	.18
Holothuroidea	*Holothuria floridana Pourtalis*	.15	.34	13.84	83.29	2.38	tr.
Bryozoa	*Schizoporella unicornis Johnston*	1.77	.31	.63	95.97	1.32	tr.
Bryozoa	*Bugula neritina Linné*	12.94	1.56	11.08	63.29	8.47	2.68

Organism		SiO_2	$(Al,Fe)_2O_3$	$MgCO_3$	$CaCO_3$	$CaSO_4$	$Ca_3P_2O_8$
Brachiopoda	*Terebratula cutensis Pourtalis*	.06	.04	.93	98.61	.36	tr.
Brachiopoda	*Craina anomala Muller*	.22	.27	8.63	88.59	1.72	.57
Brachiopoda	*Lingula anatina Gmelin*	.91	.54	2.70	1.18	2.93	91.74
Brachiopoda	*Glottidia pyramidata Stimpson*	.49	1.16	1.71	?	?	74.73
Pelecypoda	*Astarte crenata Gray*	.26	.09	None	99.65	None	tr.
Pelecypoda	*Cardium substriatum Conrad*	.11	.09	tr.	99.80	None	tr.
Scaphopoda	*Dentalium solidum Verrill*	.40	.27	.20	99.13	?	tr.
Amphineura	*Mopalia muscosa Gould*	.61	.22	.45	98.37	.35	tr.
Gastropoda	*Fasciolaria distans Lamarck*	.34	.04	.14	99.48	?	tr.
Gastropoda	*Strombus canarium Linné*	.09	.21	tr.	99.70	?	tr.
Cephalopoda	*Nautilus pompilius Linné*	.19	.15	.16	99.50	None	tr.
Cephalopoda	*Argonauta argo Linné*	.09	.13	6.02	93.67	None	tr.
Cirripedia	*Lepas anatifera Linné*	.04	.20	2.49	97.27	None	tr.
Cirripedia	*Bolanus eubrens Gould*	.40	.22	1.65	97.73	None	tr.
Malacostraca	*Callinectes sapidus Rathbun*	.06	.06	6.69	78.14	.60	14.45
Malacostraca	*Homarus americanus M. Edwards*	None	.34	8.02	79.50	1.23	10.91
Algae	*Lithothamnium glaciale Kjellman*	.45	.25	10.93	88.11	.26	tr.
Algae	*Lithophyllum oneodes Heydrick*	.10	.13	18.17	80.93	.49	.18
Algae	*Goniolithon strictum Foslie*	.02	.01	24.00	74.85	1.12	tr.
Algae	*Halimeda opuntia Lamouroux*	.41	.22	.02	99.21	.14	tr.
Algae	*Halimeda tridens Lamouroux*	1.04	.68	1.09	96.21	.98	tr.

* Compiled from F. W. Clarke and W. C. Wheeler, United States Geological Survey Professional Paper 124, 1922.
† tr.=trace.

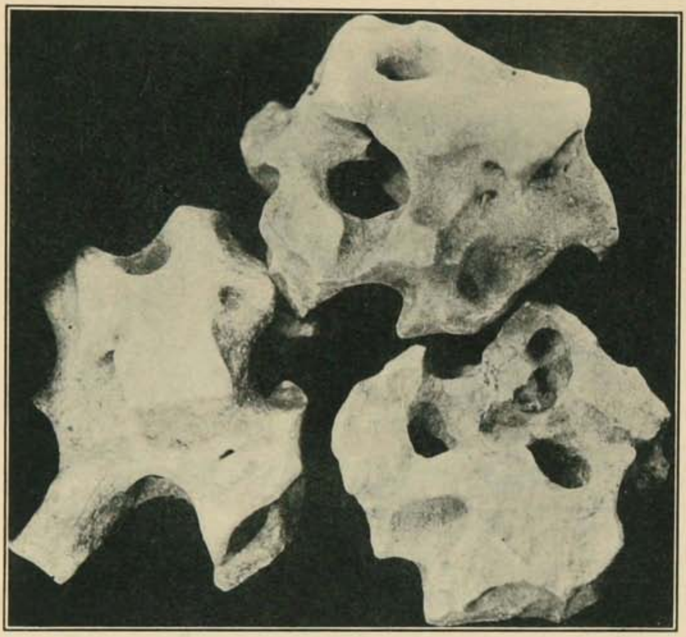

FIG. 3. — Solution cavities in the Prosser limestone from Preston.

CHARACTERISTICS OF LIMESTONE REGIONS

Certain topographic features are more or less characteristic of regions in which the surface is underlaid by limestone. Thus the massive beds tend to form cliffs, often with castellated outcrop, and to cap the erosion remnants. By far the most important characteristic, however, is the development of caves and sinks. These are especially well developed in the high-grade beds, such as those of the Prosser limestone in southern Minnesota, and in regions where such formations are associated with others of less solubility. Thus in the portion of Minnesota cited, the Prosser limestone is overlaid by the highly magnesian Stewartville dolomite. In the formation of caves the ground water as it descends along joint planes widens them by solution. It produces a like effect where it spreads out along a bedding plane. This latter effect is likely to be observed at some clayey or shaly layer, or where a less soluble formation begins. Thus great cavities known as caves are developed. These are more or less continuous to lower and lower levels, and much of the local drainage may be taken care of through such underground channels. Parts of the roof of a cave may fall in, or the overlying mantle rock or glacial drift may be washed down the widened joints, thus forming depressions or yawning chasms through which the surface waters escape to the sub-surface drainage channels. Such depressions are known as sinks. They are commonly developed in southern Minnesota, especially in Fillmore and Olmsted counties, where they occur by the score and where they lead to caves, several of which have been partially explored.

Dolomitization of Limestones

A pure limestone has the composition of calcite. So easily, however, is a portion of the calcium in the calcium carbonate molecule replaced by magnesium that very few limestones are free from this substitution. The extent to which this process has taken place varies greatly in the limestones of this state, and it is not entirely a matter of age. Those carbonates high in magnesium are dolomitic limestones or dolomites. And the process by which this substitution was brought about is known as dolomitization. It is not very clear when or how this process took place. The double carbonate of dolomite may have been formed by direct chemical precipitation from the sea water in the formation of the sediment, in some few cases, but this process is not now a major one in the sea.

Some of the lime-secreting or shell-forming organisms of the sea, especially among the plants, utilize amounts of magnesium carbonate ranging up to 10 per cent or even 25 per cent, but even that percentage of magnesium is much less than the magnesium present in the Minnesota dolomites. It seems certain therefore that the process of dolomitization must be considered one of enrichment rather than of original deposition. Dolomitization thus appears to have been due largely to a replacement of part of the calcium in the original more or less pure calcium carbonate, probably before the resulting rock had been completely consolidated.[1]

The Limestone Resources of Minnesota

The limestones belong to the class known as sedimentary rocks. Most sedimentary rocks are formed of particles derived from other rocks through the process of disintegration commonly called weathering. These fragments are carried by running water or by the wind, and are continually reduced in size as they are shifted from place to place. Finally they reach a lodgment basin, either on land or in the sea, and there accumulate in quantity and are eventually consolidated into hard rock — the sedimentary rocks. Over a long period of time it is obvious that the sediments thus accumulated must have attained great thickness and that the older ones must lie at the bottom of the series, unless by subsequent surface warping they have been folded and overturned. The Paleozoic rocks of Minnesota have not been materially affected by deformation, and the calcareous formations of greater age which have been much deformed and even greatly metamorphosed are of no value as limestones.

[1] See Edward Steidtmann, "The Evolution of Limestones and Dolomites," *Journal of Geology*, 19:323–345, 392–425 (1911); F. M. Van Tuyl, Annual Report of the Iowa Geological Survey, 25:251–422 (1914); and Frank W. Clarke, *Data of Geochemistry* (United States Geological Survey Bulletin 770, 1924), p. 565–580.

The natural grouping of the rock formations of any region is referred to as the geological column or classification. The following list is a tentative geological column for Minnesota.[1]

Geological Column of Minnesota

- Cenozoic
  - (Quaternary)
    - Recent
      - Marl, peat, and alluvium
    - Pleistocene
      - Wisconsin drift
      - (Loess deposits)
      - Iowan drift
      - (Interglacial forest beds)
      - Kansan drift
  - (Tertiary)
    - Pliocene
      - Lafayette formation?
      - (Orange gravels)
    - Eocene
      - Fort Union
- Mesozoic
  - Cretaceous
    - Coleraine (Pierre) shale
    - Dakota sandstone
- Paleozoic
  - Devonian
    - Cedar Valley limestone
  - Ordovician
    - Upper
      - Maquoketa shale
    - Middle
      - Stewartville dolomite
      - Prosser limestone
      - Decorah shale
      - Platteville limestone
      - Glenwood beds
    - Lower
      - St. Peter sandstone
      - Shakopee dolomite
      - (New Richmond sandstone)
      - Oneota dolomite
  - Cambrian
    - St. Croixian
      - Jordan sandstone
      - St. Lawrence formation
      - Franconia sandstone
      - Dresbach formation
      - (Eau Claire shale)
  - Cambrian?
    - Red Clastic
      - Hinckley sandstone
      - Red and gray shales and sandstones

[1] Modified from F. F. Grout, *Clays and Shales of Minnesota* (United States Geological Survey Bulletin 678, 1919), Plate IX.

PROTEROZOIC
- Keweenawan
  - Logan sills, Duluth gabbro, sandstones, and the Puckwunge conglomerate
- Animikian
  - Virginia (Rove, Carleton) slate
  - Biwabik (Gunflint) formation
  - Pokegama quartzite
- Algomian
  - Giants Range granite
- Huronian
  - Knife Lake slate, including Agawa formation, Sioux quarzite, Ogishke conglomerate, and other sediments

ARCHEOZOIC
- Laurentian
  - Saganaga and other granites
- Keewatin
  - Soudan formation
  - Ely greenstone

This classification or table of formations includes those names commonly used in Minnesota. Some additional names, occasionally applied to the rocks of this state, are enclosed in parentheses and placed in what appears to be their proper position in the scale. Other names, now seldom used, have been omitted, and some of the intrusives are omitted. A satisfactory classification for the whole state is not yet completed.

AGE AND DISTRIBUTION OF MINNESOTA LIMESTONES

Among the Archeozoic and Proterozoic rocks of Minnesota are calcareous beds and some secondary calcite, but no limestones. Hence these may be omitted from further attention in the present discussion. The limestones of Minnesota, therefore, belong chiefly to the Paleozoic group, and are included in the Cambrian, Ordovician, and Devonian systems that outcrop in the eastern and southeastern parts of the state. Over much of this region is a heavy covering of mantle rock, the greater part of which is glacial drift. The Mississippi River and its tributaries, especially the Minnesota, St. Croix, Cannon, Root, and Cedar rivers, have cut through this surface débris exposing excellent sections of the underlying bed rock.

The oldest limestone or dolomite in the state is a part of the St. Lawrence. This formation is of Upper Cambrian age. It includes much sandy shale and beds of glauconite, but at St. Lawrence, Scott County, 6 to 8 feet of dolomitic limestone are well exposed, and even more is shown in Nicollet and Blue Earth counties, near the village of Judson. This dolomitic horizon may be traced along the St. Croix and down the Mississippi River to the southern boundary of the state.

The Oneota dolomite forms the base of the Ordovician or the upper part of Dr. E. O. Ulrich's Ozarkian system. It is a highly dolomitic limestone, which has supplied both lime and building stone to the trade for many years. It outcrops along the Minnesota River and some of its tributaries from Garden City northward to Chaska, near which it passes below drainage level. Along the St. Croix it makes its first appearance in northern Washington County and outcrops along the tributaries and river bluffs to the Mississippi River, thence southeastward to the state line in Houston County. Along the Mississippi River the Oneota rises from river level at Hastings to the tops of the bluffs at Red Wing and continues to form the hill caps throughout the rest of its outcrop.

The Shakopee dolomite also is lower Ordovician or in the upper part of Ulrich's Canadian system. It is often so similar in physical appearance to the Oneota that the two formations are difficult to distinguish on the basis of their lithologic characteristics. The fossils are distinctive but are exceedingly rare in both formations. The distribution of the Shakopee dolomite is almost coextensive with the Oneota, although it does not quite cover that formation and is believed to occur in places where there is no Oneota.

The Platteville limestone outcrops in the high area around the Twin Cities in Dakota, Hennepin, Ramsey, and Washington counties. The Platteville limestone also outcrops along Straight River, southeast of Faribault, and from thence north and eastward along the southern branches of the Cannon River, the western and southern branches of the Zumbro River, the western branches of the Whitewater River, and the upper parts of the various branches of the Root River. The outcrops in this southern area are thus limited to Rice, Dakota, Goodhue, Wabasha, Dodge, Olmsted, Winona, Fillmore, and Houston counties.

The basal portion of the Decorah shale is a limestone that is usually high in its percentage of calcium carbonate. The limestone layers interbedded with the shales of this formation are also of rather high grade. The shale, with its accompanying limestones, is almost coextensive with the outcrop of the Platteville limestone. In fact, so closely do the basal layers (see Figure 4) cling to that formation over the region where the shale proper has been removed that they are commonly included with the Platteville. The upper part of the Decorah shale grades into the basal layers of the Prosser, which is frequently shaly. This shaly condition is more common in the northern part of the outcrop. This is true especially in St. Paul. It is necessary, therefore, to depend on the fauna to distinguish between the two formations, and even this is not a sure guide.

The Prosser limestone is the basal portion of the limestone and dolomite that has usually passed under the name Galena. It begins as a shale interbedded with limestones and may be difficult to distinguish from the underlying formation. This is the case in St. Paul, where the Galena overlies the Decorah shale in the high land on the river bluff commonly called Cherokee Heights.

While the Galena formation may be recognized from St. Paul southward, the highly calcareous lower portion known as the Prosser lime-

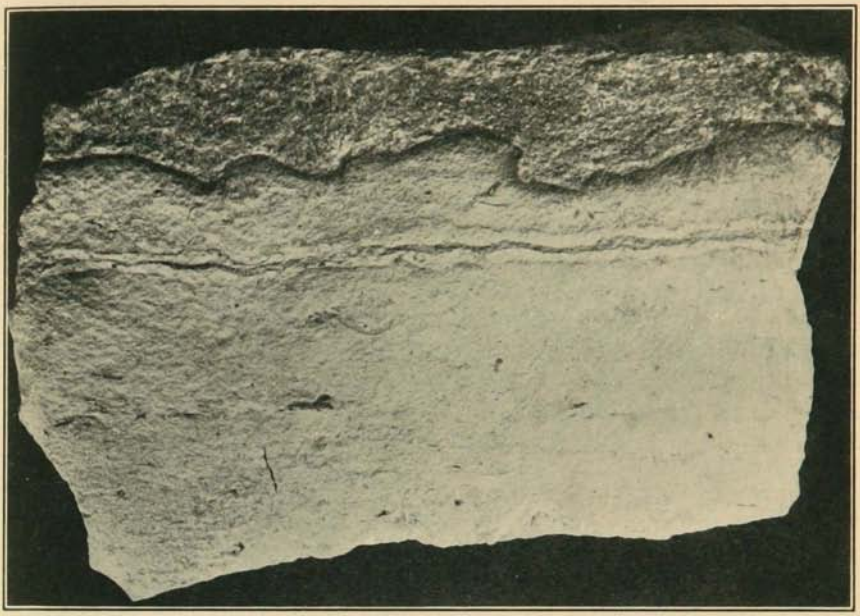

FIG. 4. — Contact between the Platteville limestone (below) and the Decorah shale in Minneapolis.

stone is but poorly developed to the north of Olmsted County. In southern Goodhue County it might be found to be of sufficient thickness and purity to be valuable commercially, but its outcrops scarcely warrant that hope. The Prosser limestone is typically developed in Fillmore County, where it attains a thickness of about 60 feet and is uniformly a high-grade limestone. It receives its name from a small gulch near Wykoff, where it is fully developed. It outcrops along all the larger streams in Olmsted and Fillmore counties, often with very little overburden.

The Stewartville dolomite is the upper part of the Galena formation. It thus overlies the Prosser limestone and may be found in outcrop from Goodhue County southward to the state line. In Fillmore County it forms the high castellated bluffs capping outcrops of Prosser limestone along the branches of Root River and their tributaries. It has been rather extensively quarried in northern Dodge County, where the covering of drift is light.

The Maquoketa shale is highly calcareous or dolomitic in southern and western Fillmore County, where it is often distinguished with difficulty from the Stewartville dolomite. Its outcrop is of slight extent, although it doubtless exists under a covering of drift to the west.

The Cedar Valley limestone is the only known representative of the Devonian in Minnesota. Its outcrop begins a few miles to the west of Granger and extends northwestward across the corner of Fillmore County, through Spring Valley, and into Mower County, where its margin is lost under the drift, although outcrops of it are rather numerous in the southern parts of both western Fillmore County and southern Mower County. Here the drift is thin and many of the road cuts show the Cedar Valley limestone. Usually this limestone is a yellowish to buff porous rock, occurring in massive beds, but at Le Roy it is a compact, hard, gray to white limestone of rare purity. The Cedar Valley is the youngest limestone in the state and fills the remnant of the synclinal area of southeastern Minnesota. When the Cretaceous sea spread over the state, it was a peneplained area that was invaded, not a structural basin as in the previous invasions of the sea during the various periods of the Paleozoic era. Although conditions of deposition over part of the state approached those necessary for the formation of calcareous deposits, with the possible exception of a small area near New Ulm there are no Cretaceous limestones in Minnesota; the nearest approach is the "oyster shell bed" on the Mesabi Range.

Of all these limestones, only the Prosser and the Cedar Valley are of sufficient purity to meet the needs of a Portland cement rock. The high calcium carbonate content of the Cedar Valley limestone makes it desirable also for pharmaceutical purposes, for which it is being used. Many of the other demands for these carbonates, such as sweetening the soil or stock feed, can use the dolomites just as well as the pure limestones, and those of this state are well suited to such needs.

In order to determine the fitness of a rock for road building or any other construction purpose the State Department of Highways has applied the following physical tests to samples from various beds.

Specific gravity.—Specific gravity is determined in the usual manner. It is the quotient obtained by dividing the weight of a specimen in air by its loss of weight when submerged in water. In other words, it is the ratio of the weight of a specimen to the weight of an equal volume of water.

Weight per cubic foot.—The weight per cubic foot of rock is the weight of a cubic foot of the solid rock before crushing. It is an index of the density or porosity of the sample.

Percentage of absorption.[1]—The absorption of water is determined by weighing the sample in air (W); then weighing the same sample in water immediately after its immersion (Wa); and finally weighing the same sample in water after 96 hours' immersion (Wb). The absorption (A) in pounds per cubic foot is expressed by the formula

$$A = \frac{Wb - Wa}{W - Wa} \times 62.37.$$

[1] See H. S. Mattimore and others, *Tentative Standard Methods for Sampling and Testing Highway Materials* (United States Department of Agriculture Bulletin 1216, September, 1928).

The percentage of absorption of water is then determined in the ordinary manner:

$$\text{Percentage of absorption} = \frac{\text{Absorption}}{\text{Weight per cubic foot}} \times 100.$$

Rocks that absorb much water are likely to be more readily broken up or reduced to finer particles under frost action than those that absorb little water.

Percentage of wear.—The percentage of wear is the ratio of dust and fine particles of rock, such as will pass through a no. 12 sieve, that have been worn from the sample in the abrasion test, to the original sample. The test was devised by the French engineer Deval and is made in a testing machine consisting of a series of cylinders 20 centimeters in diameter and 34 centimeters in depth. These cylinders rotate and are inclined 30° to the axis of rotation. Each cylinder is charged with 50 cubical pieces of the sample of a size which will pass a 3-inch but be held on a 1½-inch ring (total weight about 10 pounds). The cylinder is then rotated 10,000 turns at a rate of about 1,800 revolutions an hour. This allows the sample to be dashed from one end of the cylinder to the other with each revolution. The percentage of wear is determined on the basis of the amount of fine material worn from the sample during the test that will pass through a 12-mesh sieve.

French coefficient.—The French coefficient is obtained by dividing the percentage of wear into 40. This method of expressing the wear on the sample during the abrasion test was devised by the French engineers so that the higher figures would represent the more durable rock.

Average toughness.—The toughness test was devised to determine the resistance of the rock to continuous blows, such as those of the shod hoofs of a horse. For this test a 1-inch cylinder of the sample is used. This is placed in a small machine of the pile driver type and a standard weight is dropped upon it from constantly increasing heights until the sample breaks. The height from which the rupturing blow falls represents the toughness.

CHAPTER II

LIMESTONES AND DOLOMITES IN INDIVIDUAL COUNTIES

While only a few counties have valuable deposits of high-grade limestone, the dolomitic limestones and dolomites are used in a number of others, and it seems advisable to treat briefly each county concerned. Only the formations cropping out are considered even in the counties where other limestones or dolomitic formations are known to occur below the surface.

Hennepin County

Most of Hennepin County is heavily drift-covered, but adjacent to the Mississippi River and the lower end of the Minnesota River, in the eastern part of the county, the bed rock is at the surface or so near that it crops out along the steep bluffs of the rivers, or is easily uncovered, throughout a region several miles in width. The section exposed includes all the formations from the St. Peter sandstone to the Decorah shale. Quarries in the Platteville limestone have been opened in a number of places, but those on Johnson Street, Minneapolis, are about the only ones now active. The total quarry face is 26 feet, but the upper part includes the basal limestone layer of the Decorah shale. This latter clings so tightly to the top of the Platteville in this region that it is often difficult to locate the contact. The following is a section of the rocks exposed in the quarry of the Minnesota Crushed Stone Company at 1500 Johnson Street Northeast, Minneapolis.

Section of the Quarry of the Minnesota Crushed Stone Company, Minneapolis

	Thickness
Recent	
7. Soil and river gravel	4 ft. 0 in.
Pleistocene (Wisconsin)	
6. Red drift	8 ft. 0 in.
Decorah Shale	
5. Limestone, hard, semicrystalline, gray to brown, with calcite and pyrite cavity fillings	1 ft. 4 in.
Platteville Limestone	
4. Limestone, buff to gray, dolomitic, with numerous fossils in "nests" or lenticular streaks. Physical tests general sample 3. Also physical test sample 5 taken 7 inches above base	7 ft. 5 in.
3. Limestone, shaly, blue to gray	0 ft. 10 in.
2. Limestone, argillaceous, blue to slate-colored. Shows conchoidal fracture. Poor in fossils. Physical test general sample 2	5 ft. 4 in.
1. Limestone, hard, irregular thin laminae with shale partings. Fossils abundant. Physical test general sample 1. Also physical test sample 4, taken 5 feet above the floor of the quarry	11 ft. 4 in.

This quarry furnishes some ground rock and some unusually fine building stone, which must be carefully selected and laid to produce a pleasing and satisfactory wall. The best building stone comes from the buff beds of the upper 7½ feet of the Platteville. The main product of this quarry, however, is crushed rock for concrete and ballast.

On the basis of the physical tests applied to samples from the quarry of the Minnesota Crushed Stone Company, the following table has been constructed.

Sample	Sp. Gr.	Wt. per Cu. Ft.	Per Cent Absorption	Per Cent Wear	French Coef.	Average Toughness
1............	2.67	167	.80	3.08	13.07	11.5
2............	2.61	163	2.98	3.10	12.90	12.0
3............	2.56	160	3.73	3.70	9.25	12.5
4............	2.64	165	.1.56	5.00	8.00	9.5
5............	2.53	158	4.53	4.50	8.88	14.0

The finest outcrop of the Platteville within the county is along the river bluff on the University campus. (See Figure 5.) From this point southward, the Platteville is in almost continuous outcrop along the river to Fort Snelling. The abandoned quarries along these bluffs are partly overgrown and partly filled with earth from other excavations, but several sections are still very good. Probably one of the best is at the western end of the Franklin Avenue Bridge, where a section is exposed similar to that in the quarries along Johnson Street.

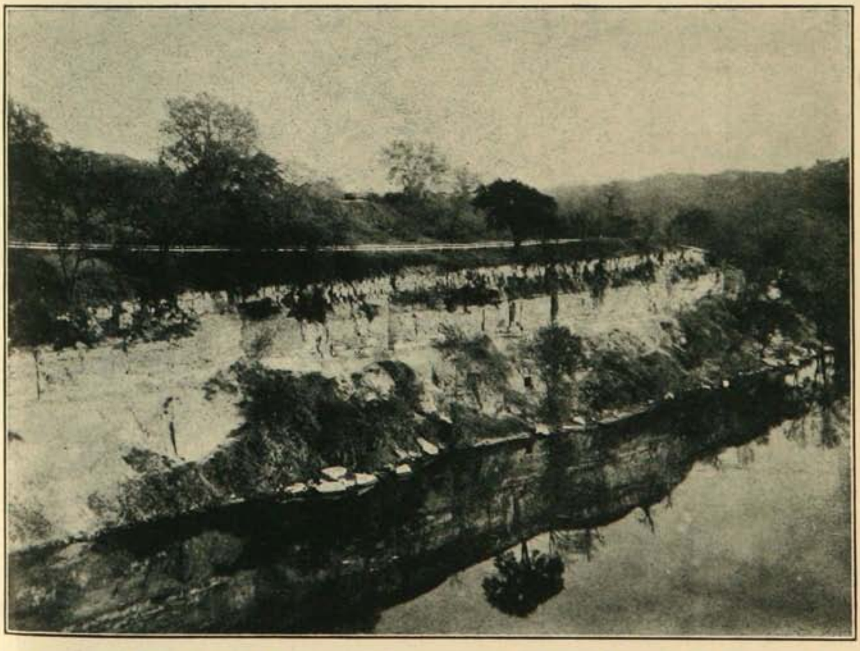

FIG. 5. — The Platteville limestone overlying the Glenwood beds and the St. Peter sandstone in the river bluff at the Washington Avenue Bridge, Minneapolis.

An excellent and well-exposed section occurs at the High Dam near the outlet to Minnehaha Creek. This gives the complete thickness of the Platteville limestone.

SECTION AT THE LOCKS, HIGH DAM, MINNEAPOLIS

	THICKNESS
21. Soil and drift	12 ft.±0 in.
Decorah Shale	
20. Limestone, bluish gray, a single layer	0 ft. 9 in.
19. Shale, argillaceous, blue	2 ft. 2 in.
18. Limestone, hard, blue, with thin shaly partings. *Pianodema* common	2 ft. 4 in.
17. Shale, gray to bluish, an altered Bentonite	0 ft. 4 in.
16. Limestone, hard, compact, pyritiferous, brown. *Lingula elderi* common	1 ft. 6 in.
Platteville Limestone	
15. Limestone, gray to brown or buff, dolomitic. Top irregular and impregnated with iron. Fossils abundant	8 ft. 2 in.
14. Limestone, compact, bluish to brown	1 ft. 4 in.
13. Limestone, shaly argillaceous blue, breaking with conchoidal fracture	1 ft. 4 in.
12. Limestone, massive, bluish to buff. A black pebble zone and evidences of corrasion at the base. Fossils few and in streaks or "nests."	2 ft. 0 in.
11. Limestone, compact, brown to gray weathering bluish. Layers thin, irregular, often nodular and separated by thinner layers of shale. Fossils usually broken	11 ft. 0 in.
10. Limestone, hard, bluish gray	0 ft. 8 in.
9. Limestone, hard, bluish gray, with small black pebbles	1 ft. 0 in.
Glenwood Beds	
8. Shale, argillaceous, gray to greenish	2 ft. 0 in.
7. Limestone, arenaceous, gray	0 ft. 2 in.
6. Shale, argillaceous, gray to greenish	0 ft. 6 in.
5. Shale, arenaceous, green	1 ft. 6 in.
4. Sandstone, argillaceous, nodular, yellow to brown	2 ft. 9 in.
St. Peter Sandstone	
3. Sandstone, white, at places iron-stained to yellow or brown. Evidences of erosion at the top	5 ft. 10 in.
2. Sandstone, white, cross-bedded	2 ft. 6 in.
1. Sandstone, massive, white, poorly cemented. Occasional hard lumps, more or less spherical. Disintegrating pyrite or marcasite has left brown streaks or patches over the outcrop. Extends to the level of the Mississippi River below the dam	65 ft. 0 in.

When the excavation for the Minnehaha sewer was cut it started at the river and tunneled through the St. Peter sandstone, finally coming to the surface at the creek a block west of Minnehaha Park, as an open cut in the Platteville limestone and basal Decorah shale. In this extension of the section the fresh samples were collected for analysis. About a mile from the river the limestone of the cut terminated abruptly on the edge of one of the buried channels so common in the Minneapolis-St. Paul area.

Analyses of samples from Hennepin County are given in the table at the end of this chapter under the numbers 7, 10, 11, 12, 135, 136, 137, 153, 154, 155, and 156.

Ramsey County

The northern and western parts of Ramsey County are heavily drift-covered. Most of the outcrops of bed rock occur along the Mississippi River bluff or within two or three miles of it. This brings virtually all the areas of outcrop within the city limits of St. Paul and its down-river suburbs. Over part of this area the bed rock belongs to the Decorah shale, and in the higher areas probably basal Galena (Prosser) limestone occurs. Some of these latter beds crop out along the river bluff at Cherokee Heights and have been cut by the clay pit at the Twin City Brick Company's plant. In the down-town district, the Platteville limestone is frequently at the surface, and it had to be quarried out in making the excavation for the St. Paul auditorium. The oldest surface rock in the county is the Shakopee dolomite. It outcrops less than a mile down the river from the southern boundary of the county and is probably just beneath the surface in adjacent parts of Ramsey County.

The only limestone quarried within the county limits is the Platteville. Limestone layers are removed from the Decorah shale and from the basal Galena (Prosser) at the brick plant, but they are not utilized. Some of them might be suitable for building purposes, but they often contain too much iron and their color is not pleasing. They are more likely to be used as crushed rock.

Along Stewart and Victoria avenues, the St. Paul Crushed Stone Company controls a large acreage and operates on an extensive scale. The quarry is located on a rock terrace one hundred or more feet above the river and in the lower portion of the Platteville limestone.

Section of Quarry of the St. Paul Crushed Stone Company at Stewart and Victoria Avenues, St. Paul

	Thickness
7. River gravels, sand, and clay	3 ft. ±0 in.
Platteville Limestone	
6. Limestone, thin-bedded, white mottled with gray streaks. Physical test sample 3	3 ft. 0 in.
5. Limestone, light gray mottled with white, compact and abundantly fossiliferous. Physical test sample 2	4 ft. 0 in.
4. Limestone, gray at places mottled with lighter color, fossiliferous. Contains small grains of pyrite or marcasite. Physical test sample 1	3 ft. 0 in.
Glenwood Beds	
3. Shale, blue to green, at places sandy	4 ft. 0 in.
St. Peter Sandstone	
2. Sandstone, white, exposed in city excavations adjacent to the quarry	15 ft. 0 in.
1. Covered interval to level of the Mississippi River	110 ft. ±0 in.

Although some of this rock has found use as a local building stone, the chief product of the quarry is crushed stone. The following table shows the suitability of the rock for concrete. The tests were made in the laboratories of the State Highway Department and under the supervision of Mr. F. C. Lang.

Sample	Sp. Gr.	Wt. per Cu. Ft.	Per Cent Absorption	Per Cent Wear	French Coef.	Average Toughness
1	2.60	162.5	1.20	4.20	9.52	14.0
2	2.63	164.0	1.78	3.10	12.90	11.5
3	2.54	159.0	3.01	5.00	8.00	10.5

One of the best sections in this region is that found at the plant of the Twin City Brick Company, where all the local formations are exposed in the river bluff and form one continuous outcrop.

SECTION OF RIVER BANK AT TWIN CITY BRICK PLANT, ST. PAUL

	THICKNESS
PLEISTOCENE AND RECENT	
21. Drift and soil	125 ft. 0 in.
GALENA (PROSSER) BEDS	
20. Limestone, bluish, with interbedded bluish shale	10 ft. 8 in.
19. Shale, blue, with thin layers of blue limestone	5 ft. 4 in.
DECORAH SHALE	
18. Shale, blue, alternating with blue limestone. Contains numerous *Zygospira*	10 ft. 8 in.
17. Limestone, hard, brown, iron-stained, with the "brassy" oolitic grains	1 ft. 9 in.
16. Shale, blue, with a fucoidal bed of limestone at the top	4 ft. 2 in.
15. Shale, soft, blue, with a few lenses of limestone	21 ft. 4 in.
14. Shale, blue, with knotty lenticular layers of limestone	12 ft. 0 in.
13. Shale, soft, blue, nearly free from limestone	4 ft. 0 in.
12. Shale, soft, blue, alternating with lenticular beds of limestone	7 ft. 0 in.
11. Shale, soft, blue, with a few thin lenses of limestone. Contains the quarrymen's "putty layer," about 9 feet above the top of the Bentonite	17 ft. 8 in.
10. Limestone, hard, blue	0 ft. 8 in.
9. Shale, soft, blue	2 ft. 2 in.
8. Limestone, hard, partly crystalline, blue	1 ft. 10 in.
7. Shale, soft, blue-green, and variable in thickness. An altered Bentonite	0 ft. 4 in.
6. Limestone, hard, blue, pyritiferous	1 ft. 3 in.
PLATTEVILLE LIMESTONE	
5. Limestone, gray to buff, fossiliferous	8 ft. 0 in.
4. Limestone, thin-bedded, argillaceous, blue, showing conchoidal fracture	5 ft. 0 in.
3. Limestone, mottled, blue	11 ft. 8 in.
GLENWOOD BEDS	
2. Shale, argillaceous, green and sandy green	5 ft. 0 in.
ST. PETER SANDSTONE	
1. Sandstone, white, friable, medium-grained, to level of Mississippi River	79 ft. 0 in.

Samples 8, 9, 149, 150, and 151 in the table at the end of this chapter are from Ramsey County.

WASHINGTON COUNTY

The northern part of Washington county is well covered by drift, but in the southern half the bed rock lies relatively near the surface. Certain butte-like hills are capped by the Platteville limestone and their steep slopes are formed by loose sand derived from underlying St. Peter sandstone. All the limestones and dolomites below, including the Platteville, crop out, but of these the St. Lawrence is of no great importance because it is unsuited to any economic use. It therefore may be disregarded.

At Stillwater the Oneota dolomite forms magnificent outcrops on the high bluffs facing the St. Croix River. The Stillwater well records 85 feet of gray dolomitic limestone immediately beneath the drift. However, the well was located just two blocks west of the city hall on a plot of land 142 feet above the St. Croix River and thus not high enough to include the total thickness of the Oneota dolomite. The following section was measured in the south edge of town.

SECTION OF BLUFF AT WOLFE BREWERY, STILLWATER

	THICKNESS
15. Soil	0 ft. 6 in.
ONEOTA DOLOMITE	
14. Dolomite, thin-bedded, vesicular to dense, gray to yellow	10 ft. 0 in.
13. Dolomite, even-bedded, fairly dense, gray	3 ft. 0 in.
12. Dolomite, massive, rough, vesicular, gray	3 ft. 6 in.
11. Dolomite, massive to thin-bedded, dense, gray	8 ft. 6 in.
10. Dolomite, massive, rough, vesicular, gray to brown	6 ft. 0 in.
9. Dolomite, massive, dense, even-bedded, gray	8 ft. 0 in.
8. Dolomite, massive, rough, vesicular, arenaceous, gray to brown	10 ft. 8 in.
JORDAN SANDSTONE (SHARP CONTACT)	
7. Sandstone, massive, cross-bedded, coarse, yellow to brown. Quartz grains reconstructed	4 ft. 6 in.
6. Sandstone, massive, cross-bedded, medium to coarse, white to yellow	32 ft. 0 in.
5. Sandstone, massive to thin-bedded, often cross-bedded, yellow to white	6 ft. 8 in.
4. Conglomerate, massive, yellow. Pebbles of sandstone flat and mostly in a horizontal position	3 ft. 6 in.
ST. LAWRENCE FORMATION?	
3. Sandstone, fine-grained, white with vermicular markings filled with green shale	2 ft. 0 in.
2. Sandstone, massive, fine-grained, and dolomitic in lower part, yellow to white, vermicular	18 ft. 0 in.
1. Covered interval to level of St. Croix River	18 ft. 0 in.

Formerly the Oneota dolomite was extensively quarried at Stillwater, and many of the local buildings are constructed of it, but the industry declined and the quarries are now abandoned. Small quarry pits, where local supplies of rock have been obtained, occur in the Oneota, the Shakopee, and the Platteville of the southern part of the county, but they are now all abandoned. These three formations are well suited to the ordinary types of construction and concrete work. Abandonment of the quarries is largely due to a falling off in demand on account of the substitution of other materials for building.

In the table at the end of this chapter, samples 157 and 158 are from Washington County.

SCOTT COUNTY

Scott County has the broad valley of the old River Warren, now occupied by the Minnesota River, as its northern and western border.

FIG. 6. — The St. Lawrence dolomite in the old quarry at St. Lawrence.

Here the thick covering of drift has been cut through, exposing the lower Ordovician and Cambrian formations.

The St. Lawrence dolomite type locality is at the old village of St. Lawrence (see Figure 6), about four and a half miles west of Jordan. The following section was measured by Alexander Winchell, who first used the name for these rocks.[1]

SECTION OF ST. LAWRENCE LIMESTONE AT ST. LAWRENCE

	THICKNESS
6. Magnesian limestone, speckled and mottled with green and having numerous greenish partings. Greatly shattered	2 ft. 0 in.
5. Magnesian limestone, buff, thick-bedded, vesicular. Contains crystals of brown spar. Quarried for building	4 ft. 0 in.
4. Magnesian limestone, reddish tinged, hard, fine, crystalline	2 ft. 0 in.
3. Magnesian limestone, irregularly bedded, buff containing green specks (probably silicate of iron) and fucoidal casts	4 ft. 0 in.
2. Arenaceous greenish shale, with partings of light clay	0 ft. 8 in.
1. Buff, magnesium limestone in thin layers	?

More recent studies of the region show that the St. Lawrence, as exposed in the old quarries of the type locality, is a glauconitic dolomite 8 feet to 15 feet in thickness, underlaid by about 15 feet of sandy gray shale. It contains *Billingsella coloradoensis* and a few scattered fragments of trilobites, which show its Cambrian age.

During the early seventies the St. Lawrence dolomite was quarried for a local building stone and used in the construction of a hotel building and two or three dwellings. The fact that these still stand, with

[1] *Report of a Geological Survey of the Vicinity of Belle Plaine, Scott County, Minnesota* (Senate Document, St. Paul, 1872), p. 8.

walls in excellent condition, demonstrates its fitness for such purposes. It is probable that the rock is equally suited to concrete or other use in crushed form.

The Oneota dolomite caps the Cambrian sandstones under cover of the drift along the bluffs of the Minnesota valley. The northward dip of the whole series of sediments brings the Oneota-Jordan contact into the flood plain of the river and beneath it in the vicinity of Merriam Junction. To the north of this point the Oneota crops out in the fields and is cut by the highway and railroad grading. About a half mile north of the junction is the old Joseph Lindhoff Quarry and lime kiln, at which the following section is exposed.

SECTION OF JOSEPH LINDHOFF (LATER J. B. CONTER) QUARRY ½ MILE NORTH OF MERRIAM JUNCTION

	Thickness
Shakopee Dolomite	
8. Dolomite, rough, cherty, gray, sometimes arenaceous	3 ft. 0 in.
Oneota Dolomite	
7. Dolomite, rough, gray to pink, thin, compact buff bed at the top	3 ft. 10 in.
6. Dolomite, thin-bedded, compact, buff	1 ft. 6 in.
5. Dolomite, hard, rough, gray to brown, often with pink streaks and cavities lined with pink crystals	11 ft. 3 in.
4. Dolomite, hard, gray to buff, streaked with pink	2 ft. 0 in.
3. Dolomite, massive, vesicular, pink to gray (bottom of quarry)	7 ft. 8 in.
2. Covered interval	18 ft. 5 in.
1. Dolomite, hard, vesicular, with streaks that are more compact. Occasional streaks of sand, gray in color. Occurs along railroad track	11 ft. 0 in.

The top bed of this section resembles the Shakopee and may belong to that formation. It is oolitic, somewhat cherty, and not so massive as the other beds. The rest is the common type of Oneota, although it appears that the formation is thin here.

The type locality for the Shakopee is the town of the same name in this county. It is shown in several quarries along the Minnesota River and in road cuts in that vicinity.

SECTION OF QUARRY AT J. B. CONTER LIME KILN, SHAKOPEE

	Thickness
5. Soil varying from zero to 6 inches	0 ft. 3 in.
Shakopee Dolomite	
4. Dolomite, pink to brown, partly crystalline, alternating with compact beds of buff color. All thin-bedded and uneven. Sample 120	7 ft. 8 in.
3. Dolomite, gray to pink, fairly massive but splitting into thinner beds. Sample 119	12 ft. 4 in.
2. Dolomite, gray to pink or brown, thin-bedded. Sample 118	5 ft. 0 in.
1. Covered interval to level of Minnesota River	16 ft. 2 in.

The chief use of the rock from this and other quarries of the neighborhood was the burning of lime; but this has long ceased to be profitable and the kilns have fallen into ruins. Even the quarries are overgrown. It is possible that part of the rock described in the above section should be included in the Oneota dolomite.

Samples 1, 47, 48, 49, 50, 51, 52, 53, 116, 117, 118, 119, and 152 in the table at the end of this chapter are from Scott County.

Dakota County

Although bed rock is seldom far beneath the surface in much of Dakota County, the quarrying industry never has been important. At Hastings both the Oneota and the Shakopee dolomites are excellently developed, and some attempt has been made in recent years to utilize them. The region is faulted and otherwise disturbed, so that the Cambrian sandstones come up in that vicinity, but the outcrops along Vermilion River remain superb. The Hastings Stone Company has taken advantage of the river bluff, about three miles southeast of town, locating its quarry where a minimum of stripping is necessary and where gravity may be used for transportation to the crusher and to the tracks below.

About the only rock produced here has been crushed rock for roads and ballast. Much of the rock is well suited to that purpose.

Section of Quarry of the Hastings Stone Company, Hastings

	Thickness
5. Soil and drift	10 ft. 0 in.
Shakopee Dolomite	
4. Dolomite, massive, gray to drab, in part oolitic, with some oolitic chert. The rock is cavernous and has few fossils	35 ft. 0 in.
New Richmond (?) Sandstone	
3. Sandstone and sandy layers of dolomite	4 ft. 0 in.
Oneota Dolomite	
2. Dolomite, a massive brown rock with often a pink and occasionally a green cast. Contains numerous cavities, many of them partly filled with crystals of quartz and some retaining traces of cryptozoan structure	40 ft. 0 in.
1. Dolomite or thin-bedded dolomitic limestone with a hard, dense texture. Interbedded with sandy layers. These beds lie below the floor of the quarry	15 ft. 0 in.

Physical tests of a sample collected from the lower part of the Oneota in the quarry of the Hastings Stone Company yielded the following data: specific gravity, 2.73; weight per cubic foot, 171; percentage of absorption, .84; percentage of wear, 3.4; French coefficient, 11.8; average toughness, 12.5.

A small amount of Shakopee dolomite has been quarried at Northfield and at Waterford. The following section was measured at Waterford.

Section along Cannon River at Waterford

Shakopee Dolomite	Thickness
12. Dolomite, massive to thin-bedded, gray, some oolitic and some fossiliferous layers. Several thin layers of sandy green shale near top	10 ft. 0 in.
11. Dolomite, hard, gray to drab, with some oolitic layers. (Outcropping in front of store.)	6 ft. 0 in.
10. Dolomite, conglomerate, containing *Hormatoma*	3 ft. 0 in.

9. Dolomite, sandy, pebbly	1 ft.	6 in.
8. Dolomite, hard, gray to drab, fossiliferous	0 ft.	7 in.
7. Dolomite, hard, sandy, gray	4 ft.	1 in.
6. Covered interval	3 ft.	0 in.
5. Dolomite, thin-bedded, gray, sandy	3 ft.	7 in.
4. Dolomite, vesicular, gray, containing a few *Hormatoma*	2 ft.	0 in.
3. Dolomite, gritty, pebbly beds alternating with fine-grained sandy beds. All gray in color and in thin, irregular beds	5 ft.	7 in.
2. Dolomite, gray, irregular layer containing *Cryptozoon*	2 ft.	0 in.
1. Dolomite, gray, irregular beds extending to level of Cannon River at the old mill	3 ft.	7 in.

The Platteville limestone has been quarried, to a very limited extent, along the Minnesota and Mississippi rivers at Mendota, where the limestone has essentially the same composition and properties as in St. Paul. Northeast of Mendota the full thickness of the Platteville is often exposed along the river bluff and in several places the Decorah shale shows above it. Trackage is available and the overburden is light, so quarrying could be undertaken with little cost.

Sample 146 in the table at the end of this chapter is from Dakota County.

Nicollet County

Nicollet County lies within the great bend or angle of the Minnesota River, which thus forms all its boundaries except that on the north. The drift covering is exceedingly heavy except where the River Warren cut through, exposing the bed rock. Outcrops are thus limited to the Minnesota valley. At St. Peter the Oneota dolomite was formerly quarried for building stone and was used locally in public buildings. These quarries have long been abandoned. The rock resembled the "Kasota stone." The Oneota dolomite was quarried in North Mankato also, but the location was on the side of the valley where heavy stripping soon became a problem and quarrying ceased. The east side of the river at Mankato is so well suited to quarrying and the stripping is so light that the industry could hardly be expected to survive west of the river.

Near Hebron or near the outlet of Nicollet Creek are excellent outcrops of the St. Lawrence dolomite on the river flats. Several small quarries have been located there, and the rock has been exposed to a depth of 8 or 10 feet, but they are all abandoned. This rock would serve as a local building stone and for agricultural purposes.

Along State Highway No. 7, about three miles east of New Ulm, Heimann's lime kiln and quarry was located in a small gulch. It was supplied from a limestone which N. H. Winchell called Niobrara. Much of the limestone was supplied from the flats toward the river, where it lies just below the surface and was easily uncovered. The old pits may still be seen over the pasture field. In the creek, running past the old kiln, are three to four feet of nodular gray limestone with much clay and shale and some red limestone. Part of the limestone appears to be of good quality and all has probably been altered by ground water.

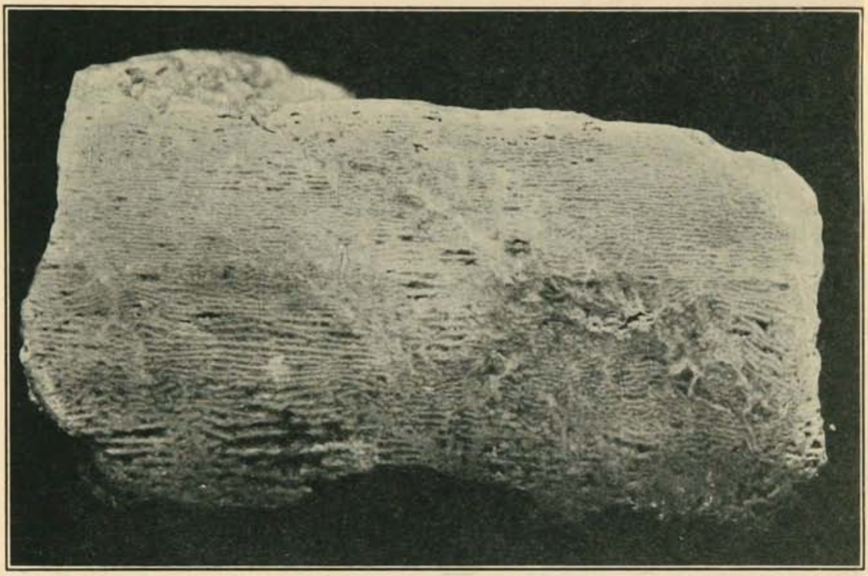

FIG. 7. — A polished specimen of Cretaceous (?) limestone from New Ulm.

Cavity fillings and calcite geodes are common. No fossils were found in the limestone or in the associated shales, but the peculiar structure of part of the limestone (see Figure 7) suggests a spring deposit. The following section along the gully to the west of Heimann's Quarry shows the character of the deposit.

SECTION OF ROCKS OUTCROPPING IN GULLY WEST OF HEIMANN'S QUARRY AND LIME KILN, NEAR NEW ULM

	THICKNESS
12. Black soil	2 ft. 0 in.
11. Shale, green and red	3 ft. 9 in.
10. Sandstone, pink	0 ft. 4 in.
9. Shale, soft, green	0 ft. 9 in.
8. Limestone, cavernous, gray to green	2 ft. 0 in.
7. Shale, argillaceous, red	3 ft. 4 in.
6. Limestone, cavernous, shaly, gray to buff	1 ft. 3 in.
5. Shale, argillaceous, green and red	1 ft. 4 in.
4. Limestone, argillaceous, shaly, greenish gray	1 ft. 0 in.
3. Shale, argillaceous, green and red	0 ft. 11 in.
2. Limestone, argillaceous, greenish gray	2 ft. 3 in.
1. Concealed, probably red shale, to level of stream	5 ft. 6 in.

Similar beds appear in several adjacent gullies and the limestones are said to have been picked up in the fields, at about the same elevation, as far east as the village of Courtland. Although several of these limestone layers are very high in calcium carbonate, the deposit appears to have little economic value.

Samples 4 and 130 in the table at the end of this chapter are from Nicollet County.

Le Sueur County

Most of Le Sueur County is a till plain lying 900 to 1,000 feet above sea level. The monotony of the plain is broken by morainic topography rising into hills fifty to one hundred feet higher along the eastern and southern margins. Only in and near the valley of the old River Warren is the drift cut away to bed rock below and quarrying made possible. From Kasota southward there is a broad rock terrace on which the Oneota dolomite lies at or near the surface.

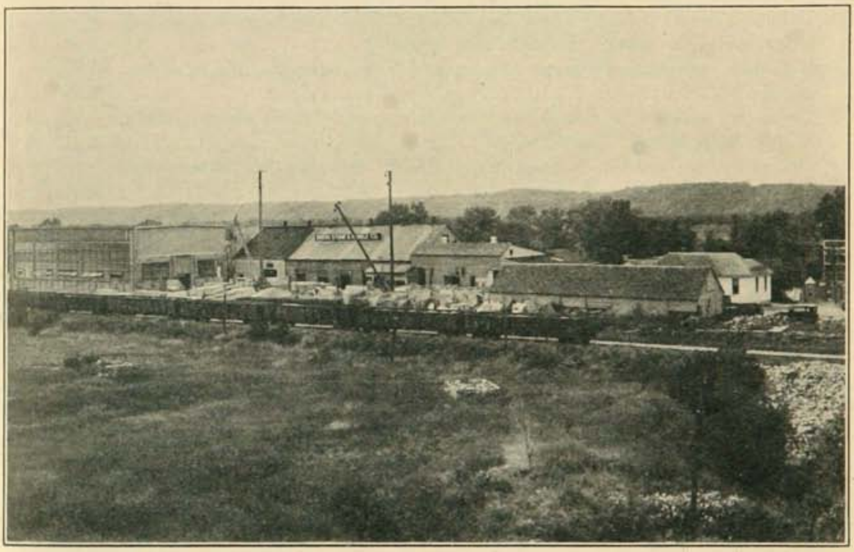

Fig. 8. — Finishing plant of the Breen Stone and Marble Company at Kasota.

The principal quarries are located at the town of Kasota, where the famous Kasota stone is produced. This stone has been quarried at this point for more than sixty years (the first quarries were opened in 1868) and shipped all over Minnesota and adjacent states. It has, in fact, been used successfully as far away as Philadelphia, Chicago, and Winnipeg. Most of the rock is sawed, carved, and finished at the quarries, where suitable mills are located. (See Figure 8.) The finer grades are polished and used for interior work in place of ordinary marble. Some layers are sold as a substitute for marble, others as travertine. Although it cannot be classified as either, the Kasota stone is more suitable to the purposes for which it is sold than marble or travertine. It is, in fact, one of Minnesota's finest building stones. It has been used in the interior of the University of Minnesota Library, in the exterior walls of the University Baptist Church, and in the new telephone building in Minneapolis, erected in 1932.

Discarded slabs from the mill find ready use in artistic walks and are suitable for rough walls, although little material from the quarries is so used. Some of the Kasota stone has been used for crushed rock, and this use is likely to increase, but the finished building stone remains the most important industry.

SECTION OF QUARRIES OF THE BREEN STONE AND MARBLE COMPANY, KASOTA

	THICKNESS
11. Soil and river deposits	4 ft. 0 in.
ONEOTA DOLOMITE	
10. Dolomite, dense, brown, with some chert. Massive to thin-bedded and shaly where weathered	8 ft. 0 in.
9. Dolomite, pink to buff. These beds are the finest building stone in half a dozen or more layers. Physical test sample 1	7 ft. 2 in.
8. Dolomite, uneven, cavernous, dense, and very massive. Physical test sample 2	7 ft. 0 in.
7. Dolomite, massive to thin-bedded or shaly, purple, dark red to yellow. Middle layer called "Castile ledge"	2 ft. 6 in.
6. Dolomite, thin-bedded, mottled gray to buff. Includes the "hummocky" layer, uneven contact at the base	6 ft. 0 in.
TRANSITION BEDS	
5. Clay or clay shale, light gray, variable in thickness	0 ft.±6 in.
4. Sandstone, medium to coarse, white with *Raphistoma* and other fossils. An erosion surface at base	6 ft. 6 in.
JORDAN SANDSTONE	
3. Sandstone, medium to coarse, white with streaks of green	6 ft. 0 in.
2. Sandstone, fine-grained, cross-bedded, white with pink spots or blotches	20 ft. 0 in.
1. Covered to level of Minnesota River	10 ft. 0 in.

Tests of dolomite from the Kasota quarries by the State Department of Highways yielded the following data:

Sample	Sp. Gr.	Wt. per Cu. Ft.	Per Cent Absorption	Per Cent Wear	French Coef.	Average Toughness
1	2.47	154.5	3.36	4.0	10.0	5.0
2	2.61	163	2.26	4.4	9.1	10.50

The Oneota dolomite has been worked at Ottawa, where formerly there were quarries, now long closed. This rock was used for local houses and business blocks, although its chief use was the burning of lime. There is an abundance of it near the surface, but it does not appear to have the desirable color or compactness of the Kasota stone.

Samples 2, 3, 144, and 145 in the table at the end of this chapter are from Le Sueur County.

RICE COUNTY

The western half of Rice County is completely covered by drift, as is the high area forming the southeastern part. But along Straight River and in the whole northeastern part, bed rock is close to the surface.

The Shakopee dolomite has been quarried at Northfield. In fact, some of the basements had to be quarried out of solid rock. The quarrying industry never attained importance in this region, and quarries that were opened have long been abandoned.

The Platteville limestone was formerly quarried near Dundas, and one of the early buildings at Carleton College (Willis Hall) was constructed of stone taken from there. The Platteville, including the basal layers of the Decorah, has been quarried for many years in and near Faribault. The Comer Quarry, located along Fall Creek two miles east of town, now owned by Mr. Jaeger, formerly supplied much building stone. This was used in a number of buildings in Faribault, including several of the buildings of Shattuck Military Academy. One or two of the lower limestone layers in the Decorah shale are exceedingly hard and compact. These have been polished and used as a marble. The following is a section of the Jaeger (Comer) Quarry.

SECTION OF JAEGER'S (COMER) QUARRY ON FALL CREEK, 2 MILES EAST OF FARIBAULT

	THICKNESS
15. Drift	30 ft. 0 in.
DECORAH SHALE	
14. Shale, blue to green, alternating with layers of bluish argillaceous limestone	7 ft. 0 in.
13. Limestone, hard, gray, full of fossils — the "marble" layers	0 ft. 10 in.
12. Shale, brown	0 ft. 2 in.
11. Shale, argillaceous, green to white. An altered Bentonite	0 ft. 2 in.
10. Shale, brown	0 ft. 3 in.
9. Limestone, gray, with pyrite and fucoids. Contacts shaly	2 ft. 1 in.
8. Limestone, shaly, brown	0 ft. 9 in.
PLATTEVILLE LIMESTONE	
7. Limestone, gray, weathers brown to buff	7 ft. 6 in.
6. Shale, nodular, bluish green	1 ft. 5 in.
5. Limestone, brown to gray, with conchoidal fracture	3 ft. 0 in.
4. Shale, blue to green, with thin nodular beds and lenses of impure limestone. The lower part is probably Glenwood	6 ft. 0 in.
GLENWOOD BEDS	
3. Sandstone, calcareous, with much pyrite	0 ft. 5 in.
2. Shale, blue to green, nodular, often quite sandy	4 ft. 0 in.
ST. PETER SANDSTONE	
1. Sandstone, white to yellow, but predominantly iron-stained. To level of Straight River	5 ft. 0 in.

This quarry is now abandoned, although it still contains great quantities of available limestone, and very little stripping is necessary.

On Straight River, about three-quarters of a mile south of Faribault, several quarries have been operated from time to time. The state formerly quarried some limestone on land adjacent to the farm connected with the Faribault Institution for the Feeble-Minded. Later this was transferred to Seims, Helmers, and Schaffner, who also acquired rights on a small adjacent tract and produced some crushed rock for a short time. The total quarry face is only about 7 feet and is now abandoned. A test of a general sample from this quarry gave the following data: specific gravity, 2.64; weight per cubic foot, 165; percentage of absorption, 1.5; percentage of wear, 3.3; French coefficient, 12.2; average toughness, 15.25.

Across the river to the south, Mr. George Lieb has opened a quarry on the side of the steep river bluff. This is the only quarry in the vicinity that is still being operated. It has some excellent rock, but the stripping is so heavy that the amount available is very limited. The Lieb Quarry produces building stone and rubble and occasionally has furnished material for a small crusher.

One of the most unexpected developments in this region is the slight thickness of the Platteville limestone and the excellent development of the Glenwood beds beneath. The latter are separated from the limestone above by a definite and uneven contact.

The following is a section of the rocks exposed in the George Lieb Quarry.

SECTION OF GEORGE LIEB QUARRY ON STRAIGHT RIVER, ¾ MILE SOUTH OF FARIBAULT

	THICKNESS
18. Drift, full of bowlders	50 ft.±0 in.
DECORAH SHALE	
17. Shale, blue, alternating with four-inch layers of fossiliferous gray limestone	12 ft. 0 in.
16. Limestone, fossiliferous, hard, gray to brown. The "marble" layer	1 ft. 0 in.
15. Shale, brown	0 ft. 1 in.
14. Shale, light gray to green, argillaceous, with pyrite nodules. An altered Bentonite	0 ft. 3 in.
13. Limestone, bluish, gray to brown	2 ft. 2 in.
12. Shale, brown to bluish, fucoidal at base	0 ft. 7 in.
PLATTEVILLE LIMESTONE	
11. Limestone, bluish	7 ft. 0 in.
10. Shale, soft, blue, argillaceous	1 ft. 4 in.
9. Limestone, argillaceous, blue	5 ft. 3 in.
GLENWOOD BEDS	
8. Shale, argillaceous, bluish to brown. Some sand grains	2 ft. 0 in.
7. Sandstone, brown, iron-stained	0 ft. 7 in.
6. Shale, soft, argillaceous, blue	1 ft. 0 in.
5. Shale, soft sandy clay, blue to yellow	0 ft. 4 in.
4. Shale, argillaceous, blue to green, with some sand grains	1 ft. 4 in.
3. Sandstone, calcareous, blue, with much pyrite	0 ft. 8 in.
2. Shale, lumpy, blue	4 ft. 0 in.
ST. PETER SANDSTONE	
1. Sandstone, yellow to white, to level of Straight River	11 ft. 10 in.

Recently (in 1932) extensive hydraulic stripping has been instituted at the Lieb Quarry and a large area of the "marble layer" has been uncovered. This rock will be used in building the new courthouse at Faribault.

Two samples from Rice County have been analyzed; see samples 15 and 140 in the table at the end of this chapter.

GOODHUE COUNTY

Much of Goodhue County is lightly covered by drift, and bed rock may be found in many places. Along the Mississippi River, rocks well down in the Cambrian crop out. Although the St. Lawrence formation is well developed, it has not been utilized. It is, moreover, too impure to be definitely included with the limestones and dolomites. This is true throughout the whole extent of the Mississippi River; hence the formation has received very little attention except in those counties along the Minnesota River.

The Oneota dolomite is excellently developed as a surface formation in the northeastern part of the county. It caps the high hills and extends down the slopes from their caps for more than one hundred feet. At Red Wing, the Oneota dolomite was formerly quarried on a large scale and used in the manufacture of lime. These quarries were located chiefly at the eastern end of Barn Bluff, but they have long been abandoned and the equipment has fallen into ruins. Even the quarries are badly overgrown. La Grange Mountain, or Barn Bluff, is a locality famous since the days of David D. Owen. The following is a section measured near the west end, probably near the locality at which Owen made his collections.

SECTION OF WEST END OF LA GRANGE MOUNTAIN, OR BARN BLUFF, RED WING

	THICKNESS
14. Drift-covered to level of the U. S. B. M., 1,001 feet above sea level	68 ft. 0 in.
ONEOTA DOLOMITE	
13. Dolomite, massive, cavernous, gray to buff	44 ft. 0 in.
12. Shale, arenaceous, gray	2 ft. 0 in.
11. Dolomite, massive, arenaceous, gray to brownish	16 ft. 7 in.
JORDAN SANDSTONE	
10. Sandstone, massive, fine- to coarse-grained, yellowish to white in color and often poorly cemented	96 ft. 0 in.
ST. LAWRENCE FORMATION	
9. Shale and arenaceous dolomite alternating gray to buff	23 ft. 0 in.
8. Silt stone, a fine-grained gray to buff arenaceous dolomite. The *Dikellocephalus minnesotensis* horizon	2 ft. 6 in.
7. Dolomite, arenaceous, alternating with gray shale	3 ft. 0 in.
6. Shale, arenaceous, fine-grained, even-bedded, blue to buff	1 ft. 10 in.
5. Dolomite, arenaceous, massive, gray to greenish	17 ft. 8 in.
4. Dolomite, arenaceous, massive, brown to yellowish, with streaks of green sand	2 ft. 0 in.
3. Conglomerate, arenaceous, massive, hard. Pebbles are of brown to yellow dolomite imbedded in arenaceous dolomitic matrix with green sand	2 ft. 9 in.
2. Sandstone, dolomitic, gray to buff, with yellow blotches	1 ft. 8 in.
1. Covered interval to level of the Mississippi River	18 ft. 8 in.

The lime from the kilns at Red Wing found a wide market and was considered the best in the state; in fact, this was the lime center of the state for many years.

The famous "Frontenac stone" came from the lower part of the Oneota dolomite near the old town of Frontenac on Lake Pepin. This stone is fine and even-textured and occurs in massive beds in which joints are so distantly spaced that the stone can be obtained in blocks of desirable size. It has been sawed and dressed for various building purposes, to which it lends itself readily. It also carves well and could probably be used rather generally to supplant some of the material now being shipped in from distant points. The Frontenac stone occurs over a large area from Frontenac to Dresbach and has been quarried on a small scale at various points. Its full possibilities, however, have never been tested. The following is a section of the old quarries at Frontenac. It is located in Section 2, Florence Twp.

SECTION OF OLD QUARRY AT FRONTENAC

	THICKNESS
5. Drift	10 ft. ±0 in.
ONEOTA DOLOMITE	
4. Dolomite, massive, coarse, hard and compact but containing numerous holes. Contains some chert- and quartz-filled cavities	28 ft. 6 in.
3. Dolomite, thin-bedded, compact, drab to pink	3 ft. 6 in.
2. Dolomite, hard, compact, gray to pale pink. Contains some chert	4 ft. 10 in.
1. Dolomite, massive, porous, gray to ashen, often with a pink tinge. This layer is the best building stone. Bottom of quarry	7 ft. 0 in.

The total thickness quarried here, when operations were fully under way, is said to have been about 65 feet. Unfortunately only the bottom portion carves well. Finished stone from these quarries was shipped to the Twin Cities, where it was used in a number of buildings.

Although the Shakopee dolomite is commonly exposed at the surface, it has been quarried only in the vicinity of Cannon Falls and in Randolph Township, Dakota County. These old quarries have long been abandoned. In fact, the industry never assumed sizable proportions. South of Cannon Falls the Platteville and Galena limestones, too, have been quarried, but only in a very limited way. The former was at one time burned for lime.

Analyses of samples from Goodhue County are given in the table at the end of this chapter under the numbers 6, 20, 73, 74, 75, 76, 132, and 160.

WABASHA COUNTY

Wabasha County is partly covered by drift and loess, but bed rock is often near the surface. A large proportion of the country rock is limestone and dolomite but little quarrying of these has been done. Near Lake City and Wabasha the St. Lawrence formation has been opened in several places, but it is chiefly a sandstone in that vicinity and may, therefore, be omitted from the present discussion. In the hills to the south of Elgin, rock for local foundations has been quarried from the Platteville limestone.

The chief opportunities for obtaining satisfactory quarry rock are in the Oneota dolomite, which immediately underlies the surface in a large area of the central and eastern parts of the county. Outcrops seem to suggest that it is as good, in every way, as the Frontenac stone.

BLUE EARTH COUNTY

Blue Earth County is heavily drift-covered except near the Minnesota River and along a few of its larger tributaries. These streams and

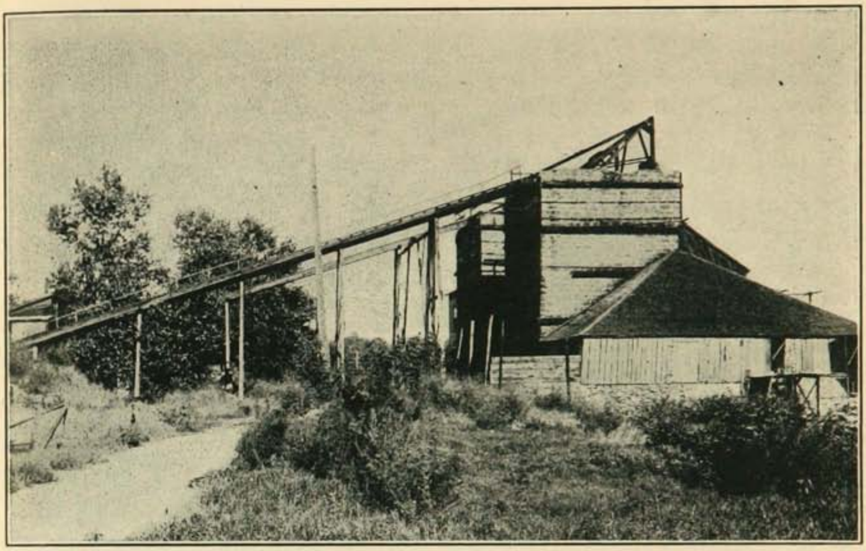

FIG. 9.— Kilns of the Mankato Lime Company at Mankato.

the River Warren, which was the outlet to glacial Lake Agassiz, have succeeded in carving through the mantle to bed rock below.

At Judson a relatively large area of the dolomitic phase of the St. Lawrence formation is at the surface. This has been quarried for building stone in several places and has furnished a very satisfactory rock for that purpose. It is a buff to gray or brown dolomite, and in many places carries a large amount of glauconite, which makes some beds quite green. The following is a section of the outcrop and quarries at Judson.

SECTION OF ST. LAWRENCE FORMATION, JUDSON

	THICKNESS
5. Soil and river deposits	0 ft. 6 in.
ST. LAWRENCE FORMATION	
4. Dolomitic limestone, thin-bedded, gray to buff or brown, with some glauconite	8 ft. 0 in.
3. Covered interval	4 ft. 0 in.
2. Dolomitic limestone, gray to brown, with much glauconite often in streaks or along the bedding planes. Fucoids and worm tubes abundant. *Billingsella* occurs near the top; also some cystoid stems	9 ft. 0 in.
1. Covered to the level of Minnesota River	5 ft. 0 in.

Number 2 of the above section contains the quarry beds usual in this region and is an interesting stone from the standpoint of construction. However, it probably will not find a market outside the local community.

The Oneota dolomite crops out abundantly along the Minnesota and Blue Earth rivers and their tributaries. Quarries have been opened in various places adjacent to the streams. Those along the Big Cobb and Maple rivers have been abandoned for years. In Mankato and its vicinity, however, the quarrying industry persists and flourishes.

Cement, lime (see Figure 9), and building stone are produced in sufficient quantity to fill any demands likely to be placed on the region. The Carney cement, a variety of natural cement sold throughout the country, is made here. Formerly the materials for this product were quarried in the southern part of Mankato, but these pits have been abandoned and the material is now quarried two miles north of the city limits, near Pilgrims Rest Cemetery, where the following section occurs.

SECTION OF QUARRY OF THE CARNEY CEMENT COMPANY AT PILGRIMS REST CEMETERY, MANKATO

	THICKNESS
11. Drift	2 ft.±0 in.
ONEOTA DOLOMITE	
10. Dolomite, weathered, thin-bedded, buff	3 ft. 6 in.
9. Dolomite, massive, buff to brown or pink; often it is mottled and has cavities	4 ft. 0 in.
8. Dolomite, massive, pink to buff, vesicular	4 ft. 2 in.
7. Dolomite, massive, buff with blotches of pink	7 ft. 6 in.
6. Shale, purple, grading into ashen gray at top	2 ft. 6 in.
5. Dolomite, massive, gray	4 ft. 2 in.
4. Dolomite, massive to shaly, gray	4 ft. 0 in.
3. Shale, soft and putty-like, gray	0 ft. 4 in.
JORDAN SANDSTONE	
2. Sandstone, massive, white, poorly cemented but with hard masses	10 ft. 0 in.
1. Covered interval to creek and lake level in old abandoned channel of Minnesota River	15 ft. 0 in.

The upper layers from this quarry are abandoned, but the lower layers are mixed and used in the product obtained from the kilns at the plant in the southern part of Mankato. (See Figure 10.) The most

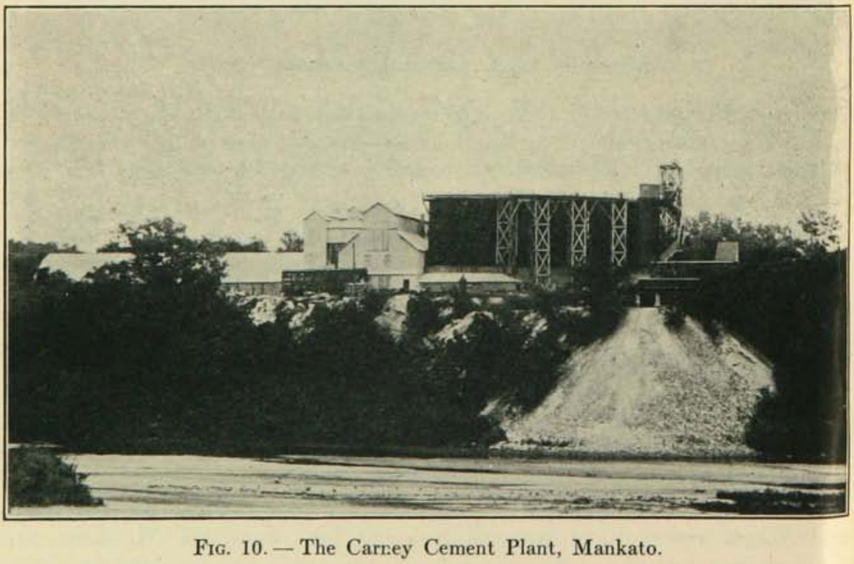

FIG. 10. — The Carney Cement Plant, Mankato.

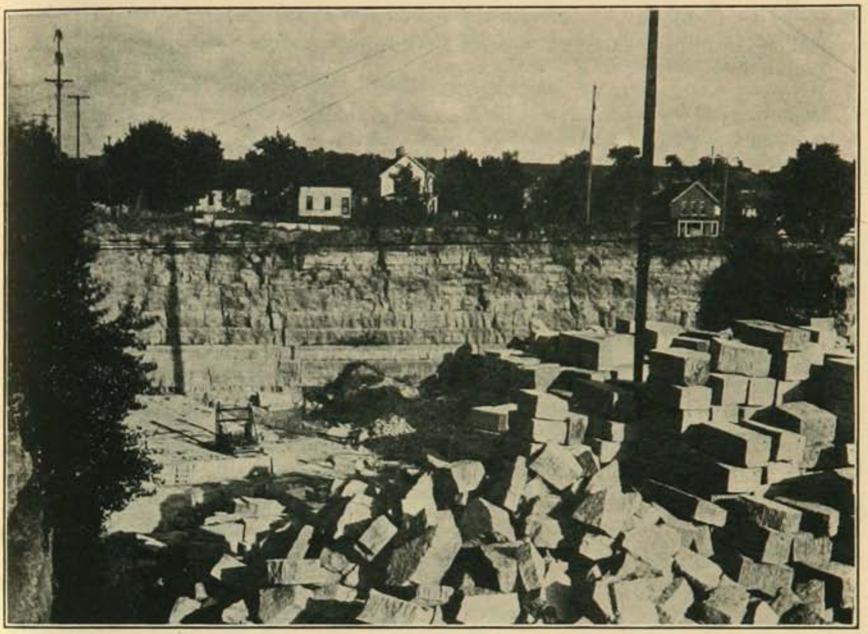

FIG. 11. — The Oneota dolomite in the quarry of the Coughlin Company, Mankato.

extensive quarries are those in the northern end of Mankato, where Fowler and Pay have operated for many years and the T. R. Coughlin Company (see Figure 11) for about as long. The quarries are adjacent and part of the time have been operated jointly under the name Mankato Stone Company. The following section is probably to be regarded as typical for the region.

SECTION OF QUARRY OF THE T. R. COUGHLIN COMPANY, MANKATO

	THICKNESS
17. Soil covering	0 ft. 6 in.
SHAKOPEE DOLOMITE	
16. Dolomite, oolitic, with occasional conglomerates, gray to brown. Beds contain some oolitic chert and weathered surfaces may show sand grains	7 ft. 4 in.
15. Covered interval	1 ft. 0 in.
14. Dolomite, sandy, brown, with some flat pebbles. Indefinite contact with beds below	2 ft. 6 in.
NEW RICHMOND SANDSTONE	
13. Sandstone, white to yellowish, with hard masses like quartzite. Some layers ripple-marked	5 ft. 0 in.
12. Shale, sandy green, uneven at base, contains a few fossils, chiefly *Raphistoma*	0 ft. 6 in.
ONEOTA DOLOMITE	
11. Dolomite, vesicular, occasionally oolitic, gray to drab, often with a pink tinge. Calcite geodes common	5 ft. 6 in.
10. Dolomite, massive, gray to yellowish, with occasional cherty masses	9 ft. 10 in.

9. Dolomite, massive, gray to brown and pink or reddish brown, usually mottled. Contains small cavities and calcite geodes. Some sand penetrates cracks to this depth and fills cavities	13 ft. 0 in.
8. Dolomite, single layer, fine gray to buff, almost without cavities	4 ft. 0 in.
7. Dolomite, massive, buff, slightly mottled, fine-grained. The best building stone in the quarry. Occurs in two layers with the parting hardly perceptible	7 ft. 6 in.
6. Shale, hard, dense, buff with purple blotches grading into purple. When unweathered this bed may appear massive	2 ft. 6 in.
5. Dolomite, massive, buff, continuing to the quarry floor and to water	3 ft. 6 in.
4. Dolomite, massive, buff to brown (covered)	9 ft. 6 in.
3. Shale, gray (covered)	3 ft. 0 in.
2. Dolomite, massive, uneven-bedded, gray to buff	7 ft. 6 in.
JORDAN SANDSTONE	
1. Sandstone, white, covered to level of Minnesota River	40 ft. 0 in.

Although building stone has been produced from these quarries for many years and is their most important product, crushed rock has been produced from the upper beds or as a by-product from the waste of the dimension blocks. Still other parts of the ledge have been burned for lime. In recent years the Shakopee dolomite, which is somewhat less magnesian, has been the chief source of the lime produced here. The oolitic beds in a slightly higher ledge a quarter of a mile to the north have supplied three or four kilns that run periodically. In order to obtain the best results, the rock has been hand-picked. This necessitated a great deal of labor and resulted in much waste.

Two samples of the rock from the Coughlin Quarry were tested in the laboratory of the State Department of Highways. Sample 1 was made from beds no. 10 and 11, which consisted of the 15 feet, 4 inches immediately below the sandstone; and sample 2 from bed no. 9, which included the rock immediately above the better building stone. The results of these tests were as shown below.

Sample	Sp. Gr.	Wt. per Cu. Ft.	Per Cent Absorption	Per Cent Wear	French Coef.	Average Toughness
1	2.34	159	2.85	4.28	10.64	12.5
2	2.43	152	4.68	7.6	5.27	5.0

Samples 77, 78, 79, 80, 81, 82, 83, 87, 88, 89, 90, 115, 142, and 143 in the table at the end of this chapter are from Blue Earth County.

WASECA COUNTY

Waseca County is entirely drift-covered. Several of the deeper wells pass through it to bed rock beneath, but none of them is available for quarrying.

STEELE COUNTY

Steele County is drift-covered except in the north-central part, where Straight River has cut through, exposing beds near Clinton Falls and Medford that belong to the lower part of the Maquoketa shale. These have been quarried to some extent a mile south of Clinton Falls, where

6 to 8 feet of a shaly blue to brown limestone crops out in the river. This rock is suited to the ordinary agricultural purposes of the immediate vicinity but it probably has no greater value.

Two samples from Steele County (54 and 55) have been analyzed, and the results are given in the table at the end of this chapter.

Dodge County

Dodge County is mostly drift-covered, but in the eastern and northeastern parts, along several branches of the Zumbro River the mantle is cut through to bed rock. The lowest rock exposed belongs to the Shakopee dolomite, but it covers a very small area of river bottom in the northeast corner of the county and is probably not available for any commercial purpose.

The best and most widely distributed limestones of the county are those belonging to the Ordovician system. These include the Platteville, the Galena, and the calcareous beds of the Maquoketa shale. These have been quarried at Wasioja and at Mantorville. At Wasioja there are several large quarries, now abandoned, which produced rock for many years. At the height of activity they had rail connections and shipped rock to many points. The following is a section of the upper quarry on land now owned by B. H. Bielengberg.

Section of Bielengberg Quarry, Wasioja

	Thickness
6. Drift and soil	5 ft. 0 in.
Maquoketa Shale	
5. Limestone, thin-bedded, shaly, gray. Beds were formerly burned for lime.	12 ft. 0 in.
Galena (Stewartville) Dolomite	
4. Dolomite, massive, gray to buff, separating into thin beds on weathering	18 ft. 2 in.
3. Dolomite, massive, fossiliferous, gray to buff	6 ft. 8 in.
2. Dolomite, thin-bedded, porous, gray	1 ft. 6 in.
1. Covered to level of Zumbro River	5 ft. 0 in.

The dolomitic beds of this quarry, and of the lower quarry a short distance down the river, were formerly cut for building purposes. Although both pits are well suited to that use and to ordinary agricultural purposes, the quarries are badly overgrown and probably will not be reopened.

At Mantorville are two quarries, both of which have operated within comparatively recent years. The McDonough Quarry has a quarry face of about 45 feet, all of which is Galena, belonging to the Stewartville phase. In the village of Mantorville itself is located the quarry of the Pierson Stone Company, of which the following is a section.

Section of Quarry of the Pierson Stone Company, Mantorville

	Thickness
6. Drift	15 ft.±0 in.
Galena (Stewartville) Dolomite	
5. Dolomite, massive, gray to buff, with a few fossils	20 ft. 0 in.

4. Dolomite, thin to medium beds, gray to buff. Fossil fragments common	7 ft.	9 in.
3. Dolomite, thin-bedded to shaly, gray to brown	6 ft.	6 in.
2. Dolomite, gray, 6- to 14-inch beds	5 ft.	6 in.
1. Covered interval to level of river	20 ft.	0 in.

This quarry produced heavy construction beds and some sawed stone for trimming. There is no crusher. No tests were run of the rock from the Pierson Quarry, but several samples were tested from the McDonough Quarry, where crushed rock has been produced.

Sample 1 was from the lower 10 feet of the McDonough Quarry. Sample 2 was taken from the upper 35 feet of the McDonough Quarry. The data in the accompanying tabulation were obtained in the laboratory of the State Department of Highways.

Sample	Sp. Gr.	Wt. per Cu. Ft.	Per Cent Absorption	Per Cent Wear	French Coef.	Average Toughness
1	2.31	144	4.1	11.7	3.42	5
2	2.34	146	5.6	8.8	4.55	6

Samples 134, 138, and 139 in the table at the end of this chapter are from Dodge County.

Olmsted County

Although large areas of high land in Olmsted County (see Figure 12) are deeply covered by drift, much of the surface is well dissected by branches of the Zumbro, Whitewater, and Root rivers, so that rock exposures are abundant and widely distributed. Both the Oneota and the

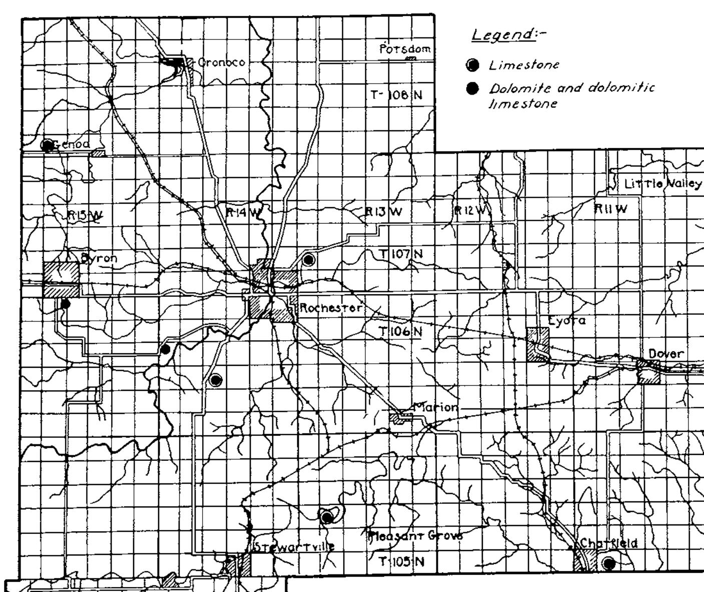

Fig. 12. — Map of Olmsted County showing the locations of samples taken for analyses.

Shakopee crop out in Oronoco Township, but neither is utilized. The Platteville and basal limestone layers of the Decorah shale have been quarried in several places, the most important of which are in the vicinity of Rochester. At the State Hospital a quarry is still being worked.

SECTION OF STATE HOSPITAL QUARRY, ROCHESTER

	THICKNESS
8. Soil and drift	5 ft.±0 in.
DECORAH SHALE	
7. Shale, blue to brown, argillaceous, with beds of gray to brown limestone. One layer is full of *Zygospira nicoletti*	3 ft. 0 in.
6. Limestone, hard, gray to blue, with thin shaly partings. Very fossiliferous	2 ft. 2 in.
5. Shale, yellow to brown	0 ft. 4 in.
PLATTEVILLE LIMESTONE	
4. Limestone, compact, hard, blue to gray weathering to buff or yellowish; extends to bottom of quarry	14 ft. 0 in.
3. Limestone, buff to brown (covered)	10 ft. 9 in.
GLENWOOD BEDS	
2. Shale, blue to green, argillaceous, sandy below (covered)	10 ft.±0 in.
ST. PETER SANDSTONE	
1. Sandstone, white to yellowish, partly exposed along road up quarry hill	10 ft.±0 in.

This rock has been used locally in various state buildings and to some extent for residences and business houses in the city of Rochester. Several crushers have been kept busy much of the time. A general sample from this quarry tested in the laboratory of the State Department of Highways yielded the following data: specific gravity, 2.60; weight per cubic foot, 163; percentage of absorption, 1.86; percentage of wear, 3.3; French coefficient, 12.1; average toughness, 13.0.

Various other quarries have operated in this vicinity and exposed virtually the same section. It is a fair grade of rock for concrete and good for the usual agricultural purposes.

The lower Galena or Prosser limestone is well developed in the southern part of the county. It is a very high-grade rock suitable for the manufacture of Portland cement. Much of it runs 92 per cent to 98.3 per cent $CaCO_3$ and from .79 per cent to 2.82 per cent $MgCO_3$, which is well within the limits usually stated for such purposes. It is also an excellent rock for use as a soil-sweetener.

About three and a half miles east of Rochester, along the old route of State Highway No. 7, nearly forty feet of the Prosser limestone is found. The following section was measured at that point.

SECTION ALONG OLD STATE HIGHWAY NO. 7, 3½ MILES EAST OF ROCHESTER

	THICKNESS
PROSSER LIMESTONE (LOWER GALENA)	
10. Limestone, irregularly bedded, compact, gray, often crinoidal	39 ft. 1 in.
DECORAH SHALE	
9. Shale, bluish to greenish, argillaceous, soft, with a few limestone layers	27 ft. 11 in.
8. Limestone, blue to gray, highly fossiliferous	3 ft. 0 in.
7. Shale, blue	0 ft. 6 in.

PLATTEVILLE LIMESTONE	
6. Limestone, blue to gray	7 ft. 8 in.
5. Limestone, blue to gray, partly crystalline	1 ft. 0 in.
4. Limestone, blue to buff	3 ft. 7 in.
3. Limestone, buff to brown	12 ft. 9 in.
GLENWOOD BEDS	
2. Shale, sandy, blue to green	12 ft. 8 in.
ST. PETER SANDSTONE	
1. Sandstone, white to yellowish to bottom of outcrop	10 ft. 8 in.

One of the large cement companies in 1930 purchased a large tract of land four or five miles to the southeast of this locality, where it contemplates the erection of a suitable plant.

Somewhat better rock occurs along State Highway No. 20, 5.2 miles north of Chatfield, where the following section is exposed.

SECTION ALONG STATE HIGHWAY NO. 20, 5.2 MILES NORTH OF CHATFIELD

	THICKNESS
27. Soil and drift	3 ft.±0 in.
GALENA (PROSSER) LIMESTONE	
26. Limestone, compact, gray. Sample 45 from lower part and sample 46 from upper part	8 ft. 0 in.
25. Limestone, thin-bedded, shaly, with some bands of soft gray shale	19 ft. 8 in.
24. Shale, olive to gray, with thin lenticular beds of limestone	1 ft. 0 in.
23. Limestone, compact, gray, with nodular calcareous gray shale. Sample 44	6 ft. 0 in.
22. Limestone, hard, compact, gray to bluish	4 ft. 8 in.
20. Shale, nodular, gray	1 ft. 9 in.
19. Limestone, massive, gray, with numerous fossils. Sample 43	7 ft. 4 in.
18. Shale, calcareous, nodular, gray	1 ft. 9 in.
17. Limestone, massive, gray	2 ft. 0 in.
16. Shale, with nodular calcareous layers, light gray to drab	1 ft. 2 in.
15. Limestone, massive, gray. Sample 42	8 ft. 0 in.
DECORAH SHALE	
14. Shale, argillaceous, bluish to olive, with interbedded layers of limestone containing yellowish oolites	3 ft. 3 in.
13. Shale, argillaceous, blue-gray to olive green, with thin lenses of limestone	10 ft. 0 in.
12. Shale and limestone poorly exposed	17 ft. 0 in.
11. Shale, argillaceous, bluish, some limestones with *Pianodema*	10 ft. 0 in.
10. Shale, argillaceous, bluish	0 ft. 5 in.
9. Limestone, bluish	0 ft. 8 in.
8. Shale, argillaceous, bluish	0 ft. 5 in.
7. Limestone, compact, brown, full of *Zygospira nicolleti* and trilobites	1 ft. 4 in.
6. Shale, argillaceous, bluish	0 ft. 5 in.
5. Limestone, gray to bluish, containing *Lingula elderi*	0 ft. 5 in.
PLATTEVILLE LIMESTONE	
4. Limestone, massive, gray to buff, in old quarry along highway	21 ft. 0 in.
GLENWOOD BEDS	
3. Shale, argillaceous, green and sandy yellow shale	5 ft. 0 in.
ST. PETER SANDSTONE	
2. Sandstone, white with yellow streaks	14 ft. 0 in.
1. Covered to level of creek	12 ft. 0 in.

A section of even greater interest is that along the Troy road in the southern part of the county, just north of the town of Chatfield, where the following was measured.

SECTION OF WATERWORKS HILL, ALONG TROY ROAD, AT NORTH EDGE OF CHATFIELD

	THICKNESS
15. Drift	6 ft. 0 in.
GALENA (PROSSER) LIMESTONE	
14. Limestone, compact, hard, gray, often thin-bedded, probably includes some shale not well exposed. Sample 38 from lower part, 39 from middle, 40 from upper	32 ft. 0 in.
13. Limestone, compact, hard gray, outcrop partly overgrown. Sample 36 from lower part, 37 from upper part	21 ft. 4 in.
12. Covered interval	16 ft. 0 in.
DECORAH SHALE	
11. Shale, argillaceous, blue, alternating with layers of limestone, partly weathered and poorly exposed	10 ft. 8 in.
10. Limestone, hard, blue-gray. The "marble layer" or "trilobite bed" of the Decorah shale. Sample 35	1 ft. 0 in.
9. Limestone, compact, blue to gray. Sample 34	2 ft. 2 in.
8. Shale, white. The putty layer or Bentonite	0 ft. 2 in.
7. Limestone, hard, gray. Sample 33	0 ft. 7 in.
PLATTEVILLE LIMESTONE	
6. Limestone, hard, gray to buff	5 ft. 8 in.
5. Limestone, hard, compact, blue-gray with numerous fossils. Iron-stained at top	16 ft. 8 in.
4. Limestone, poorly exposed, apparently thin-bedded or shaly	2 ft. 0 in.
GLENWOOD BEDS	
3. Shale, sandy, greenish to yellowish, partly covered	5 ft. 0 in.
ST. PETER SANDSTONE	
2. Sandstone, friable, white but iron-stained at the top	26 ft. 8 in.
1. Sandstone, friable, white. The lower 30 feet mostly covered to the cross-roads at edge of town	40 ft. 0 in.

This outcrop is excellently located for utilization of the Prosser limestone. Moreover, the same hill contains clay that appears to be suitable for mixture with the limestone in the manufacture of Portland cement. It is on the edge of town and has good railroad facilities.

Another excellent outcrop that includes much of both phases of the Galena occurs a mile west and a mile north of Pleasant Grove, where the following section is exposed.

SECTION ALONG COUNTY ROAD 1 MILE WEST AND 1 MILE NORTH OF PLEASANT GROVE AND IN THE J. P. CHASE QUARRY

GALENA (STEWARTVILLE) DOLOMITE	THICKNESS
7. Dolomite, buff to yellowish, with secondary calcite. Becomes porous on weathering	28 ft. 0 in.
6. Covered interval	12 ft. 0 in.
5. Dolomite, buff to tan. Sample 129 is a general Stewartville	16 ft. 5 in.
GALENA (PROSSER) LIMESTONE	
4. Limestone, fine-grained, brown to gray. Well exposed in quarry. Sample 128	16 ft. 0 in.

3. Limestone, fine- to medium-grained, gray to brown. Samples 125, 126, 127	27 ft. 4 in.
2. Limestone, coarse, massive, gray to mottled. Sample 124	1 ft. 0 in.
1. Limestone, thin-bedded, knotty, gray to buff. Sample 123. To level of north branch of Root River	7 ft. 0 in.

Samples 13, 14, 33, 34, 35, 36, 37, 38, 39, 40, 42, 43, 44, 45, 46, 67, 68, 69, 70, 71, 72, 120, 121, 122, 123, 124, 125, 126, 127, 128, 129, 131, 133, and 141 in the table at the end of this chapter are from Olmsted County.

Winona County

Winona County lies partly in the so-called "driftless area," but a large portion of the high ground is loess-covered, and thus a large part of what would probably be outwash and residual soils is obliterated. In general the bed rock is close to the surface and ranges from the Cambrian sandstones to late Middle Ordovician beds.

The St. Lawrence dolomite has become so arenaceous and silty in this part of its outcrop that it is scarcely recognizable from the lithological standpoint. It may therefore be omitted from the present discussion.

The Oneota dolomite (see Figure 13) caps the bluffs along the Mississippi River throughout the county and forms the prominent walls of the picturesque valleys leading away from the river. It has been quarried in a number of places, especially in the vicinity of Winona, and furnishes a good grade of cut stone and crushed rock. The following section of the quarry of the Biesanz Stone Company is typical.

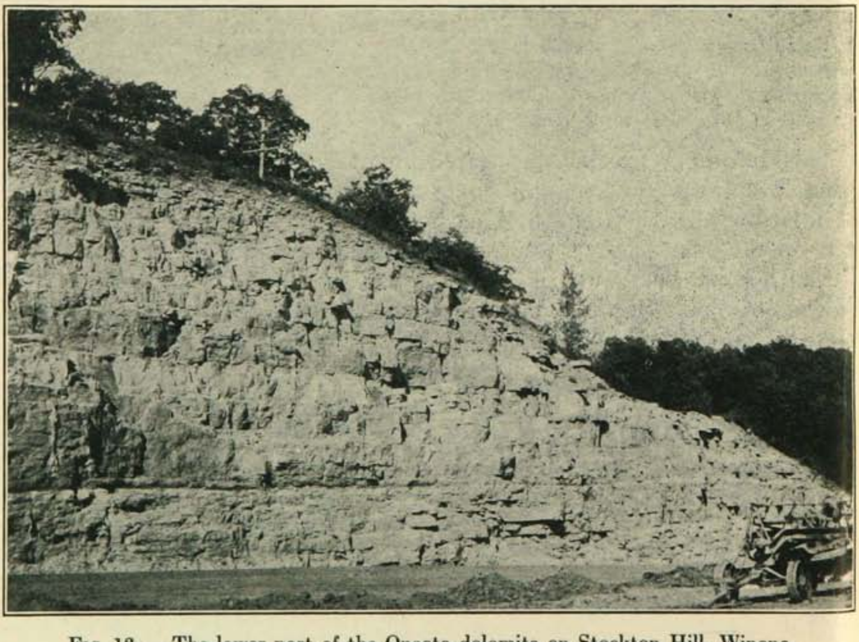

Fig. 13. — The lower part of the Oneota dolomite on Stockton Hill, Winona.

SECTION OF QUARRY OF THE BIESANZ STONE COMPANY, 3 MILES NORTHWEST OF WINONA

	THICKNESS
RESIDUAL	
5. Mantle rock consisting of sandy clay soil and broken rock	4 ft. 8 in.
ONEOTA DOLOMITE	
4. Dolomite, arenaceous, massive, laminated, porous, white to buff and yellow. Contains some flint nodules. Physical test sample 3	11 ft. 6 in.
3. Dolomite, very porous, soft, gray to yellow; contains flint nodules. Physical test sample 2	3 ft. 11 in.
2. Dolomite, fine-grained, crystalline, very porous, hard, tough; the best building stone. Contains flint nodules. Physical test sample 1	3 ft. 8 in.
1. Approximate distance of Mississippi River level below quarry floor	300 ft. 0 in.

Samples collected from this quarry were tested in the laboratory of the State Highway Commission. The results were as shown in the accompanying tabulation.

Sample	Sp. Gr.	Wt. per Cu. Ft.	Per Cent Absorption	Per Cent Wear	French Coef.	Average Toughness
1	2.46	254	4.3	16.4	2.44	6.75
2	...	...	..	...	...	...
3	2.33	146	6.0	14.2	2.82	5.5

A more imposing section is that in the south end of the city, where a prominent bluff and hill, known as "Sugar Loaf," occurs. Nearly the whole top of this hill has been quarried away, only a thin shaft of rock, resembling a monument, remaining on the floor of the quarry. The following is a section of the hill and quarry.

SECTION OF "SUGAR LOAF" AT WINONA

	THICKNESS
ONEOTA DOLOMITE	
17. Dolomite, rough, cavernous, brown, containing chert nodules and much quartz	25 ft.±0 in.
16. Dolomite, massive, brown to buff (quarry floor)	30 ft. 0 in.
15. Dolomite, massive, drab to buff, upper part knotty and probably of algal origin	7 ft. 6 in.
14. Dolomite, compact, with fragmentary shell-like masses, buff to green mottled with pink	1 ft. 0 in.
13. Dolomite, buff with green and pink streaks	0 ft. 10 in.
12. Dolomite, *Cryptozoon* bed, buff to pink	0 ft. 9 in.
11. Dolomite, compact, uneven-bedded, oolitic, with occasional calcite crystals	5 ft. 0 in.
10. Dolomite, buff, thin-bedded to massive, oolitic with scattered sand grains	1 ft. 6 in.
JORDAN SANDSTONE	
9. Sandstone, dolomitic, thin-bedded, with angular sandstone pebbles. Shows crystals of calcite. Buff-colored sandstone with a sharp contact at the top	1 ft. 10 in.
8. Sandstone, massive, brown to buff, with angular sandstone fragments and crystals of calcite	1 ft. 3 in.
7. Sandstone, friable, yellow, with some hard nodular lumps	1 ft. 11 in.
6. Sandstone, calcareous, poorly cemented, cross-bedded, white to yellow	4 ft. 0 in.
5. Sandstone, layers of very firmly cemented sand alternating with layers of poorly cemented sand, white to yellow or brown	75 ft. 8 in.

St. Lawrence Formation

4. Dolomite, beds of fairly pure dolomite alternating with arenaceous dolomitic layers, yellowish to brown	11 ft.	4 in.
3. Covered interval doubtless including the balance of the St. Lawrence and the Franconia	278 ft.	6 in.
2. Sandstone, coarse, yellow to white, poorly cemented, probably Dresbach	1 ft.	6 in.
1. Covered interval to level of Mississippi River at Winona	105 ft.	0 in.

The Oneota was formerly used to a large extent as a local building stone, and stone flagging of this age is common throughout the downtown district of Winona.

The Chicago and Northwestern quarry, about two miles east of Lewiston, has been operated in this same portion of the Oneota dolomite. Its products have been used chiefly by the railroad company. The total thickness of the Oneota at this point is 150 feet.

Although the Shakopee dolomite covers a large area, as the surface rock it has never been utilized in a large way in this part of the state. It is much more massive than in the type locality and resembles even more closely the Oneota dolomite, from which it is separated, however, by the well-developed and persistent New Richmond sandstone about 40 feet thick.

In the southwest corner of the county, the Platteville and remnants of the higher limestones cover the hills to the south of St. Charles. These are of local importance only, being suitable for agricultural purposes or for use as crushed rock for road material.

Samples 5, 59, 60, 84, 85, 86, 147, and 148 in the table at the end of this chapter are from Winona County.

Mower County

Mower County is a gently undulating till plain, but the bed rock is often near the surface. Although there are patches of shales and calcareous beds of probable Cretaceous cropping out here and there, nearly

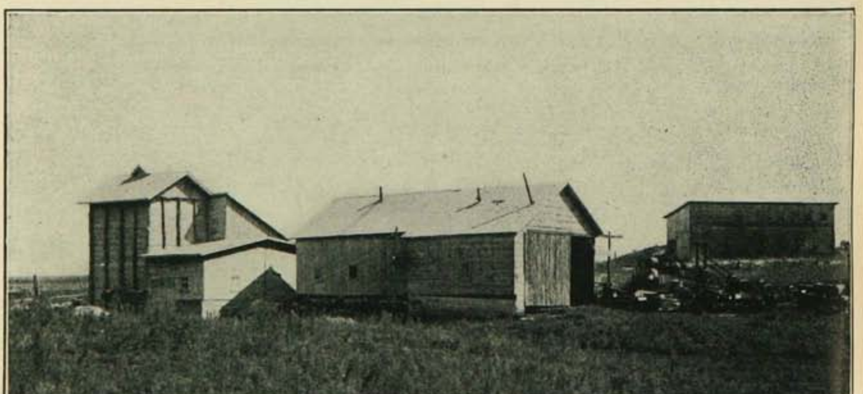

Fig. 14. — Plant of the Hickok Calcium White Rock Company at Le Roy.

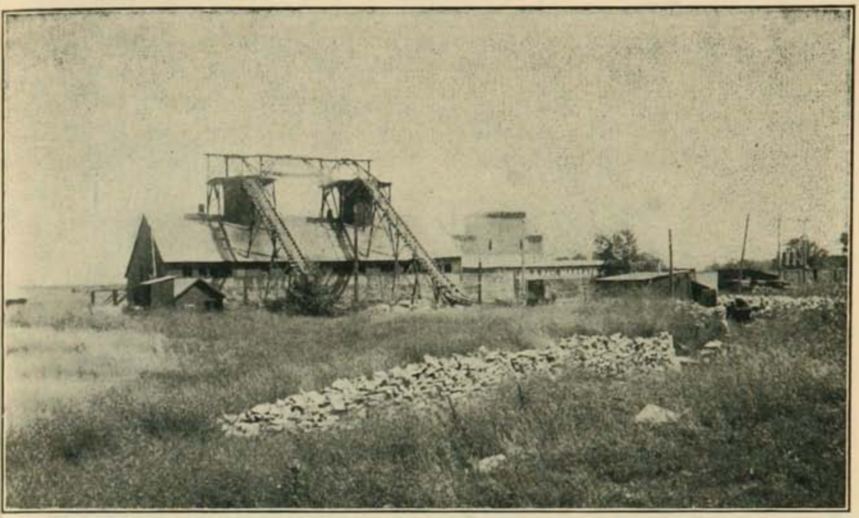

Fig. 15. — The Fowler and Pay lime kiln at Le Roy.

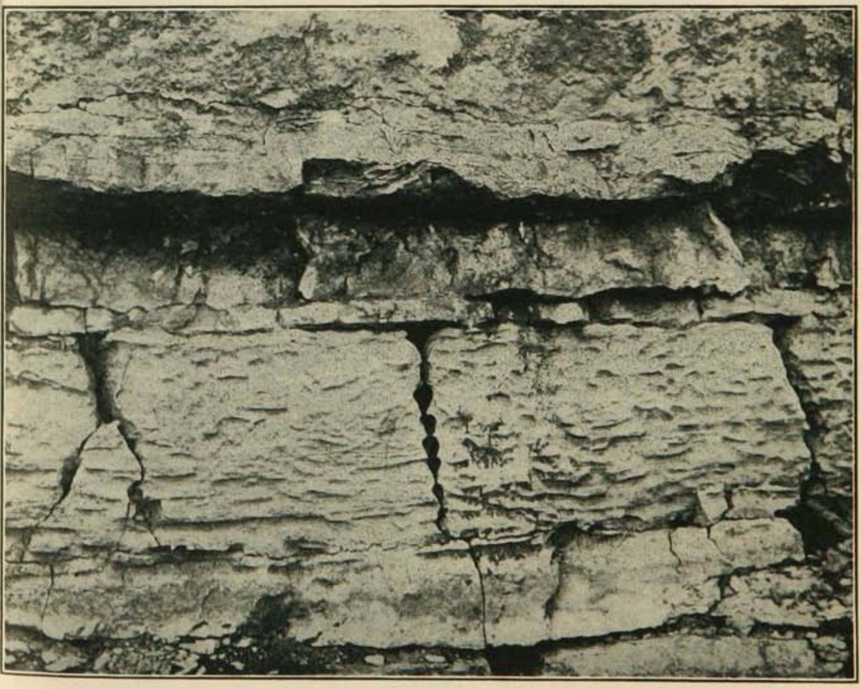

Fig. 16. — The upper Cedar Valley limestone at Le Roy.

the entire county appears to be directly underlaid by Cedar Valley limestone of Devonian age. This limestone crops out along Bear and Deer creeks and the upper Iowa River in the eastern part of the county. On the west side it crops out along the Cedar River and its tributaries. Along Bear Creek, west of Hamilton, it is a cavernous, tough, massive, yellow to buff dolomitic limestone that abounds in poorly preserved fossils.

At Le Roy, in the southeastern corner of the county, the Cedar Valley has a very high-grade, compact white limestone overlying the ordinary yellowish to brown dolomitic limestone beds. The white limestone lies near the surface, over a limited area, and needs little or no stripping. It makes an excellent white lime and has been sold for various other purposes where an unusually high content of $CaCO_3$ is desired. Several quarries have been opened at this place. The Hickok quarry and plant (Figure 14) lie north of town and have supplied quantities of this rock to the high-grade limestone market. Fowler and Pay have quarried the white beds (Figure 16) and burned them for lime (Figure 15) over a period of more than twenty years. Their quarry is still active, and the following is a section measured near the kiln.

Section of Fowler and Pay Quarry, Le Roy

	Thickness
Pleistocene and Recent	
11. Soil and drift	3 ft. 6 in.
Devonian (Cedar Valley Limestone)	
10. Limestone, gray to brown, thin-bedded, partly weathered	4 ft. 0 in.
9. Limestone, fairly massive, gray to white, with a few fossils	2 ft. 0 in.
8. Limestone, gray to brown, traces of fossils	1 ft. 3 in.
7. Limestone, gray, fairly fossiliferous	0 ft. 10 in.
6. Limestone, gray to brown, with poorly preserved *Stromatoporoidea*	0 ft. 8 in.
5. Limestone, dense, gray to white	2 ft. 5 in.
4. Shale, calcareous, green to gray	0 ft. 6 in.
3. Limestone, dense, gray to white, rather massive, containing a few fossils	2 ft. 4 in.
2. Covered interval	1 ft. 0 in
1. Limestone, massive, gray to brown to bottom of pit near lime kiln	7 ft. 0 in.

Fowler and Pay also operate a quarry along Rose Creek, three miles south of Austin, where a natural cement is produced. (See Figure 17.) Here the following section is exposed.

Section of Fowler and Pay Cement Quarry along Rose Creek, 3 Miles South of Austin

	Thickness
Pleistocene and Recent	
4. Soil and drift gravels	2 ft. 0 in.
Cretaceous?	
3. Clay, blue and red, in pockets over the uneven surface of the limestone	5 ft. 0 in.
Devonian (Cedar Valley Limestone)	
2. Limestone, blue to gray, weathering to buff. Fossils rare	10 ft. 0 in.
1. Limestone, massive, gray to buff, containing some chert and limestone pebbles in the lower part. To level of Rose Creek	15 ft. 0 in.

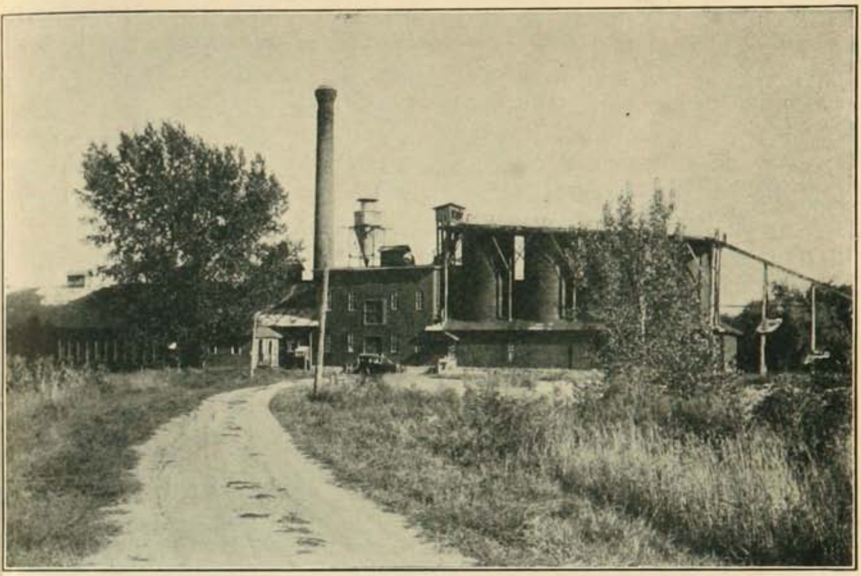

FIG. 17. — The Fowler and Pay Cement Plant on Rose Creek, Austin.

The rock from this quarry produces a fair grade of natural cement, but the Devonian as a whole, except the light gray to white beds at Le Roy, is not regarded very highly either as a building stone or as lime.

Along the Cedar River and one or two of its west branches, a small amount of quarrying has been done. The rock was struck also in Austin during the excavations for the sewage disposal plant, but no quarrying has been done. At some places along the river, southward from Austin, the Devonian rocks are very fossiliferous and the fauna varies from place to place. It appears to be a late Middle Devonian assemblage of species. At Le Roy, however, the fauna is probably Upper Devonian.

Samples 23, 24, 25, and 41 in the table at the end of this chapter are from Mower County.

FILLMORE COUNTY

Fillmore County (see Figure 18) is foremost in the state in its supply of high-grade limestone. Nearly the whole central part is covered by such rock, while most of the remainder is covered by the dolomites. In the western part of the county the bed rock is well covered by drift; but this thins toward the east, where its place is partly taken by loess. Much of the county is well dissected by streams and the rock is therefore well exposed. Numerous quarries have been opened, from time to time, in the limestones and dolomites, and have supplied building stone, crushed rock, lime, and ground rock for improving the soils. The application of ground rock to the soil has been largely by means of a small crusher moved about as necessary to supply the local demand. Although farmers seem to prefer the purer limestones for this purpose, the results appear to be about the same whether these or the dolomite are used. The Oneota dolomite is the lowest formation furnishing limestone or dolomite. It is excellently exposed at Lanesboro, where it has been quarried and extensively used as a building stone. An unusually fine section of this and the later rocks is exposed along State Highway No. 9 in the neighborhood of Preston, beginning at the dam at Lanesboro.

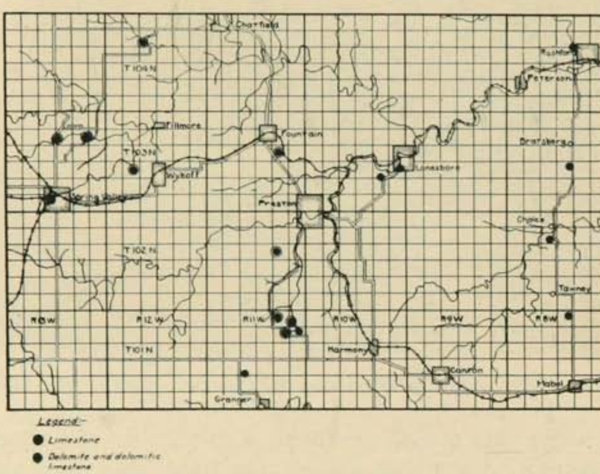

FIG. 18. — Map of Fillmore County showing the locations of samples taken for analyses.

SECTION ALONG STATE HIGHWAY No. 9 AT LANESBORO

	THICKNESS
20. Soil and residual rock	6 ft. 0 in.
PLATTEVILLE LIMESTONE	
19. Limestone, weathered, buff, grading upward into soil	5 ft. 0 in.
18. Limestone, compact, thin-bedded, bluish, with shaly partings. Fossiliferous	4 ft. 9 in.
17. Limestone, sandy, gray	1 ft. 0 in.
16. Sandstone, calcareous, gray	0 ft. 6 in.
GLENWOOD BEDS	
15. Shale, argillaceous, blue-green, with some sand	0 ft. 7 in.
14. Sandstone, medium to fine, yellow to brown	1 ft. 3 in.
13. Shale, argillaceous, olive green to darker green	2 ft. 3 in.
12. Sand, white, mingled with blue clay	0 ft. 6 in.
11. Shale, argillaceous, soft and plastic, bluish green	1 ft. 7 in.
10. Sand, yellow, cemented with limonite	0 ft. 3 in.
ST. PETER SANDSTONE	
9. Sandstone, white, discolored yellow	1 ft. 6 in.
8. Sandstone, medium- to fine-grained, massive, cross-bedded, white to yellowish	13 ft. 9 in.
7. Covered, evidently sandstone	74 ft. 7 in.
SHAKOPEE DOLOMITE	
6. Dolomite, gray to drab, in part oolitic, with large crystals of calcite occupying former cavities	23 ft. 8 in.
5. Dolomite, massive, gray, with calcite-filled cavities. Sharp irregular contact at base	27 ft. 2 in.

FIG. 19. — The Shakopee dolomite along State Highway No. 9 about two miles west of Lanesboro.

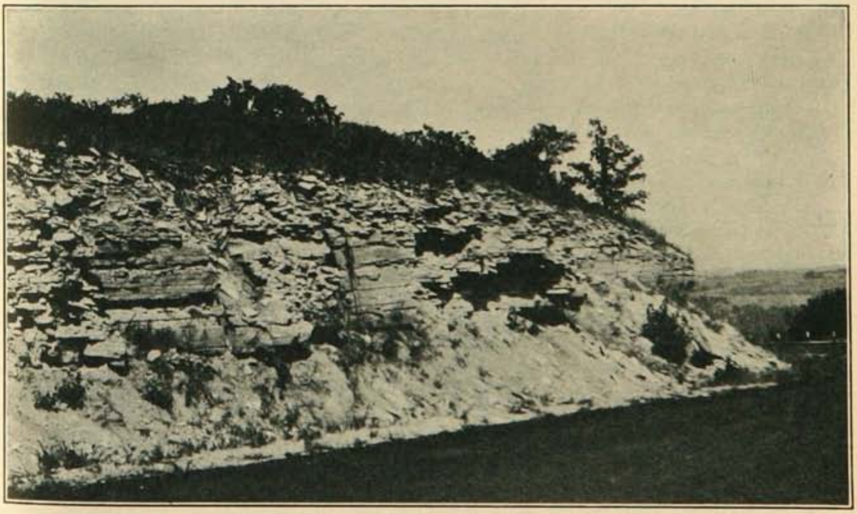

FIG. 20. — The Platteville limestone cropping out at the top of the grade along State Highway No. 9, two and one-half miles southwest of Lanesboro.

NEW RICHMOND SANDSTONE	
4. Sandstone, even-bedded, ripple-marked, yellow to buff or white	26 ft. 2 in.
3. Sandstone, hard, rough, dolomitic	11 ft. 11 in.
ONEOTA DOLOMITE	
2. Dolomite, massive, buff to gray or drab, with calcite-lined cavities. Some chert	120 ft. 0 in
1. Covered from State Highway No. 9, at western edge of town, to level of Root River above the dam	16 ft. 0 in.

A very similar section occurs at Preston, where the Oneota has also been quarried.

Although the Shakopee dolomite is well developed in this county (see Figure 19), it usually has not been quarried. It resembles very closely the Oneota dolomite, although analyses show it to have slightly less magnesium. It is a rough massive stone that might find use in construction of a type that would require such beds; or it might be suitable for crushed rock.

The Platteville limestone seldom exceeds 15 or 20 feet (see Figure 20) in this county, and has been quarried in only a few places. The higher limestones are better and much more prominent. Along State Highway No. 20, one mile south of Fountain, the following section is exposed.

SECTION ALONG STATE HIGHWAY NO. 20, 1 MILE SOUTH OF FOUNTAIN

	THICKNESS
16. Drift-covered to top of hill	15 ft. 0 in.
PROSSER LIMESTONE	
15. Limestone, compact, gray to drab	5 ft. 0 in.
14. Limestone, compact, hard, blue to drab, weathering into thin beds	24 ft. 0 in.
DECORAH SHALE	
13. Shale, argillaceous, bluish green, alternating with beds of blue limestone	10 ft. 4 in.
12. Covered interval	18 ft. 3 in.
11. Shale, argillaceous, blue, with lenses of limestone	10 ft. 4 in.
10. Limestone, two layers, hard, gray, the *Lingula elderi* bed	1 ft. 4 in
9. Shale, argillaceous, light gray to olive green	0 ft. 7 in.
8. Limestone, massive, compact, gray	2 ft. 1 in.
7. Shale, soft, light gray to white, a Bentonite	0 ft. 4 in.
6. Limestone, compact, gray, in two beds	0 ft. 10 in.
PLATTEVILLE LIMESTONE	
5. Limestone, thin-bedded to shaly, gray to bluish	5 ft. 10 in.
4. Limestone, thin-bedded, knotty, irregular layers, blue to gray, shale partings	9 ft. 6 in.
GLENWOOD BEDS	
3. Shale, argillaceous, gray to olive green with yellowish sandstone layers	3 ft. 3 in.
ST. PETER SANDSTONE	
2. Sandstone, yellow, poorly cemented	1 ft. 0 in.
1. Covered interval to creek level	18 ft. 3 in.

The Prosser limestone, which forms the upper part of this section, is a very pure limestone suited in every way to the manufacture of Portland cement. (See Figure 21.) The clay shale of the Decorah occurs just

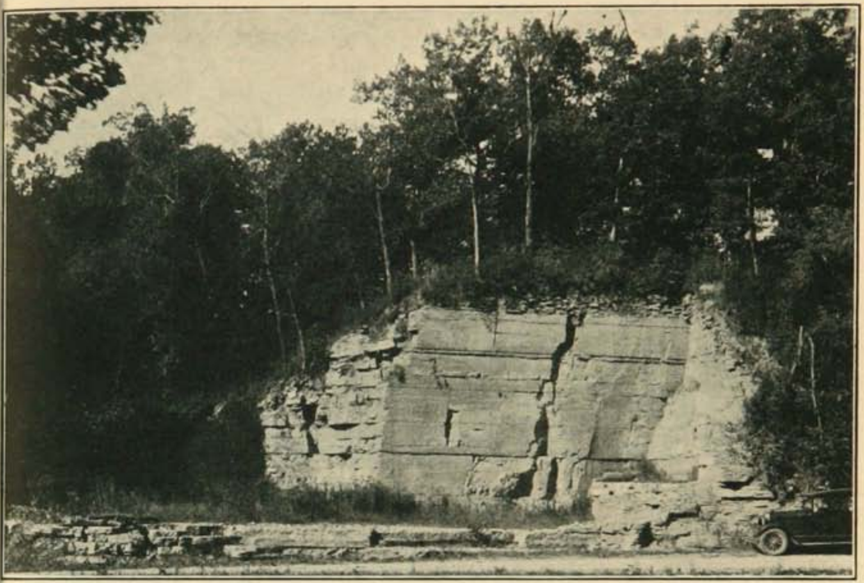

FIG. 21. — The Prosser limestone along Lost Creek, six miles west of Chatfield.

below the Prosser; its quality is such that it also could be used in making Portland cement. The layers of limestone occurring in the shale are usually free from dolomite and could be added to the Prosser above for the mix. The region around Fountain seems particularly well suited for cement manufacture. In many other places where the high-grade limestone is well developed, the Decorah shale is under a deep cover.

The best outcrop of the Prosser limestone (lower Galena) is that along Dr. E. O. Ulrich's type section on Prosser Creek, two and a half miles west of Wykoff, where the following measurements were made.

SECTION ALONG PROSSER CREEK, 2½ MILES WEST OF WYKOFF

	THICKNESS
17. Drift-covered	15 ft. 0 in.
STEWARTVILLE DOLOMITE	
16. Dolomite, cavernous, yellow to buff, fossils common	36 ft. 0 in.
15. Dolomite, vesicular, in thin, knotty layers, yellow, fossiliferous	10 ft. 6 in.
14. Dolomite, fairly massive, yellow to gray, fossiliferous	12 ft. 4 in.
13. Dolomite, fossiliferous, gray to brown. Sample 32 from bottom	14 ft. 6 in.
12. Shale, argillaceous, yellowish	1 ft. 0 in.
PROSSER LIMESTONE	
11. Limestone, compact, drab. Sample 31	4 ft. 6 in.
10. Limestone, compact, hard, drab, very fossiliferous	15 ft. 6 in.
9. Limestone, compact, in part crystalline, thin-bedded to shaly, bluish. Sample 30 taken at the base	8 ft. 0 in.
8. Limestone, compact, drab, with some chert, fossiliferous	13 ft. 4 in.
7. Limestone, compact, drab, with numerous fossils. Sample 29 taken at the base	19 ft. 4 in.

6. Limestone, massive, compact, drab	10 ft. 4 in.
5. Limestone, compact, drab, at line of small caves. Sample 28 taken at the base	9 ft. 2 in.
4. Limestone, argillaceous, massive but weathering into thin knotty beds, blue to gray	17 ft. 10 in.
3. Limestone, compact, drab, passing into argillaceous beds. Sample 27 taken at the base	10 ft. 4 in.
2. Limestone, compact, drab to blue	3 ft. 2 in.
1. Covered interval to level of Deer Creek at outlet of Prosser Creek	5 ft. 4 in.

A famous old lime kiln which used the Stewartville dolomite in burning lime is located on Deer Creek, three miles north of Spring Valley. It bore the name "Lime City." (See Figure 22.) The upper part of this ledge really belongs to a limestone phase of the basal Maquoketa shale, and this appears to have been the preferred rock for burning. In recent years this pit has supplied crushed rock for the county highways.

SECTION AT OLD LIME CITY QUARRY

	THICKNESS
PLEISTOCENE	
6. Drift and soil	10 ft.±0 in.
MAQUOKETA SHALE	
5. Limestone, thin-bedded with shaly partings, blue to brown, fossiliferous	30 ft.±0 in.
STEWARTVILLE DOLOMITE	
4. Dolomite, rough, vesicular, gray	20 ft. 0 in.
3. Dolomite, compact, massive, gray to ashen	20 ft. 0 in.
2. Dolomite or dolomitic limestone, compact, hard, gray	15 ft. 0 in.
PROSSER LIMESTONE	
1. Limestone, compact, gray to level of Deer Creek	4 ft. 0 in.

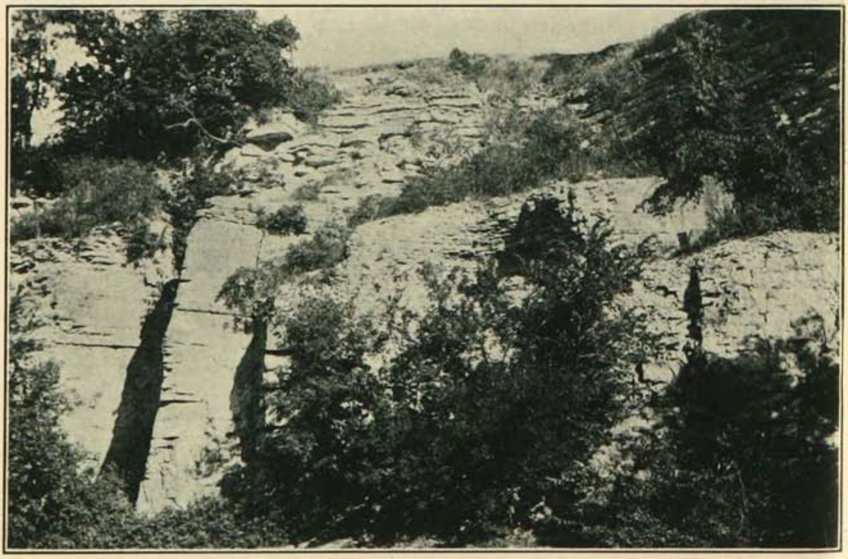

FIG. 22. — The Stewartville dolomite and basal Maquoketa shale in the Lime City quarry, Spring Valley.

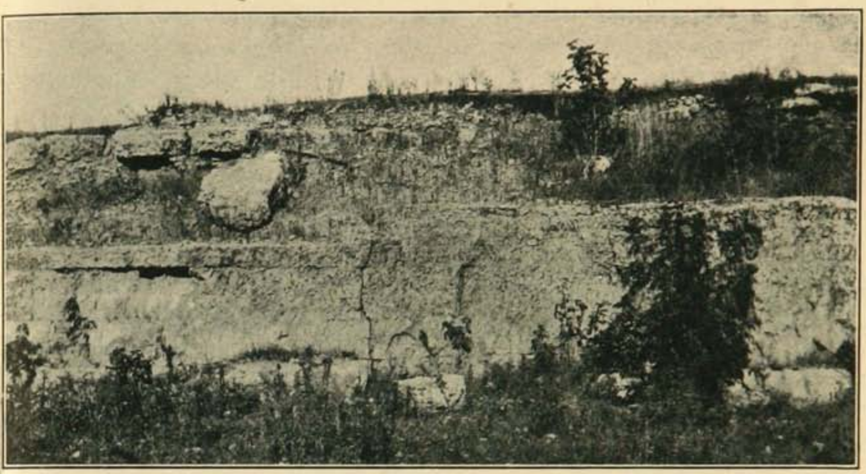

FIG. 23. — The Cedar Valley limestone at Spring Valley.

The Devonian of this county is not utilized, even in a small way, although it has furnished some rock in the past. The more massive brown layers, which are hard and tough, have qualities that might make an attractive building stone if it were properly finished. The following section was measured at the Larsen Quarry in Spring Valley. (See Figure 23.)

SECTION OF LARSEN'S QUARRY, SPRING VALLEY

	THICKNESS
PLEISTOCENE AND RECENT	
4. Soil and drift	1 ft. 0 in.
DEVONIAN (CEDAR VALLEY LIMESTONE)	
3. Limestone, massive but badly weathered, gray to buff or brown, abundantly fossiliferous	5 ft. 0 in.
2. Limestone, massive, buff, abundantly fossiliferous	3 ft. 0 in.
1. Limestone, brown to buff, very fossiliferous to quarry floor	3 ft. 4 in.

Samples 16, 17, 18, 19, 21, 22, 26, 27, 28, 29, 30, 31, 32, 56, 57, 58, 61, 62, 63, 64, 65, 66, 91, 92, 93, 94, 95, 96, 97, 98, 99, 100, 101, 102, 105, 106, 107, 108, 109, 110, 111, 112, 113, and 114 in the table at the end of this chapter are from Fillmore County.

HOUSTON COUNTY

Houston County lies in the extreme southeastern corner of the state. Under the mantle rock most of its surface is covered by the dolomites. These are deeply eroded by Root River and the smaller tributaries of the Mississippi River, thus exposing deep valleys in the Cambrian sandstones. The southwestern corner is covered by hills of St. Peter sandstone capped by Platteville and later limestones.

In Houston County, as in Winona County, the upper portion of the Oneota is cherty. This varies from practically all chert to irregular cherty masses making up nearly 50 per cent of the rock, and it may extend from 50 to 90 feet below the top. The Oneota has been quarried in a number of places, among which are La Crescent, Hokah, Brownsville, and Caledonia. None of these, however, has been worked on a large scale. The following section of Mt. Tom at Hokah gives some of the details of the stratigraphy in this region.

SECTION OF MT. TOM, HOKAH

	Thickness
19. Residual soil covering to top of Mt. Tom	50 ft. 9 in.
ONEOTA DOLOMITE	
18. Dolomite, massive, arenaceous, gray to drab beds in old quarry near top of Mt. Tom	50 ft. 3 in.
17. Covered interval	22 ft. 4 in.
16. Dolomite, mostly covered, but occasional outcrops of sandy dolomite	33 ft. 6 in.
15. Dolomite, coarse, sandy, gray	27 ft. 11 in.
14. Covered interval	11 ft. 2 in.
JORDAN SANDSTONE	
13. Sandstone, mostly covered, but with occasional outcrops showing massive coarse-grained, cross-bedded sandstone	117 ft. 3 in.
ST. LAWRENCE FORMATION	
12. Covered slope below sandstone outcrops, probably St. Lawrence	33 ft. 6 in.
11. Shale, shaly green sand interbedded with thin shaly sandstones	44 ft. 8 in.
FRANCONIA	
10. Green sand, glauconitic beds with thin-bedded shaly sandstone. Trilobite fragments common	31 ft. 10 in.
9. Sandstone, micaceous, shaly, with much glauconite	22 ft. 4 in.
8. Green sand, glauconitic beds, and arenaceous shales alternating with massive sandstones	16 ft. 9 in.
7. Sandstone, medium-grained, poorly cemented, yellow to greenish yellow	3 ft. 9 in.
6. Sandstone, fine-grained, cross-bedded, yellow to white. *Obolella* abundant	7 ft. 7 in.
DRESBACH FORMATION	
5. Sandstone, coarse, massive, white	22 ft. 6 in.
4. Sandstone, medium-grained, thin-bedded, often shaly, varying in color from brick red to white	5 ft. 1 in.
3. Sandstone, coarse, hard, purple and brown, variegated with yellow	2 ft. 0 in.
2. Sandstone, massive, medium-grained, in part cross-bedded, poorly cemented, white with yellow stains	25 ft. 11 in.
1. Sandstone, massive, with some shaly beds, white to yellow and brown; to level of Mill Creek at depot	11 ft. 2 in.

Several small quarries occur in the Oneota dolomite to the east of Caledonia. They have supplied rock for local use but are too far from transportation to be worked in a large way.

The Shakopee dolomite is well developed in this region. It lies above a thick New Richmond sandstone and resembles very closely the Oneota dolomite. It is not utilized, although, as usual, there seems no reason why it should not be as valuable as the older rock below.

In the southwestern part of the county, where the Platteville limestone and lower beds of Decorah shale cap the hills of St. Peter sandstone, several small quarries have been opened. One of these that has served the highway department is located along State Highway No. 44, six and a half miles southwest of Caledonia. The desirable rock is Platteville limestone.

SECTION OF QUARRY ALONG STATE HIGHWAY No. 44, 6½ MILES SOUTHWEST OF CALEDONIA

	THICKNESS
7. Soil and weathered shale	2 ft. 0 in.
DECORAH SHALE	
6. Shale, argillaceous, greenish, with interbedded layers of limestone. Weathered and somewhat distorted	2 ft. 5 in.
5. Limestone, compact, hard, blue, full of fossils. The "trilobite" layer	2 ft. 5 in.
4. Shale, argillaceous, gray	0 ft. 1 in.
PLATTEVILLE LIMESTONE	
3. Limestone, thin-bedded, prominently jointed, blue. Fossils common	31 ft. 2 in.
GLENWOOD BEDS	
2. Shale, argillaceous and sandy, green to bluish, weathering yellow to brown	3 ft. 0 in.
ST. PETER SANDSTONE	
1. Sandstone, white, only a small amount showing in gutter	2 ft. 0 in.

Samples 103, 104, 159 in the table at the end of this chapter are from Houston County.

SUMMARY

From the foregoing account and from the list of analyses that follow, it is evident that Minnesota possesses limestones and dolomites of great value to the state. The various uses of such rocks have been enumerated on some of the preceding pages. It remains to mention specifically some of the advantages of certain deposits within the state.

The dolomites and the dolomitic limestones, which are well distributed over the southeastern part of Minnesota, are as valuable in the neutralization of an acid soil as are the high-grade limestones. In fact, it has been found that slightly less of the dolomitic limestone than of the high-calcium rock is necessary to a given soil. By the aid of the portable crusher the farmer often can obtain the required rock from his own land, thus reducing to a minimum the expense of renewing his soil. The rocks suitable for agricultural purposes are the dolomitic beds of the St. Lawrence formations, the Oneota dolomite, the Shakopee dolomite, and Platteville limestone, the calcareous beds of the Decorah shale, the Prosser limestone, the Stewartville dolomite, much of the Maquoketa shale, and the greater part of the Cedar Valley limestone.

Oyster shells are commonly supplied to poultrymen as eggshell material for their hens. Every year large quantities of such material are used in Minnesota in the expanding poultry business of the state. It has been discovered that the hens will use and prefer flaked limestone of a high calcium content. The white limestone at Le Roy is now supplying this grit to the poultrymen at less cost than oyster shells, and it has been found that the flaked white lime goes twice as far as oyster shells.

A few of the dolomites meet the requirements (40 per cent or more of $MgCO_3$) for the lining of open-hearth furnaces, but most of them are too high in their silica content to be desirable. The Shakopee dolomite found at the towns of Shakopee and Tawney has the desired percentage of $MgCO_3$, and 1.5 per cent or less of silica. Almost the same thing may be said of the Oneota dolomite at Merriam Junction and Rushford; at this latter place the silica content is only 1 per cent.

The Prosser limestone of Fillmore and Olmsted counties and the limestone layers of the underlying Decorah shale are of a high grade and fairly well suited to the manufacture of whiting. Their content of $MgCO_3$ is low, rarely exceeding 4 per cent, and the content of $CaCO_3$ is high, in some places ranging up to 96 per cent or more. The color of this rock, however, is a light drab to blue, and the powder resulting from grinding is not a pure white. The very high-grade white limestone (Cedar Valley limestone) at Le Roy is well suited to the manufacture of whiting. This rock is nearly white in color and runs 97 to 98 per cent or more $CaCO_3$. The areal distribution, however, is limited, and the thickness of the deposit is not great. Whiting is used as one of the chief constituents, or as an ingredient, in the manufacture of putty, paints, asphalt, linoleum, rubber, shoe polish, tooth paste, etc.

The composition of some of the dolomites suggests their future use in the manufacture of magnesia, an important industry not represented in the state. For this purpose a rock with 43 to 48 per cent $MgCO_3$ is generally required. The Oneota limestone at Merriam Junction and that at Shakopee along the Minnesota River fall within this limit. The Oneota dolomite has the desired composition for this purpose at various points along the Mississippi river and tributaries, particularly at Frontenac, Winona, and Lanesboro. The Cedar Valley limestone at Spring Valley is equally high in its content of $MgCO_3$ and probably is suited to the same purpose.

Lime has been manufactured from most of the limestones and dolomites of the state and in many localities. At the present time, however, this product is produced only from the highly calcareous beds of the Cedar Valley limestone at Le Roy and from the Shakopee dolomite at Mankato. The former makes an unusually fine quality of high-calcium lime. The Prosser limestone of Olmsted and Fillmore counties could produce a lime of comparable quality.

A natural cement is produced from the Oneota dolomite at Mankato and from the argillaceous beds belonging to the Cedar Valley limestone along Rose Creek near Austin. The Mankato plant produces the material that sells under the name "Carney cement," favored by contractors for certain kinds of construction. The capacity of the Carney Cement Plant at Mankato is 3,000 barrels per day. At Rose Creek, where the younger Devonian beds are used, the material is more impure and the quality of the product is different. It has been suspected that this latter may have the desired composition for the "rock wool" now used for house insulation.

Up to the present time no Portland cement has been produced from Minnesota materials. There are, however, several limestones in the state that have the proper composition for such materials. These are the Prosser limestone of Olmsted and Fillmore counties and the Cedar Valley limestone at Le Roy. In the area of the Prosser limestone shale is also available and conditions appear to be suitable for manufacture. There is a good demand, and it is likely that manufacture of Portland cement will be started eventually in one of these areas. Thus another industry will be added to the state.

Sugar refining requires a lime that is almost free from magnesium. Since most commercial lime contains too much magnesium, it is usual for the sugar refiner to buy selected limestone and burn his own lime. The white limestone at Le Roy is excellently suited to that purpose; it ranks among the purest calcium carbonate deposits of the United States.

Pharmaceutical trade requires a very pure limestone, such as that found at Le Roy, and this trade is being supplied, to some extent, from that region.

Locality List of Limestone Samples Taken for Analyses

SAMPLE

1. St. Lawrence limestone, St. Lawrence, Scott County. From the fossiliferous layer with grains of green matter (probably glauconite). Specimen highly crystalline and of a brownish color.
2. Oneota dolomite (Kasota stone), Kasota, Le Sueur County. Sample of the pink layer sawed and polished by the Breen Stone and Marble Company. This is a marketable horizon. It consists of pink to buff beds of fine dolomite 14 feet thick.
3. Oneota dolomite, White Cliff or White Rock Bluff, Ottawa, Le Sueur County, on Charles Schwartz's farm along the Minnesota River. Sample from the 6-foot bed of brown to reddish brown or pink magnesian limestone with a little chert. Fossils common but poorly preserved.
4. Oneota dolomite from cliff opposite Sibley Park, Mankato, but in Nicollet County.
5. Oneota dolomite, 6½ miles from Winona on State Highway No. 7, Winona County. Sample from the massive building beds in the lower part of the formation.
6. Shakopee dolomite, Cannon Falls, Goodhue County. Sample from the oolitic beds below the dam at Cannon Falls.
7. Platteville limestone, High Dam, Minneapolis, Hennepin County. Sample from the 11-foot bed (bed no. 11 in the High Dam section), which is mostly compact brown to gray limestone weathering bluish. Composed of thin, irregular, often nodular layers separated by thinner shaly layers. Fossils broken and segregated in thin layers.
8. Platteville limestone, Ford Plant, St. Paul, Ramsey County. Sample from bed 5 feet, 3 inches thick (bed no. 9 in the Ford Plant section), which is composed of argillaceous, thin-bedded limestone showing conchoidal fracture and containing few fossils.
9. Platteville limestone, Ford Plant, St. Paul, Ramsey County. Sample from bed 8 feet, 8 inches thick (bed no. 10 in the Ford Plant section), which is composed of highly fossiliferous gray to bluish dolomite, the fossils being more abundant in streaks or pockets.
10. Platteville limestone, High Dam, Minneapolis, Hennepin County. These beds are an argillaceous, compact brown limestone, often mottled and weathering to bluish. Sample from bed no. 11 in the High Dam section.
11. Platteville limestone, High Dam, Minneapolis, Hennepin County. Sample from bed no. 14, a bluish to brown, compact limestone with few fossils.

SAMPLE

12. Platteville limestone, High Dam, Minneapolis, Hennepin County. Sample of bed no. 13, which is a shaly, argillaceous, blue limestone breaking conchoidally.
13. Decorah shale, near District School 34, along State Highway No. 20, north of Chatfield, Olmsted County. Sample from bed no. 3 (the "marble layer"), which is composed of compact, bluish-gray limestone with abundant fauna.
14. Decorah shale, along State Highway No. 7, 3½ miles east of Rochester, Olmsted County. Sample is from bed no. 8 and is fossiliferous blue to gray limestone identical in appearance with the sample from bed no. 13.
15. Decorah shale, Jaeger's Quarry, Faribault, Rice County. Sample from bed no. 13 ("marble layer") of the section at Jaeger's Quarry, which is made up of hard gray limestone and is full of fossils.
16. Galena limestone, Masonic Park, Fillmore County. Sample from bed no. 3 of Masonic Park section, which is dense, gray to light gray limestone with abundant fauna especially well developed in a 3-inch layer in the middle.
17. Galena limestone, Fountain, Fillmore County. Sample from the lower Galena.
18. Galena limestone, Masonic Park, Fillmore County. Sample from bed no. 6, which is gray to bluish-gray, fossiliferous limestone with shale partings at the top.
19. Galena limestone, Masonic Park, Fillmore County. Sample from bed no. 9, which is rather thin-bedded, prominently jointed, gray to ashen-colored dolomite. Some layers are crystalline, others are more dolomitic.
20. Galena limestone, along State Highway No. 20, 4.9 miles south of Cannon Falls, Goodhue County. Sample from bed no. 4 of Cannon Falls section, made up of gray to bluish limestone containing *Receptaculites oweni.*
21. Maquoketa formation, 1 mile northwest of Granger, Fillmore County. Sample from shaly outcrop in road.
22. Cedar Valley limestone, Larsen's Quarry, Spring Valley, Fillmore County. Sample from bed no. 2 of Larsen's Quarry section, which is composed of buff-colored, massive limestone with abundant fossils.
23. Cedar Valley limestone, Le Roy, Mower County. Sample from the brown magnesian layers forming bed no. 1 of the section at the Fowler and Pay quarry, 1 mile east of Le Roy, Minnesota.
24. Cedar Valley limestone, Fowler and Pay quarry, Le Roy, Mower County. Sample from bed no. 6, which is gray to brown limestone containing indistinct masses resembling stromatoporoids.
25. Cedar Valley limestone, Fowler and Pay quarry, Le Roy, Mower County. Sample from bed no. 5, which is gray to white, compact limestone apparently containing no fossils.
26. Galena limestone, 2½ miles southwest of Preston, Fillmore County. Sample of Prosser limestone.
27. Galena limestone, Prosser Creek, Wykoff, Fillmore County. Sample from basal Prosser limestone.
28. Galena limestone, Prosser Creek, Wykoff, Fillmore County. Sample from lower middle Prosser limestone.
29. Galena limestone, Prosser Creek, Wykoff, Fillmore County. Sample from middle Prosser limestone.
30. Galena limestone, Prosser Creek, Wykoff, Fillmore County. Sample from upper middle Prosser limestone.
31. Galena limestone, Prosser Creek, Wykoff, Fillmore County. Sample from upper Prosser limestone.
32. Galena limestone, Prosser Creek, Wykoff, Fillmore County. Sample from basal Stewartville dolomite.
33. Decorah shale, Troy Road (Waterworks Hill), Chatfield, Olmsted County. Sample from bed no. 7, which is basal in position and composed of hard gray limestone.
34. Decorah shale, Troy Road (Waterworks Hill), Chatfield, Olmsted County. Sample from bed no. 9, which is composed of compact blue to gray limestone.
35. Decorah shale, Troy Road (Waterworks Hill), Chatfield, Olmsted County. Sample from bed no. 10, which is the "marble layer" or "trilobite" bed, composed of hard blue-gray limestone.
36. Galena limestone, Troy Road (Waterworks Hill), Chatfield, Olmsted County. Sample from upper part of bed no. 13, which is compact gray limestone (Prosser limestone).

SAMPLE

37. Galena limestone, Troy Road (Waterworks Hill), Chatfield, Olmsted County. Sample from lower part of bed no. 13, which is compact gray limestone (Prosser limestone).
38. Galena limestone, Troy Road (Waterworks Hill), Chatfield, Olmsted County. Sample from upper part of bed no. 14, which is composed of hard, compact, gray limestone, often thin-bedded (Prosser limestone).
39. Galena limestone, Troy Road (Waterworks Hill), Chatfield, Olmsted County. Sample from middle part of bed no. 14, which is composed of hard, compact, gray limestone, often thin-bedded (Prosser limestone).
40. Galena limestone, Troy Road (Waterworks Hill), Chatfield, Olmsted County. Sample from lower part of bed no. 14, which is composed of hard, compact, gray limestone, often thin-bedded (Prosser limestone).
41. Cedar Valley limestone, Fowler and Pay quarry, Le Roy, Mower County. Sample from bed no. 6, which is gray to brown limestone containing indistinct masses resembling stromatoporoids. Sample same as Sample 24.
42. Galena limestone, along State Highway No. 20, near District School 34, Chatfield, Olmsted County. Sample from lower part of bed no. 7, which is massive, compact limestone with few fossils (Prosser limestone).
43. Galena limestone, along State Highway No. 20, near District School 34, Chatfield, Olmsted County. Sample from middle part of bed no. 7, which is massive, compact limestone with few fossils (Prosser limestone).
44. Galena limestone, along State Highway No. 20, near District School 34, Chatfield, Olmsted County. Sample from upper part of bed no. 7, which is massive, compact limestone with few fossils (Prosser limestone).
45. Galena limestone (Prosser limestone), along State Highway No. 20, near District School 34, Chatfield, Olmsted County. Sample from upper part of bed no. 9, which is weathered gray limestone, hard and with few fossils.
46. Galena limestone (Prosser limestone), along State Highway No. 20, near District School 34, Chatfield, Olmsted County. Sample from lower part of bed no. 9, which is weathered gray limestone, hard and with few fossils.
47. Oneota or Shakopee dolomite, Merriam Junction, Scott County. Sample of bed no. 6, which is rough, cherty dolomite, sometimes arenaceous.
48. Oneota dolomite, Merriam Junction, Scott County. Sample from bed no. 3, which is rather massive, hard, rough, gray to brownish dolomite, often with pink streaks and cavities containing pink crystals.
49. Oneota dolomite, Merriam Junction, Scott County. Sample from bed no. 5, which is composed of rough, gray to pink dolomite, with a compact, thin, buff bed at the top.
50. Oneota dolomite, Merriam Junction, Scott County. Sample from bed no. 4, which is compact, buff dolomite, fairly thin-bedded.
51. Oneota dolomite, Merriam Junction, Scott County. Sample from bed no. 1, which is massive, vesicular, pink dolomite, weathering gray.
52. Oneota dolomite, Merriam Junction, Scott County. Sample from the railroad cut near the quarry but somewhat lower.
53. Oneota dolomite, Merriam Junction, Scott County. Sample from bed no. 2, which is made up of compact, hard, gray to buff dolomite streaked with pink.
54. Maquoketa limestone, Clinton Falls, Steele County. Sample of lower part.
55. Maquoketa limestone, Clinton Falls, Steele County. Sample of middle part.
56. Oneota dolomite, along State Highway No. 9 at south edge of Lanesboro, Fillmore County.
57. Shakopee dolomite, along State Highway No. 9, 1½ miles southwest of Lanesboro, Fillmore County. Sample taken just above the New Richmond sandstone.
58. Platteville limestone, along State Highway No. 9 on the grade south of Lanesboro, Fillmore County. Sample from the top.
59. Oneota dolomite, Winona, Winona County. Sample from bed no. 15 of the Sugar Loaf section, which is rough, cavernous, brown dolomite containing a large quantity of quartz.
60. Oneota dolomite, Winona, Winona County. Sample from bed no. 14 of the Sugar Loaf section, which is massive, brown to buff dolomite, 30 feet thick.
61. Galena limestone (Prosser limestone), Lime City (Spring Valley), Fillmore County. Sample from bed no. 1, 3 feet above the water level, where this formation consists of a very fossiliferous, compact, gray limestone.

SAMPLE

62. Galena limestone (Stewartville dolomite), Lime City (Spring Valley), Fillmore County. Sample from bed no. 2, which is a fairly hard limestone.
63. Galena limestone (Stewartville dolomite), Lime City (Spring Valley), Fillmore County. Sample from bed no. 3, which is a fairly compact dolomite, ashen in color.
64. Galena limestone (Stewartville dolomite), 2.8 miles north of Spring Valley, Lime City, Fillmore County. Sample from bed no. 4, which is rough, vesicular dolomite.
65. Maquoketa shale, Lime City (Spring Valley), Fillmore County. Sample from bed no. 5, which is a thin-bedded limestone here, and rarely shaly.
66. Maquoketa shale, Lime City (Spring Valley), Fillmore County. Sample from bed no. 5, which is a thin-bedded limestone here, and rarely shaly.
67. Platteville limestone, Troy Road (Waterworks Hill), Chatfield, Olmsted County. Sample from bed no. 6, which is hard, gray to buff limestone.
68. Platteville limestone, Troy Road (Waterworks Hill), Chatfield, Olmsted County. Sample from bed no. 5, which is a hard, compact, blue to gray limestone with numerous fossils, and which is iron-stained at the top.
69. Platteville limestone, State Quarry (State Hospital), Rochester, Olmsted County. Sample from the top beds.
70. Platteville limestone, State Quarry (State Hospital), Rochester, Olmsted County. Sample from the middle beds.
71. Platteville limestone, State Quarry (State Hospital), Rochester, Olmsted County. Sample from the bottom beds.
72. Decorah shale, State Quarry, Rochester, Olmsted County (State Hospital). Sample from the basal limestone.
73. Oneota dolomite, Old Frontenac Quarry, Frontenac, Goodhue County. Sample from bed no. 4, which is a coarse, massive, dolomitic limestone, hard and compact but full of holes, with some chert- and quartz-filled cavities.
74. Oneota dolomite, Old Frontenac Quarry, Frontenac, Goodhue County. Sample from bed no. 3, which is thin-bedded, compact, drab to pink dolomite.
75. Oneota dolomite, Old Frontenac Quarry, Frontenac, Goodhue County. Sample from bed no. 2, which is composed of several beds of hard, gray, drab to pale pink dolomite with some chert.
76. Oneota dolomite, Old Frontenac Quarry, Frontenac, Goodhue County. Sample from bed no. 1, which is the basal layer and is composed of massive, porous dolomite of a gray to ashen color, often with a pinkish tinge; the pores glisten with crystals.
77. Oneota dolomite, quarry of the Carney Cement Company (Pilgrims Rest Cemetery), Mankato, Blue Earth County. Sample from upper part of bed no. 8, which is massive, buff to brown or pink dolomite with mottled cavities.
78. Oneota dolomite, quarry of the Carney Cement Company (Pilgrims Rest Cemetery), Mankato, Blue Earth County. Sample from bed no. 7, which is of massive, buff-colored dolomite with splotches of pink and is 2 feet, 10 inches thick.
79. Oneota dolomite, quarry of the Carney Cement Company (Pilgrims Rest Cemetery), Mankato, Blue Earth County. Sample from the upper part of bed no. 6, which is purple, shaly dolomite.
80. Oneota dolomite, quarry of the Carney Cement Company (Pilgrims Rest Cemetery), Mankato, Blue Earth County. Sample from the lower part of bed no. 6, which is ashen, gray dolomite.
81. Oneota dolomite, Pilgrims Rest Cemetery, Mankato, Blue Earth County. Sample from bed no. 10 from the natural outcrop below the bluff of the quarry of the Carney Cement Company, which is thin-bedded, weathering to buff, dolomitic layers.
82. Oneota dolomite, quarry of the Carney Cement Company (Pilgrims Rest Cemetery), Mankato, Blue Earth County. Sample from bed no. 5, which is massive, gray dolomite with several poorly developed bedding planes.
83. Oneota dolomite, quarry of the Carney Cement Company (Pilgrims Rest Cemetery), Mankato, Blue Earth County. Sample from bed no. 8, which is a massive layer of pink dolomite weathering to buff and vesicular in places.
84. Oneota dolomite, Winona, Winona County. Sample from bed no. 7 of Sugar Loaf section, which is arenaceous dolomite, gray to brown.
85. Oneota dolomite, Winona, Winona County. Sample from bed no. 8 of the Sugar Loaf section, which is slightly arenacecous dolomite with an oolitic texture in part.

SAMPLE

86. Oneota dolomite, Winona, Winona County. Sample from bed no. 12 of the Sugar Loaf section, which is fine-grained, laminated, arenaceous, pink dolomite.
87. Oneota dolomite, quarry of the Carney Cement Company (Pilgrims Rest Cemetery), Mankato, Blue Earth County. Sample from upper part of bed no. 7, which is massive, buff-colored dolomite with splotches of pink.
88. Oneota dolomite, quarry of the Carney Cement Company (Pilgrims Rest Cemetery), Mankato, Blue Earth County. Sample from lower part of bed no. 9, which is composed of massive beds of buff to brown or pink dolomite with mottled cavities.
89. Oneota dolomite, quarry of the Carney Cement Company (Pilgrims Rest Cemetery), Mankato, Blue Earth County. Sample from bed no. 10, which is thin-bedded and weathers to buff dolomitic beds.
90. Oneota dolomite, quarry of the Carney Cement Company (Pilgrims Rest Cemetery), Mankato, Blue Earth County. Sample from bed no. 9, which is composed of massive beds of buff to brown or pink dolomite with mottled cavities.
91. Galena limestone (Prosser) from Archie Felland land, SW¼ Sec. 1, Bristol Twp., Fillmore County.
92. Galena limestone (Stewartville dolomite), Sec. 12, Bristol Twp., Fillmore County.
93. Decorah shale, along State Highway No. 20, 1 mile south of Fountain, Fillmore County. Sample from base of the Decorah.
94. Shakopee dolomite, 1½ miles south of Tawney, E½ Sec. 3, Newberg Twp., Fillmore County.
95. Galena limestone (Prosser), Sec. 11, Bristol Twp., Fillmore County. Sample from upper part of Prosser limestone on John Hahn's land.
96. Galena limestone (upper Prosser or lower Stewartville), Sec. 11, Bristol Twp., Fillmore County. Sample from John Hahn's land.
97. Shakopee dolomite, along State Highway No. 9 out of Lanesboro, Fillmore County. Sample from upper part of Shakopee dolomite, which is thin-bedded, often oolitic, with large masses of calcite crystals in cavities.
98. Shakopee dolomite, along State Highway No. 9 out of Lanesboro, Fillmore County. Sample from lower part of the formation, which is a thick-bedded dolomitic limestone with calcite crystals filling cavities.
99. Platteville limestone, along State Highway No. 9 near Lanesboro, Fillmore County. Sample from the Lanesboro section.
100. Oneota dolomite, above State Highway No. 9 near Lanesboro, Fillmore County. Sample from the Lanesboro section.
101. Oneota dolomite, along State Highway No. 9 near Lanesboro, Fillmore County. Sample from upper part of the Oneota dolomite.
102. St. Lawrence formation, west edge of Rushford, Fillmore County, on State Highway No. 9. Sample from upper part of the formation.
103. St. Lawrence formation, along State Highway No. 9, 2 miles west of Hokah, Houston County. Sample of the "trilobite" bed, which is about a foot to 16 inches thick.
104. St. Lawrence formation, along State Highway No. 9, 2 miles west of Hokah, Houston County. Sample from the dolomitic beds, which are just below the "trilobite" beds.
105. Galena limestone (Prosser), along State Highway No. 20, 1 mile south of Fountain, Fillmore County. General sample of Prosser limestone made up from six samples taken through part of the formation exposed.
106. Platteville limestone, along State Highway No. 20, 1 mile south of Fountain, Fillmore County. General sample of the Platteville limestone.
107. Galena limestone (Stewartville dolomite), along State Aid Road No. 6 above the crusher, west of Chatfield, Fillmore County. General sample of the Stewartville dolomite.
108. Galena limestone (Prosser), along State Aid Road No. 6 above the crusher, west of Chatfield, Fillmore County. General sample of the Prosser limestone.
109. Galena limestone (Prosser), along State Aid Road No. 10, about 8 miles south of Preston, Fillmore County. General sample from Mr. Thatcher's land.
110. Galena limestone (Stewartville dolomite), along State Aid Road No. 10, about 8 miles south of Preston, Sec. 3, Bristol Twp., Fillmore County.
111. Oneota dolomite, County Quarry, Rushford, NE¼ Sec. 22, Norway Twp., Fillmore County. Sample from top of the Oneota.

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112. Oneota dolomite, County Highway Quarry, ½ mile south of Choice, Sec. 9, Prebble Twp., Fillmore County. Sample from the lower Oneota.
113. Galena limestone (Prosser), Prosser Creek, Wykoff, Fillmore County. General sample of the Prosser limestone from the ten samples ranging through the Prosser Creek section.
114. Galena limestone (Prosser), Masonic Park, Fillmore County. General sample of the Prosser limestone taken throughout the Masonic Park section.
115. Shakopee dolomite, Fowler and Pay quarry, Mankato, Blue Earth County. Sample of the Shakopee dolomite that is being burned for lime at the upper kilns; about 8 feet exposed.
116. Shakopee dolomite, J. B. Conter quarry, west end of Shakopee, Scott County. Sample from bed no. 4, which is pink to brown, crystalline dolomite, alternating with compact buff beds; all fairly thin-bedded and uneven.
117. Shakopee dolomite, J. B. Conter quarry, west edge of Shakopee, Scott County. Sample from bed no 3, which is gray to pink dolomite, fairly massive but splitting into thinner beds.
118. Shakopee dolomite, J. B. Conter quarry, west edge of Shakopee, Scott County. Sample of bed no. 2, which is thin-bedded, gray to pink or brown dolomite.
119. St. Lawrence formation, Jordan, Scott County. Sample of the lowest outcropping rock in the bed of Sand Creek about 150 feet above the bridge at Lower Brewery.
120. Galena limestone (Stewartville dolomite) from the western part of Sec. 18, Rochester Twp., Olmsted County.
121. Galena limestone (Stewartville dolomite), 1 mile south of Byron, Olmsted County.
122. Galena limestone (Prosser), along State Highway No. 59, 4 miles south of Rochester, Olmsted County, in Sec. 21, Rochester Twp., Olmsted County. General sample from nine samples.
123. Galena limestone (Prosser), on county road, 1 mile west and 1 mile north of Pleasant Grove, Olmsted County, near the quarry on the V. P. Chase land. Sample taken 4 feet, 4 inches above the north branch of Root River from bed no. 1, which is rather thin-bedded, knotty limestone, buff in color.
124. Galena limestone (Prosser), on county road, 1 mile west and 1 mile north of Pleasant Grove, Olmsted County, in the Chase Quarry. Sample from bed no. 2, which is fossiliferous, mottled, coarse-grained limestone, brownish gray in color. Sample taken 3 feet, 3 inches above sample 123.
125. Galena limestone (Prosser), Chase Quarry, on county road, one 1 mile west and 1 mile north of Pleasant Grove, Olmsted County. Sample from bed no, 3, taken 9 feet, 2 inches above sample 124.
126. Galena limestone (Prosser), Chase Quarry, on county road, 1 mile west and 1 mile north of Pleasant Grove, Olmsted County. Sample from bed no. 3, taken 5 feet, 4 inches above sample 125.
127. Galena limestone (Prosser), Chase Quarry, on county road, 1 mile west and 1 mile north of Pleasant Grove, Olmsted County. Sample from bed no. 4, which is fine-grained, brownish-gray limestone, taken 10 feet above sample 126.
128. Galena limestone (Prosser), Chase Quarry, on county road, 1 mile west and 1 mile north of Pleasant Grove, Olmsted County. Sample from bed no. 4, taken 8 feet above sample 127.
129. Galena limestone (Stewartville dolomite), on county road to Rochester, 1 mile west and 1 mile north of Pleasant Grove, Olmsted County. General sample from four taken throughout the Stewartville outcrop.
130. St. Lawrence formation, on north bank of the Minnesota River opposite the lower end of Judson, but in Nicollet County.
131. Galena limestone (Prosser), on county road off 11th Avenue Northeast, 2½ miles northeast of Rochester, Sec. 29, Haverhill Twp., Olmsted County. Composite analysis from four samples from two beds.
132. Decorah shale, on State Highway No. 20, 3 miles south of Cannon Falls, Sec. 31, Cannon Falls Twp., Goodhue County, at the creek tributary to the Little Cannon River, on the property of R. M. Poe. Composite analysis from three samples (1 at lowest exposure, 2 in middle, 3 at top of exposure).

SAMPLE

133. Galena limestone (Prosser), on county road, 1 mile west of Genoa, Olmsted County. Composite analysis from three samples.
134. Galena limestone (Prosser), 1½ miles southeast of Berne, NW¼ Sec. 19, Milton Twp., Dodge County. General sample from seven samples.
135. Platteville limestone, quarry of the Minnesota Crushed Stone Company, Johnson Street, Minneapolis, Hennepin County. Sample from bed no. 1.
136. Platteville limestone, quarry of the Minnesota Crushed Stone Company, Johnson Street, Minneapolis, Hennepin County. Sample from bed no. 2.
137. Platteville limestone, quarry of the Minnesota Crushed Stone Company, Johnson Street, Minneapolis, Hennepin County. Sample from bed no. 4.
138. Stewartville dolomite, McDonough Quarry, Mantorville, Dodge County. Sample from the 8 to 10 feet forming the lower part of the quarry.
139. Stewartville dolomite, McDonough Quarry, Mantorville, Dodge County. Sample from the 35 or more feet forming the upper part of the quarry.
140. Platteville limestone, State Quarry, Faribault, Rice County. Sample from the 10-foot face exposed in the quarry.
141. Platteville limestone, State Hospital Quarry, Rochester, Olmsted County. Sample from the 21-foot face exposed in the quarry.
142. Oneota dolomite, Coughlin Quarry, Mankato, Blue Earth County. Sample from the upper 15 feet of the formation, or the 15 feet just below the sandstone.
143. Oneota dolomite, Coughlin Quarry, Mankato, Blue Earth County. Sample from the 10 feet immediately below beds from which sample 142 was taken.
144. Oneota dolomite, quarry of the Breen Stone (Babcock and Wilcox) Company, Kasota, Le Sueur County. Sample from the 7 feet, 2 inches of pink to cream-colored "polish ledges."
145. Oneota dolomite, quarry of the Breen Stone (Babcock and Wilcox) Company, Kasota, Le Sueur County. Sample from the 10 feet below the "polish ledges."
146. Oneota dolomite, quarry of the Hastings Crushed Stone Company, Hastings, Dakota County.
147. Oneota dolomite, quarry of the Biesanz Stone Company, near Winona, Winona County. Sample from the lower 3 feet, 8 inches of the quarry.
148. Oneota dolomite, quarry of the Biesanz Stone Company, near Winona, Winona County. Sample from the upper 11 feet, 6 inches exposed in the quarry.
149. Platteville limestone, quarry of the St. Paul Crushed Stone Company, Stewart and Victoria avenues, St. Paul, Ramsey County. Sample from the lower 3 feet of the quarry.
150. Platteville limestone, quarry of the St. Paul Crushed Stone Company, Stewart and Victoria avenues, St. Paul, Ramsey County. Sample from the middle 4 feet of the quarry.
151. Platteville limestone, quarry of the St. Paul Crushed Stone Company, Stewart and Victoria avenues, St. Paul, Ramsey County. Sample from the upper 3 feet of the quarry.
152. St. Lawrence dolomite from the old quarry near St. Lawrence, Scott County.
153. Calcite from a geode in the basal layer of the Decorah shale, Minnehaha sewer cut, Minneapolis, Hennepin County.
154. Platteville limestone, from the upper part of the Minnehaha sewer cut, Minneapolis, Hennepin County.
155. Platteville limestone from the upper surface at the contact with the Decorah shale in the Minnehaha sewer cut, Minneapolis, Hennepin County.
156. Decorah shale from the basal layer in the Minnehaha sewer cut, Minneapolis, Hennepin County.
157. St. Lawrence formation, *Dikellocephalus minnesotensis* horizon, Stillwater, Washington County.
158. St. Lawrence formation, *Dikellocephalus minnesotensis* horizon, Fairy Glen, Stillwater, Washington County.
159. St. Lawrence formation, *Dikellocephalus minnesotensis* horizon, Mt. Tom, Hakah, Houston County.
160. St. Lawrence formation, *Dikellocephalus minnesotensis* horizon, Barn Bluff, Red Wing, Goodhue County.

Analyses of Minnesota Limestones *

Sample	Insoluble Silica, etc.	Oxides (Iron, etc.)	Total Insoluble	CaO	$CaCO_3$	MgO	$MgCO_3$
1..........			7.76		50.66		40.81
2..........			11.55		48.49		39.83
3..........			8.99		51.02		40.06
4..........			11.23		49.95		39.01
5..........			7.53		49.59		41.96
6..........			8.48		46.74		41.11
7..........			16.44		70.90		10.54
8..........			39.43		33.65		22.16
9..........			13.42		47.88		35.78
10..........			18.75		69.58		7.46
11..........			21.22		45.60		30.23
12..........			41.01		37.74		21.01
13..........	Not determined	Not determined	4.96	Not determined	92.77	Not determined	2.22
14..........			6.34		92.59		1.19
15..........			3.78		93.56		2.13
16..........			7.38		90.88		1.97
17..........			3.08		94.23		2.01
18..........			3.28		91.70		5.04
19..........			5.51		88.52		5.96
20..........			12.16		75.14		11.81
21..........			18.62		80.30		1.63
22..........			2.02		54.48		43.58
23..........			2.60		60.69		38.56
24..........			0.66		98.15		1.25
25..........			1.01		97.76		1.38
26..........	2.50	.42	2.92	53.85	96.10	.51	1.07
27..........	17.90	.58	18.48	44.70	79.80	.81	1.69
28..........	2.87	.12	2.99	53.40	95.30	.85	1.78
29..........	2.78	.23	3.01	53.40	95.30	.86	1.80
30..........	6.15	.20	6.35	49.40	88.10	2.90	6.07
31..........	4.16	.37	4.53	52.35	93.40	1.20	2.51
32..........	4.68	.94	5.62	50.20	89.60	2.41	5.05
33..........	3.75	.88	4.63	52.50	93.70	.77	1.61
34..........	4.17	.71	4.88	52.30	93.30	.70	1.46
35..........	5.61	.59	6.20	51.60	92.00	.43±.1	.90±.2
36..........	6.01	.74	6.75	51.70	92.30	.38	.79
37..........	2.13	1.09	3.22	52.40	93.50	1.35±.1	2.82±.2
38..........	1.96	.49	2.45	54.25	96.75	.59	1.23
39..........	4.47	.87	5.34	52.55	93.75	.46	.96
40..........	4.75	.54	5.29	52.10	92.95	.51	1.07
41..........	.76	.28	1.04	55.35	98.65	.48	1.00
42..........	4.31	.50	4.81	52.70	94.05	.80±.1	1.67±.2
43..........	5.88	.53	6.41	51.60	92.30	.81	1.69
44..........	4.69	.46	5.15	52.65	94.00	.74	1.55
45..........	5.33	.56	5.89	52.45	93.55	.59	1.23
46..........	4.94	.66	5.60	52.45	93.55	.69	1.44
47..........	2.20	1.30	3.50	30.1	53.6	20.9	43.7
48..........	3.70	2.30	6.00	29.7	53.0	19.3	40.4
49..........	3.70	2.70	6.40	29.9	53.4	19.0	38.8
50..........	6.60	1.40	8.00	28.9	51.6	19.1	40.0
51..........	3.4	2.6	6.00	30.4	54.2	18.8	39.4
52..........	4.3	1.3	5.60	29.9	53.4	19.1	40.0
53..........	1.7	0.3	2.00	30.2	53.9	20.9	43.7

* Analyses of samples 1 to 25 by R. J. Leonard; 26 to 46 by L. Wallace Cornell and James E. Halst; 47 to 134 by L. Wallace Cornell; 135 to 151 by R. E. Kirk; 152 to 160 by R. J. Leonard.

ANALYSES OF MINNESOTA LIMESTONES — *Continued*

Sample	Insoluble Silica, etc.	Oxides (Iron, etc.)	Total Insoluble	CaO	$CaCO_3$	MgO	$MgCO_3$
54..........	11.1	1.2	12.30	34.9	62.3	12.1	25.3
55..........	9.4	0.5	9.90	46.5	83.0	3.4	7.1
56..........	4.1	0.2	4.30	29.7	53.0	20.8	43.5
57..........	7.7	0.5	8.20	32.1	57.3	16.8	35.2
58..........	5.0	0.4	5.40	52.0	92.8	0.7	1.5
59..........	3.1	0.7	3.80	29.6	52.8	21.0	44.0
60..........	4.1	0.4	4.50	29.4	52.5	20.6	43.1
61..........	2.5	0.3	2.80	48.6	86.7	5.1	10.7
62..........	2.3	0.3	2.60	41.7	74.4	11.0	23.0
63..........	2.4	0.3	2.70	45.7	81.5	7.5	15.7
64..........	1.7	0.4	2.10	47.8	85.2	6.1	12.7
65..........	16.0	0.8	16.80	45.5	81.2	0.9	1.9
66..........	5.3	0.3	5.60	52.0	92.8	0.6	1.3
67..........	6.6	1.1	7.70	50.8	90.6	0.9	1.9
68..........	7.5	1.2	8.70	49.2	87.8	1.8	3.8
69..........	11.7	2.7	14.40	29.7	53.0	15.4	32.2
70..........	8.7	1.5	10.20	39.3	70.1	9.4	19.7
71..........	13.0	1.9	14.90	30.3	54.1	14.6	30.6
72..........	11.6	4.4	16.00	30.3	54.1	14.4	30.1
73..........	1.3	1.0	2.30	30.5	54.5	20.8	43.5
74..........	8.8	1.3	10.10	28.8	51.4	18.8	39.3
75..........	1.1	0.5	1.60	30.3	54.1	21.3	44.5
76..........	3.7	0.5	4.20	29.5	52.6	20.8	43.5
77..........	10.8	7.5	18.20	28.9	51.6	14.1	29.5
78..........	10.4	1.1	11.50	27.4	48.9	18.9	39.5
79..........	30.5	1.2	31.70	21.6	38.6	14.2	29.7
80..........	26.5	1.8	28.20	22.0	39.3	15.2	31.8
81..........	21.8	1.1	22.90	23.5	42.0	16.3	34.1
82..........	13.5	1.4	14.90	26.2	46.8	18.0	37.7
83..........	12.4	1.3	13.70	26.5	47.3	18.4	38.5
84..........	73.6	0.2	73.80	14.8	26.4	0.1	0.2
85..........	15.9	1.2	17.10	28.7	51.3	15.0	31.4
86..........	3.2	0.6	3.80	30.8	55.0	19.7	41.2
87..........	10.6	1.2	11.80	27.5	49.1	18.4	38.5
88..........	9.2	1.3	10.50	27.6	49.3	18.9	39.6
89..........	15.3	1.5	16.80	26.2	46.8	17.2	36.0
90..........	9.8	1.0	10.80	27.6	49.3	18.9	39.6
91..........	4.1	0.4	4.50	52.5	93.6	0.9	1.9
92..........	5.1	0.5	5.60	37.0	66.0	13.6	28.4
93..........	5.1	0.5	5.60	51.8	92.4	1.0	2.1
94..........	1.2	0.4	1.60	32.4	57.8	19.5	40.8
95..........	4.1	0.2	4.30	52.4	93.5	1.0	2.1
96..........	10.0	0.6	10.60	43.2	78.1	5.8	12.1
97..........	2.8	0.4	3.20	32.2	57.5	18.7	39.1
98..........	4.0	0.5	4.50	33.8	60.3	17.0	35.5
99..........	7.3	0.6	7.90	50.7	90.5	0.6	1.3
100..........	2.1	0.3	2.40	30.3	54.0	20.9	43.7
101..........	3.8	0.5	4.30	31.5	56.2	19.0	39.7
102..........	73.1	1.4	74.50	13.2	23.6	1.1	2.3
103..........	26.2	2.1	28.30	22.2	39.6	15.4	32.2
104..........	24.9	2.6	27.50	23.2	41.4	14.8	31.0
105..........	2.9	0.4	3.30	53.6	95.6	0.4	0.9
106..........	8.5	0.6	9.10	49.7	88.7	0.7	1.5
107..........	5.9	0.4	6.30	50.4	89.9	1.6	3.4
108..........	4.9	0.3	5.20	50.6	90.3	1.8	3.8
109..........	2.4	0.2	2.60	53.9	96.1	0.7	1.5

ANALYSES OF MINNESOTA LIMESTONES — *Concluded*

Sample	Insoluble Silica, etc.	Oxides (Iron, etc.)	Total Insoluble	CaO	$CaCO_3$	MgO	$MgCO_3$
110..........	5.2	0.5	5.70	45.4	81.0	6.7	14.0
111..........	1.0	0.2	1.20	32.0	57.1	20.0	41.8
112..........	4.1	0.3	4.40	31.5	56.1	19.1	39.9
113..........	6.8	0.5	7.30	50.2	89.5	1.7	3.6
114..........	7.2	0.5	7.70	49.3	88.0	2.1	4.4
115..........	3.1	1.1	4.20	30.8	55.0	19.8	41.4
116..........	6.9	1.8	8.70	28.7	51.1	19.2	40.2
117..........	1.5	1.3	2.80	30.6	54.6	20.6	43.1
118..........	1.3	0.6	1.90	30.6	54.6	21.2	44.3
119..........	23.0	3.4	26.40	22.2	39.6	16.0	33.4
120..........	6.6	1.9	8.50	41.0	73.1	8.6	18.0
121..........	6.3	0.7	7.00	46.3	82.6	5.0	10.4
122..........	7.0	0.5	7.50	50.3	89.8	1.3	2.7
123..........	10.9	0.7	11.60	48.1	85.9	1.1	2.3
124..........	6.4	0.4	6.80	50.2	89.6	1.9	4.0
125..........	6.4	0.4	6.80	50.6	90.3	1.5	3.1
126..........	2.8	0.3	3.20	52.5	93.70	1.7	3.50
127..........	7.3	0.5	7.80	48.8	87.00	2.8	5.80
128..........	6.5	0.4	6.90	48.4	86.40	3.6	7.50
129..........	4.9	0.3	5.20	46.1	82.30	6.3	13.20
130..........	4.6	2.5	7.10	29.5	52.60	19.4	40.50
131..........	6.2	0.6	6.80	51.5	91.90	0.8	1.70
132..........	4.6	1.6	6.20	45.3	80.90	6.1	12.80
133..........	11.5	1.0	12.50	45.9	81.90	2.7	5.60
134..........	13.0	0.7	13.70	42.8	76.40	4.8	10.00
135..........			12.79		77.42		6.39
136..........			23.80		45.76		26.44
137..........			15.89		46.15		29.98
138..........			18.05		49.38		31.12
139..........			11.58		52.93		32.58
140..........			16.91		67.43		14.87
141..........			11.11		63.75		19.28
142..........			16.00		48.72		33.95
143..........			11.67		50.97		33.01
144..........			13.18		49.54		32.34
145..........			8.94		54.58		30.99
146..........			3.26		56.82		40.02
147..........	Not determined	Not determined	11.40	Not determined	54.04	Not determined	28.76
148..........			8.34		52.79		28.20
149..........			12.28		70.67		13.66
150..........			17.74		72.67		9.67
151..........			36.85		40.07		21.81
152..........			9.08		49.70		41.55
153..........			0.72		98.69		1.38
154..........			12.94		53.51		33.88
155..........			19.79		46.19		32.77
156..........			10.77		84.38		4.04
157..........			52.93		25.68		19.83
158..........			54.43		20.01		17.32
159..........			53.67		20.32		17.02
160..........			52.20		21.42		16.88

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PART II

THE MARLS OF MINNESOTA

George A. Thiel

CHAPTER I

THE NATURE AND ORIGIN OF MARL

Definition and General Appearance

The term marl as used in this report is confined to the soft, earthy material, composed largely of calcium carbonate, that is found as a fresh-water deposit in lake basins and bogs and in marshes or low areas that were once covered with water. (See Figure 24.) Its color varies with the amount of impurities it contains. It is usually grayish-white or buff,

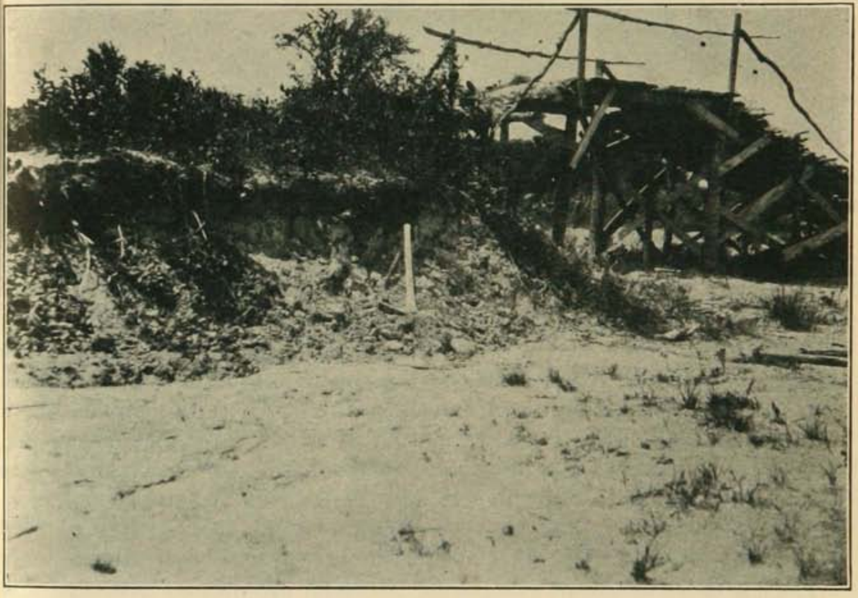

Fig. 24. — A deposit of dry marl eight feet above the present lake level. The marl is excavated and loaded into trucks and wagons for distribution to local farms.

but darker colors may be seen where the marl is contaminated with peaty organic material. After exposure to the atmosphere, a wet marl that was almost white turns to a drab color, but upon complete drying it tends to lighten again. (See Figure 25.) The purer samples become white or slightly cream-colored when thoroughly dried. In its original state in the lake marl is about one-half water.

In hardness and consistency fresh marl resembles softened butter. In some of the marsh deposits that are partially drained it is firm enough to be cut in blocks and handled with a shovel. When piled up it tends

Fig. 25. — A bed of dry marl exposed in an abandoned bay of a small lake in Stearns County, near St. Cloud.

to settle and spread slightly, but it will not run down to a level surface. In a thick bed, compacted under its own weight, marl has the consistency of common mortar when ready for use. In some lakes where deposition is still in progress the water appears to be only a few inches deep. If the water is agitated, however, the apparent bottom is set in motion and is found to be a suspension of freshly precipitated calcium carbonate, which rises to the surface in much the same way as a finely divided precipitate in a beaker clouds the solution when stirred.

Texture

The particles or grains composing the marl are usually very fine and powdery. In some marls the shells of small snails and snail-like molluscs are very abundant, while in others no traces of shells are found. Under certain conditions a coarsely granular texture is developed, and upon careful examination it is found that the marl is made up of an accumulation of small concretionary granules composed of radiating grains or needles of calcium carbonate.

Source of Marl

The ultimate source of the calcium carbonate deposited as marl is undoubtedly the glacial drift with its heterogeneous mass of clay, sand, gravel, and bowlders. Most of the state is covered with a mantle of glacial waste varying from a few feet to over 500 feet in thickness. The total average thickness of the glacial drift is approximately 100 feet. In some regions it lies in great level sheets or prairies many miles in extent, while elsewhere it is piled up in a great succession of hills, mounds, and ridges. Because of its origin this glacial débris contains an appreciable amount of fresh or chemically unaltered rock fragments. In some parts of the state fragments and pebbles of limestone are abundant; in other regions finely divided rock-forming minerals, some of which contain calcium compounds, constitute the major part of the drift. Soil waters percolating through these limy clays and gravels carry with them dissolved carbon dioxide, and the combined action of the dissolved gas and water leaches out the soluble lime compounds from the soils through which it filters. Most of the calcium carbonate is taken into solution as calcium bicarbonate, $CaH_2(CO_3)_2$, and when present in an appreciable amount it gives water the property commonly called temporary hardness. The chemical reaction may be expressed as follows:

$$\text{Lime carbonate} + \text{water} + \text{carbonic acid gas} = \text{calcium bicarbonate}$$
$$CaCO_3 \quad H_2O \quad CO_2 \quad CaH_2(CO_3)_2 \text{ (soluble)}$$

Since Minnesota was invaded by several ice sheets, each of which advanced from a different region in Canada, various types of glacial drift were deposited. Some of these drift sheets contain more calcium-bearing minerals than others, and consequently more lime has been leached and carried to the depressions, where it is now being precipitated as calcium carbonate or marl. The distribution of the marl deposits indicates a much greater supply of available calcium carbonate in some types of drift than in others. This relation of available calcium carbonate to the amount leached from various types of glacial deposits will be discussed later.

The process of deposition of marl is a very slow one. It has undoubtedly been going on for many centuries, for the lakes in which it is accumulating, together with the glacial débris that surrounds them, have been in existence during the whole of postglacial time. In the remote past, marl deposition was perhaps much more rapid than at present, for the more soluble calcium compounds in the glacial clays were without doubt the first to be removed by the percolating ground waters. That the deposition is still in progress is shown by the fact that many pieces of rock, bits of wood, twigs, dead stalks of grass, and weeds are coated with a film of lime carbonate.

Most of the calcium carbonate is brought into the lakes by means of hard-water springs, rather than by the streams or inlets flowing into lakes at the surface. The waters of the streams are for the most part surface waters that have gathered in the valley from over a wide area. Most of this stream water has not percolated through a very great thickness of glacial drift, and consequently, even though it was charged with carbon dioxide as it fell as rain, the amount of $CaCO_3$ it has taken into solution is small.

Causes of Deposition

The manner of deposition of marl in fresh-water lakes and bogs is not as yet thoroughly understood. Some of the agents of deposition have been subjected to careful investigation and the processes involved studied in detail. Other possible agents have been suggested and postulated as active in the precipitation of calcium carbonate, but the reactions have never been subjected to laboratory investigations. It is agreed that lake waters charged with calcium bicarbonate deposit calcium carbonate when carbon dioxide escapes or is removed, but there is still some difference of opinion as to how the removal of CO_2 is accomplished. Of the theories advanced, no one alone seems to account fully for the deposits of marl as they actually occur.

The following theories have been suggested; and undoubtedly each of the processes named has contributed to the deposition of some marl but the proportion due to each has not been determined.

1. The theory of chemical precipitation.—The theory of chemical precipitation was advocated by Blatchley,[1] who studied the marl deposits of Indiana. He attributes the loss of CO_2 to a decrease in pressure and an increase in temperature as the underground waters issue into a lake basin.

Spring water discharged into a lake is colder than the water already in the lake basin. Calcium bicarbonate is more soluble in cold water than in warm water, and consequently some of the dissolved material is precipitated as calcium carbonate soon after the cold spring water enters the lake, in which the water is warmer. Furthermore, percolating ground water may carry a higher percentage of carbon dioxide than lake water, and the percentage of calcium bicarbonate held in solution in spring water may, therefore, be proportionately increased. Where such spring water flows into a lake, a part of the carbon dioxide escapes, the water becomes supersaturated with calcium bicarbonate, and precipitation takes place.

The association of the larger marl deposits with springs in the lakes of Indiana lends support to Blatchley's interpretation. In Michigan, however, the marl is not confined to the immediate neighborhood of the springs. There most of the springs are surrounded by sand and muck. Furthermore, the reaction suggested takes place only when the ground water is at or near the saturation point with respect to calcium carbonate. If the amount of lime carbonate in solution is not great, the water can hold it in solution in the lake with or without free CO_2.

The results of experiments bearing on the solubility of calcium carbonate in fresh lake waters are summarized by Hale.[2] Water at ordinary temperature and pressure containing no free CO_2 may yet contain per-

[1] W. S. Blatchley and G. H. Ashley, *The Lakes of Northern Indiana and Their Associated Marl Deposits,* Annual Report of the Indiana Department of Geology and Natural Resources (Indianapolis, 1901).

[2] D. J. Hale, "Marl and Its Application to the Manufacture of Portland Cement," Geological Survey of Michigan, Vol. 8, Part 3, p. 41–47 (1903).

manently .38509 grams of calcium bicarbonate or .238 grams of $CaCO_3$ per liter. The analyses of waters from Michigan show a content of calcium carbonate of from .175 to .250 grams per liter. Thus the carbonated waters of the springs and marl lakes are generally far below the point of precipitation. The water of these springs and lakes could take into solution 100 or more parts per million of calcium carbonate instead of being overburdened and precipitating them as marl. Spring waters cannot precipitate their bicarbonate as marl by the simple chemical process of precipitation from solution, because they are not saturated.

More recent results of investigations of thermal stratification in lakes show the influence of area, depth, and temperature on the precipitation of marl. Kindle[1] has made a study of numerous small and large lakes

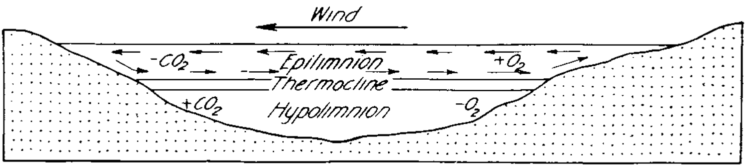

FIG. 26. — Diagram of a lake basin showing the control of thermal stratification over circulation and quantity of dissolved gases. The diagram illustrates limitation of summer circulation of water to the epilimnion and the summer distribution of CO_2 and O_2. The signs + and — in the diagram indicate the tendency during the summer of the dissolved O_2 to increase above and to decrease below the top of the thermocline, while the CO_2 shows the reverse tendency. (After Kindle.)

in Ontario and concludes that the calcium carbonate of the marl beds is precipitated from the water in summer during the period of most marked thermal stratification.

Complete vertical circulation of water in lakes takes place for only a short period in the spring and in the autumn. It is then that the lakes have a nearly uniform temperature at or near 4° C. In the autumn, surface waters reach 4° C., which is the temperature of maximum density and gravity. A vertical circulation is then established as the colder water near the surface settles and replaces the warmer water toward the bottom. In the spring the melting ice yields surface water that is heavier than the waters below, and complete vertical circulation is again established. In early summer a thermal stratification is developed that checks a general vertical circulation, and the water is divided into an upper warm-water zone (epilimnion), a lower cold-water zone (hypolimnion), and an intermediate zone (thermocline) of changing temperatures. (See Figures 26 and 27.)

The thermocline zone is a horizon of great importance in the precipitation of marl. During the summer months a disconformity in temperature and in chemical composition is developed. The hydrogen ion

[1] E. M. Kindle, "The Role of Thermal Stratification," Transactions of the Royal Society of Canada, Vol. 21, Sec. 4, p. 1–35 (1927); "Types of Thermal Stratification in Lakes," *Journal of Geology*, 37:150–157 (1929).

concentration above it differs from that below. Furthermore, the supply of oxygen above it is greater than below. This difference in oxygen is due to the contact with the air, together with the photosynthesis of numerous aquatic plants that thrive within the epilimnion. Ward[1] reports that in Lake Michigan 64 per cent of the plankton or floating life was found within two meters of the surface. Undoubtedly, similar conditions prevail in smaller lakes. Thus the epilimnion shows an increase in oxygen and a corresponding decrease in carbon dioxide, whereas the hypolimnion is characterized by a depletion of oxygen through the oxidation of organic sediments and by an increase in CO_2 due to the lower temperature of the water. Where the lake water is shallow the epilimnion extends to the floor of the basin and the water may be saturated or nearly saturated with respect to calcium carbonate and deposits of marl may be formed on the bottom within the limits of the epilimnion zone. In the deeper waters the acidity may be sufficient to redissolve calcareous sediments falling into them.

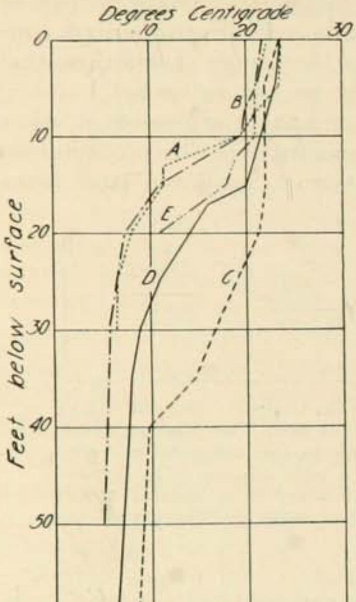

FIG. 27. — Summer curves for temperature for five lakes in Ontario. (After Kindle.)

The conditions most favorable for the deposition of marl in larger lakes are developed only when the thermal stratification is protected from the mixing effect of high winds and waves. Numerous examples of such protection are seen in the bays of the large lakes of Crow Wing and Wright counties. In these bays the warm upper layer of the water promotes the growth of algae and other plants that use the supply of CO_2 and produce an abundance of oxygen through photosynthesis.

If the temperature of the water is a factor in the deposition of marl, lakes in high latitudes should not contain marl beds. Kindle states that no marl deposits have been found in North America north of 60°. Furthermore, no recent marl deposits are known to exist in the glacial lakes in high latitudes of Europe.

2. The theory of biochemical precipitation: Plants. — Certain forms of aquatic plants show the presence of minute crystals and incrustations of calcium carbonate on their stems and branches while in active growth in the water. Of these plants the *Characeae* or stoneworts are the most conspicuous. (See Figures 28 and 29.) They grow not only near the surface in shallow water where the bottom is unoccupied by other plants

[1] H. B. Ward, *A Biological Examination of Lake Michigan in the Traverse Bay Region* (Bulletin of the Michigan Fisheries Commission, no. 6, 1896).

but also in the deeper parts of the lakes and ponds, for they thrive also where light is feeble and where the temperature is comparatively low.

From his studies on the marl deposits of Michigan, Davis concludes that most of the calcium carbonate deposited in lake basins owes its origin to the action of *Chara* and *Zonotrichia,* the latter a group of algae.

In the development of new tissue all green plants take in carbon dioxide through their leaves and stems and utilize the carbon and some of the oxygen in building up the complex molecules of cellulose that serve as the basis of all plant tissues. The oxygen that is not required in the process is again released. Where aquatic plants grow in water that contains an excess of calcium held in solution by free carbon dioxide, the abstraction of that gas by the growth of plants may cause calcium carbonate to be precipitated. Furthermore, where such small amounts of calcium bicarbonate are present that no free carbon dioxide is required to hold it in solution, the oxygen liberated by the plants may produce the precipitation of calcium carbonate. The following chemical equation expresses the reaction:

$$CaH_2(CO_3)_2 + O = CaCO_3 + CO_2 + H_2O + O$$

Calcium bicarbonate + oxygen = calcium carbonate + carbon dioxide + water + oxygen

While the contribution of *Chara* to the formation of marl in some lakes cannot be doubted, there are lakes where other aquatic plants play an equally important rôle. Furthermore, numerous lakes have been observed in which *Chara* is abundant and no marl is being deposited. From material collected from Clear Lake, Ontario, the following species have been identified: *Potamogeton prisillus L.; Potamogeton heterophyllus Schreb; Potamogeton Richardsoni Rydle; Potamogeton nutans L.; Chara Sp.;* filamentous algae.[1]

Several species of *Potamogeton* have the calcium carbonate so loosely attached to the leaves that wave action may detach much of the accumulation of lime carbonate, and when analyzed the leaves may yield a low calcium carbonate content. Plants selected in protected bays, free of wave action, often have attached to them more lime than their own weight.

FIG. 28. — Sketch of a lime-secreting alga (*Chara vulgaris*) commonly found in fresh-water ponds and lakes. (After Grabau.)

Blue-green algae also are instrumental in separating lime carbonate from water. These organisms are so small that their presence may not be detected in or above a growing marl bed. Their delicate fibers can scarcely be detected in a mass of freshly precipitated $CaCO_3$. More than twenty species have been identified in the marlyte pebbles of Mink Lake described by Kindle.

Diatoms also are very abundant in the epilimnion. In some regions they form half of the plankton of lakes. A calcium carbonate film formed

[1] E. M. Kindle, "The Role of Thermal Stratification," Transactions of the Royal Society of Canada, Vol. 21, Sec. 4, p. 1-35 (1927).

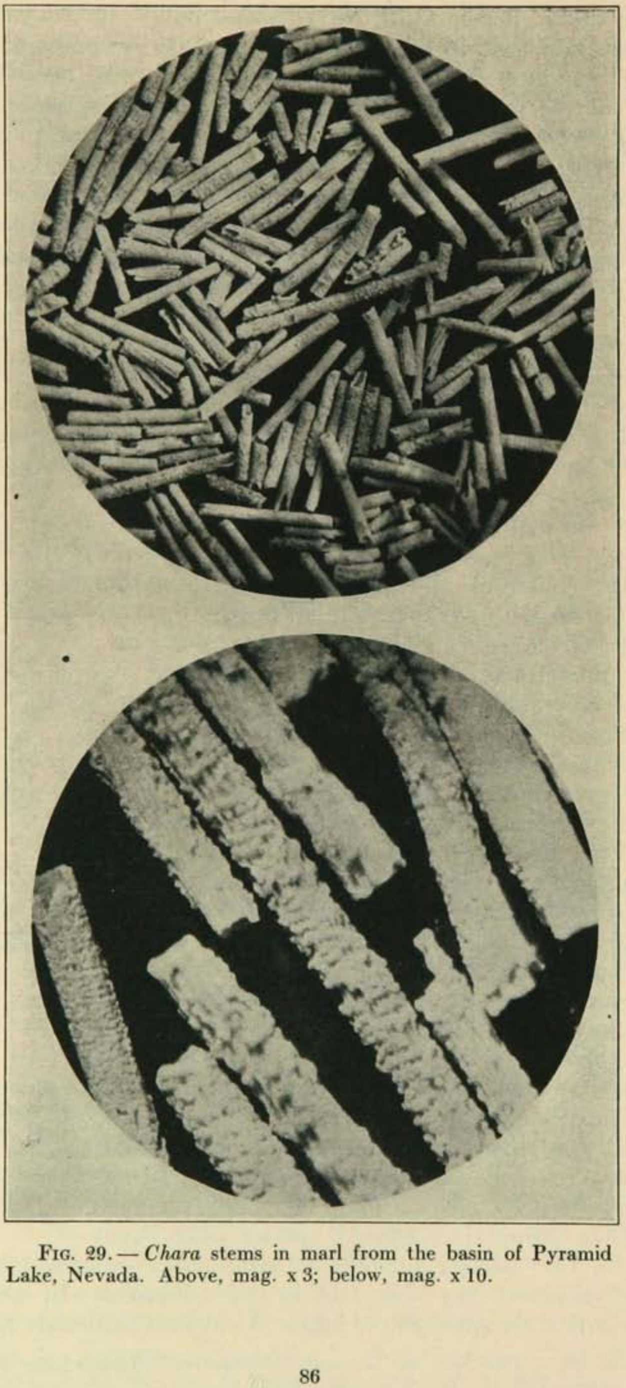

Fig. 29. — *Chara* stems in marl from the basin of Pyramid Lake, Nevada. Above, mag. x 3; below, mag. x 10.

on a spoon attached for two months to a stake about a foot below the surface of the water in a lake showed more than 50 diatoms to a square millimeter. A piece of the $CaCO_3$ film smaller than a thumbnail contained twenty-seven species of diatoms.[1]

Recent work by Johnston and Williamson on the agencies in the deposition of calcium carbonate has shown that the chemical action of liberated oxygen produced by photosynthesis is a purely physical effect and is due to a decrease in the pressure of the carbon dioxide, brought about by the oxygen tending to sweep the CO_2 out of the water.

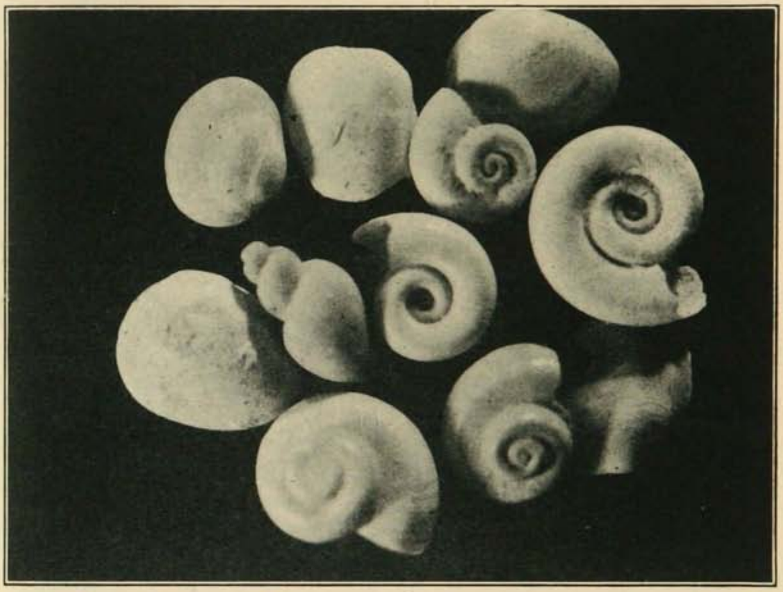

FIG. 30. — Mollusca shells from a marl bed near Brookston. Such shells are characteristic of many marl deposits. Mag. x 12.

Animals. — Certain groups of molluscs (see Figure 30) are abundant in some of the fresh-water lakes, and their presence is evidence that they contributed to the formation of the marl beds in the lakes they inhabit. These snail-like animals abstract calcium compounds from the lake water and utilize it in the formation of their shells. In composition the shells are identical with marl. An analysis of pure shells from a marl bed shows that they help to form the purest part of the bed and that the proportions of their compounds as compared with a very pure marl without shells are very nearly the same. It was formerly thought that most of the marl owed its origin to mechanically disintegrated and crushed shells. The presence of delicate and frail shells with perfect outlines at a depth of from 12 to 18 feet below the surface seems to indicate

[1] Kindle, *op. cit.*

that not all the fine grains of marl around these shells could have been formed from shell fragments. If such had been the case, some in partly broken-down stages should be present also. It is true that shells are more or less plentiful in many marl beds, especially in those contaminated with peaty organic matter, but it is believed that they are nevertheless minor agents in the formation of most deposits.

3. *The theory of mechanical sedimentation.* — According to the theory of mechanical sedimentation, the lime carbonate of the marl beds is derived from the finely divided particles distributed through the glacial drift. Some geologists believe that glacial action crushed and ground

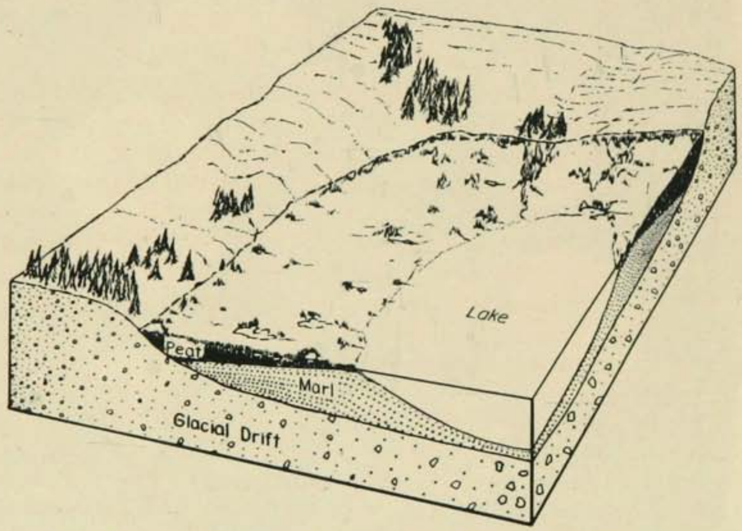

FIG. 31. — Diagram of part of lake basin showing the relation of marl and peat deposits in a growing marl bed.

limestone to a very fine-grained powder and that after the glacial period the particles of carbonate were washed from the drift into the drainage channel and carried in suspension by the streams, as clay and fine sands are transported. Because of difference in density it was separated from the clay and deposited separately in the lake basins.

Although marl could so accumulate from a drift composed chiefly of finely powdered limestone, it is not likely that this process has been effective in Minnesota. The drift sheets of Minnesota are high in clay and fine sand. More clay than calcium carbonate, therefore, would be carried into the basins.

Modes of Occurrence of Marl Deposits

Since beds of marl owe their origin to the precipitation of lime carbonate from solution, it follows that marl is always found in areas that were originally covered with water. (See Figure 31.) This does not mean that all deposits are confined to the immediate vicinity of present-day lakes, for during postglacial time the regional ground-water level has been lowered and many old beach lines of lakes can be traced readily over areas that are now well-drained and cultivated land. Marl also underlies partially drained swamps, and in some places it is found in the banks of streams that have cut their channels into a bed of marl as the outlet of a former lake or bog was lowered.

Not all the lakes of the glaciated area contain marl. The reason is that glacial lake basins are formed in a number of different ways, and some, therefore, are better fitted than others as reservoirs for the accumulation of marl.

Classes of Minnesota Lakes

Minnesota lakes may be classified as (1) glacial lakes, including rock-basin and drift-basin lakes and (2) stream-valley lakes.

Most of the rock-basin lakes are confined to the northeastern part of Minnesota. They owe their origin to glacial scooping and gouging in regions where the rock structure was most favorable for such action. Such lakes have shores of solid rocks, often in the form of high but rounded rock hills, with only isolated patches of thin sheets of glacial drift. Since marl owes its origin to calcium carbonate leached from the drift, its source is a very limited one in such regions. No marl beds have been found in typical rock basins.

The drift-basin lakes owe their origin to the irregular deposition of the débris brought into the region by the ice of a continental glacier. They may be classified according to their relations with different types of drift into *morainic basins* and *outwash basins*. The morainic lakes may be further classified according to the outlines of their basins into (a) "kettlehole" lakes, (b) irregular lakes, and (c) chain lakes.

"Kettlehole" lakes are round, cauldron-shaped depressions found in the hilly moraines. They are commonly of great depth. The original depressions are the counterparts and complements of the round hills and knobs that characterize moraine topography. Some of these basins were formed by the irregular deposition of drift at the terminus of the glacier, while others owe their origin to great blocks of ice that became imbedded in glacial débris where the lake basin is now located. By the melting of the ice a depression was made having the approximate outline and size of the ice block. Because of their depth these lakes are fed by spring water that has percolated through many feet of drift and is more highly charged with mineral water than that of the more shallow lakes. In regions of coarse sand and gravelly moraines, marl beds are numerous in such kettlehole basins.

The "irregular lakes" are irregular both in surface outline and in depth. They show many bays, narrows, and branching lobes with numerous islands and peninsulas. The bottoms of the basins are extremely uneven, deep pools and shallow areas occurring without order. They are very numerous in the terminal moraines and are found also in ground moraine areas where depressions without outlets have their basins deeper than the regional ground-water level. Many of the basins have been partially drained, and the shrunken lakes are surrounded by extensive swamps or peat bogs covered by a luxuriant growth of sedges and mosses. In such basins the marl is now buried below a layer of peat varying from 1 to 20 feet in thickness. *Chain lakes,* as the name implies, are series of lakes occurring in a chain-like order, short distances separating the individual basins. They may represent the axis of a drainage channel of glacial time, the result of erosion by the enormous streams which flowed from the retreating and melting glaciers, but in some places they are located along the valleys of preglacial streams. Where the basins are deep, marl beds may be found in any of the lakes in the chain, but where the lakes are shallow the greatest amount of marl is found in the lakes toward the upper end of the chain.

Outwash basins are depressions in the surface of the outwash plain beyond the terminal moraines. They are commonly fairly shallow with very gentle slopes, and they may cover extensive areas. They are now occupied by some of the largest but shallowest lakes in the state. Some of the basins in coarse outwash sands and gravels contain thick marl beds, but in regions where fine sands and clays were washed from the terminal moraines, very few marl deposits were discovered.

Stream-valley lakes are commonly developed upon flood plains during the normal meandering of rivers. These lakes are narrow and shallow and usually have a curved outline. Broad lake-like expanses of water also may be formed as the upward growth of a flood plain ponds back the water at the mouths of tributaries. The reverse also is accomplished where a tributary stream of high velocity deposits sediment in the main river, ponding it back until it covers its old flood plain. An illustration is the Mississippi River at Lake Pepin. Farther north along the valleys of both the Minnesota and the Mississippi rivers small lakes are found on the beds of abandoned marginal channels. Where such lakes are fed by springs issuing from the walls of the valley, extensive deposits of marl may be located.

Nature of Material Associated with Marl

Marl is confined to those depressions that were once filled with water and that are now marshes, bog ponds, or lakes. In nearly every actively growing marl lake a series of stages of development may be noted. The following succession is perhaps the most characteristic: first, the near-shore marl bed deposited nearly to water level and covered by a thin layer of marshy and peaty growth; second, the fringing zone of shallow water where precipitation and deposition of marl are most active; and third, the inner and deeper zone where precipitation is slower and the marl bed thinner and of a lower grade.

With fluctuations of the water level, silt from the shore-wash may become interbedded with the marl, and during a time of excessive rainfall streams may carry sand for some distance from shore. At Star Lake a 4-inch seam of sand is encountered in a marl bed 15 feet below the surface of the marl. Thin seams of organic material with sharp contacts may be found in very pure marl, and in some basins organic matter permeates the entire deposit. It is derived from the tissue of lime-secreting plants, and undoubtedly some is washed into the lake by surface drainage.

The Overburden of Marl

During the time of active deposition a marl bed must have very little covering other than water. As soon as the upper surface of the deposit approaches the surface of the water, rushes, sedges, and other marsh vegetation gain a foothold in the newly deposited marl and use it as soil. The thickness to which the remains of such vegetation accumulate over the marl is governed by the relation of the surface of the marl to the ground-water level. When the water level remains stationary for a great number of years, a thick bed of peat grows over the marl. Soper refers to "built-up" deposits of peat in Minnesota that are from 10 to 15 feet thick. If the water level is lowered while marl deposition is in progress, the marl dries fast and only a thin bed of peat is formed. In well-drained basins the peat may be thoroughly decomposed, so that it serves as soil for more hardy vegetation. In a few places heavy forests of birch, maple, ash, and elm trees sufficiently large to be cut for lumber were found growing in a thin bed of humus over a deposit of marl from 6 to 8 feet thick. Along river valleys the marl is frequently covered with sand and gravel. In Cass County along the Leaf River a marl bed covered by from 3 to 6 feet of sand may be observed in the banks of the stream.

Materials below Marl Beds

In most deposits there is a sharp contact between marl and its underlying foundation. The nature of the material is determined to some extent by the character of the glacial drift of the region. Sand or clay usually forms the floor of the basins. Very rarely is there any muck or peat underlying the marl. Such relations indicate that calcium carbonate deposition began after postglacial drainage channels were well established and when clay or sand deposition at some distances from shore was virtually at a standstill. In a few basins marly clay beds were encountered in regions of clayey moraine, and in each case it was evident that the clay had been washed in by the streams or by wave action on the clay banks of the shore line.

CHAPTER II

THE RELATION OF MARL DEPOSITS TO DIFFERENT TYPES OF GLACIAL DRIFT

General Glacial Features

A study of the deposits of glacial drift in Minnesota by Leverett,[1] Sardeson, and others has revealed that the glacial deposits, which cover nearly the entire state, are the result of more than one invasion of the ice. After each invasion the ice left a deposit of rock débris gathered from the surface of the earth over which the ice passed. In Minnesota these deposits show a peculiar, complex history; they indicate not only recurring stages of glaciation separated by long stages of de-glaciation but also complexity of ice movement in a given glacial stage.

Some of the advances were so widely separated in time that the drift deposits of any one invasion had large valleys cut in them by the action of streams before the next invasion occurred. In some localities the later advances failed to cover all the earlier deposits, and consequently these now form the surface of the earth. In such regions the degree of erosion of the surface of the older can be compared with that of the younger deposits. It is found that the older deposits have been so greatly eroded and are so ramified by drainage lines that no lakes or undrained basins remain on them, while the younger drift deposits have numerous lakes and undrained basins, as well as large, poorly drained areas that the streams have not yet reached. It is because they are not covered by the latest drift that Rock and Pipestone counties in southwestern Minnesota and Goodhue, Dodge, Wabasha, Olmsted, Winona, Fillmore, and Mower counties in southeastern Minnesota have no lakes and basins, as have neighboring counties that were covered by that drift.

The invasions of the ice into Minnesota not only took place at different times but came from more than one direction at about the same time. In the earlier invasions the greater part of the state was covered by ice coming from Manitoba. This is shown by limestone fragments and pebbles derived from rock formations of that country which are imbedded in the lower part of the drift over the whole state except its northeast part. The movements in the closing stage of the glacial epoch were more largely from the northeast, but more than half the state was invaded from the northwest. The ice sheets were as follows:

1. The Superior lobe of the Labrador ice sheet, an extension of ice southwestward from the Superior basin nearly to Mille Lacs.

2. The Patrician ice sheet, which had a southward movement from

[1] F. Leverett, *Quarternary Geology of Minnesota and Parts of Adjacent States* (United States Geological Survey Professional Paper 161, 1932).

the highlands north of Lake Superior across eastern Minnesota to points a little beyond St. Paul.

3. The Keewatin ice sheet, which moved southward through Manitoba and across western Minnesota.

After the melting of the ice that came from the northern highlands, the Keewatin ice sheet extended over some of the ground that ice had vacated. It crossed the Mesabi Range into the St. Louis basin, and it also moved northeastward from near Minneapolis into Wisconsin. The advance of earlier drift deposits is known from the presence of a thin deposit of clayey and limy drift containing rock material brought from Manitoba. This covers the drift that was deposited by ice coming from the highlands northwest of Lake Superior. The drift from these highlands, together with that from the Lake Superior basin, forms the stony red drift of eastern Minnesota, while that from Manitoba forms the clayey and limy gray drift that covers almost all the rest of the state.

Different Drift Sheets as Sources of Marl

Since the drift sheets are of sufficiently different composition to show variations in color, it is at once evident that there are also differences in composition. Generally speaking, the gray drifts are clayey and limy, with comparatively few stones and bowlders, and the red drifts are sandy or loamy, with great numbers as well as great varieties of rock fragments, varying from gravel pebbles to bowlders weighing many tons.

From the composition of the drift it has been commonly assumed that the gray, limy drift would be a better source of marl than the red, stony drift of eastern and central Minnesota. Figure 32 on page 94 shows, however, that a greater number of marl deposits are found in the red drift areas of the state than in the regions of the gray drift. This is undoubtedly due to the difference in texture of the two types of drift. Even though the gray drift contains a higher percentage of calcium carbonate, its texture is so fine that it is relatively impervious, and consequently the leaching action of ground water is retarded.

Percentage of Soluble Carbonates in Various Types of Glacial Deposits

Red Drift		Gray Drift	
Sample No.	Per Cent $CaCO_3$	Sample No.	Per Cent $CaCO_3$
1	4.29	11	14.66
2	1.69	12	13.28
3	5.53	13	18.10
4	3.98	14	10.65
5	5.23	15	7.36
6	2.41	16	8.00
7	11.52	17	16.34
8	19.85	18	11.15
9	0.98	19	6.48
10	1.89	20	8.11
Average	5.73		11.41

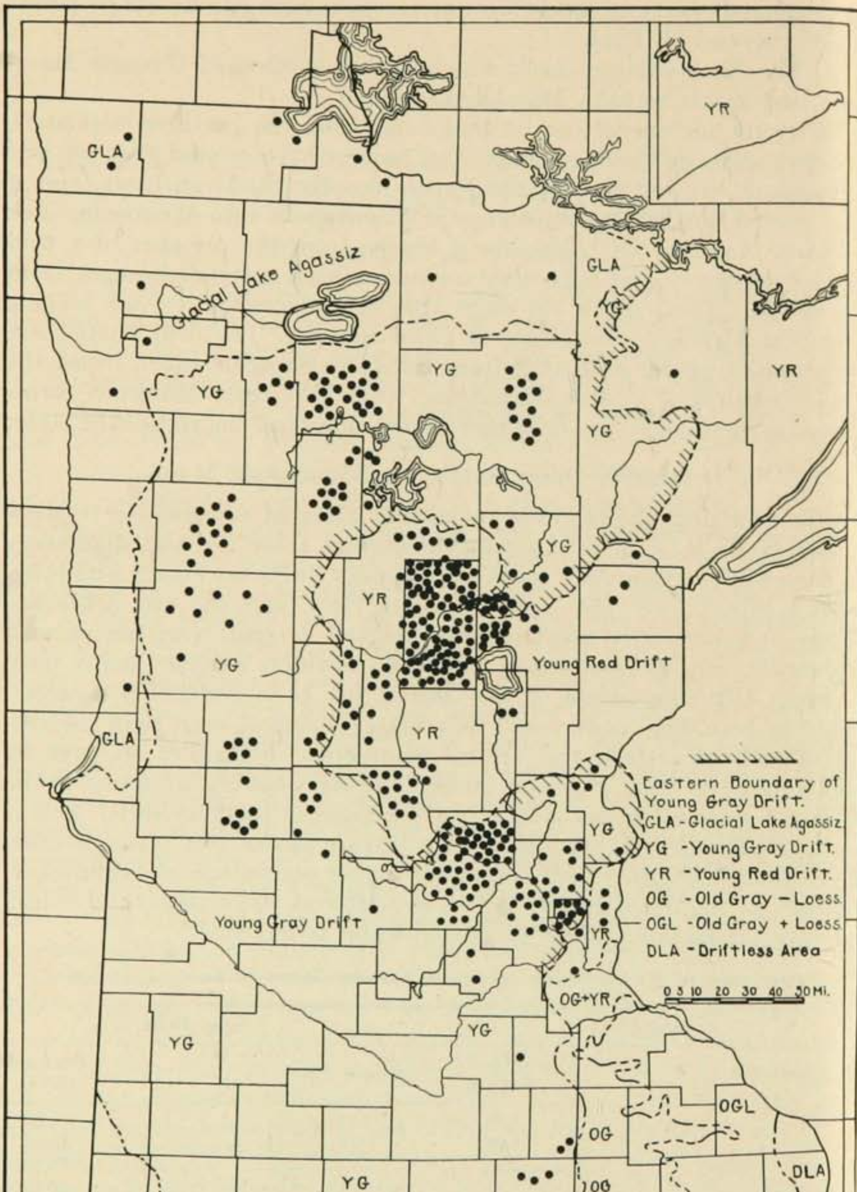

FIG. 32. — Outline map of Minnesota showing the distribution of marl deposits and their relation to different types of glacial drift.

Description of Samples *

Red Drift

1. Red drift from fresh road cut east of Cedar Lake, Aitkin County. A sandy clay with lime carbonate cementing fissures. Classified as morainic sand.
2. Clayey red drift from pit east of Pelican Lake, Crow Wing County. Classified as coarse sandy outwash.
3. Red drift from road cut through hill that borders large marl deposit near Clearwater. Classified as coarse sandy outwash.
4. Red sandy clay from road cut on west shore of Mille Lacs about 3 miles south of Garrison. Classified as morainic sand.
5. Gravel from ridge a mile south of Pillager. Classified as outwash.
6. Sand from pit near the road along the east shore of Lake Edward, Crow Wing County. Classified as outwash sand.
7. Clayey red drift from cut through a hill 3 miles northeast of Swanville. Classified as till clay.
8. Fine sand from cut through a hill a mile north of Princeton. Classified as till clay.
9. White sand from pit on the east shore of Pelican Lake, Crow Wing County. Classified as outwash sand.
10. Red sandy drift from cut through hill about five miles west of Mora, Kanabec County. Classified as red till.

Gray Drift

11. Drift from cut through hill near Richmond, Stearns County. Classified as outwash sand.
12. Drift from road cut, about 4 miles north of Elk River, in Sherburne County. Classified as morainic sand.
13. Drift from cut on east shore of Wautab Lake, Stearns County. There is a thick marl bed in the lake. Drift classified as sandy moraine.
14. Gray laminated clay west of Mississippi River in Minneapolis. Classified as clayey moraine.
15. Gray laminated clayey drift near Albert Lea, Freeborn County. From area of clayey moraine.
16. Fine-grained silty swamp clay, Freeborn County. Area of clayey moraine.
17. Clayey glacial silt from near Grand Forks in the Red River Valley. Classified as glacial lake sediments.
18. Same region as sample 17.
19. Loess clay from the old gray drift sheet of Steele County.
20. Fine-grained gray drift clay from Freeborn County.

* Based on classifications by Leverett and Sardeson.

Mechanical Analyses of Drift Samples

In order to compare the texture of different types of drift, a series of mechanical analyses were made on a group of representative samples. The drift to be analyzed was thoroughly mixed in a sampling cloth, and a sample of 100 grams was taken for the determination. The material was placed in a series of six Tyler-scale screens. The screens were arranged one above the other, in such a way that the sieve openings became successively smaller toward the bottom. The set was then placed in a "Ro-tap" test screener and shaken for 5 minutes. The Ro-tap produces the same circular and tapping motion used in hand-sieving, but it does it more uniformly and efficiently. The different mesh material was weighed and the percentage of material retained in each screen calculated. The cumulative percentage for each screen was calculated also by determining what part of the material would remain on a certain sieve if it were the only one used. If the material was clayey and had a tendency to be lumpy, it was gently tapped and rubbed in a mortar with a padded

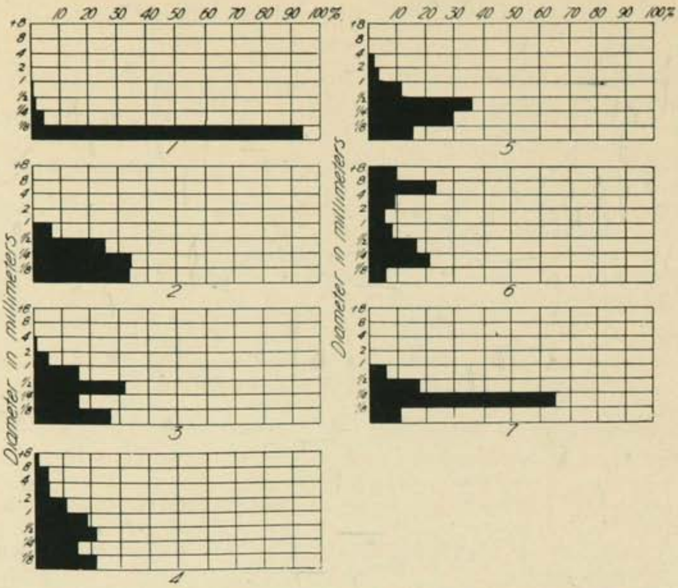

FIG. 33. — Diagrams showing the texture of various types of glacial deposits in Minnesota. Horizontal lines show percentage of different sizes in the samples: 1. windblown sands; 2 and 3. outwash sands; 4. clayey gray drift; 5. clayey red drift; 6. sandy moraine; 7. fine outwash sands.

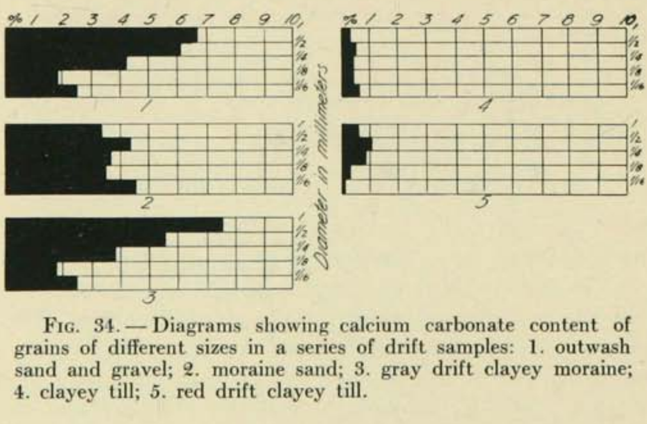

FIG. 34. — Diagrams showing calcium carbonate content of grains of different sizes in a series of drift samples: 1. outwash sand and gravel; 2. moraine sand; 3. gray drift clayey moraine; 4. clayey till; 5. red drift clayey till.

pestle before screening. Rubber stoppers were also placed in each screen to break up the drift into its detrital grains. The results of these tests are plotted in Figure 33.

In order to determine the texture of the calcium carbonate fragments in the drift, each of the different mesh materials from the above screening tests was analyzed, and the amount of calcium carbonate was determined. The results plotted in Figure 34 indicate that most of the calcium carbonate is in the coarse material, in the form of small limestone fragments. All the samples contained less than 5 per cent of lime carbonate in the material finer than 100 mesh.

Correlation of Marl Deposits with Texture of Drift Sheets

Glacial drift is deposited in a number of characteristic topographic forms. The most widespread are the hilly moraines, outwash plains, and till plains. These may be further subdivided on the basis of texture into clayey moraines and sandy and stony moraines; clayey till plains and stony and sandy till plains; and coarse, gravelly outwash plains and fine-grained sandy outwash plains. The majority of the marl beds that have been discovered in the state are located in areas of outwash gravels and in sandy and stony moraines. (See Figures 35 and 36.) Their occurrences with respect to the texture of the glacial deposits are summarized in the accompanying table.

Number of Marl Beds Occurring in the Several Types of Glacial Deposits in Minnesota Counties

County	Sandy Moraines	Clayey Moraines	Outwash	Till Plains	Total
Aitkin	18	..	5	1	24
Anoka	..	..	9	..	9
Becker	7	..	6	..	13
Beltrami	..	4	15	4	23
Benton	..	..	3	..	3
Carlton	1	1	..	..	2
Carver	..	2	..	..	2
Cass	5	..	..	2	7
Chisago	..	..	1	2	3
Clearwater	..	..	7	..	7
Crow Wing	5	..	76	..	81
Dakota	..	..	1	..	1
Douglas	1	4	..	..	5
Freeborn	..	1	1	1	3
Hennepin	5	..	5	2	12
Hubbard	5	..	5	1	11
Isanti	2	..	..	1	3
Itasca	..	7	6	..	13
Kandiyohi	..	..	1	..	1
Kittson	..	..	2	..	2
Meeker	..	..	1	..	1
Mille Lacs	..	1	2	..	3
Morrison	4	..	2	1	7
Otter Tail	5	1	2	..	8
Pine	..	..	..	1	1
Pope	5	..	2	..	7
Ramsey	..	1	8	..	9
Rice	..	1	..	..	1
St. Louis	2	1	..	..	3
Sherburne	1	..	22	2	25
Stearns	5	1	8	2	16
Steele	..	..	2	..	2
Todd	1	1	3	3	8
Wright	..	5	14	4	23
Washington	1	..	2	..	3

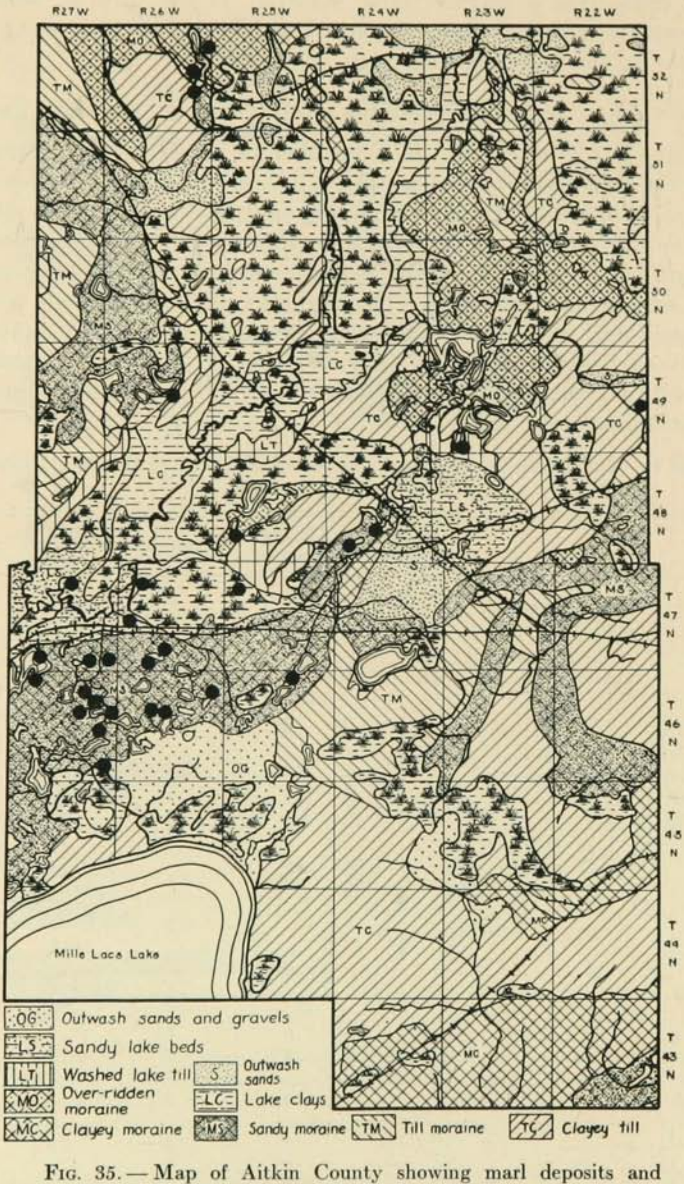

FIG. 35. — Map of Aitkin County showing marl deposits and their relation to different types of glacial drift.

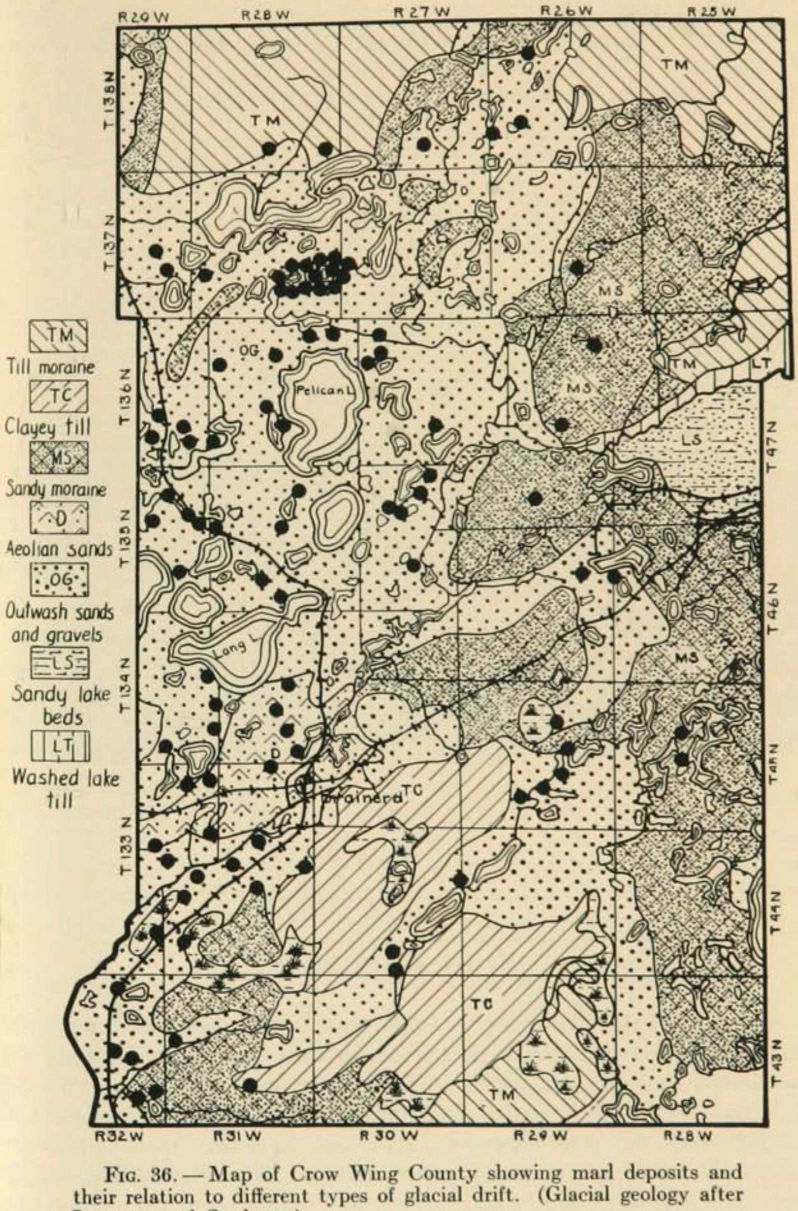

FIG. 36. — Map of Crow Wing County showing marl deposits and their relation to different types of glacial drift. (Glacial geology after Leverett and Sardeson.)

Calcium Carbonate Content of Ground Water from Wells in the Gray and the Red Drift Sheets
(Parts per million.)

County	Gray Drift	Red Drift
Stearns		72
	60	
		60
		60
		57
	103	
	115	
	97	
	73	
	22	
Todd	41	
	115	
	193	
		58
	9	
Morrison		70
		70
		84
		59
Hubbard	110	
	44	
	57	
Washington		68
Ramsey		55*
Dakota		55
Kandiyohi	88	
	224	
	65	
Meeker	93	
	115	
	154	
	88	
Average	138	59

* Average of 9 drift wells near St. Paul.

Since the greatest number of marl beds occur in regions where th surface formations are outwash gravels, it may be contended that suc formations cover the greatest amount of territory. A study of the drif shows, however, that outwash areas are not the most widespread of the surface formations. The clayey till plains cover a far greater number of square miles than any other type of deposit. The clayey type of moraines also are more abundant and more widespread than the sandy and stony moraines. Yet more than twice as many marl beds are found in depressions in sandy moraines than in clayey moraines. One must conclude, therefore, that more lime carbonate is leached from the glacial sediments that have a relatively coarse texture, even though the calcium carbonate content of the drift that is being leached is not so high as that of the fine-textured, clayey varieties that are typical of the young gray drift. In sandy, coarse soils more rain water seeps into the earth and joins the ground-water circulation and less is carried away in the immediate run-off than where the soil is a fine-textured, impervious clay.

The accompanying table, which is a comparison of the calcium carbonate content of ground water from the young gray and the young red drifts, shows that calcium bicarbonate is more abundant in the water in wells in the gray drift. On the basis of such observation, one would

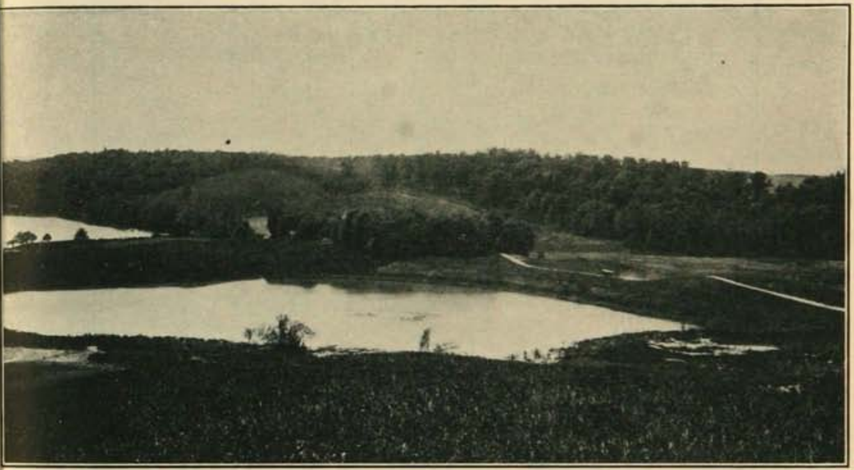

FIG. 37. — Small lake basins in glacial moraine in Dakota County, showing the type of topography most favorable for the leaching of calcium carbonate from the drift.

expect to find more marl in the gray drift areas. However, the fine texture of the gray drift retards the circulation to such an extent that very little of the lime carbonate ever reaches the lake basins.

Relation of Marl Deposits to Glacial Topography

In a region where the glacial drift has sufficient calcium carbonate and where its texture is favorable for the leaching of calcium bicarbonate, the character of the topography seems to be a factor in determining the number and size of the marl deposits. With other conditions favorable, the presence of high, rugged, morainic hills favors the formation of large deposits of marl. (See Figure 37.) The reason for this correlation is undoubtedly the fact that the higher the hills the greater the thickness of drift, and the more extensive, therefore, the gathering ground for the leaching solutions that carry dissolved mineral matter to the glacial basins. High topographic relief would tend also to increase the hydrostatic head of the ground water. This in turn would increase the rate of circulation and diffusion of the water and the amount of

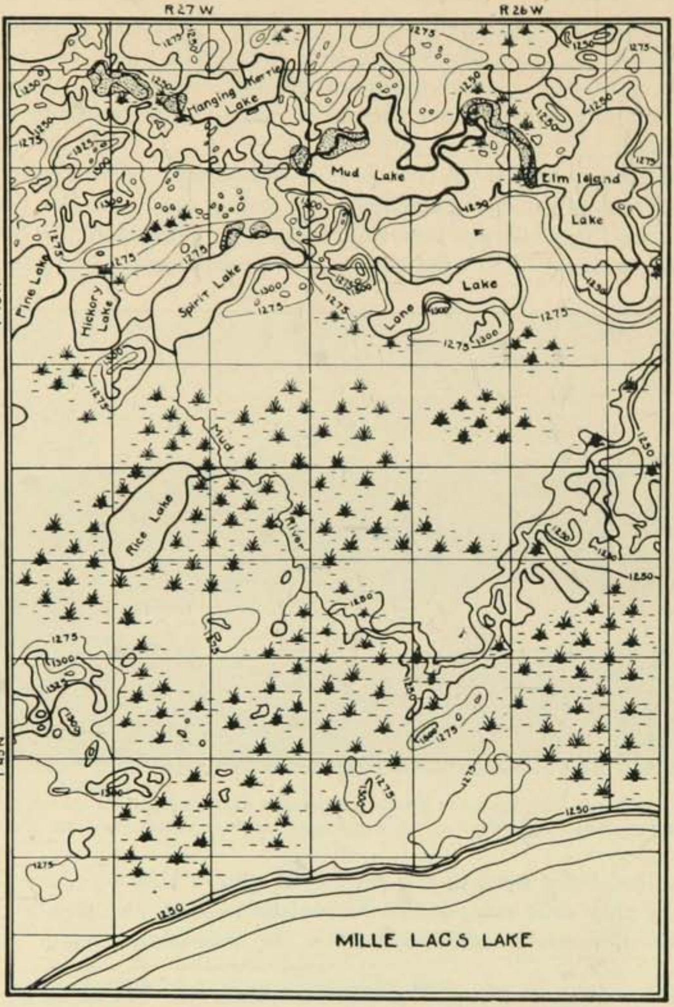

FIG. 38.—Map of the southwestern part of Aitkin County showing the occurrence of marl (the stippled areas) in the rugged morainic topography, and its absence in the bogs to the south.

carbon dioxide held in solution. An increased rate of circulation of a solvent accelerates the rate at which a solute is dissolved. The ground waters in a region of flat topography are more sluggish than those in an area of morainic hills.

Artesian circulation also favors the formation of marl beds. In a number of localities the structural relations of the glacial deposits are such that an impervious till overlies porous sands and gravels that are filled with water under considerable hydrostatic pressure. Where glacial basins are sufficiently deep to allow such sands to outcrop on the floor or around the margins of the basin, deep springs discharge into the lake. This is strikingly shown in central Pope County around Lake Minnewaska, where the water level of the lake is about 200 feet below the surrounding hills. Numerous springs occur on the hill slopes, and flowing wells are obtained at moderate depths, even at elevations a number of feet above the level of the lake. Extensive marl beds have been deposited around some of the springs and on the floor of part of the lake basin. Artesian circulation also exists along the west margin of the high morainic hills in Douglas, Otter Tail, and Becker counties, where numerous deposits of marl are located in the glacial basins.

The association of marl beds with high morainic hills and the absence of such marl deposits in basins in flat areas of fine outwash sands may be shown in a great many localities. Figure 38 is a typical example. A zone of very irregular morainic hills crosses Aitkin County from east to west in the region between Mille Lacs and the valley of the Mississippi River. There are numerous marl beds in the basins among the hills, but none were discovered in the lakes that occupy basins where there is only slight relief.

This correlation of marl with topographic relief is the opposite of what might be expected on the basis of the mineral content of ground water. Dr. I. S. Allison has recently shown that hard water is more common in flat regions than among morainic hills. This condition is undoubtedly due to the fact that ground water is more nearly stagnant in regions of slight relief and therefore eventually becomes charged with a higher salinity. Very little of this water reaches the lake basins, however, and little of its calcium carbonate is, therefore, extracted to form marl.

CHAPTER III

PROSPECTING FOR MARL

No fixed rules can be formulated to guide the prospector to the discovery of marl, but a summary of a few of the characteristic relationships between marl and its surroundings may prove useful.

1. Marl is formed either by precipitation from solution or through the activity of acquatic organisms. It is found, therefore, only in places that were once or are still covered with water. It is not necessarily confined to the immediate vicinity of present existing bodies of water, for the general water level has fallen, and many former shallow lake basins, covering thousands of acres, are now drained and dry land.

2. In basins where the water level was lowered rather rapidly, the marl may be exposed at the surface with very little if any muck or peat as an overburden.

3. In partially drained marshes and bogs the marl is found below a layer of peat that varies from 1 to 20 feet in thickness.

4. Marl is most commonly found under the type of peat which develops around lakes and ponds. It is either sedge-grass peat or pond peat composed of the remains of plants such as reed grass, cat-tails, bulrushes, and grasses.

5. Very little marl has been found in the extensive basins covered with sphagnum moss. Most of these so-called "muskegs" or swamps represent built-up peat deposits on flat and poorly drained areas that were not covered with water sufficiently long for marl to accumulate.

6. Marl is found in or around hard-water lakes. It is the presence of calcium bicarbonate that gives water the property usually known as temporary hardness. If the lake water is soft, the calcium carbonate content is so low that no marl deposits are formed.

7. Hard-water springs around the margins of a lake basin or on the floor of the basin may have marl deposited near the mouth of the spring.

8. In a chain of lakes, marl is more commonly found in the lakes toward the head of the chain. Where all the lakes in the chain are bordered by high morainic hills, this criterion is of little value.

9. In or around a large lake the most marl is usually found in abandoned embayments or indentations of the shore line. Open beaches and banks of wave-swept drift rarely have marl associated with their sediments.

10. More marl is found in the basins in regions where the glacial drift is composed of open-textured gravels and sands than where impervious clayey tills cover the surface. This is true even if the lime carbonate content of the clay is higher than that of the sands.

11. More marl has been deposited in lakes among morainic hills than in lake basins in flat areas. This is true of any type of drift. Of two glacial basins with similar drift, the one with the greater thickness of glacial drift above its water level will contain the most marl.

Methods Used in Prospecting and Testing Marl Deposits

It has not been possible to sample and test many of the marl beds in great detail in the short time spent in the field. It is doubtful, moreover, whether the results of such detailed work, were it undertaken, would justify the great expense that would be involved, for many of the deposits are of a grade suitable only for agricultural purposes, and for such uses detailed analyses and estimates of tonnage are not essential.

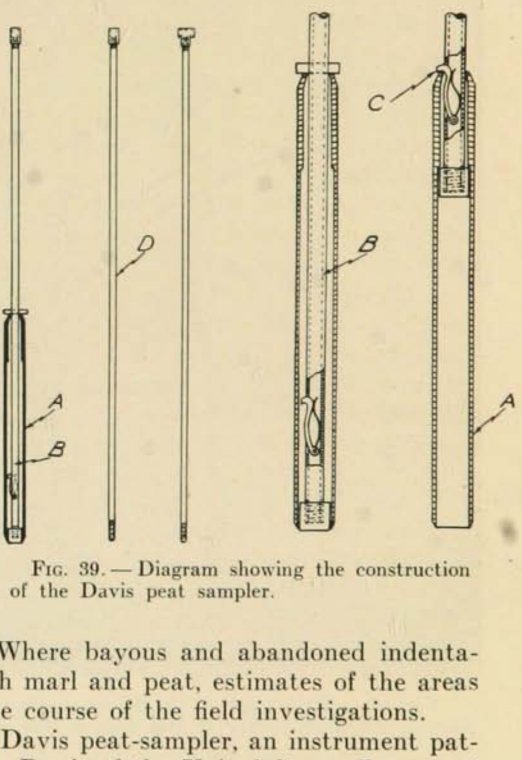

Fig. 39. — Diagram showing the construction of the Davis peat sampler.

Many of the bogs in the northern part of the state are mapped with a fair degree of accuracy on the government township maps, and several counties have soil maps, surveyed by the Bureau of Soils of the United States Department of Agriculture, which show the exact boundaries of the peat-covered bogs and marshes. These maps have been used to a large extent in determining the areas of the bogs underlaid by marl beds. Where bayous and abandoned indentations of lakes are now filled with marl and peat, estimates of the areas were made on the ground in the course of the field investigations.

Methods of sampling.— The Davis peat-sampler, an instrument patented by the late Dr. Charles A. Davis of the United States Bureau of Mines and especially designed for making soundings and taking samples of peat bogs, was used for most of the field sampling of wet marl.

The essential part of this tool is a stout brass tube about a foot long and seven-eighths of an inch in inside diameter. (See A, Figure 39.) The lower end of the tube is sharpened, and inside the upper end a shoulder or ring of brass one-sixteenth of an inch thick is closely fitted and riveted to serve as a stop for the piston and catch. Inside the cylinder is a piston (B), or three-fourths-inch rod, that exactly fits the opening in the upper part of the tube and is bushed out at the lower end by a ring of brass to fit the cylinder. This lower end of the piston is slotted on one side, and in the slot is fastened a spring catch (C) that automatically locks when the piston is drawn up and out of the cylinder. A metal peg driven through a hole in the piston at the proper distance from its upper end and at right angles to its long axis prevents its being pushed out of the cylinder at the outlet end. The whole can be quickly and firmly fastened to a rod of gas pipe (D) by a screw thread in the upper end of the piston. When used, this tool is pushed down the required distance into the peat or marl. A sample is taken by drawing up the rod and the attached cylinder until the catch is heard to lock at the top of the length of cylinder, after which the cylinder is pushed down into the peat or marl about its own length. This action fills it unless the peat or marl is very wet or very hard. After the cylinder is full it may be drawn to the surface without danger of loss or of mixing with the overlying material. The enclosed sample may then be pushed from the cylinder by unlocking and pushing the piston. The sampling rod may be lengthened to reach any desired depth by the addition of separate units of pipe. (See D, Figure 39.)

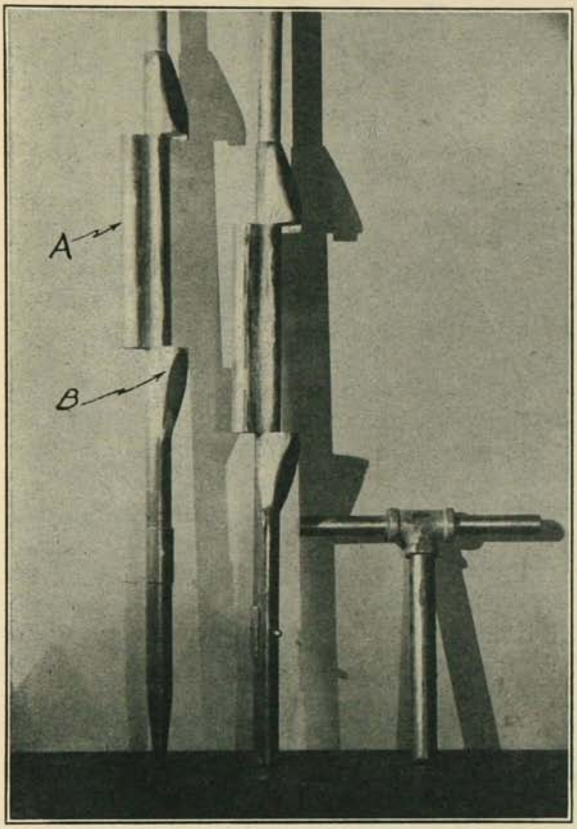

FIG. 40. — Photograph of the Michigan marl sampler, showing the sample-barrel of two units of the sampler.

The Michigan marl-sampler (see Figure 40), designed by Professor H. H. Musselman of Michigan State College, was also used. This sampler has the advantage of taking multiple samples at definite intervals, and the sample tubes are capped at the top and closed at the bottom, so watery marl cannot escape from the tubes while it is being withdrawn from the test hole.

This sampler consists of five sections of one-fourth-inch pipe, each 3.5 feet long. The sections are interchangeable, and each carries a sampling tube so mounted that it can swing out of alignment with the pipe when the sampler is rotated. (See A, Figure 40.) The method of operation is to force the rod into the ground with the sample tubes in such a position that they are protected at each end by the solid caps, which are welded to the pipe and tapered so that they can be pushed into the marl. (See B, Figure 40.) When the desired depth is reached, the rod is rotated to the right. The caps rotate with the rod, but the resistance of the marl keeps the sampling tubes stationary, so that after a quarter turn their ends are open. The rod is then raised six or eight inches and the tubes are filled. It is then rotated back to the left and the ends of the sampling tubes are closed. After the rod is raised, the sample cores are removed with a plunger. For detailed work this sampler has the advantage of being able to cut samples from depths of 20, 16, 12, 8, and 4 feet all in one operation. In reconnaisance work, however, the manipulation of this sampler requires more time than the Davis sampler.

Collection of samples for analysis.—Since the object of this preliminary survey was primarily to discover the location and distribution of marl, only the general outlines of the deposits were determined and the collection of samples was made accordingly. In every case, however, efforts were made to collect samples that were representative of the entire deposit. Where multiple sampling was done, cores were taken at depth intervals of 3 feet in the marl bed and at intervals of 100 feet over the surface. Composite samples of many of the smaller deposits were collected by mixing the cores taken at the several 2-foot intervals. The size of the samples that went into the composite sample was kept as uniform as possible.

Since no moisture determinations were to be made of the samples collected during this survey, the samples were placed in small cloth sacks of closely woven material to prevent any seepage of lime carbonate. The samples were dried slowly without being allowed to come in contact with each other. This was done by suspending them from a rod across the back compartment of the automobile used as a means of transportation in making the survey.

Large Deposits of Marl Discovered in Minnesota

1. Most of Hill Lake at Hill City (detailed description on page 114) seems to be underlaid by marl of high quality. The exact character and total extent of the deposit has not been determined, but a preliminary survey indicates that the deposit is worth careful investigation. Transportation facilities are favorable, a railroad passing over the marl bed.

2. Star Lake and its vicinity in Crow Wing County contain a large amount of marl. (See pages 135–136.) The deposit is continuous through Bass Lake and Kimble Lake, and another extensive bed is found in and around Long Lake, about a mile away. This series of deposits is located about ten miles from the nearest railroad. The topography and character of the glacial drift are such that railroad construction would not be difficult. It is near the markets of Brainerd, Little Falls, St. Cloud, and

PARTIAL ANALYSES OF MINNESOTA MARLS FROM SOME OF THE LARGER DEPOSITS

(In percentages.)

Location	Insoluble	Oxides	$CaCO_3$	$MgCO_3$
Aitkin County				
Hill City	3.78	nd*	90.84	2.45
Crow Wing County				
Star Lake	1.00	.10	91.20	1.30
Star Lake meadow	8.20	.30	85.20	1.30
Bass Lake	7.30	.40	84.50	1.90
Long Lake	1.64	nd	94.61	
Nokay Lake	23.70	1.40	70.10	1.30
Hennepin County				
Robbinsdale	3.00	.20	87.80	2.70
Ramsey County				
Lake Gervais	8.70	.40	84.80	1.30
Stearns County				
Avon	9.54	nd	81.84	trace
Otter Lake	4.80	.40	85.10	1.90
Clearwater Lake	10.30	.40	76.70	2.10
One mile west of Clearwater	27.90	.50	66.20	2.30

* nd = not determined.

Staples, all of which are located in the central part of the state. There are also good transportation facilities to the Twin Cities.

3. A large deposit of marl is found at Robbinsdale in Twin Lakes at the north margin of the city limits of Minneapolis. Partial analyses indicate that it is of high grade. If the marl is uniformly thick throughout the entire lake basin, an enormous tonnage is available. It has the advantage of proximity to a market and ideal railroad facilities. A branch of the Soo Line passes over a narrows in the lake.

4. Southeastern Stearns County has several large deposits that deserve investigation because of their favorable location. One large deposit is located in a chain of lakes west and south of Clearwater. (See the map on page 173.) Much of this is dry marl around the margins of lake basins and above the present water level. This deposit is excellently located with respect to railroad facilities. The Great Northern Railroad tracks cross the north end of the deposit and the same tracks cross a good clay deposit several miles from the marl bed.

Partial analyses of the clay near the marl deposits show that it contains SiO_2 45.60 per cent, Fe_2O_3 4.90 per cent, Al_2O_3 12.60 per cent, CaO 10.20 per cent, and MgO 3.60 per cent. In a clay suitable for cement the silica content should be from 2.5 to 4 times as great as the total of ferric oxide and alumina. The ratio of alumina to ferric oxide should be about 3 to 1, and not less than 1 to 1, and the amount of magnesium should be less than 5 per cent. In the Clearwater clay the silica content is nearly 2.7 times as great as the total of the ferric oxide and alumina and the ratio of alumina to ferric oxide is about 3 to 1. With the magnesium content of the marl low, the 3.6 per cent of MgO in the clay would not be too high. Both the marl and the clay deposits of the Clearwater area are worthy of further study.

Another large deposit is located in Otter Lake and the western part of Clearwater Lake, northwest of Annandale. All the marl is wet, but the area and the tonnage of marl are undoubtedly greater than the deposits near the village of Clearwater.

A third location of extensive marl beds in Stearns County is the group of lakes near Avon. (See the map on page 178.) Six lakes, all within a radius of a mile from the village, are underlaid by high-grade marl. No clay deposits were sampled in that vicinity, but extensive clayey moraines are found less than two miles north of the village. The Great Northern Railroad passes between the basins of the group of lakes.

Other large deposits are found in less favorable locations. The following are worth investigating: Irving Lake and the northward extension of its basin under the swamp at Bemidji; the deposit near Backus; Riley Lake, north of Taconite; and Nokay Lake, east of Brainerd.

CHAPTER IV

MARL DEPOSITS IN INDIVIDUAL COUNTIES

Aitkin County

All three drift sheets, the Superior, the Patrician, and the Keewatin are present in Aitkin County. The Superior drift covers several townships in the southeast part; the Patrician (young red) drift is at the surface in the western part of the county; and the Keewatin drift covers most of the northern half and extends in places a few miles into the southern half of the county.

The glacial deposits show very characteristic modes of occurrence and the relation of the marl beds to different types of drift is strikingly developed. (See Figure 32.)

Several large areas of typical ridged morainic drift occupy nearly one-fourth of the surface of the county. Two moraines of the Superior lobe are found in the eastern part of the county. All the moraines were formed by the Patrician ice sheet, but those in the northern half were overridden to some extent by the Keewatin ice. As a result of this overriding the surface has, on the whole, been made smoother, but in a few places the later ice movement appears to have pushed up sharp hills where the former surface was only slightly ridged. Most of the marl is in the southern part of the county in the small basins among the sharp knolls and ridges of the sandy red drift moraines.

A large extinct glacial lake basin, commonly known as Glacial Lake Aitkin, lies north of the town of Aitkin. It is the drained muskeg that embraces 75 to 100 square miles in the west-central part of the county. Another large basin area occurs around the north shore of Mille Lacs and extends from there northeastward. In addition to these large bogs hundreds of smaller ones, some of them several square miles in area occur widely scattered throughout the county.

The large bogs of the north-central part of the county are of the open marsh, built-up type and undoubtedly were never covered with water for a sufficiently long period of time for the deposition of marl to be initiated.

Descriptions of the marl beds that were sampled and tested are given below. (See Figure 41.)

T. 46 N., R. 27 W., Cedar Lake.—Cedar Lake (see Figure 42) is located in a deep basin in the morainic hills at the south margin of glacial Lake Aitkin. Numerous springs issue into the eastern bay of the lake from the steep, clayey knobs and ridges along the shore. Extensive marl deposition took place when the water stood about two feet above its present level.

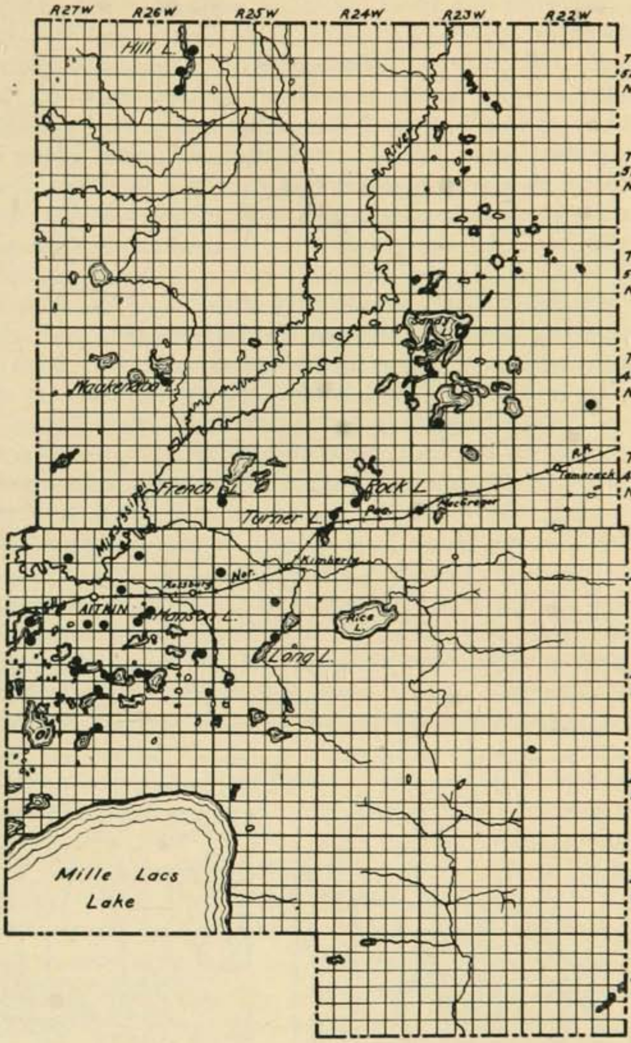

FIG. 41. — Map of Aitkin County showing marl deposits.

In Section 5, around the south margin of the bay, a marl bed covers about 3 acres to a depth of from 4 to 15 feet, with an overburden of 1 to 2 feet of peat. Much of the marl is above the water level. It is readily accessible, a road running a few rods from the margin of the deposit. Samples contained 83.5 per cent soluble carbonates.

T. 46 N., R. 27 W., Sec. 13.—In SE¼ Sec. 13 (see Figure 43) a partially drained embayment of Mud Lake covers an area of approximately 20 acres. It supports a luxuriant growth of wild rice. Six to 8 feet of good marl underlies most of the bay. Some of the marl has been excavated, and a sample from the stock pile contained 69.20 per cent soluble carbonates.

T. 46 N., R. 27 W., Sec. 14, Hanging Kettle Lake.—Hanging Kettle Lake occupies a basin in the same morainic belt as Cedar Lake. An abandoned bay at the southwest end of the lake is now sufficiently well drained to support tame hay. A thin bed of poor marl 1 to 2 feet thick underlies about 20 acres of meadowland around the bay. The marl is thinnest near the present shore line and becomes thicker toward the center of the bay. All the marl is contaminated with peaty organic matter.

Another deposit of marl in Section 14 of the same township is located in and around the small lake west of Hanging Kettle Lake, on the west side of Minnesota Trunk Highway No. 35. The marl bed is continuous around the basin westward into NE¼ Sec. 15. At the east end of the lake some of the marl has been excavated under the supervision of the Division of Soils of the University of Minnesota. The lake covers an area of approximately 80 acres. Its marl bed varies from a thickness of 4 to 8 feet along the southeast margin to over 18 feet in the northeastern bay. A sample from the stock pile showed 64.40 per cent soluble carbonates.

T. 46 N., R. 27 W., Sec. 24, Spirit Lake.—Spirit Lake is surrounded by steep, clayey-morainic hills. The marl is confined to small abandoned bays along the northwestern shore line of the lake. The marl is from 4 to 8 feet thick and covered with 4 to 6 feet of peat. A composite sample from a group of holes contained 54.80 per cent soluble carbonates.

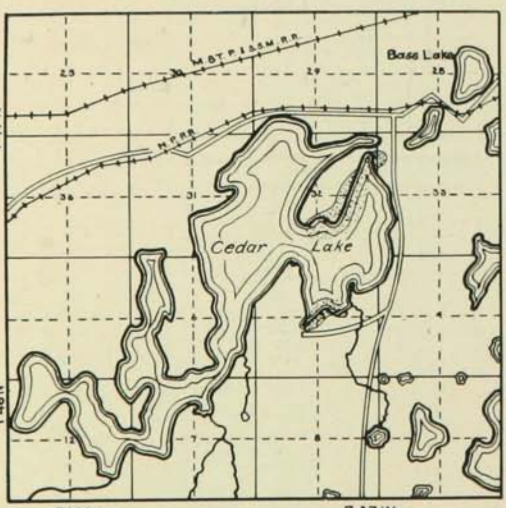

FIG. 42.—Map of Cedar Lake, Aitkin County. The stippled areas are marl deposits.

FIG. 43.—Map of a group of lakes southwestern Aitkin County. The stippled areas are marl deposits.

T.47 N., R.27 W., Cedar Lake.—An extensive bed of marl is found along the southeast margin of the long, narrow point of land that extends into Cedar Lake. (See Figure 42.) In NW¼ Sec. 33 an embayment that was once part of the lake contains a bed of marl over an area of 4 acres. It is 4 feet thick and covered by 6 feet of peat. Farther southwestward, toward the end of the point, a narrow zone about 15 acres in area contains 10 to 12 feet of marl, covered by 4 to 6 feet of mucky peat. Composite samples taken from various depths contained 47 per cent soluble carbonates.

Other small deposits in this township were located in Section 10, northwest of Aitkin, and in small bogs in Sections 35 and 36.

T.47 N., R.26 W., Secs. 32 and 33, Hanson Lake.—Hanson Lake is located a short distance south of the beach of the extinct glacial Lake Aitkin, in an area of rolling sandy moraine. An 8- to 10-foot bed of marl extends along the north shore of the lake under 7 feet of peat. The marl is poor and grades downward into clay. A composite sample, representing samples taken every 3 feet, contained 20.7 per cent soluble carbonates.

Another small bog with a thin bed of marl is found in SW¼ Sec. 32. It covers an area of about 2 acres and has an overburden of 6 feet of peat. An analysis showed 64.20 per cent soluble carbonates.

There are two marl beds in this township within the area of glacial Lake Aitkin. One is located in Section 8, the other in Section 19. These areas represent depressions in the floor of the old lake bed that were sufficiently deep to hold water after the Mississippi River cut its channel through the floor of the lake. The marl is covered by 6 to 8 feet of peat and is of a clayey character, grading downward in clay that is tough and rubbery when wet.

T.46 N., R.26 W., Sec. 18, Mud Lake.—Mud Lake is one of a chain of lakes in the sandy moraine south of Aitkin. It is surrounded by sharp hills and knobs of pockety drift, some of which show zones of secondary lime cementing the pebbles and bowlders. Along the west side of the lake approximately 20 acres of meadowland is underlaid by a marl bed 10 feet in thickness. The marl has very little overburden, locally nothing more than a thin grassy sod. A composite sample representing samples taken at intervals of 3 feet contained 70.20 per cent soluble carbonates.

T.46 N., R 26 W., Sec. 17, Mud River.—An area of 15 to 20 acres of meadowland in the valley of Mud River is underlaid by 4 to 6 feet of fair clayey marl. It is covered with 3 feet of peat and grades downward into clay. Analyses showed 41.80 per cent soluble carbonates.

T.46 N., R.24 W., Sec. 12.—A small lake extends across Section 12 in a northeast-southwest direction. A partially filled and drained embayment at the east end of the lake contains a thick bed of poor marl. It covers an area of about 10 acres to a thickness of 10 feet. The marl is under 6 feet of grassy peat.

T. 49 N., R. 26. W., Sec. 22. — A small lake south of Waukenabo Lake receives the water from the latter through a small stream that flows south to Willow River and thence to the Mississippi River. The lake covers an area of about 80 acres and the entire basin is covered with marl. Undoubtedly the same bed is continuous in the swampy area extending southwestward toward Round Lake. Around the south margin of the lake the marl bed is 8 to 12 feet thick and is covered with 3 feet of peat. Some of the marl has been excavated for local use. A composite sample composed of samples taken at intervals of 3 feet contained 68.90 per cent soluble carbonates.

T. 52 N., R. 26 W., Hill Lake. — One large deposit of marl is found in this township, in Hill Lake at Hill City. Hill Lake is approximately 4 miles in length and about a half mile wide. Marl underlies most of the lake, covering an area of at least 1,000 acres. The marl varies in thickness from 1 to 2 feet near shore to 6 feet at 25 yards from shore. In deeper water its thickness varies from 8 to 18 feet. The marl is exposed at the south end of the lake, where the water is shallow, and it may also be observed along the west shore at the tourist camp.

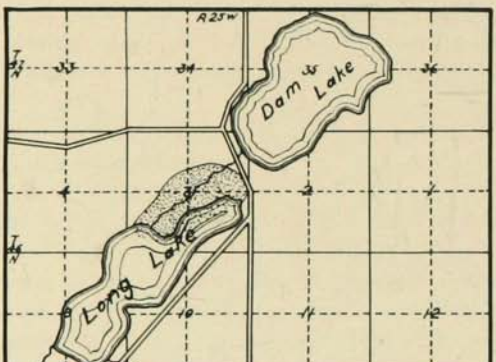

FIG. 44. — Map of Long Lake and Dam Lake, Aitkin County. The stippled areas are marl deposits.

If the marl owes its origin to the activity of Chara then very little deposition is in progress at the present time, for the water is clear and free of vegetation. Along most of the shore line hardwood forests extend down the slopes to the water's edge. A number of composite samples showed an average content of 89 per cent soluble carbonates.

T. 48 N., R. 24 W., Secs. 29 and 32, Turner Lake. — Turner Lake is in a basin among a group of sandy morainic hills that stood as an island in glacial Lake Aitkin. A small swamp surrounds the west end of the lake. About 2 acres of the swamp is underlaid by an 8-foot bed of marl. It is covered with 7 feet of peat and is underlaid by fine sand. A composite sample contained 27.60 per cent soluble carbonates.

T. 48 N., R. 24 W., Sec. 28, Rock Lake. — The presence of a small bed of marl around the southwest bay of Rock Lake was reported by Mr. A. Rollin, the county agricultural agent. The deposit was not sampled.

T. 48 N., R. 25 W., Sec. 30, French Lake. — The location of a small marl bed around the southwest bay of French Lake was reported by Mr. A. Rollin, the agricultural agent of Aitkin County. The deposit was not sampled.

T. 47 N., R. 25 W., Secs. 18 and 19.—In Sections 18 and 19, northeast of Rossberg, several square miles of flat bog land that represents an embayment of glacial Lake Aitkin are ditched and cultivated. A thin bed of marly clay, not over 2 feet thick, underlies the whole area. It is covered with 2 feet of grassy peat and is underlaid by a very fine-grained, sandy clay. Samples of the marl carried 16.95 per cent soluble carbonates.

T. 46 N., R. 25 W., Sec. 3, Long Lake.—A zone of meadowland along the stream flowing from Long Lake into Dam Lake through NE¼ Sec. 3 (see Figure 44) is underlaid by a bed of fair marl that varies in thickness from 6 to 10 feet. It is covered by 7 feet of peat and underlaid by sand. The marl covers an area of about 15 acres. Analysis of a composite sample representing samples taken at intervals of 3 feet showed 50.40 per cent soluble carbonates.

Several other deposits have been reported, but were not sampled. These include small beds in Sec. 24, T. 49 N., R. 22 W., and in Sec. 32, T. 49 N., R. 23 W.

Analyses of Marls of Aitkin County

Location	Sample No.	Per Cent Soluble Carbonates
T. 49 N., R. 26 W., Sec. 22	161	68.90
T. 49 N., R. 23 W., Sec. 32	167	22.20
T. 48 N., R. 24 W., Sec. 29	165	27.60
T. 48 N., R. 24 W., Sec. 28	166	43.50
T. 47 N., R. 27 W., Sec. 32	153	61.80
T. 47 N., R. 26 W., Sec. 32	162	20.70
T. 47 N., R. 25 W., Sec. 18	163	16.95
T. 46 N., R. 27 W., Sec. 32	149	46.80
T. 46 N., R. 27 W., Sec. 32	150	47.70
T. 46 N., R. 27 W., Sec. 27	158	54.80
T. 46 N., R. 27 W., Sec. 14	146	64.40
T. 46 N., R. 27 W., Sec. 14	147	70.00
T. 46 N., R. 27 W., Sec. 14	148	68.20
T. 46 N., R. 27 W., Sec. 5	151	85.40
T. 46 N., R. 27 W., Sec. 5	152	82.80
T. 46 N., R. 26 W., Sec. 18	156	70.20
T. 46 N., R. 26 W., Sec. 17	160	41.80
T. 46 N., R. 26 W., Sec. 12	157	69.20
T. 46 N., R. 26 W., Sec. 12	159	40.00
T. 46 N., R. 25 W., Sec. 3	164	50.40

Anoka County

General glacial features.—Much of Anoka County is covered by fine dune sand. Many of the dune areas are now covered with large wire-grass marshes where the dune sands have choked the drainage channels. Most of the dunes were probably formed during the closing stages of the glacial epoch, but in a few places they are still in active migration.

All of Anoka County lies within the limits of the Grantsburg lobe of the Keewatin ice sheet, and its surface therefore is covered with a sheet of young gray drift. This is exposed at the eastern edge of the dune

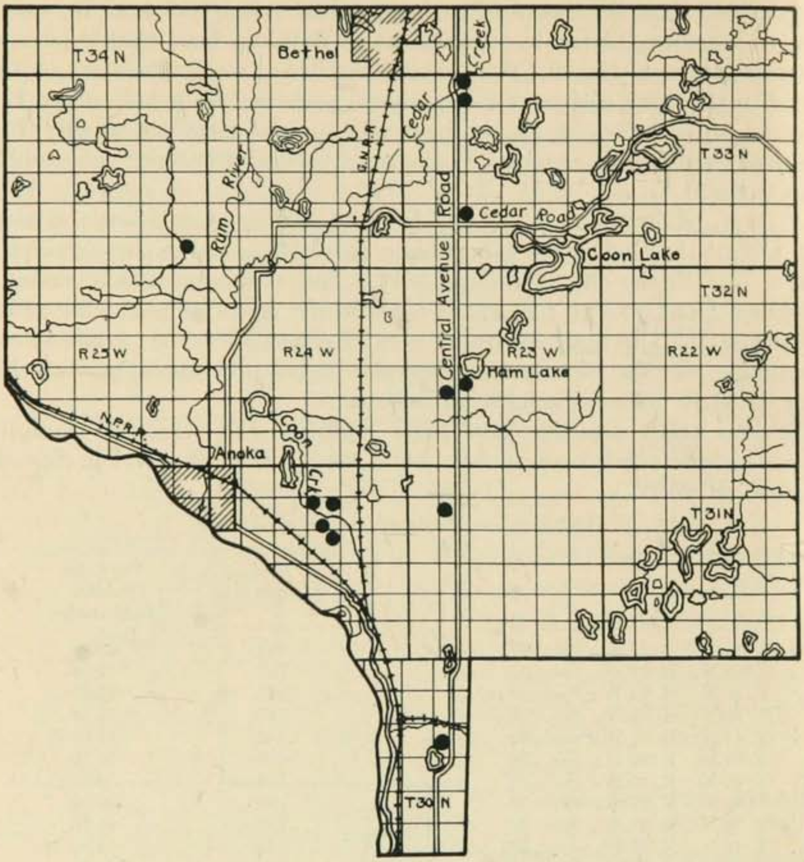

Fig. 45. — Outline map of Anoka County showing marl deposits.

area in a plain of clayey calcareous till in the southeastern part of the county. In the northwestern part of the county, morainic ridges of the gray drift rise prominently above the surrounding plains. There is a fine, gravelly outwash immediately bordering these morainic ridges on the east and south as far as Rum River.

The glacial basins or bogs occur chiefly in the central and northern parts of the county. There are numerous large wire-grass marshes in the south-central portion, but they are mainly of the built-up bog types and contain very little marl, if any.

Descriptions and analyses of the marl beds that were sampled and tested are given below. (See Figure 45.)

T. 33 N., R. 25 W., Sec. 36. — About 100 acres of the peat land in S½ Sec. 3 are underlaid by marl, which is covered by 4 to 6 feet of peat and is underlaid by clay. The marl is thickest near the stream and becomes thinner toward the margin of the basin. A composite sample consisting of samples taken at intervals of 3 feet contained 77.70 per cent $CaCO_3$.

T. 33 N., R., 23 W., Sec. 5. — Cedar Creek runs diagonally from the northeast to the southwest across Section 5. Its valley is floored by a zone of peat land covering approximately 80 acres. Marl beds are confined to the deeper basins along the valley. Where the Central Avenue road crosses the valley the peat is 3 to 5 feet thick and is underlaid by 4 to 6 feet of marl. The marl grades into sandy clay with depth. Collected samples showed an average of 62.50 per cent $CaCO_3$.

T. 33 N., R. 23 W., Sec. 29.—Most of the section is covered with peat. At the intersection of the Cedar road with the Central Avenue road the peat is 5 feet thick and is underlaid by 3 to 6 feet of fair marl. The marl covers at least 40 acres. The region is well drained and the marl readily accessible. The samples contained an average of 48.80 per cent $CaCO_3$.

T. 32 N., R. 23 W., Sec. 20.—The southwest bay of Ham Lake covers NE¼ Sec. 20. Much of the south half is swamp land. The Central Avenue road follows the north-south quarter line through the section, and in the region where it crosses the swamp a thick marl bed underlies the peat. The peat is about 5 feet thick and is covered by a heavy growth of tamarack, spruce, and birch. The thickness of the marl varies from 6 to 10 feet. Analyzed samples contained 62.20 per cent soluble carbonates.

T. 31 N., R. 24 W., Sec. 10.—Most of Section 10 is drained bog land and consequently is covered with peat. Coon Creek crosses the section from the northwest to the southeast, and a tributary flowing through the center of the section enters it from the north. The marl is found in the deeper portions of the valley near the streams. In the NW¼ an area of 20 acres has a marl bed from 4 to 6 feet thick below 6 feet of peat. Along the creek in the NE¼ the marl is 8 to 10 feet thick. The lime carbonate content is highest near the middle of the bed. A group of composite samples average 64.80 per cent $CaCO_3$.

T. 31 N., R. 24 W., Sec. 15.—A lobe or embayment from the valley of Coon Creek extends southward into N½ Sec. 15. Part of the bog area lies within the limits of the University of Minnesota Experimental Farm. The region is surrounded by rolling topography produced by wind-blown loamy sands. The marl bed varies from 5 to 10 feet in thickness and is covered by 3 to 5 feet of peat. Most of the marl is high in organic matter and grades into fine, clayey sand at depth. Analyses of composite samples contained 57.80 per cent soluble carbonates.

Analyses of Marls of Anoka County

Location	Sample No.	Per Cent Soluble Carbonates
T. 33 N., R. 25 W., Sec. 36	218	77.7
T. 33 N., R. 23 W., Sec. 29	214	48.8
T. 32 N., R. 23 W., Sec. 20	208	62.2
T. 32 N., R. 23 W., Sec. 5	213	62.5
T. 31 N., R. 24 W., Sec. 15	209	59.1
T. 31 N., R. 24 W., Sec. 15	210	56.8
T. 31 N., R. 24 W., Sec. 10	211	66.9
T. 31 N., R. 24 W., Sec. 10	212	63.7

Becker County

General glacial features. — Becker County has a continuation of the high, rugged moraines of Otter Tail County often referred to as the Leaf Hill Moraine. A number of till plains and outwash gravel plains also are characteristically developed. There is one large bowlder-strewn till plain in the southeastern part of the county, followed by extensive plains of outwash gravel toward the north and west. Beyond these is a very rugged, sandy moraine, and still farther westward are gently undulating clayey moraine and till plains. In the midst of the great sandy moraine

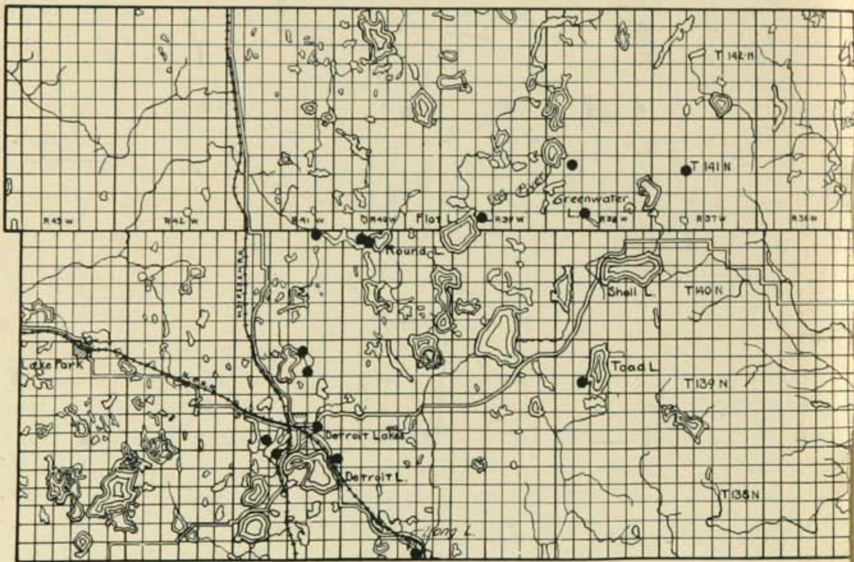

Fig. 46. — Map of Becker County showing marl deposits.

is an outwash plain extending southwestward from immediately north of the city of Detroit Lakes into northwestern Otter Tail County. A similar gravelly outwash tract is found in the midst of the great sandy moraine in the northern part of the county.

Glacial basins are very abundant. Upham estimated the area of lakes in this county to aggregate 137.5 square miles, and Leverett estimated the swamp land at about 250 square miles. Marl deposition is confined to basins in the gravelly outwash and sandy moraine areas.

Descriptions and analyses of the marl beds that were tested and sampled (Figure 46) are given below.

T. 139 N., R. 41 W., Little Floyd Lake. — Little Floyd and Big Floyd lakes (see Figure 47) are located in basins at the boundary between the sandy moraine to the north and the gravelly outwash that extends southward to Detroit Lakes. At the south end of Little Floyd Lake a filled embayment extends for a short distance along the valley of a small stream to the south of the lake. Two feet of fair marl underlies an area of about 4 acres. The marl is covered with 3 feet of peat. A composite sample contained 64.10 per cent soluble carbonate.

In the northwestern bay of Little Floyd Lake and westward across the road to the northeast bay of Big Floyd Lake a narrow zone of marl has been deposited. On the west side of the road near the waterline several acres are underlaid by 4 to 5 feet of poor to fair marl covered by 2 feet of peat. Samples contained 57.40 per cent $CaCO_3$.

T. 139 N., R. 41 W., Sec. 34.—At the southeast margin of the city of Detroit Lakes, including part of the city's baseball park, is a filled embayment of Detroit Lake. Most of the embayment, covering an area of about 10 to 15 acres, is underlaid by 4 feet of marl covered by 3 to 5 feet of peat.

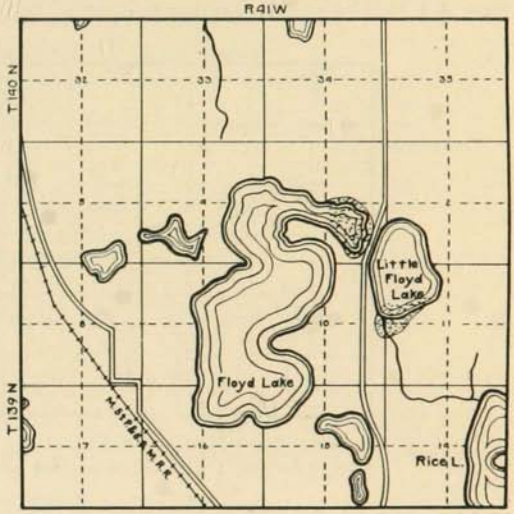

FIG. 47.—Map of Floyd Lake, Becker County. The stippled areas are marl deposits.

T. 140 N., R. 41 W., Buffalo Lake.—Buffalo Lake is a basin in the sandy moraine of the north-central portion of the county. Marl deposition was active in the northwestern portion of the lake when the water stood at a higher level. Around the west end of the lake a terrace of marl (see Figure 48) extends from the base of the moraine hills to the present water level. The marl is exposed at the surface and is from 8 to 10 feet deep. Some of it is very pure, containing as high as 95 per cent soluble carbonate. Composite samples composed of small samples taken at depth intervals of 3 feet assayed 72.10 per cent soluble carbonate. The marl extends out under the lake but was not tested beyond the waterline.

The east end of Buffalo Lake extends into the next township, where the entire bay is covered with marl under the water. An extension of the bay eastward during a higher water stage deposited marl over 100 yards beyond the present shore line. Near the road the marl is from 2 to 4 feet thick with no peat covering. A sample from near the waterline tested 78.5 per cent soluble carbonates. The deposit is of high grade and readily accessible.

Along the valley of the stream connecting Buffalo Lake and Round Lake is a zone of meadowland about one-fifth of a mile wide and nearly a half mile long. The area is covered by a thick bed of grassy peat below which is 4 feet of fair to good marl. Analyzed samples contained 73 per cent $CaCO_3$.

T. 139 N., R. 38 W., Toad Lake.—Toad Lake is in a basin at the north end of the outwash gravel area in the southeastern part of the county. It is bordered to the north by an exceptionally hilly moraine with very sharp knobs and ridges. Very little swamp or bog land surrounds the lake. On the west side of the lake a small bay extends southwestward into NE¼ Sec. 17. A small bog not over 5 acres in area extends beyond the bay. It is covered by 2 to 4 feet of peat underlaid by a marl bed 12 feet thick. A composite sample contained 48.50 per cent soluble carbonate.

T. 138 N., R. 41 W., Sec. 4.—Along the stream valley in the NW¼ Sec. 4 a bed of marl varying from 2 to 8 feet in thickness is found below

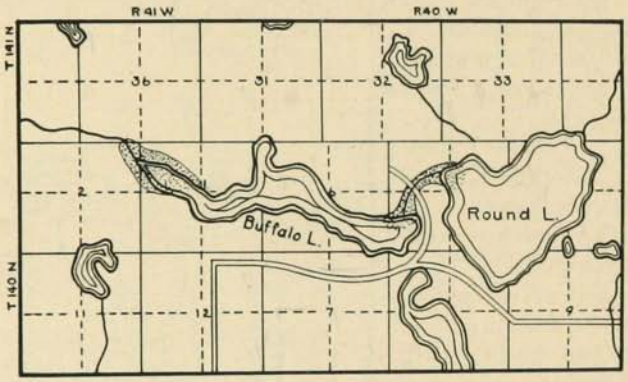

Fig. 48.—Map of Buffalo Lake and Round Lake in Becker County. The stippled areas are marl deposits.

3 feet of peat. The marl is continuous below the water of the bay. Th deposit covers at least 20 acres and is of good grade.

T. 138 N., R. 41 W., Sec. 1.—To the east of Detroit Lake in Section a small swampy bog, formerly connected as a bay of the lake, is locate between the Northern Pacific Railroad and the state highway. A sma pond fills the center of the swamp and is surrounded by a zone of wire grass marsh. This in turn is surrounded by a zone of tamarack an spruce trees. The entire bog covers about 8 acres. It is underlaid b a bed of marl from 6 to 8 feet thick, covered by 4 feet of peat. A composite sample contained 74 per cent $CaCO_3$.

T. 138 N., R. 40 W., Long Lake.—Long Lake is in a glacial basin in the gravelly outwash area that extends from the central portions of Otter Tail County northward into south-central Becker County. West and south of the lake is a region of rugged sandy moraine. At the east end of the lake a swampy area about 100 yards wide and a quarter of a mile long extends eastward to the Otter Tail River. The bog is covered with 2 feet of peat under which is a bed of sandy marl varying from 1 to 4 feet in thickness. A group of samples showed an average content of 40 per cent soluble carbonate.

T. 141 N., R. 39 W., Sec. 33.—Marl has been reported in the bog land along Egg River in W½ Sec. 33. About 120 yards east of the bridge over the river the marl may be seen along the floor of the stream. It is nearly pure white when dry and is undoubtedly of high grade.

T. 141, R. 38 W., Sec. 33, Greenwater Lake. — This lake is in a deep moraine basin in the sandy moraine that crosses Section 33. The banks of the lake are high and steep. A filled embayment at the northwestern end of the lake is partially filled with marl. An area of about 3 acres is underlaid by 4 feet of clayey marl covered by 2 feet of peat. A composite sample contained 46.60 per cent $CaCO_3$.

A small marl bed has been reported in Section 17, but it was not sampled.

ANALYSES OF MARL OF BECKER COUNTY

Location	Sample No.	Per Cent Soluble Carbonates
T. 141 N., R. 38 W., Sec. 33	282	46.6
T. 141 N., R. 38 W., Sec. 17	275	81.0
T. 140 N., R. 41 W., Sec. 2	277	64.5
T. 140 N., R. 41 W., Sec. 1	278	72.1
T. 140 N., R. 40 W., Sec. 5	279	78.5
T. 140 N., R. 40 W., Sec. 5	280	73.2
T. 139 N., R. 41 W., Sec. 34	276	73.2
T. 139 N., R. 41 W., Sec. 10	268	64.1
T. 139 N., R. 41 W., Sec. 3	269	57.4
T. 139 N., R. 38 W., Sec. 17	281	48.5
T. 138 N., R. 41 W., Sec. 1	270	74.0
T. 138 N., R. 40 W., Sec. 35	271	40.3

BELTRAMI COUNTY

General glacial features. — The southern shore of glacial Lake Agassiz crosses Beltrami County a short distance south of Red Lake. Much of the bed of this lake is still a muskeg swamp. In the southern portion of the county a series of clayey and sandy moraines extends in a northwest-southeast direction across the county. In the region of Bemidji a zone of outwash sands and gravel extending westward from Cass Lake crosses the county. In this outwash area most of the marl beds of the county are located.

In his study of the peat deposits of Beltrami County, Soper took soundings at fifteen widely separated localities in the muskegs of former Lake Agassiz. No marl beds were encountered below the peat. In most places the peat rests on a bluish laminated, sandy clay.

Descriptions and analyses of the marl beds that were tested and sampled are given below. (See Figure 49.)

T. 149 N., R. 33 W., Sec. 33. — Julia Lake is at the north margin of a clayey moraine that extends east-west across the county. A small stream connects it with Mud Lake, the eastern bay of which is less than a half mile distant. The two lakes serve as the headwaters of Mud River, which flows northward into Lower Red Lake. A strip of swampy bog several hundred feet wide connects the two lakes and is underlaid by sandy marl. The marl is 16 feet thick near the stream and is overlaid by 3 feet of peat. A composite sample composed of samples taken at depth intervals of 3 feet contained 67.70 per cent $CaCO_3$. Marl also underlies the north bay of Julia Lake, but it was not sampled.

In Section 31 marl underlies the narrow zone of swampy bog that fringes the south shore line of Mud Lake.

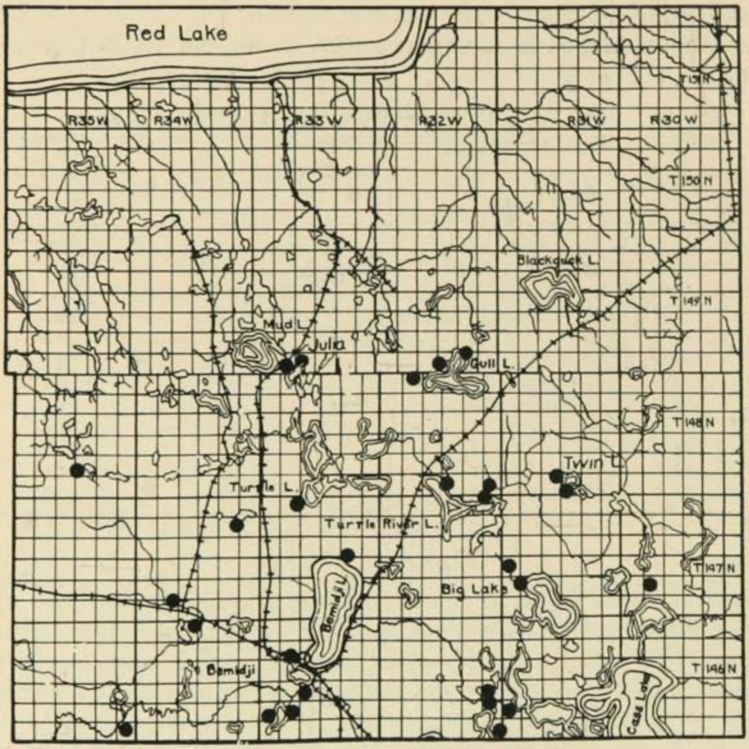

FIG. 49. — Map of the southern half of Beltrami County showing marl deposits.

T. 148 N., R. 32 W., Sec. 4, Gull Lake. — Marl beds around Gull Lake have been reported by Mr. M. B. Taylor, the county agricultural agent. In Sec. 4, T. 148 N., R. 32 W., marl is found in a filled embayment that was formerly a part of the west bay of the lake. Northeastward in the next township another deposit is located in Sec. 35, T. 149 N., R. 32 W. Neither of these deposits was sampled.

T. 148 N., R. 32 W., Turtle River Lake. — Turtle River Lake lies in both Turtle River and Port Hope townships. Its basin is at the north margin of the extensive gravelly outwash area that extends from the lake southward to Bemidji. North of the lake is hilly, sandy, and clayey moraine. The northeast portion of the lake tapers into a long narrow bay from which a sluggish stream flows toward the north. Most of the bay is a marl-filled bog. (See Figure 50.) There is no peat over the marl. Locally wire grass and rushes are growing on the upper surface of the marl. The depth of the deposit was not determined, but a sampling rod 20 feet long failed to reach the floor of the marl. It covers an area of about 20 acres and contains 90 per cent soluble carbonates. It is readily accessible, as a road grade is built over the deposit.

Smaller deposits are located along the north shore of the lake. In Section 34 a terrace of dry sandy marl about a foot thick is exposed along the roadside. A sample contained 38 per cent soluble carbonates.

T. 148 N., R. 31 W., Twin Lakes.—Marl has been reported in NE¼ Sec. 33 and in SW¼ Sec. 34, around the south and west shore line of Twin Lakes. The deposits were not sampled.

A small deposit has also been located in NE¼ Sec. 28, T. 148 N., R. 35 W., north of Pinewood.

T. 146 N., R. 33 W., Lake Irving.—Lake Irving (see Figure 51) lies in a glacial basin in typical gravelly and sandy outwash. Its basin serves as the channel for the Mississippi River. The northwest bay of the lake once covered the swampy area of over 20 acres that extends northward beyond the road and railroad in SE¼ Sec. 8. This bay of the lake, once over 25 feet deep, is now filled with marl. It is one of the most extensive and thickest marl beds discovered in the state. The deposition of marl in this embayment was completed so long ago that a heavy forest of tamarack and spruce and locally of maple and birch trees now grows on its surface. A thin bed of peat also has developed over the marl. The deposit is over 20 feet thick over an area of at least 20 acres. Some of the marl has been excavated by the Department of Agriculture and used as a soil-sweetener for the acid soils of the outwash sands. A group of composite samples averaged 86.40 per cent soluble carbonates.

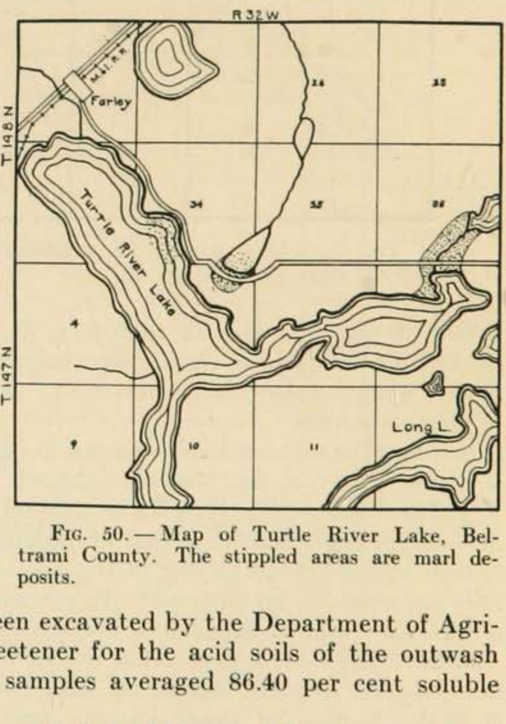

FIG. 50.—Map of Turtle River Lake, Beltrami County. The stippled areas are marl deposits.

T. 146 N., R. 33 W., Marquette Lake.—Marquette Lake (see Figure 51) lies to the south of the Mississippi River but is connected with the river by a wide channel that is locally lake-like in character. In Sections 20 and 29 abandoned embayments of the lake, now drained meadowlands, are underlaid by marl. In Section 29 a 10-acre area covered with

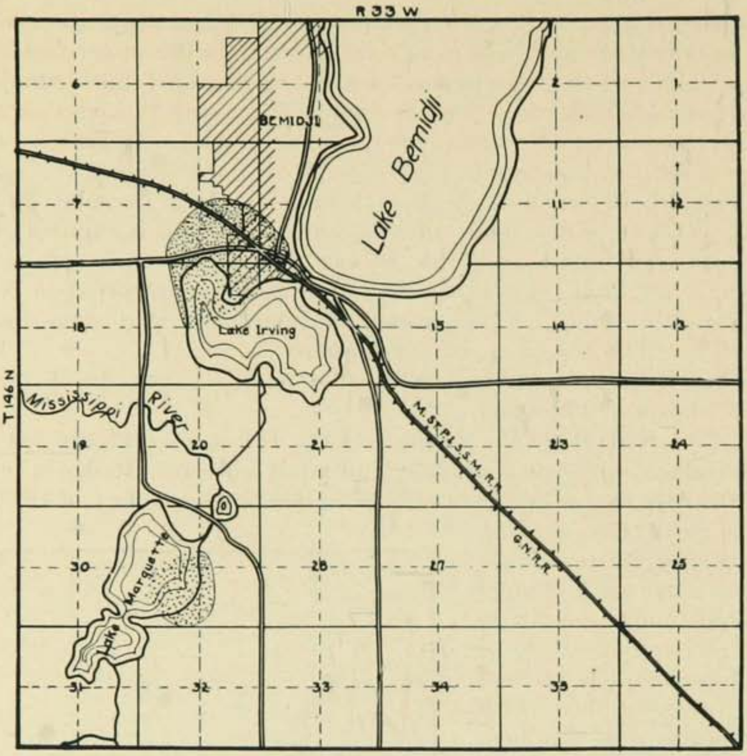

FIG. 51. — Map showing the occurrence of marl near Bemidji. The stippled areas are marl deposits.

4 feet of peat has from 2 to 6 feet of marl. The marl bed thickens toward the lake and is continuous under the water of the bay. A composite sample taken from below the peat contained 73.20 per cent soluble carbonate.

Another deposit has been reported in SE¼ Sec. 30, on the west side of the lake. This marl bed was not sampled.

T. 146 N., R. 32 W., Wolf Lake. — Wolf Lake bears a relation to the Mississippi River similar to that of Andrusa Lake. (See Figure 52.) The stream enters the north end of the lake and has its outlet only a half mile eastward at the same end. An extensive marl bed covers the region of the inlet and is continuous for some distance out under the lake. Another marl bed is located on the east side of the lake in the SE¼ Sec. 36 and extends southward into Sections 1 and 2 of T. 145 N., R. 32 W. Neither of these deposits was sampled for analysis.

T. 146 N., R. 31 W., Andrusa Lake. — Andrusa Lake basin is also part of the channel of the Mississippi River. (See Figure 52.) The river enters the southwest bay and flows out of the lake through the narrow channel connecting the basin of Allen's Lake with that of Andrusa.

Where the river enters the lake a wire-grass swamp covers an area of about 40 acres along the valley. Most of the bog is filled with marl. The marl is covered with less than a foot of peat and extends to a depth of 6 to 8 feet. A composite sample contained 83.40 per cent $CaCO_3$.

A group of deposits reported by the agricultural county agent, Mr. M. B. Taylor, but not sampled, includes the following locations:

(1) SW¼ Sec. 34, T. 146 N., R. 32 W., at the northeast bay of small lake.
(2) Sec. 4, T. 146 N., R. 32 W.
(3) Sec. 36, T. 146 N., R. 32 W.
(4) Sec. 32, T. 147 N., R. 34 W.
(5) Sec. 11, T. 147 N., R. 34 W.
(6) Sec. 19, T. 147 N., R. 31 W.
(7) Sec. 31, T. 147 N., R. 31 W.
(8) Sec. 29, T. 147 N., R. 30 W.

Analyses of Marls of Beltrami County

Location	Sample No.	Per Cent Soluble Carbonates
T. 149 N., R. 33 W., Sec. 32	291	67.7
T. 148 N., R. 32 W., Sec. 34	290	38.8
T. 147 N., R. 32 W., Sec. 1	289	84.8
T. 146 N., R. 33 W., Sec. 29	284	73.2
T. 146 N., R. 33 W., Sec. 8	285	75.7
T. 146 N., R. 33 W., Sec. 8	286	86.4
T. 146 N., R. 31 W., Sec. 30	287	83.2

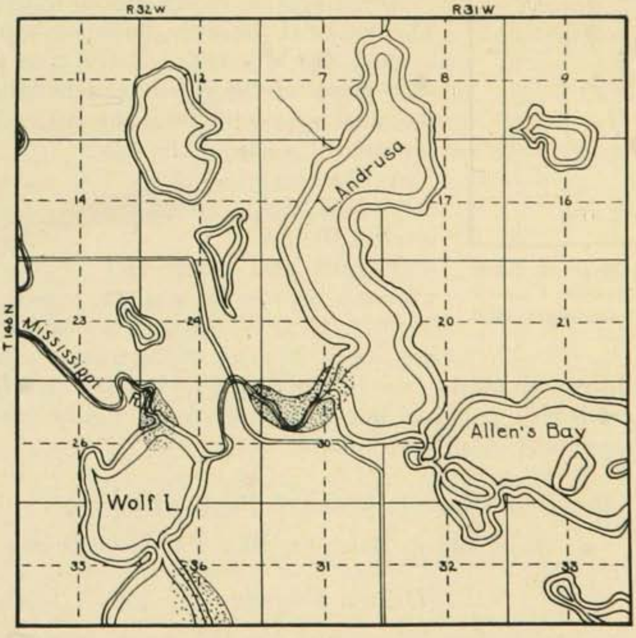

Fig. 52.—Map of a group of lakes along the channel of the Mississippi River in Beltrami County. The stippled areas are marl deposits.

Benton County

General glacial features. — Benton County is covered by the young red (Wisconsin) drift. Most of the county is occupied by an extensive till plain that is clayey to loamy in composition. The only moraine is a narrow one in the northeastern part of the county. There is a sandy plain of outwash gravels in the western portion, with narrow belts of dune sand where the sand is sufficiently fine-grained.

There are very few glacial basins in Benton County. The swampy areas which occupy shallow basins in the undulating till plains or the small pockets in the moraine area are mostly filled with peaty muck. Few of the basins contained clear water for a sufficiently long period of time for marl deposits to accumulate. Furthermore, most of the county is covered with a clayey till that tends to retard the leaching of lime carbonate and its migration toward the glacial basins.

Several good marl beds have accumulated in the gravelly outwash region in the northwestern part of the county. Descriptions and analyses of those that were tested and sampled are given below.

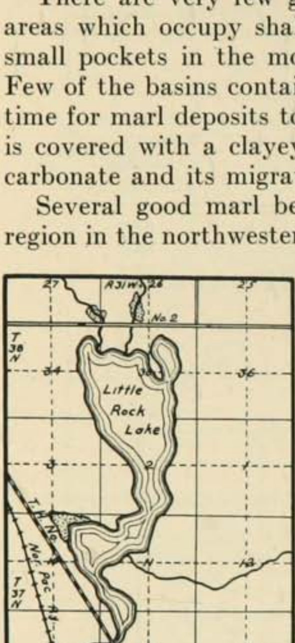

Fig. 53. — Map of Little Rock Lake, Benton County. The stippled areas are marl deposits.

T. 37 N., R. 31 W., Little Rock Lake. — Little Rock Lake occupies the only large basin in Benton County. It is located in the southern portion of the glacial outwash area. The regional drainage lines are north-south toward the Mississippi River, and undoubtedly much of the calcium carbonate now in the marl beds came from the outwash gravels toward the north of the lake.

At the north end of the lake marl is found at a considerable distance above the present level of the lake.

Toward the south end of the lake a widened bay loops westward into Sec. 10, T. 37 N., R. 31 W. Around the west end of the bay about 20 acres of the former extension of the bay is filled with marl. (See Figure 53.) The bed is 6 to 8 feet thick and is covered with 2 feet of fine wet sand. A composite sample contained 80.5 per cent soluble carbonate.

Bigstone, Blue Earth, and Brown Counties

No marl was discovered in Bigstone, Blue Earth, or Brown County.

Carver County

Carver County is largely covered by the great morainic system formed on the east margin of the Keewatin ice sheet. This young gray drift is clayey and therefore quite impervious to the circulation of ground water. Only two marl beds have been discovered in this county. One is located in the basin of a small lake about one and one-half miles north of Lake Waconia. The marl covers an area of about 4 acres. It is from 2 to 4 feet thick and is overlaid by 8 feet of mucky peat. A composite sample contained 54.50 per cent calcium carbonate.

A deposit near Chaska has been reported by Mr. A. T. Faber. It was not sampled.

Cass County

General glacial features.—Nearly all of Cass County is covered by the young gray Keewatin drift. A small area in the southeast corner of the county lies within the limits of the young red or Patrician ice sheet. The county is separable into several distinct regions on the basis of the types of glacial deposits. To the north on the south side of the Mississippi River and Winnibigoshish Lake is a plain of sandy gravel that extends south about as far as the grade of the Great Northern Railroad. To the south of this area, on the borders of Leech Lake, is a great till plain with a pebbly clay loam drift. Still farther south the drift changes to a sandy and gravelly tract of rolling morainic topography which covers several townships of this district and extends westward in a broad belt across Hubbard County to the headwaters of the Mississippi River.

Small bogs are distributed throughout the county. Many of them are along the former shores of the numerous lakes. Most of the big bogs of the NE¼ of the county are in a region of clayey till plains or moraines and no marl is found in their basins. Soundings in the region of Bena and Federal Dam show that the peat is underlaid by fine sands or clay. The smaller bogs in the central and southern parts of the county are of two types, muskegs and meadows. Some of these represent filled lakes while others are built-up deposits in shallow basins. All the marl is confined to the first type.

Descriptions and analyses of the marl beds that were sounded and sampled are given below. (See Figure 54.)

T. 144 N., R. 31 W., Swamp Lake.—Swamp Lake is located west of Leech Lake. Its basin is in a region of bowlder clay or till plains. In the vicinity of the lake the till is very stony and somewhat sandy. An extensive cedar swamp covers about 80 acres along the west side of the lake. Soundings taken at irregular intervals across the swamp indicate that the whole basin is underlaid by a thick bed of marl. Its total depths could not be determined, but a sampling rod 20 feet long failed to reach bottom. The deposit is covered by about 5 feet of peat. A composite sample composed of small samples at depth intervals of 3 feet contained 83.80 per cent $CaCO_3$.

T. 140 N., R. 29 W., Child Lake.—Child Lake is located south of Leech Lake and east of Hackensack in Section 16. Its basin is in a rugged, sandy, and gravelly moraine from which lime carbonate is readily

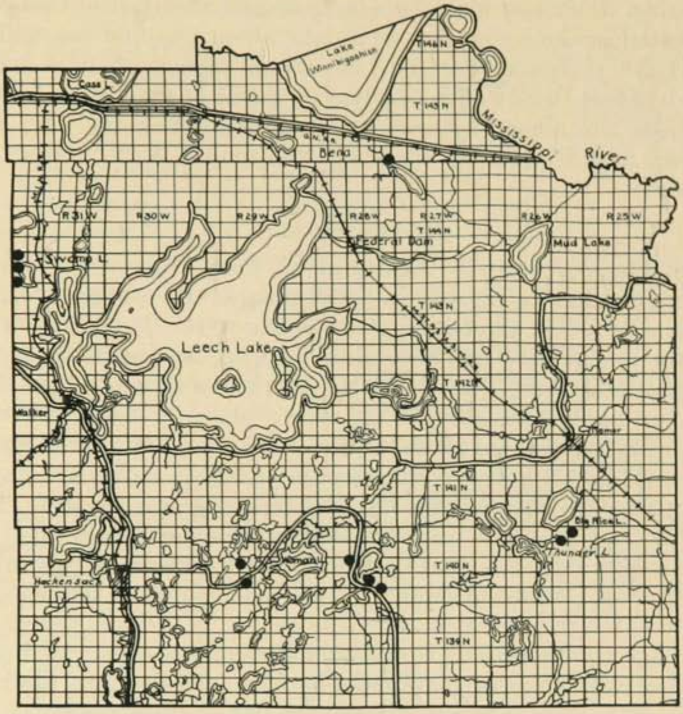

FIG. 54. — Map of the northern part of Cass County showing marl deposits.

leached by the percolating ground water. A wire-grass bog occupies former extension of the bay at the south end of the lake and extend southward for nearly a mile along the valley of a small stream. A be of marl 4 to 6 feet thick underlies the whole bog area. It is covered wit 5 feet of grassy peat. A composite sample contained 81.50 per cen soluble carbonate.

A thin marl bed in the bog in SE¼ Sec. 21 has been reported also bu has not been sampled.

T. 140 N., R. 28 W., Little Boy Lake. — Little Boy Lake is in a glacia basin at the east end of the sandy moraine that crosses the county south of Leech Lake. A number of small filled embayments that were at one time deeper bays are underlaid by marl deposits. (See Figure 55.)

In E½ Sec. 15, on the west side of the lake, a 10-acre area has a 4-foot bed of marl covered with 6 feet of peat. A composite sample contained 61.40 per cent soluble carbonates.

At the south end of the lake, along the stream that connects it with Wabedo Lake, a narrow belt of bog is underlaid by a marl bed 2 to 6 feet thick containing 61.80 per cent soluble carbonate.

In Section 26, in the bay receiving the waters from the swampy area in the southeast corner of the township, marl has also been reported. It was not sampled in this survey.

T. 140 N., R. 26 W., Thunder Lake.—Thunder Lake is in a glacial basin in a narrow belt of high sandy morainic hills in the eastern part of the county. A long, narrow bay extends northeastward for nearly 2 miles from the east shore of the lake. A narrow fringe of filled bog surrounds the bay between the base of the morainic hills and the present waterline. Most of the bog is underlaid by high-grade marl. An area of about 15 acres has a marl bed from 6 to 10 feet thick covered by 4 to 5 feet of peat. A group of samples showed an average analysis of 90.30 per cent soluble carbonates.

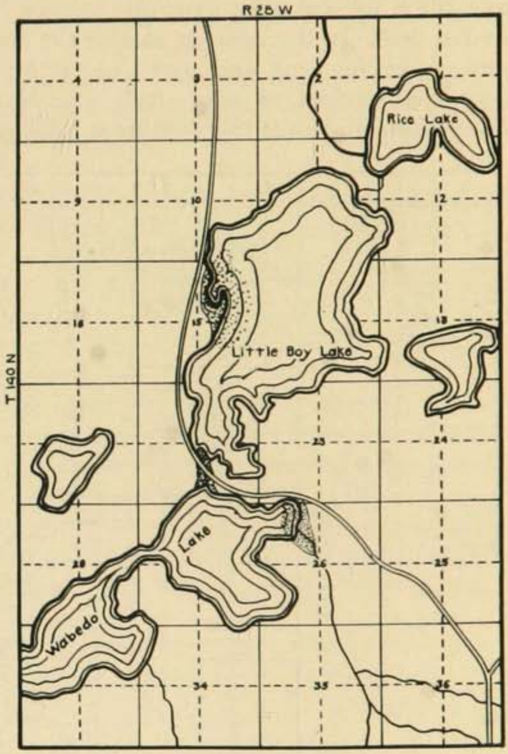

FIG. 55.—Map of Little Boy Lake and vicinity. The stippled areas are marl deposits.

In the southern part of the county marl is found in the area of gravelly outwash that parallels the Crow Wing River. Small deposits have been reported at the following locations:

1. Near Pillager, in the basin of former Pillager Lake, about a mile north of the village.

2. Secs. 18 and 19, T. 135 N., R. 32 W. Also westward in Wadena County, in the bog that surrounds the small lake on the county line. Marl is exposed along the drainage ditch.

3. Sec. 13, T. 135 N., R. 32 W., in the small basin along the creek channel.

ANALYSES OF MARLS OF CASS COUNTY

Location	Sample No.	Per Cent Soluble Carbonates
T. 145 N., R. 30 W., Sec. 18	288	36.4
T. 140 N., R. 29 W., Sec. 16	294	81.5
T. 140 N., R. 28 W., Sec. 22	296	61.8
T. 140 N., R. 28 W., Sec. 15	295	61.4
T. 140 N., R. 26 W., Sec. 2	297	90.3

Chisago County

General glacial features. — Chisago County was almost entirely covered by the Grantsburg lobe of the Keewatin ice sheet. A few square miles in the southeast corner of the county show the young red drift at the surface, and toward the valley of the St. Croix River the young gray till is present only as a thin veneer over the ridges and knolls of the red drift. In the western part of the county is a broad strip of dune sand, extending east and north as far as Harris. There are two conspicuous moraines of gray drift, one along the east side of Sunrise River, formed along the southeast side of the Grantsburg lobe, an

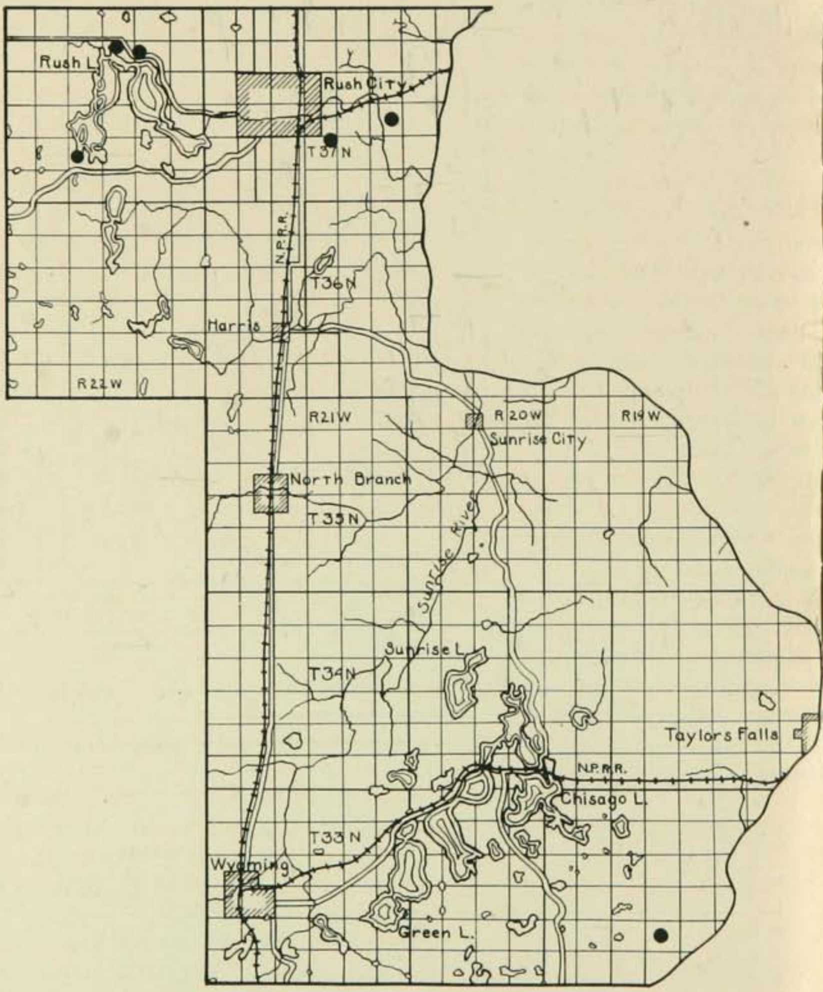

Fig. 56. — Map of Chisago County showing marl deposits.

another in the northwest part of the county, formed along the northwest edge of the lobe.

The greatest number of glacial basins occur in the moraine in the southeastern part of the county. Since, however, the glacial drift there is mostly clayey till, very little marl is being deposited in the lake basins. In the central part of the county the lakes seem to be along the courses of partly filled valleys, with fine-grained impervious clay along the shore line.

The conditions most favorable for marl deposition are in the northern part of the county, where small areas of sandy moraine and gravelly outwash deposits are found in the marginal moraine of the Grantsburg lobe of the ice sheet.

Descriptions and analyses of the marl beds that were sounded and sampled are given below. (See Figure 56.)

T. 37 N., R. 22 W., Rush Lake.—The basin of Rush Lake is in the northwest marginal moraine of the Grantsburg lobe of the Keewatin ice sheet. It is very irregular in outline, and several of the narrow elongated bays are bordered by steep morainic hills. In these bays and filled embayments the marl beds occur.

In Section 10 a narrow belt of bog parallels the valley of a creek flowing into the lake. The area is underlaid by 3 to 5 feet of shelly marl that grades downward into shelly sand. A composite sample contained 26.60 per cent soluble carbonate.

West of the creek in a number of places the beach gravels are thoroughly cemented with calcium carbonate. Still farther west, in NW¼ Sec. 10, another small bed of poor shelly marl is located below 4 feet of peat.

Around the southwest bay of the lake in Section 28 about 5 acres of the bay are filled with shelly marl and peat. Organic material contaminates all the marl. A composite sample contained 57 per cent soluble carbonate.

Other small deposits have been reported along the streams in Secs. 24 and 27, T. 37 N., R. 21 W., and in Sec. 29, T. 33 N., R. 19 W., but they were not sampled.

Clearwater County

Because of the predominance of clay moraine and clayey bowlder plains over its surface, Clearwater County has few deposits of marl. (See Figure 57.) There are several large sandy moraines in the southern part of the county, but they contain only a few lake basins. The marl deposits that have been discovered are in the belts of outwash gravels in the central part of the county. These gravels represent extensions of the large area in the vicinity of Bemidji.

T. 147 N., R. 36 W., Secs. 25 and 36.—A deposit of marl covering several hundred acres has been reported by Mr. J. R. Halton. The bed is located in Sections 25 and 36, about three and a half miles east and south of Shevlin, in the meadow and bog land around a small lake. It reported to be about 20 feet thick and of good quality.

T. 146 N., R. 36 W.—Small deposits, some of high-grade marl, hav been reported in the outwash gravels in the northwestern part of th township. In S½ Sec. 3 and in Sec. 4 two small bogs are underlaid b marl. A small lake in NE¼ Sec. 11 has a thin bed of marl in the bo

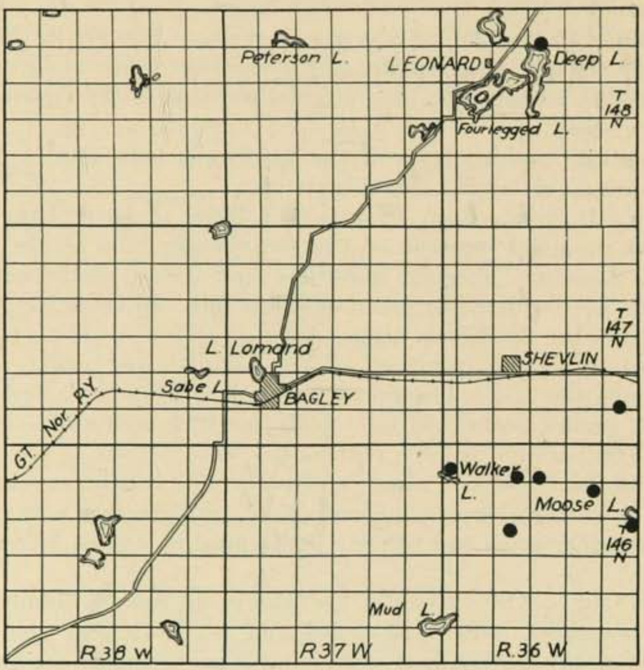

FIG. 57.—Map of the central part of Clearwater County showing marl deposits.

surrounding the lake. The west end of Moose Lake occupies part NE¼ Sec. 13 and extends eastward into the next township. A bed marl covers the southwestern portion of the basin.

In the northwestern part of the township a small bed of marl is foun in the basin of Walker Lake, and another deposit has been discovere in N½ Sec. 16.

T. 147 N., R. 37 W.—A bed of marl has been located in the meadow land along the Clearwater Creek west of Bagley. This deposit was no sampled.

T. 148 N., R. 36 W.—Marl has been located at the margins of Deep Lake on the farm of A. P. Rymes, one and one-half miles east of Leon ard. This deposit was not sampled.

Crow Wing County

General glacial features.—A number of glacial features, combined with the general drainage of Crow Wing County, make it a region especially favorable for the deposition of marl. It has more than four times as many marl deposits as any other county in the state. The enormous area of rolling outwash gravel in the north-central part of the county,

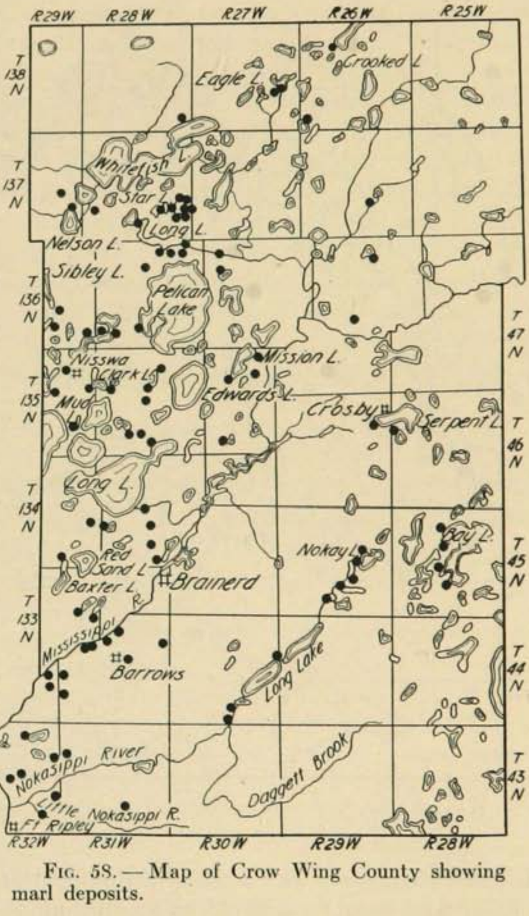

Fig. 58.—Map of Crow Wing County showing marl deposits.

located with its regional drainage toward the Mississippi River and bordered both on the north and on the south by high moraines of coarse and porous drift, forms an area very favorable for the leaching of lime carbonate.

The northern half of the county is dotted with hundreds of lakes that occupy irregular depressions in the glacial drift. Many of the depressions are partly or entirely filled with peat or marl. Over 60,000 acres in the county are classified as peat land. Some of this land is of tl built-up bog type and carries no marl.

Descriptions and analyses of the marl beds that were sounded an sampled are given below. (See Figure 58.)

T. 138 N., R. 27 W., Eagle Lake. — Eagle Lake basin is in an area sandy moraine and is bordered by a series of high, sandy hills along tl

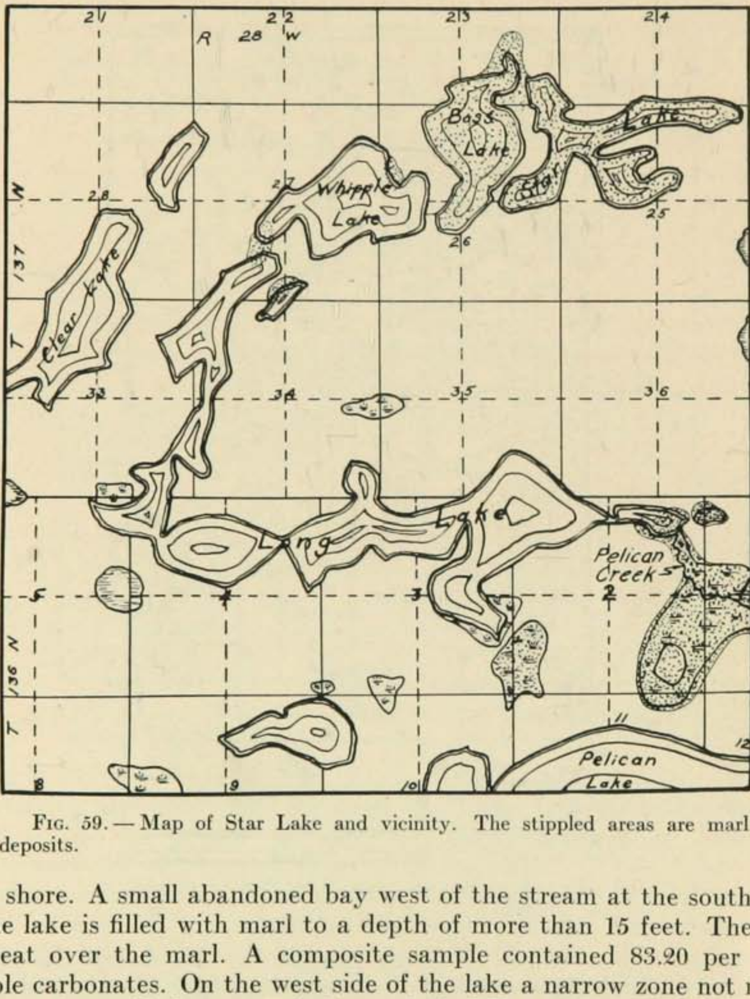

FIG. 59. — Map of Star Lake and vicinity. The stippled areas are marl deposits.

west shore. A small abandoned bay west of the stream at the south e of the lake is filled with marl to a depth of more than 15 feet. There no peat over the marl. A composite sample contained 83.20 per cen soluble carbonates. On the west side of the lake a narrow zone not mor than 200 feet wide between the base of the hills and the present wate line is covered by a bed of marl 4 feet thick. Near the center of the lak marl deposition is now in progress. A low island in the lake is covere with marl, showing that the island was once below the water level.

T. 138 N., R. 26 W., Crooked Lake. — Crooked Lake is in a long, nar row, valley-like basin in the northeastern part of the county. Marl found covering the sand and gravel of the abandoned beach lines around the south portion of the lake. In the southwestern bay an area of 3 or 4 acres has a marl bed from 8 inches to a foot thick.

T. 138 N., R. 26 W., Sec. 29.—A filled bay along the northeast shore of the small lake between Sections 29 and 30 has several acres underlaid by a poor grade of marl. The marl is covered with 3 feet of peat.

T. 137 N., R. 29 W., Nelson Lake.—Nelson Lake lies in Sections 23, 24, 25, and 26. A wire-grass swamp covering approximately 30 acres occupies a former extension of the lake toward the south and southwest. From 15 to 20 feet of very watery marl fills the bog area. It is covered with 6 feet of grassy peat and is underlaid by a rubbery blue clay. A composite sample contained 68.40 per cent soluble carbonates.

T. 137 N., R. 28 W., Star Lake.—The region around Star Lake has one of the most extensive deposits of marl in the state. (See Figure 59.) It is one of a group of seven lakes in irregular basins in an area of coarse, gravelly, and sandy drift. The topography is sufficiently rugged to allow the active circulation of ground water toward the basins. The general geologic setting is such that very favorable conditions exist for the leaching of lime carbonate. A number of bogs around the lake were formerly part of the lake basin. Soper estimated the area of bog land to be 90 acres.

The entire lake, which covers approximately 300 acres, together with all the bog, is underlaid by a marl bed ranging from 15 to more than 20 feet in thickness. Around the southeast bay an area 350 feet by 500 feet has marl exposed at the surface 3 feet above the present water level. Along the outer margin of the filled embayment the marl is 6 feet thick, and it becomes deeper toward the waterline, where it is more than 15 feet thick.

The drained open meadow in NE¼ Sec. 25 is a former arm of the lake bordered on the north by a high esker-like ridge. Near its margin marl is deposited in a bed 4 feet thick. In line with the axis of the bay, near the present drainage ditch, the marl is 12 to 18 feet thick.

In NW¼ Sec. 25 marl is exposed at some distance beyond the shore line, but here the bed is only 3 to 6 feet thick. All along the north shore of the lake, marl is visible at the water's edge, but the exposures do not represent the true thickness of the marl, since much of it has been pushed and piled up by the ice.

Along the narrow channel connecting Star and Bass lakes in Section 23, a filled embayment covers about 50 acres in the SE¼ of the section. Here the marl is from 4 to 8 feet thick. A number of tons have been removed from a pit near the northeast end of Bass Lake for use in the construction of the roads maintained by the county. The northern half of Bass Lake is also underlaid by marl.

At the east end of Kimble Lake in Sec. 26, T. 137 N., R. 28 W., a thin bed of marl covers the sands of the former beach lines. On most of the low terraces it is less than a foot thick and is contaminated with sand.

Many of the pebbles and rocks in the stream connecting Bass ar Kimble lakes are coated with lime carbonate.

At the southwest end of Kimble Lake in Sec. 27, T. 137 N., R. 28 W a thin bed of marl is exposed where the stream connects this lake wit the north bay of Long Lake. Here the marl is from 1 to 3 feet thic Farther south in the same section a 10-acre area underlaid by marl skir the small lake east of the north tip of Long Lake. Here the marl from 4 to 8 feet thick, with a thin covering of peat. In NW¼ Sec. 2 T. 137 N., R. 28 W., a small pond is fringed and partially filled by 3- to 5-foot bed of poor marl under 4 feet of peat. It contains 61.40 p cent soluble carbonates.

In W½ Sec. 30, T. 137 N., R. 28 W., a cat-tail swamp with partially d composed tamarack stumps parallels the course of a creek that flo northward to Whitefish Lake. A marl bed 2 to 6 feet thick underli the swamp. It is covered with 4 feet of peat. The deposit covers at lea 20 acres and is of a good grade. It contained 80.10 per cent soluble ca bonates.

T. 137 N., R. 26 W., Sec. 27.—An irregular muskeg covered wi sphagnum is in a shallow basin in low, rolling topography in NE¼ Se 27. It covers an area of about 5 acres and is underlaid by a marl be 2 feet thick under 5 feet of peat. A composite sample contained 38. per cent soluble carbonates. The deposit is readily accessible, being on a few yards from the county road.

T. 136 N., R. 29 W., Sibley Lake.—Sibley Lake is located west a southwest of Pequot, near the county line between Crow Wing and C counties. Around its southeast bay in Section 22 a filled embayme extends to and southward beyond the road along the section line. area of about 30 acres is underlaid by a thick marl bed covered by 8 10 feet of peat. A 20-foot sounding rod failed to reach the bottom the marl. The County Highway Department has dredged some of t marl for road construction. A composite sample contained 59.10 per ce soluble carbonates.

T. 136 N., R. 29 W., Sec. 27.—South of Sibley Lake is a small la that once stood at a higher level. A belt of meadowland 100 yards wi parallels its southeastern shore line for a distance of over a quarter a mile between the road and the lake. The entire area is covered by thick stratum of peat and marl. A marl bed 8 to 10 feet thick is buri under 8 feet of peat. The bog is partially covered with a growth of w lows and water birch. A composite sample of the marl contained 60 p cent soluble carbonates.

Two other small deposits have been located in this township, one i the swamp in SE¼ Sec. 26 and another in NW¼ Sec. 36.

T. 136 N., R. 28 W., Secs. 1 and 2.—An extensive area of open meado bog exists along Pelican Creek about three-quarters of a mile north o Pelican Lake. This bog occupies an estuary between two lakes and i now underlaid by at least 2 feet of marl. In the SE¼ of the sectio where a growth of wild rice covers about 20 acres of the bog, the marl is much thicker but of a poorer quality. The entire deposit covers an area of 250 acres. The marl is covered by an average thickness of 5 feet of peat. Samples from the thin marl bed in the NE¼ of the section contained 84 per cent soluble carbonates, whereas those from the rice swamp to the southeast showed only 55 per cent.

T. 136 N., R. 28 W., Secs. 2 and 3, Long Lake.—The south bay of Long Lake extends into the south half of both Sections 2 and 3. In SW¼ Sec. 2 a filled embayment of the lake is drained and cultivated. Below 5 to 7 feet of partially dried peat a bed of marl more than 15 feet thick covers about 15 acres. A composite sample contained 91.60 per cent soluble carbonates. In SE¼ Sec. 3 a low terrace of marl extends around the south bay of Long Lake. The marl is exposed at the surface but locally is overgrown by brush. The deposit is less than a foot thick at its outer margin but is 5 feet thick near the present waterline. It contains 94 per cent soluble carbonates. A pit has been opened by the County Highway Department, and many tons have been removed for road construction.

T. 136 N., R. 28 W., Sec. 9, Schaffer Lake.—A thick bed of fair marl fills the west bay of Schaffer Lake. Most of the lake is filled with sandy muck, but about 8 acres around the west bay are underlaid by from 4 to 18 feet of marl covered with 2 feet of peat. A composite sample contained 60 per cent soluble carbonate.

A small filled embayment along the north shore of the lake also contains marl. An area of about 4 acres is separated from the lake by the grade of the county highway. The bog has a marl bed about 3 feet thick.

T. 136 N., R. 28 W., Pelican Lake.—Along the west side of Pelican Lake a narrow point of land over two miles long extends into the lake as a peninsula. In Section 28 a large area of the point was once below the water level of the lake. In the SE¼ of the section a former embayment covers an area of over 80 acres. It is underlaid by 4 to 8 feet of poor marl, contaminated with organic material. A layer of peat and clayey organic muck covers the marl. A group of samples showed an average analysis of 42 per cent soluble carbonate.

In the NW¼ of the section and extending westward into Section 29 in a small shallow bog with a thin bed of marl under a covering of sphagnum moss. It contained 44 per cent soluble carbonates.

T. 136 N., R. 28 W., Secs. 30 and 31, Upper and Middle Cullen Lakes.—A big deposit of good marl fills a former bay of Middle Cullen Lake in N½ Sec. 31. The marl is west of the junction of Upper and Middle Cullen lakes. The area is several feet above the present water level and is sufficiently well drained to support a heavy growth of spruce and tamarack trees. It is now pasture and meadowland. The owner of the property has excavated some of the marl for local use. It fills an area of about 10 to 15 acres to an undetermined depth. A sounding rod 20 feet long failed to reach the bottom of the marl. It is covered by 3 feet of peat and is isolated from the present lake shore by a growth of hard wood timber on a former beach.

A layer of marl a few inches thick is deposited along both sides of the channel connecting Upper and Middle Cullen lakes in SE¼ Sec. 30. Much of it is covered with nearly 2 feet of sandy fill.

T. 136 N., R. 27 W., Sec. 6.—A belt 100 yards wide along the creek that crosses the S½ of the section has a marl bed from 2 to 4 feet thick under 5 feet of peat. At some places thick sandbars cover the peat. The marl contained 55 per cent soluble carbonates.

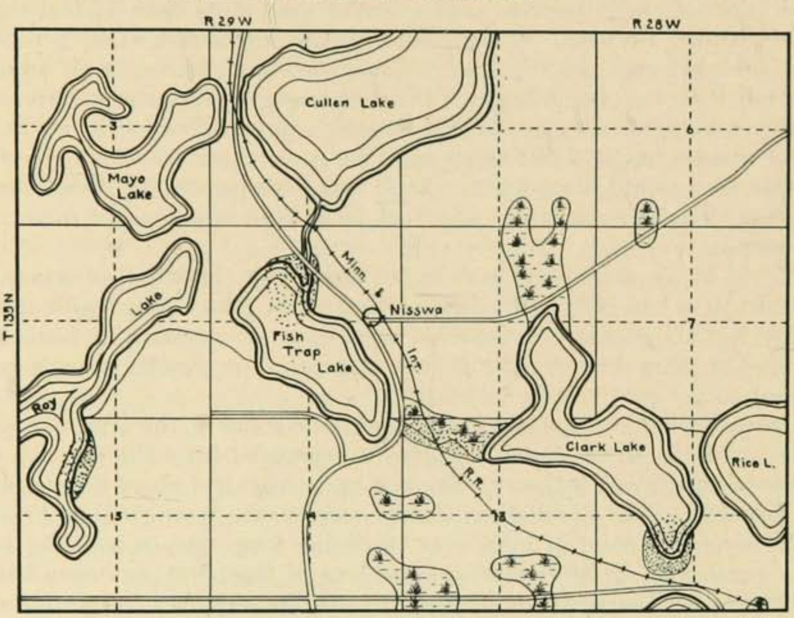

FIG. 60.—Map of a group of lakes near Nisswa, Crow Wing County. The stippled areas are marl deposits.

T. 136 N., R. 27 W., Sec. 7.—A small embayment isolated by an old beach from Lizard Lake contains a bed of marl 2 feet thick under 7 feet of peat. The filled bay covers about 8 acres. A composite sample contained 73.60 per cent soluble carbonates.

T. 136 N., R. 27 W., Sec. 28.—A small bed of marl has been reported in SE¼ Sec. 28. It was not sampled.

T. 135 N., R. 29 W., Fish Trap Lake.—A former bay of Fish Trap Lake extended from the north end of the lake to the grade of the Minnesota and International Railroad. It covers an area of over 20 acres. A shallow stream, filled with a growth of wild rice, flows through the bog connecting Fish Trap and Cullen lakes. The whole area is a wire-grass bog partially filled with marl. (See Figure 60.) The marl bed is 10 to 12 feet thick and is covered with 4 feet of peat. A composite sample contained 75 per cent soluble carbonate.

T. 135 N., R. 29 W., Clark Lake.—Clark Lake basin is on the east margin of the township and extends into Sections 7 and 18 of the adjoining township. In N½ Sec. 13, about 4 acres of the southwest bay are filled with marl and peat. (See Figure 60.) The outer margin of the filled bay is covered by a heavy growth of willows and the inner zone is a floating wire-grass bog. Beyond the waterline most of the bay has a thick growth of wild rice. The marl bed is 4 to 6 feet thick and is overlaid by 2 feet of peat. A composite sample contained 66.20 per cent soluble carbonates.

T. 135 N., R. 29 W., Roy Lake.—The basin of Roy Lake is in the west-central part of the township, in an area of rugged sand and gravel hills. In NW¼ Sec. 15 (see Figure 60) is a small bay filled with marl and peat to about 2 feet above the water level. The remaining portion of the shore line is bordered by steep hills that extend to the water's edge. The marl covers an area of about 8 acres to a thickness of 6 to 10 feet. It is covered by 3 feet of peat. A composite sample contained 80 per cent soluble carbonate.

T. 135 N., R. 28 W., Garden Lake.—Garden Lake is located at the corners of Sections 9, 10, 15, and 16, west of Lake Edward. Its northeast bay in NW¼ Sec. 10 is partly filled with marl and peat. About 40 acres of the embayment are now covered by a heavy growth of tamarack and spruce. A thin bed of marl, not more than a foot thick, underlies about 3 feet of peat. The marl thins out to a seam a few inches thick near the waterline. A sample contained 83.60 per cent soluble carbonate.

T. 135 N., R. 28 W., Sec. 16.—A shallow basin almost completely filled with peat and marl covers most of the SW¼ of the section. It was once a shallow lake. Around the muddy pond at the south section line, 9 feet of marl underlies 3 feet of peat. This thick bed extends over only 2 or 3 acres. Farther northwestward a thin bed of poor marl contaminated with peaty material underlies the whole marshy area. A group of samples averaged 52 per cent soluble carbonates.

T. 135 N., R. 28 W., Gladstone Lake.—Around the southeast bay of Gladstone Lake, a former extension of the lake is now completely isolated by a succession of ice-shoved beach lines. A heavy growth of sphagnum has built the bog several feet above the water level. A small bog to the west of the road has a 2-foot bed of marl under 7 feet of peat. It contained 84 per cent soluble carbonate. East of the road the marl is slightly thicker, but the peat cover also is thicker. A composite sample showed 80.50 per cent soluble carbonate.

T. 135 N., R. 28 W., Sec. 33.—A bed of marl covering several acres has been reported in SE¼ Sec. 33, west of the northeast bay of Long Lake. It was not sampled.

T. 135 N., R. 27 W., Mission Lake.—Mission Lake is in a glacial basin a mile west of the Mississippi River. The lake is bordered by rolling gravelly drift. Marl is present under the water of the lake and on low dry terraces around the south and east portions of the basin. Along the west shore of the southwest bay, an old lake terrace is covered with about a foot of dry hard marl. (See Figure 61.) Locally the marl is covered with ferruginous clay that is weathered red. Some of it may represent bog iron ore. A heavy forest of ash and elm covers the marl bed. A large area has been stripped and the marl removed for road construction. A composite sample contained 40 per cent soluble carbonates.

Along the east shore of the lake, marl is present in the valley of the outlet to the Mississippi River. A narrow zone of low swampy ground is underlaid by 2 feet of clayey marl under 18 inches of sod. The marl contains 30 per cent soluble carbonates. Farther north in Section 4 a wide belt of meadowland that was once part of the lake basin is now drained. A marl bed less than a foot thick covers an area of about 100 acres. There is a thin layer of sod above the marl.

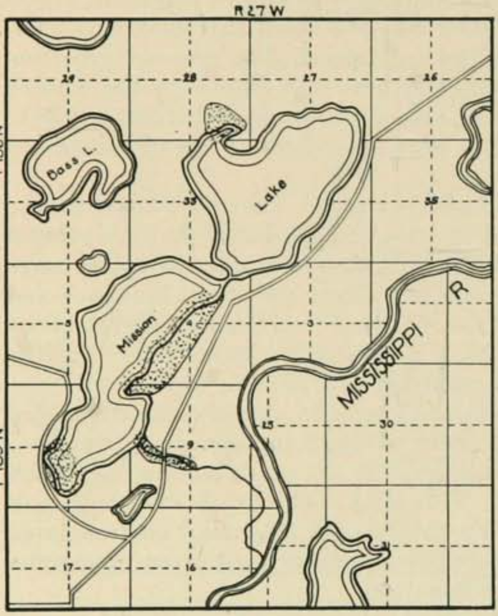

FIG. 61. — Map of Mission Lake, Crow Wing County. The stippled areas are marl deposits.

T. 135 N., R. 27 W., Sec. 29. — An embayment from the channel of the Mississippi River occupies over 40 acres in NE¼ Sec. 29. A small pond near the corner of the section is surrounded and underlaid by a marl bed that extends south for a distance of nearly a half mile. The marl is under 4 feet of peat.

T. 135, R. 29 W., Mud Lake. — Mud Lake is located in a glacial basin on the narrow strip of land that separates Gull Lake, Round Lake, and Hubert Lake. The basin is so nearly filled that wild rice thrives on its floor. A zone of floating bog nearly 100 yards in width surrounds the present waterline. This belt is underlaid by 10 to 15 feet of very wet marl. The marl bed is thickest near the waterline and undoubtedly extends out over the floor of the shallow lake. A composite sample showed 35 per cent soluble carbonates.

T. 134 N., R. 29 W., Secs. 23 and 24. — A mud-filled pond with a narrow arm-like bay extending toward the southwest occupies part of NW¼ Sec. 24. A 2-foot bed of marl covers an area of at least 10 acres to the east of the state highway. It is covered with 6 to 8 feet of peat. A composite sample contained 70.8 per cent soluble carbonate.

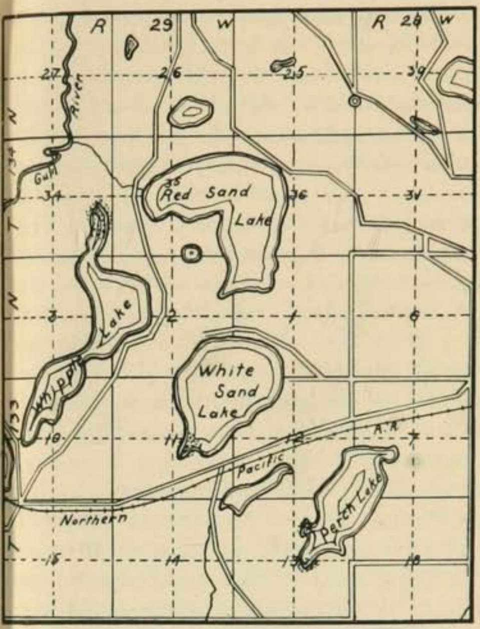

Fig. 62. — Map of a group of lakes west of Brainerd. The stippled areas are marl deposits.

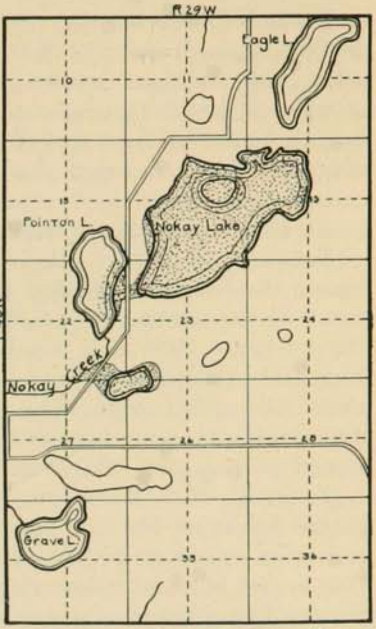

Fig. 63. — Map of Nokay Lake and vicinity, Crow Wing County. The stippled areas are marl deposits.

In Section 23, west of the highway, an extension of the same bog has a thin bed of marl in a narrow zone along the center of the marsh. It is covered with 8 to 10 feet of peat. There is no marl near the waterline of the partially filled pond farther toward the southwest in S½ Sec. 23.

T. 134 N., R. 29 W., Whipple Lake. — The north arm of Whipple Lake extends into SE¼ Sec. 34. (See Figure 62.) The water level of this arm is so low that wire grass is now growing over most of the lake sediments. Around the margin of the deeper portion of the bay is a bed of marl 2 feet thick below 8 to 10 feet of peat. The marl is high in organic matter. A group of samples averaged 65 per cent soluble carbonates.

Another small deposit has been reported in Section 25. It was not sampled.

T. 134 N., R. 28 W., Sec. 21. — In SW¼ SW¼ Sec. 21 a thin seam of blue marl less than 6 inches thick is found below the sod of the meadow that covers nearly 40 acres in that quarter of the section. The seam is too thin to be excavated. A sample carried 30 per cent soluble carbonates.

T. 134 N., R. 28 W., Sec. 28. — Two to 3 feet of poor marl, contaminated with peat, is located in SE¼ Sec. 28, around a muck-filled bog and pond. Drumlins of sandy drift are scattered throughout the swampy area, which covers nearly 40 acres. The marl is covered with 10 feet of peat. A sample contained 55 per cent soluble carbonates.

T. 134 N., R. 28 W., Sec. 33.—A drained wire-grass swamp occupies a shallow basin in the S½ of this section. It is bordered on the west by a high ridge of coarse sandy drift, and the east and south margins show abandoned beach lines of a former glacial lake. About 60 acres of the bog are underlaid by 3 feet of poor peaty marl covered with 8 to 10 feet of grassy peat. A composite sample contained 47.80 per cent soluble carbonates.

Another small deposit reported in Section 35 was not sampled.

T. 133 N., R. 29 W., White Sand Lake.—A small bed of fair marl covers the floor of a shallow pond that occupies an abandoned embayment of the south arm of White Sand Lake. (See Figure 62.) Ice shoved beach lines now separate it from the lake. A level sandy area surrounds the pond. The road grade of State Highway No. 2 passes along its south margin. The pond covers an area of about 4 acres, all underlaid with marl from 2 to 8 feet thick. A composite sample contained 66 per cent soluble carbonates.

T. 133 N., R. 29 W., Perch Lake.—Perch Lake is in a coarse, sandy glacial basin, on the line between Ranges 28 and 29. (See Figure 62.) A former extension of the southwest bay occupied an area of 10 acres that is now bog and meadowland in S½ Sec. 13. A thin layer of marl less than a foot thick was deposited over the lake sands before the water receded, and marl deposition is still in progress under the water of the present bay. Along the axis of an old bay in the SE¼ of the section, the marl is from 3 to 5 feet thick under 3 feet of peat. This thicker bed of marl covers less than an acre. A small test pit has been opened and a small amount of marl excavated for local use.

Other small deposits have been located in Sections 15 and 23 in this township. They were not sampled.

T. 46 N., R. 29 W., Serpent Lake.—Serpent Lake is located in a glacial basin between Deerwood and Crosby. It is surrounded by coarse, gravelly drift hills. The west arm of the lake lies in Sections 12 and 13, Klondike Twp. The west end of the basin has an area of several acres filled with peat and marl. At the outskirts of Crosby the marl is over 18 feet thick under about 2 feet of peat. It is also continuous on the floor of the lake in the southwest bay. A composite sample contained 85 per cent soluble carbonates.

South of Serpent Lake a small pond is located near the line between Ranges 28 and 29. It covers 3 or 4 acres in Sections 13 and 18 to the north of the Northern Pacific Railroad grade. The pond is being filled with a thick growth of peat. Near the waterline a 4-foot bed of marl underlies 14 feet of peat. A sample of the marl contained 58.60 per cent soluble carbonates.

T. 45 N., R. 29 W., Nokay Lake.—The basin of Nokay Lake lies in the area of outwash gravels that extends in a northeast-southwest direction across the county. Extensive deposits of marl occupy the bogs around the basin of the lake (see Figure 63) and underlie the meadowland along the streams to the southwest. Marl deposition is now in progress on the floor of the lake, but its depth was not sounded beyond the waterline. In NW¼ Sec. 14 along the west shore of the lake a 4-foot bed of dry marl occupies a terrace along a former beach. The marl is continuous over an area of about 4 acres. Much of it is covered with dry beach sand. Over 100 loads have been removed for fertilizer and road construction. Near the southeast corner of Section 14 a zone of bog land occupies a low area that once connected Nokay Lake with the smaller lake to the southwest. Along the stream a belt 50 yards wide is underlaid by a foot of good marl. A sample showed 80 per cent soluble carbonate.

Still farther south in E.½ Sec. 22 a partially drained terrace of marl covers a zone about 100 yards wide along the east side of the lake. The marl bed is 5 feet thick and covers about 5 acres. A composite sample yielded 75 per cent soluble carbonates. There is no peat over the marl.

In SE¼ Sec. 22 a drained meadow extends from a rice-filled pond westward to Nokay Creek. A bed of marl from 2 to 6 feet thick occupies about 15 acres of the meadow. The marl is covered by 3 feet of grassy peat. A sample contained 80 per cent soluble carbonates.

Other deposits in Nokay Lake Twp. have been reported in S½ Sec. 10 and in SW¼ Sec. 28. These deposits were not sampled.

T. 45 N., R. 28 W., Bay Lake.—Bay Lake is in an extremely irregular basin in the sandy moraine of the southeastern part of the county. It is bordered by sharp ridges and knobs, such as are characteristic of morainic topography.

In W½ Sec. 22 one of the numerous bays of the lake is being filled with peat and marl. An area covering about 4 acres is underlaid by 8 feet of poor marl under 6 feet of peat. A sample contained 49 per cent soluble carbonates.

Along the section line between Sections 9 and 10 another bay contains a bed of marly clay 8 feet thick under 6 feet of peat. It occupies an area of about 6 acres. The marl carries 30 per cent soluble carbonates.

T. 44 N., R. 31 W., Sec. 4.—Heald's Pond was once an embayment connected with the channel of the Mississippi River. The pond covers an area of about 10 acres. Around the margin of the northeast part of the basin 2 feet of marl is exposed at the surface, but at the waterline it is covered with 8 feet of peat. Around the west side of the pond only a thin seam of marl covers the sandy floor of the basin. A group of samples averaged 50 per cent soluble carbonates.

T. 44 N., R. 31 W., Sec. 8.—Two small deposits of dry marl are located in S½ Sec. 8. Both are in dry kettles that were once flooded by the waters of the Mississippi River. One is locally known as Hayes' marl bed and the other as Freeman Young's marl.

Hayes' deposit is a bed approximately 2 feet thick lying below nearly

ANALYSES OF MARLS OF CROW WING COUNTY

Sample	Location	Per Cent Soluble Carbonates
1	T. 133 N., R. 29 W., Sec. 13	60.9
2	T. 133 N., R. 29 W., Sec. 13	48.7
3	T. 133 N., R. 29 W., Sec. 13	59.6
4	T. 133 N., R. 29 W., Sec. 11	66.4
5	T. 44 N., R. 31 W., Sec. 4	23.0
6	T. 44 N., R. 31 W., Sec. 4	62.35
7	T. 44 N., R. 31 W., Sec. 8	74.4
8	T. 44 N., R. 31 W., Sec. 8	83.7
9	T. 44 N., R. 31 W., Sec. 8	90.4
10	T. 43 N., R. 31 W., Sec. 18	84.7
11	T. 43 N., R. 31 W., Sec. 18	81.9
12	T. 43 N., R. 32 W., Sec. 22	51.5
13	T. 43 N., R. 32 W., Sec. 25	1.3
14	T. 135 N., R. 29 W., Sec. 26	30.9
15	T. 135 N., R. 29 W., Sec. 26	nd*
16	T. 134 N., R. 29 W., Sec. 24	70.8
17	T. 134 N., R. 29 W., Sec. 24	75.3
18	T. 135 N., R. 28 W., Sec. 18	76.2
19	T. 135 N., R. 28 W., Sec. 18	71.9
20	T. 135 N., R. 28 W., Sec. 18	70.0
21	T. 135 N., R. 29 W., Sec. 13	66.2
22	T. 135 N., R. 29 W., Sec. 13	70.7
23	T. 135 N., R. 29 W., Sec. 15	80.0
24	T. 137 N., R. 28 W., Sec. 25	92.8
25	T. 137 N., R. 28 W., Sec. 25	57.5
26	T. 137 N., R. 28 W., Sec. 25	39.6
27	T. 137 N., R. 28 W., Sec. 25	78.8
28	T. 137 N., R. 28 W., Sec. 25	91.3
29	T. 137 N., R. 28 W., Sec. 25	90.0
30	T. 137 N., R. 28 W., Sec. 25	86.2
31	T. 137 N., R. 28 W., Sec. 25	86.2
32	T. 137 N., R. 28 W., Sec. 25	85.8
33	T. 137 N., R. 28 W., Sec. 25	87.8
34	T. 137 N., R. 28 W., Sec. 25	89.8
35	T. 137 N., R. 28 W., Sec. 25	77.8
36	T. 137 N., R. 28 W., Sec. 25	51.9
37	T. 137 N., R. 28 W., Sec. 25	79.0
38	T. 137 N., R. 28 W., Sec. 23	90.5
39	T. 137 N., R. 28 W., Sec. 23	86.9
40	T. 136 N., R. 28 W., Sec. 2	83.5
41	T. 136 N., R. 28 W., Sec. 2	nd
42	T. 136 N., R. 28 W., Sec. 2	88.5
43	T. 137 N., R. 28 W., Sec. 23	83.6
44	T. 137 N., R. 28 W., Sec. 23	77.9
45	T. 137 N., R. 28 W., Sec. 23	86.4
46	T. 137 N., R. 28 W., Sec. 23	83.5
47	T. 137 N., R. 28 W., Sec. 23	80.9
48	T. 137 N., R. 28 W., Sec. 26	88.6
49	T. 136 N., R. 28 W., Sec. 2	54.8
50	T. 136 N., R. 28 W., Sec. 2	91.6
51	T. 136 N., R. 28 W., Sec. 2	94.4
52	T. 136 N., R. 28 W., Sec. 2	78.5
53	T. 136 N., R. 28 W., Sec. 2	84.5
54	T. 137 N., R. 28 W., Sec. 27	61.4
55	T. 137 N., R. 28 W., Sec. 30	80.1

* nd = not determined.

Sample	Location	Per Cent Soluble Carbonates
56	T. 137 N., R. 29 W., Sec. 23	68.4
57	T. 137 N., R. 29 W., Sec. 23	58.6
58	T. 135 N., R. 29 W., Sec. 11	76.4
59	T. 135 N., R. 29 W., Sec. 11	62.7
60	T. 135 N., R. 29 W., Sec. 11	77.0
61	T. 136 N., R 29 W., Sec. 27	59.3
62	T. 136 N., R. 29 W., Sec. 27	53.6
63	T. 136 N., R. 29 W., Sec. 27	66.6
64	T. 136 N., R. 29 W., Sec. 22	55.0
65	T. 136 N., R. 29 W., Sec. 22	59.1
66	T. 136 N., R. 28 W., Sec. 31	76.5
67	T. 136 N., R. 28 W., Sec. 31	81.2
68	T. 136 N., R. 28 W., Sec. 31	79.8
70	T. 136 N., R. 28 W., Sec. 28	61.8
71	T. 136 N., R. 28 W., Sec. 28	40.4
72	T. 136 N., R. 28 W., Sec. 28	42.3
73	T. 136 N., R. 28 W., Sec. 28	44.3
74	T. 136 N., R. 28 W., Sec. 28	71.5
75	T. 136 N., R. 28 W., Sec. 9	60.6
76	T. 136 N., R. 28 W., Sec. 9	39.3
77	T. 135 N., R. 28 W., Sec. 10	83.6
78	T. 135 N., R. 28 W., Sec. 16	53.6
79	T. 135 N., R. 28 W., Sec. 16	39.8
80	T. 135 N., R. 28 W., Sec. 16	53.8
81	T. 135 N., R. 28 W., Sec. 16	61.2
82	T. 136 N., R. 27 W., Sec. 7	66.9
83	T. 135 N., R. 27 W., Sec. 8	46.3
84	T. 135 N., R. 27 W., Sec. 8	1.6
85	T. 135 N., R. 27 W., Sec. 8	35.9
86	T. 135 N., R. 28 W., Sec. 29	84.5
87	T. 135 N., R. 28 W., Sec. 29	80.5
88	T. 133 N., R. 29 W., Sec. 11	31.4
89	T. 134 N., R. 29 W., Sec. 34	65.5
90	T. 134 N., R. 28 W., Sec. 33	47.8
91	T. 134 N., R. 28 W., Sec. 28	55.4
92	T. 134 N., R. 28 W., Sec. 28	nd
93	T. 134 N., R. 28 W., Sec. 21	28.2
94	T. 135 N., R. 27 W., Sec. 21	30.3
95	T. 135 N., R. 27 W., Sec. 4	62.3
96	T. 137 N., R. 26 W., Sec. 27	38.4
97	T. 138 N., R. 26 W., Sec. 29	78.3
98	T. 138 N., R. 27 W., Sec. 23	83.2
99	T. 136 N., R. 27 W., Sec. 7	73.6
100	T. 136 N., R. 27 W., Sec. 6	55.0
101	T. 136 N., R. 26 W., Sec. 32	34.1
102	T. 136 N., R. 26 W., Sec. 32	43.6
139	T. 45 N., R. 28 W., Sec. 22	49.6
140	T. 45 N., R. 28 W., Sec. 10	29.9
141	T. 45 N., R. 29 W., Sec. 23	69.2
142	T. 45 N., R. 29 W., Sec. 22	79.2
143	T. 45 N., R. 29 W., Sec. 22	75.1
144	T. 45 N., R. 29 W., Sec. 14	80.0
145	T. 45 N., R. 29 W., Sec. 14	70.3
154	T. 46 N., R. 28 W., Sec. 18	58.6
155	T. 46 N., R. 29 W., Sec. 13	84.2

3 feet of sand. It rims the basin about 8 feet above its floor. A pit has been opened on the west side of the basin and a small amount of marl has been excavated for agricultural uses. The marl is dry and very hard. A representative sample taken from the pit contained 83 per cent soluble carbonate. Freeman Young's deposit is an irregular seam, not more than 2 feet thick, covering several acres in a low, kettle-like area in a cultivated field. The marl is covered with nearly 2 feet of clayey fill. A sample contained 75 per cent soluble carbonates.

T. 44 N., R. 31 W., Sec. 12.—A drained swamp along the creek that flows westward into the Mississippi River covers an area of nearly 80 acres in the W½ of the section. A thin bed of marl less than a foot thick covers most of the marsh. It is buried under 3 feet of tough sod and peat. Other deposits found in this township in Sections 15, 18, and 30 were not sampled.

T. 44 N., R. 30 W.—Thin deposits of marl have been reported in the marshes along the streams in Sections 13, 27, and 34. None of these beds were sampled.

T. 43 N., R. 32 W., Sec. 22.—A partially drained marsh occupies about 80 acres in E½ Sec. 22. The basin extends from the railroad grade north of Fort Ripley eastward beyond the section line. A bed of fair marl from 2 to 4 feet thick covers the floor of the basin. A layer of peat 6 feet thick has accumulated over the marl. A composite sample contained 52 per cent soluble carbonates.

T. 43 N., R. 32 W., Sec. 13.—Nokay River flows from the east to the southwest across S½ Sec. 13. In the SW¼ of the section some of the meadowland in the river is underlaid by a thin layer of fair marl.

T. 43 N., R. 32 W., Secs. 25, 26, 35, and 36.—About 2 miles east of Fort Ripley, Daggett Brook flows through a small lake and several shallow basins that were once connected with the lake but are now partially drained wire-grass marshes.

In S½ Sec. 25 about 20 acres are included in the bog. In SE¼ Sec. 26 over 40 acres of marshy ground lie along the brook. The same area extends southward to include about 20 acres in NE¼ Sec. 35. The N½ of Sec. 36 is occupied by a small lake, the west end of which is filled with peat and marl. All the swamp and bog areas are underlaid by marl that varies from 5 to 8 feet in thickness and is covered by 4 feet of peat.

T. 43 N., R. 31 W.—On the section line between Sections 18 and 19 is a small lake surrounded by a wire-grass bog. A road passes over the bog around the south shore of the lake. The basin of the lake is surrounded by very rugged, sandy gravel hills. A thick bed of high-grade marl covers the floor of the basin. The marl deposit is from 8 to 14 feet thick and is covered by about 3 feet of peat. The bog has an area of about 40 acres. A composite sample contained 91 per cent soluble carbonate.

A thin bed of marl has been located in the marshy area in N½ Sec. 27. It was not sampled.

DAKOTA COUNTY

The largest areas of bogs in Dakota County occur along the valley of the Minnesota River. Numerous soundings were made between Savage and Mendota, but in every case a fine sandy bottom was encountered below 8 to 10 feet of silty and sandy peat. In the central part of the county are a number of wide shallow basins with "built-up" peat beds, but it is certain that few of them were filled with water long enough for marl deposition to take place.

South of Farmington, near the intersection of the Castle Rock road with State Highway No. 1, such a shallow basin covers parts of Sections 31 and 32. The peat is built up to a thickness of about 8 feet. Below it is a bed of marly clay about 6 feet thick. It contained 26.20 per cent soluble carbonate.

DODGE COUNTY

Most of Dodge County is covered with the pre-Wisconsin or old gray drift. The only marshy areas occur along the west border and these are filled with silty and marshy peat. No marl beds were discovered.

DOUGLAS COUNTY

Douglas County is entirely within the area of the young gray or Keewatin glacial drift. The western half of the county is occupied by a prominent morainic system, to the east of which are small outwash plains of sandy gravel. Most of the eastern part of the county is a

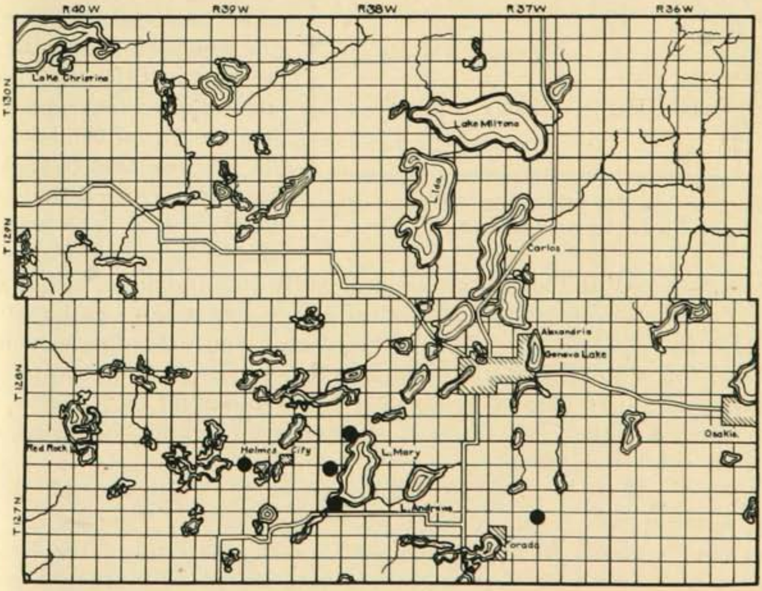

FIG. 64.—Map of Douglas County showing marl deposits.

region of clayey till plains. The largest bog areas of the county are Miltona Twp. and Spruce Hill Twp. These, however, are in a regi of fine glacial sands, and no marl deposits were formed in their basin There are many small lakes in the moraine in the western part of t county, but most of them are in basins in impervious clay. Most of t

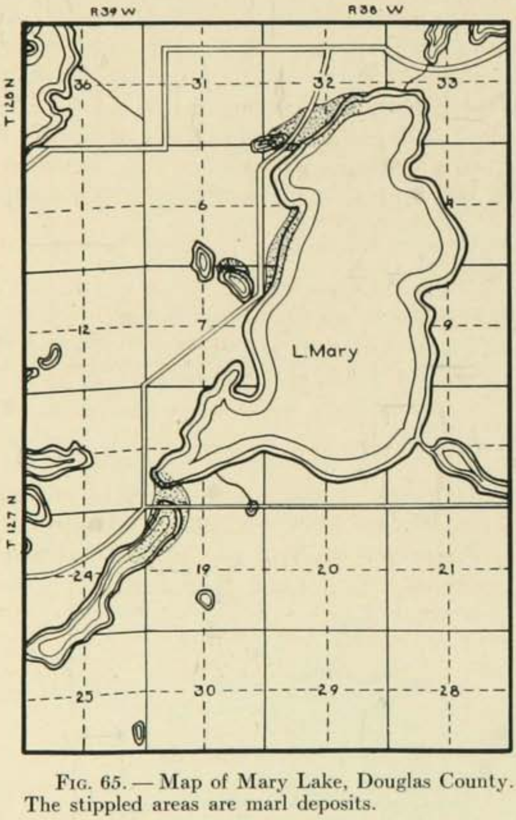

Fig. 65. — Map of Mary Lake, Douglas County. The stippled areas are marl deposits.

marl is in the region sandy moraine southwest Alexandria. (See Figure 6 Descriptions and analyses the marl beds that w sounded and sampled given below.

T. 127 N., R. 38 W., La Mary. — Lake Mary is in glacial basin in a sandy t plain. The water level w once from 4 to 6 feet high than at present, and nume ous abandoned beaches ma be seen around its shore Around the northwest b some of the beach grave are cemented with mar Similar conditions were ob served at various point along the western shore. A the southern end of the lak in Sections 18 and 19 a area of filled bog separates former arm of the lake fro its southwestern bay. Whe the road crosses the bay thick bed of poor marl fil the basins. (See Figure 65 The marl is over 20 feet thick, but it is badly contaminated with orga matter. A composite sample contained 34 per cent soluble carbonate.

T. 127 N., R. 38 W., Sec. 7. — In N$\frac{1}{2}$ Sec. 7 and extending northwa into Sec. 6 is a small partially filled lake basin that was once an estu of Lake Mary. An area of about 20 acres is underlaid by 8 feet of p marl covered with 2 feet of peat. A composite sample contained 26. per cent soluble carbonate.

T. 127 N., R. 39 W., Sec. 10. — In Section 10, southwest of Holm City, a small lake occupies the northwest corner of the section. T basin covers about 40 acres. The north and east part of the basin covered by 3 to 6 feet of poor marl, contaminated with organic matt It contained 36.40 per cent soluble carbonates.

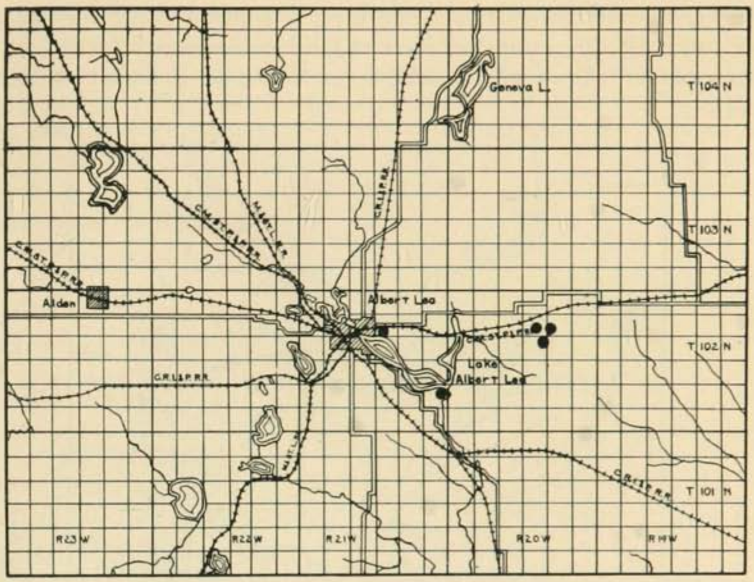

FIG. 66. — Map of Freeborn County showing marl deposits.

T. 127 N., R. 37 W. — East of Forada station is an extensive marsh that represents a filled lake in an area of outwash gravels. The marsh covers about 900 acres. The entire area is underlaid by a marl bed from 4 to 6 feet thick. The marl is covered with about 7 feet of peat.

FARIBAULT AND FILLMORE COUNTIES

No marl deposits were discovered in Faribault or Fillmore County.

FREEBORN COUNTY

Freeborn County, on the southern border of Minnesota, was covered by the young gray or Keewatin drift of the late Wisconsin glaciation. This county was near the east margin of the ice sheet, and therefore strong moraines trend in a north-south direction across the eastern part of the county. These moraines are composed largely of clayey till, but they also include a few gravelly knolls. An extensive outwash plain of sandy gravel lies immediately north and west of Albert Lea along the eastern border of a strong moraine. All the marl located in this county is in the areas of gravelly outwash near Albert Lea. (See Figure 66.)

T. 102 N., R. 20 and 21 W., Albert Lea Lake. — Albert Lea Lake is in a deep glacial basin at the southeast margin of an area of coarse sand and gravel outwash. Around the northwestern end of the lake at the outskirts of the town of Albert Lea an extensive former embayment is filled with marl and peat. (See Figure 67.) In Sections 9 and 10 a belt nearly 200 yards wide extends along the shore for about a half mile. Near the waterline the marl bed is 6 feet thick with only a few inches of grassy sod over its surface. The marl is continuous under the water of the bay. All the soundings showed marl contaminated with clay and organic matter. A composite sample contained 50 per cent soluble carbonates.

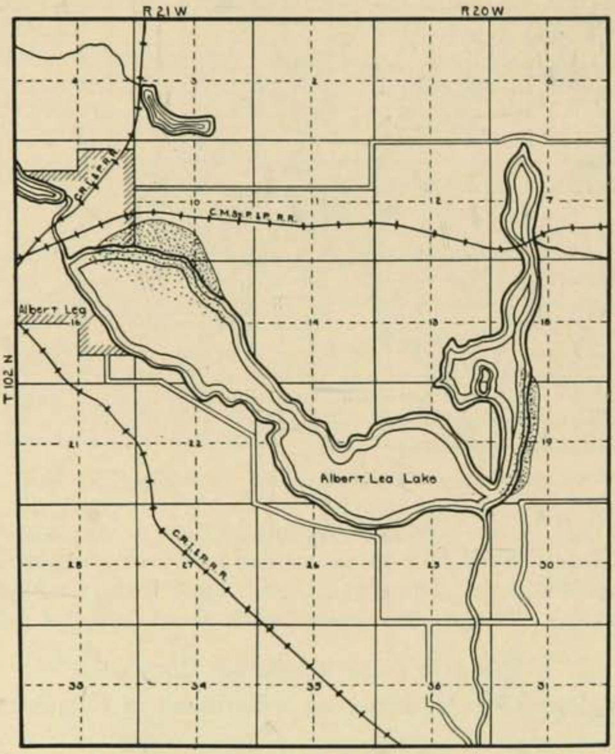

FIG. 67. — Map of Albert Lea Lake. The stippled areas are marl deposits.

Around the southeast bay in Section 25, a short distance north of the bridge, marl occurs as a narrow shelf, not over 50 feet wide, above the waterline. It is exposed without a covering of peat. At the waterline the marl bed is 5 feet deep. A composite sample contained 45 per cent soluble carbonates.

T. 102 N., R. 20 W., Hayward Marsh. — A shallow basin known as Hayward Marsh occurs in Hayward and Oakland twps., ten miles east of Albert Lea. Much of it is now drained and cultivated. The area of the marsh is about 5 square miles. It is covered by about 3 feet of brown to black peat. The lower 8 to 12 inches of the peat contains shell marl in a matrix of organic matter. No samples of the deposit were analyzed.

HENNEPIN COUNTY

General glacial features. — With the exception of a small area in Minneapolis, all of Hennepin County was covered by the Keewatin ice sheet

In the eastern part of the county, however, a rugged red drift moraine was present when the Keewatin ice sheet advanced, so the red drift is now veneered with a thin bed of young gray drift. Many of the early gravel plains and ridges that were overridden by the Keewatin ice were greatly disturbed, and much of the red drift has been incorporated with the gray drift. There are extensive outwash plains of gray drift gravel and sand in the district south of Minneapolis between the Mississippi and Minnesota valleys.

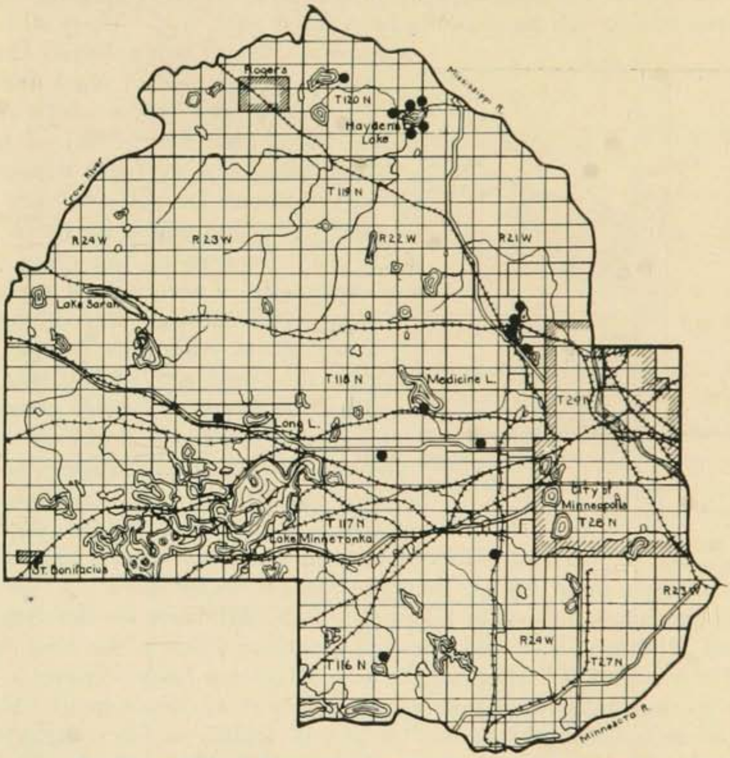

FIG. 68. — Map of Hennepin County showing marl deposits.

The irregular morainic hills are separated by depressions and basins, most of which are sites of lakes and swamps. In the clayey moraines no marl has been deposited in the basins, but in the pockety drift areas representing a mixture of stony red and sandy gray drift, small beds of lime carbonate have accumulated.

Descriptions and analyses of the marl beds that were sounded and sampled are given below. (See Figure 68.)

T. 120 N., R. 22 W., Haydens Lake. — Haydens Lake, southwest of Anoka, is at the west margin of the zone of outwash gravels that parallel the valley of the Mississippi River. South and west of the lake are sharp morainic hills of gray drift. The eastern side of the basin is filled above the water level with peat and marl. (See Figure 69.) About 8 acres a underlaid by 6 to 8 feet of marl under 5 feet of peat. The marl is co tinuous under the water of the lake. A composite sample containe 52.20 per cent of soluble carbonates.

South of the lake in the valley of Elm Creek nearly 40 acres meadowland are underlaid by a bed of marl covered with less than 2 fe of peat.

T. 118 N., R. 21 W., Twin Lakes. — The Twin Lakes are in a bas in the flood plain of the glacial Mississippi River north of Robbinsda Alluvium and lacustrine deposits have filled part of the basin so that narrow channel now connects the tw lakes. A thick bed of marl underlie the western side of the south arm o the lake. (See Figure 70.) A lowering of the lake level has exposed an area of about 5 acres, and very littl peat has accumulated over the marl It may be seen at the grass roots The marl is of a very good grade and is over 20 feet thick near the present waterline. A composite sample from near the south end of the lake contained 91 per cent soluble carbonate.

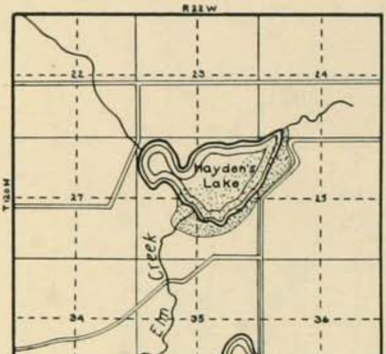

FIG. 69. — Map of Hayden's Lake, Hennepin County. The stippled area is a marl deposit.

In the bog at the north end of the south lake, also, the marl is over 20 feet thick, both north and south of the Soo Railroad bridge over the channel. At the extreme north end of the northern twin, a bay is filled with marl to a point higher than the present water level.

This enormous deposit of high-grade lime carbonate on the very outskirts of Minneapolis should prove of economic value in the near future.

T. 118 N., R. 22 W., Medicine Lake. — Medicine Lake occupies a basin in the ground moraine of young gray till west of Minneapolis. Marl is being deposited in both the northwest and southwest bays. Around the southwest bay it has filled an area of about 7 acres to a thickness of 4 to 6 feet. No peat has developed over the marl. A composite sample contained 80 per cent soluble carbonates.

T. 118 N., R. 23 W. — In Section 33, about one and one-half miles west of Long Lake, a small bog contains a bed of poor marl about 7 feet thick under 8 to 10 feet of peat. The marl contained 47 per cent soluble carbonates.

T. 117 N., R. 22 W. — In Section 2, south of Superior Boulevard, a small kettle-like basin in the moraine is filled with marl and peat. A heavy growth of cat-tails and rushes covers the surface of the bog. A bed of poor marl from 5 to 7 feet thick is buried under 8 feet of peat. A composite sample of the marl contained 28.6 per cent soluble carbonates.

T. 116 N., R. 22 W.—An extensive deposit of marl has been located in Section 22 along the valley of Purgatory Creek, southwest of Hopkins and just north of Staring Lake. The deposit covers an area of about 100 acres and is covered with less than 2 feet of peat. The marl is from 2 to 8 feet thick and contains 80 per cent lime carbonate.

Other small marl deposits are located along a number of streams. There is a thin bed along Nine Mile Creek, Bloomington Twp., and another along Shingle Creek in Brooklyn Twp. Isolated small areas occur in basins along Pioneer Creek in Independence Twp.

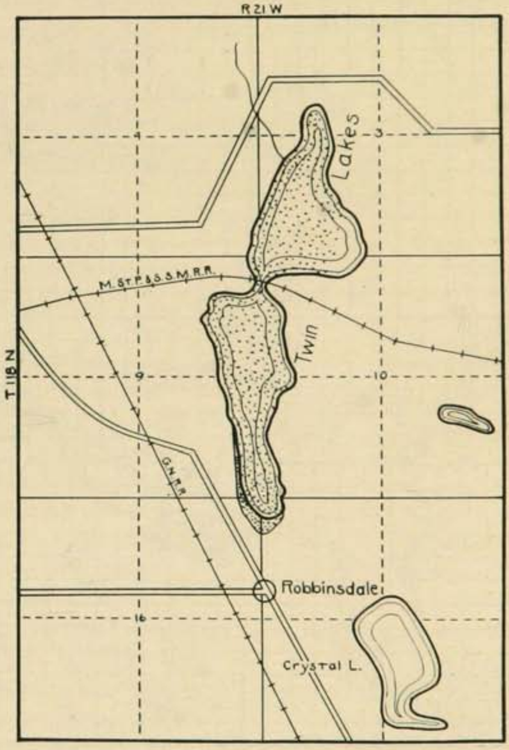

FIG. 70.—Map of Twin Lakes, near Robbinsdale. The stippled area is a marl deposit.

ANALYSES OF MARLS OF HENNEPIN COUNTY

Location	Sample No.	Per Cent Soluble Carbonates
T. 120 N., R. 22 W., Sec. 26....................	219	52.2
T. 118 N., R. 23 W., Sec. 33....................	239	46.4
T. 118 N., R. 22 W., Sec. 26....................	240	79.8
T. 118 N., R. 21 W., Sec. 9....................	•216	90.5
T. 118 N., R. 21 W., Sec. 9....................	217	87.6
T. 117 N., R. 22 W., Sec. 3....................	238	28.6

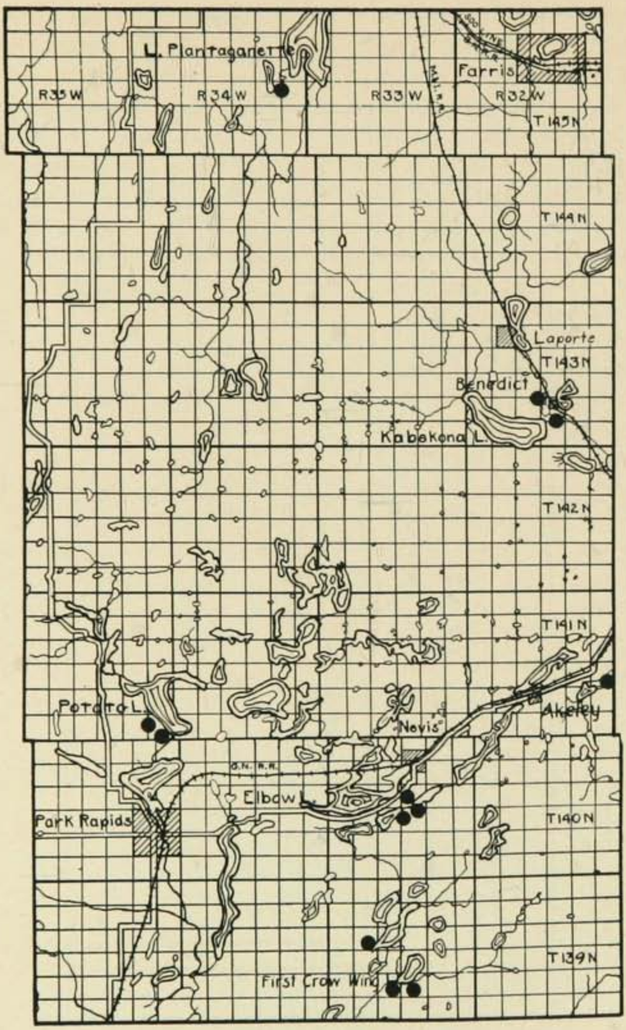

FIG. 71. — Map of Hubbard County showing marl deposits.

HUBBARD COUNTY

Hubbard County lies entirely within the area of the young gray drift. The southern end of the county is covered by a large plain of sandy gravel in which are a number of small lakes and marshes. North of this is a great moraine of coarse sandy gravel, in which a number of lakes occupy the depressions between the morainic hills. It is from this moraine that the outwash plain to the south was derived. Toward the northern border of the moraine it becomes clayey and grades into a till plain that occupies most of the northern third of the county.

Hubbard County has no large open bogs comparable to those in the counties farther north and west. Most of the bogs occur along streams or around small lakes. The marl deposits are confined to basins in the sand moraine and to the outwash gravels of the southern part of the county. (See Figure 71.)

Descriptions and analyses of the marl beds that were sounded and sampled are given below.

T. 143 N., R. 32 W., Secs. 22 and 27. — In the region of Benedict, a narrow zone of outwash gravel and sand extends from the northwest toward Leech Lake. Marl is found in several of the shallow basins within this belt. In SE$\frac{1}{4}$ Sec. 22, a 4-foot bed covers an area of about 6 acres. It is overlaid by 2 feet of peat. In W$\frac{1}{2}$ Sec. 27 peaty marl underlies the whole area of the bog. It is of poor grade. A composite sample contained 54 per cent soluble carbonates.

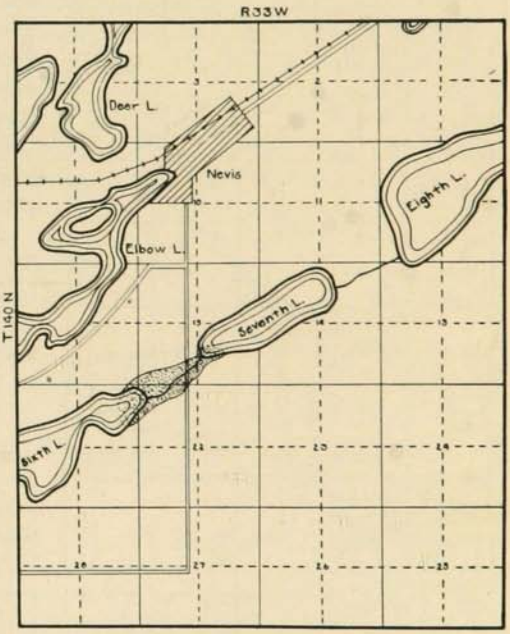

Fig. 72. — Map of a group of lakes near Nevis. The stippled areas are marl deposits.

T. 141 N., R. 35 W., Potato Lake. — The basin of Potato Lake is in the sandy moraine north of Park Rapids. An area of about 8 acres west of the south end of the lake in Section 36 represents an abandoned embayment of the lake that is now dry and cultivated. It is overlaid by 2 feet of dry, hard peat, below which is a bed of clayey marl. The marl was too hard to penetrate with a Davis sampler. It contained 35 per cent soluble carbonates. Marly clay is found also in the banks of the creek at the south end of the lake.

T. 141 N., R. 32 W. — Shingob Lake occupies a basin 2 miles east of Akeley in Section 25, near the eastern margin of the county. A low terrace of marl, deposited while the lake stood at a higher level, is now exposed along portions of the east side of the lake. The deposit is readily accessible from the road that follows the southeast shore of the lake.

T. 140 N., R. 33 W. — A chain of lakes occupies a series of basins in the glacial outwash of the southeastern part of the county. (See Figure 72.) They are the headwaters of the Crow Wing River and are therefore referred to as Crow Wing Lakes. Abandoned bays and meadowlands are common along the chain. Between Sixth and Seventh lakes in Section

15, south of Nevis, about 40 acres along the valley are underlaid by marl. The marl bed is from 8 to 12 feet thick and is covered with 2 feet of peat. A large pit has been opened by the agricultural department of the state and a stock pile made where the marl is allowed to dry. It is hauled by truck for local use. A composite sample from the stock pile contained 88 per cent soluble carbonates.

T.139 N., R.33 W.—In Section 28, to the west of First Crow Wing Lake, a marl bed is located under a thin layer of peat in the meadowland along the stream. It is confined to a narrow zone along the stream. Some of the marl has been excavated for highway construction purposes.

A thin seam of poor marl contaminated with organic material is found in Section 27 along the valley of the stream that enters the lake from the east. It was not analyzed.

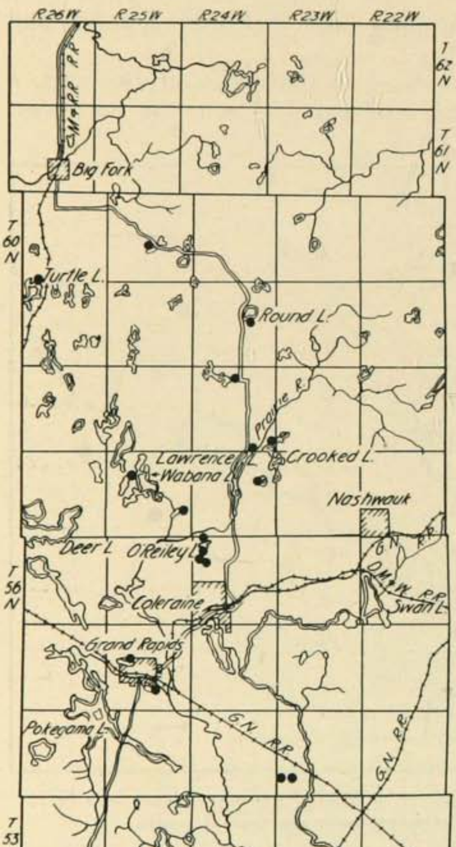

Fig. 73.—Map of eastern Itasca County showing marl deposits.

Itasca County

General glacial features.—Itasca County lies near the east margin of the Keewatin drift sheet. The eastern half of the county is diversified in topography. The Mesabi Range crosses the southeast portion in a northeast-southwest direction and has a covering of morainic drift superposed on it throughout most of its course. The northeastern part of the county is covered by extensive till plains. In the western half of the county are vast sandy tracts with a level to gently undulating surface.

Many of the morainic hills are composed of clay, and in such regions no deposits of marl were located. Directly north of Grand Rapids the moraines are a mixture of Patrician and Keewatin drift. Here the till is more loosely textured because of the presence of bowlders and smaller stones gathered up from the older drift sheet. Because of the more open texture, lime has been leached and carried to the basins, where it was precipitated as marl. The greatest number of marl beds in the county are found in the zone of overridden moraines north of Coleraine. (See Figure 73.) Descriptions and analyses of the marl beds that were sounded and sampled are given below.

T. 60 N., R. 25 W., Sec. 22.—A small lake occupying the NE¼ of the section is drained by a stream that flows from the southwest bay of the lake toward the south. In the SW¼ of the section a belt of meadowland parallels the stream. A bed of fair to poor marl covers the floor of the lowland over an area of about 12 acres. The marl is from 3 to 5 feet thick and lies below 2 to 6 feet of peat.

T. 59 N., R. 26 W., Turtle Lake.—The east bay of Turtle Lake is bordered on the east and north by very irregular and steep glacial hills composed mainly of old gray drift veneered by a thin sheet of Keewatin or young gray drift. Some lime carbonate has been leached from this overridden moraine and deposited as marl in the lake basin. It is contaminated with clay washed into the lake from the adjoining hills. The calcium carbonate content of the marl is too low to be of economic value.

T. 59 N., R. 24 W., Round Lake.—The basin of Round Lake is in an area of till plains composed of mixed sands and stony clay. Around the south bog of the lake an abandoned embayment is filled with peat and marl. The marl bed covers an area of about 4 acres. It is from 2 to 4 feet thick and is covered by 3 to 5 feet of peat.

T. 58 N., R. 24 W.—Marl has been located in S½ Sec. 3 along the stream valley. This deposit was not sampled.

T. 58 N., R. 24 W., Crooked Lake.—Along the north shore of Crooked Lake east of its outlet into Prairie River, part of the lake basin has been filled with peat and marl. The marl deposit covers only a few areas. It was not sampled.

T. 57 N., R. 25 W., Wabana Lake.—Small deposits of marl have been reported in several of the bays of Wabana Lake. They were not sampled.

T. 57 N., R. 25 W., Sec. 25.—A small lake occupies part of NW¼ Sec. 25. A partially filled embayment near the inlet at the northeast bay of the lake is underlaid by 2 to 4 feet of marl over an area of 10 acres. It is covered by a thin layer of gray peat.

T. 57 N., R. 24 W.—The basin of Lawrence Lake is an expanded portion of the valley of Prairie River. Where the lake narrows down to a normal stream valley in NW¼ Sec. 2, a zone of bog land parallels the stream. Marl underlies the bog and is continuous for some distance on the lake floor. Near the stream the marl ranges from 1 to 4 feet in thickness. It covers an area of about 5 acres.

A small lake basin occupies an area at the southwest corner of Section 12 and extends into Sections 11, 13, and 14. This basin is surrounded by a zone of peat and floating bog. Marl underlies the entire basin to a thickness of from 1 to 6 feet.

T. 56 N., R. 24 W., O'Reiley Lake.—O'Reiley Lake occupies an irregular basin, or rather two basins separated by a narrow channel, in Sections 5, 6, 7, and 8. (See Figure 74.) An extensive marl deposit fills the former embayments on the west side of the south lake and is continuo along the channel toward the north basin. Marl is present locally als along the east side of the south lake, but the deposits are thinner. Ove 100 acres in Section 7 are underlaid by a marl bed over 20 feet thicl

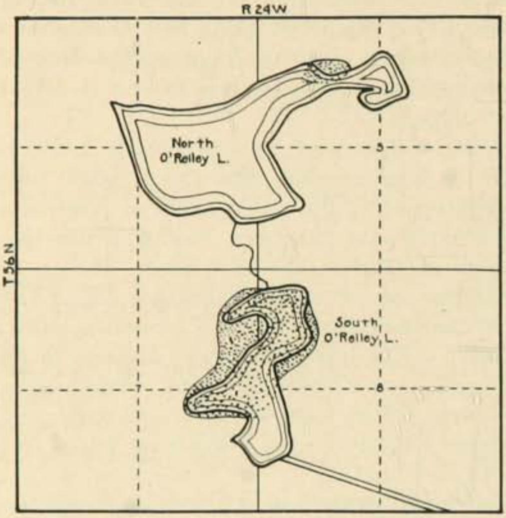

Fig. 74. — Map of O'Reiley Lake, north of Coleraine. The stippled areas are marl deposits.

The following compositi was found in samples co lected by Mr. Ben Liebe man of Coleraine: $CaCO_3$ 91.75 per cent; $MgCO_3$, 5. per cent; SiO_2, 2.10 per cen Fe_2O_3, .17 per cent.

T. 55 N., R. 25 W. — In the vicinity of the city of Grand Rapids a number of deposits of marl are locate in the bays of the smal lakes. In E½ Sec. 17 a sean of marl less than a foot thic underlies the east bay of the lake, and in Section 27, southeast of the city limits, several acres of meadowland east of the lake contain a thin bed of marl below the sand.

T. 54 N., R. 23 W. — A small deposit of marl has been reported in the bog around a lake in Sections 29 and 30. This deposit was not sampled.

T. 149 N., R. 27 W. — A small deposit of marl exposed along the road grade between Sections 27 and 34 has been reported by C. A. Dahlquist of Bergvilla. This deposit was not sampled.

Jackson County

One thin bed of marl has been located on Sec. 13, T. 103 N., R. 38 W.[1] The deposit was found while a ditch was being dug through the section. The marl is buried beneath about 10 feet of peat and muck. It is approximately 3 feet thick and covers an area of several acres. A composite sample contained 97 per cent soluble carbonates.

Kanabec County

A large swampy area in T. 38 N., R. 25 W., in the southwest corner of Kanabec County is underlaid by a seam of poor, peaty marl. It is thickest around the margins of the small lakes in Sections 35 and 36.

Kandiyohi County

Most of Kandiyohi County is covered by a fine-textured clayey moraine of Keewatin drift. None of the basins in the clayey areas con-

[1] Reported by the Thompson Lands Company, Windom, Minnesota.

tain marl. In the region around New London, however, a belt of sandy moraine and outwash gravels extends in a northwesterly direction toward Glenwood. Several thin beds of marl have been located in filled and drained basins in this part of the county.

In New London Twp. (T. 121 N., R. 34 W.) marl has been located in SW¼ Sec. 16 under 4 to 5 feet of mucky peat. A picked sample contained 72 per cent soluble carbonates. The marl underlies cultivated soil. A similar deposit has been reported on the NE¼ of the same section.

Kittson County

This county lies in the extreme northwest corner of the state and is entirely within the area formerly covered by glacial Lake Agassiz. All the present basins represent depressions on the floor of the lake. The extensive swamps in the northeastern part of the county were sounded by Mr. E. K. Soper and were found floored with lake-washed tills and lake sediments.

Several marl beds have recently been discovered. Mr. Andrew Carlson of Hallock, Minnesota, has reported the presence of a deposit in NW¼ Sec. 32, T. 162 N., R. 45 W. It covers an area of about 40 acres and is from 8 to 20 feet thick. About 2 feet of mucky soil overlies the marl.

A number of thin seams of marl have also been found in the peat areas northeast of Karlstad.

Koochiching County

Nearly all of Koochiching County lies within the area formerly covered by the waters of glacial Lake Agassiz. Vast unbroken swamps covering approximately a million acres occupy the northern three-fourths of the county. These swamps are covered with peat beds, most of them of the built-up or high-moor type and consequently not underlaid by marl. Numerous soundings taken over these swamps show that the peat is underlaid by lake clays and sands.

A small deposit of marl located in Sec. 10, T. 66 N., R. 22 W., has been reported by Mr. C. Durheim of Cook, Minnesota. The deposit was not sampled.

Lake of the Woods County

This county is wholly within the limits of the area formerly covered by glacial Lake Agassiz, and consequently has much drained or partially drained swamp and bog land at the present time. Most of the swamps represent built-up or high-moor marshes that have accumulated over lake sediments. Numerous soundings made by Mr. Soper during an investigation of the peat resources of the state have shown the presence of fine glacial sands and lake clays under the peat.

Several small deposits of marl have been discovered. A low-grade marl bed locally known as the Henderson Pit is located in Sec. 2, T. 60 N.,

R. 31 W., near Baudette. Samples contained 30 per cent soluble carbonates. Similar material has been located in the meadowland along the Baudette River.

Meeker County

Only one marl bed was discovered in Meeker County. It is located in Sec. 2, T. 119 N., R. 30 W., north of the village of Darwin. The marl occurs in a drained lake basin, most of which is now meadowland. The marl bed is thickest along the stream at the north end of the lake, where from 4 to 6 feet of marl are overlaid by 6 or 8 feet of peat. The marl is high in organic matter. A composite sample contained 18 per cent soluble carbonates.

Mille Lacs County

The young red (Patrician) drift covers most of Mille Lacs County. In the southeast corner a moraine of Keewatin gray drift that represents a marginal moraine of the Grantsburg lobe covers parts of several townships. The northern part of the county is crossed by a prominent moraine of red drift, but the region from Onamia southward toward Princeton is largely a till plain. Many of the lakes and swamps occupy wide glacial valleys out in the old gray drift that were only partly filled by the later young red or Wisconsin drift of Patrician age. The marl beds that were located in the county are in the regions of morainic topography.

Descriptions and analyses of the deposits that were sounded are given below. (See Figure 75.)

T. 42 N., R. 27 W., Ogeche Lake.—Ogeche Lake is a southwestward extension of Vinland Bay of Mille Lacs. It is now separated from the big lake by a series of low sandy beaches cut by a small stream that is the outlet of Mille Lacs into the Rum River. (See Figure 76.)

Several hundred acres of bog land parallel the shores of the bay and the stream in Sections 5 and 8. This whole area is underlaid by a bed of poor marl covered with 6 to 8 feet of mucky peat. The marl bed varies from 4 to 8 feet in thickness and grades downward into mucky lake fill. A group of composite samples averaged 48 per cent soluble carbonates.

T. 36 N., R. 26 W., Silver Lake.—Silver Lake is located about a mile east of Princeton, near the north margin of the extensive area of wind-blown soil that covers parts of Sherburne, Mille Lacs, Isanti, Anoka, and Chisago counties. The lake basin is so nearly filled that rushes and wild rice grow over most of its floor. The shores are low and are composed of fine eolian sands. A series of soundings in the meadowland and boggy areas near the waterline showed 10 feet of poor peaty marl below 6 to 8 feet of peat and black muck. A composite sample contained 39.30 per cent soluble carbonates.

T. 36 N., R. 27 W.—An area over a mile in length in Section 25 and extending southwestward into Section 35 surrounds a shallow basin containing a boggy, rice-filled lake. The entire basin covers an area of about 300 acres. Most of the basin contains a bed of poor peaty marl under 4 to 10 feet of peat and black muck. An average sample contained 45.70 per cent soluble carbonates.

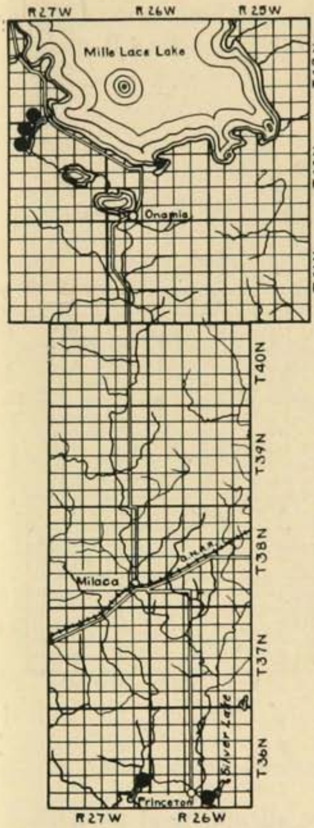

Fig. 75. — Map of Mille Lacs County showing marl deposits.

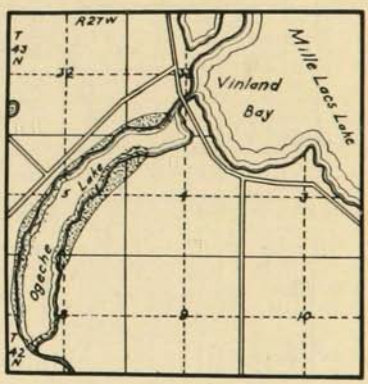

Fig. 76. — Map of Vinland Bay of Mille Lacs. The stippled areas are marl deposits.

Analyses of Marls of Mille Lacs County

Location	Sample No.	Per Cent Soluble Carbonates
T. 42 N., R. 27 W., Sec. 5	138	48.2
T. 36 N., R. 27 W., Sec. 25	137	45.7
T. 36 N., R. 26 W., Sec. 34	136	39.3

Morrison County

General glacial features. — The Mississippi River crosses Morrison County from north to south a little west of the center of the county. A broad belt of sandy outwash, the flood plain of the early postglacial river, parallels the valley. A similar zone of outwash gravels parallels the Crow Wing River along the northern border of the county. Th greater part of the county is a till plain encircled on the west by prominent red drift moraine that occupies the northwestern part of t county and the eastern part of Todd County. This moraine is very co plex and has small outwash aprons as well as lakes and swamps. M of the marl is in the sandy moraine of the northern part of the coun (See Figure 77.) There are several large bogs in the till plains of t

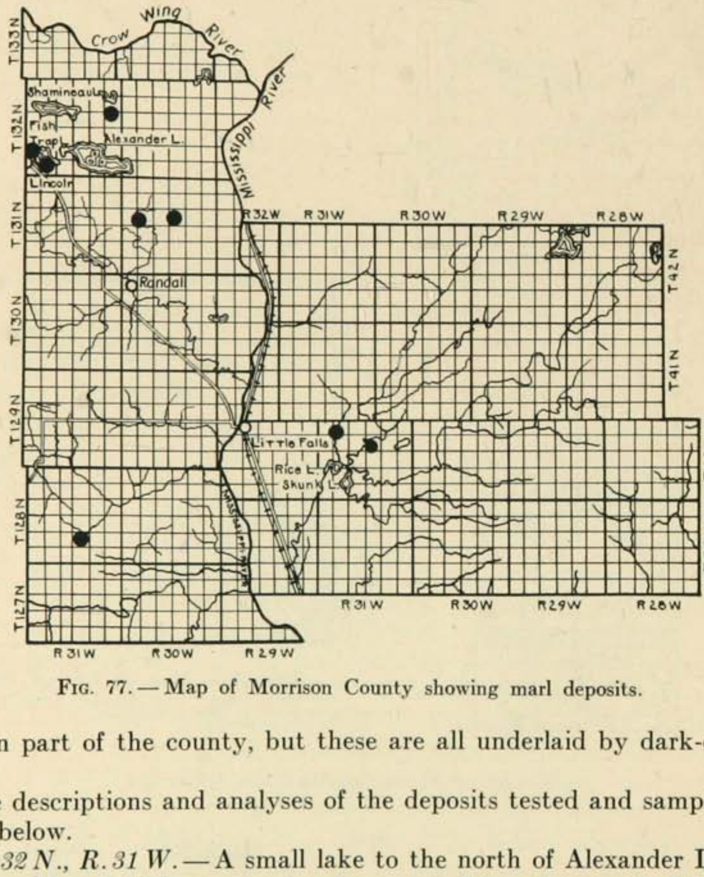

FIG. 77.—Map of Morrison County showing marl deposits.

eastern part of the county, but these are all underlaid by dark-colored clays.

The descriptions and analyses of the deposits tested and sampled are given below.

T. 132 N., R. 31 W.—A small lake to the north of Alexander Lake in Sections 12 and 13 has several embayments formerly a part of the lake but cut off by high beaches produced by the ice-shove. A small bay in SW¼ Sec. 12 is underlaid by high-grade marl that covers an area of about 4 acres. It is covered by 5 feet of peat. The marl is too hard to penetrate with a Davis sampler and consequently its thickness was not determined. A sample of the upper 3 feet of the bed contained 94. per cent soluble carbonates.

T. 132 N., R. 31 W., Fishtrap Lake.—Fishtrap Lake is in a deep bas in the high sandy moraine near the village of Lincoln. Around the nort west bay, part of a former embayment is filled with peat and marl.

few hundred yards north of the resort hotel at Lincoln an area of about 6 acres is underlaid by a 3-foot bed of poor marl. It is covered with 8 to 10 feet of peat and grades downward in a black mucky lake sediment. A composite sample contained 56 per cent soluble carbonates.

T. 131 N., R. 30 W.—Parts of Sections 18 and 19 are covered by a heavily wooded spruce and tamarack swamp. Soundings showed 2 to 3 feet of fair to poor marl under 6 to 8 feet of peat. The marl bed was contaminated with organic material wherever it was sampled. A composite sample contained 55 per cent soluble carbonates. In Section 15 a low swampy area of about 6 acres surrounded by high morainic hills is partly filled with peat and marl. A marl bed from 4 to 6 feet thick is covered by 6 to 8 feet of peat. The marl is dark is color as a result of admixture with organic matter and grades into limy clay with depth. A composite sample contained 63.20 per cent soluble carbonates.

T. 128 N., R. 31 W.—A marl bed 6 feet thick underlies about 8 acres of the meadowland and swamp land along the stream in N½ Sec. 27. The marl is deeply buried under 10 to 12 feet of peat. A composite sample contained 82 per cent soluble carbonates.

T. 40 N., R. 31 W.—A small bog in SW¼ Sec. 10 is sufficiently filled and drained to support a heavy growth of cat-tails over its surface. The basin covers an area of about 4 acres. It is underlaid by a bed of marl 3 feet thick under 4 feet of peat. The deposit is readily accessible, as there is a good road less than 100 yards from the margin of the bog. A composite sample contained 85.50 per cent soluble carbonates.

Analyses of Marls of Morrison County

Location	Sample No.	Per Cent Soluble Carbonates
T. 132 N., R. 31 W., Sec. 31	103	55.95
T. 132 N., R. 31 W., Sec. 12	108	94.5
T. 131 N., R. 30 W., Sec. 19	110	55.3
T. 131 N., R. 29 W., Sec. 15	111	63.2
T. 128 N., R. 31 W., Sec. 27	112	82.0
T. 40 N., R. 31 W., Sec. 10	109	85.5

Otter Tail County

General glacial features.—The most prominent topographic features of Otter Tail County are the intricate systems of moraines that were formed along the east margin of the Keewatin ice sheet. Most of the moraines are composed of sandy or gravelly loam, but in the western part of the county clayey drift predominates. About 50 square miles along the western edge of the county were covered by the waters of glacial Lake Agassiz, and there the present surface is composed of recent lake sediments.

There are two very extensive outwash areas in the county. That in the eastern part, known as the Parkers Prairie Plain. slopes northeastward toward the Crow Wing River. It is an outwash from the Leaf Hills moraine, which extends along its western border, and from which a very high spur known as Leaf Mountain extends toward the southwest. The second large outwash area surrounds Otter Tail and Battle lakes. Here the sands are of a finer texture and are mixed with clay.

All the marl beds that were discovered are located in basins in the regions of sandy moraines and outwash gravels. (See Figure 78.)

Descriptions and analyses of the marl deposits that were sampled and tested are given below.

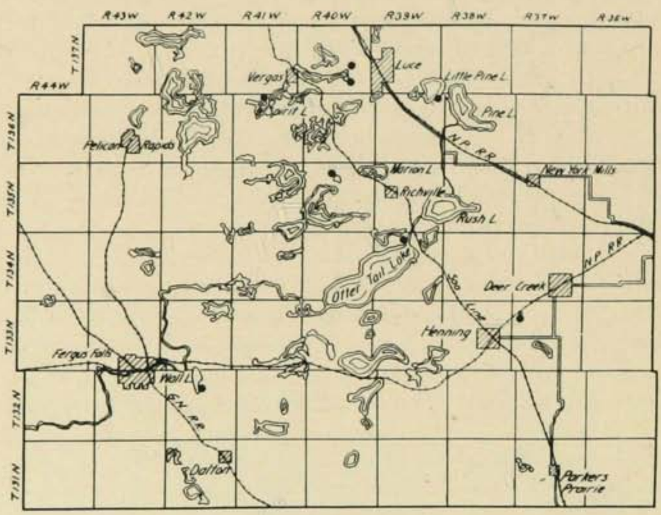

FIG. 78. — Map of Otter Tail County showing marl deposits.

T. 137 N., R. 40 W., Rice Lake. — Rice Lake is located 2 miles west of Luce in a glacial basin near the east margin of a very rugged sandy moraine. A former extension of the south bay of the lake, along the valley of a stream, is filled with peat and marl. (See Figure 79.) A bed of marl over 18 feet thick covers an area of at least 20 acres. It is overlaid with 4 to 6 feet of grassy peat. A composite sample contained 68 per cent soluble carbonates.

T. 137 N., R. 40 W., Long Lake. — Long Lake occupies a long narrow basin skirted by sharp knobs and ridges of sandy moraine. At the east end of the lake a former bay is now isolated by a series of sandy beaches. The filled bay, now drained and cultivated, occupies an area of about 10 acres. A bed of fair to poor marl underlies the whole area. (See Figure 79.) It is covered with 2 feet of peat. A group of samples averaged 43 per cent soluble carbonates.

T. 136 N., R. 41 W., Spirit Lake. — Spirit Lake is one of a chain of lakes in the rugged sandy moraine south of Vergas. A small filled embayment, once connected with the northeast bay of the lake in Section 4, is underlaid with marl. The bog covers an area of about 3 acres. There is still a small pond at the center of the bog. Around the pond 5 feet of peat overlies a 10-foot bed of fair marl. A composite sample contained 60 per cent soluble carbonates.

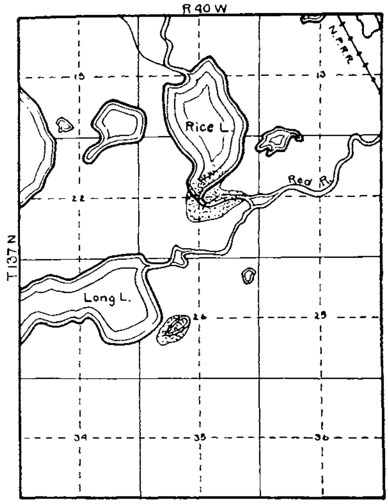

FIG. 79.—Map of Rice Lake and part of Long Lake in Otter Tail County. The stippled areas are marl deposits.

T. 136 N., R. 39 W., Little Pine Lake.—Pine Lake and Little Pine Lake occupy broad shallow basins near the east margin of the vast outwash plain that extends across the northeastern part of the county. A thick bed of impure marl, of fair grade, covers an area of about 10 acres in the bog land north of the stream that connects the two lakes across Section 1. The bog is a filled extension of the lake basin. The marl bed is exposed at the grass roots and is over 18 feet thick. A composite sample contained 66 per cent soluble carbonates.

T. 135 N., R. 40 W.—A small lake in Section 9 is fringed by about 12 acres of swampy land around its northwest margin. A growth of small tamarack covers most of the swamp. A marl bed from 1 to 5 feet thick under 6 feet of peat underlies the swampy area. A group of samples averaged 62 per cent soluble carbonates.

T. 134 N., R. 39 W., Otter Tail Lake.—At the northeast end of the lake, where the Red River flows into it from Rush Lake in SE¼ Sec. 4, the river is a wide, shallow, lake-like stream. A zone of bog land nearly a quarter of a mile wide and over a mile long parallels the stream. About 40 acres of the southern portion of the bog are underlaid by marl. The bed is 6 to 10 feet thick and is covered with 3 feet of grassy peat. A composite sample showed 54 per cent soluble carbonates.

T. 133 N., R. 37 W.—Marl has been reported in a bog in Section 8 between Deer Creek and Henning along the Northern Pacific Railroad. The deposit represents a filled lake. The combined thickness of the peat and marl is from 10 to 12 feet. The marl was not sampled.

T. 132 N., R. 42 W., Wall Lake.—The basin of Wall Lake is located in a narrow strip of outwash gravel five miles east of Fergus Falls. A filled embayment of the south end of the lake is located along the section line between Sections 9 and 16 of this township. About 20 acres around the south bay are underlaid by 10 to 15 feet of clayey marl that grades into clay with depth. There is no peat over the marl. A group of samples averaged 61 per cent soluble carbonates.

ANALYSES OF MARLS OF OTTER TAIL COUNTY

Location	Sample No.	Per Cent Soluble Carbonates
T. 137 N., R. 40 W., Sec. 26	273	43.3
T. 137 N., R. 40 W., Sec. 23	272	68.0
T. 136 N., R. 41 W., Sec. 4	267	60.5
T. 136 N., R. 39 W., Sec. 1	274	66.0
T. 135 N., R. 40 W., Sec. 9	266	62.5
T. 134 N., R. 39 W., Sec. 4	265	54.2
T. 132 N., R. 42 W., Sec. 9	264	61.2

PENNINGTON COUNTY

A deposit of marl near Thief River Falls has been reported by Mr. B. F. Nudland.

PINE COUNTY

Only one marl deposit was discovered in Pine County. It is located in SE¼ Sec. 21, T. 38 N., R. 21 W. A thin body of shelly marl underlies 10 acres of the meadowland along the creek north of the village of Rock Creek on State Highway No. 1. About 3 feet of peat overlie 3 to 6 feet of poor shelly marl that grades into clayey sand with depth. A composite sample contained 46.80 per cent soluble carbonates.

PIPESTONE COUNTY

No marl deposits were discovered in Pipestone County.

POLK COUNTY

A marl bed near Melvin has been reported by Mr. O. T. Larson of that city.

POPE COUNTY

General glacial features.—Part of the great moraine system formed on the east margin of the Keewatin ice sheet enters Pope County at the north and swings toward the southeast corner of the county. A very extensive outwash apron occupies the angle of turn outside of the moraine system. This outwash plain is built unusually high and contains several deep basins. Only a small part of the moraine to the west is as elevated as the outwash area. In the western part of the county is another moraine. This follows the Chippewa Valley and has an outwash plain covering the southwestern part of the county.

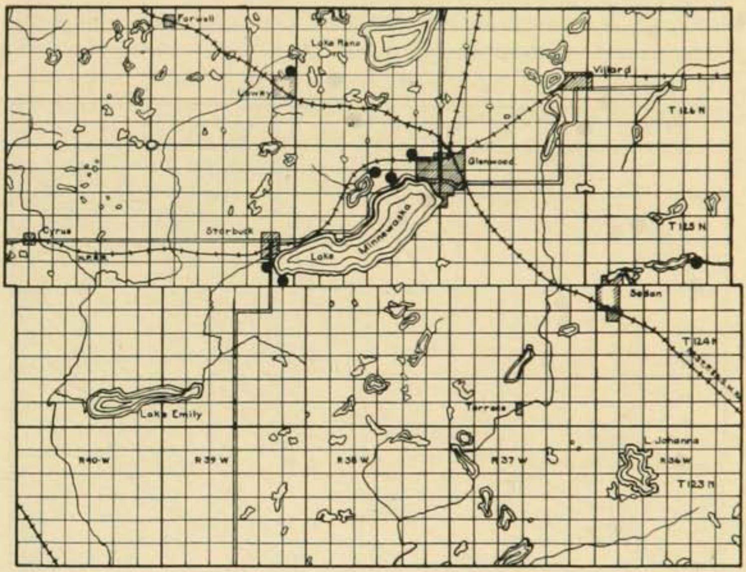

FIG. 80. — Map of Pope County showing marl deposits.

Most of the marl discovered in the county is found in the region of Lake Minnewaska (see Figure 80), where the relations of the glacial drift are such that artesian circulation brings the ground water, which has circulated at some depth, to the surface around the margins of the lake basin.

T. 125 N., R. 38 W.—A bed of marl covering several acres occurs about one and one-half miles west of the town of Glenwood, near the track of the Northern Pacific Railroad. The deposit is located at the head of the ravine between the railroad and Lake Minnewaska. It is from 2 to 4 feet thick and is covered by 2 to 10 feet of drift and soil washed from the steep slopes above the deposit. This marl bed had an origin somewhat different from that of most bog deposits. It occurs on the upper slope of a range of hills surrounding the lake, about 300 feet above the lake level. The deposit has a slight slope toward the lake. It is located near the contact between the upper loose, sandy yellow drift and the lower hard and compact, clayey, blue-gray drift. A large spring issues from this contact near the marl. The marl is distinctly laminated and overlies a bed of black mucky sediment containing a large amount of organic matter.

West of Glenwood in Sections 10 and 11 (see Figure 81) a small lake occupies a basin that was once part of Lake Minnewaska. At the east end of the lake a filled embayment covers an area of about 15 acres. This former bay is filled with marl to a depth of over 20 feet. The marl is continuous under the water of the lake. Around the margin of the bay a thin layer of peat, less than a foot thick, overlies the marl. Near the waterline it is exposed at the surface. A composite sample contained 55 per cent soluble carbonates.

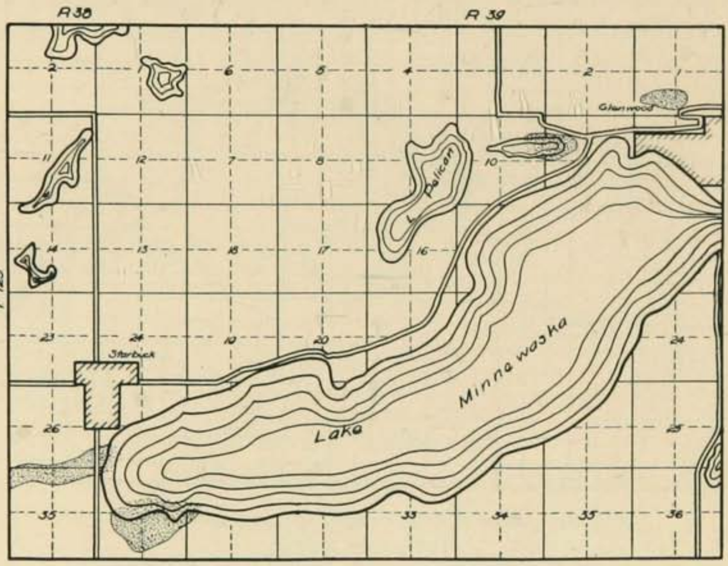

FIG. 81. — Map of Minnewaska Lake at Glenwood. The stippled areas are marl deposits.

T. 125 N., R. 39 W. — At the west end of Lake Minnewaska (see Figure 81), on the southern outskirts of the village of Starbuck, marl underlies the boggy and drained meadowland along the creek. The road around the west end of the lake crosses the bed of marl. Along the stream an area of about 12 acres is underlaid by 2 to 4 feet of peaty marl under 4 to 6 feet of peat. A composite sample contained 41.40 per cent soluble carbonates.

Farther southeastward from Starbuck in Section 36, around the southwest bay of the lake, a thick bed of marl occurs on a terrace 15 or 20 feet above the present level of the lake. Intermittent streams from the high moraine hills to the south have cut gullies into the marl so that it now outcrops along their banks. It covers an area of 10 acres to a thickness of 8 to 12 feet. A group of representative samples contained 90 per cent soluble carbonates.

ANALYSES OF MARLS OF POPE COUNTY

Location	Sample No.	Per Cent Soluble Carbonates
T. 125 N., R. 39 W., Sec. 26	249	41.4
T. 125 N., R. 39 W., Sec. 25	262	91.0
T. 125 N., R. 38 W., Sec. 10	248	55.3

RAMSEY COUNTY

General glacial features. — Most of Ramsey County is covered with red drift moraines and outwash gravel plains among the morainic ridges. The moraines, though filled with gravelly pockets, are usually surfaced with clayey till. In the western part of the county a thin veneer of gray till covers the knolls and ridges of red drift.

The marl beds discovered in the county are located in regions of sandy moraine and outwash gravels. The deposits sounded and sampled are listed below.

T. 30 N., R. 22 W., Lake Vadnis. — This lake occupies a sandy basin at the north margin of an outwash area in the southwestern part of the

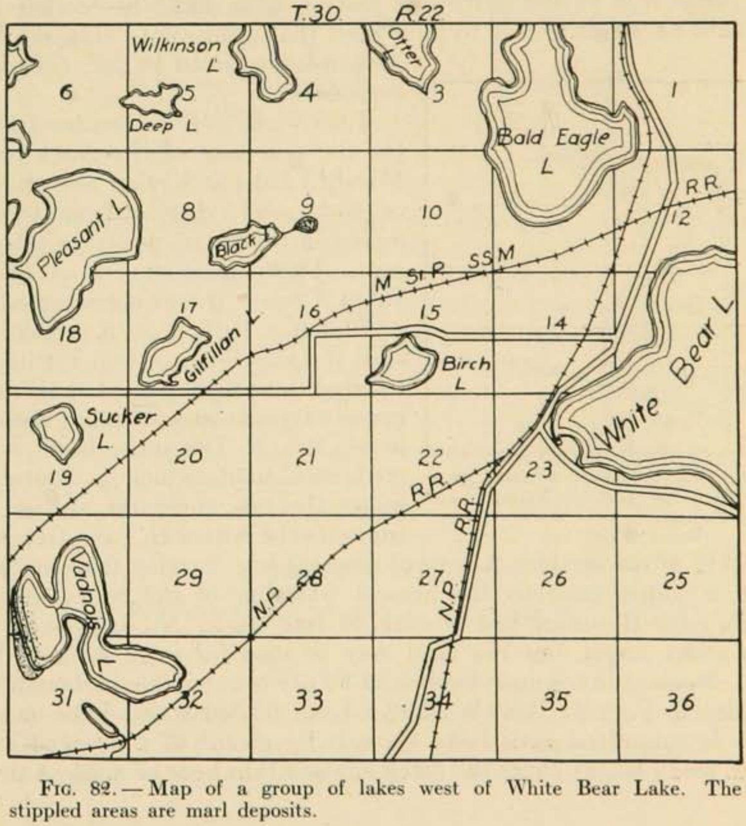

FIG. 82. — Map of a group of lakes west of White Bear Lake. The stippled areas are marl deposits.

township. A zone from 50 to 100 yards wide along the west side of the west bay of the lake in Sections 30 and 31 is underlaid by poor marl. (See Figure 82.) Below 6 feet of peat a thin bed of marl grades into clay at depth. A composite sample contained 64.60 per cent soluble carbonates.

Farther toward the south near the center of Section 31 a thin bed of marl was exposed along a trench dug in the construction of an aqueduct for the water supply system of the city of St. Paul.

T. 30 N., R. 22 W., Black Lake.—A drained bog east of Black Lake occupies an area of nearly 200 acres in W½ Sec. 9. The bog represents a small lake filled with peat and marl. A bed of peaty marl 8 feet thick underlies 5 to 8 feet of peat. Because of the high organic content of the marl, no samples were analyzed.

T. 30 N., R. 23 W.—A small lake in Sections 19 and 20 west of Long Lake at New Brighton is underlaid by marl around its east and south portions. About 12 acres of drained meadowland at the south end of the lake represent a former extension of the lake. The area is underlaid by a bed of marl from 4 to 8 feet thick. There is no peat over the marl. A composite sample contained 35 per cent soluble carbonates.

A small area at the northwest end of Long Lake in Section 18 is underlaid by 2 feet of fair to poor marl that grades into clay at depth. A sample contained 50 per cent soluble carbonates.

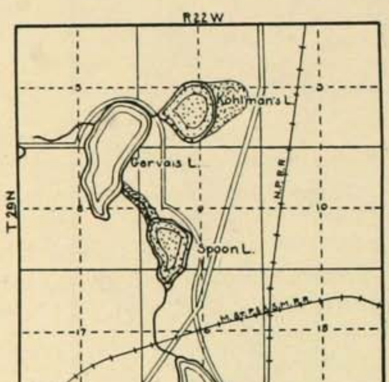

FIG. 83.—A group of small lakes near St. Paul. The stippled areas are marl deposits.

T. 30 N., R. 23 W., Marsden Lake.—On the east side of the north end of Marsden Lake in Section 10 a thin bed of good marl, ranging from 6 to 18 inches in thickness, underlies 2 feet of peat. The deposit covers an area of about 3 acres. It was not sampled.

T. 29 N., R. 22 W.—A small lake east of Lake Gervais (see Figure 83), referred to as Kohlman's Lake on some maps, covers an area of about 160 acres in S½ Sec. 4. The entire basin is covered with marl, which is continuous under the bog along the stream that connects the lake with Lake Gervais in the SW¼ of the section. A zone of quaking bog, varying from 50 to 200 yards in width, encircles the present waterline of the lake. Near the water's edge the marl bed is over 20 feet thick. No soundings were made under water, but the marl may be seen for some distance from shore. A composite sample contained 52 per cent soluble carbonate.

In Sec. 9, T. 29 N., R. 22 W., Keller Lake (called Spoon Lake on older maps) is connected with Lake Gervais by means of a dredged creek. Several small basins along the creek contain thin beds of marl. A dredging project along the east side of the lake has exposed and excavated high-grade marl. Soundings taken near shore show that a zone from 100 to 200 feet wide has a marl bed from 2 to 10 feet thick without a cover of peat. The marl is continuous under the water on the floor of the lake. A group of samples averaged 83 per cent soluble carbonates.

ANALYSES OF MARLS OF RAMSEY COUNTY

Location	Sample No.	Per Cent Soluble Carbonates
T. 30 N., R. 23 W., Sec. 19	206	35.2
T. 30 N., R. 23 W., Sec. 18	207	50.4
T. 30 N., R. 22 W., Sec. 30	200	64.6
T. 29 N., R. 22 W., Sec. 9	201	82.8
T. 29 N., R. 22 W., Sec. 8	202	78.2
T. 29 N., R. 22 W., Sec. 4	203	49.5
T. 29 N., R. 22 W., Sec. 4	204	63.8
T. 29 N., R. 22 W., Sec. 4	205	43.1

RED LAKE COUNTY

A marl bed near Red Lake Falls has been reported by Mr. H. E. Palmer.

REDWOOD, RENVILLE, AND ROCK COUNTIES

No marl beds were discovered in these counties.

RICE COUNTY

Rice County is covered with clayey young gray drift in the form of till plains and morainic belts. About 100 square miles along the eastern side of the county lie outside the limits of the young gray or Wisconsin drift. Here the old gray drift is exposed at the surface. Because of the predominance of clayey moraine, very little lime carbonate has been concentrated as marl in the glacial basins. Only one deposit of marl was discovered. It is located in a small basin among the steep morainic hills one and one-half miles west of Shields Lake in Sec. 4, T. 110 N., R. 22 W. Here a partially drained bog nearly half a mile in diameter contains a bed of poor marl 6 to 8 feet thick under 10 feet of peat. The marl contains 26.20 per cent soluble carbonates.

ROSEAU COUNTY

A marl deposit near Warroad has been reported by Mr. William Rosencrantz.

ST. LOUIS COUNTY

More than one-fourth of the area of this large county is swamp land. It includes most of the basin of former glacial Lake Upham, which covered hundreds of square miles in the southwestern part of the county.

This basin is now covered with extensive muskegs. The glacial lake waters receded before much marl had accumulated. Soundings made in the vicinity of Meadowlands, Floodwood, Elmer, Zim, and Island indicate that the big bog is underlaid by plastic blue and gray clay and fine sandy lake sediments. In Section 22 southwest of Meadowlands the peat is underlaid by fine-grained, marly clay.

Several marl beds have been located in the southern part of the county in the stony red drift area. A large accessible deposit is located in W½ Sec. 12, T. 50 N., R. 19 W., near Brookston on the farm of August Tetrick. Another high-grade deposit covering about 40 acres is located in SW¼ Sec. 13, T. 52 N., R. 18 W., near the village of Alborn. The marl is 30 feet thick and contains 95 per cent soluble carbonates.

A deposit near Sparta has been reported by Mr. W. E. Bender.

Scott County

No marl deposits have been discovered in this county.

Sherburne County

The Grantsburg lobe of the Keewatin ice field covered all of Sherburne County with the exception of a few square miles along the northern edge. Its morainic ridges and knolls are therefore a mixture of the young red drift that the ice overrode and of the young gray drift it carried from the northwest. In some areas it is predominantly red. The outwash along the north margin of the Grantsburg lobe left large areas of sand and fine gravel in the northern part of the county. Along the valley of the Mississippi is a wide belt of gravelly outwash that grades into finer sand toward the north-central part of the county, where much of the sand has been redistributed by the wind. Here dune topography is superimposed on the glacial drift surface.

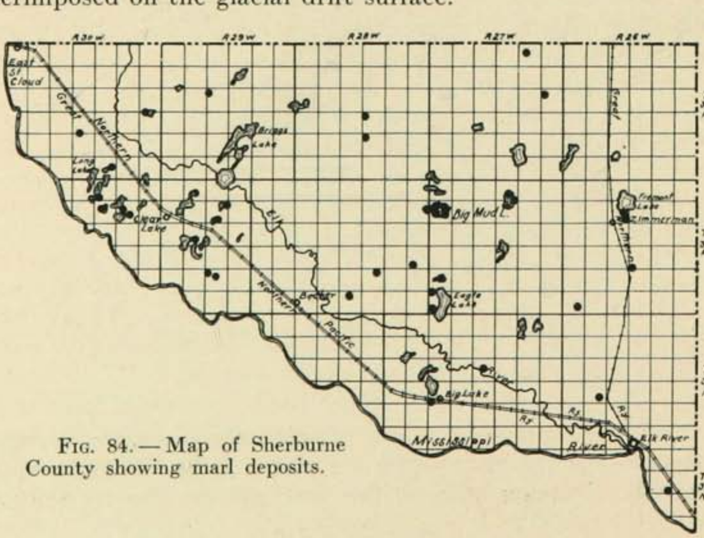

Fig. 84. — Map of Sherburne County showing marl deposits.

Most of the marl is found in regions of coarse sands or gravelly outwash. Descriptions and analyses of the deposits that were sounded and sampled are given below. (See Figure 84.)

T. 35 N., R. 30 W., Secs. 13 and 24.—A small bog occupies about 20 acres on the section line between Sections 13 and 24. Along the west side of the basin an area of several acres is underlaid by a marl bed 4 feet thick, covered by 1 to 2 feet of peat. A sample tested 86 per cent soluble carbonates.

T. 35 N., R. 30 W., Sec. 27.—An area of less than an acre in S½ Sec. 27 has a seam of marl about a foot thick under 2 feet of wet peat. A sample contained 58 per cent soluble carbonates.

T. 35 N., R. 30 W., Sec. 34.—A small basin near the center of Section 34 has an area of about 2 acres underlaid by 6 feet of marl. It is covered with 3 feet of mucky fill. A sample tested 70 per cent soluble carbonates.

T. 35 N., R. 28 W., Sec. 22.—In NW¼ Sec. 22 a small basin has an area of 2 acres underlaid by about 4 feet of wet marl, beneath which is a foot of peaty fill. A sample contained 68 per cent soluble carbonates.

T. 35 N., R. 28 W., Sec. 27.—In NW¼ Sec. 27 a swampy depression has a marl bed covering about 8 acres. It is underlaid by 4 feet of good marl under a foot of peat. A composite sample contained 84 per cent soluble carbonates.

T. 35 N., R. 27 W., Sec. 2.—In NW¼ Sec. 2 a small drained depression has a thin bed of marl covering less than an acre. It varies from 1 to 3 feet in thickness and is covered with less than a foot of sod. A sample contained 93 per cent soluble carbonates.

T. 35 N., R. 27 W., Sec. 13.—In W½ Sec. 13 a small wet basin is underlaid by 3 feet of good marl under 4 feet of peat. A sample contained 85 per cent soluble carbonates.

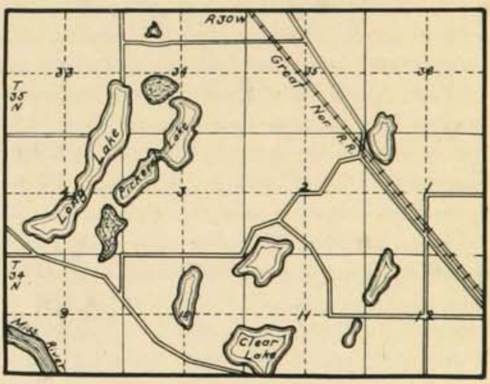

FIG. 85.—A group of lakes near Clear Lake. The stippled areas are marl deposits.

T. 34 N., R. 30 W., Sec. 4.—A small lake southeast of Long Lake occupies part of SE¼ Sec. 4. (See Figure 85.) Around the south and east sides of the lake an area of 5 acres is filled with marl and peat. The lime carbonate bed is 10 to 12 feet thick under 3 feet of peat. A composite sample contained 78 per cent soluble carbonates.

T. 34 N., R. 30 W., Sec. 10.—Along the north-south quarter line of Section 10 an old lake basin, now dry meadowland, covers an area of at least 80 acres. The entire basin is covered with fair to poor marl. The marl bed is 8 to 12 feet thick under 3 feet of peat. A composite sample contained 65 per cent soluble carbonates.

T. 34 N., R. 30 W., Sec. 11.—In NW¼ Sec. 11 a former lake basin covering about 50 acres contains a bed of marl 2 to 4 feet thick under 6 feet of peat. A composite sample contained 65 per cent soluble carbonates. A small pond near the center of the section in a depressed area also contains a thin bed of poor marl.

T. 34 N., R. 29 W., Sec. 5.—The north end of Clear Lake extends into SW¼ Sec. 5. An area of 15 acres at the end of the lake represents a former extension of the bay. It is now filled with more than 20 feet of marl, over which a bed of peat about 2 feet thick has accumulated. A series of representative samples contained 77 per cent soluble carbonates.

T. 34 N., R. 29 W., Sec. 9.—A small dry basin in NE¼ Sec. 9 has a marl bed 3 feet thick covering about 3 acres. It is covered with 1 foot of dry sod. A sample contained 91 per cent soluble carbonates. In the SW¼ of the section marl is located at the north end of a small boggy lake. The marl covers an area of about 10 acres to a thickness of 15 feet. It is covered with 2 feet of peat.

T. 34 N., R. 29 W., Sec. 17.—Parts of three lake basins occupy S½ Sec. 17. Near the south quarter line is a dry basin formerly occupied by a lake. In this basin an area of about 20 acres is underlaid by 3 feet of fair marl. Only a thin sod covers the surface of the marl. A composite sample carried 65 per cent soluble carbonates.

T. 34 N., R. 29 W., Sec. 28.—In NW¼ Sec. 28 a small dry basin of a former lake occupies an area of about 15 acres near the road that follows the north-south quarter line. The floor of the basin is covered with 5 feet of fair marl under 2 to 4 feet of peat. A sample of the marl contained 58 per cent soluble carbonates.

T. 34 N., R. 28 W., Sec. 24.—A glacial basin in S½ Sec. 24 is surrounded by a zone of drained bog encircling a partially filled pond. A bed of marl 20 feet thick covers the floor of the basin. It covers an area of about 10 acres and is covered with less than a foot of peat.

T. 34 N., R. 28 W., Sec. 33.—A small basin surrounded by a high beach ridge occupies the center of N½ Sec. 33. It is entirely drained and overgrown with weeds and grass. The floor of the basin is covered with a bed of good marl 4 feet thick under 3 feet of peat. The deposit covers an area of about 15 acres. A sample of the marl contained 84 per cent soluble carbonates.

T. 34 N., R. 27 W., Sec. 7.—Big Mud Lake occupies the major portion of the northern two-thirds of Section 7. The lake basin is so nearly filled that grasses and sedges thrive on its floor. A marl bed 6 to 12 feet thick covers its eastern bay. There is no peat over the marl, but the entire bed is contaminated with black organic material. A composite sample contained 58 per cent soluble carbonates.

T. 34 N., R. 27 W., Sec. 30.—A small basin a short distance north of Eagle Lake which was formerly a pond contains a bed of poor marl covering an area of about 5 acres. Although there is no covering of peat, the deposit is contaminated with organic matter. A typical sample contained 43 per cent soluble carbonates.

T. 34 N., R. 27 W., Sec. 31.—A bed of good marl from 5 to 7 feet thick covers an area of about 20 acres in the meadowland along the stream in the SW¼ of the section. There is only a thin covering of sod over the marl. A sample contained 75 per cent soluble carbonates.

In NW¼ Sec. 31 a small pond west of the north end of Eagle Lake is enclosed by high hills of coarse sand. A narrow boggy zone around the pond has a bed of good marl from 6 to 8 feet thick under 7 feet of peat. A composite sample contained 86 per cent soluble carbonates.

T. 34 N., R. 26 W., Fremont Lake.—Fremont Lake covers most of E½ Sec. 9 to the northeast of Zimmerman. The entire floor of the basin is covered with a growth of wild rice and weeds. At least 40 acres of the south bay are underlaid by fair to poor marl under a cover of over 10 feet of peat. A sample contained 58 per cent soluble carbonates.

T. 34 N., R. 26 W., Sec. 31.—A shallow depression in the SE¼ of this section has several acres underlaid by a thin bed of poor, peaty marl. A sample contained only 35 per cent soluble carbonates.

T. 33 N., R. 27 W., Sec. 16.—In the E½ of the section a small boggy area is underlaid by 6 feet of marl. It is covered with 4 feet of overburden. A typical sample contained 80 per cent soluble carbonates.

T. 33 N., R. 27 W., Sec. 19.—At the south end of Big Lake, to the south of the highway and the track of the Northern Pacific Railroad, is a filled lake basin that was once connected with Big Lake. The basin covers an area of 20 acres. A bed of poor, peaty marl 15 feet thick covers the floor of the basin. It is covered with 4 to 6 feet of peat. A composite sample contained 36 per cent soluble carbonates.

T. 33 N., R. 26 W., Sec. 20.—In SE¼ Sec. 20 a few miles northwest of Elk River a depression now partially drained covers an area of about 6 acres. A bed of marl 15 feet thick, overlaid with 2 feet of peat, covers the floor of the basin. A sample contained 85 per cent soluble carbonates.

T. 32 N., R. 26 W., Sec. 11.—A small glacial kettle in SE¼ Sec. 11 has a bed of marl 4 feet thick over an area of about an acre. The marl is covered with 4 feet of peat. A sample contained 70 per cent soluble carbonates.

ANALYSES OF MARLS OF SHERBURNE COUNTY

Location	Sample No.	Per Cent Soluble Carbonates
T. 34 N., R. 30 W., Sec. 11	178	65.6
T. 34 N., R. 30 W., Sec. 11	179	46.8
T. 34 N., R. 30 W., Sec. 10	177	65.6
T. 34 N., R. 30 W., Sec. 4	180	78.4
T. 34 N., R. 29 W., Sec. 28	175	58.6
T. 34 N., R. 29 W., Sec. 17	176	65.0
T. 34 N., R. 28 W., Sec. 33	173	84.0
T. 34 N., R. 27 W., Sec. 31	169	74.5
T. 34 N., R. 27 W., Sec. 31	170	86.4
T. 34 N., R. 27 W., Sec. 30	171	43.4
T. 34 N., R. 27 W., Sec. 7	172	58.2
T. 34 N., R. 26 W., Sec. 9	181	58.2
T. 33 N., R. 27 W., Sec. 19	174	36.4

Sibley County

No marl has been discovered in Sibley County.

Stearns County

General glacial features.—The eastern part of Stearns County is covered by a prominent morainic system of the young red or Patrician drift, with smaller areas of till plains and outwash gravels. The western and central parts are covered by the young gray or Keewatin drift, which overlaps the western edge of the young red for some distance. In fact, much of the southeastern part of the county has an outwash from the young gray over the young red drift.

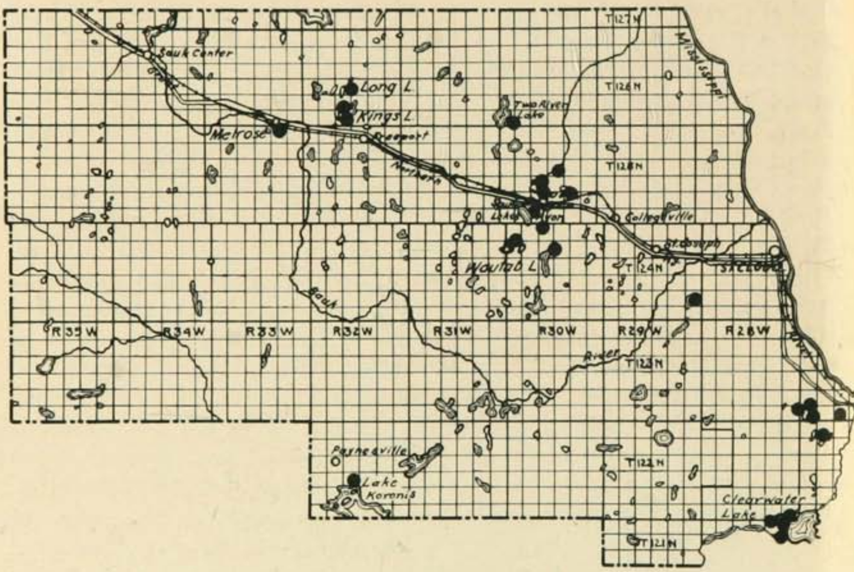

Fig. 86.—Map of Stearns County showing marl deposits.

Most of the marl is formed along the marginal area of the Keewatin ice sheet, where belts of outwash sands and gravels derived from the limy gray drift contain many limestone fragments. (See Figures 86 and 87.)

T. 126 N., R. 32 W., Long Lake.—This lake occupies a deep narrow basin in an area of rugged sandy moraine 4 miles northwest of Freeport. It extends from near the center of Section 28 northward across Section 21. A low terrace of marl, deposited when the lake stood at a higher level, is now exposed along the west side and in an abandoned bay along the stream in NE¼ Sec. 28. Marl is present under the water of the lake also. Soundings near the waterline on the west side of the lake showed 18 feet of high-grade marl. A composite sample averaged 84 per cent soluble carbonates.

T. 126 N., R. 32 W., Kings Lake.—This lake is in a basin near the west margin of the sandy moraine that crosses the north-central part of the county. Around its southwest bay in NE¼ Sec. 33 is an area of partly drained meadowland that was once part of the lake basin. It covers approximately 20 acres. The entire area is underlaid by good marl. Near the waterline the marl is from 10 to 12 feet thick with only a few inches of sod over its surface. A composite sample contained 67 per cent soluble carbonates.

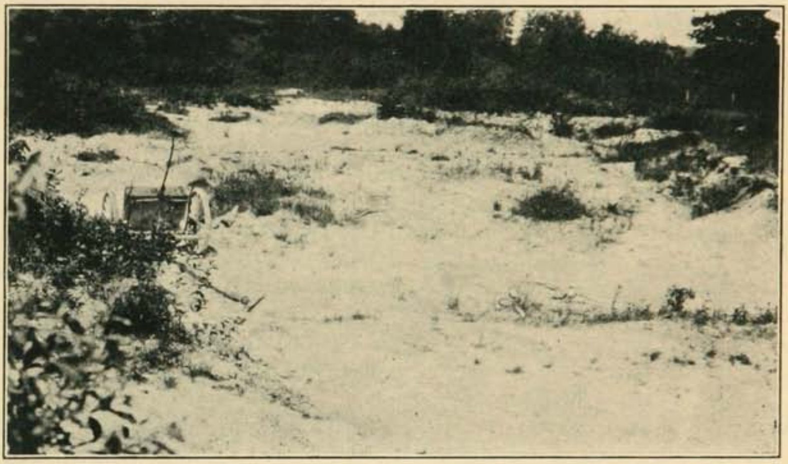

FIG. 87.—Photograph of a dry marl bed in a drained bay of a small lake near Clearwater. Over five thousand tons of marl have been excavated for agricultural purposes.

T. 126 N., R. 30 W., Two Rivers Lake.—This lake occupies a sandy basin surrounded by high morainic hills in the southwest corner of the township. An area of low sandy flats on part of the basin of the lake when the water stood at a higher level, is now exposed along the southeastern part of the lake. Several acres of this low terrace are covered with a layer of marl from 2 to 6 inches thick. A sample of the marl deposit contained 65 per cent soluble carbonates.

T. 125 N., R. 33 W.—A small pond less than a mile east of Melrose is surrounded by a heavy growth of rushes and cat-tails in the part of the basin that is filled with peat to a point above the water level. A layer of medium-grade marl about 2 feet thick is interbedded with the peat near the present waterline. It is covered with 8 to 10 feet of black mucky fill and is contaminated with organic material throughout. A sample contained 70 per cent soluble carbonates.

T. 125 N., R. 30 W.—Some of the largest and most favorably located marl deposits in the state are found in the group of lakes near Avon. (See Figure 88.) They are in a small area of coarse outwash sands near the east margin of the young gray drift. Undoubtedly the limestone pebbles and limy sands derived from that drift sheet have contributed most of the calcium carbonate now in the marl beds of the bogs.

T. 125 N., R. 30 W., Secs. 26 and 27.—A small lake on the section lines between Sections 26 and 27 east of Avon represents a former arm of the larger lake in W½ Sec. 27. Both lakes lie to the north of the highway and the railroad tracks at the outskirts of the village. The smaller lake is separated from the larger by an old sandy beach that was built above the water level by the action of ice. The entire area from the old beach to the waterline of the smaller lake is underlaid by marl. The bed varies from 6 to 8 feet in thickness and is covered with 4 to 6 feet of peat. It is continuous under the water of the lake. A composite sample contained 69 per cent soluble carbonates.

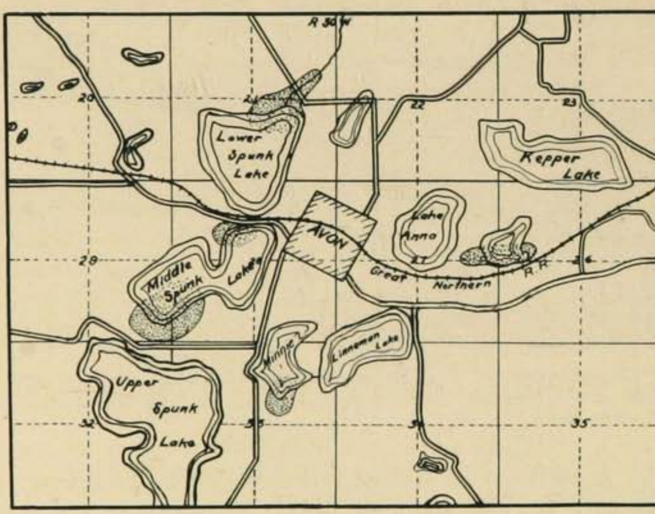

FIG. 88.—A group of lakes near Avon. The stippled areas are marl deposits.

In SE¼ Sec. 26, south of the paved highway, is a small swamp covering an area of about 3 acres. It is underlaid by a marl bed 4 feet thick under 6 to 8 feet of peat. A sample averaged 72 per cent soluble carbonates.

T. 125 N., R. 30 W., Lower Spunk Lake.—Most of NE¼ Sec. 21 north of Avon is meadowland and bog that was formerly an extension of the northeast bay of Lower Spunk Lake. At least 80 acres are underlaid by a bed of marl varying from 4 to 15 feet in thickness under only 2 or 3 feet of peat. The deposit is very readily accessible, for the county road passes directly over the bay, and the Great Northern Railroad is less than a mile away. A composite sample of the marl contained 85 per cent soluble carbonates.

T. 125 N., R. 30 W., Middle Spunk Lake.—Around the south margin of the southwest bay of Middle Spunk Lake in SE¼ Sec. 29 an area of about 15 acres, representing a filled portion of the lake, has a deposit of marl from 4 to 20 feet thick. The marl is continuous under the water of the bay. No peat has been deposited over the marl. A composite sample contained 78 per cent soluble carbonates.

T. 125 N., R. 30 W., Sec. 33, Minnie Lake.—At the south end of Minnie Lake, beyond the mud-filled bay that connects it with Linneman Lake, an area of drained meadowland is underlaid by marl. The deposit covers an area of about 4 acres. The marl is 4 feet thick under 8 feet of peat and badly contaminated with organic matter. A sample contained 66 per cent soluble carbonates.

T. 125 N., R. 30 W., Sec. 15.—A small deposit of fair to good marl is found in the basin of a small pond. The pond is located in SE¼ Sec. 15, northeast of Avon. It covers an area of about 8 acres at the margin of a high moraine. The marl is from 4 to 6 feet thick and lies below 3 feet of peat. Most of it is dry and can be readily obtained by driving to the margin of the bog. A good road passes within 100 feet from the deposit.

T. 124 N., R. 30 W., Big Wautab Lake.—This lake occupies a basin in a very rugged sandy moraine. The drift knobs and ridges are so steep that much of the land is not being cultivated. A low terrace of marl is exposed around the northeast bay of the lake, where the waterline has receded from 50 to 400 feet from the base of the morainic hills. There is no peat over the marl. In a number of places the waves from the lake have cut a steep bank in the marl bed. Above the water level the marl is dry and hard. An area of 3 or 4 acres is sufficiently hard to support the weight of a heavy truck. A good road passes over the marl bed at the northeast extremity of the bay. A group of samples averaged 78 per cent soluble carbonates.

T. 124 N., R. 30 W., Sec. 8.—A drained and dry meadow occupying an area of about 5 acres is located at the northeast end of a small lake near the center of Section 8. The lake is bordered by very steep hills of sandy moraine on both the east and the west. A bed of marl from 10 to 20 feet thick underlies the meadow. It is covered with 3 feet of peat. A composite sample contained 75 per cent soluble carbonates.

T. 124 N., R. 29 W.—A marsh in S½ Sec. 25 represents a marl-filled lake upon which successive accumulations of vegetation have built up a bed of peat about 3 feet thick above the old lake level. The area of the marsh is about 160 acres. The marl is high in organic matter near the upper surface but grades into purer calcium carbonate at depth. No analyses were made of this deposit.

T. 122 N., R. 32 W., Lake Koronis.—Lake Koronis occupies a basin at the south margin of the narrow sandy moraine that extends from northeast of Paynesville to Green Lake and New London. A small bay to the north of the northeast bay of the lake was formerly connected with the main body of water. This bay is filled with peat and marl to a point above the present water level. The marl is 6 to 8 feet thick over an area of about 4 acres. It is covered with 5 feet of peat. A composite sample contained 69 per cent soluble carbonates.

T. 123 N., R. 27 W. — The most accessible large marl deposit discovered in the state is located in Sec. 33, T. 123 N., R. 27 W., about a mile and a half west of the village of Clearwater. (See Figure 89.) The water level of the lake has been lowered so that a bed of dry marl 8 to 10 feet thick is available above the present lake level. There is no overburden of peat on the marl. Analyses show 70 per cent to 95 per cent soluble carbonates.

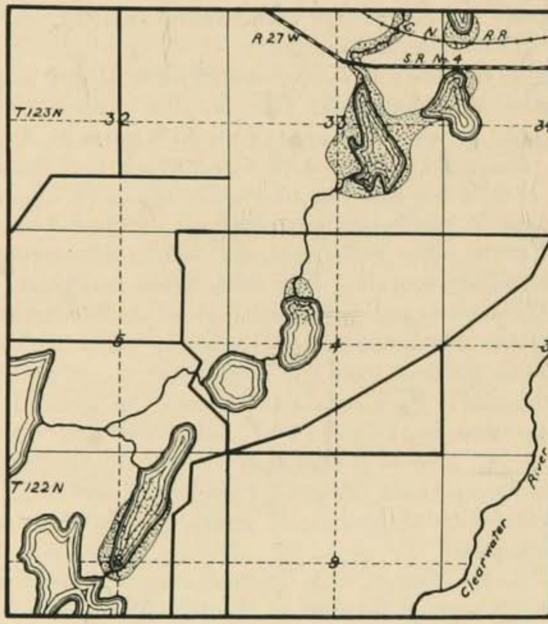

Fig. 89. — A group of lakes near Clearwater. The stippled areas are marl deposits.

Along the east side of the lake near the waterline the marl is from 14 to 18 feet thick and continuous over the floor of the lake under the water. No soundings were made beyond the waterline. Around the southwest bay a former arm of the lake has been cut off by the filling of marl and a lowering of the water level. An area of 10 acres around the bay is filled with marl to a depth of over 20 feet. The marl is continuous under the meadowland along the western shore of the lake, but there it pinches out to a thickness of about 10 feet. The lake, bog, and dry marl areas taken together cover about 200 acres within the limits of Section 33. About 8,000 tons have been excavated for agricultural purposes from a pit on the east side of the lake.

In W½ Sec. 34 is another basin partly filled with marl. A narrow zone of low dry land connects it with the marl bed of Section 33. At the east end of the lake the marl is 15 to 18 feet thick near the waterline.

but an area of about 4 acres of dry marl extends to the east, where it tapers to 6 or 8 feet in thickness.

T. 122 N., R. 27 W., Secs. 5 and 8.—The lake basins in Sections 5 and 8 are connected with the same chain as those of the township to the north near Clearwater. In fact, marl deposition is in progress throughout the entire group. A bed of marl from 4 to 12 feet thick is located in a zone 100 yards wide along the east side of the lake in NE¼ Sec. 8 and in SE¼ Sec. 5. The marl is continuous under the water of the lake. No soundings were made beyond the waterline.

T. 121 N., R. 27 W., Clearwater Lake.—Clearwater Lake occupies an enormous basin in the outwash area along the northern margin of the Grantsburg lobe of the Keewatin ice sheet. Only the northwest bay of the lake is in Stearns County. It extends southeastward for a distance of nearly 8 miles into Wright County. All the northwest bay is underlaid with marl from 10 to 15 feet thick.

In Secs. 1 and 2, T. 121 N., R. 27 W., a vast acreage of marl underlies the bog around Otter Lake and the small lake to the southwest. East of the road that crosses the bog in SW¼ NE¼ Sec. 2 the marl is 12 to 15 feet thick. The bog covers an area of at least 100 acres. A composite sample contained 88 per cent soluble carbonates.

Analyses of Marls of Stearns County

Location	Sample No.	Per Cent Soluble Carbonates
T. 126 N., R. 32 W., Sec. 33	255	67.0
T. 126 N., R. 32 W., Sec. 33	256	83.6
T. 126 N., R. 30 W., Sec. 31	118	64.8
T. 125 N., R. 33 W., Sec. 2	254	69.8
T. 125 N., R. 30 W., Sec. 33	121	66.6
T. 125 N., R. 30 W., Sec. 29	120	78.0
T. 125 N., R. 30 W., Sec. 27	114	68.6
T. 125 N., R. 30 W., Sec. 27	115	71.8
T. 125 N., R. 30 W., Sec. 21	116	70.7
T. 125 N., R. 30 W., Sec. 21	117	84.5
T. 125 N., R. 30 W., Sec. 15	119	79.0
T. 124 N., R. 30 W., Sec. 9	123	83.6
T. 124 N., R. 30 W., Sec. 9	124	68.6
T. 124 N., R. 30 W., Sec. 9	125	74.8
T. 124 N., R. 30 W., Sec. 9	126	78.2
T. 124 N., R. 30 W., Sec. 8	122	75.3
T. 123 N., R. 27 W., Sec. 33	127	59.4
T. 123 N., R. 27 W., Sec. 33	128	77.7
T. 123 N., R. 27 W., Sec. 33	129	84.2
T. 123 N., R. 27 W., Sec. 33	130	66.4
T. 123 N., R. 27 W., Sec. 33	131	88.2
T. 123 N., R. 27 W., Sec. 33	132	92.2
T. 122 N., R. 32 W., Sec. 21	245	66.8
T. 122 N., R. 28 W., Sec. 36	135	78.3
T. 122 N., R. 27 W., Sec. 8	133	69.0
T. 121 N., R. 28 W., Sec. 2	134	87.5
T. 105 N., R. 19 W., Sec. 1	259	58.9
T. 37 W., R. 31 W., Sec. 10	113	80.5

Steele, Stevens, and Swift Counties

No marl beds have been discovered in Steele, Stevens, or Swift County.

Todd County

General glacial features.—A high and sharply ridged red drift moraine system extends in a north-south direction in the eastern part of the county. It is from 3 to 6 miles wide and contains numerous basins and small lakes. The Keewatin ice sheet apparently moved along the west base of this prominent moraine and left a thin sheet of clayey bowlder till over most of the western part of the county. This veneer of young gray drift is deposited over a deeply eroded surface of the old gray drift, and the present drainage of the west-central part of the county usually follows broad swales that mark the course of the interglacial streams. This is especially true to the northwest of Long Prairie and northward toward Bertha.

The marl deposits are confined to the southeastern part of the county (see Figure 90), in the red drift moraine, which is more rugged and porous and offers, therefore, a greater hydrostatic head for the percolation of ground water than do the clayey till plains to the west. Descriptions and analyses of the marl deposits sounded and sampled are given below.

T. 133 N., R. 32 W.—A long, narrow, shallow basin is located in W½ Sec. 5, about one and a half miles east of Staples. The basin is partly filled with peat and marl. A low, drained, boggy area extends westward into Section 6. Marl has been exposed to a thickness of over 4 feet along a drainage ditch through this area. It is covered with 5 to 7 feet of clayey fill.

T. 133 N., R. 32 W., Sec. 35.—A marl deposit has been reported in Rice Lake, five miles south of Staples. This deposit was not sampled.

T. 129 N., R. 33 W.—A swampy area in W½ Sec. 32 near Lake Charlotte, about a mile south of Long Prairie, has a bed of poor marl under 3 feet of peat. The deposit covers an area of about 20 acres. A sample contained 80 per cent soluble carbonates.

T. 128 N., R. 34 W.—A small bog in W½ Sec. 36, T. 128 N., R. 34 W., about a mile southeast of the village of Little Sauk, represents a marl-filled lake basin. The bog is well drained so that the surface of the marl is partly dried. The basin is surrounded by high morainic hills. Numerous springs issue from the hillsides around the northwest and southeast margins of the bog, and several terraces of marl are found near the springs. There is no peat covering over the marl. The marl is over 20 feet thick at a distance of 100 feet from the east margin of the basin. A few carloads of marl have been excavated and shipped for agricultural purposes. The excavating machinery was dismantled when this survey was made. A group of samples averaged 80 per cent soluble carbonates.

Several small deposits northwest of Little Sauk in Sections 10 and 28 have been reported, but these were not sampled.

T. 128 N., R. 32 W. — A thick bed of high-grade marl is located at the north end of a lake in Sec. 12, T. 28 N., R. 32 W., southwest of the vil-

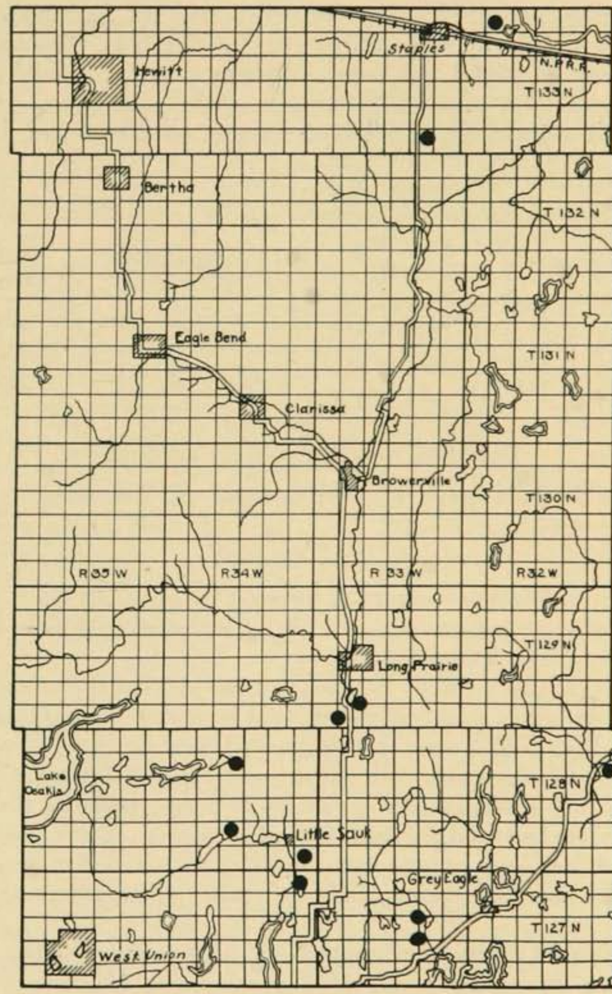

FIG. 90. — Map of Todd County showing marl deposits.

lage of Swanville, directly east of the county line between Todd and Morrison counties. Marl is found both at the outlet and in the northeastern bay of the lake. The marl is from 2 to 10 feet thick and is overlaid by 2 feet of peat. A great number of shells of small gastropods and pelecypods are present in the marl.

T. 127 N., R. 34 W.—In W½ Sec. 1, T. 127 N., R. 34 W., about 20 acres of meadowland along the stream are underlaid by a thin bed of marl. A small deposit also encircles the lake in the S½ of the section. It extends southward into NW¼ Sec. 12.

T. 127 N., R. 33 W.—A meadow about two miles southwest of Grey Eagle occupies part of SE¼ Sec. 10, SW¼ Sec. 11, and NE¼ Sec. 15. A small lake occurs at the eastern edge of the bog. The area of the marsh consists of about 200 acres. It represents a former lake, now filled with marl and peat. Test holes near the road across the bog in SW¼ Sec. 11 showed 8 to 12 feet of marl under 2 to 3 feet of peat.

Analyses of Marls of Todd County

Location	Sample No.	Per Cent Soluble Carbonates
T. 129 N., R. 33 W., Sec. 22	305	90.9
T. 128 N., R. 34 W., Sec. 28	307	64.6
T. 128 N., R. 34 W., Sec. 26	304	88.3
T. 127 N., R. 33 W., Sec. 1	306	64.0

Traverse and Wabasha Counties

No marl deposits have been discovered in Traverse or Wabasha County.

Wadena County

Nearly all of Wadena County is covered by outwash sands, but most of the sand is very fine-grained and free of limestone pebbles. Very little marl, therefore, has been deposited.

In Sec. 33, T. 135 N., R. 33 W., on the farm of August Larson a deposit of marl is located in a narrow basin that was once a marginal channel of the Leaf River. The area is well drained, and the marl is covered by a heavy growth of spruce, soft maple, and basswood timber. It varies from 2 to 6 feet in thickness over about 20 acres. Some of the marl has been excavated and sold for agricultural purposes. A composite sample contained 86 per cent soluble carbonates. Another bed covering only a few acres has been discovered about two miles upstream along the same river.

A thin seam of marly peat containing shells is interbedded with peat in a meadow two miles south of Wadena along the Great Northern Railroad. The area contains about 640 acres. The marl is too high in organic matter to be of any use other than as a fertilizer.

Other deposits have been reported in Huntersville Township and in Lyons Township, but these were not sampled.

Waseca County

No marl deposits were discovered in Waseca County.

Washington County

The young red drift covers the surface of most of Washington County. A small area northward from White Bear Lake has the young gray drift that was brought into the county from the west by the Grantsburg lobe of the Keewatin ice sheet. The margin of the young red drift lies back a few miles northwest of the junction of the St. Croix and Mississippi rivers, leaving the old red drift exposed in a narrow belt in the southeastern part of the county south of the village of Afton.

There are a large number of lakes and bogs in the northern portion of the county, whereas the southern half contains very few. No marl was found in the basins in the clayey moraines of the northern half, but several deposits were discovered in the lakes in the regions of outwash gravels and sandy moraines. (See Figure 91.)

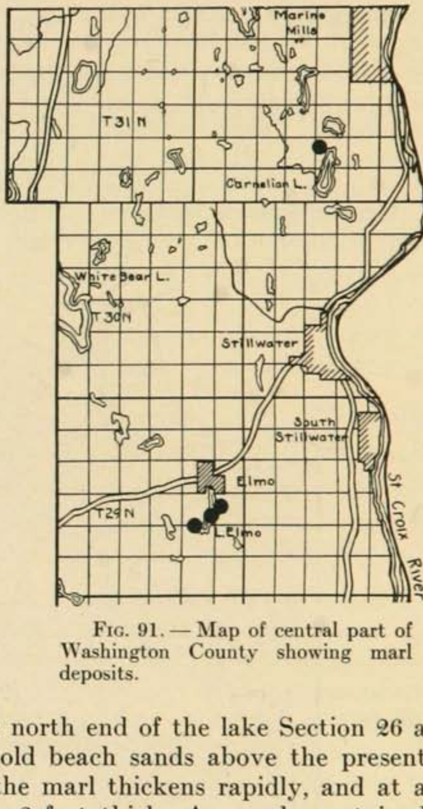

Fig. 91. — Map of central part of Washington County showing marl deposits.

T. 31 N., R. 20 W., Carnelian Lake. — This lake occupies a basin among the steep and irregular hills of sandy red drift moraine in Secs. 26 and 35, T. 31 N., R. 20 W. Marl is being deposited on the floor of the lake. Along the west side of the north end of the lake Section 26 a thin seam of poor marl covers the old beach sands above the present water level. Beyond the waterline the marl thickens rapidly, and at a distance of 100 feet from shore it is 3 feet thick. A sample contained 28.80 per cent soluble carbonates.

T. 29 N., R. 21 W., Lake Elmo. — Lake Elmo occupies a depression in an area of outwash gravels about six miles southwest of Stillwater in Secs. 23, 24, and 26, T. 29 N., R. 21 W. The entire floor of the lake is covered with marl. It varies in thickness from a few inches near shore to 4 feet at 100 feet from the waterline. Along the west side of the south end of the lake in Section 26 some of the lime is exposed on a low terrace above the present water level. There a pit has been opened and some of the marl excavated for use as fertilizer on local farms. A group of typical samples averaged 78 per cent soluble carbonates.

Watonwan County

No marl deposits were discovered in Watonwan County.

Wilkin County

The only marl beds discovered in Wilkin County are thin seams located in Secs. 33 and 34, T. 133 N., R. 45 W., west of Rothsay. There artesian circulation favors the migration and consequently the leaching action of ground water. The calcium carbonate deposited as marl was undoubtedly brought into the swamp by the large springs along its margins.

Winona County

No marl deposits were discovered in Winona County.

Wright County

General glacial features. — Wright County is crossed by several irregular moraines of young gray drift deposited by the Grantsburg lobe of

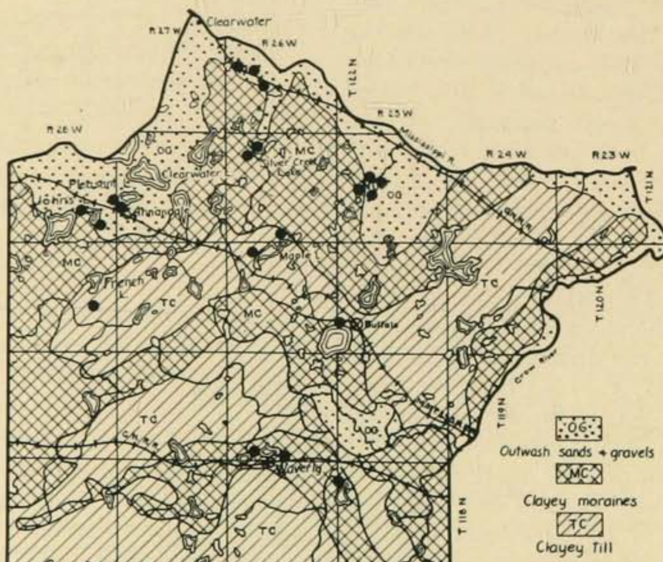

Fig. 92. — Map of Wright County showing the glacial geology and the occurrence of marl deposits. Most of the marl occurs in areas of outwash sands and gravel. (Glacial Geology after Leverett and Sardeson.)

the Keewatin ice sheet. Outwash aprons and plains of sandy gravel are extensively developed in the northern part of the county, where the glacial streams discharged from the moraines on the north side of the lobe to the Mississippi Valley. About 150 square miles of the total area of the county are covered with gravels and sands that contain numerous limestone fragments and pebbles derived from the limy northwest drift. Most of the marl deposits are confined to basins in such outwash areas. (See Figure 92.)

Descriptions and analyses of the deposits that were sounded and tested are given below.

T. 122 N., R. 26 W., Secs. 17 and 18.—A long, narrow lake basin extends in a northwest-southeast direction in NW¼ Sec. 17 and NE¼ Sec. 18, about three miles southeast of Clearwater. The southern half of the lake basin is covered with marl. In the boggy zone near the waterline at the south end of the lake the marl is only a few inches thick, but at a distance of 50 feet from shore it thickens to over 2 feet. The marl covers about 10 acres. A sample tested 78 per cent soluble carbonates.

A drained marsh in SW¼ Sec. 17 represents a former arm of the lake. It extends southeastward from the lake and then turns south toward the road on the south line of the section. A belt 100 yards wide along the axis of the marsh is also underlaid by marl, which is 2 feet thick under 6 feet of peat.

Near the center of Section 18 a small kettle-like basin is located to the west of the Clearwater road. The depression, now dry, represents a marl- and peat-filled pond. An area of about 2 acres contains a bed of marl from 6 to 10 feet thick under 8 feet of peat. A composite sample contained 64 per cent soluble carbonates.

T. 121 N., R. 26 W., Silver Creek Lake.—This lake occupies a depression at the south end of a narrow arm of glacial outwash that extends southward from the valley of the Mississippi River for a distance of about 8 miles. The lake is located in SE¼ Sec. 5 and NE¼ Sec. 8. At the north end of the lake at the village of Silver Creek a thin bed of marl forms a low terrace from 25 to 100 feet wide about 2 feet above the present water level. The marl is not more than a foot thick and overlies the old beach sands. There is no peat over the marl. Under the water near the north shore is a fill of peaty, marly muck that grades downward into bluish-gray clay. A similar fill underlies the marsh ground along the creek to the north of the lake. A sample of the dry marl from the terrace contained 67 per cent soluble carbonates.

Around the southeast shore of the lake, in NE¼ Sec. 8, an area of about 10 acres represents part of the floor of the lake when the water stood at a high level. This lowland is all underlaid by a thin bed of fair marl.

T. 121 N., R. 26 W., Secs. 33 and 34, Maple Lake.—The northeast bay of Maple Lake extends into the southeast portion of this township. In SE¼ Sec. 33 marl deposition is now in progress in the bay beyond Cedar Point. Near shore on the west side of the bay the marl is covered with sand washed from the steep sandy bank that forms the shore line. A few hundred feet from shore, under 3 feet of water, the marl is 5 feet thick over a sandy floor. A sample contained only 26 per cent soluble carbonates.

A thin seam of peaty marl averaging about a foot in thickness overlies the send in the zone of reeds and rushes along the north shore in Sec. 5, T. 120 N., R. 26 W. A sample contained 20 per cent soluble carbonates.

T. 121 N., R. 28 W., Pleasant Lake.—The town of Annandale is located on the southern shore of Pleasant Lake. To the west of the town the southwest bay of the lake, which extends westward into Section 24 of this township, is being filled with marl. At 50 feet from shore, under 3 feet of water, the marl is about 4 feet thick. The southwest bay covers an area of about 40 acres. A sample taken near Ferguson's Resort contained 57 per cent soluble carbonates.

T. 121 N., R. 28 W., Johns Lake.—Most of the basin of Johns Lake is located in Section 26, a mile west of Annandale. The northwest bay of the lake is almost completely filled with peat and marl. A narrow zone along the center of the bay is open water. The remainder is covered with a quaking bog. Near the edge of the water along the south side of the bay the marl is from 5 to 8 feet thick under 3 feet of peat. The bay covers an area of about 40 acres.

A narrow belt of bog with marl is also found along the east shore in the SE¼ of the section, between the present shore line and the road.

T. 120 N., R. 28 W., Secs. 13, 14, and 23.—A small lake occupies an area of about 80 acres at the corner of Sections 13, 14, 23, and 24. The north end of the lake is being filled with peat and marl. South of the road that crosses NE¼ Sec. 14, southeast of French Lake, the boggy zone around the lake has a bed of marl 3 feet thick under 4 feet of peat. The marl becomes clayey at depth and grades downward into a rubbery bluish-gray clay. A sample of the deposit contained 40 per cent soluble carbonates.

T. 120 N., R. 25 W., Buffalo Lake.—Buffalo Lake is located in an enormous basin in the rugged clayey moraine that crosses the central portion of the county from east to west. A small drained bog at the north end of the lake in Section 30 at the west margin of the village of Buffalo was once an embayment of the lake. It is now filled with marl and peat. A marl deposit over 20 feet thick covers an area of about 3 acres. The marl is overlaid by 3 to 5 feet of peat. It is very accessible, as State Highway No. 69 passes over the south margin of the deposit. Some of the peat land over the marl is being cultivated for truck gardens. A composite sample of the marl contained 68 per cent soluble carbonates.

T. 121 N., R. 25 W., Sec. 16.—A group of lakes southwest of Monticello occupy depressions in the flood plain of the early postglacial Mississippi River. (See Figure 93.) The region is one of typical outwash gravels covered with a thin veneer of sandy soil. In W½ Sec. 16 a basin nearly a mile long and about a quarter of a mile wide is being filled with marl. On the east side of the lake the marl bed is 15 feet from an old beach line and over 20 feet thick near the present waterline. The deposit is not covered with peat. It is of high grade and easily available. A composite sample contained 90 per cent soluble carbonates.

T. 121 N., R. 25 W., Sec. 17.—A lake basin similar to that in Section 16 is located in the central part of Section 17. It covers an area of about

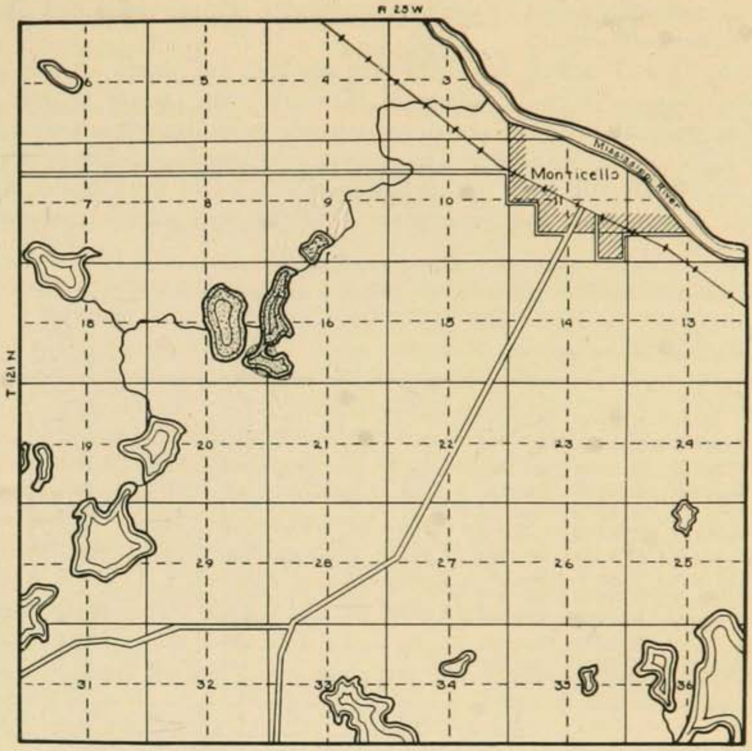

FIG. 93. — Map of a group of lakes near Monticello. The stippled areas are marl deposits.

100 acres. The entire lake floor is covered with marl. A low terrace of the marl is exposed along the west shore north of the small creek that flows into the lake. Here the marl bed is 15 feet thick near the present waterline. There is no peat over the marl. A composite sample contained 55 per cent soluble carbonates.

T. 116 N., R. 25 W., Sec. 7. — A former lake basin covers most of W½ Sec. 7. The lake has been drained by a big ditch so that its floor is sufficiently dry to be pastured. It is still somewhat boggy near the center of the basin. It contains an area of at least 200 acres. A bed of fair to poor marl about 3 feet thick covers most of the basin. It is covered with 2 feet of marly peat. A composite sample of the lower part of the bed contained 40 per cent soluble carbonates.

T. 119 N., R. 26 W., Waverly Lake. — The basin of Waverly Lake is located in Sections 32 and 33 north of the village of Waverly. It is bordered by a series of irregular hills and knobs of clayey moraine. The west end of the lake in Section 32 is surrounded by a meadow and a boggy zone that covers about 20 acres. This portion of the basin is underlaid by a bed of clayey marl ranging from 4 to 8 feet in thickness.

It is covered with 5 feet of peat. A composite sample contained 38 per cent soluble carbonates.

The north and east shores of the lake are high and sandy. Around the southeast bay north of the village of Waverly a low terrace of peat and marl has been built above the present water level from the base of the sandy hills to the waterline. This partially drained bog covers 4 or 5 acres. It is underlaid by a bed of fair marl 4 to 6 feet thick under 2 feet of peat. A composite sample contained 45 per cent soluble carbonates.

Analyses of Marls of Wright County

Location	Sample No.	Per Cent Soluble Carbonates
T. 122 N., R. 26 W., Sec. 18	226	64.1
T. 122 N., R. 26 W., Sec. 18	227	78.0
T. 122 N., R. 26 W., Sec. 17	228	50.9
T. 121 N., R. 28 W., Sec. 24	232	57.3
T. 121 N., R. 26 W., Sec. 33	230	26.4
T. 121 N., R. 26 W., Sec. 5	229	66.8
T. 121 N., R. 25 W., Sec. 17	237	54.4
T. 121 N., R. 25 W., Sec. 16	236	90.0
T. 120 N., R. 28 W., Sec. 23	234	39.5
T. 120 N., R. 26 W., Sec. 5	231	20.2
T. 120 N., R. 25 W., Sec. 30	235	68.4
T. 119 N., R. 26 W., Sec. 33	242	45.5
T. 119 N., R. 26 W., Sec. 32	243	38.4
T. 118 N., R. 25 W., Sec. 7	241	37.9

Yellow Medicine County

No marl deposits were discovered in Yellow Medicine County.

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