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ALFRED C. LANE, STATE GEOLOGIST

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PART III
MARL [BOG LIME]
AND ITS APPLICATION TO THE MANUFACTURE OF
PORTLAND CEMENT

BY
DAVID J. HALE
AND OTHERS

ACCOMPANIED BY TWENTY-THREE PLATES
AND
FORTY-THREE FIGURES

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To the Honorable, the Board of Geological Survey of Michigan:

HON. A. T. BLISS, *Governor and President of the Board*.
HON L. L. WRIGHT, *President of the Board of Education*.
HON. DELOS FALL, *Superintendent of Public Instruction and Secretary of the Board*.

GENTLEMEN—Herewith I transmit as Part III, the concluding part, of Vol. VIII, a report containing the results of examination of the raw materials of the Portland Cement industry, more particularly the beds commonly known as marl, but more properly known as bog-lime, for the more nearly pure calcium carbonate a bed is the more valuable it is.

My original plan was for a brief report something upon the order of that by H. Ries in Part I of this volume, arrangements for which were made about the same time, to be prepared wholly by Mr. Hale. But the subject grew upon him, and he obtained the promise of cooperation from Messrs. Lathbury and Spackman and E. L. Humphrey, whom we have to thank for their valuable papers.

I had also expressed to C. A. Davis my feeling that, for reasons which I have elsewhere given, none of the theories then current were competent to account for the origin of these very extensive and pure deposits of calcium carbonate. He suggested the agency of the algæ, and at my request worked the matter out, with the results herein incorporated, and I believe his contribution is a most valuable addition to science. In the meantime, facts of one sort and another kept accumulating, and so the present report was built up. I trust that its lack of unity may be atoned for by its value. If it trespasses rather far into the field of manufacturing for the economic geologist, I can only say that Mr. Hale thought that this would be useful, and that some description of the methods of manufacture were needed to understand those properties of the raw material which were most valuable.

This volume is already too large, or I should have been tempted to add to the treatment of the three materials for cement considered herein, clay, coal and bog-lime, a fourth part on limestone. The State contains much limestone suited for the manufacture of Portland cement, and the question between it and bog-lime is a business one, whether it is cheaper to grind up the limestone or evaporate the water out of the marl. The output of a plant will ordinarily be increased by using ground limestone.

Nothing in science is final, and this report is not the last word on the subject. Prof. E. D. Campbell of the University at Ann Arbor is even now at work on a very important series of papers, affecting, however, more especially the theory of manufacture.

With great respect I am your obedient servant,
ALFRED C. LANE,
State Geologist.

CHAPTER I.
INTRODUCTION.

The grayish mud underlying our lakes and marshes has but very recently become one of the greatest resources of our state. On account of its position, being covered in most part by water or muck, it is not often seen and few people are familiar with its name or appearance.

Factory men have, however, after having become aware of its presence in such quantities in the state, made good use of it as a raw material for the manufacture of the best Portland Cement. A factory was started at Kalamazoo in 1872 (a description of its marl bed is found in Ch. V, Sec. 1). Here the old set or dry kiln process proved too costly and the site was abandoned. The first successful factories were started at Bronson and Union City. At the former place the marl was discovered by a section foreman who was sinking piles to support a railroad bridge which was to span the creek draining the deposit. The Bronson works use the Ransome rotary kiln wet process and the Union City factory, which first used the older style set kiln, are also adopting the wet process.

These plants have proved very successful and the interest among capitalists and landowners throughout the State has been intense to know more about the industry and how to gauge the true value of marl lands.

It will not be possible in the following pages to describe the raw material marl and its factory requisites so that any one may at once identify his marl bed as either worthless or specially fitted for cement manufacture. This comes only with the examination of many beds and the correct summing up of numberless possibilities all of which cannot be so minutely described as to be foreseen. The work of deciding on the final merits of a bed should be left where it belongs, with a specialist. The writer will then be satisfied if, from reading the following pages, landowners and amateur prospectors can form a clear idea of what commercial marl is, how to go about prospecting for it, and how to decide correctly whether a given bed warrants a thorough examination for factory purposes.

Chapter II touches lightly upon other uses of marl. Much may be found in the early State and United States reports concerning these uses.

Chapter III discusses the adaptability of marl to cement manufacture.

In Chapter IV it is intended to give a description of as many views as possible of the origin of marl in the hope that there may be something of truth in one or all. Aside from its prime interest from a scientific point of view this chapter should afford some clue as to the location of marl beds and assist in their discovery by the explorer.

Chapter VII is intended to show both the magnitude of the cost and the numberless details to be calculated to a nicety by any individual or company embarking in the enterprise of cement manufacture.

CHAPTER VI gives many details which it is hoped will be useful to any one interested in the subject and shows somewhat the variation in mode of occurrence.

Credit is due to A. C. Lane, State Geologist, for his advice and assistance in the work throughout, also to Lathbury & Spackman of Philadelphia for their article and cuts of machinery. I also wish to tender thanks to the many men throughout the State who have assisted me in sounding beds and aided me with timely information.

Assistance was given to Prof. I. C. Russell in the preparation of Ms report on the Portland Cement Industry of the State, in the Twenty-second Annual Report of the U. S. Geological Survey, which he has therein acknowledged, but his report did not come to hand until this report was being read in page proof, so that we are not able to incorporate all the additional valuable information therein contained.

CHAPTER II.
USES OF MARL.

§ 1. Quicklime.

Marl has long been known in this State for its use in many different ways.* On the shore of many marl lakes there are to be found the remains of old lime kilns. These were erected for the purpose of burning the marl to lime. By a slow fire from beneath the organic matter was partly burned out and the carbon dioxide was driven off, leaving a fairly pure calcium oxide or the ordinary quicklime. Many log houses are still standing which were built with mortar of this kind or even with the unburned marl itself. But on a large scale this proved too costly a process compared with that later employed, which is the burning of limestone for lime. The reason for the greater costliness of the marl method is that the marl is really too bulky to handle with profit, for after the water is driven off there remains but little over half the original bulk as dry marl. From ten to fifty per cent of what remained after drying would then be burned as organic matter, implying a further shrinkage. On the other hand the limestone is more compact, has as a rule less organic matter, and is drier so that there is not the immense waste of fuel in driving off the water in the form of steam before the actual work of burning takes place. For these sufficient reasons limestone has taken the place entirely of marl as a raw material for the production of commercial lime.

*Winchell, 1860, p. 131. See also Houghton's reports, 1838, p. 34; 1839, 1840, p. 94, etc.

§ 2. Fertilizer.

Marl is used widely as a fertilizer. New Jersey marl is very much more useful than ours on account of its valuable content of phosphorus. As the marl of Michigan contains little besides calcium and magnesium carbonates it has scarcely a commercial value for this purpose as the cost of transportation to any distance would easily exceed the value of the benefit derived from it as a fertilizer. Its real value, however, when in close proximity to the land upon which it is to be used, is often underestimated. Many beds of marl in this State were visited which lay very near to land which they would enrich, upon a judicious application, and the benefit to be derived from such application would have been greater than that from application to factory purposes. If marl is dug and allowed to lie over winter till it has been exposed to freezing and thawing, its lumpy tendency will be overcome and if then spread on a tough clay it will break it up and make it more easily cultivated. On the other hand, if it is to be applied to a coarse sand it will fill up the interstices of the coarser soil, rendering it able better to hold moisture and retaining humus which would, if allowed, accumulate, as well as other fertilizers which may be added. The chemical effect of marl is not described minutely, as much may be found written elsewhere on the subject. The effect, though slow in making itself felt, is very beneficial, as the lime of the marl gradually makes soluble for the plant the otherwise insoluble constituents of the soil. It must not, therefore, be taken for granted that, because a marl bed does not prove fit for the manufacture of Portland Cement, it is altogether useless to an agricultural community. Despite the amount of time and trouble so far devoted to the explanation of its value as a fertilizer its use for this purpose is not fully understood or taken advantage of.

§ 3. Minor uses.

There are several other uses for marl which cause but little demand. It is often used in tooth and scouring powder and as adulterant for paints. As these uses on account of the very small demand they could create for marl are of scarcely any commercial importance it is proper to pass on to its prime use in the manufacture of Portland Cement.

CHAPTER III.
THE USE OF MARL FOR CEMENT MANUFACTURE.

§ 1. Description.

The name "marl" is often heard but not with the precise meaning in which it is used in Michigan. It is a somewhat general name applied in different parts of the country to substances which differ in appearance and characteristics. Descriptions are given in the United States Geological Reports of extensive deposits of '"marl" or "green sand" in New Jersey. These deposits occur in a distinct geological formation and contain the remains of animals and hence are rich in phosphates. They are called "green sands" from their color and are much prized on account of their phosphorus as fertilizers. The marls in North and South Carolina cover some two thousand miles area and like the New Jersey marl belong to a different geological era from ours. Another meaning of marl which more easily fits the term as used in Michigan is the name marl as applied to calcareous clays. In this sense of the word, however, half of Michigan could be called marl, for the light colored clays which form half our clay banks are calcareous or very rich in calcium carbonate. The indefinite or uncertain meaning of the term "marl" is very well illustrated by the definition as given in our dictionaries. "A deposit of amorphous calcium carbonate, clay, and sand in various proportions characterized usually by the most prominent ingredient; as clay-marl; shell-marl, a valuable fertilizer; green sand marl, a valuable mixture of green sand and clay."

The first step in the study of Michigan "marl"* should be to distinguish it carefully from the marls of other localities and from other formations closely allied to it in appearance and chemical composition. First of all our marl is nearly a pure "amorphous calcium carbonate." This is likewise true of several other similar compounds. An amorphous calcium carbonate is a mineral compound, calcium carbonate, the particles of which appear not to exist in a crystalline form.** Chalk is an amorphous carbonate as well as limestone. The composition of pure marl, chalk, and limestone agree very closely, but they differ much in the tenacity with which the individual particles cohere and in their content of moisture. Our marl as now considered is much like the other two in color and grain, but is more bulky and usually contains more organic matter. On the other hand a very good example of a calcium carbonate which is not amorphous, but is crystalline, is marble. This has undergone changes which have made its molecules very tenacious of one another so that it would be too expensive to grind it into powder for the manufacture of cement as in the case of the materials before mentioned. The marl then, closely resembles in composition chalk and limestone and lacks with them the crystalline formation of marble,** although the last is a calcium carbonate. The four materials of like composition decrease in the tenacity with which their particles cohere in the following order; marble, limestone, chalk, marl. The last named, our own raw material, is then the most easily ground and, in that respect at least, much the easiest to pulverize for intimate mixture with clay in the manufacture of Portland Cement.

The marl of our State should also be distinguished clearly, not only from kindred materials, but also from other materials bearing the same name. It was above mentioned that the New Jersey and Carolina marls belonged to a distinct former geological period. Our own deposits as far as can be ascertained are distinctly of the present time and occur in an area limited by the former extent of the ice-sheet. They extend about the Great Lakes, being found in Wisconsin and both peninsulas of Michigan, extending northward into Canada and southward into Indiana and Illinois. It is not a continuous bed, but lies only in the deep pockets or holes and old drainage valleys left by the glaciers. As so far seen it has never been covered by over thirty or forty feet of modern drift.

Before it is studied further as definite a description as possible should be given of its appearance and composition with variations carefully noted so that it may be easily and certainly identified. It is often mixed with clay and the combination, a calcareous clay, is termed "marl." This usage does not give the meaning of marl as it is now used in Michigan in the cement industry,*** but confuses it with clay with which it should be sharply contrasted. Again marl is found either mixed with sand, organic matter, or shells, to such an extent that its own characteristics are not clearly shown. It will therefore here be described as it exists in a fairly pure condition.

First it is found under lakes or swamps in the form of a mud consisting of from 25% to 50% moisture. In this condition it may appear dark gray, about the color of wood ashes, or nearly white. Upon drying it becomes much lighter in color. It coheres slightly and upon drying lumps much as does clay, but upon weathering breaks down into a friable mass. A very pure marl tastes much like chalk and often has a more granular appearance than the darker samples. As compared with the clay which is often found in its neighborhood it is much lighter bulk for bulk, and if each is stirred up in water the marl water clears much more quickly as its granular nature causes it to deposit first, while on the other hand, the particles of clay remain suspended in the water for some time before complete sedimentation takes place and the water becomes clear. Also upon the addition of an acid to two samples, one of marl and one of clay, the former will effervesce with formation of gas much more freely than the latter. The easiest way to distinguish marl from sand is by detecting the presence of grit. The particles of marl crumble easily upon compressing between the thumb and finger while fine sand feels hard. Shells, or their remains, are easily distinguished by their form and usually though not always form a greater or lesser portion of the marl. The greatest adulterant of marl, always forming at any rate a part of it, is organic matter. Its proportion can be roughly estimated by color of the mixture,—the darker the sample, the greater the percentage of organic matter. This may be sometimes so large that the marl becomes practically a muck or so small that it scarcely affects the pure white of the calcium carbonate.

As the contamination and consequent variation in appearance of marl is important to both manufacturer and scientist, its cause should be thoroughly understood. As stated in the definition, an impure marl derives its name from the impurity which predominates. It has been stated briefly how to distinguish the true marl from each of its impurities when the marl and its adulterant exist as separate samples. Sand, clay and organic matter are not only found near the marl, but intimately mixed with it. The following analyses are those of three samples of so called marl taken from the same chain of lakes.

Insoluble.	Aluminum and Iron Oxides.	Calcium Carbonate.	Magnesium Carbonate.	Organic matter.
(1) 75.04	1.90	14.02	6.05	2.99
(2) 57.04	4.30	22.06	12.45	4.15
(3) 15.14	13.73	43.13	1.66	26.34

The measure of purity in each of the above samples must be found in the column under calcium carbonate. It is readily seen that all are very low and that each sample is very impure. The impurity in each case is, however, due to a different cause. No. 1 was largely sand, and in confirmation, notice the high per cent of "insoluble." Though of a marly nature it is full of grit, as could easily be detected by the touch. No. 2 is largely clay and has also a high "insoluble." It has besides nearly twice the magnesium carbonate of No. 1. The reason for this is that clays laid down at the same level as marls nearly always have a high per cent of magnesium carbonate as well as calcium carbonate, which increases the proportion of the former as compared with the percentage in true marl. No. 3 shows a more even distribution of the different impurities, but organic matter predominates. This appeared as a dark grayish muck and resembled but slightly a pure marl. It contains also 13.73% of iron and aluminum oxides so that it inclines somewhat toward a bog iron. It was found fifty feet under water.

In all of the above samples the marl has partly lost its identity, becoming in the several instances, a marly sand, a marly clay, and a marly muck. A careful examination of the color, grittiness, weight and effect of acid will soon reveal the true nature of the mixture and to what ingredient the contamination is due.

Fortunately for the factory interests of the State, marl is not often subject to such great variation in appearance and composition, but has somewhat definite characteristics of its own. Its exact chemical nature together with its factory requisites will be considered in the final section in this chapter. All that will help the prospector to identify it on the ground is to know that it is generally somewhat granular in appearance, in color varying from that of dark ashes to dirty flour, is sticky and sometimes even soapy and greasy to the touch, and is distinguished from clay by its greater bulk and granular nature, from sand by the absence of grit (it usually contains a trace at least of quartz sand or diatomaceous silica), and from organic matter by its lighter color.

*More properly bog lime. L.

**But see notes on microstructure in the last chapter.

***Though correct enough in itself. The Michigan "marl" is more properly bog lime. L.

§ 2. General distribution.

The physical appearance of Michigan is necessarily of much interest to the prospector. Glacial action in past ages diversified the surface of the State and has left it ridged and hollowed thoroughly. Whatever may be taken as the agent of marl deposition, it is certain that these glacial valleys furnish the most favorable conditions for its existence and are its most usual resting place and that the present drainage furnishes the direct cause for its impurities.

§ 3. Prospecting tools.

The first thing necessary in prospecting is to get tools to work with. Several machines have been patented for the purpose, but as an owner usually wishes to sound only his own locality, the simpler and less costly the apparatus, the better.

The following is the description of a very simple outfit which is all that is necessary in the majority of beds. It must, however, be manipulated with care to obtain strictly trustworthy results.

1. Weld an ordinary two inch augur on a three-eighths inch gas pipe two feet long.

2. Thread the unwelded end of the pipe for coupling.

3. Cut three lengths of pipe each in half, or cut each into four equal lengths if it is desired to carry the outfit long distances. Thread the ends of the pipe for coupling.

4. Get couplings enough to couple all together making a continuous rod with an augur attached.

5. A "T" coupling must be inserted on the rod farthest from the augur and through this a rod or stick can be passed to turn the rod. A better way is to screw into each free end of the "T," a rod or a piece of gas pipe eighteen inches long. This makes a handle to the augur that can be inserted at any distance from the end. Usually a pair of Stillson wrenches are needed to untwist the pipe, which becomes very tightly connected during the boring.

Three-eighths inch pipe will be found to lift out much easier than half-inch, but will not stand boring to a great depth. If three-sixteenth inch is used it is liable to kink badly when sunk to any depth. On the other hand inch pipe cannot be thought of for the purpose as it would take a jack screw to lift the rod out. In the use of any size pipe or any style of sounding implement it must always be borne in mind that the quicker the work of sinking the rod, securing the specimen, and raising it is performed, the easier the work can be done. The reason for this is that the marl consists of finely divided particles partly suspended in water, making a mud. When the rod shoves aside these particles it takes them but a short time to pack around it. If it is withdrawn quickly before the particles assume their new position, about half the friction of marl against pipe is avoided and the work of withdrawal much lessened.

This is the simplest and most easily prepared and also the cheapest means of reaching the marl. Care must be taken to bore, twisting the handle as the rod is shoved down. It can generally be shoved through the mud with application of but little force, but if this is done the pod of the augur will remain filled with the surface marl which is first encountered in its descent and will bring that same marl to the surface again instead of filling with that at the bottom. Also the couplings must be very firmly started when each new length of pipe is added as the rod penetrates the marl. Many outfits are lost by the neglect of this little precaution. There is no reason why this simple apparatus should not do good work in most of the marl beds of the State. It can be made to penetrate a marl of medium consistency with considerable ease, requiring two or three men to run it. When the augur strikes sand at the bottom of the bed or in its course downward it can generally be detected by the peculiar grating sound and jar of the pipe in the hands of the operator. When it strikes clay the increased difficulty of boring is at once made manifest and it is well to immediately hoist the rod, as after boring a short time in the clay beneath the marl the apparatus will be freed with great difficulty. In deep borings care must be taken to keep the rod moving if possible, either up or down, as its recovery is easier.

This apparatus suffices for a fairly dense marl because the augur will clear itself of the surface drift on the way down and will retain fairly well the clean sample taken at the bottom. It will not, however, take true samples where the grass or roots are very thick at the top and the marl is so fluid as not to be retained readily on the pod of the augur. In beds of this nature a different device will be required to obtain samples which will give a trustworthy idea of the center of the bed. A rather clumsy but efficient device has been used (Fig. 1), which is a remodelling of that used by Mr. Parr of Onekama.

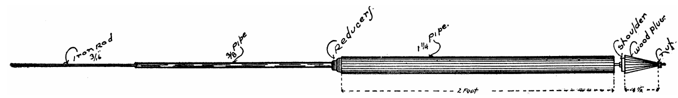


Figure 1. Farr's Liquid Marl sampler. For description see p. 11.

1. Cut a piece of inch gas pipe two feet length.

2. Thread one end of the same.

3. Screw reducers on the threaded end till the last reducer can take a half or three-eighths inch pipe.

4. If no time and materials are at hand to make a disk to close one end of the large pipe the following effective but clumsy device may be used: Upon the end threaded according to direction, screw three-eighths inch pipe of any desired length to form the rod.

5. Sharpen the open edge of the inch pipe and fit into it a plug with a shoulder that fits against the rim, allowing the plug to penetrate a half inch into the open end of the inch pipe.

6. Sharpen the end of the plug opposite the shoulder and bore a hole lengthwise through the plug.

7. Pass a three-sixteenths inch iron rod through the plug from the shoulder end and bolt it by screwing a nut upon the end opposite the shoulder, which end should be sharpened so as to more easily penetrate the marl.

The end of the rod may be threaded for several inches and a nut first screwed on, then the end of the rod passed through the plug and the nut on the end screwed tight against the plug. This will hold the plug from being shoved up the rod by the force of the thrust against the marl, and the nut on the end will prevent the plug being pulled from the rod.

The rod with the plug securely fastened on the end is then inserted in the open end of the cylinder formed by the inch pipe and is passed up through that and the three-eighths inch pipe which has already been screwed to the upper end of the inch pipe. The free end of the rod may project through the pipe at the upper end.

When placed in the water the apparatus is in the form of a long rod of three-eighths inch piping, at the lower end of which is a cylinder of inch pipe. The lower end of this is closed by the plug which fits easily against the lower end of the cylinder by the shoulder already described. This plug is manipulated by means of the iron rod to which it is firmly bolted, which runs up through the hollow rod to the operator above.

Method of Operating.

The plug is first held firmly against the mouth of the cylinder by means of the rod. The whole apparatus is then shoved down the desired length. The pipe is then raised, the rod being held stationary and after raising the rod is then shoved down to its former level, being shoved tightly against the shoulder of the plug. In this position both are then raised to the surface, the plug shoved out by means of the rod, and the sample taken from the cylinder. This takes a perfect sample to a depth of about 18 feet and can be rigged in a short time at any good hardware store. It is cumbersome on account of handling the long iron rod, but is perfect and very trustworthy for any marl not too solid to be penetrated by this means. The plug keeps all grass, roots, silt and foreign matter from the cylinder while it travels downward, and after the sample is taken, the plug being again shoved against the mouth of the cylinder, excludes all foreign matter during the ascent of the sample.

A slot could be devised to close the mouth of the cylinder, and divide it into two halves. This could be made to rotate when the cylinder was at the desired depth and allow the marl to enter, and then being rotated half around again, could close the orifice while the rod ascended. This is not a contrivance that could be fitted out In a few minutes, but when once made would be much less cumbersome as dispensing with the iron rod. This apparatus is easily made and can be relied upon to give perfectly satisfactory results.

One other must be mentioned and that is one invented and manufactured by Robert G. Hunt & Co., Chicago, Ill. It consists of a piece of steel about 18 feet long and much the shape of the half of a long gun barrel slit longitudinally. The end which first enters the marl is capped and pointed with steel so that it will penetrate more easily, and the other is surmounted with a handle for raising. The two edges running lengthwise are sharp so as to cut the marl. When the instrument has been shoved to the depth desired it is turned half around, filling it with a clean swath of marl its whole length. When it is withdrawn there is a perfect sample of the bed from top to bottom and any portion of it can be sampled if desired. It is not suitable for liquid marl as the sample would run out before the apparatus could be raised to the surface. A device for very fluid marls will be found described in the account of the operations at Cloverdale.

§ 4. Location of marl.

With a general idea of its location and the means at hand for sounding, the question next presents itself, "Where is it most likely to be found?" As has been said, marl is found in the hollows or glacial valleys that scar all parts of our State. Its more definite location is a puzzling and interesting study. The facts so far ascertained will here be given, but the theory of its origin which they seem to sustain will be given in Chapter IV.

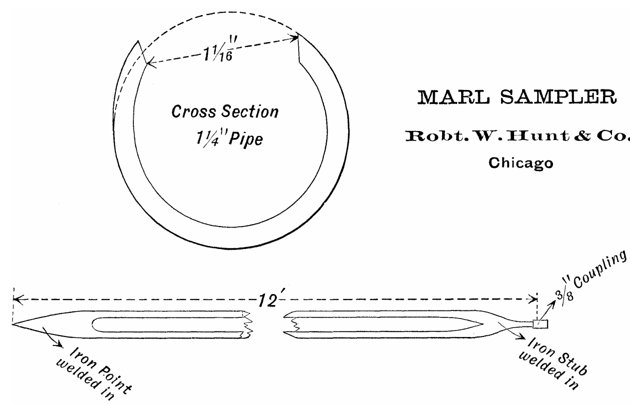


Figure 2. Hunt Marl Sampler.

1. Marl is always found in some place that was originally covered with water.* The water level of Michigan has fallen within recent years so that the old water lines of lakes can be easily traced even by the casual observer. The marl therefore is not confined to the immediate vicinity of present existing bodies of water. It underlies dried up swamps sometimes a thousand acres in extent and the banks of what now appear small streams are solid marl. However, upon noticing the comparative depth and altered course of such a stream, and its source when the low lands through which it flowed were all covered with water, its banks often prove to have once been the bottom of a large channel or lagoon. Often, also, a large swamp can be easily identified as the bottom of a large dried up lake.

*Somewhat similar subaerial deposits are known as calcareous tufa or travertine. L.

2. The next point of interest is that the water above marl is usually hard, containing first of all calcium and magnesium carbonates in fairly large proportions.* In the Cloverdale region (Fig. 3, Chap. VI, Sec. 2) the general observation of people living about the lakes was that the marl is found in a hard water lake, but not in one containing soft water. A half day's sounding in Mud or Round Lake yielded but one sample of very organic marl a few feet in depth and lying in mid-lake under ten feet of silt. This was a lake with very soft water while the water of one a few hundred feet from it, which contained 20 to 30 feet of marl, was hard. Little Lake (Chap. V, Sec. 7) contained nothing but silt and did not even respond to the hard water test.

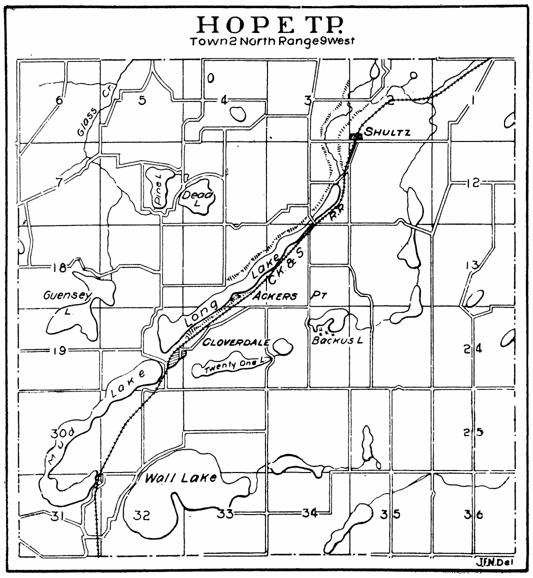


Figure 3. Map of Cloverdale district. By a mistake the r in Guernsey is omitted. Sec. 18.
The lake on Sec. 22, is properly Balker or Horseshoe Lake, the name given being an error in the county atlas.

*See analysis of water in description of Peninsular plant. L.

3. A fact closely connected with the foregoing is that hard water springs are everywhere found in close connection with marl lakes. One striking example of the converse of this fact was noticed at Escanaba. There both springs and marl were said to be absent, and flowing wells were tapped only at great depths, though the district was solid limestone.

4. The presence of water and its hardness both being somewhat related to the presence or absence of marl another closely related and interesting study is the comparative level of marl lakes and those lakes or depressions in which marl is absent. As there could be found no reliable contour maps showing the levels of different points in Michigan an aneroid barometer was tried, but it was found that only those lakes contiguous to each other could be at all accurately compared. The results of these comparisons agreed very well and served in the end to establish a somewhat general rule, that of two depressions, the one most deeply indenting the surface of the land, will contain the marl. It is also true that the deeper depression will contain the harder water, provided it cuts the deeper water bearing strata of subsoil. This conclusion was very often verified in the hilly country where the surface is deeply cut by streams and lakes. It is also quite generally the rule in comparing adjacent marshes for the presence of marl. Still it must be considered dangerous to conclude that a deep depression always forms the basin for the hard water bearing strata about it, as these same strata may slant away from, rather than toward such a basin.

No general rule can be formed which will guide the prospector unerringly to the presence of marl. As the marl is in nearly every case covered by finely deposited sediment, muck, other marsh growth, or water, its exact location and depth can be determined only by actual soundings made through its covering. Still the guides here given have proved rather useful in the absence of any other helps whatever, and as simple results of experience must not be taken as fixed rules.

5. In a chain of lakes the marl is generally deeper and of better quality in the lakes toward the head of the chain. Where the head lake has had no large body of water or stream other than a spring stream opening into it, the marl appears of purer quality and with less of foreign matter overlying it than do any of the lakes below it. In two of the chains of lakes so noticed the head lake formed the first of the series and so lay that there never could have been any other natural drainage than the one in action at the present time. This rule works well in the case of a series of two lakes, the upper one of which is fed by springs. The marl lies bare and of greater depth to the upper end of the upper lake, and sediment above the marl, if it occurs in large quantity, is liable to be in evidence toward the lower end.

6. In a large lake or one unevenly and thinly underlain with marl the deepest marl is often found in bayous or indentations of the shore-line. In such cases the marl generally thins very rapidly to the deeper portions of the lake.*

*See description of Onekama Lake.

§ 5. The distribution of marl in a single bed.

In the consideration of this subject much depends upon the stage of the deposition in which the bed to be sounded exists at the time. For marl beds exist in two different states. The first is the dried up lake or marsh, the second, the hard water lake where the marl is still depositing.

In the old lake bed or marsh the marl deposit is basin shaped. It generally has one or more centers toward which the marl deepens regularly. The marl has evidently deposited as long as water remained. As the marl reached the surface or the water dried down to the surface of the marl or both, vegetation started upon the shallows and sealed the deposit over very evenly. Where the lake bottom proper was even in the first place, the marl deposit is very regular. This was shown in some old dried up lake beds of the Upper Peninsula where the deposit was laid down evenly, increasing from the outside edge two feet in depth, to the center twenty-five feet. It is the rule and not the exception in marshes entirely covered by vegetation and containing no open water, but underlain with marl. It must be remembered that many of our inland lakes and marshes have their bottoms, uneven in their nature, cut and seamed with terraces, kettles, and holes left by receding glaciers. In the evening or blanketing process of marl deposit these holes are leveled over. In such cases the depth of marl can be calculated with only general accuracy and the above rule can scarcely be verified. A fair illustration of even deposit would be that at Central Lake in Antrim County, Plate I. See also Chapter VI, §16. An illustration of uneven deposit or better uneven depth caused by sudden variation of contour of lake bottom would be the lakes sounded at Cloverdale (Plate I, Diagrams 1 to 4).

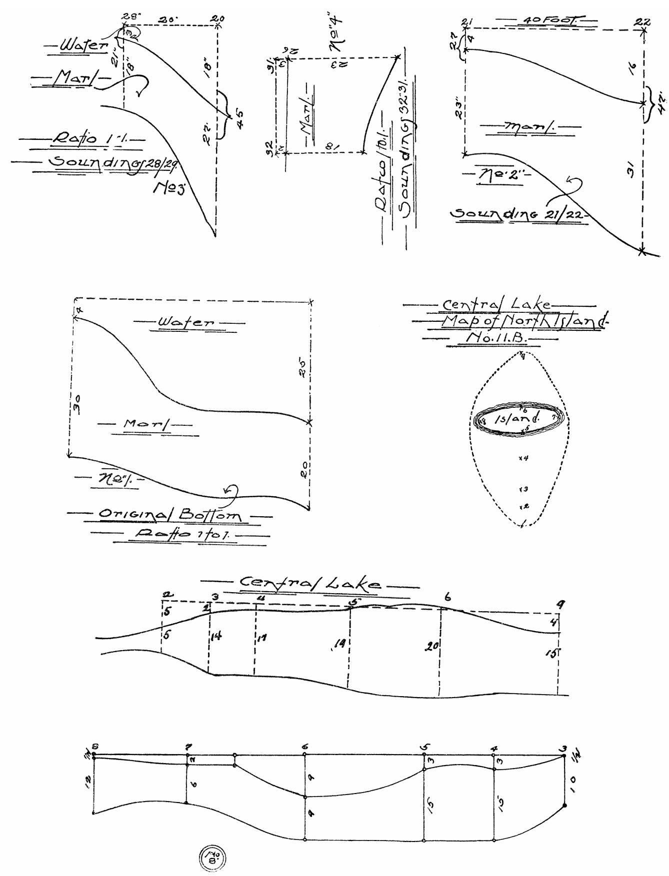


Plate I. Marl soundings, 1, 2, 3, 4, 11A, 11C.

It is very often the case, however, that the marl bed does not cover the whole depression formed by the original lake bed or by the marsh as it appears at the present day. In such a case the main body of the marl forms a basin of its own which is liable to lie as at Portage Lake, Onekama (Fig. 14), in an indentation or nook of the greater basin forming the marsh. It may or may not lie near the deepest portion of the original basin. The sealed marl bed is on the whole the more regular in its increase and decrease in depth, and is, excepting in the case or exception of an uneven original bottom, regularly deepest toward the center of the deposit.

In the lake where the deposit is still continuing or just being discontinued, the variation in depth is markedly the opposite.

In this condition the lake is nearly always surrounded by a fringe of shallows containing the deepest and purest marl. In deep water the marl may be much shallower, may cease entirely or may be a marly muck, the first and third named conditions prevailing in nearly all cases in deep water.

In studying this second condition it is found that marl forms most rapidly in shallows or about points. This was strikingly illustrated at Long Lake, near Cloverdale. This was being cut into two different bodies of water, by decrease in depth of water and at same time by rapid growth of marl, which was 33 feet in depth in the narrows at Ackers Point. Thus Horseshoe or Balker Lake was being cut into two lobes or basins and the marl was very deep at the narrows connecting and on the points of marl growing out to separate the lobes. Nearly every actively growing marl lake represents three stages or steps of growth, the shore or marsh of marl bed grown to water level and sealed over by marsh growth, the actively depositing marl of the fringing shallows, and the deeper parts which are more slowly filling up with a cruder and more impure marl. Eventually the fringe of shallows will grow to the surface or far enough for rushes to catch organic matter to form a solid covering of growth. As the center of the lake grows shallower with increased depth of marl the marl becomes whiter and deposition more active, the marl fills to water level and is sealed like the former fringe of shallows. We have then from the second condition a growth to the first condition, a completed and preserved marl bed. When the water was higher during the deposit of the shallows marl* the shore marl will have deposited to a higher level than that in mid-lake. When sounded we often say that the "surface" is deepest at the center, when in reality the marl was deposited to a second lower water level and then filled in with marsh growth to nearly the level of the shore fringe of shallows. In such a case it is noted that the shallow marl is of much finer quality because it was deposited in shallow water while the marl in mid-lake was deposited in deep water, and this latter was suddenly brought to the surface by a fall of water level and covered with an organic blanket preventing a finer deposit.

In deposits of the second or uncompleted condition the gradation in quality, due to the variation in content of organic matter, is often very marked and seldom absent. The shore shallows unless very deep deposits, are the purest, then as soundings are made toward the center the bed decreases in thickness and the marl decreases in quality, organic matter steadily increasing at the expense of the calcium carbonate.

Below are given a table of soundings in lakes about Cloverdale, pages 78, 79, 80 and table of analyses made of samples taken, page 80. On page 82 is a list or key to all the samples of marl elsewhere taken, of which analyses were made. On page 83 are the partial analyses of these samples. It will be seen by consulting the table that several samples are marked A and B. The samples marked A were taken near the bottom of the bed and those marked B were taken at the surface of the bed directly over the first sample marked A.

Owing to the fact that the deposits were very heavily adulterated with clay and sand it is difficult to compare for increase of organic matter.

*As for instance at Cedar Lake in Montcalm County. L.

TABLE OF SOUNDINGS, CLOVERDALE DISTRICT.

No.	Analysis.	Location of Sounding.	Depth of water.	Depth of marl.	Bottom.
		Long Lake.			Tamarack log on bottom.
1	1A....	In Narrows at Ackers Point...........	2	30	Gravelly sand.
2	1B....	Surface of above......................			
3	2A....	100 yards east of No. 1................	4	17	
4	....	Same as above.........................	....	10	3 ft. into fine sharp sand.
5	2B....	Same as above. Sampled at surface.			
6	....	200 yards east of No. 3................	24	10	
7	....	Sand of No. 6. Not preserved........			
8	3A....	Shallows 200 yards southeast of No. 6.	4	30	Very fine sand.
9	3B....	Surface of No. 8.......................			

TABLE OF SOUNDINGS, CLOVERDALE DISURICT—*Continued.*

No.	Analyses.	Location of Sounding.	Depth of water.	Depth of marl.	Bottom.
10	4......	About center of lake..................	25	20	Heavy gravel.
11	....	Surface of above......................			
12	....	At lower narrows......................	6	12	
13	....	East of rocky islet....................	4	9	
14	5A....	Beyond No. 12 toward outlet..........	3	33	Heavy gravel.
15	5B....	Surface of No. 14......................			
16	....	To side toward springs. Marl sandy..	2	2	
17	....	In narrows.............................	2	10	
18	....	Surface of No. 17 not preserved Muck sample of No. 6 taken near here....			Pepper and salt sand.
21	....	Northwest of rocky islet..............	4	23	
22	....	Fishing hole...........................	16	31	
23	....	Just outside of narrows north of Ackers Point.............................	2½	17	Fine sand.
24	....	Half way between Nos. 22 and 23.....	2	17	
25	....	200 yards south of No. 23..............	4	25	
26	....	At point of lake opposite Cloverdale.	3	25	
27	....	Opposite springs issuing beneath blue clay at end.........................	3	25	
28	....	Just below boxed spring (x)..........	3	18	
29	....	20 feet out from No. 28................	18	27	
30	....	Just west of Cloverdale, south side...	4	23	
31	....	Opposite Beechwood Point...........	3	23	
32	....	Shallows in toward Beechwood Point	2	17	
		Balker or Horseshoe Lake, Lobe Next to Outlet.			
33	....	In front of narrows at lower end......	2	23	
34	....	In narrows.............................	2	30	
35	....	Shore opposite landing................	3	27	Gravel.
36	11.....	Up lake on slight point................	3	29	
37	....	Just outside of No. 36 in deep water..	13	15	
38	....	In straight line across slight neck to south shore..........................			
39	....	Sample can No. 5 of water taken over No. 40................................			
40	9.....	Deepest sounding made. Brought up trailing water plant which had powerful odor of polecat*................	50	10	
41	....	At mouth of large boiling spring 200 feet toward outlet from point on south shore marking previous line of soundings. No. 4 collected at this spring..................................	0	32	muck. Marl dark blue.
42	....	200 feet west of 41 at the end of series of soundings across lake.............	2	37	
43	....	Toward upper end of lake from No. 42	2	27	
44	....	At outlet of lake. Jar No. 9 taken at surface................................	½	32	
45	....	Center of basin. Jar of water No. 6..	10	30	
46	....	In inlet from other lobe, forming narrows..................................			
		Guernsey Lake.			
47	15B..	Blue clay flats at narrows.............	2	4	muck.
48	....	In west channel or arm of south lobe.	8	30	
49	12A...	West shore of shallows................	6 in.	27	
50	12B...	Surface of same........................			
51	....	30 feet out from 49.....................	5	24	Sand bottom.
52	13B...	Surface of No. 51......................			
53	14A...	100 yards south or up from No. 51......	4	20	Sand.
54	14B...	Surface of No. 53......................			
55	15A...	Bottom of Mud Lake...................	33	5	
		Pine Lake.			
1	16.....	Cove of landing at lower end.........	3	20	
2	17.....	In front of boiling spring on opposite side..................................	6 in.	10	
3	....	In outlet...............................	6 in.	10	
4	....	First line across narrows.............			
5	18.....	Out from No. 4.........................	3	15	
6	19.....	In line across..........................	9	9	
7	....	In line across..........................	2	6	
8	20.....	At farther side.........................	6 in.	12	

*Chara foetida (?). L.

ANALYSES OF CLOVERDALE SAMPLES.

Number.	Insoluble in HCl.	Al_2O_3. Fe_2O_3.	$CaCO_3$.	$MgCO_3$.	Organic Matter.	Remarks.
1A........	3.34	2.55	84.30	3.18	6.63	Long Lake.
1B........	2.35	2.94	82.11	2.64	9.96	
2A........	2.95	.04	85.00	4.62	6.39	
2B........	1.84	2.00	81.00	10.21	4.95	
3A........	20.54	2.30	67.53	3.48	6.15	
3B........	75.04	1.90	14.02	6.05	2.99	Sand and gravel.
4..........	11.70	3.92	69.30	3.17	11.91	
5B........	14.15	1.18	75.15	....	....	Mg. precipitated.
6..........	32.32	4.62	42.14	2.91	18.01	
7..........	13.04	2.70	40.00			
9..........	15.14	13.73	43.13	1.66	26.34	Balker Lake.
10..........	4.64	2.00	65.09	3.28	24.99	Balker Lake.
11A........	57.04	4.30	22.06	12.45	4.15	Mostly clay. Guernsey Lake.
12B........	7.20	1.25	64.12	2.38	24.05	
13A........	55.10	6.80	25.28	3.10	9.74	
13B........	13.70	2.24	65.00	2.72	16.34	
14A........	61.10	4.50	21.00	11.76	1.64	Clay and sand.
14B........	1.44	.90	84.50	4.19	8.97	
15A........	41.94	3.80	47.23	3.79	3.24	Clay.
15B........	65.64	5.35	16.60	9.53	2.88	Checked volumetrically
16..........	11.97	1.45	75.62	3.44	7.52	Pine Lake.
17..........	1.80	.80	83.00	2.38	12.02	
18A........	5.04	1.84	74.46	2.31	16.35	
18B........	3.06	.95	85.04	4.20	6.75	
19A........	D.34	2.00	86.43	2.42	7.81	
19B........	2.04	1.84	84.46	2.83	2.83	
20A........	3.55	3.50	80.18	3.33	9.44	
20B........	1.24	1.60	88.30	3.03	5.83	
21..........	9.70	10.90	71.00	1.92	6.48	
Kent 16....	.14	.73	90.30	3.21	4.82	

For position and depth of samples above analyzed see preceding table of soundings of Cloverdale region.

LOCATIONS OF SAMPLES COLLECTED FROM DIFFERENT PARTS OF THE STATE BY D. J. HALE AND ANALYZED BY A. N. CLARK.

No. 4. Marl from Big White Fish Lake. Springs emptying near contain iron and sulphur.

6. Marl of Lime Lake, 17 feet below surface of bed.

7. Shell marl at surface of same bed (Lime Lake). At first pure white, it turns' brownish red upon exposure to the air.

12. Marl near spring at Corinne. Very hard and difficult to bore in with ordinary augur.

13. Marl at Wetmore in bottom of boiling spring.

18. Central Lake. Head of lake. Deep sounding.

19. South end of lake, 27 feet deep. Below level of bed.

21. In channel S. E. of S. Island, Central Lake. (Intermediate Lake.)

25. Center of Mound Spring.

26. N. side of Mound Spring.

28. 10 feet below the surface of Mound Spring, Central Lake.

29. Clay on Clout's farm, Central Lake.

30. Low clay west side of Central Lake.

31. Mixed strata of clay in brickyard at Central Lake.

32. 33 and 34 are three depths of clay on a side hill near Central Lake.

32. The highest layer consisting of broken down shale or clay.

33. Shale below 32.

34. Lowest shale.

37. Black shale from a sixty foot shaft west of E. Jordan 4 or 5 miles. Shaft was mined without success for coal.

38. Green shale lower in level than black shale of sample 37.

27. Iron from north side of Mound Spring, Central Lake.

PARTIAL ANALYSES OF SOME OF THE SAMPLES COLLECTED FROM DIFFERENT PARTS OF THE STATE BY D. J. HALE AND ANALYZED BY A. N. CLARK.

Number.	$CaCO_3$.	$MgCO_3$.	Fe_2O_3. Al_2O_3.	Insoluble.	Remarks.
4	23.57	1.89	6.75	56.95	Red sandy marl.
6	92.00	0.57	....	....	Very white. Ferrous iron, 70%.
7	90.00	.30	....	....	Brown on exposure to air. Fe 0.72.
12	76.07	1.59	1.00	19.00	White.
13	90.71	1.51	1.60	4.50	Cream color.
18	42.32	2.04			
19	57.32	1.51			
21	90.90	1.59			
25	32.76	1.89			
26	27.32	0.53			
28	1.09	1.73			
29	.18	1.05			
30	4.82	1.51			
31	20.18	1.40			
32	.36	1.66			
33	.44	.98			
34	1.25	1.89			
37	3.21	1.96			
38	2.00	2.42			
27	85.00	1.13	5.65	....	Red shale.

Above samples were analyzed by acid solution the same as for marls and limestones. The method gives too low results for CaO where samples consist mostly of clay.—A. N. Clark.

Upon comparison of the eight double samples marked A and B, page 20, it will be found that five of them show an increase of organic matter of the deep soundings over the surface soundings.* If the surface samples are taken directly at the surface they are liable to show greater organic matter due to the presence of roots of grass and rushes in shallow water, as these generally form a thick somewhat impervious mat over the surface of a bed of shallows. If soundings or samples 6 and 7 above are compared, it will be seen that both are high in calcium carbonate and that the surface marl is more impure than that at a depth of 17 feet. This was a shell marl bed and may form an exception to the rule that the deepest marl has less of carbonate and more of organic matter. This rule cannot be too much emphasized as it forms one of the few guides in the examination of a typical marl bed. If the marl all lies under deep water it will vary little in content of organic matter being nearly the same at the bottom as at the top. Such was the case in the bed at Rice Lake, which contained a bed 35 feet in depth and yet the marl did not vary as much as in many smaller lakes, remaining about the same at the bottom as at the top. On the other hand a chain of small lakes was examined which had marl in the shore shallows 30 feet in depth. It was nearly pure on top, but at bottom was scarcely more than a muck.

*As also in analyses furnished by Michigan Portland Cement Co. L.

In lakes where the deposit of marl is continuing at present or has only recently ceased, the conditions governing its location are highly interesting. In such cases it appears to have covered the lake bottom evenly like a sediment, but with this difference, that it is a sediment that fills in and helps very much to do away with inequalities in an uneven lake bottom. This was very strikingly illustrated in the series of soundings at Cloverdale given above. (See also Chap. V, Sec. 2.)

In a marl lake which is depositing at the present time there will 'be seen little if any black sediment. The common river or lake alluvium or sediment that will naturally accumulate is surrounded by the white particles of marl and forms a part of the marl bed, but of course loses its dark color, becoming light in color like the remainder of the bed. Twigs, limbs of trees that fall into the water, the water plants themselves that die and would naturally become black and so color the bottom, are surrounded by the white marl particles and are transformed into a part of the bed. When this process is in active operation the bottom of the lake shallows is perfectly white from the transforming power of the forming marl. The prospector can readily trace out the point at which this process has ceased by the presence again of sediment on the lake bottom, giving it its customary black color. And this symptom is a satisfactory and sure index to the variation of the marl bed. Where sediment has begun to form, instead of being coated by marl, the marl will decrease in depth beneath as the sediment increases in depth above, and where there is any great depth of sediment above there will be found little marl beneath it.*

The position of this lake sediment must, however, be thoroughly understood. It lies under the water and above the marl and when it begins to cover the marl, it is pretty good evidence that the bed has ceased growing. When the bed on the other hand, from any cause such as the fall of the water level to the surface of the bed or the growth of the bed up near to the surface of the water, gives marsh growths, etc., a chance to form on the surface of the bed, growth will stop and the bed will become sealed over and forever afterward will be a part of a marsh or dry lake bed, assuming at once the condition spoken of under dry lake beds.

*This is illustrated also by soundings near Riverdale, Gratiot Co. L.

It has been already stated that the edges of lakes where marl is at present forming contain the deepest marl. It is true that the rule in regard to these lakes is decrease of depth toward the center, for the marl is not at the present day forming as well in deep water as in shallow. Its quality toward deep water decreases by virtue of increase in per cent of organic matter. This seems a reliable rule with few exceptions and has been found so true as to be depended on in almost every case. The marl rapidly deteriorates till in very deep water it becomes little more than a mucky marl or perhaps a bog iron. The marl at this depth exists in a fine state of suspension and could be taken only with an instrument so tight as to hold water as well as marl. A sample was taken in fifty feet of water while at the sides of the lake a few hundred feet distant there were twenty-five to thirty feet of fair marl. In this short distance with sudden increase to a great depth the marl has become almost a muck losing the characteristic light color of marl.

The presence of springs, while characteristic of a marl region, has nothing to do with the depth of marl at a given spot. Though the presence of hard water in and about a marl lake is expected as a rule and may generally be calculated upon, a spring is no guide whatever to the location of the deepest marl. One spring will be found to bubble through marl many feet deep while another spring in the same lake and containing water fully as hard is as likely to be surrounded for any distance by pure sand, or to issue from the ground through pure lake silt or through muck. If anything, the balance of instances is against marl near springs as they, if not in the lake issuing from marl, start small rivulets of water which, as the outlets of the springs, bring down a slight drift of sand or other foreign matter. In highly charged hot water mineral springs such as may be easily found in the Rocky Mountains or in Europe, the minerals contained in the water are upon its arrival at the surface immediately released from solution and thrown down as a deposit at the mouth of the spring. The method of deposition and the location of such deposit is obvious. Our springs certainly do not discharge their burden of lime immediately and therefore give no sure clue to the manner in which the deposit is brought about or to the whereabouts of the marl deposit.

§ 6. Surroundings of marl.

It is of the greatest practical importance to the prospector to note carefully the surroundings of marl. In the definition and identifications of marl attention was called to the immense variation in appearance and chemical constitution of marl brought about by the impurities with which it often becomes contaminated. In the surroundings of marl the prospector must always seek the direct source of these impurities and it is for this reason that the location of marl in relation to its surroundings must always be carefully noted.

(a) Shore wash. Marl can never be considered as a deposit occupying very large single areas as do many other minerals. It is confined to those depressions which have once formed lakes and are now lakes or marshes. It then fills a pocket or hollow of the above description and is directly subject to the natural forces that act upon the hills and banks forming the rim of the depression which is nearly always the shore line of the lake. If the indentation is deep the shore line will be a bluff of clay or sand. If the marl and the water which must have originally covered it extend up under or close to the commanding bluff, the action of rain or running water can be nearly always traced in surface wash upon the marl, for gravity will then bring down upon the marl which is in process of formation, large quantities of sand or clay, depending upon whether the bluff is sand or clay. The presence of sand may still be expected even when the banks of the lake are very low, providing the deposit of marl is very deep. The reason is this. If we consider that a marl bed 30 feet in depth is stripped from a lake we have a valley originally thirty feet deeper than the one which lies before us filled with 80 feet of marl. Still in case of very low banks the deep marl bed was always covered by water and the slant of the bank alone will do much to govern the amount of sand or clay washed down upon the bed. In such cases, if a deep marl bed terminates abruptly at the foot of its bank or bluff, the deposit will be found to be thoroughly mixed with the wash of the overhanging bank. Soundings in such cases reveal a layering of sand then a layer of marl and then of sand and so on to the bottom. Or it may appear from the shore to some little distance out that there is nothing but sand. Upon sounding it is found that the sand and gravel from the shore have swept down and over the marl completely covering it for some distance out, the marl in some cases being found to terminate very abruptly against a steep bank and underneath a covering sheath of sand. This is the immediate and very local effect of the banks or shores of the lake upon the appearance and constitution of the marl bed about its edge, but in such cases the marl is rather thoroughly mixed with sand or gravel some distance out and is entirely unfit for manufacture. A lake with steep banks or with marl lying close under low banks must be watched closely for local traces of mixing. Long Lake at Cloverdale is an example of this.

(b) Streams. The next contaminating agent is running water. A stream running through a sandy or clay ravine upon a bed of marl in a lake can generally be traced for some distance by the presence of sand, muck, silt and other foreign substance in the marl. In many cases the formation of marl seems to have been prevented entirely. But on the other hand the course of streams changes rapidly, as does the drainage of many lakes, so that a stream is often found flowing over marl which has been already formed, very likely before the stream existed at that point. If a stream coming from another lake flows over marl all the way and comes from a marl lake its evil effects as a sand bearer are very slight. If it comes with considerable force from a sandy region and has been rather permanent it produces a large patch of sand for some distance about the inlet, and there is an entire absence of marl. Small rivulets and ditches formed or dug in recent years across a marl bed, carry in their path large amounts of sand and even gravel, which sometimes render the marl unfit for use. They should be watched with great care by the prospector to see that they do not bring impurities in quantities sufficient to destroy the value of the marl. Marl when once formed in a rather solid bed is not easily penetrated by sand bearing waters. Springs which bubble up through marl beds from a sandy bottom beneath do not often cause the sand to permeate the bed in large amounts. The sand brought by streams flowing over established beds does not penetrate the bed to any great depth provided such a bed is rather solid. If, however, the sand bearing agent, such as a stream or wash from hills, has been at work layering or steadily mixing with the bed at all depths during its formation, the bed will be found to be mixed with the adulterating sand or gravel for long distances, sometimes completely destroying the commercial value of the deposit.

(c) Surface. This is a name used to designate the covering of the marl, whatever that may be. The first covering of marl has always been water. It is formed under water and it is necessary as long as it grows that it be destitute of all other covering. Exception or explanation must accompany this statement. The natural clothing of a marl which is in active growth is generally a characteristic water plant* growing on the marl. This covers large areas in the usual marl shallows, and is seldom found lacking in an actively growing bed. It is small, lying close to the bed, reclines and almost trails and has very bare branches which issue from the stem in whorls or circles completely surrounding the parent stem. These plants, together with all other objects not possessing the power of motion, are thickly covered with a whitish coating of the marl. This condition of active formation of marl ceases when the shallows approach the surface of the water so closely that rushes and marsh growth of all kinds can obtain a foothold on the marl as a soil. The marl then becomes coated with a surface of muck and marl deposit ceases. When the marl rapidly dries out there remains but a thin coating of marsh growth which may remain as only a few inches of soil surmounted by ordinary marsh grass. There is then practically no surface or one which may be easily removed by the dredge. If, on the other hand, the surface next to the marl remains very wet, it is conducive to a very luxuriant marsh growth which may sometimes consist of from two to seven feet of loose roots and rushes. Sometimes a thick wood has sprung up on the bed consisting of trees of large size or a very thick tangle of underbrush. This means a tough surface of roots to be removed before the marl can be used and its nature should be carefully noted by the prospector. This is one way in which a marl bed is covered and gets its surface.

*Chara, see chapter by C. A. Davis. Lu

(d) Silt under water. When the conditions have become unfavorable for further formation of marl, the silt which is constantly deposited from lake water, ceases to be enveloped by the particles of marl and falls upon the bed, making a dark covering. This sometimes forms over a bed or a part of it and the growth then ceases. In time the deposit of silt reaches the surface of the water or the water sinks to that of the silt. In either case the silt is exposed so that marsh growth gets foothold and seals the deposit as before. One marl bed was found where there were layers of this silt with its attendant marsh growth intervening between layers of marl. The rule is in nearly every instance, however, that when sediment of the nature of silt or marsh growth is found beneath the marl such a layer is an indication that the bottom of the bed has been reached.

(e) Lining of marsh growth or decayed plant life. It is true that pure lake sediment often smothers and seals the growth of a marl, even when the bed is covered with many feet of water. There is another very interesting phenomenon which the prospector notices when he has penetrated often to the bottom of some beds. Just before the sounding apparatus penetrates the sand or clay underlying the bed, it passes through a thin layer of nearly pure organic matter which seems to be the finely compressed and decomposed residue of plant life. It is green or blue in color, fine in texture, and it forms a very sharply defined layer a few inches thick. It lies just under the marl between the marl and sand forming an organic lining. It contains some lime and does not effervesce very freely with acids. This layer was noticed in several rather deep deposits.*

*Compare what is said about Schizothrix. L.

(f) Organic matter permeating deposits. Remains of plant life always form a characteristic part of a marl bed, but the prospector will find a more or less sharp distinction between two kinds associated with the bed:

(A). Organic matter of the marl deposit.

This organic content of the marl bed varies with the depth of the bed and the depth of the water above the marl. It is as much a part of the marl bed as is the content of lime. It can be depended upon that this content of plant remains will increase in two ways; first, from the shallows toward the center of a lake or marsh, and, second, from the surface of a thick deposit toward the bottom of that deposit. This is one of the rules with fewest exceptions and will serve as one of the best practical guides to the prospector. This rule works, of course, only in the absence of outside influences; i. e., when the composition of the bed is not interfered with by drainage, water streams, etc. The consideration of this leads directly to that of

(B). Organic matter of drainage.

When a stream brings in much silt or drift of any kind the conditions favoring the deposit of marl cease to exist, then a heavy admixture of organic matter follows with no fixed rule by which to judge it except perhaps direction and force of the water which may empty upon the deposit. In the majority of such cases the dividing line between marl and foreign matter is sharp enough so that the area of the marl can be fairly outlined. Yet this sometimes varies and the influence of the foreign organic matter is felt for a varying distance into the body of the marl deposit.

(g) Materials underlying marl. The various soils which surround and influence the quality of the marl bed have been described and it now remains to describe the substratum or foundation upon which the marl lies. The thin layer of organic matter which often forms the lining of the bed has already been described.

In Rice Lake, at the bottom of thirty-five feet of marl, a thin layer of pure organic matter lay under the marl and rested upon sand. This layer was pierced in nearly all soundings in the lake, where bottom was struck.

Marl never lies on muck or organic matter of any great depth. The usual foundation is sand or clay. The majority of beds lying upon clay seem to indicate that the marl is a distinct deposit differing from clay and that if the clay is mixed with marl to any extent it is due to a sedimentary deposit of the clay by water flowing off of some adjacent clay bed. Instances were seen where, in this way, clay of a highly magnesian composition was freely mixed with the marl deposit. In most cases there is, however, a sharp line of division between marl and clay.

Perhaps the most characteristic material which forms the final basis of marl deposits is sand. This is in nearly every case a fine quartz sand which may be mixed with fine grains of mica, forming "pepper and salt sand." If the deposit of marl is lined with the .above described layer of organic matter the material, whether it be sand or clay forming the basis or foundation for the marl, does not work into the deposit affecting the uniformity of its quality. If coarse gravel takes the place of the fine sand bottom it indicates the former presence of flowing water and foreign matter of all kinds so far described must be watched for by the prospector.

A fact in this connection is noteworthy. This is that an amount running from 1% to 3% of fine quartz sand is fairly well distributed through most deposits of marl. This seems to be strictly separate from the ordinary surface washings of coarse sand. In one case, Onekama Lake, the sand of this special kind was nearly absent. But on the bottom of the deposit and in some cases at intervals toward the surface, there were thin layers of half decayed organic matter. In some cases the wood, at 10 or 15 feet beneath the marl, was well preserved so that the fibre could be split. In one instance at Ackers Point, Cloverdale, a well preserved tamarack log was struck at the depth of thirty feet. It lay on the bottom of the true lake bed as a sounding near by showed sand at the same depth.

(h) Materials overlying marl. It is difficult to judge of the age of a marl bed by its covering. Large areas of marl are covered by marsh. This generally is in a semi-fluid condition so that it jars with the tread for yards around. It will remain in such a condition as long as the water level allows the water to stand within a foot or so of the surface of the marl. In such a condition the marsh growth of rushes and their roots grow rapidly and surface soil, etc., is caught making a spongy growth of sometimes five to eight feet-or more in thickness. Solid ground may form over it and the presence of marl be unsuspected. When, however, a shaft is sunk or railroad spikes are driven, or a grading put on the ground, the presence of marl is attested. The spikes sink suddenly or the grading sinks, or the shaft is suddenly filled with mud. All these things have occurred, showing that the marl is often buried deeply. In such cases the water at the level of the marl kept it fluid all the time. A surfacing of marsh growth develops rapidly and leads one to think the marl very old on account of the thickness of the surface upon it. On the other hand, if water level sinks, the marl dries out and no luxuriant vegetation grows excepting the ordinary marsh grass. There are hundreds of acres of this that may be very much older than that covered by marsh growth. At Rice Lake there was a marsh growth of from two to six feet which must have been largely grown since the lake bottom was drained but a few years ago.

§ 7. Method of prospecting a given area.

The general rules for the location of marl beds by the prospector have been given. Also those more particular laws which will assist in judging of the probable effect on the bed of foreign materials surrounding, above, around, and beneath the bed. After a marl bed is located in a valley or depression, either as a lake or marsh or combination of both, the next step is to estimate the area and depth. If a surveyor's outfit is to be had the work can of course be performed with unquestioned accuracy. Lines may be run measured distances and at right angles to these, another set of measured lines making of the marl a checker board of squares the intersecting lines of which should be fifty to one hundred feet apart. At these intersections soundings could be made and the depth noted upon the plat of the bed. As it very often happens the prospector does not carry surveying or measuring instruments, a practical and at the same time accurate method of testing the bed must be devised, as follows:

(1) A record of everything done must be kept and this record must be made as soon as each fact is ascertained, not trusting to the memory any detail.

(2) Soundings must be made as nearly as possible in straight lines with the lines parallel to each other.

(3) The best and most permanent marks by which to locate the soundings made and the work done are the section lines and boundary lines of landowners. A bed can usually be located as included within boundaries of a quarter section or of a forty or eighty acre plat of ground.

(4) To measure the distance between soundings, the woodman's method of pacing the ground can be resorted to. Soundings should be made at first not over fifty feet apart, but if the deposit, after many soundings, is found to be very regular in both depth and quality, the distance may be increased to one hundred or two hundred feet, care being taken to at once decrease the distance between soundings upon the slightest signs of change of quality or sudden unevenness in depth.

(5) If soundings are entirely upon land the distance is more easily calculated, but if on water and in summer it is more difficult to determine accurately. In making deep soundings in shallows on water it is safest to use boats. A rough frame or planking will serve to bind the boats together and the soundings may be made between the boats, the operators standing upon the cross planks as nearly as possible at the center. It is often found possible, where the bed is not very thick, for the soundings to be made with augur and pipe from one boat, the boat being rocked by the persons in it to exert a leverage on the side in raising the pipe. This sometimes fails, resulting in inability to raise the pipe, which becomes stuck in the marl. It must always be remembered that small pipe and quick handling make light work.

§ 8. Commercial importance of composition.

It will now be well to consider marl in regard to the manner in which its chemical composition affects its usefulness for factory purposes.

In the following treatment the impurities of marl will not be considered but the fairly pure marl only, leaving out sand, clay, and extraneous organic matter. The best marl and that which should most nearly typify marl as an economic deposit lies, we will say, in a small inland lake. It is covered by but a few feet of water and by no silt or foreign matter whatever. It is growing at the present time. It rests on a bed of fine quartz sand, which does not affect its composition to any great extent. The influx of surface waters and drainage streams has not interfered with the purity of the deposit. This lake is fed mainly by hard water springs. Such are the surroundings of a very pure marl when it is in the process of deposition.

(1) Appearance.

The marl on the shoals or marl flats of such a lake is very white and somewhat granular. The marl near or not quite at the surface is very much the purer and will generally give the higher analysis if it is not mixed with roots of water plants in gathering the sample. We see such high analyses of marl quoted frequently as 95% to 98% calcium carbonate. This is all true enough, but represents usually but a small portion of the bed which in reality would average much below such a percentage if the analysis of a sample from the bottom of a thirty foot bed were to be given, even if the deeper sample were to be taken over the same spot as the shallow. Marl of the above location, at the surface of an actively depositing bed is often very granular and even gritty to the touch. Upon a careful examination it will be found that the grit is composed entirely of marl and not of sand, as might at first be supposed. The marl is seen gathered into pebbles and has often formed about roots and small objects of every kind. When the root has died and rotted down it often leaves a hollow pebble around which the marl continues to form.* Toward the bottom of a thirty foot deposit, at the same place, few if any of such accretions will be found present. The marl is at the same time finer grained, more adulterated with organic matter and darker in color. Toward the center of such a bed, in deeper water, the marl is also darker in color at the surface, the concretions disappearing also. It is this reason that single chemical analyses reveal little of the nature of a bed. As far, however, as the exact nature of marl and its identity as distinguished from every other calcareous deposit are concerned, a pure bed as above described serves as the best illustration of one very important fact to the manufacturer, which is that marl as a distinct deposit and free from all contamination varies very much in its own composition, in the same bed at the same spot.

*Produced by Schizothrix. See C. A. Davis' paper. L.

(2) Composition.

With the foregoing understanding an endeavor will be made to explain the composition of marl. Marl is certainly due to one clearly defined agency. (1) It derives its composition from the carbonates contained in the hard water of the springs. It is not deposited immediately around the springs. A secondary agent in the deposition is the growth of shells, snail shells, bivalves, etc., which have died leaving their shells to more or less increase the depth of the calcareous deposit of marl. In places favorable to their growth, or where they have been sifted from the surrounding marl by wave motion they form a nearly solid bed, while in other places they and their broken down forms are nearly if not entirely absent. The following are the analyses of fairly pure samples of marl from different parts of the State.

MARL ANALYSES.

	Calcium Carbonate.	Magnesium Carbonate.	Ferric Oxide.	Alumina.	Insoluble Silica.	Soluble Silica.	Moisture.	Organic Matter.	Sulphuric Acid (SO_3).	Phosphorius.
1	74.480	0.50	2.36	0.54	7.20	....	1.25	12.88	0.89	
2	82.142	4.620		0.9775	1.151	....	16.27	11.173	0.00	0.037
3	89.965	1.672	0.999	0.158	1.222	....	9.750	5.984	0.00	0.03
4	83.045	1.201	Undete	rmined	3.569	....	....	11.700	0.485	0.00
5	87.000	0.910	1.30	0.070	0.780	0.130	0.600	9.800	0.270	
6	97.000	1.010	1.260	0.08	....	....	....	....	.30	
7	94.496	1.250	....	0.432	....	2.528	0.235	0.790	0.00	0.150
8	92.91	1.89	0.53	0.21	....	1.54	2.01	0.80	trace.	
9	77.1	3.28	....	1.92	9.64	....	....	10.99		
10	92.1	3.2	....	.76	....	.22	....	3.7		
11	60.00	3.00	....	0.62	.30	....	34.60	1.50		
12	....	....	.10	.14	1.90	....	0.64	5.69	.56	.01
13	93.8	....	....	....	0.73	....	differen	ce 1.17		
14	92.79	2.27	....	0.52	3.25					
15	93.75	2.42	.25	.55	1.01	.18	differen	ce 1.84	trace.	
16	91.34	.77	.40	.55	.78	.42	....	5.79	.26	

KEY TO PRECEDING TABLE.

1. Marl from Alpena, Mich., W. E. Courtis, analyst.

2. Marl, Cass City, Michigan, same analyst.

3. Marl, Cass City, Michigan, same analyst.

4. Marl, Grass Lake, Michigan. This sample was dried at 100 degrees centigrade, dry residue 42.11%. Undetermined 3.569. Same analyst.

5. Near Grayling, Michigan. Average sample when dried lost 61% of its weight. Same analyst.

6. Same sample, but figured without organic matter.

7. From lake shore near Grand Rapids. This sample loses 6.376$ of water and volatile hydrocarbons when heated to 100 degrees centigrade. The silica is not sand. The 0.235 moisture is combined water. Phosphorus as tricalcic phosphate. It also contains chlorine as sodium chloride, 0.119%. Same analyst.

8. Marl from Alpena, Michigan. Total 99.87.

9. Grass Lake, Michigan. Was collected by A. C. Lane and analyzed by F. S. Kedzie.

10. Marl at Peninsular Plant, Cement City, Goose Lake, Mich. Total 99.98.

11. Marl at Cedar Lake, Montcalm County. Not dried. Analyzed by F. S. Kedzie.

12. Marl near Grayling, Michigan. M. A. C. bulletin 99; CaO 45.16, MgO 0.32; K_2O 0.37. Dried marl is 49% of original weight of sample.

13. This sample is the same marl as 11, but a different sample and figured dry. The marls as taken contained 9.95% water. F. S. Kedzie analyst.

14. Naubinway marl. World's Fair report, p. 132.

15. Light marl, Michigan Portland Cement Co., H. E. Brown, chemist.

16. Blue marl, Michigan Portland Cement Co., H. E. Brown, chemist.

Additional analyses will be found elsewhere in the report under the descriptions of individual deposits, by reference to index. See also table of tests,

Nearly all of these samples are very high in calcium carbonate and are well fitted for the manufacture of cement.

(3) Interpretation.

In the first place the percentages as here seen represent but a small portion of the bed as it is gathered in sampling. On the other hand it does not represent the true proportion of compounds which enter into the composition of the finished cement. The sample, as shown in many of the remarks in the key given above, is, when received at the laboratory, evaporated to dryness, so that water evaporation during analysis will not affect the final percentages by the steady loss of weight of the sample which would continue to dry. In evaporating to dryness a sample generally loses from 40% to 60% of its weight, or in other words, a bed of marl as it lies ready for prospecting is at least half water, which must be lost in the process of manufacture. With this understanding each compound above named will be considered separately.

Calcium Carbonate.

This is the one necessary compound to be considered in the manufacture of the cement. It should be at least 90% of the dried sample. The calcium carbonate is derived by some agent from the hard water of the lake above or at one time above it.

It is pure white and largely influences the color of the whole sample of marl depending upon the percentage of it contained. In the process of analysis the calcium carbonate is separated into two most ordinary compounds. In analyses given out from a laboratory these are often stated separately, a percentage of calcium oxide and one of carbon dioxide being given, part of the carbon dioxide belonging originally to the magnesium carbonate. In such a case the easiest way to get from the stated analysis of the sample the percentage of calcium carbonate is to add to the stated percentage of calcium oxide 78.577 of itself. We will have, within a very small fraction of a per cent, the amount of calcium carbonate which the calcium oxide represents.

In the process of manufacture as well as in that of analysis, the calcium carbonate is broken up into calcium oxide and carbon dioxide. The carbon dioxide, which is a gas, passes off as a smoke and is not of any use in the finished cement, which should be free from it. It follows from this that after the 50% or 60% of water is driven off, 44% of the percentage of calcium carbonate is lost as gas and does not enter into combination in the finished cement. The all important compound $CaCO_3$ enters the factory in a wet, finely divided state, best fitted for mixing it most easily with clay, is dried, then heated, expelling the carbon dioxide and leaving it as calcium oxide surrounding the other finely divided particles of clay which contain the silica to be made soluble by the action of the intense heat of the rotary kiln.

Magnesium Carbonate.

This is a compound analogous in many ways to the calcium carbonate. As seen in the above analyses it exists in the marl in very small percentages. This is the case when the marl is pure. A large percentage of magnesium carbonate in marl as pure as the above would not be characteristic of marl as a deposit. It would show generally that some clay had become mixed with the marl. For in such cases, when clay is laid down at the level of marl or during the deposit of marl, it generally contains a larger per cent of magnesium carbonate than does the marl,* and so influences markedly its composition. In such cases the percentage of insoluble matter, or silicates and aluminates is much higher than in the marls given above, on account of the increase in per cent of silica in clay over that in the natural marl, which of itself would contain a low per cent of silica. The magnesium carbonate has not been found to add to the real value of the marl, and it is certain that if it is present in any large amounts it will be a positive detriment to the finished cement. As the marl will vary from day to day in its content of organic matter and other components it is well to have the dangerous elements as much as possible absent. It must also be remembered that one of the greatest troubles is too much carbonates in clay. For this reason if for no other the marl should be low in magnesia. As seen, however, in the above analyses the purer marls are nearly free of magnesium carbonate and it seldom causes trouble in samples with a very high calcium carbonate content.

*See analyses of clay given elsewhere in this report and in Part I.

Ferric oxide and alumina.

These are very likely deposited as ferrous hydrates in the marl bed. As such they are nearly colorless. When, however, a deep sample of very white marl is brought to the surface and exposed to the air for some time it may turn to a red or brownish red tinge from the oxidation of iron. These are seldom deposited in the marl in amounts to cause trouble. A case has before been pointed out where a marl with high content of organic matter showed also a very large percentage of iron and aluminum oxides. This fact is remarkable, that an intensely iron spring may discharge its highly mineral waters at the edge of a very pure marl bed. The grass about the spring will be covered with oxidized iron showing a red slime or even a bog iron effect, but the marl itself is not influenced in the slightest. It will generally be noticed that marls with the highest organic content also contain the highest percentage of iron and alumina.

Insoluble and soluble silica.

The per cent of insoluble silica is traceable to several sources. First of all, nearly all beds contain fine quartz sand independent of the ordinary coarse drainage sand and pebbles that may be washed into the bed as already explained. This sand can sometimes be found to permeate the bed from top to bottom, even when the bed is thirty feet deep. If, however, there is a very even layer of the organic lining above referred to, the sand does not seem to penetrate as well, if at all. The sand will be found in the purest beds to vary from a fraction of a per cent to several per cent in amount. This is in the case of a comparatively pure marl. In case a clay has at any time mixed with the bed the content of insoluble silica will vary, but will remain larger together with other disturbing features, such as the increase in magnesia before mentioned. Sometimes such a condition will produce an increase in content of magnesia toward the bottom of the bed, while in a pure bed little if any regular variation of magnesia has been discoverable with increase in depth from which sample may have been taken.

Soluble silica.

The marl is intimately associated with the remains of plants, no matter how pure it may be or at what depth it may be sampled. The same may be said in regard to shells although samples have been found where the shell formation could not be traced. It is certain that plants, especially diatoms in the course of their growth, render a very small amount of silica soluble. This of course would remain in the body of the marl after the death of the plant. Certain shells are said to have the same power. The amount of silica in a good marl is very small. The soluble silica will not be in amount to help or hinder greatly, for, as may be seen in the analyses cited, it is but a fraction of a per cent. The insoluble silica is, however, higher in per cent and it is that which must be watched closely. It ought not to exceed three or four per cent for the reason that it interferes with the balancing of the silica and calcium content of the slurry and prevents the best burning of the mixture. Insoluble silica as sand is one of the most refractory substances known. It is not as finely divided as clay silica, does not make as intimate a mixture with the lime of the marl and does not flux so easily. Although sand marl cement can be made, sand is entirely out of place in the process used in Michigan, and should be guarded against carefully in the selection of raw material.

Organic matter.

Organic matter is a necessary evil in relation to marl. It is of no positive harm except that it increases the weight and bulk of marl without adding to it its usefulness. It is burned out as nearly as possible in the manufacture of cement and all that remains is ash. As noticed in the sample above given, where the calcium carbonate content falls suddenly it is nearly balanced by increase in organic matter. It has already been explained how profoundly organic matter influences the character of a bed. The law of its own variation can be depended upon to hold true where outside agents have not also contaminated the bed. It will also be noticed that in the very pure samples where organic matter is nearly absent the marl has but a trace of other compounds beside calcium carbonate and that where it increases in a large degree, all the elements already mentioned spring into prominence again. If, then, marl is very free from organic matter it is liable also to be free from dangerous compounds. If it is high in organic matter it will be bulky to handle, will not yield a large percentage of calcium oxide for the production of cement, and will necessitate continual watching for fear of dangerous compounds.

Sulphuric and phosphoric acids, chlorine, etc.

These compounds, if present in large quantities, would be dangerous. They cause little trouble unless the marl is highly organic when, as before explained, it is of little use anyway. Sulphuric acid is often present in dangerous amounts in otherwise commercial marls. In the above samples some have been given in full and then figured without the organic matter. This is not a true representation of the real value of the sample as it exists in the marl bed and is not intended as such. Care should be taken to discount the high and flattering percentage of calcium carbonate shown by such an analysis. This reconstruction of the real analysis is made to determine whether or not the dangerous elements would, in the burned marl, exist in sufficient quantity to forbid its use. The percentages exist in such reconstructed analyses as they would enter into the formation of the cement and directly influence its formation. Perhaps, this one fact should be borne in mind, that in the new proportion of compounds brought about by burning, the carbon dioxide derived from the carbonates of calcium and magnesium is driven off also by the heat before the marl has reached the proportions which it possesses upon incipient vitrification. In order then to give the truest percentage estimate of the marl as its component parts would exist when ready for use, the analyses should be figured with both organic matter and carbon dioxide absent.

Having noticed the various ingredients and their variation, the final question to the prospector is fitness of marl as shown by analyses. The sample, not the bed, is suitable if it contains 90% or over of calcium carbonate and no dangerous element in large proportions. If the marl runs over 90% of calcium carbonate it is not liable to have other ingredients in dangerous proportions, provided the bed is a characteristic deposit, not mixed with any of the adulterating foreign matters before mentioned. As a matter of fact it would be hard to find a bed, all samples of which are above 90% calcium carbonate of depth or extent suitable for manufacturing purposes. The reason for this is the steady variation of organic matter before mentioned.

§ 9. Location and size of bed.

Besides quality of the marl there are other points worthy of notice. Is the bed located on a railroad or one of the Great Lakes? If it is found necessary to build a railroad to the deposit, the extra cost must be reckoned, compared with competing raw material more favorably located. If the bed is located where vessels can easily reach it from the Great Lakes, it has one of the best natural advantages.

The expression has often been heard, upon the sounding of a small bed of marl to the depth of 15 or 20 feet, "Oh, here is marl to last for years." Besides quality and location, the size is the third vital point always under consideration, and one which the owner should be able to determine himself. To illustrate the point clearly, the changes which the marl undergoes up to the time of partial vitrification, will be reviewed as nearly as possible.

The marl as it lies in ordinary swamp consists of from 40% to 60% by weight of water. First this water must be evaporated from the slurry and then whatever organic matter is contained in the marl must be oxidized, burned out, passing away to remain functionless in the finished cement. Still another important shrinkage in volume and weight must take place. The remaining useful calcium carbonate is also oxidized, losing 44% of its weight in the form of carbon dioxide, which passes off as gas with the smoke of the kiln. Shrinkage or gain in weight of the other ingredients is slight on account of their small percentage.

Take for example, sample No. 5 of the foregoing analyses.

(1) 100% less 61% equals 39% dry marl.

(2) 87% of 39% equals 33.93% of original wet marl as calcium carbonate.

(3) Calcium oxide is always 56% of a given weight of calcium carbonate.

(4) 56% of 33.93 equals 19% of original weight of wet marl as calcium oxide.

Of sample No. 5, but 19% therefore of the weight of the sample as it was taken from the marsh, enters into the final weight of finished cement as an active cementing agent. Nearly all of the remainder passes off as useless gas or as water requiring great expense in heat to evaporate it. While this sample is rather low in calcium carbonate, probably the very best samples of fairly wet marl could not show above 25% calcium oxide available after burning. This has a direct bearing upon the question of area and depth of marl necessary for cement manufacture. The estimates given by the factories in active operation in the State, figure 1½ to 2 cubic yards of marl as equal to one barrel of Portland Cement. This would vary according to the purity of the marl and the amount of water contained. The water is a necessary evil; by the wet or slurry process there must be enough water so that the marl will mix and pump readily, though, after mixing all the water must be evaporated in the burning which requires expense in fuel. Taking 1½ cubic yards as the equivalent of one barrel of cement it will be well to calculate the consumption of an ordinary fourteen rotary mill.

(1) 1½ cu. yds. equal 40.5 square feet of marl one foot deep.

(2) 14 rotary mill produces 1000 barrels cement per day.

(3) 1000 times 40.5 equals 40,500 cubic feet of marl per day consumed.

(4) 43,560 square feet equal to one acre.

(5) Dividing 43,560 by 40,500 we find there are 1.0755 days work in an acre one foot thick.

(6) In 200 acres 200 times 1.0755 equal 215.1 days work. This is about the number of days the factory would run out of a year. If the deposit were 25 feet thick, such a deposit 100 acres in area would run a 14 rotary factory 25 years. Such a rate of consumption of raw material seems enormous and according to this estimate there are few single beds of marl that would furnish raw material for a length of time to guarantee the erection of a plant. Certainly a strip of marl 75 to 100 acres in area would scarcely warrant the erection of a large mill. The largest cement corporations in the State buy all the marl in a given vicinity comprising several lakes. In considering the largest area of bed for one factory it must be remembered that marl cannot be transported any distance to a factory. The factory must be located on or very near the bed. The immense shrinkage in volume of marl during process of manufacture has already been shown. The expense of carrying marl any distance cannot be met when competing with other factories located on their beds and with the immense limestone districts of other parts of the country.*

In conclusion, a marl must be of the best and the most uniform quality, it must be free from its natural adulterants, it must be located near some waterway or on a railroad, must be 15 or 25 feet in thickness over an area of several hundred acres. Such qualifications all included in one vicinity, are very difficult to find. High quality throughout, unlimited quantity, and fine natural location are necessary, for a good article must be manufactured and shipped easily and cheaply and upon an enormous scale to make the manufacture of marl a very paying and useful industry in the State.

*Compare, however, what is said concerning the Hecla Portland Cement Co.

CHAPTER IV.
THEORIES OF ORIGIN OF BOG LIME OR MARL.

§ 1. Introduction—the various theories.

An effort will be made to give all the ideas obtainable upon this phase of the subject. It is fact and no more than natural, that every one who has examined marl deposits has some one view as to the origin of so peculiar a resource. With the knowledge the prospector now has of the nature of marl it would be very helpful to arrive at a correct conclusion as to the origin of marl deposits. This would rapidly aid in pointing out the most probable location of the marl and would prepare the explorer somewhat beforehand as to the exact quality of the marl and would inform him as to the necessity of a more or less minute examination of different parts of the bed to pass upon its fitness for practical purposes.

A scientific conclusion in regard to the origin of marl is also a small contribution to the exact knowledge of the geology of the State of Michigan and as such should be of permanent scientific value. In the hope that out of many opinions the truth will finally come, space is given in this place to all views obtainable upon the origin of marl. Prof. Davis's work on the subject is given a separate chapter (Chap. V), while the others will be stated as clearly as possible under this heading.*

*Some farther suggestions, and observations, microscopic and otherwise, by me, will be found in the last chapter. L.

(1) Shell theory.

The idea has often been expressed by those who examine a bed that shells are the origin of marl. There are certainly beds that verify this statement. Some are beds of nearly solid shells, and shells too that are well preserved to a depth of fifteen or twenty feet. In such cases, no doubt, the location of the bed has been especially favorable to the formation of shells. Samples of shell formation from Florida have been seen where the shells formed a calcareous mass of shells and their broken down remains, very similar to the purely shell marl of our own State.

(2) Sedimentary theory.

This theory is that the lime existing as it does in our State in fine particles distributed through the soil, was washed by the action of the water from the pebbles and limestone rock of the State during the glacial period. That after the ice had melted the limestone sediment of finely ground rock was washed into the drainage valleys left by the ice in melting, and formed a fine sediment much like a clay, but being of a different density than clay, was deposited separately, forming the beds we now have.* This idea was suggested by H. P. Parmelee.

*Or possibly where the rock was practically all limestone, the glacial rock flour might be almost wholly composed of calcium carbonate. L.

(3) Chemical theory.

This theory, one that was found to be held by many chemists of the State, is at least, a very plausible solution of the cause of the formation of marl. It is based on this fact or principle in chemistry. Carbon dioxide by its presence in water aids it in holding in solution a greater amount of calcium and magnesium carbonates. The minerals are held in the form of double carbonates of calcium and magnesium. When a water containing carbon dioxide under pressure and a larger amount of the carbonates than it could otherwise hold in solution without the presence of the carbon dioxide escapes from confinement underground, and is exposed to the air, the carbon dioxide as a gas, escapes and the carbonates, no longer held in solution by the presence of the gas, are precipitated as simple carbonates of calcium and magnesium. There is no doubt whatever that such a reaction takes place in many instances which can be cited in nature. The idea here held is that all the conditions are correct for such reaction. The water of our springs is confined in underground waterways, or better, reservoirs. The gas cannot escape and is under pressure. The carbonates washed from the soil and lime rock are in the water and in solution as evinced by its clearness. When the spring flows out from beneath a hill the water spreads out in the calm inland lake, is released from pressure and perhaps warmed, and the gas escapes, and the carbonates are precipitated to the bottom in the form of a marl. Such is this popular and striking theory. It has much to recommend it. Some if not all the conditions named are present. The cases in nature where such change undoubtedly takes place are to be found in our mineral springs of the West and Europe, and in calcareous tufa of our own State. The heavy mineral springs are surrounded at their very openings by the minerals precipitated from them as the waters issue. In most of these cases the process of precipitation has been aided by the cooling of the waters which are very hot. Hot water such as these contain will also take into solution a much greater percentage of minerals.

From the above comparison it will be seen that though minerals are somehow precipitated in both cases, the conditions are not exactly identical and it would be dangerous, therefore, to reason from one to the others.

The conclusions reached in the search for an origin for marl deposits are much the same as those reached by Prof. Davis in his report, which is given in full in Chapter V. The endeavor will be made in the following pages to show wherein the several theories above named point to the real causes of the formation of marl, and also to record the steps taken to test the relative value of the same, as made in the special survey of the State requested of me by the State Geologist.

§ 2. Shells.

Shells form a greater or less part of a marl bed. Their presence is sure evidence that they are an agent in the origination of a bed. An analysis of pure shells from a marl bed shows that they help to form the purest part of the bed and that the proportion of their compounds as compared to that of a very pure marl without shells is very nearly the same. They are, however, but a minor agent in the formation of most beds. Their existence and plentiful growth depend upon much the same causes which are responsible for the principal agent of cement formation. They are therefore plentiful in most beds in the marl, because they are produced at the same time and under the same conditions as the marl. Many marl beds may be seen on the other hand, which contain few if any shells. They are not broken down so that their identity is lost, as many would have us believe, for where shells exist in a bed, they may be seen at some depth, delicate and frail but perfect in outline, so that if they are the sole cause of marl their fellows should have remained in great numbers and many partly broken down, instead of here and there a perfect shell at fifteen and twenty feet below the surface. In soundings of twenty to fifty feet beneath the surface of the water under that many feet of marl or in the center of a lake, they are nearly and often entirely absent. They could scarcely be held responsible for the presence of marl in such quantity at that depth.

§ 3. Sedimentary theory.

Among all reasoners upon the subject there is no difference of opinion as to the ultimate source of marl. It certainly came from limestone through erosion and the carrying power of water. Another basis point of this theory is also true. Marl is deposited much like a sediment. It lies very evenly unless disturbed by sudden jumps in the outline of the lake bottom. Further proof of the theory does not appear to exist. Marl deposits do not seem to occur regularly in given districts, they do not appear to extend in a given direction and so far this theory has not assisted in the location or accounted for the peculiar facts which hold good in this formation.*

*It does apply to some of the fine grained calcareous clays, such as those used for white brick at various points. But in no case is the separation of calcium carbonate mud from other mud anywhere near as perfect as in the bog lime. L.

§ 4. Chemical theory.

According to the theory of simple chemical precipitation of marl from spring waters, the marl should be deepest, piled or crusted about the mouths of these springs and stopping by its accumulation their outlets. Such is not the case as the marl does not confine itself to the immediate neighborhood of these springs which are in most cases surrounded by sand or muck.

According to this same theory, if the water managed to escape and mingle in the lake beyond, the marl should then deposit evenly all over the bottom of the lake as it does in depositing in a kettle or basin. This is also contrary to fact as marl is very intermittent, in its deposit, is often not deepest in the deepest portions of the lake, and does seldom form a layer continuous and even over an entire lake bottom. Another question of importance is this: Is there with the relative proportions of carbon dioxide and carbonates existing in our inland lakes to-day more than enough of the latter to exhaust the power of the water at its ordinary temperature and pressure to hold in solution the percentages of carbonates existing in these waters, or will the spring water not be able to easily hold in solution the small amount of carbonates with or without the free carbon dioxide? If the calcium carbonate is not great enough to overburden the water it can be held in solution in the lake with or without the presence of the free carbon dioxide. In this case the carbon dioxide can escape from the water or remain with it, but the water can yet hold in solution its salts of calcium and magnesium and carry them out of the lake without depositing them as marl.

Two facts are to be ascertained before this theory can show the necessary conditions under which it may be possible to operate. (1) What is the point of solubility of our spring waters, or the percentage of those salts necessary to produce over saturated solution? (2) Is the percentage of calcium and magnesium salts in the ground water below or above the percentage? If below the theory must be groundless for it must be above in all cases supplying a cause for all phenomena in regard to the formation of marl.

(1) The point of saturation of spring waters and the influence of carbon dioxide upon the same.

After search the carefully conducted series of experiments of Treadwell and Reuter upon the solubility of carbonates was found by the State Geologist and an abstract, translated from the German by him, will be found elsewhere.

(2) We have to compare with the results of these experiments the actual proportions of calcium carbonates existing in the spring waters of lakes and springs of Michigan, as given below. (See page 46 and also the hardness tests of Cloverdale on page 131.)

According to Treadwell and Renter's carefully made experiments, water at ordinary temperature and pressure containing no free CO_2 may yet contain permanently 0.38509 grams of calcium bicarbonate or .238 $CaCO_3$ per liter, while the authorities quoted below estimate it at differing temperatures and pressures from .7003 to 3. per liter. Now the analyses of waters from Michigan show a content of calcium carbonate from .175 to .250 grams per liter or 175 to 250 parts in a million. With this in mind it can easily be seen that the carbonated waters of our 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 in a million of calcium carbonate instead of being over burdened and precipitating them in marl.* It appears very clearly that Treadwell and Reuter's experiments are carried on under artificially produced conditions which tally closely with those found in our springs and lakes. They have decided for us carefully the precipitating point at which carbonated waters with various pressures of free CO_2, and temperatures usually 59° F. cease to bear in solution carbonates in the form of the bicarbonate. They find that point above that of Michigan spring waters, or in other words show very clearly that our spring water can generally take more salts into solution instead of being ready with slight changes of temperature and pressure to precipitate those which they already carry. In other words our spring waters cannot precipitate their bicarbonate as marl by the simple chemical process of precipitation from a saturated solution, because they lack considerable of being saturated.

*Compare also the analyses in U. S. G. S., Water Supply Paper No. 31.

ANALYSES OF JARS OF WATER FROM CLOVERDALE DISTRICT BY A. N. CLARK FOR STATE GEOLOGIST AT MICHIGAN AGRICULTURAL COLLEGE LABORATORY. INTENDED TO BE TIGHTLY SEALED AND PROMPTLY ANALYZED BUT NOT THOROUGHLY SATISFACTORY, CO_2 NOT ENTIRELY RELIABLE. RESULTS STATED IN PARTS IN 1,000,000.

Number of Sample.	Location.	Carbon Dioxide.	Calcium Carbonate.	Magnesium Carbonate.
1	Boiling spring at the head of Long Lake	0.00	100.00	67.80
2	Water at outlet of Long Lake, running creek	44.00	217.00	100.00
3	Well in vicinity	3.30	160.00	69.7
4	Large boiling spring near sounding, No. 41	19.3	200.00	75.3
5	Horseshoe Lake, between sounding 39 and 40, in 50 feet of water	19.8	117.00	85.6
6	From bottom of marl basin in 10 feet of water, sounding 45	6.	100.00	75.6
7	Surface of basin. Marl 6 inches beneath water surface	....	70.	58.
8	Spring at side of Horseshoe Lake (N. lobe, not sounded)	15.4	160.	81.7
9	Spring at head of Guernsey Lake, surrounded by gravel	66.	130.	61.3
10	Surface water at Guernsey Lake	0.	40.	71.1
11	Water at bottom of Mud Lake (35 feet) with 18 parts per million dissolved Fe_2O_3 & Al_2O_3	6.6	53.6	trace
12	Water from surface of Mud Lake	0.	30.	trace.
13	Seepage spring on Mud Lake	0.	80.	62.
14	Water from well on divide between Long and Mud Lakes, 35 feet. Quicksand at 18 feet, with 12 parts dissolved, Fe_2O_3 & Al_2O_3	60.	80.	28.
15	Water from drive well 25 feet into spring, which formerly emptied into Long Lake, between Long and Mud Lakes; with 24 parts dissolved Fe_2O_3 & Al_2O_3	39.6	240.	116.
16	Stagnant water in ditch which formerly connected Mud Lake and Long Lake. Metallic scum and red bottom; with 16 parts dissolved Fe_2O_3 & Al_2O_3	44.	48.	16.6
17	Water from well on high divide between Long and Twenty-One Lakes; with 50 parts of Fe_2O_3 & Al_2O_3	39.6	156.	203.4
18	Spring above level of Pine Lake	22.	170.	80.2
19	Outlet from Pine Lake, Pine Creek	6.6	80.	76.6
20	Large boiling spring near outlet of Pine Lake.	11.	136.	81.7
21	In 25 feet of water, center of Pine Lake	6.7	80.	69.6
		4.4	87.	75.

WATER OF OTHER REGIONS ANALYZED FOR CARBONATES.*

No.	Location.	Free CO_2.	$CaCO_3$ $MgCO_3$.
1	Fremont flowing well	0	100
2	Water, spring in marl bottoms, Corrinne	26.40	210
3	Water at Straits of Mackinac	0	130
4	Traverse Bay at Traverse City	0	150
6	Duck Lake near Green Lake. Spring at head of lake	....	Marl
7	Outlet of Duck Lake. Sandy bottom	0	165
8	Water south end of Central Lake	24.2	200
10	Clear water of Mound Spring near Central Lake	0	190
11	Water in spring 100 feet above Central Lake	0	190
12	Flowing well in East Jordan	0	210
13	Kettle near Manistee Junction, is 15 or 20 feet lower than Round Lake near by; it is supposed to discharge by an underground channel in the Pere Marquette River	0	110
14	Long Lake, Manistee Junction, red water	0	205
15	Water, Round Lake, Manistee Junction	0	185
16	Outlet of Long and Round Lakes, Manistee Junction	6.60	175

* The content of CO_2 here given cannot be relied on as the bottles were stoppered with cork, permitting the escape of the gas. Analyzed by A. N. Clark at the M. A. C. Laboratory.

§ 5. Indications by circumstances of occurrence.

In discussing the origin of marl to form as perfect a chain of evidence as possible the conditions obtaining must be determined as accurately as possible.

If analogies are used as proofs the conditions in both analogies must be alike. If this is not followed fatal mistakes are likely to occur.

An agent has produced an effect which is before us in the form of marl beds. The bearing of the facts concerning position, composition, variation in composition, location, variation in depth, foundation or basis and covering, which we have described, should be studied with this in mind: The marl beds lie upon the surface or in the present geologic stratum, and since they are not covered by any great thickness of earth and are clearly produced since the glacial period from the fact that they lie in the hollows left by the glaciers, the agencies producing them must be modern as well.

Marl has been described elsewhere as a complex compound. In the impure marl there are large percentages of insoluble matter which can readily be traced to the presence of foreign clay, sand and organic matter. It can be readily seen that these have nothing to do with the production of marl and therefore the very purest samples of marl must be considered in order to arrive at a conclusion in regard to its origin. As marl is analyzed in the laboratory it consists of calcium carbonate, forming nearly the entire percentage, magnesium carbonate (always in very small percentages, that is, in the very pure sample), iron and alumina, organic matter and traces of sulphuric acid and sometimes phosphates.

The following is the analysis of such marl:

Calcium carbonate	95.231
Magnesium carbonate	.946
Ferric oxide	.536
Alumina	.159
Silica insoluble	1.205
Silica soluble	1.316
Organic matter	1.510
Water	.300
Phosphoric acid	traces.
Sulphuric acid	slight traces.
Chlorine	slight traces.
Alkalies	traces.
Total	101.203

Very likely such a marl as the foregoing is as nearly as possible to purity as can be obtained. The content of organic matter is too low to be typical, while the content of soluble and insoluble silicates is a trifle high.

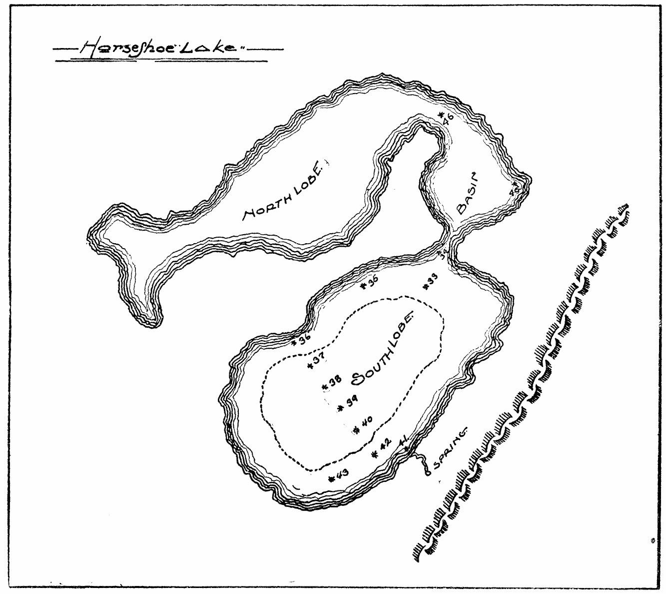
There is always the marked difference in percentage between magnesium and calcium carbonates above, excepting when a clay forms a part of the deposit, when the percentage of magnesium carbonate may increase to large percentages. In very pure marls or in those containing 90% and over of calcium carbonate, the magnesia does not form any large proportion. It is noticeable that in the study of deposits for factory purposes, it is found that where other impurities increase the magnesia increases as well. The only direct source of carbonates about to be studied is the water which in all cases lies or has at one time lain above the deposit. Now if all the salts contained in the hard water were precipitated, the proportions between the calcium and magnesium in the water should be the same as the proportion of calcium and magnesium in the marl. Such is not at all the case. Notice in the foregoing analyses of waters from springs and lakes about Cloverdale (pp. 20 and 21), that the proportion of calcium carbonate to magnesium carbonate is about 2 : 1. No analysis of marl was ever seen in which the proportion was anywhere nearly equal,* the proportion of 90 : 3 being the most typical. This brings to light a very important principle or lack of principle ruling the formation of marl and as it occurs with other compounds besides magnesia it will be well to notice it in the outset, to wit, the lack of the relationship as established between the compounds in the water and the compounds in the marl. This is most easily illustrated by the wide distance between percentages of calcium carbonate and magnesium carbonate in the marl deposit. As found in water $CaCO_3 : MgCO_3 :: 2 : 1$, but in marl :: 90 : 3. In relationship of iron and alumina it cannot be shown as well that they differ because in both marl and water they are found in much smaller amounts. They are always very low in the purest marls. Especial search has been made for bog iron in the presence of marls. Here we meet a very interesting fact; marl does not occur in admixture or in the immediate presence of bog iron ore. One locality was noticed where a marl lake was drained by a creek that had bog iron ore along its course, but no bog iron could be found in, or immediately surrounding the marl. There is only one case in which the iron may increase to any appreciable extent. This is in deep water soundings where the marl has been displaced by a mucky marl. Such was the case in the following sample of muck-marl found in 54 feet of water at center of Horseshoe Lake, Cloverdale region:

	per cent.
Insoluble	15.14%
Fe_2O_3 (Al_2O_3)	13.73
$CaCO_3$	43.13
$MgCO_3$	1.66
Organic matter	26.34

The surprising features of this analysis are the high per cent of iron and aluminum oxides and organic matter.

*This may perhaps be accounted for upon the chemical theory by greater solubility of magnesium salts, for we have as yet no exact data as to the relative solubility of the calcium and magnesium carbonates, and yet it is not likely that so great a difference would exist. L.

The chemical agency in the deposit of iron oxide must therefore be different in the case of springs from that working in the marl beds into which these same springs empty. For example, an intensely hard water spring is seen to empty into a pure marl lake. The growth of water plants along from the spring is coated with a thick deposit of iron oxide. No marl is deposited. On the other hand, in the lake immediately below there are but traces of iron and nearly all the deposit is calcium carbonate. This leads us to conclude that the agencies most active in the precipitation of iron and calcium are different at the spring and in the marl bed as the same water furnishes material for both. There is plenty of iron left for precipitation in the lake as the waters emptying out of the same show about the same percentage of iron.



SKETCH MAP OF HORSESHOE LAKE, CLOVERDALE, T. 2 N., R. 9 W.

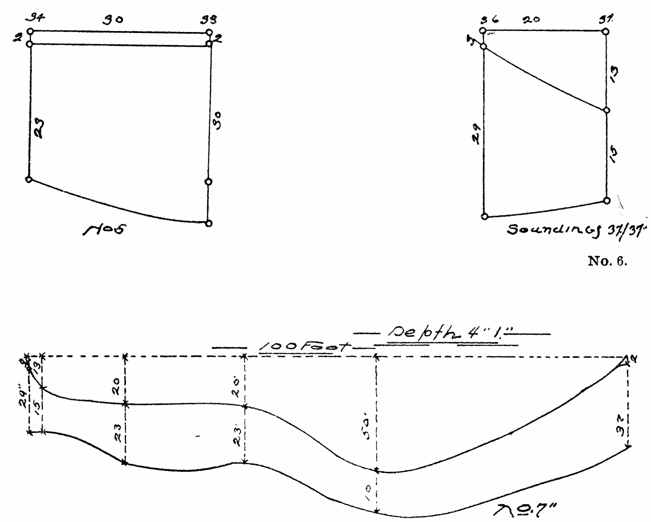


Plate II. Horseshoe lake, Cloverdale district, T. 2 N., R. 9 West, with diagrams of soundings.

Sulphuric and phosphoric acid are usually estimated as salts. In the purest marls they are scarcely ever far above 0.30%. In deep specimens where there are large proportions of organic matter they sometimes run higher.

The organic matter is a component part of every marl which plays a very important part in its history. As we speak now of the purest marls only, it is here found in small percentages. It can never really be said to be absent and is that compound or constituent part of the marl which is the most widely fluctuating. There are found certain exceptions (see Lime Lake, p. [55]) where the marl is a nearly solid shell bed. In such a case, the conditions having been always favorable to the growth of shells, the quality remains constant even at a great depth. The ordinary marl bed varies in composition. It is very much higher in content of organic matter at the bottom than at the top. It often happens in a bed thirty feet in depth that at the top it is 95% $CaCO_3$ and at the bottom 65% to 80%. The change is generally due to increase in organic matter at the expense of the content of calcium carbonate. In a lake, of which the bottom is entirely covered with marl and the shallows around the shores consist of deep marl covered with but a few feet of water, the marl toward the center of the lake, as the water deepens, becomes much higher in content of organic matter and of course suffers in its percentage of calcium carbonate.

The content of magnesium carbonate does not increase with depth of the sounding, but may vary, either becoming slightly greater or less. If clay has sifted in with the marl it usually shows in a higher percentage of magnesium carbonate.

Marl beds are not seen to show any variation in the content of iron, chlorine or other such foreign substances where springs directly above such beds contain the same.

Having reviewed the extensive variation in composition and depth, together with the condition of surface and basis for deposit, the next important consideration is the water above the marl.

The water of our springs and lakes as shown by our analyses on pages 46 and 131, runs as follows:

Free CO_2, 0 to 44 parts in a million.

$CaCO_3$, 80 to 217 parts in a million.

$MgCO_3$, 62 to 100 parts in a million.

This excludes the soft water lake and the well on the divide which seem to be extremes on either side.

The water so laden flows from the springs into the lakes by the springs upon high land and by the water holes or living springs which empty under water in the lake and are indicated by open water in the dead of winter and are avoided by skaters as air holes. In either case the cold water will at once flow down till it reaches the deeper parts of the lake, being naturally heavier than the somewhat heated water about it. The water of the spring holes must carry all its CO_2 with it as there is no open air for it to escape to. The running water of the upland springs must lose some of its CO_2, but not all as it is a gas, heavier than air and does not escape easily.

There has been some careful research into the behavior of lake waters,* and an instrument called the thermophone has been invented to trace accurately the changes of temperature at great depths, not easily reached by an ordinary thermometer. It was found by a study of Lake Cochituate, near Boston, that in very deep water the bottom temperature remained the same and the water stagnant throughout half the year and that in the fall and spring a general vertical circulation of the water took place. "The diatoms and some of the infusoria are most abundant in spring and fall, or during the two seasons of the year when the water circulates freely from the top to the bottom." The temperature of our lake waters controls their density and their density their power to move by the law of convection, the warmer water rising, the colder sinking. The position of the water again controls its power of getting to the air and losing its carbon dioxide. It will be seen by careful perusal of the experiments of Messrs. Warren and Whipple that our deeper lake waters must have a systematic movement each year. In the deeper portions of 30 to 50 feet depth or more, the water remains at or near the point of 39.2° F. or that of greatest density. It is a little above that point in winter while the surface water next the ice is of course nearer freezing point. The water in the deeper portions of the lake already referred to moves in spring and fall changing places with the surface waters. It then acts as a reservoir of cold heavily laden carbonated waters which replenish the surface waters, and the carbonates and CO_2 are carried to the surface where any free CO_2 may escape. It is then clear that the very cold water of our springs may not in summer flow at once to surface of the lake and is not at once thoroughly aerated by contact with the air at the surface of the water, but on the contrary flows to the deeper parts of the lake and is buried for a season till convection brings it to the surface when it naturally spreads out, being the warmer, and has free access to the air.

*Warren and Whipple, Meteorological Journal, June, 1895. Technology Quarterly, July, 1895, VIII, 2, pp. 125 to 152.

Now we find that to no great extent is the marl precipitated in deep water. In soundings made in 40 and 50 feet of water, the marl nearly lost its nature, becoming marly muck. When we allow a basin with spring water to stand, the CO_2 collects in bubbles on the bottom and sides and little rises to the surface. In the same way we can tell that it collects on the bottom of a lake, for if we stir the bottom small bubbles of gas find their way to the surface. This is the condition in which the water remains as it lies deep in mid lake.

It is difficult to tell from a comparison of the analyses of lake waters and those of the springs that flow into them whether any carbonates and CO_2 are lost by precipitation from the fact that the lake waters must of necessity be diluted by surface drainage waters and rain water containing no carbonates. It will therefore be necessary to compare the springs with each other, the wells with each other, and the lakes, taking each sounding that corresponds in position with the other. The Cloverdale Lakes may be graded in the intensity of their deposit, the first named having the deepest marl and most active deposition, the last having but traces, in the following order: Horseshoe, Long, Price, Guernsey, Mud Lakes. Upon comparing Nos. 1, 8, 9, 13, 18, 20, which are samples of spring water, analyses of which are given on page 46, it will be found that the most intensely marly lakes have the springs with the greatest content of carbonates and grade down to the soft water lake, which in turn has a spring with the smallest content of carbonates. Upon comparison of well samples 3, 14, 35, 16, 17, the same rule applies, but not with equal clearness as the well near Mud Lake was scarcely more than a surface well.

Nos. 7, 10 and 12 are the surface samples of Horseshoe, Guernsey, and Mud lakes. They again show the same order of the marl deposit. They all lack free CO_2 and contain carbonates in the order of the marl deposit. Horseshoe is the greatest and Mud Lake is again least.

Nos. 5, 11, 21 form a comparative set of the deep waters of Horseshoe, Mud and Pine lakes. The relation is again maintained without break although the free CO_2 in Mud and Guernsey are nearly the same.

For comparison of water in the lake itself we have Nos. 5, 6, 7, of Horseshoe Lake. These are named in the order of their depth, No. 5 being taken in 50 feet of water in mid lake, No. 6 in a marl basin and at the bottom next to the marl, and No. 7 at the very surface. It will be seen that according to these analyses, the water is steadily and rapidly losing its content of CO_2 and carbonates as it approaches the surface. At the bottom it had the highest (19.88 parts CO_2), at ten feet it has but 6 parts, and at the surface nothing. The carbonates are lost much in the same proportion, less of the magnesium carbonate being lost than of the calcium carbonate. This tallies very well with the marl which gains more calcium than magnesium.

The above comparisons deduced from the table of analyses would point to the following conclusions.

The deep springs furnish the hard waters for the marl lakes.

The cold water sinks to the deeper parts of the lake, which contain a supply of carbonates and CO_2.

When this water reaches the surface by aid of convection, it loses its CO_2 entirely or in part and its proportion of carbonates suffers as well. It must be borne in mind in this consideration, that water and CO_2 must differ in volume as the temperature rises. The water as a liquid would not have a great change of volume in rising from its temperature of greatest density in mid lake to luke-warmness at the surface under a summer sun. On the other hand carbon dioxide would be almost entirely lost and would expand greatly. While its content per liter of water at the depth of 10 feet would be much less than at the bottom of the lake, one thing is certain that at the surface it is lost entirely, not being contained in any of the samples taken from the surface of any of the lakes.

Having discussed the composition of marl itself we find it influenced by the depth of water over it and by its own depth.

Upon the study of water and its content of carbonates we find the opposite. The deep water contains the greatest amount of carbonates, but does not release them till shallow water or the surface are reached. Heat and the seasons play an important part in renovating the deep water, bringing it to the surface where it loses its carbonates by some agency.

The conditions of marl formation have been discovered as nearly as possible. It is found that the carbonated waters even if at first rendered stagnant are brought twice a year to the surface, to light and heat, but that according to carefully conducted experiments, they cannot lose their carbonates by simple precipitation of the carbonates upon withdrawal of CO_2 because none of the compounds in question are in great enough proportion to form a saturated solution.

For a pure analogy and not as a proof, let us look at other parallel cases in nature where chemical compounds exist in such mild proportions that it does not seem possible for change to take place, but nevertheless such change is going on upon a large scale. The nitrates or compounds of nitrogen can not readily be formed and made, soluble from the compounds existing in the soil and plants would suffer without them. They are formed, however, by the interposition of an outside agent. This is a minute living organism that forms upon the roots of the plant at the same time, forming a large amount of soluble nitrates for the use of the plant. This is a case of chemical recombination impossible without the aid of this living organism. The process of biochemical down-tearing is so varied and frequent that it need hardly be pointed out. The process of rotting so necessary to the destruction of plant and animal life and its recombination in simpler forms fit for plant food, is accomplished by millions of bacteria. Acids, alkalies and numbers of new compounds are formed where if chemical action alone were depended upon, plant life would starve in need of less complex food.

It is here in the discussion of precipitation of calcium carbonate in the form of marl, that a new set of phenomena or conditions must be duly represented and described.

There are clearly live marl lakes, i. e., lakes that are depositing at the present time. The deposit is carried on in shallows in intensely marly lakes. It is not confined to plant organisms that can be seen with the naked eye. The reason for this is clearly proven. All live and dead plants or all inanimate objects on the bottom are covered with the white deposit of calcium carbonate. The objects covered need not necessarily have grown in the water. Many trees may dip half decayed branches into the water, yet these twigs are covered with a thick coating of the marly substance. The numerous water plants upon the bottom in the shallows are also thickly coated with white. One plant especially thrives in these shallows. It is to be easily distinguished by its whorls or leaves at each joint.* It would seem probable that these plants, especially in shallow water would act as distributors for their coating of marl, as the ice of winter mast certainly tear them out, in being floated to different parts of the lake as the ice breaks up in the spring.

The marl in the shallows of such a lake forms around everything, forming pebbles around rushes and roots that extend above the surface of the bed. The pebbles are somewhat hard and in boring they sometimes seem like stones. The roots die away leaving a hollow nearly enclosed pebble. The marl in these cases forms fine accretions and is very granular, seeming at first exactly like sand, but yielding to repeated efforts to crush it with the finger. Upon closer examination of plants upon which the marl is depositing it is found that they are coated with a fine slime which is more or less whitened by the presence of the particles of marl. When a lake or portion of the same lake is examined where the deposit is not so active, the same slime is found, but it is not so thick and it is transparent rather than white, on account of the absence of the white particles of marl. Such was the case in a chain of lakes near Colon, the difference between the lower and the upper of the lakes being very marked in this respect. The active precipitation of marl in this manner was first remarked in notes on Horseshoe Lake near Cloverdale. It is an interesting fact that, while the shores of this lake were thickly encrusted with thick marl in the process of precipitation, the marl at the center was of the poorest, though not over a few hundred feet removed. Several actively depositing lakes have been noted since. Such a lake was usually the upper lake of a chain. It received little drainage water and had the first of the spring water. The precipitation, while it is taking place must be very rapid. Stakes stuck in the marl as anchors for fishermen are whitened by the deposit of marl; branches, twigs, etc., sometimes have an incrustation of a quarter of an inch or more in thickness. Even in such lakes the marl when traced out into deep water, becomes darker and heavier in organic matter, and if sounded to the bottom, shows much the same increase in organic matter. It appears the only feasible and true explanation of the origin or exact method of precipitation of marl that minute water organisms absorb the CO_2 from the water in building up their life and leave the calcium carbonate to precipitate upon the twigs, plants, or bottom, or anything available. That the visible water plants serve mainly to precipitate the marl I can hardly believe as it clings to the dead twig as thickly as to the live. Moreover it fastens to wood that has not had life while in the water and could not have evolved carbon dioxide.

*This is the Chara referred to by Davis, Chapter V. L.

There is every reason, however, to believe that these plants aid in increasing the content of calcium carbonate in the marl deposits even in the deepest water. In 50 feet of water at the center of Horseshoe Lake, a long trailing vine was brought up from the bottom, these vines often winding about the augur. The vine had the distinct and very strong odor of pole cat. It was without doubt some one species of the Characeæ. The family are well known for their high content of calcium salts.

The *Chara foetida* as analyzed by Gustav Bischof is as follows:

	per cent.
Ash of dried plant	54.84
Of this ash calcium oxide	54.73
Carbon dioxide	42.60

Such a plant dying would add a considerable portion of its substance to the formation of a marl bed.

It is not difficult to believe that the Characeæ are responsible for the growth of the marl bed when the actively depositing marl beds are seen to be covered thickly with a luxuriant growth of this plant. As they have stems and finest branches thickly coated with the calcium carbonate also, every crop each year forms an addition to the bulk of the marl bed. This luxuriant growth is often in water so shallow that in winter the ice must freeze down nearly to the bottom, enclosing the plants, stem and branch. In the spring when the ice loosens and is shifted into deeper water by the winds, a large number of these plants must be carried and deposited in mid lake. This will account in part for the distribution of marl in deep water. It is hardly deemed possible, however, that Characeæ are the sole cause of the growth of our vast beds of marl, for the following reasons:

Actively depositing marl is found in the absence of these plants. In the absence of these plants the marl encrusts all objects around, dead or alive. Fully as thick an incrustation has been found upon dead twigs and old stubs stuck up in water by fishermen, in a lake nearly devoid of Characeæ, as in those the bottoms of which are covered with plants. Another very significant fact is that in cases where the plants themselves are taken from the water, they are found surrounded by a gelatinous scum. Where the marl is not depositing thickly this scum is nearly transparent, while on thickly depositing beds its surface is whitened by the presence of the particles of calcium carbonate.

We must notice in connection with this another important fact. Where the marl is depositing upon a bare bottom, upon rocks and pebbles as noticed at Long Lake, Cloverdale, the accretions as deposited, have a pronounced inner lining of chlorophyl.* This green color does not show upon the outside of the incrustation which shows the white or gray color of marl. Such a deposit is very soft and breaks apart easily when in the water. When, however, it is exposed to the air for some time it hardens so that it is difficult to tear apart. The pebbly concretions formed in some lakes are rather hard and gritty even under water and were even found in two cases at the depth of 6 to 10 feet in the marl bed, feeling like pebbles when struck in boring, yet the beds were almost entirely free from silica in any form. Free sand was entirely absent. The very hard pebble like accretions seen in both instances were on the south side of the lake in question.

It seems possible that other forms of plant life, invisible to the naked eye, also assist in the precipitation of the salts from the water. While the Characeæ in shallow water are coated thickly with marl, in deep water there is no sign of the scummy or gelatinous covering, nor is the marl of anywhere near as limy a composition, showing that the precipitation process is largely if not entirely inoperative in deep water. Yet in water 20 to 25 feet deep there is often if not always a fair marl. Sample No. 4 (sounding 10) at the center of Long Lake, Cloverdale, shows at the bottom of a 20 foot marl bed in 25 feet of water, 69.30% calcium carbonate and 11.91% organic matter.

*Showing the presence of the blue green algae, referred to in Davis' paper. I have noticed in Higgins Lake, the sand of the bottom continuously cemented in a thin layer about 1-10 of an inch thick, brown above and green below. L.

There is another very remarkable feature about very intensely hard water lakes. The waters are often as clear as crystal. Every dark particle of organic matter not only settles to the bottom, but is covered as well with the marly precipitate. The plants and debris of mid lake are buried by the marl as well as those nearer the shallows, but the deposit of marl must be much more rapid in the latter because of the greater content of calcium over organic matter which it always contains.

There can be little doubt that purely chemical precipitation of marl from our dilute spring and lake waters would be impossible. The analyses of the Characeæ and their presence in such large numbers proves them to be surely responsible for a part of the composition of the marl bed, especially in deep water. For in deep water the organic content is always very high and the forms of the water plants can always be distinctly traced, embedded and preserved in the impure marl. The analyses always show a great proportion of organic matter in deep water marl, or in most marls taken at great depths, whether in deep water or at the bottom of a deep bed or both. On the other hand a local precipitation takes place and that very actively. Moreover it takes place at or near the surface and very little in deep water. That was well shown by samples 5, 6 and 7 of the waters at Horseshoe Lake, Cloverdale district. These were in their order, analyses of water at 50 feet in mid lake, water on bottom at 10 feet in depth, and water at the very surface. From deep water to the surface the CO_2 escapes entirely and the carbonates are least at the surface also.

The manner in which the marl is laid down also favors a precipitation process. Where the regularity of the bottom will allow it the marl is deposited so evenly that it is sometimes impossible to note any such variation in depth, the marl remaining very even over an extended area and then increasing or decreasing gradually. Of course in many cases, our lake bottoms being full of sudden jogs, the marl must vary also. As a rule it behaves much like an even deposit or sheet, leveling hollows and decreasing the abruptness of sudden rises in the original bottom. See for measurements taken, Cloverdale, Central Lake, Rice Lake.

Another point of significance is that near the surface, there are many samples of marl taken which have a content of 95% calcium carbonate and sometimes but a fractional per cent of organic matter, the latter indicating the proportion of plant tissue used in building up such a portion of the deposit. According to such analyses (see commercial analyses of marl in the appendix) the plant life remaining as organic matter would not be sufficient to account for the production of such very pure marl, being sometimes but a fraction of a per cent.

The following would then appear as the most plausible explanation of the manner of precipitation of marl.

The mineral is washed from the soil and finds its way to our deep underground springs as a bicarbonated salt.

These springs issue from the deep cuts and clefts left by the glaciers and called by us lake valleys.

Analyses of the water and parallel experiment prove that the solution of carbonates and free carbon dioxide are in too small quantity to form a saturated solution and therefore cannot from purely chemical laws precipitate as marl on the bottom of the lakes.

The very dense cold waters of the springs, whether they issue from bottom or sides of the lake, seek by their greater weight the deeper portions of the lake. They remain there with their burden of salts and CO_2 till the semi-annual overturning of the still water, when they approach the surface. When the water reaches the surface, it is warmed by the direct rays of the sun. If the place is sheltered and the water is shallow, the bottom reflects the rays of the sun still further heating it. If in deeper water not all the rays of the sun are stopped as they are wasted in heating a greater depth of water to a less temperature. The warmer the water the better all plant life thrives in it. These plants are of two kinds, the larger fixed plants that may be seen without the aid of microscope and those invisible to the naked eye.

The former or larger fixed plants live on the bottom and absorb a large percentage of the carbonates in their growth and also give off free oxygen. The smaller plants are movable, being carried slowly through those portions of the water where they have sufficient sunlight and warmth to multiply rapidly. They must also give forth oxygen in large quantities, but as they must live toward the surface or warmer part of the water and be capable of reaching every particle of it, they form a more perfect oxygen carrier and serve to furnish oxygen in a very thorough manner for precipitation of the salts from their weak solution. They could thrive only at or near the surface in deep water on account of the lack of heat and while supplying an even distribution of oxygen, would not thoroughly do so as in shallow water.

The result of this is that in very shallow water the precipitating process is rapid wherever sunlight and warmth have made the very best conditions possible for the growth of plant life. Here the rate of formation of marl is more rapid and while plant remains are always found, the proportion of precipitated salts is greater than that remaining from the breaking down of gross plant tissue. The method of precipitation is a process of accretion. That is to say, every particle of organic matter, silt, etc., that finds its way into these waters where the process of marl making is very rapid, is surrounded by a coating of marl and sinks to the bottom, forming forever a portion of the deposit. The Characeæ and larger water plants containing lime in their formation are torn from their places by ice in winter, or perhaps to some degree by the action of the wind and disintegrate in the deeper parts of the lake, helping to form the deposit. The plants which themselves form in deep water are not encrusted to any extent with the marl and then when they disintegrate do not make as marly a formation. Moreover the dead drift of silt and other matter which must always fall into a lake is not in mid lake coated as thickly as in shallow water where the process is much more rapid. These particles sink to the bottom of the lake and form a part of the bed as they do in the shallows, but on account of the lack of precipitation upon them they add a higher amount of organic matter to the growing bed. As the water in turn throughout a depth of 50 feet is none of it heated so warm as on shallows where nearly all the heat is reflected from the bottom, the finer more minute water plants do not multiply so fast or furnish as much oxygen. Where the heat is greatest at the surface they must, however, cause a deposit to some extent. It follows from these conditions that the marl must form more slowly in deep water and that its organic content must be greater.* As many of our lakes are filled with marl varying from twenty feet in mid lake to thirty or forty feet in depth on shallows or points near shore, or in marshes at that depth at the center, the following must have once been the condition:

Our lakes were originally thirty or forty feet deeper when their basins contained no marl. The marl first deposited was deposited in much deeper water than this as the water level of our lakes has sunk greatly in the last few years. All the soundings made in deep water or to the bottom of deep deposits show them to be, one and all, of a more impure character than those in our shallows at the surface. The only exception found was a nearly pure shell deposit which at surface contained 90% calcium carbonate and at a depth of 17 feet 92%. See Nos. 6 and 7, page 83.

So universally does this rule apply that in one case a sudden change of former water level could be traced by a like sudden variation in the quality of the marl overlying the bottom. A broad glacial chain of dried lake beds extended from east to west. There were lakes above which emptied through a narrow stream which flowed over a bed. A line of soundings from north to south at right angles to the length of the system showed an extensive shallow which originally lay on the north side. At about the center of the depression was the deep channel of the former body of water. Then at the south side was another area of shallows. Nearly all was dry land excepting the small stream named. Instead of the valley being filled nearly even with the deposit of marl and enclosing marsh growth, the deep channel was marked upon the surface as a sharp depression. The shallows were of finest marl ever seen, being nearly pure calcium carbonate with but a trace of organic matter and other salts. It formed a shallow deposit some six or seven feet in depth. The channel was very impure and formed a rather sharp line of contrast with the pure shoal marl, following the rule above mentioned regarding the quality of marl as accounted for by depth of water over it.

*See paper by Wesenberg-Lund, p. 68.

The whole basin was once covered with water, the area of pure marl consisting of a terrace of shallows on either side. This deposited pure marl in shallow water till it reached the surface and marsh growth sealed the deposit on the shallows, stopping its growth. The marl in deep water formed in a much more impure state on account of the greater depth of water over it. It would have filled to the surface, becoming purer with shallower water if the drainage had not in some way altered so that the water level sunk to the surface or near the surface of the marl and organic matter in the shape of marsh growth choked and sealed the deposit. This peculiar suddenness of change in quality and formation was traced for a half mile to the first chain of upper lakes. The channel broadened in places, but its surface never showed other than a silt formation, the marsh at the present time being in process of sealing the deposit. The upper lake of the chain, however, while it showed a gradual decrease in quality with increase of depth was actively depositing in the shallows at the upper end.

We would conclude that in former times the process of marl formation was much slower on account of the greater depth of water and that our fall of water level of late years has hastened the process, bringing deeper water nearer the surface and heat and sunlight. We also conclude that the great clearness of our lakes is due to the fact that every particle of floating silt and dust and matter no matter how large or small, is surrounded by the fast depositing marl and buried in the deposit. It is noticeable that many lakes where the process has ceased and the marl is being covered with silt, show a very dirty reddish water due to particles of deteriorating organic matter. Yet these lakes are fed by springs and have outlets.

It is difficult always to account for the presence of marl in one lake and its absence in another. In most cases there is found a difference in water supply. Mud Lake and Long Lake, Cloverdale district, were one soft water, and the other hard. The former was fed by surface soft water springs and the latter by deep water springs. The wells near each showed the same difference in hardness of water. In portions of the State where there are no hard water springs no marl is found. Such were said to be the conditions surrounding the limestone district about Escanaba. A prospector who had explored carefully said that there were no marl lakes within thirty miles. The hard water was tapped only by the deepest artesian wells. It was noticed where two lakes were near enough together to be compared that the one indenting the general outline of the country deepest and tapping the most hard water springs, contained the deepest deposit.

There is yet another circumstance which must be accounted for. This is the presence in one part of the lake of a marl deposit which may taper off to a sandy or clay bottom not covering the whole lake bed. In the first place it will be noticed that in a lake not covered entirely with marl, it favors with its presence the bayous, points, and shallow water and in most instances, though not always, avoids deep water. As light and heat are always necessaries of plant life the facts of the location of the deposit in shallow water in the presence of the same is very good argument for the theory of vegetable origin. But there is still a further fact to account for. Even in shallows a bed may end or taper to the original bottom, generally becoming toward the edges much more, highly organic in its nature. This is illustrated by the fact that sometimes at one end of a lake, generally though not always the upper end, the marl is bare or has not ceased depositing and at the lower end becomes a deposit of lake silt, or in another case the marl is bare of silt at one end, though covered with water and is at the other end covered by a few inches to a few feet of silt. In other words the marl has changed its position for depositing or has continued to deposit at one end and has ceased entirely for some time to deposit at the other end and the deposit there is sealed to some depth with silt, over which there lies several feet of water. A good illustration of this was seen at Central Lake. The depth at both ends to the original bottom was nearly the same. The quality of the marl was about the same for the same depth, but the marl had ceased depositing at one end and had continued actively at the other. We must conclude from this that the conditions for successful growth of the marl producing plants of our lakes change in different parts of the lake, causing a more or less permanent cessation of the process of marl making. At Portage Lake, Onekama, this process seems to have been interrupted at intervals and continued again according to the layers of marl and organic marsh growth alternating. However, as this was the only instance seen of the kind, it would not be safe to assume from the instance of one lake, that such was the rule.

It can scarcely be argued that marl is the result entirely of the breaking down of the structure of gross plant growth for the same reason that shells cannot be said to account for the formation of all marl. At a depth of thirty-five feet stems and branches of small size may be well defined in samples taken as can the forms of small shells. Wood of a more fibrile texture is preserved in a nearly fresh state and the grain can be clearly separated. It can hardly be said that different parts of the same plant have deteriorated at such a different rate as to leave in one portion a nearly perfect branch or shell and right beside it a marl formation that cannot be found to resemble plant tissue or anything else excepting an amorphous form of mineral. The lack of any finely preserved lime formation of the tests of minute animals or the forms of fresh water plants,* also discourages the idea that the bodies of the same have died and formed the deposit. The clearest explanation would therefore seem to be that of a chemical precipitate brought about by plant life both great and small, abstracting CO_2, and acting where conditions for its existence are most favorable.

One of the strongest of reasons why the purely chemical theory is not true is lack of marl in some shallows and its presence in others. The lime bearing water must be distributed evenly to all shallows and should precipitate upon all at an equal depth. This is often contrary to fact, while on the other hand it would be possible for a local precipitation to be brought about in the presence and only in the presence of water plants producing oxygen.

As these views of the subject are nearly if not exactly† the same as those of Prof. Davis, given in another portion of this work, it has not been thought necessary to repeat his chain of evidence or any of his ideas except to bring out those points in the constitution and location of marl beds which would seem to prove the same idea from different facts of observation.

*But see Davis' observations, pp. 74 to 80. L.

†The main difference between Mr. Hale and Prof. Davis is that the former is more inclined to look to microscopic plants and to the abstraction of CO_2 by plant life generally as inducing a chemical precipitation favored by light and heat. L.

CHAPTER V.
A CONTRIBUTION TO THE NATURAL HISTORY OF MARL.
BY C. A. DAVIS.

§ 1. Historical introduction.

Botanists have long been familiar with the fact that, in some regions, aquatic plants of all, or nearly all, types are covered with a more or less copious coating of mineral matter, while in other localities the same types of plant life are free from any trace of such covering. In New England, for example, plants growing in the water are generally without such coating, while in Michigan and adjoining states it is generally present. In many lakes and streams the mineral deposit on the stems and leaves of the higher plants is very noticeable, and nearly all vegetation growing in the water is manifestly an agent of precipitation of mineral matter.

Various writers in Europe* and America† have called attention to the influence of the low types of plants growing in and around hot springs and mineral springs, on the formation of silicious sinter, calcareous tufa, and other characteristic deposits of such springs, and the connection between the beds of calcareous tufa which are sometimes formed about ordinary seepage springs whose waters carry considerable calcareous matter in solution and certain species of moss has been suggested, but so far as the writer knows, no one has given attention to the possible relation of vegetation to the more or less extensive beds of the so called marl, found about, and in, many of the small lakes in Michigan and the adjacent states. As has been pointed out elsewhere, this “marl,” more properly lake lime, is made up principally of nearly pure calcium carbonate, "carbonate of lime," with greater or less admixture of impurities. When dry and pure it is white or slightly cream colored, nodular, coarsely granular to finely powdery, very loosely coherent and effervescing freely in acids. On dissolving it, particles of vegetable and other organic and insoluble matter are found scattered through the solution.

*Cohn: Die Algen des Karlsbader Sprudels, mit Rucksicht auf die Bildung des Sprudel Sinters: Abhandl. der Schles. Gessell., pt. 2, Nat. 1862, p. 35.

†Weed: Formation of Travertine and Silicious Sinter by the Vegetation of Hot Springs. U. S. Geol. Surv., IX, Ann. Rept., p. 619, 1889.

§ 2. Ultimate sources.

The ultimate source of this material, except the vegetable matter, is, undoubtedly, the clays of glacial deposits and like disintegrated rock masses. These clays are rich in finely divided limestone and in the softer rock-forming minerals, some of which contain calcium compounds. Percolating water, containing dissolved carbon dioxide, the, so called carbonic acid gas, readily dissolves the calcium and other metallic salts up to a certain limit. The water with the dissolved matter in it runs along underground until an outlet is reached and issues in the form of a spring. This, in turn, uniting with other springs forms a stream which runs into a lake, carrying along with it the greater part of its mineral load. If the amount of carbon dioxide contained in the water is considerable, some of it will escape on reaching the surface, because of decrease of pressure, and with its escape, if the saturation point for the dissolved mineral matter has been reached, a part of this matter must 'be dropped in the form of a fine powder, as the water runs along over the surface. Theoretically, then, some, if not a great part of the dissolved matter, should be thrown down along the courses of the streams which connect the original outlets of the water from calcareous clays and lakes where marl occurs, and we should find the marl occurring in small deposits along these streams wherever there is slack water. Moreover, we should expect the waters of these springs and streams to show more or less milkiness on standing exposed to the normal pressure of the atmosphere at usual temperatures. Actually, however, none of these phenomena have been noted and we infer that there is not a large amount of carbon dioxide, and not an approach to the saturation point for calcium bicarbonate, in the springs and streams feeding marly lakes.*

*This point is considered more extensively later. L.

§ 3. Alternative methods of deposition.

We are then left, among others, the following alternatives, explanatory of marl formation: (1) The marl is not being formed under existing conditions, but has been formed in some previous time when conditions were not the same as now. (2) The amount of dissolved salts is so small that the saturation point is not approached until after the lakes are reached and the slow evaporation added to the reduction of the amount of dissolved carbon dioxide in the water brings about deposition of the mineral salts. (3) Some other cause, or causes, than the simple release from the water of the solvent carbon dioxide must be sought.

The first of these suggestions is met by the fact that marl is found in lakes at and below the present level of the water, and that it extends in most of them to, or even beyond, the very edge of the marshes around the lakes, and over the bottom in shallow parts of living lakes, even coating pebbles and living shells. (2) The water of lakes with swift flowing and extensive outlets, such as most of our marly lakes have, is changed so rapidly that little if any concentration of a given volume of water would occur while it was in the lake, and there is no probability that any of the lakes visited by the writer have ever been without an outlet. Indeed many of them have outlets which occupy valleys which have been the channels of much larger streams than the present ones. Moreover, definite measurements which, however, are subject to further investigation, have been made, which show that the volume of water flowing out of these lakes is practically the same as that flowing into them, i. e., the loss by evaporation is too small a factor to be taken into account. Farther, recent investigations* have shown that calcium, as the bicarbonate, is soluble to the extent of 238 parts in a million, in water containing no carbon dioxide. As most of our natural waters, even from limy clays, contain no more than this amount of this salt, even when they carry considerable free carbon dioxide, and many analyses show a less amount of it, the fact becomes plain that even if the carbon dioxide were all lost there would be no precipitation from this cause. (3) Considering these objections as valid it seems fitting to examine into the possibility of the plant and animal organisms living in the waters of the lakes being the agents which bring about the reduction of the soluble calcium bicarbonate to the insoluble carbonate even in waters low in the amount of dissolved mineral matter, and containing considerable carbon dioxide.

That mollusks can do this is shown by the fact, which has frequently come under the writer's notice, that the relatively thick and heavy shells of species living in fresh water are partly dissolved and deeply etched by the action of carbonic acid after the animals have, by their processes of selection, fixed the calcium carbonate in their tissues, precipitating it from water so strongly acid and so free from the salt that resolution begins almost immediately. No natural water seems so free from calcium salts that some species of mollusks are not able to find enough of the necessary mineral matter to build their characteristic shells.

While some limited and rather small deposits of marl are possibly built up, or at least largely contributed to, by molluscan and other invertebrate shells,** the deposits which are proving commercially valuable in the region under consideration, do not contain recognizable shell fragments in any preponderance, although numerous nearly entire fragile shells may be readily washed or sifted from the marl. The average of quantitative determinations of the shells and shell debris in three samples of marl from widely separated localities was less than one per cent of the entire weight of the marl and of these the highest contained but a trifle over one per cent, 1.04%. The conditions under which marl are found are such that the grinding of shells into impalpable powder, or fine mud, by strong wave action is improbable, if not impossible, for exposed shores and shallow water of considerable extent are necessary to secure such grinding action, and these are not generally found in connection with marl.

We are, then, reduced to the alternative of considering the action of plants as precipitating agents for the calcium salts. It has been shown already that plants generally become incrusted with mineral matter in our marly lakes, and it is easy to demonstrate that the greater part of the material in the incrustation is calcium carbonate. It is also easy for a casual observer to see that in many cases the deposit is not a true secretion of the plants, for it is purely external, and is easily rubbed off, or jarred off from the outside of the plants in flakes, while the tissues beneath show no injury from being deprived of it, and again as has already been pointed out, the same species of plants in some sections of the country do not have any mineral matter upon them. It has also been remarked in a recent important paper,† that the amount of the incrustation varies with the depth of water in which the plants grow, i. e., the amount of light they receive, the season, and the roughness of the surface water, waves causing the incrustation to break up and fall off. The deposit is formed incidentally by chemical precipitation upon the surface of the plants, probably only upon the green parts, and in performance of usual processes of assimilation of the plant organism.

*Treadwell and Reuter: Ueber die Loeslichkeit der Bikarbonate des Calciums und Magnesiums. Zeitschrift fur Anorganish-Chemie, Vol. 17, p. 170. Summarized elsewhere in this report.

**C. Wesenberg-Lund: Lake-lime, pea ore, lake-gytje, Medd. fra Danskgel Forening U. Copenhagen, 1901, p. 146.

†C. Wesenberg-Lund, p. 156.

§ 4. Cause of deposition upon aquatic plants.

All green plants, whether aquatic or terrestrial, take in the gas, carbon dioxide, through their leaves and stems, and build the carbon atoms and part of the oxygen atoms of which the gas is composed into the new compounds of their own tissues, in the process releasing the remainder of the oxygen atoms. Admitting these facts, which are easily demonstrated by any student of plant physiology, we have two possible general causes for the formation of the incrustation upon all aquatic plants.

If the calcium and other salts are in excess in the water, and are held in solution by free carbon dioxide, then the more or less complete abstraction of the gas from the water in direct contact with plants causes precipitation of the salts upon the parts abstracting the gas, namely, stems and leaves. But in water containing amounts of the salts, especially of the calcium bicarbonate, so small that they would not be precipitated if there were no free carbon dioxide present in the water at all, the precipitation may be considered a purely chemical problem, a solution of which may be looked for in the action upon the bicarbonates, of the oxygen set free by the plants. Of these, calcium bicarbonate is the most abundant, and the reaction upon it may be taken as typical and expressed by the following chemical equation:

$$\underbrace{CaH_2(CO_3)_2}_{\text{calcium bicarbonate}} + \underbrace{O}_{\text{oxygen}} = \underbrace{H_2O}_{\text{water}} + \underbrace{CaCO_3}_{\text{calcium carbonate}} + \underbrace{CO_2}_{\text{carbon dioxide}} + \underbrace{O}_{\text{oxygen}}$$

in which the calcium bicarbonate is converted into the normal carbonate* by the oxygen liberated by the plants, and both carbon dioxide and oxygen set free, the free oxygen possibly acting still farther to precipitate calcium monocarbonate.

It is probable that the plants actually do precipitate calcium carbonate, both by abstracting carbon dioxide from the water and freeing oxygen, which in turn acts, while in the nascent state, upon the calcium salt and precipitates it, but in water containing relatively small amounts of calcium bicarbonate the latter would seem to be the probable method. In all likelihood these methods for accounting for the precipitation of calcium carbonate will sufficiently explain the ordinary thin and relatively insignificant incrustation which is found on the higher plants, but for the algæ it is doubtful, or even improbable that they account for all the facts, as will be shown further on.

The calcium salt is deposited in minute crystals, and by the aggregation of these crystals the incrustation is formed on the plants. The crystals are distinguishable as such only for a short time on the newer growth of plants, but the incrustations are said to show a recognizable and characteristic crystalline structure when examined in thin section under a compound microscope with polarized light.

*Which is only very slightly soluble, 100 parts to the million.

§ 5. Relative importance of Chara (Stonewort).

Not all aquatic plants in the same lake seem equally active in the precipitation of mineral matter. Not even all species of the same genera, although growing side by side, will be coated equally, a fact which seems to indicate some selective metabolic processes not understood. Considering the precipitation of calcium carbonate by plants as established, even if the exact physiological and chemical processes by which this precipitation is brought about, are not yet worked out fully, it is still necessary to consider the constancy of the action and the sufficiency of the agency to produce the extensive deposits of marl which are known.

If one confines his studies simply to the seed-producing plants and other large vegetable forms which are conspicuous in lakes during the summer season, while he will find them covered with a thin coating of manifestly calcareous matter, he will at once be convinced that such work as these plants are doing is but a small factor in the total sedimentation of the lake. On the other hand, if a visit be made to a lake in early spring or late fall; all plants of the higher types will not be found, so that it becomes apparent that this agency is merely a seasonal one and works intermittently. Farther study of the plants of the same body of water, however, shows that the algæ, the less conspicuous and entirely submerged plant organisms must be taken into account before we finally abandon plants as the agents of precipitation. Of these, two groups, differing widely in structure, habits and method of precipitation, will be found. The first and most conspicuous, and probably the most important as well, is the Characeæ or Stoneworts. These plants are well known to botanists, and may readily be recognized by their jointed stems, which have at each joint a whorl of radiating leaves and branches, which are also jointed. Both stems and branches are made up of long tubular cells,* extending the length of the internodes or spaces between the joints. There is a large cell in the middle and a series of smaller ones around it, their walls touching but not usually compressing each other, so that the cylindrical shape of each cell is generally maintained and the cross section of the stem appears like a relatively large ring surrounded by a single row of small ones tangent to each other, and to the central large one. The outer, or cortical cells, are usually more or less spirally twisted around the large central one, and all the cells are thin walled and delicate, the plants containing no thick walled tissue or cells of any sort. The structure of the plant is so well marked and peculiar, that it cannot well be mistaken for that of any other, and so makes it easy to identify even small fragments of it. In some species the stems and branches are covered with a thick coating of mineral matter, are almost white, and very brittle because of this covering. These plants not only grow near the surface in shallow water of our ponds and lakes where the bottom is unoccupied by other plants, but in the deeper parts as well, and, as they thrive where light is feeble, they continue to grow throughout the year, although in winter they must grow less rapidly than in summer, because ice and snow on the surface of the lakes make less favorable light conditions.

*See Plate XVI.

Analytical Tests.

The sufficiency of these plants alone to fix and deposit calcium carbonate in large quantities is indicated by the following: In November, 1899, the writer collected a large mass of plants of Chara sp. ?, from which five stems, with a few branches, were taken at random and without any particular care being taken to prevent the brittle branches from breaking off. The stems were each about 60 cm. long, and after being dried for some days, they were roughly ground in a mortar and dried for one-half hour at 100 degrees C., dried and weighed until the weight was constant. The weight of the total solid matter obtained in this way from five plants was 3.6504 grams, 0.73 grams per plant. This was treated with cold hydrochloric acid diluted, twenty parts of water to one of acid, filtered, washed, and the residue dried at 100 degrees C., on a weighed filter paper, until weight was constant. The weight of insoluble matter was 0.5986 grams; of the total soluble matter 3.0518 grams, or .6103 grams per plant. In the lake from which the material analyzed was derived from 50 to 80 plants were counted to the square decimeter of surface in the Chara beds.

A partial quantitative analysis of material from the same source, but using stronger acid to effect solution (hydrochloric acid, diluted with four parts of water,) gave the following results:

Insoluble residue	11.19%
Iron and aluminum oxides	0.722
Calcium carbonate	76.00
Magnesium carbonate	2.359
Soluble organic matter obtained by difference	9.279

The composition of the insoluble residue was obtained by heating the residue to redness in a platinum crucible for one-half hour, and the 11.19 per cent of this matter was found to consist of:

Combustible and volatile matter	9.243%=82.6%
Mineral matter	1.947 =17.4

The mineral matter was found to be:

Silica	1.787%=92.4%
Not determined	.160 = 7.6

Microscopic examination showed the silica to be largely composed of whole and broken tests of diatoms, minute plants which secrete silicious shells and attach themselves to the Chara stems and branches.

The mineral matter obtained in this analysis, reduced to parts per hundred, gives the following:

Calcium carbonate	93.76
Magnesium carbonate	2.93
Silica and undetermined mineral matter	2.40
Iron and aluminum oxides	.89

This, with a small decrease in the mineral matter and a small amount of organic matter added, would be the composition of ordinary marls, and would be a suitable sample to consider in connection with Portland Cement manufacture.

The large amount of silica may be explained by the fact that the material analyzed was collected at a season when diatoms are especially abundant.

The following is a copy of an analysis of the marl from the beds lying about the lake from which the Chara plants were taken. This analysis was made by L. G. Leltz, chemist for the Alma Sugar Company, season of 1900-1901:

H_2O and organic matter	7.438%
Sand (insoluble silica)	0.104
Carbon dioxide	38.48
Calcium oxide	52.28
Iron and aluminum oxides	0.61
Magnesium oxide	0.455
Sulphur trioxide	0.32
Soluble silica	0.0532
Chloralkalies	0.07
Phosphorus pentoxide	0.12
	99.9302

It may be well to call attention to the fact that in many marls, especially those of large deposits, which the writer has examined chemically, the silica has been found to be mainly in the form of diatom shells, and hence, because of the small size and great delicacy of structure, it is available as a source of silica for calcium silicate in cement making. If such deposits as are made up largely of diatom shells were adjacent to marl beds, it is possible they might be considered as clay and be used in cement making.

Some of the silica in marl was found by mechanical analysis to consist of grains of white quartz of rather large size for sand. These may have been carried into the lake by winds, by drifting ice, by fish or by birds. The fact that these sand grains were white and of a rounded character, would point to the fish or to birds, which use such matter in their gizzards, as most probable agents of transportation, especially as no dark colored grains were found.

From the above considerations, it is evident that both because of the quality and quantity of its works, Chara may be considered an important agent in marl production, and it only becomes necessary to account for the chalky structure of the deposits to make the chain of evidence complete.

All algæ are plants of very simple structure, without tough or complicated tissues. Chara stems and branches are made up of aggregations of thin walled cells, and when the plants die the cell walls must rapidly decay and the residue of lime be left. In a laboratory experiment to determine this factor, it was found that a mass of the broken-up plants in the bottom of a tall glass vessel filled with water became decomposed very quickly, giving the characteristic odor of decaying vegetable matter, and after a few weeks all organic matter had disappeared, leaving the incrustations in tubular, very brittle fragments.

In studying the structure of marl, the writer has found that near the top of the beds there is usually a "sandy," or even a coarsely granular structure. This is noticeable at times, at all depths from which the samples are taken, i. e., in some cases it extends through the bed. Close examination of such marl shows that this coarseness is due to the remains of the characteristic Chara incrustations, and that the "sand" and other coarse material is made up of easily identifiable fragments of the coatings of stems and branches of the plant. The presence of such coarse matter near the top of the beds may be considered due to sorting action of the waves, and such surface currents as may be caused in ponds and small lakes, in shallow water, by wind action. If these agents are effective in producing the coarser parts of the deposits they may also be considered so in connection with the finer parts as well, for the matter produced by the breaking and grinding up of fragments is held in suspension for a longer or shorter time, carried about by currents, and finally sinks to the bottom in the quieter and deeper parts of the lakes. This has not been left, however, as mere conjecture, but a series of mechanical analyses of typical white marl from different localities was made. The method of analysis used was a simple one, a modification of the beaker method, used in soil analysis. The samples, chosen at random from large average specimens from the deposits under investigation, were dried in an air bath at 110° C., for sufficient time to remove any included moisture, and weighed. Each sample was then mixed with distilled water in a large beaker and thoroughly stirred with a rubber tipped glass rod, care being taken to keep up the stirring until all lumps caused by the adhesion of the finer particles to the coarser had been broken up. Care was also taken that no more crushing should take place than was absolutely necessary.

After disintegration of all lumps was accomplished, the water with the finer particles in suspension, was poured off into another beaker, and fresh water added to the first and the material again stirred. This was continued until the water was nearly free from the finer matter and became clear on standing a short time. The coarse material left in the bottom of the beaker was dried, sorted into various grades by a series of sieves and each grade weighed. The finer material was also sorted by stirring, settling and decantation, and that of different degrees of fineness dried and weighed. The finest matter was separated from the water by filtering through a weighed filter and the water concentrated by evaporation and again filtered to remove any of the calcium carbonate dissolved in the various processes, and the final residue of water was evaporated in a watch glass and weighed. An exceedingly interesting feature of this latter experiment was the finding of a water soluble calcium salt, in small quantity it is true, but still easily weighable, and not to be neglected. The results of such an analysis of a sample from the Cedar Lake marl beds gave the following results. The sample was the one of which a chemical analysis is given above, and was taken from a hole made with a spade by cutting away the turf over the marl, then taking out sufficient marl to be reasonably sure that there was no peat or other surface matter present, and the sample used from a spadeful thrown out from two or three feet below this. From this sample about thirty grams were taken and treated as described above, and after the coarser material had been separated from the finer by washing and drying, it was passed through a set of standard guage sieves 20, 40, 60, 80 and 100 meshes to the linear inch, after which all shells and recognizable shell fragments, sand grains and vegetable fragments up to the 60-mesh siftings were removed and weighed separately.

The following grades of material were obtained by this sorting: (1) That too coarse to pass through the 20-mesh sieve, (2) that held by the 40-mesh sieve, (3) that held by the 60-mesh, (4) that held by the 80-mesh, (5) that held by the 100-mesh, (6) that which passed through 100-mesh, (7) that which was filtered out, (8) water soluble .salts, (9) shells, shell fragments, etc.

Analysis (1) is the result of the analysis made and the material graded as described:

	Cedar Lake Marl.	Littlefield Lake Marl.	Coldwater Marl.	Residue from dead Chara.
	1.	2.	3.	4.
Grade (1)..........	32.25%	31.52%	0.36%	1.12%
" (2)...........	6.06	14.48	3.53	24.43
" (3)...........	7.58	12.76	6.51	14.63
" (4)...........	2.90	2.56	3.34	8.26
" (5)...........	4.81	6.74	6.44	7.81
" (6)..........	15.64(1)	30.42	28.99	33.83
" (7)...........	30.52		49.12	
" (8)..........		0.27	1.02	0.39
" (9)...........	0.28	1.04	0.69	0.12
	100.04	99.89	100.00	90.59

(1) In this case determined by drying down the residue and weighing.

A second analysis was made from a specimen made up of twenty samples taken by boring with an augur over about one-half the deposit at Littlefield Lake, Isabella County, most of the samples coming from a depth of at least twenty feet below the surface of the deposit. This analysis is given as 2:

Grade	(1)..............................	= 31.52%
"	(2)..............................	= 14.48
"	(3)..............................	= 12.76
"	(4)..............................	= 2.56
"	(5)..............................	= 6.74
"	(6) (7)..............................	= 30.42
"	(8)..............................	= 0.27*
"	(9)..............................	= 1.04
		99.89

A third sample from the holdings of the Michigan Portland Cement Company, at Coldwater, a fine high grade white marl, very powdery, gave Analysis 3:

Grade	(1)..............................	= 0.36%
"	(2)..............................	= 3.53
"	(3)..............................	= 6.51
"	(4)..............................	= 3.34
"	(5)..............................	= 6.44
"	(6)..............................	= 28.99
"	(7)..............................	= 49.12
"	(8)	= not determined.
"	(9)..............................	= 0.69
Soluble matter and loss by difference........		= 1.02
		100.00

These samples represent (1) the central, (2) the north central and (3) the southern parts of the Lower Peninsula of Michigan, respectively, and may be taken as typical of the marl deposits of Michigan. When it is stated that, in general, it is easily possible to recognize with a simple microscope, particles which are held by the 100-mesh sieve or even those which pass through it, if the finer matter has been carefully separated by washing, as characteristic Chara incrustation, or Schizothrix concretions, it will be seen that these results show conclusively that a large part of the marl from these three samples is identifiable as of algal origin and studies of the marl from other localities give1 similar results. The Coldwater sample (3) was exceedingly fine in texture, and it was difficult to avoid loss in sorting and weighing, as every current of air carried away some of the particles, and some also adhered to the sieves and weighing dishes, in spite of all the usual precautions against such loss. Even this sample shows nearly fifty per cent of easily identifiable Chara incrustation. The fineness of the particles in a given marl bed varies much in different parts of the bed and the degree of fineness is probably largely dependent upon the conditions of current and wave action under which the bed was formed as noted in another place. This fact was noted at Littlefield Lake, where samples of marl were collected along exposed shores near the wave line, which were ninety-five per cent coarse fragments of Chara incrustation and Schizothrix nodules, while in other parts of the shore line the marl was of such fineness that it was like fine white clay.

*The soluble matter contains a certain undetermined amount sodium and potassium, salts as well as soluble calcium compound.

References in Literature.

Fragments of the Chara incrustation are generally easily recognized, even when of minute size, because they preserve, usually very perfectly, but sometimes less so, the peculiar form of the stem, branches, leaves and fruits of the plant. This fact has led various authors, both geologists and botanists, to note the occurrence of "fossil" Chara stems and fruits in the beds of lakes and even in marl beds. Sir Charles Lyell* as early as 1829 described a marl bed in Forfarshire, mentioning as especially interesting the finding of "fossil" Chara fruits and stems. In two editions of the "Principles of Geology,"† which have been consulted, the same writer points out the importance of the remains of Chara to the geologist in characterizing entire groups of strata, and describes and figures the fruits and stems of recent species *Chara hispida* from Bakie Loch, Forfarshire. He also mentions the occurrence of Chara in abundance, in several lakes in New York State. Geikie** mentions the occurrence of Chara as a true fossil in the beds of "a form of travertine from which fresh water shells and a rich assemblage of plants have been obtained." These beds are "lower Eocene, the limestones of Killy and Sizanne, Basin of Paris." *Chara Lyelli* fruits are figured.

*Lyell "On a recent formation of fresh water Limestone in Forfarshire." Transactions Geolog. Society, 2, p. 241, 1829.

†6th Ed., Vol. 3, p. 350, 1842; 9th Ed., p. 766-7, 1853.

**A. Geikie; Text-book of Geology, 2nd Edition, p. 853, p. 859, 1859.

Kerner† says, "The spore fruits of Stoneworts (Characeæ) have been found over and over again inclosed in these formations of lime." He points out also that it is possible for calcareous strata of great depth to be produced by plants in fresh water.

Schimper‡, Solms-Laubach§, Seward‖ and Wesenberg-Lund¶ all mentioned these plants as agents of deposition of lime formations, the latter especially showing the plants able to produce extensive deposits of what he terms "Characeæ-lime" in the lakes of Denmark.

Mosely**, in speaking of the deposits of "tufa" about the remarkable springs near Castalia, Ohio, mentions the fact that the deposit "is composed mostly of petrified Chara."

Even when this structure is destroyed, as may be the case with the thin and incomplete incrustations, it is frequently possible to recognize fragments of the tubes with the compound microscope. Finally in Chara as in other plants the incrustation is distinctly crystalline in the ultimate form of the constituent particles, and when it has disintegrated, the crystals and their fragments are found to constitute a large per cent of the finer particles of the resulting marl. On the growing tips of the younger branches and leaves of Chara, numbers of isolated crystals of calcium carbonate may be seen, and farther back the crystals become more numerous, then coalesce into a thin fragile covering, and finally on the lower part of the plant the covering becomes dense and thick. It is evident, therefore, that the decay of the younger parts of the plants would furnish a mass of more or less free or loosely aggregated crystals of microscopic size which would retain their crystalline form, in some degree at least, for an indefinite time and be recognizable, hence the presence of these micro-crystals in marl is another indication of the origin of the deposits.

†Kerner and Oliver; Nat. Hist, of Plants, Vol. 1, p. 261.

‡Schimper, W. Ph. "Traite de Paleontologie Vegetale," Vol. 1, p. 216, 1869.

§Solms-Laubach, Fossil Botany, pp. 36-37, 1891.

‖Seward, A. C., Fossil Plants, V, p. 69, pp. 222-228, 1898.

¶Wesenberg-Lund. C., loc. cit., pp. 155-156.

**Mosely, E. L., Sandusky Flora, p 87, Ohio State Academy of Science, special papers, No. 1, 1899.

Source of Thick Crusts.

The larger fragments of Chara incrustation as found in marl are frequently much thicker and heavier than those which occur among the fragments of recent origin, namely those obtained from any part of living, vigorously growing Chara from beds of the plant existing in the ponds from which the marl may have been obtained.

While the subject needs further investigation, it is probable that such thickened incrustations have originated in several ways, the principal ones being, if the writer's notes have any bearing on the subject, as follows:

First, On short, stunted plants that grow for a long time on unfavorable soil, such as sand, or pure marl. Such plants have relatively very short internodes, and generally thick incrustations.

Second, From the growth of the lime secreting blue-green algæ, such as Schizothrix, Zonotrichia, etc., either upon living Chara, or upon fragments of broken incrustation as a nucleus.

Third, From the inclusion of the fragments within the nodules formed by the growth of the blue-green incrusting algæ in shallow water and the subsequent destruction of the nodules by wave or other disintegrating action, in which case, the thickened fragments may be left either free, or attached to other material. In this way, several fragments may be cemented together and such aggregations have been observed by the writer.

Fourth, By the deposition of calcium carbonate on fragments of incrustations, a deposition caused by the decomposition of soluble organic calcium salts, left free in the water by the decay of dead Chara plants, through the reducing action of chemical compounds derived from the decay of organic matter, or the growth of bacteria, or both.

Fifth, By the deposition in more or less coarsely crystalline form of the calcium carbonate which is dissolved by water percolating through the marl. This is probably considerable in amount and takes place in a manner analogous to, if not identical with, the formation of concretions in clays and shales. It is probable that in this way, the crystals may be formed which rather rarely are found filling the cavities left by the large axial cells in Chara incrustations. The fact that in the great majority of cases these cell cavities are entirely empty, or simply mechanically filled with fine particles of marl, is the most serious objection to considering that this form of chemical precipitation is an important one in the history of marl, but that it is occasionally operative is most probable.

Sixth, It is possible that the thick incrustations may have been formed at some earlier period in the history of the lakes when conditions were more favorable for the development of Chara and its activities were greater. This is not probable, however, for the thick incrustations are frequently found from the surface of the marl beds throughout the deposits.

A check analysis was made of a specimen of material made up from the washings and fragments of a mass of Chara plants collected from Cedar Lake, and allowed to die slowly, and break up in water kept cold and fresh by conducting a small stream from the hydrant through it. The plants gradually died, broke up and settled to the bottom of the containing vessel, and seemed to undergo farther disintegration there, eventually forming a relatively finely divided deposit which was of rather dark color when wet. A quantity of this was dried at 100 degrees C., some of the larger and longer fragments of stems were removed and the residue weighed and subjected to the same treatment as the marl samples. Ten grams was the amount taken, and the analysis yielded the results given by No. 4, page 76.

It will be seen that nearly as much fine matter was present in this material as in the finest of the marls analyzed and that the finer grades of sifted material are quite as well represented, as in the finer marl. The material is somewhat more bulky for a given weight and is perhaps slightly darker in color, but not much more so, than many samples of marl. Grade for grade it is identical in appearance and structure to the marl samples, and the only possible difference that can be detected is the slightly greenish tint due to the organic matter present in the plant residue. It is also noticeable that the larger pieces do not show as thick an incrustation as do larger pieces from the marl samples, and, of course, Schizothrix and other coarse matter is not present.

It will be seen by inspecting the analyses that shells and recognizable shell fragments are but a very insignificant part of the total quantity of the marl. It is surprisingly small when all things are taken into account. While it is probably true that not all the minute shell fragments have been separated in any of these analyses, it is also true that the weight of such particles as were overlooked, is more than counterbalanced by marl fragments, which are included within the cavities of the whole shells and adhere to both broken and whole shells, in crevices and sculpturings, in such a way as to refuse to become separated in the processes of washing out the marl. The whole shells are mainly small fragile forms, many of them immature, and it is evident that they would be broken by any action that would crush the Chara incrustation.

§ 6. Marl beds without Chara.

As is easily observed in many marl lakes, and as has been pointed out to the writer by several students of lake life, marl beds are often found in parts of lakes in which there are no well developed beds of Chara.

At least two explanations of this may be offered without appealing to other modes of marl formation, both of which may be applicable, either independently or together, in individual cases. The first of these is that such beds of marl were formerly occupied by Chara, but for some reason or reasons, the conditions for growth became unfavorable and the colonies disappeared, or became insignificant and escaped notice. The second explanation takes into account the action of waves and currents upon the deposits near thriving growths of Chara and assumes that the more remote marl deposits may be the result of such action combined with the transporting power of the surface and other currents which may exist in the lakes.

In support of the former consideration are the notes of Dr. Henry B. Ward on Pine Lake in the Traverse Bay Region of Michigan. He says:*

"Pine Lake has undoubtedly undergone some considerable modification, within recent geological times. The old outlet to the northward is easily traced through a line of tamarack swamp to Susan Lake;—thence to Lake Michigan, it follows a small stream which is at present the outlet of Susan Lake. The marl bottom which underlies a very considerable part of Pine Lake can by borings be found not far from the surface at various points around the lake. The gravel and glacial drift are evidently at present being washed out into the lake over the marl and the thickness of the latter decreases gradually as one recedes from the shore. Mollusca are not very abundant and while the species recorded by Mr. Walker are recent and most of them at least found in this locality at present, the existing conditions are inadequate to account for such a bed of marl, and I am inclined to believe it to be the bed of an older lake now gradually disappearing."

He also says:

"On the marl one finds no living thing save here and there scanty tufts of dwarfed Chara, which was never found in fruit: it was uniformly encrusted by heavy calcareous coating."

Here, as the author so clearly points out, there has been a change in the lake within recent geological time and with this it is possible that the agencies producing the marls have become less active. The fact that Dr. Ward mentioned Chara as growing abundantly on the south arm of the lake would point to that plant having been more abundant formerly than now, but as the lake has not been visited, nor specimens of the marl seen by me, no claim is made that the beds described were formed by Chara.

*H. B. Ward, "A Biological Examination of Lake Michigan, in the Traverse Bay Region." Bull. Mich. Fish Com. No. 6, p. 65.

§ 7. Association of marl and peat.

Chara may also be looked upon as an important agent in giving the peculiar distribution to marl which has been noticed by .everyone who has "prospected" beds of this material. The fact is frequently noticed that beds of several, and even as much as twenty or more, feet in thickness will "run out" abruptly into beds of "muck," or pure vegetable debris (peat), of equal thickness. This distribution may show that up to a certain time conditions unfavorable to the growth of Chara and favorable to other plants obtained, until a depth of water was reached at which Chara was able to occupy the bed of muck, covering it from the bottom up, and holding the steep slope of the muck in place by mechanically binding it there by its stems and the root-like bodies by which it is connected with the mud. From the time when the Chara began its occupation of the muck the amount of organic matter left would decrease, and the amount of calcareous deposit would increase, until the latter predominated. The disturbing factors of currents and waves can be disregarded, for these abrupt unions of marl and muck are found, so far as the observations of the writer go, in most sheltered places, and not where either currents or waves could ever have operated with any force or effectiveness. Moreover, in a lake where the marl is evidently now actively extending, the slope was observed to be nearly perpendicular, and the steep banks thus formed were thickly covered with growing Chara to the exclusion of other large forms of plant life, and the lower parts of the growing stems were buried in mud which was mainly pure marl.

§ 8. Turbidity due to marl.

That the finer parts of marl deposits may readily be moved from place to place in lakes in which they exist and where any part of the deposit is exposed to wave action, seems demonstrated by a series of studies, suggested by the milky appearance of the waters of some marl lakes. This has been considered by some investigators as possibly due to the presence of calcium carbonate, precipitated from the water, either by liberation of dissolved carbon dioxide or by a change of temperature of the water after it has reached the lakes.* The writer has not found among the marl lakes of Central Michigan, that those with turbid water were common, even where marl banks were apparently forming with considerable rapidity. "Merl" or Marl Lake in Montcalm County, situated on the same stream as Cedar Lake, and a mile or more below it, is, however, one of the lakes in which the water is usually of almost milky whiteness and has sufficient suspended matter in it to render it nearly opaque for depths over a meter or a meter and a half. The conditions in this lake are widely different from those at Cedar Lake and other marl lakes in the vicinity and are suggestive of the cause of the turbidity. At Cedar Lake, there is a border of grassy and sedgy marsh extending around the lake on three sides, that is generally underlain by marl, and the lake bottom slopes sharply and abruptly from the edge of the marsh to a depth of at least 10 meters. In other words the lake is simply a deep hole, with steep sides, and, perhaps, represents the deepest part of the more extensive lake which formerly occupied the area included by the marsh and marl beds. This marsh covering is generally found upon all the marl beds of the region and the lake may be said to be typical, for the locality in which it lies, for there are several others near by, which are practically identical in essential points of structure.

*25th Annual Report, State Geologist of Indiana.

At Marl Lake, however, the filling of the lake has not reached the same stage. There is practically no open marsh, but the lake is shallow for seventy-five or a hundred meters from the shore, then abruptly deepens to an undetermined depth over a relatively small area. The bottom over the shallow area is of pure white marl and the water is apparently not more than sixty or seventy centimeters deep at the margin of the central hole, while near the shore it is scarcely a third as deep. In brief, here is a lake in which there is a broad platform of marl surrounding a deep hole, which again, is all that remains of the deep water of a lake which is filling with marl. Boring shows that the bed of the lake is nearly as far below the surface under the marl platform as where the marl has not yet been deposited. Upon the shoreward margin of the platform, and in small areas farther out upon it, the turf-forming plants are beginning to establish themselves, but as yet they have not made any marked impression, seeming to have a hard struggle to get a foothold.

The conditions are then, a broad area of shallow water, overlying a wide platform of marl, which, if a strong wind should reach it, would be stirred to its depths, and with it, the lighter parts of the marl upon which it rests. The marl thus stirred up, in turn is carried to all parts of the lake by surface and other currents and makes the water turbid.

These facts led to an investigation into the rapidity with which marl once stirred up would settle out of perfectly still water and some interesting results were obtained. The experiments were made as follows:

(1) A glass tube 1.58 m. long and 2.5 cm. wide was filled with distilled water, and a quantity of finely divided marl was added and thoroughly mixed by shaking. The tube was then clamped in a vertical position and left perfectly still until the marl had settled out, record being kept of the rate of settling. At first the heavier particles settled rapidly, forming as does clay in settling out from water with which it is mixed, distinct stratification planes, which after a few days disappeared, and only the lighter parts of the marl remained in suspension. These were distinctly visible for five weeks on looking through the tube towards a good light, and at the end of six weeks a black object lowered into the tube, in a well lighted room, was not visible beyond 90 cm. from the surface of the water.

(2) A glass cylinder with a foot, 38 cm. high and 7 cm. wide, having a capacity of a little more than a litre was nearly filled with distilled water and the residue from the washings of a sample of marl from which the coarser matter had been separated, was thoroughly shaken up in it. This was left to subside as in the first experiment, and at the end of ten weeks the bottom of the vessel was barely visible. The results obtained by Barus,* in his work on the subsidence of solid matter in suspension in liquids, show that settling is much more rapid in water containing dissolved salts even in small proportion than in distilled water, so check experiments were made as follows: (1) A cylinder approximately the size of the one used in the second experiment above, was filled with water in which a small amount of calcium chloride had been dissolved, and ammonium carbonate was added until a precipitate was formed. The contents of the jar were then stirred thoroughly and left to settle. In three days the entire precipitate had settled out and the liquid was clear. In this case, however, it was deemed probable that the conditions were not at all like those occurring in nature and a second experiment in which the marl was shaken up with the ordinary natural water of the region, obtained from a river partly fed by marl lakes. In comparison with distilled water the subsidence was notably more rapid than from distilled water for the finer part of the marl, but for fifteen days there was distinct turbidity noticeable.

These results indicate that if for any cause the marl in one of the marl lakes is stirred up effectually, as it may be where the beds are exposed to wave action, that the water will remain turbid for some time, and the chances are that even in summer time there will be sufficiently frequent high winds to keep the water always turbid. It may be stated that in some of the lakes which have been studied by the writer the marl has filled the entire lake to within a meter or less of the surface of the water, with some parts even shallower. Until such shallows are occupied by plants and turfed over, the water is likely to be turbid from the mechanical action of waves upon the deposits. At Littlefield Lake, described elsewhere,† the water is only slightly turbid, although there are extensive marly shallows and exposed banks, but there the body of the water is extensive and of considerable depth, while the greater part of the exposed marl is granular and the particles too coarse to be held long in suspension, and the finer parts too small and too well protected to be reached by effective waves, so that the amount of suspended marl is not great enough to produce marked turbidity in the entire body of water. It is worthy of note that the residue filtered out from the sample of Chara fragments (Analysis 4) was sufficiently fine to give a marked turbidity to distilled water for several days and at the time of filtering had not subsided. It is difficult to account for the fact that the deeper parts of marl lakes are generally free from any thick deposits of a calcareous nature. Lack of records of sufficient exploration makes any statement purely tentative, but about 7-9 meters seems to be limit of depth of the recorded occurrence of Chara plants.** The remains of the plants then would only accumulate in place, over bottoms above that depth, and the material reaching greater depths would have to be that held in suspension in the water, hence be relatively small in quantity and accumulate slowly. A probable additional cause is that in the greater depths (i. e., over 9 meters) a greater abundance of dissolved carbon dioxide, due to the decomposition of organic matter in relatively cold water under pressure, dissolves the fine particles of marl which reach these depths, but at present no data are at hand on which to base a conclusion as to the exact efficiency of this cause.††

*Subsidence of fine solid particles in liquids, Carl Barus, Bull. U. S. Geol. Survey, No. 36.

†Journal of Geology, VIII, No. 6, and this report, p. 92.

*C. Wesenberg-Lund: Loc. cit., p. 156. A. J. Pieters: Plants of Lake St. Clair, Bull. Mich. Fish Commission, No. 2, p. 6. Compare, however, reports of the Indiana Survey.

††But see tests 11 and 12, etc., of water in the Cloverdale district, p. 46. L.

§ 9. Conclusions.

From these investigations it seems: First, that marl, even of the very white pulverulent type, is nearly made up of a mixture of coarse and finer matter, covered up and concealed by the finer particles, which act as the binding material. Second, that the coarser material is present in proportion of from 50% to 95% of the entire mass. Third, that this coarser material is easily recognizable with the unaided eye and hand lens as the incrustation produced on Schizothrix and Chara, principally the latter, to particles less than one one-hundredth of an inch in diameter. Fourth, that the finer matter is largely recognizable under the compound microscope as crystalline iii structure and derived from the algal incrustations by the breaking up of the thinner and more fragile parts or by disintegration of the younger parts not fully covered. Fifth, that some of this finer matter is capable of remaining suspended in water a sufficient time, after being shaken up with it, to make it unnecessary to advance any other hypothesis to explain the turbidity of the water of some marl lakes, than that it is caused by mechanical stirring up of the marl by waves or other agency. Sixth, that shells and shell remains are not important factors in the production of the marl beds which are of the largest extent. Seventh, there is in marl, a small amount of a water soluble calcium salt, possibly calcium succinate, readily soluble in distilled water after complete evaporation of the water in which it was first dissolved.

§ 10. Method of concentration by Chara.

After these facts were developed studies were undertaken to determine the method of concentration and precipitation of the calcium carbonate by Chara. Some such studies have already been reported upon by various authors, but none of these have apparently been exhaustive, and the original papers are not at hand at the present writing, although abstracts of the more important ones have been seen.

As has been already indicated elsewhere, the calcium carbonate is present on the outside of the plant as an incrustation and this is made up of crystals, which are rather remote and scattered on the growing parts of the plants and form complete covering on the older parts, which is uniformily thicker on the basal joints of the stems than it is on the upper ones. Considering the hypothesis that the deposition of the salt was the result of purely external chemical action, as not fully capable of satisfying all the existing conditions, the formation of the incrustation was taken up as a biological problem and investigation was made upon the cell contents, at first, microscopically by the study of thin sections. Various parts were sectioned while still living and the attempt was made to find out if the calcium carbonate were present, as part of the cell contents in recognizable crystalline form. In no case were such crystals found, although reported by other observers.

Next an attempt was made to determine the presence of the calcium in soluble form in the cell contents by the use of a dilute neutral solution of ammonium oxalate. An immediate response to the test was received by the formation of great numbers of minute characteristic octahedral crystals of calcium oxalate on the surface and embedded in the contracted protoplasmic contents of the cells. The number of these crystals was so large and they were so evenly distributed through the cell contents, that it was evident that a large amount of some soluble calcium salt was diffused through the cell sap of the plant. The next step was to isolate this compound and to determine its composition. A considerable quantity of the growing tips of Chara were rubbed up in a mortar and the pulp was thoroughly extracted with distilled water. This water extract was filtered, concentrated by evaporation on a water bath, and tested to determine the presence of calcium. An abundant precipitate was again obtained by using ammonium oxalate, which on being separated and tested proved to be calcium oxalate. It was evident that the calcium salt in the plant was stable and readily soluble in water. This latter fact was farther demonstrated by evaporating some of the extract to dryness and again taking it up with water. Almost the entire amount of the calcium salt was redissolved, only a small portion of it becoming insoluble, precipitating as the carbonate. This ready solubility demonstrated that the salt was not derived from the incrustation on the portions of the plant used, and the same fact excluded from the list of possible compounds, salts of the more common organic acids found in plant juices. Qualitative chemical tests were, however, made to determine, if possible, whether any of these acids were present, with negative results, and it was demonstrated by this means that there was but a single salt present and not a mixture. Search was then made to determine the acid present and a result was obtained which was so unexpected that it was seriously questioned, and the work was gone over again. The second result confirmed the first, and the work of ascertaining the correctness of these two results was turned over to Mr. F. E. West, Instructor in Chemistry in Alma College, who had special training and much practice in organic analysis. His work was done entirely independently with material gathered at a different season, and by another method of analysis, but his results were identical with my own and show that calcium exists in the water extract of Chara as calcium succinate, Ca ($C_4H_4O_4$). The fact that the succinate is one of the few water soluble salts of calcium and that there is a soluble salt of the metal in the cell sap of the plant, makes it probable that this is the compound which the plant accumulates in its cells. It is not yet possible, from actual investigation, to explain the method by which the calcium salt is abstracted from the lake water, where it exists as the acid or bicarbonate, or as the sulphate,* in small per cent, and concentrated in the cells of the plant as the calcium succinate and later deposited upon the outsides of the small cells as the normal or monocarbonate in considerable quantities. Culture experiments which were undertaken by the writer to determine under what conditions of soil, light and temperature Chara thrives best, incidentally demonstrated that the plant actually gets its lime from the water about it and not from the soil. One of the soils which was used as a substratum in which to grow plants was pure quartz sea-sand, which had been thoroughly washed and tested with acid to be certain that no calcium salt was present in it. The plants grew in this medium readily, and on the newer parts, developed nearly if not quite as many calcium carbonate crystals as plants growing on pure marl. It should be apparent, however, to even the casual observer, that the plants cannot take all the lime they use in forming incrustations from the soil, for if they did the marl beds, being made up principally of Chara remains, would never have accumulated, for the material would have been used over and over again and could not increase in amount.

In the present state of our knowledge of the life processes of aquatic plants it seems hardly possible to state the probable method of formation of the calcium succinate or even the probable use of it to the plant and no attempt will be made by the writer just here to do so. It does seem probable, however, that this compound accumulates in the cells until it reaches sufficient density to begin to diffuse through the cell walls by osmosis. Outside the cells it is decomposed directly into the carbonate, possibly by oxidation of the succinic acid by free oxygen given off by the plants, possibly, by the decomposition of the acid by some of the organic compounds in the water due to bacterial growth in the organic debris at the bottom of the mass of growing Chara. The water extract of Chara rapidly changes on standing, undergoes putrefactive decomposition, becomes exceedingly offensive in odors developed, and a considerable quantity of calcium carbonate crystallizes out on the bottom and sides of the containing vessel, while the succinic acid disappears, gas being given off during the process more or less abundantly. Whether these changes take place on the outside of living plants has not yet been determined.

In regard to the species of Chara which seems to be the active agent in precipitation in the lakes of Central Michigan, it is the form commonly known as *Chara fragilis*, but it is probable that careful study of the species throughout the range of the marl will reveal, not a single form, but a number of allied species, engaged in the same work. It may be well to suggest that in lakes to which silt is brought by inflowing streams, or which have exposed shores where the waves are constantly cutting and stirring up rock debris, the more slowly accumulating marls will be either so impure as to be worthless, or so obscured as to escape notice altogether, even where Chara is abundant. It may also be pointed out that shallow water, strong light, and a bottom of either clay, sand, or muck, present conditions favorable for the growth of the higher vascular plants, and that these cause such rapid accumulation of vegetable debris that the calcareous matter may be hidden by it, even when Chara is a well marked feature of the life of a given lake.

This view is amply supported by the presence of large accumulations of Chara plants heavily incrusted with calcium carbonate, at the storm-wave line along the shore of Saginaw Bay, in Huron County. These windrows, however, soon disappear, leaving nothing more than a limy layer in the sand, scarcely to be distinguished from the rest of the wave-washed shore, and ultimately all trace of them is lost.

*The formation of $CaCO_3$ incrustation by Chara in water impregnated with $CaSO_4$ accompanied by the liberation of H_2S is reported in a book called the "Universe."

§ 11. Blue-green algæ and their work.

Another plant form, like Chara, an alga, but of a much lower type, which is concerned in the formation of marl, is one of the filamentous blue-green algæ, determined by Dr. Julia W. Snow, of Smith College, to be a species of Zonotrichia, or some closely related genus. The work of this species is entirely different in its appearance from that of Chara, and at first glance would not be attributed to plants at all. It seems to have been nearly overlooked in this country, at least, by botanists and geologists alike, as but three references to it have been found in American literature.* Curiously enough, however, material very similar, if not identical, to that under consideration has been described from Michigan in an English periodical devoted to algæ.† In this the alga is identified as Schizothrix fasciculata Goment. Mr. F. S. Collins of Maiden, Mass., has identified Schizothrix fasciculata as present in the concretions from Littlefield Lake, but does not specify it as the form which has the calcareous covering. The plant grows in relatively long filaments formed by cells growing end to end, and as they grow, the filaments become incased in calcareous sheaths. The feature of the plant which makes it important in this discussion, however, is its habit of growing in masses or colonies. The colony seems to start at some point of attachment, or on some object like a shell, and to grow outward radially in all directions, each filament independent of all others and all precipitating calcium carbonate tubules. The tubules are strong enough to serve as points of attachment for other plants, and these add themselves to the little spheroid, and entangle particles of solid matter, which in turn are held by new growths of the lime-precipitating Zonotrichia, and thus a pebble of greater or less size is formed which to the casual observer is in no wise different from an ordinary water rounded pebble. These algal calcareous pebbles show both radial and concentric structure and might well be taken for concretions formed by rolling some sticky substance over and over in the wet marl on which they occur but for the fact that a considerable number of them show eccentric radial arrangement, and that the shells of accretion are likewise much thicker on one side than on the other, and finally, because the side which rests on the bottom is usually imperfect and much less compact than the others. The pebbles are characteristically ellipsoidal in shape. The radial lines, noticeable in cross sections of the pebbles, are considered by the writer to be formed by the growth of the filaments while the concentric lines probably represent periods of growth of the plants, either seasonal or annual. Included within the structure are great numbers of plants, besides the calcareous Zonotrichia, among them considerable numbers of diatoms, and it is probable that a large part of the algal flora of a given lake would be represented by individuals found in one of these pebbles. It is probable that to a certain extent they disintegrate after the plants cease to grow, for they are never very hard when wet. It is possible to recognize them, as lumps of coarser matter, even in very old marl, and the writer has identified them in marl from Cedar Lake, which was taken from a bed a foot or more above, and several rods away from, the lake at its present level. From the fact that these pebbles have been found, by the writer in four typical marl lakes in different parts of Michigan (in Zukey Lake and Higgins Lake by Dr. A. C. Lane, who was struck with their peculiar character) and have been reported from a number of others by Mr. Hale and other marl hunters, it is probable that they have a wide distribution in the State and are constant if not important contributors to marl beds. It may be said in passing that the limy incrustations which are found upon twigs, branches, shells, and other objects in lakes and streams, and called generally "calcareous tufas," are of similar origin and are formed by nearly related, if not by the same plants that form the pebbles.

Studies have been begun by the writer to solve, if possible, some of the questions which have arisen in connection with the statements embodied in this paper, but enough has already been done to show that these forms of fresh-water algæ are important lime-precipitating agents now, and to suggest the possibility that in all likelihood they have been more active in former geological times, and that, as has been suggested again and again by botanists, the formation of certain structureless limestones, and tufa deposits may have been due to their work.

*McMillan: Minn. Plant Life, 1899, p. 41. Penballow: Botanical Journal, 1896. p. 215; J. M. Clarke. "The Water Biscuit of Squaw Island, Canandaigua Lake, N. Y." Bull, of the N. Y. State Museum, No. 39, Vol. 8, p. 195, 1900.

†G. Murray: Phycological Memoirs No. XIII, 1895, p. 9, Pl. XIX.

§ 12. Littlefield Lake, Isabella County.

Early in June, 1900, the writer visited this interesting body of water, and from its peculiar form, and the deposits about it, it seemed worthy of special description.*

The country about the lake is of a well-marked morainal structure, the till, however, being sandy in places, and noticeably gravelly and bouldery throughout, and was formerly heavily covered with pine. The lake occupies a deep depression in a trough-like valley, surrounded by moderately high morainal hills, and from its apparent connection with a series of swamp valleys, suggests a glacial drainage valley, but as it was not followed for any distance, its origin was not determined.

The lake itself is about one and one-half miles long, by three-fourths of a mile broad in the widest part, which is near the middle of the long axis and the shape is that of an irregular blunt ended crescent. It was said to be over eighty feet deep in the deepest part, but no soundings were made by the writer. Its greatest length is from northwest to southeast, with the outlet at the southern end. There are no considerable streams entering it, but at least three small brooks fed by springs from the surrounding hills were noted flowing in, and the outlet is of such size that a boat may be easily floated on it at high water, although its level is maintained during the summer by a dam about two miles below the lake. The main inlet was not seen by the writer.

The shore lines are relatively regular, especially on the east and north sides, the convex side of the crescent, with banks twenty or more feet high close to the water on the east, while on the west side are two rather deeply indented bays. At either end are three small ponds, parasite, or daughter lakes, and surrounding the entire shore except on the eastern side, and the northeastern, or inlet, end is a cedar swamp which is underlaid by marl. The outlet is through the most southerly of the daughter lakes, and the entire shore of the lake is formed by beautifully white marl, the exposures varying in width from a few feet to three or four rods in width, so that as one overlooks the lake from one of the surrounding hills it seems to lie in a basin of white marble.

There are three small islands in the lake, two relatively near together at the northern end, and one quite near the shore at the south end. These islands are also of marl, covered partly with a thin layer of vegetable matter and a scanty growth of grass, bushes and cedar. There is a visible connection, under water, between at least one of the islands and the shore, and it is probable that all of them are thus connected by submerged banks. The marl on the islands is from twenty-five to thirty feet deep, with sand below.

Explorations in the swampy border of the lake, show that the shore was formerly more irregular than now, and that the marl extends back from the water in some places for at least one-fourth of a mile, gradually becoming more and more shallow until the solid gravel or clay is reached. The marl is frequently thirty feet deep along the shore and at no place was it found to be less than fifteen feet deep at the present shore line, the shallowest places being along the shore where the high bank comes down near the water. The deepest vegetable deposit, or peat, found in one hundred and fifty borings in all parts of the deposit was three feet. The main deposits of marl are about the southeast end and along the western side of the lake, with a body of considerable size, underlying a swampy area at the north end. Of the six daughter lakes, four are very small, an acre or two in extent and entirely surrounded by deep marl, the connection between three of them and the mother lake being shallow and narrow, a few inches deep, and a few feet wide, and only existing at high water, while two of the other three are of much larger size, with marl points extending out from either side of the straits which are still relatively wide and deep.

Of the two bays on the west side of the lake, one is much narrower than the other and at the mouths of both, marl points are extending towards each other to a noticeable degree.

At all points along the shore, the slope of the marl is very abrupt from the shallow water to the bottom, always more than forty-five degrees, and frequently nearly ninety, this steepness being noticeable in the small as well as in the parent lakes, while on the east side of the island, at the south end of the lake, the wall of marl seemed positively to overhang, although this appearance was probably due to refraction.

The texture of the deepest part of this marl deposit is apparently that of soft putty, a sounding rod passed through it with comparative ease, and samples brought up have a yellowish or creamy color, which disappears as they dry, leaving the color almost pure white. At the surface the marl is coarser, slightly yellowish and more compact. Where it lies above the water line it is distinctly made up of granular and irregular angular fragments, resembling coarse sand, but the fragments are very brittle, soft and friable, and may be converted into powder by rubbing between the thumb and fingers.

On the parts of the shores where apparently the wave action is chiefly exerted, there are small rounded calcareous pebbles, mixed with molluscan shells, drift material and considerable quantities of stems, branches and more or less broken fragments of the alga, Chara, all parts of which are heavily incrusted with calcareous matter. This Chara material was often piled up in windrows of considerable extent at the high water mark.

The marl banks of the lake, from a little below the water's edge down as far as could be seen, were generally thickly covered with growing Chara, at the time of the writer's visit and wherever a plant of it was examined it had a heavy coating of limy matter, which was so closely adherent to the plant, as to seem a part of it, and because of this covering, the plants were inconspicuous, and would easily escape notice.

Little if any other vegetation of any character was growing in the lakes at this season. Indeed, from the steep slope of the banks of marl, it would be hardly possible for any considerable amount of vegetation of higher types than algæ, to flourish here, because of the lack of light at the depth at which it would have to grow to establish itself.

As Chara of several species, is known to occur within our limits, at depths as great as thirty feet, and probably grows at even greater depths, where the water is clear and the bottom soil is of the right character, i. e., of clay, finely divided alluvial matter, marl, etc., it is apparent that there must be an immense growth of this type of plants in such a lake as the one under discussion. That there is an abundance of Chara in Littlefield Lake is shown by the amount of drift material, composed of the plant, which had accumulated in heaps at the high water wave marks along the shore at various places.

From even a casual inspection of this drift accumulation, it is evident that it is the source of much of the granular and sandlike marl on the beaches, and in the coarse upper layers of the deposit. This wind and wave accumulated material was dry and bleached, and was very brittle, so fragile indeed, that a mere touch was generally sufficient to break it into fragments and it passed by insensible gradation from the perfect, unbroken, dried plant form at the high water mark, in which every detail, even the fruit, is preserved, to inpalpable powder at, and below the water's edge.

In other words we have in Chara, a plant of relatively simple organization, and one able to grow in abundance under most conditions of light and soil which are unfavorable to more highly developed types, a chief agent in gathering, and rendering insoluble, or precipitating, calcium and other mineral salts brought into the lake from the clays of the moraine around it by the stream, spring and seepage waters. After precipitation is accomplished and the plant is dislodged, or dies, it drifts ashore, where after decomposing and drying out the small amount of vegetable matter, the various erosive agents at work along shore break up the incrusting chalky matter, and the finer fragments are carried into deeper water, the coarser are left along the lines of wave action.

The pebbles mentioned above as occurring on parts of the shore, are also the result of the development and growth of an alga, Zonotrichia or a nearly related genus, a much lower type than Chara, having a filamentous form. The vegetable origin of these pebbles would not be suspected, until one is broken open when recently taken from the water, when it is found to show a radiating structure of bluish green lines, the color indicating the presence of the plants, as it is characteristic of the group to which Zonotrichia belongs.

The relation of the deposits about Littlefield Lake to the direction of the prevailing strong winds of the region, is probably significant.

The area of deposition is at the southeast end and along the whole western side of the lake. The winds which would be most effective in the valley of the lake would be those from the north and northwest, which would drive the surface waters down the lake towards the southern end, and, striking the shore on the eastern side, currents formed thus would be turned across the lake to the west, depositing sediment at the turning area and in slack water beyond. The daughter lakes are not easily accounted for, except in a general way, that they were formerly deep bays, which, by the building out of points of marl on either side of their mouths, were finally enclosed. The tendency, already noted, for existing bays to have points of marl, of spit-form, extend from either side of the mouth would seem to indicate this as a probable method of formation. On the island at the south end of the lake there was manifestly a strong current, which was running southeasterly and depositing fine marl on the east side of the island, the wind at the time the observation was made, blowing gently from a few points north of west.

As has been already noted, the islands consist of marl from twenty-five to thirty feet deep, the bottom on which they are built up being, to judge from soundings, made with an iron rod, of rather fine sand. These foundations of sand have deeper water all around them, if soundings, said to have been made by local fishermen, can be relied upon, so it is possible they represent shallows in the original lake bottom, upon which after Chara had established itself, the marl accumulated, both by direct growth of the plants and by sedimentation. It may be worthy of mention, that the Chara growing on the steep banks, may in part, account for their steepness, by acting as holding agents, bind the particles of sediment in place by stems and the rootlike organs which the plant sends into the mud. It is probable that but a small part of the Chara that grows in the lake, ever reaches the shore wave line, and much must break up by the purely chemical processes, resulting from the organic decay in relatively deep water.

*See Plate XIX.

APPENDIX, ON THE SHELLS OF MARLS. BY BRYANT WALKER.

Detroit, Michigan, Nov. 25th, 1901.

A. C. Lane, Esq., Lansing, Michigan:

My Dear Sir.—I enclose my report on the mollusks found in the seventeen lots of marl material received from yourself and Prof. Davis during the last two years. I have not included the recent species, of which several lots were received from Prof. Davis, as their determination was not particularly pertinent to the marl fauna. I can send you a list of them if you desire. There is, however, nothing of special interest in them and the list of Saginaw Valley shells, which you made use of in your former report,* will include them all.

Taken as a whole the fauna of the marl deposits does not differ from the present fauna of that portion of the State from which they come. Nor have I found in the specimens from any particular locality any special peculiarities, which would indicate peculiar local conditions of environment. Individual variations occur more or less frequently, but no more than is often found in similar collections of recent species. The inference is, therefore, that the marl fauna lived under substantially the same environmental conditions as the present fauna does or at least not sufficiently different to produce any special or characteristic variations.

The one species peculiar to the marl deposits of this State is *Pisidium contortum* Prime. It was originally described from the Post-glacial formation at Pittsfield, Mass. It occurs abundantly in the marl deposits both in Michigan and Maine. It has recently been found living in one locality in the latter State and it is quite possible that it may yet be found alive in this State. But so far as our present knowledge extends it is extinct in Michigan. Why this one species out of the fifteen, to say nothing of the other genera represented in the marl, included in our list, should have failed to survive, while all the others are still abundantly represented in our present fauna is very curious. I have been entirely unable to imagine any adequate explanation.

The characteristic feature of the marl fauna is the great relative abundance of certain of the smaller species. This is especially noticeable in *Planorbis parvus* Say, *Valvata tricarinata* Say and *Amnicola limosa* Say and *lustrica* Pils. The larger *Planorbis bicarinatus* Say and *campanulatus* Say occur in nearly every lot of material, but the number of individuals is comparatively small. *Pisidium* both in the number of species and individuals is also a characteristic feature of the marl as it is indeed of our present fauna. There is probably no district in the United States, in which this genus abounds to a greater extent, both in species and individuals than in the inland waters of this State.

The terrestrial species represented in the marl are few both in number and individuals. This is what would naturally be expected, as those that do occur are the occasional examples that have been washed into the water from the adjacent land. Such as have been found present no peculiarities as compared with recent specimens from the same region.

The almost complete absence of the *Unionidæ* from the collections is also noticeable.

The peculiar variations noted in *Valvata tricarinata* Say from Cement City are of considerable interest. A similar tendency to unusual variation, although in another direction, has been noticed in the same species from a Post-glacial deposit near Niles in this State (Nautilus XI, p. 121). In both instances, however, the variation was not common to the whole colony, but was limited to a very few individuals. It cannot therefore be attributed to any peculiar conditions in the environment for in that case it would undoubtedly be more general in effect.

Yours very truly,
(Signed) BRYANT WALKER.

N. B.—Please don't forget to give Dr. V. Sterki the credit for identifying the *Pupidæ* and *Pisidia*.

NOTES.

Numbers refer to numerals in table.

1. Fragment or fragments only,

2. Young shells, just hatched, undoubtedly recent.

3. Apparently recent.

4. Fragment, possibly *S. avara* Say.

5. Peculiar form.

6. Peculiar form, probably *L. humilis* Say.

7. Peculiar form.

8. Young.

9. Undoubtedly recent.

10. One left valve with teeth wholly reserved, one right valve with anterior laterals and cardinals reversed.

11. One valve with posterior laterals reversed.

12. Two samples with the apertural portion of the last whorl separated from the body whorl. One example with the superior and peripheral carinæ present, the umbilical carina wanting, its position however is represented by a slight angulation of the whorl. This remarkable variety has never been seen before among hundreds of examples examined. So far as I know there is no previous record of its occurrence. Should other examples be found it would be entitled to rank with the varieties already described. But as only single specimens from two different localities have been noticed it may be only an individual variation or "sport."

13. One example with the superior and peripheral carinæ present, basal one obsolete. See Note 12.

14. Deformed.

LOCALITIES.

1. Shell-bearing deposits in digging a well about 100 feet northeast of Sec. 36—13—5 E. A. C. Lane, Coll. No. 1.

2. Marl from A. F. Gorton. Lake near Howell. A. C. Laney Coll. No. 2.

3. E. ½ S. E. ¼ Sec. 3—11 N.—5 E. A. C. Lane, Coll. No. 3.

4. Cascade near Grand Rapids. A. C. Lane, Coll. No. 4.

5. Cedar Springs. A. C. Lane, Coll. No. 5.

6. Sec. 22, T. 10 N., R. 11 W. A. C. Lane, Coll. No. 9.

7. T. 11 N., R. 11 W. A. C. Lane, Coll. No. 10.

8. Pickerel Lake, Newaygo County. A. C. Lane, Coll. No. 11.

9. Indian Lake. A. C. Lane, Coll. No. 12,

10. Fremont Lake (12 N., 14 W.), Newaygo County, 150 to 200 feet above lake. A. C. Lane, Coll. No. 14.

11. Cut between Sec. 24 and 25, Spaulding Township, Saginaw County. A. C. Lane, Coll. No. 15.

This is a sand deposit of Lake Algonquin?

12. Marsh north side of Cedar Lake, Cedar Lake Station, Montcalm County. Lane and Davis, Coll.

13. Dry marl bed ¼ mile east of Cedar Lake Station, Montcalm County. Lane and Davis, Coll.

14. Marsh on east side of Mud Lake, N. W. ¼ S. W. ¼, Sec. 3, T. 12 N., R. 4 W. Lane and Davis, Coll.

15. From bank of ditch, N. W. ¼ S. W. ¼, Sec. 3, T. 12 N., R. 4 W. Gratiot County. Lane and Davis, Coll.

16. Bottom of ditch from Mud Lake. N. W. ¼ S. W. ¼, sand section, Gratiot County, "possibly washed from marl." Lane and Davis, Coll.

17. Goose Lake. Cement City. J. G. Dean.
This is the marl of the Peninsular P. C. Co.

LIST OF SPECIES.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Polygyra albolabris Say											x[1]?						
" sp.							x[2]										
Zonitoides arboreus Say							x[3]					x[3]					
" minusculus Binn							x[3]										
Vitrea indentata Say							x										
Euconulus fulvus Dr.																	x
Helicodiscus lineatus Say							x										
Strobilops labyrinthicus Say	x?																
Bifidaria pentodon Say						x											x
Vertigo ventricosa var. elatior Sterki																	x
Succinea retusa Sea	x													x			x[1]?
" sp	x[4]																
Carychium exiguum Say																	x
Limnæa stagnalis L.								x[1]?			x[1]?					x	x[1]
Limnæa reflexa Say											x						
" palustris Mull											x						
" desidiosa Say				x[1]?		x		x		x?			x	x		x	x
" " v decampii Streng					x	x		x[5]?				x					x
" humilis Say													x				x
" sp.	x[1]		x[6]							x[7]			x[14-8]	x[14]		x	
Physa heterostropha Say						x		x						x			x
" gyrina Say		x									x						
" elliptica Lea											x			x			x
" aucillaria Say																x	
" integra Hald																x	
" brevispira Lea				x?													
" sp.	x[1]				x			x[8]		x[8]		x[8]	x[1]				x
Planorbis bicarinatus Say		x		x	x	x		x	x	x	x	x	x	x		x	x
" campanulatus Say		x			x	x		x		x	x	x		x		x	x
" deflectus Say						x		x						x		x	x
" exacutus Say				x						x				x		x	x[8]
" parvus Say	x	x		x	x	x	x	x	x	x	x	x	x	x		x	x
" trivolvis Say											x						
Segmentina armigera Say	x[1]																
Valvata tricarinata Say		x				x		x	x			x	x	x[13]		x	x[12]
" tri. v confusa Walker		x		x	x	x		x	x	x		x	x	x		x	x
" tri. v unicarinata DeKay					x	x		x		x		x		x			x
" tri. v simplex Gld.							x	x		x							x
" sincera Say																	x
Campeloma integra Say											x						
" sp								x[8]								x[8]	
Amnicola lustrica Pils				x	x	x	x	x		x			x	x		x	x

LIST OF SPECIES—CONTINUED.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Amnicola limosa Say		x[1]		x	x	x		x		x	x			x		x	x
" walkeri Pils.						x		x?					x?			x	x
Paludestrina nickliniana Lea														x			
Pleurocera sp.											x[1]	x					
Goniobasis livescens Mke											x						
Unionidæ								x[1]									x[1]
Unio sp.											x[1]						
Anodonta grandis v. footiana Lea		x[9]													x[3]		
Sphærium simile Say											x			x[1]?		x	x
" striatinum Lam				x		x[9]											x
" rhomboideum Say																	x
" occidentale Pme	x																
" sp.						x[9]											
Calyculina truncatum Lind						x											x
" securis Pme		x[1]				x[9]								x		x	
" sp								x[8]						x[1]			
Pisidium roperi Sterki	x																
" noveboracense Pme	x	x?												x		x[9]	
" affine Sterki	x			x								x				x	x
" pauperculum Sterki		x?		x				x[11]								x?	
" variabile Pme		x		x			x			x	x					x[11]	x
" medianum Sterki		x			x	x		x		x		x		x		x	x
" compressum Pme				x		x				x	x		x	x		x	
" scutellatum Sterki			x									x					
" contortum Pme			x														
" tenuissimum Sterki					x			x									x
" walker Sterki											x?						
" peraltum Sterki						x											
" strengii Sterki																x	
" splendidulum Sterki												x		x[10]			
" rotundatum Pme													x?				
" sp.	x							x		x			x			x	x

x Present.
x ? Identification doubtful.

*Vol. VII, Part III.

CHAPTER VI.
RECORD OF FIELD WORK BY D. J. HALE.

§ 1. Lansing—Summer, 1899.

Before starting on a longer tour of inspection a short trip was made from St. Joseph through White Pigeon, Bronson, Coldwater, Quincy, and several other towns near which marl had been reported. The surroundings of the marl, its location and manufacture and any other points needing investigation were to be noted.

White Pigeon.—The first bed visited was that of Mr. Theodore E. Clapp on Section 17, St. Joseph County, two miles southeast from White Pigeon, and one and a quarter miles from the Lake Shore & Michigan Southern railroad. The following are his figures on the bed. The depth is from six to thirty feet with average depth twenty feet, area 100 acres. The marl at the center of the lake is about twenty-two feet deep, at the edges thirty feet deep, water in shallows two to four feet in depth. The marsh land about the lake is underlain with the deepest marl, and this greatest depth is between the lobes of the lake. The marl is not overgrown sufficiently with marsh grass for cattle to graze upon it safely. For sounding the deposit he used two inch drive well pipe cut into six foot lengths, and fitted with couplings so that they could form a continuous rod. Upon one length an augur was welded. This was the apparatus used to bring up the specimens. Mr. Clapp made fifteen soundings, requiring a force of five men.

Tests were carried on during the winter through ice. The analysis of the marl made at Purdue University was as follows:

Moisture	.81%
Insoluble in Hydrochloric acid	1.46%
Silica	.37%
Iron and Alumina	.56%
Calcium oxide	51.00%
Magnesium oxide	1.02%
Potash	.17%
Soda	.52%
Carbonic Acid	41.10%
Organic matter combined with water	4.01%
Sulphuric acid	trace.
Phosphoric acid	trace.
	101.02

The above analysis would indicate a first class marl. The marl between the lobes of the lake, which was before remarked as deepest, in this instance probably marked the center of the lake. According to Mr. Clapp's soundings the deepest water did not contain the deepest marl, but rather the shallows at the edge of the lake toward the center of the whole lake basin. The lake basin would be the whole depression including the two lobes of the lake, and the low marsh surrounding it.

Bronson, Quincy, Coldwater.

After leaving this lake the old glacial valley or chain of marl lakes extending irregularly through Bronson, Quincy, and Cold-water was examined. It was near Bronson, while sinking piles for a bridge over a creek that a section foreman discovered a marl bed. The whitish or greyish soft mud which he found there, proved upon analysis to be a marl suitable for cement. A thriving factory was started upon this same land, also one at Union City some fourteen miles distant. One is built at Coldwater and another completed at Quincy, these two belonging to the Michigan Portland Cement Co. This constituted the district which was at the time (1899) actively devoted to the manufacture of marl, although factories were in the process of building in many parts of the State.

The bed and factory at Bronson were first examined. The factory itself is located on a sandy island a few acres in extent. These islands are sprinkled through the marl bed, and upon some of them good sized trees are growing. The deposit is one of the old lake valleys above mentioned. In reply to questions asked Mr. Wheeler, the chemist of the factory, the following facts were given. The area of marl is estimated at 1,300 acres. It follows the bed of Swan Creek, and two or three other streams from Spring Lake. The depth varies from one to fifty feet according to measurements made with solid iron rods. Beneath the marl there is a white quartz sand, the outline of which is regularly undulating, which Mr. Wheeler accounts for by the former action of waves. The marl is about thirty to forty per cent water. The lake basin is in the form of an oblong one mile wide and several miles long.

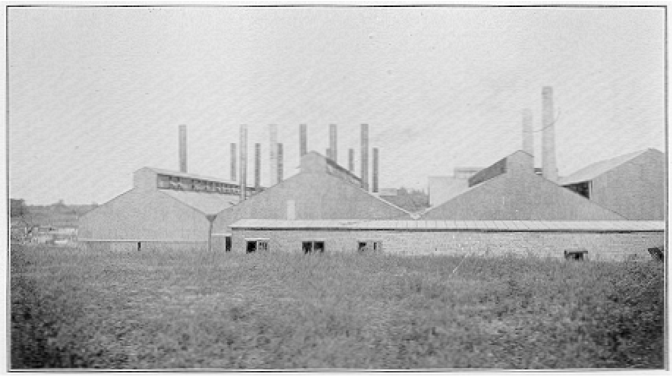


Plate III. Coldwater plant of Wolverine P. C. Co.

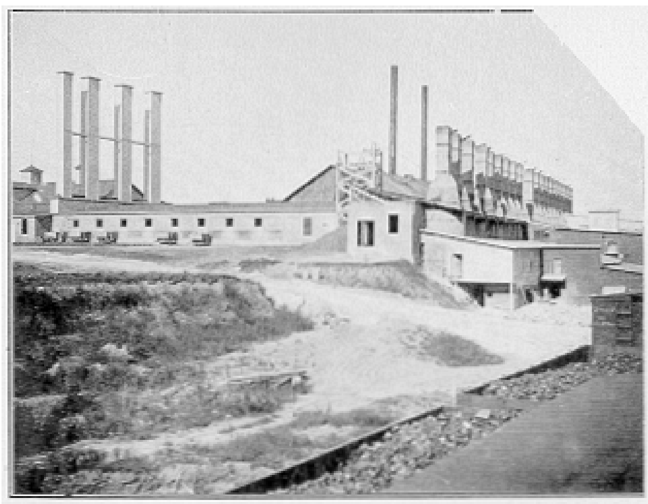


Plate III. Union City plant of Peerless P. C. Co.

The factory contains seven rotaries and six tanks with an output of 1,000 barrels per day. The occurrence of marl under one part of the marsh does not signify that it will be found under the whole marsh. The bed is thickest at the center. It contains no bog iron ore, and few shells. The well water in the vicinity is rather soft. His analysis of the marl is as follows:

Volatile matter	45.64%
Insoluble matter	1.72%
Iron and aluminum oxides	1.17%
Calcium oxide	49.21%
Organic matter	7.07%
	104.81

Further analyses and descriptive notes will be found in the last chapter.

The marl is dug by an ordinary dipper dredge which scoops out the marl to a depth of twenty-two feet and empties it into small cars in which it is hauled to the factory. The dredge first removes the surface from one to six feet of tough marsh grass, roots, etc., and piles it up at one side or dumps it in place where the marl has already been removed. As the water stands at within from one to two feet of the surface, after a small channel is cleared the dredge has water room to float over the marl which is to be removed. The marl when first dug is much darker on account of being nearly half moisture, but after drying, it becomes about the color of light wood ashes. The next point of interest visited was the clay pit from which the supply of clay for this factory is derived. The pit is on a siding about two miles south of the factory. It is in this vicinity that the great stratum of Coldwater shales is uncovered. In this case the shale does not quite reach the surface, and a shaft seventy-five feet deep has been sunk to penetrate the surface soil, and from the vertical shaft a tunnel with several smaller branches has been dug through the solid shale. A regular mining hoist is used to reach shale and hoist it to the surface. Clay is transferred from the head of the tunnel to the shaft by small cars run on a wooden track. The clay, which is a shale compressed until it shows lines of cleavage, is hard like a rock and is blasted by giant powder as coal is mined.*

The next point visited was Coldwater. Between Bronson and this city the land is rolling and very stony. It does not present the sudden contrast in outlines which characterizes the marl regions, further north.

The Coldwater mill is located near several small lakes. The manager of the works who was present during the prospecting could not see that there was any regularity in the depth of marl. It showed no greater thickness in the center. The soundings were a succession of sudden changes in depth. Compare the soundings at the lower end of Long Lake in the Cloverdale region. It must be remembered that these lakes were lined with clear marl at the bottom as at Cloverdale and not a completely leveled marsh filled in with vegetation as at Bronson. It is well to notice how the different lakes compare with swamps in increase of depth toward the center of the marl deposit. The marl lands at this point available for cement manufacture were said to aggregate two thousand acres. The beds in this chain of lakes are to be worked by two fourteen-rotary mills, one at Coldwater, and the other at Quincy.

The clay used at Coldwater differed somewhat in appearance from that used at Bronson. It is a surface clay mixed blue and grey in color. Its advantage lies in its easy access and cheap grinding.

*For analysis see Part I, p. 41 (Clays and Shales by H. Ries).

Jonesville.

At Jonesville, Mr. Chase Wade was interviewed. A factory was completed at this point. The bed to be utilized has an area of from seventy-five to eighty acres with an average depth of twenty-five feet. The analysis showed from ninety-three to ninety-five per cent of calcium carbonate.*

*See report by W. M. Gregory, upon the plant of the Omega P. C. Co.

Kalamazoo.

The return trip from Lansing to St. Joseph was made by way of Hastings and Kalamazoo. At the town of Cloverdale the Chicago, Kalamazoo & Saginaw railroad passes through a cluster of lakes, and on account of the promising outlook it was deemed advisable to make a thorough investigation later, the result of which is given in the description of the Cloverdale district.

Kalamazoo was next visited, and the site of the former cement plant was examined. A chain of three small lakes form a deep valley with a rate of fall so great that a small water flume bringing water about a half a mile from the creek at the headwaters of the lake furnished ample water power for a large mill. The lower of the three lakes was nearly dry and the marl exposed was very light colored with many shells. In this lake there was little or no surface muck. In the upper, however, the depth of marsh surface was so great as to render the marl scarcely available for manufacturing purposes. One of the first factories started in the State was built on this marl bed, but with the old kiln process and with the expensive method of handling raw materials, it did not pay.*

The next marl bed reported was in the vicinity of Niles. It was five and a half miles east of the town, and covered about forty acres. Deep wells in the vicinity were said to have very hard water, and the hills surrounding terminated abruptly at the edge of the marsh and were of gravel.

*The quality was very good, as is shown in many places in Kalamazoo, where 20 years has made little impression on the cement. L.

§ 2. Cloverdale.

The peculiar formation of the region about Cloverdale makes a very interesting locality for the study of the formation and occurrence of marls. By consulting a map of Michigan it is seen that the townships of Hope, Barry, and Prairieville of Barry County contain an unusually large number of inland waterways and lakes. (Fig. 3.) The country is a network of deep depressions forming dry channels, gullies, water courses and lake beds. Between channels are high gravel and clay hills. The soil is very heavy but forms a greatly varying mixture. At one place it may be a tough till of clay, gravel and boulders which may be traced a short distance and then may be replaced by fine sand, clay or gravel. A cross section of the land as seen in cuts in side hills, washouts or wells shows as much if riot more variation. The bottoms of gullies and kettles left by the receding water generally have a blue, black or red clay bottom hidden by a few inches to as many feet of loam or sand. These dense clays formed the bottoms of numerous lakes and channels, many of which have dried out with the fall of water level, but the largest and deepest of which form the present lakes of the township above mentioned. Within a radius of three or four miles of Cloverdale, Hope Township, on the C. K. & S. there are five lakes and several other holes not entirely dry, a fair sample of the latter class being "Twenty-one Lake" west of Cloverdale. The five lakes examined, all of which contained marl, were Long, Bound, Balker or Horseshoe, Guernsey and Pine.

The purpose of the investigation was to study the mode of formation, extent and quality of the marls and clay in and about the lakes, so as to ascertain if possible their origin and their adaptability to cement manufacture. As the marl is supposed to originate in one of several possible ways from the salts contained in underground waters, the relative hardness of spring and well waters surrounding the lake to the hardness of the surface of the lake and its deep water together with its outlet, was determined. This required the collection of samples of water in small fruit jars, which after filling were shipped to the Michigan Agricultural College for analyses. On page 46 will be found a table and key to analyses with a brief enumeration of results obtained. The surroundings of the beds themselves, the nature of the soil, and general impressions as to the formation of the whole lake may throw light upon the changes which may have brought about these curious deposits. These were therefore noted where possible and the conclusions drawn from these facts have been noted in Chapter IV.

To determine depth and outline of marl beds and to obtain samples at any depth the following apparatus was made. It consisted of fifty-four feet of inch pipe (three 18-feet lengths each cut in two making six pieces each nine feet long). Each piece was threaded on both ends and when a coupling had been screwed upon one end of each pipe the whole could be united into a continuous tube fifty-four feet long.

Fifty-four feet of one-half inch pipe was cut, threaded and coupled as above except that the couplings were turned down slightly in a lathe so that when coupled with the half inch pipe, they would allow it to pass freely within the inch pipe. Two shorter pieces (each four feet) of one-half inch pipe were provided, threaded as the others, but each shod to suit solidity of the material to be penetrated. The lake bottoms investigated in this region varied from a fine almost impalpable mud suspended in very deep water to very sandy or very dense clay carbonate. The very sandy and very muddy bottom would be washed off the worm of an ordinary augur. To obviate this difficulty and to preserve the specimens while being hauled to the surface, one of the short pipes was shod with a device which is somewhat of a miniature of a well drivers sand pump. It consists of a cylinder of iron just the diameter of a half inch coupling hollowed out and chisel pointed. Upon one side of the chisel surface a hole is drilled up the center to the hollow, which hollow is the exact size of the inside diameter of the one-half inch pipe. The hole is stopped on the inside by a ball valve, the ball being retained within the cylinder by a wire passing through the cylinder at right angles to its length three-eights of an inch from the bottom of the hollow. A thread is cut on the inside of the upper end of the cylinder making the end with threading just the size of a half inch pipe when threaded. It must, therefore, screw inside a coupling which joins it to the short piece of the pipe. When chugged down the valve allows the soft mud to spurt up into the cavity but when lifted the ball drops down into the hole drilled through the bottom, stopping the egress of the contents through the hole by which it entered. At each fresh downward thrust of the chisel the content of the cylinder increases, rising in the hollow half inch cylinder to the top where elbow or one-way coupling may be screwed on to direct the outflow which may be received for examination.

The other short pipe was shod with an augur, the worm of which was similar to a ship augur, but the stock of which was hollow so as to allow whatever ascended through the worm to pass up into the half inch pipe as in the previous case. When the marl was somewhat solid as was the case when the chisel was used, an iron poker one-fourth inch in diameter was used to shove the specimens out of the pipes. These are the only means so far seen which serve to bring to the surface a correct specimen of lake bottom from any depth. Specimens of lake marl were brought to the surface from beneath several feet of mud and fifty feet of water. The outer pipe serves solely as a protection and support to the inner pipe which is liable to break loose from the couplings when forced to great depths. This outfit while absolutely necessary for scientific research was not used by me in later soundings. Where the marl becomes nearly as dense as a limestone, as in the several instances in the Northern Peninsula, the chisel of the sand pump with a double tube, the outer being shoved down as the inner cuts its way through, is the best outfit that can be used. But as the marl in two-thirds of the cases seen lies on top about like "butter in summer," and at the bottom like "butter in winter," an ordinary 1½ inch augur welded on to ½ inch pipe will retain the marl and stand the strain necessary for numberless soundings. If one man is sounding alone he may use ⅜ inch or ¼ inch pipe, but is liable to bury the lower half of his rod out of reach in some marl bed.

With the outfit first described, which was fitted up in half a day at a machine shop in Kalamazoo, five lakes were examined in five days with a crew of four section men. A raft was made by slightly fastening two boats together with a framework of boards, the two heaviest boards lying parallel to each, other across the boat amid-ship. These furnished a footing and prevented the tip of the boats from pressure of lifting on their inner gunwhales.

Four men rigged a boat raft from a pair of boats and old lumber in about half an hour. They then rowed to any desired position, anchored at bow and stern and made soundings. Specimens were generally taken from bottom and surface of the marl bed at the same spot. Boats and men were then taken to the next lake by team, about a day's work being expended on each lake.

The first lake examined was Long Lake (Fig. 3, p. 14). It is about three and one-half miles long and very narrow, being nearly cut in two by Ackers Point. The C. K. & S. R. R. runs parallel to it and bounds it nearly the whole length on the southeast side. The town of Cloverdale lies nearly all south of the railroad and at the southwest corner of the lake.

The surroundings of the lake are worthy of notice as perhaps having a remote bearing upon the origin of the lake and its contents. The southwest or upper end of the lake is bounded by an abrupt hill or bluff about seventy-five feet high, consisting of a dense till or mixture of tough clay, gravel, and boulders, and crowned by hard wood timber. This hill is flanked upon the south by lower land than on the north, the only land touching the lake being a heavy blue clay, which has flowing beneath it several springs. That on the south forms a narrow isthmus between Long Lake and Round Lake lying to the southwest. A canal or ditch had at one time been dug through this neck of land to a distance of two to three hundred feet, and the fall of water from Round into Long Lake was 16 feet, furnishing water to drive a mill. The surface of the neck of land, beneath which is clay and quicksand, is sand. The banks of Long Lake are flanked on the northwest and southeast sides by high, rolling, gravelly clay hills, which end abruptly at the shore and through which several cuts have been made by the railroad.

The lake rapidly narrows at the northeast, and to its outlet, which is a small creek flowing through a narrow low land into other holes which have once been lakes but could not be reached in any way with sounding apparatus. When the water was higher the whole must have looked like a large river without low lands, with little current, and abrupt shores.

The first sounding was made in the narrow channel connecting the two halves of the lake at Ackers Point. From here soundings were made at short intervals circling the shore to the right and south side toward the outlet, from thence returning on the west side to place of beginning, and from there on the north side of upper half around the upper end past Cloverdale, and back on south side to place of beginning.

The bottom immediately about Ackers Point was of heavy sand and gravel for some little distance out, probably having been washed down from the point over the bed. The first sounding, 40 feet out from heavy gravel shallows, showed a depth of 30 feet of marl, and at the bottom a fairly solid tamarack log, sample of which was bored and torn out, being brought to the surface by the augur.

See pages 18 to 21 for a list of soundings taken, showing depth of water, depth of marl, nature of bottom and analysis number where a sample was preserved for analysis. This number, upon reference to the accompanying table of analysis, will give the chemical constituents of the sample as far as determined.

The sounding No. 1 at Ackers Point was one of the deepest made and the sample taken was among the purest. As the lake widens from the narrows the shallows spread out and divide, following the north and south shores. The shallows extend out from the lowlands on shore perhaps 200 feet, gradually deepening, when there is a sudden jump into deep water, making a shelf much like a sand bar in a river, but not to be expected in a lake. Where opportunity offered, soundings were made on the edge of the shelf and in the deep water outside to determine exactly what was the relationship of depth of water, marl, bottom and true bottom. For the sake of clearness this relationship is pictured crudely by diagrams, which will be referred to by numbers.

Diagram 1, Plate I, shows the shelf as found by soundings Nos. 8 and 10. It will here be seen that the fall of level of the true bottom is more gradual than that of the marl or false bottom as the layer of marl decreases 10 feet. It is not well to form an opinion upon this one relationship, but to watch if it holds true in further comparisons. It is also noticeable that samples 3A and 3B, or specimens taken from Nos. 8 and 9 on the shelf show more sand than No. 10 (4) taken off in deep water. This comparison was made about half way down the lower lobe of the lake. The shallows finally again covered the bottom and joined, making an extensive flat which continued to the outlet. At the head of this flat, and about the center of the lake, was the next object of interest. This was a rocky islet about 40 feet long and 10 feet wide, formerly a cigar-shaped, stony shallow along the center of the lake. The largest boulders are just above water. All are covered with a thick, very soft, white coating of lime, which is fastened to glacial pebbles, covering them all much like a snow storm, i. e., thickest on top and scarcely at all upon the under side, though the stone may be free from others and exposed to the water. The white coating of lime hardens quickly when exposed and dried in air. A cross section shows two layers of granular friable lime, between which is a layer of green organic matter or chlorophyl revealing the presence of living organisms.

Soundings 13 and 21 were made in the mid channel, 13 to the south and 21 to the north of the island, showing conditions on each side of it. With the depth of water the depth of marl is, respectively, 9 and 23 feet, showing that the north channel was originally much deeper, the marl now filling both and making them very shallow.

The conditions thus shown immediately at the beginning of the large shallows at the foot of the lake are interesting. A rocky islet just reaches the surface of the water. From this islet the depth of marl increases from a coating a fraction of an inch thick to 23 feet thick on the north, 9 feet thick on the south, with a shallow channel 4 feet of water. Soundings Nos. 12 to 14 show the conditions in a line down the lake, 12 before the island is reached, 14 after passing around the island in a line toward the outlet. These soundings show again that the island is surrounded in two other directions by 12 and 33 feet of marl. The increase is not, as the soundings would indicate, sudden, but gradual, the island seeming like a bouldery outcrop of the bottom, which is at No. 12 heavy gravel, at the island bouldery, and at No. 3 at 33 again fine lake sand.

Taken as a whole, soundings 12-22, inclusive, show somewhat the shape of the lake bottom under the shallows to the foot of the lake and as far into its outlet as the raft could be propelled. In no case is the water over 6 feet deep, except in the swimming hole near the north bank. Soundings 14 and 17, taken in nearly a straight line, show a deep channel which narrows and runs into the shallow outlet. No. 16, taken to the north and left of these, shows but a trace of sandy marl with a gravelly bottom. No. 16 is more notable, as it was taken from the foot of a hill from which several springs issue. Prodding 50 feet to the south of 16 shows about the same condition, proving that the bed rapidly narrows, but the sudden jump downward in No. 17 shows that the outlet still remains the old channel, though nearly choked up with marl, with no surface muck. Proddings not recorded as soundings show that southwest of sounding 16, returning to Ackers Point along the north side of the lake, the muck and gravel from steep hills encroach upon the bed. The sudden contrast in the nature of the bottom is shown by comparing sample 6 of table, which is a muck from the narrowest outlet, with Nos. 5A and 5B, fair samples of marl in deep or old channel.

Nos. 21 and 22 (Plate I) are again parallel to Nos. 8 and 10. No. 21, the same referred to as north of Rocky Island, was taken just outside the swimming hole. Diagram 2 shows the relative change in depths of water, marl and true bottom. Here the relation in fall of marl and true bottom is exactly reversed as compared with Diagram 1. The marl bottom or shelf is less pronounced than the original shelf made by the true bottom before marl was deposited because the marl bottom is like a thick bottom before marl was deposited, is like a thick blanket taking away the sharpness of the edge and by its own increase in thickness of 8 feet, making the fall less sudden and the lake bottom more nearly level. Still the increase of water from 4 to 16 feet is so immediate that outline of the white bottom seems to sink suddenly out of sight. The original bottom with an almost immediate fall of (47-23) 24 feet must once have formed a bold precipitous terrace or more likely in this case a small deep kettle.

By the above soundings, together with many proddings and examination of bottom in shallow water by the eye, the following general idea of the broad shallows at the foot of the lake and merging into its outlet is given: The bottom of the deep mid lake suddenly rises to form an extensive shallow. It even shows above the water's surface in the stony islet, but slopes down on either side of the islet to form deep channels, the one on the north being deeper (27 ft.), the one on the south 13 feet. The bottom is somewhat uneven and pebbly where it is shallow. On the other hand there are many holes, the largest of which, the swimming hole, is 47 feet deep below water with the bottom surrounding it 27 feet. Besides holes there is a deep middle channel north of the stony islet and running into the outlet. The bottom rises on each side to a pebbly shore covered toward the outlet with muck or sandy marl in very thin layers.

The shore on the north side has the steep hills and springs back of it. The marl lies upon this original bottom covering it, nearly filling up the old channel and hiding all but the deepest hole, which it helps to fill. It, however, forms but a thin incrustation on the rocky islet, but in the channel thickens again to natural depth. It merges into sand and mucky marl (Analysis No. 6) toward shore, but shows admixture of sand even in the deep channel.

Upon continuing up the lake on the north side, leaving the broad shoal, a layer of sand is found between Nos. 22 and 23. But the shoaling marl again thickens on approaching Ackers Point on north side, showing no unusual features excepting that it can be easily seen that the old channel past Ackers Point has been filled to a depth of 30 feet with marl like the channel described leading out of the lake, and also that the marl is much thicker immediately in the narrows and about the point than along the shore down the lake.

From the point opposite Cloverdale the lake widens with a slight bend reaching out to the north toward the only low land. No. 27 was taken to find if the depth were any greater below the springs which emerge from the heavy clay lowland at the north corner of the lake, but no great difference in depth between that and many other soundings taken in the absence of the springs could be noted. The depth and quality of marl here are just the opposite to sounding 16 at the foot of the lake. In this case a fairly deep layer (25 ft.) of marl, with fine sand bottom, was found, while No. 16 showed 2 feet of sandy marl with gravel bottom.

At the foot of the steep till bluff before referred to as forming the boundary of the head of the lake there was a boxed spring (Sample 1, p. 46, taken here). Below this spring the water was shallow and appeared to be a sand bar, but upon investigation from boat with sounding apparatus the marl was found to run almost up to the bluff at a good depth, but the sand has washed over it to such a depth that it was reached with difficulty by the pipes. In coming down the northwest shore, which was described as mostly sand in places where marl was struck, it was found that the marl was interlayed with sand, the augur first sinking through soft marl, then grinding in sand. This would seem to point toward a washing action of the sand over the marl during the period of deposit of the marl. Nos. 28 and 29 (Diagram 3, Fig. 4) were another parallel set (Plate I), showing the position of the marl overlying the shelf, being made close to shore under the bluff arid in shoal water. The soundings were taken as closely as possible to each other and the changes in depth are very sudden. The marl layer again tends to break the abruptness of the descent of the true bottom. The difference in depth of water on and off the shelf being greatest before the deposit of marl, for before deposit the shelf was 24 feet high, after deposit 15.*

Another test opposite Beechwood Point, a short distance below Cloverdale, showed the gradual increase in depth of marl, from deep shoal water in as far as possible toward Beechwood Point, at right angles to the length of the lake. In 50 feet the increase of depth of marl is 5 feet to an increase in depth of water of 1 foot (see Fig. 4, Soundings 31 and 32).

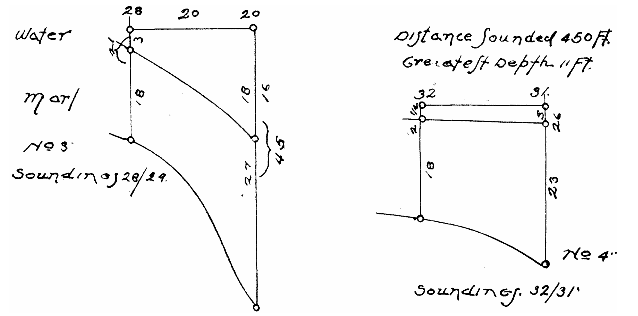


Figure 4. Diagrams 3 and 4, of soundings 28, 29, 31, 32, Long Lake.

The general idea of the lake as given by the foregoing examination is that of a very long, narrow body of water. It consists of two quite distinct parts, the deep water and the surrounding extensive terrace or bar. Over the whole the marl lies as a thick and more or less even deposit which thins toward the shore edges where it is pretty thoroughly mixed with sand, clay or muck. The sudden changes in thickness of the marl layer seem due in greater part to the inequalities in the bottom, which is full of jogs, channels and holes. In all cases excepting Diagram I, the marl in covering the terrace or shelf made by the bottom always lessens its very abrupt descent, being thicker just outside the shelf in deep water than in the shoal water upon the shelf. In this lake variation in the composition of the marl is very marked. In close proximity to the shore the marl is quite thoroughly mixed with sand. This condition extends out one or two hundred feet, as in samples from Sounding 8. Other instances before alluded to show the marl to be layered with sand and next to the very steep hill at the southwest end the sand has washed completely over, hiding the marl.

*(45-21) instead of (18-3), see Fig. 4.

In this lake the marl layer seems to lie heaviest on the south side of the lake. It covers the whole lake bed, including the bottom 45 feet deep at the center, but lies heaviest over the terrace on the south side and has choked and completely filled holes and channels as deep as the mid lake 47 feet (Diag. 2, Plate I). Compare with sounding 10 mid lake, also No. 14 deep channel. A comparison of their soundings shows the former capacity of the lake. On account of the repeated admixtures of sand and muck the duplicate analyses furnish little data for consideration of difference in depth excepting in the deepest sounding, as 1A and B, 2A and B, 3A and B. These, the most nearly pure samples taken show, if anything, an increase of organic matter with increase of depth. There is no doubt that within a short distance of the bottom sand has worked up into the bed so that a sample, though taken with the greatest care, will show high in sand when taken within two or three feet of the true bottom. Here as in nearly all soundings taken during my experience the deeper soundings and the surface samples differ considerably in appearance, the deeper being fine grained, compact and of a steel-blue tinge, which with a high per cent of organic matter, becomes darker.* The surface samples were generally whiter, more flaky in appearance and lighter. No. 4 (Sounding 10) is of interest on account of its position 45 feet below the surface in Mud Lake. Like the other deep soundings it is high in "organic matter" and matter insoluble in HCl. No. 6 is a fair example of the mucky marl of the lake, little of which was found and that at the narrowed outlet. Notice the increase in organic matter and insolubles which far exceeds all but 3B, which was mostly sand. With this increase of organic matter there is an increase of iron and aluminum as there is also in No. 4, the mid lake sounding. This is natural, as organic matter is supposed to aid in the deposit of iron.

*See pp. 16 and 18.

All in all, sand arid organic matter have penetrated this bed from beneath and from the edges. Only in mid lake in the thickest part of the deposit for some distance from the surface down is the marl free from foreign matter. The bold shores and the manner in which the sand is found constantly washed over and against the beds are perhaps good explanations of this condition.

Organic matter as a constituent of the marl is found in largest percentages in the bottom of the deepest parts of the lake.

Mud or Round Lake, as before described, lies southwest of Long Lake, the two being separated by the high clay and gravel hill. This lake continues southwest, paralleling the railroad for a short distance, then winding to the north. The lobe at Cloverdale and nearest Long Lake was examined for marl. The water of its outlet could not be sampled as it was at the other end of the lake, its waters emptying in a nearly opposite direction from those of Long Lake, the hill forming a divide. The hardness of the water as compared with Long Lake, was as 1 to 16, being nearly as soft as rain water. The bottom was heavy gravel or muck with finer sand. Of all the soundings made but one revealed the presence of marl. This marl of poor quality was found 38 feet below surface beneath several feet of silt and by the deepest sounding made in the lake.

Standing at the divide between the lakes the general contour of the bluffs or shores of the two lakes would show Mud Lake to be much higher, about 15 feet according to the fall of water at the mill. The hills about it are not as bold and upon the whole its waters do not so deeply indent the surface of the country. The springs which do not flow from the hills slip out at the shore line, are softer and probably are not from as low a level as those of Long Lake, being mostly surface drainage.

The wells in Cloverdale and those near the two lakes and on the divide were tested. The deep drive wells of Cloverdale were of the hardest water found. The deeper one on the divide was hard, the surface one soft.

As the people's idea of hardness and softness of waters in a given vicinity are very conflicting some method was sought to obtain a definite comparison of waters upon the field.

A standardized soap solution was made in the laboratory by titrating a known volume against a known weight of crystalized $CaCO_3$ or marble, so that every cubic centimeter of the solution needed to make a suds with 50 cc. of water, would imply one degree of hardness,—one grain per U. S. gallon of calcium carbonate or its equivalent.

The soap solution was carried in the field and measured against 50 cc. of spring or well water tested. The figures below, opposite the well or spring located, are the number of cc. of the solution required to neutralize 50 cc. of the water and form a comparative test of the hardness of the water in question:

1. Well, Hotel at Cloverdale	20.00
2. Water of Mud Lake	1.00?
3. Water of Long Lake	16.00
4. Deep well on divide between lakes	16.6
5. Ludwigs (box spring at foot of hill)	12.2
6. J. L. Chamberlain's well west of hotel	16.6
7. Simon Dayton shallower well on divide	8.0
8. Deep drive well Southwestern Michigan	13.

From this it will be seen that the lakes contrast sharply. The deep wells (Nos. 1 and 6) are hard, shallow wells on divide, No. 7 medium, and Mud Lake very soft.

No. 5, the deep spring, is quite hard.

No. 8, from non-marl region, is softer than deep well waters of this locality.

In comparison the waters of the two lakes form, a sharp contrast. It is the settled idea in this part of the country that a hard water lake means marl and a soft water lake the absence of it. Several instances besides this under my direct observation were given me and I have never in my own experience found a lake which tested very soft water to show anything but traces of marl.*

In the case in question Mud Lake is not cut so deeply into the glacial drift as Long Lake. While there is sand and gravel on the edges, deeper there is a clay hard-pan, while Long Lake is in fine sand bottom. On the divide between the two in the wells driven there is said to fee a heavy clay layer. Under these circumstances the only explanation to be seen is that Bound Lake receives the surface drainage of soft water and is withheld front seepage into Long Lake by a clay hard-pan. Long Lake cuts deeper into the drift and receives the hard water springs and drainage from the same layer as the deeper wells.

*See analysis of Goose Lake water, of Peninsular P. C. Plant.

The next lake tested (Pl. II) was Balker or Horseshoe Lake. It lies about two miles east of Cloverdale and a mile in direct line at right angles to the C. K. & S. in the N. E. ¼ of Sec. 22 of Hope Township. It draws one of its names from its shape. It has two lobes or arms and a basin into which both empty and from which issue its outlet. All the attention was devoted to the south lobe and basin as a raft and tools could not be propelled into the north arm on account of the shallowness of the channel which was filled with marl, covered with a few inches of water. The two arms, like the sides of a horseshoe, are surrounded by a low marsh covered with tamarack, a good part of which must have recently been covered with water as it is but little higher than the lake surface. The south arm as it now exists is nearly round or elliptical in form. The east end consists of a large and very shallow flat upon which the first soundings were made. This flat leads into the basin by a narrows almost choked with marl. Here it is well to remark that the marsh vegetation characteristic of marl flats in general is a long cylindrical reed without leaves or branch, which shoots up many feet from a marl bottom or grows in very shallow water, as in this case, where it almost blocks passage of a boat. It is true that this reed* is found to greater or less degree on sandy or mucky bottoms, but it is one of the few practical guides to the location of marl, though like all others never entirely trustworthy.

Except for the shallow flat mentioned the rest of the lake has the shelf-like bottom already noted, the shallows forming a ring but 20 or 30 feet wide about the abrupt descent into deep water. Soundings were made on the edge of the shallows and across the lake from two sight points to determine if possible the profile of the bed or its cross section as cut across the lake. Before describing the various soundings it will be well to notice that the lake proper, which so far as determined is underlaid with a deep deposit of marl does not cover anywhere near all the depression lying between the steep bluffs. The lake as a whole more deeply indents the surface of the country than does Long Lake. The bluffs are steeper and more abrupt, the springs are noticeably larger and more numerous especially near the lake proper, which lies horseshoe shaped, curving around the south and west side of the valley, the remainder of which is covered with low tamarack marsh. The springs are also of harder water.

*Scirpus lacustris? L.

The soundings were begun at the approach to the narrows in the south arm. The bottom as at Ackers Point, Long Lake, rises at the mouth of the narrows into a flat shallows. Soundings 33 and 34 (Diag. No. 5) were taken approaching from the center of the lake toward the shallowest place in the narrows leading into the basin. The distance between soundings is about 50 feet, and while the depth of water remains the same, original bottom sinks 7 feet, i. e., the depth of marl increases that much. The real bottom of the lake is the opposite in incline to false bottom. This is paralleled in Long Lake where the narrows at Ackers Point, though choked with marl, were nearly as deep as the remainder of the lake, as the false bottom has a gradual incline, riot terraced like the sides, but built up by marl. This is true in the east shallows of the lake, but not true of terraces on north shore. (See Diagram No. 6.)

The next surprise is the relation of 36 and 37. No 36 is taken on the usual terrace and 37 just outside (see for slopes of bottom Diagram No. 6). Here the depth of original bottom is less by 3 feet toward the center of the lake than on the shore terrace. As this shore was lined with marsh it is hardly possible that the marl extends in a perpendicular bank against an opposite solid bank or shore, but in all probability the marl layer extends out a great distance under the marsh. This could not be determined, but this must be inferred from a comparison of the soundings of the other terraces before made. I know of no possible explanation of the almost immediate drop of level (29-15), 14 feet in thickness of marl bed unless currents of long ago where different water level and direction of drainage may have cut marl out in some places and filled in others. (See Fig. 5, Diag. No. 6.) From this short point, upon which No. 36 was taken, the line of the soundings was continued straight across a slight neck in the lake to the neighborhood of springs on slightly higher ground. No. 38 showed increase in depth of marl again. At No. 39 a sample of water was taken by lowering a corked jug to the bottom, pulling the string allowing it to fill and at once raising to the surface and putting the water into the fruit jar which was sealed as usual. (Analysis 5, page 46.)

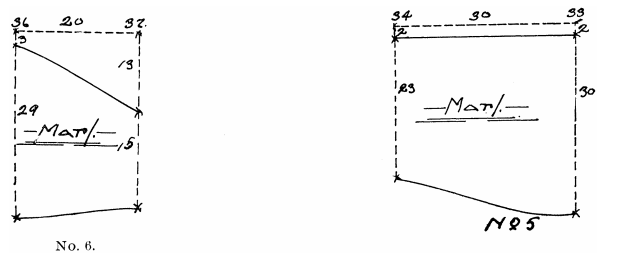


Figure 5. Soundings 33, 34, 36 and 37, Horseshoe Lake, T. 2 N., R. 9 W.

No. 40, the deepest sounding anywhere made, was interesting both from what it revealed and left buried in obscurity. All the pipe in the apparatus was used without touching the original fine sand bottom of the lake. At the depth of 60 feet the sample which was almost fluid was retained by the sand pump and is shown in Analysis 9 of the table on p. 20. This analysis shows the highest per cent of Fe_2O_3 and organic matter of any taken in the lakes. There was no clay and comparatively little sand as shown by the low per cent insoluble. It is also lacking in $MgCO_3$, showing a decidedly lower per cent than the rest of Horseshoe Lake. This, as may be noticed in later soundings, is not the only lake in which the marl of the deeper portions gains greatly in organic matter. But such an increase in iron has not been elsewhere noticed.

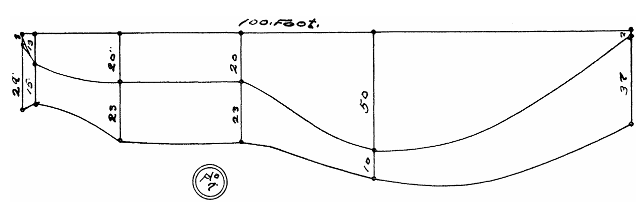


Figure 6. Section showing Soundings 36, 37, 38, 39, 40 and 42 of Horseshoe Lake.

Sounding 41 was a little to the east of the foregoing series, at the mouth of a very large spring. This spring emptied from beneath a bank at some distance back from the water's edge and by a small rill into the lake. The boats were shoved in as far as possible and a sounding taken in a few inches of water. The pipes sank with little effort to a depth of 32 feet. The sample from the very bottom was like that at the top, a fine silt with a trifle of lime which could be faintly detected by acid. The spring formed a large reservoir 8 feet across and 5 feet deep. At the bottom was its fountain a foot across and boiling up through black silt. The analysis of this sample of water is No. 4 of page 46. The peculiar phenomenon here witnessed was that one of the largest and hardest springs should show no trace of marl immediately in or at its outlet.

But next comes Sounding 42, made perhaps 50 feet to the west and completing the outline series, the whole of which are set forth, making a cross section of the lake bottom as shown in Fig. 6. Sounding 42, but a short distance from the spring and within 25 feet of solid ground, a bank about 15 feet high, showed marl to 37 feet depth, the deepest sounding anywhere on the lakes.

And here it is well to remark that Horseshoe or Balker Lake had the uniformly thickest layering of marl of any of the five. It in fact was so thick that its nature was difficult to discover on account of the slowness and labor in making deep soundings. Whatever the agents were by which such a bed was laid down they should be apparent in so thick a bed. The springs were large and their water hard, but no visible connection between the water of the springs and the marl of the lake could be discovered. The largest spring and its immediate vicinity were free from all but traces of lime. A very deep layering, about same depth as marl, of silt replaced the marl in and about the spring and at its outlet. The interesting phenomena apparent on the Rock Islet in Long Lake, namely the thick lime coating of the pebbles, was again manifested in a part of the lake at the shallows at the foot of the lake next to the narrows leading into the basin. This shallow area covered several acres and was from 1 to 2 feet in depth. The marl layer as shown by the first two soundings varied from the center in toward the narrows from 23 to 30 feet in depth. In an ordinary marsh, especially in the reeds or rushes, the bottom is black or dark-brown from dead rush, twigs, silt, and other marsh accumulations, but the bottom here, even in the reeds which ought to catch and hold everything that came to them, was gleaming white marl. In fact it was very much lighter in color than the specimens at the bottom which were in almost every case steel-blue in color. This color with a lack of a trace of organic matter at the surface was in this particular case perhaps explained by a more minute examination of the bottom. A branch of a dead tree leaned over and where it touched the water disappeared from sight. Upon following it beneath the water's surface it was found to have become coated with white lime covering, essentially the same in structure and appearance as that of the pebbles in Long Lake. There was the same triple coating of green or chlorophyl between the layers of granular lime. In the distribution the lime reminded one of the limbs of a tree after a snowstorm, the greatest thickness of lime being on top and scarcely any underneath. This coating was not confined to twigs, but included anything that had fallen into the s water, all being covered so that they lost their identity and blended closely with the brownish white bottom.

The last portion of the lake investigated was the basin. This basin is nearly circular in form, is shallow and overgrown with round rushes at the margin and increases gradually to about 10 feet depth at center. Its waters, clear as crystal, lie over a very deep bed of marl. It has three arms, one leading from the north arm of the Horseshoe Lake, one from the south arm and lastly the outlet or creek. All are so overgrown with rushes and choked with marl that boats are forced through with difficulty. The soundings made and marked in the list make the average uniform depth of marl about 30 feet. The clearness of the water can perhaps be accounted for by the fact that every particle of foreign matter, organic or otherwise which might find its way into the pool, seems to be surrounded and buried by the lime as described in the case of twigs. Whether the lime or marl be precipitated carrying down the organic matter with the marl or whether the particles attract the lime by the assimilating action of minute animal or plant organisms one result is here obtained. The water is left so pure and clear and free from foreign matter that fish or water plants can be seen entirely across the basin. Here it is well to remark that the bottom was overgrown with a plant much in appearance like a small pine tree. In the middle of the lake sound at 40 feet, a deep water plant was brought us, smelling exactly like a pole cat.*

The best samples of Balker Lake were not analyzed. The very deep samples were tough and steel-blue, were evidently high in clay and organic matter, but on the whole not so sandy as those of Long Lake.

As will be seen by descriptions on page 46, samples of water were taken from two springs, from the deepest part at sounding 41, from the surface and outlet of the basin and it can be easily seen that on account of the intensely marly nature of the lake its waters should reveal something of the marl's origin.

It is impossible to reconstruct the lake as it once existed. Its bold shores and large marsh hint at a far greater depth and volume of water with currents which may have done something toward disturbing the evenness of so thick a layering of marl.

*See pp. 56, 89.

As in reality a small portion of the whole bed was examined the rest lying under the adjoining marsh, the cross section (Fig. 6) is rather incomplete arid the individual soundings do not show the pronounced relations between true and false bottom. Attention is especially called to the sounding mid lake, which shows the remarkable difference in quality of the marl in the deep water, as it contains much iron and organic matter and only about half calcium carbonate. It has been suggested as an explanation that the organic matter of the lake upon account of the dish-like shape of the lake tends to slide into the central or deeper portions, giving them a more highly organic character.

It was especially noticeable that Long Lake contained a more caustic marl than Horseshoe Lake. In Long Lake the hands of the operators were severely chapped and seamed, while this was scarcely noticeable in Horseshoe Lake. The marl did not seem to bite.

A review of the springs of Horseshoe Lake hardly seemed to justify the theory of immediate precipitation of lime. There was no trace of marl in or around them although at a distance of a few hundred feet the deepest marl was found. Upon the whole this lake is very deeply indented in the surface of the country, having high, steep bluffs. The portion covered by water has a steep terrace or shelf, less shallows than Long Lake, with a deeper and larger lake center. It has a thicker, more homogeneous marl with considerable organic matter distributed most largely toward a somewhat clay bottom.

The next lake visited was Guernsey. This lake lies northwest of Cloverdale about 1½ miles in Secs. 17, 18, 19, Hope Township. Its two long lobes form like Long Lake what might have once been an old river valley. This is continued by a rather narrow marsh and creek forming an outlet. This marsh, several miles away, is said to contain bog iron.

The lower lobe only could be examined, as it was impossible to get the raft through the narrows between the lobes. The lobe examined appeared something like a mitten. The wrist forms the extension, shallows and narrows leading to the north arm the hand. The main body of deep water is fringed with shallows. The thumb to the west was a long lagoon lying in marsh. The south end was all sandy bottom destitute of marl. Yet the usual terrace was there and so close to shore that teams must be careful not to drive in far for fear of suddenly slipping off the shelf into deep water. A spring was found near the south end, of which the water was sampled in jar 9. (See page 46, Chap. IV.) A small deposit of iron was on the vegetation, but no trace of lime could be seen in the vicinity of the spring. As proddings were made from time to time up the east side of the lake a sandy marl was found which increased to a depth of several feet as usual at the approach to the narrows. There were broad flats or shallows which, being covered with marl, gave the neighboring fishermen the idea that there must be an extensive deposit of marl. Upon actual sounding it was found that the flats were covered by 1 to 3 feet of water, beneath which was 3 to 4 feet of marl and below this a tough, almost impenetrable blue clay bottom. The lagoon opening on the west side, described as the thumb, contained nothing but fine silt to a depth of 25 to 30 feet. It seems queer, but is a fact, that upon the west side of the narrow tongue of marsh dividing off the lagoon there should be pure silt of the ordinary marsh or river formation, while upon the east side in lake proper there were 20 to 25 feet of the best marl in the lake, the bottom also in the latter case showing strict terrace formation, which was tested in the usual way by Soundings 49 and 51. In this case the bottom was found nearly level and about the same depth beneath water level as that in the lagoon. West of it the difference in the terrace was, in this, the first instance cited, caused by difference in thickness of marl layer. But this is a very slight terrace. Compared with real ones previously examined there is but a four foot fall. This could have easily been displaced or washed over the sand, which is further south and to which it sinks. An examination of analyses 12A and B, 13A and B, and 14A and B shows a very interesting condition of the bed. The surface samples, 12B, 13B and 14B show by far the higher lime and in every case a much smaller percentage $MgCO_3$, but far the higher percentage organic matter and lower percentage insolubles. In other words the marl is at the surface fair marl but with considerable organic matter, but at the bottom it merges into a blue clay which of course is higher in insolubles, higher in $MgCO_3$ and much lower in organic matter, except in case of 14A. The $MgCO_3$ is not very high, and as the clay is very fine grained, if not too deeply buried, it could be used mixed with the marl for factory purposes.

14B is one of the best samples found in the lakes and was taken in Sounding 32.

To recapitulate the important features of this lake. It is long and river-like, undoubtedly one of the old glacial valleys like Long Lake. The layering of marl lies toward the west side of the south lobe, is underlain by blue clay, is from 2 or 3 to 28 feet deep, is not as uniformly thick as Horseshoe Lake, does not cover the whole lake, is flanked upon the west side by a deep lagoon filled with silt. Its springs show no unusual trace of marl. It does not indent the surrounding hills very deeply, being the shallowest placed lake so far visited.

The next lake examined was Pine Lake. This lake, north of Cloverdale, is in Sections 8 and 9 of Hope Township. The portion covered by water when the lake was examined rendered its outline very different from that given on the county atlas. It consists of three large lobes, the narrows of which were larger and less obstructed than any so far visited. Time permitted only the examination of the south lobe and its connecting narrows. The first sounding was made at the cove or landing where stock and teams are driven and row-boats usually land. The surface of the marl is muddy, which is an unusual occurrence not found elsewhere in the lake. It may be due to the constant roiling at the water's edge. The next sounding was made across that end of the lake at a large boiling spring. This spring was about a yard across and its location was marked by a large number of bubbling fountains which boiled up through the marl 10 feet thick. This is the first case where marl was found in or about a spring. The analysis of this marl (No. 17) shows it to be remarkably free from sand or clay, but quite high in organic matter. Although the bottom from which the spring came was fine sand like the rest of the lake, and although the water was washed up through it and the marl, the ascending stream seems to have no power left to mix the sand with the overlying marl.

As the remainder of the south lobe presented no unusual appearance, a series of soundings were made across the first narrows, which were perhaps 100 feet wide. These soundings are numbered from 3 to 8 on the record sheet. Figure 7 shows the cross section of the bottom as platted from the soundings.

By this it is seen that from Sounding 3 to Sounding 7 there was a deep original channel nearly filled with marl except where gouged out in the center of the modern narrows. On the west side Sounding 8 shows another channel almost entirely filled with marl. As the true bottom shows no sudden terrace or shelf so the marl or false bottom, though it slopes to form the deep depression of mid-channel, does so gradually without the sudden step or terrace formations. To appreciate this compare true and false bottom here and in Diagram 3, Plate I. From the way the marl lies it would appear worn away in mid-channel. It would be unfair to establish this as a fact as the marl might have formed more easily about the side or points forming the narrows and so have built out into the channel.

The samples taken from this lake are analyses Nos. 16, 17 and 18 A and E, 20A and B. They average better than those of other lakes of the group. The first, No. 1.6 (Sounding No. 1), is the poorest. Though taken about 30 feet from shore and at a depth of 20 feet, the sample contains considerable sand which has evidently worked out from the shore. This is shown by a high per cent of "insoluble in HCl." The surface was before described as being covered with organic matter, the only black bottoms on the lake and probably due to the landing.

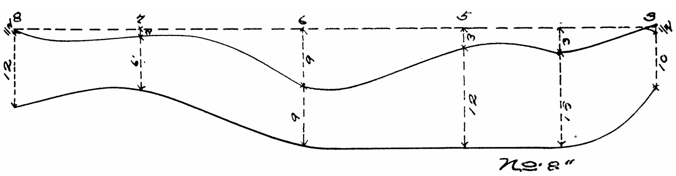


Figure 7. Section at Pine Lake, soundings 3 to 8.

No. 7, taken in front of the boiling spring at 10 feet depth, shows a very high per cent of organic matter though otherwise light in Al_2O_3, Fe_2O_3, insolubles, and $MgCO_3$. The especially low percentage of insolubles and Al_2O_3, Fe_2O_3 are interesting, as the sounding showed the spring boiled up through a 10-foot bed of marl. At the bottom was fine sand. This sand was not mixed with marl as would appear natural, but the sample taken was unusually free from insolubles as the first column indicates. Again, this sample is the freest from Fe_2O_3, Al_2O_3 of any taken. The spring then left none of its iron in passing through clear marl, but carried it away in solution. Near by there is an outlet to this lake and this outlet, several miles away, contains a large deposit of bog iron ore though within the immediate vicinity there is no trace of it and the samples are free from all but slight amounts of iron and alumina; .8% to 3½%. In 19, 20 and 21 both surface (B) and deep (A) samples were taken. These samples belong to Soundings 5, 6 and 9, respectively. (See Diagram No. 8.) These soundings form part of the cross section of the narrows and are about 20 feet apart. Some investigators have thought that deep samples show higher percentage of magnesia than do shallow, so it was thought advisable to compare analyses of surface and deep samples in order, if possible, to arrive at a conclusion as to the increase in percentage of magnesia. Such a conclusion might assist in tracing the origin of marl. In the three pairs of analyses, 18, 19, 20, the first two show the highest magnesia at the surface while 20 is a little in favor of the deep samples. In two cases out of three, 18 and 20 against 19, the organic content is the greater with the increased depth. In all three instances Fe_2O_3, Al_2O_3 is highest in deep samples. In 19, where the organic matter varies least with depth, Fe_2O_3, Al_2O_3 varies least. This sample, Sounding 6, is, however, but 9 feet in depth, giving the least distance of any of the three soundings sampled, between surface and deep sample. It is noticeable that there is less variation in any of these components than in the soundings where distance between samples is greater. In two out of three the insoluble matter is highest in the lower sounding. In comparison of future samples from different depths it will be well to keep in mind the mutual relation with varying depth of the samples in order to find if possible the constant variation in composition of a marl bed. This would be of little aid to the factory chemist as the dredge makes a clean cut from bottom to top, but may assist in our scientific research for the origin of marl.

For the sake of clearness and to give some system to the perusal of further descriptions it is thought best to review the work upon the five lakes so far discussed.

CLOVERDALE REGION—SUMMARY.

Long Lake is covered with a sheet of marl varying from 20 to 30 feet in depth. The bottom of the lake is not level and even, but has a more or less regular terrace on the south side, a deep channel which runs from mid lake under the marsh at the present outlet, narrowing at the same time to a width of thirty or forty feet. This channel, which forms the deeper portions of the lake, is choked at Ackers Point, about mid-way and the lakes outlet, with a depth of marl of about thirty feet. At a depth of twenty-five feet of water in mid lake there is twenty feet of marl, showing that the bed thins in water of that depth.

Besides the main channel there are many sudden holes in the outline of the original sand bottom, and also a sandy islet where pebbles and stones crop out at the surface. To each side of this islet the channel, while it is not as deep as toward the outlet of mid lake, is filled evenly with marl. The depth from surface of water to original bottom is, on the north side of the island, 27 feet, on the south side 13 feet, while the depth of water is four feet in both cases.

The accompanying map of the lake and cross sections of the bed are made to show the manner in which the marl is deposited upon the terraces. The effect of the marl in all cases is to round over and fill up holes. It deposits sparingly upon the rocky islet and fills the channels to each side. It thins toward the center, but produces a less sudden descent from the terraces than would have been found on the original bottom, before the deposit of marl.

The deposit lies evenly at both ends, and along the southeast shore, but is thin and persistent only at points which project from the northwest shore.

The lake being three miles long and but a few hundred feet wide, and having high gravel and clay hills, is very subject to washings of surface soil. Its composition is heavily influenced by sand and clay rendering it of little use for factory purposes.

The waters flowing into the lake by its springs are very hard, as were also the deep drive wells of the immediate vicinity. The lake adjoining, called Mud or Round Lake was remarkable for its contrast. It apparently received the soft waters of surface seepage, was clearly of higher level, with sand, clay and mud bottom. A trace of marl under several feet of muck was found in thirty-five feet of water. The saying that "hard water makes hard marl" was very well exemplified in these two lakes. From a view of the two so close together, yet so different in their content of marl and the hardness of their waters, it would appear that Mud Lake indented the surface of the country less and did not receive the drainage of the springs from the deeper strata of soil. Its surface is about fifteen feet higher than that of Long Lake and the ditch connecting the two lakes had furnished water fall sufficient to run a mill.

Horseshoe Lake (Plate II) contains the deepest and most actively depositing bed of marl and the deepest of any of the lakes investigated in this region. The lake as it now exists encircles a portion of the whole basin in the form of a horseshoe, the remainder being covered by marsh. The largest and most intensely carbonated springs and lake water were found here.* This lake, running from 20 to 37 feet of marl on shallows. It also shows the same tendency to fill the sudden step made by the greatly increasing depth from the shallow terraces to deep water. In this deposit the greater variation in composition resulting from increase in organic matter, is seen every time a deep and a shallow sounding are taken in the same spot for comparison. The great coldness of the deep water of mid lake is sharply contrasted with the luke-warm water of the shallows. The great abundance of plant life in shallow water and the thick incrustation of every object covered by shallow water are very striking, as are the absence of incrustation plants from deep water.† This is the remainder of a very large deeply indented lake basin, which has held the hard waters of its deep springs for many centuries. Nearly all the basin is sealed by marsh growth. The portion remaining consists of the waters of Horseshoe Lake, which are actively depositing the best grade of marl at the surface of its shallows.

The portion of Guernsey Lake examined is remarkable for its strictly local deposit of marl. The thumb described contains very good marl on its east side and a corresponding depth of loose lake silt on its west side in the lagoon. On the one side the particles of silt are surrounded by the deposit of marl, making a marl bed with 22% calcium carbonate at bottom and 64% calcium carbonate at surface, while on the other side of the tongue of land fifty feet away there is a deposit of twenty to thirty feet of pure silt. At the head of the lake there is no marl at all, though there is a terrace and a spring of water containing 130 parts in the million of calcium carbonate, which is a fair average. It appears from this that conditions are not always favorable for the growth of marl, given the same kind of bottom and the same water. True, the conditions are not exactly identical with those of the deep deposit at Horseshoe Lake. The springs are not so plentiful or of such hard water. The sandy spot alluded to is bare and unsheltered.

Pine Lake shows fairly hard water, a good deposit of marl over the entire lake and not as great difference in content of organic matter as Horseshoe Lake or Guernsey Lake. This was a case where a spring bubbled up through ten feet of marl without bringing sand into its composition or otherwise affecting its quality. We must conclude that the immediate locality of springs has no effect upon the position of the marl either in regard to depth or quality.

The samples of water taken are interesting only from one point of comparison. For the whole list of samples and analyses of some, see page 46, Chap IV.

$CaCO_3$ COMPARED IN PARTS PER MILLION.

Springs.	Wells.	Surface.	Water medium deep.	
Horseshoe 200, 160		70	100	117
Long Lake 100	160, 156	40		
Guernsey 130		40		
Pine Lake 170, 136				80
Mud Lake 80		30		53.6

From these comparisons and those made with soap solution in the field, it appears: that the most intensely marl lakes have the most heavily carbonated waters, the soft water lake showing much poorer in all cases; that in the lake itself, the deep water contains the most gas and carbonates and that they uniformly disappear in every lake at the surface, the gas being lost entirely and the carbonates in a fairly even proportion. These well, spring and lake waters substantiate the idea that the water's hardness is responsible for the presence of the marl in a somewhat direct ratio to the strength of the carbonates it contains.

*See Nos. 4, 8 and 5, page 46, Chapter IV.

†Wesenberg-Lund.

§ 3. Pierson Lakes.

I visited Big and Little Whitefish Lake, southwest of Pierson three or four miles, Pierson Township, Mecosta County.

The general outline of the land is a rather monotonous level, but in the neighborhood of the lakes it is considerably broken, but not as much as at Cloverdale. Big Whitefish Lake is about three miles long by a mile wide. Its shore level sinks into extensive shallows consisting of somewhere between 20 and 30 feet of marl. At near the center a "blind island" rises from the very deep water and is covered by about 25 feet of marl. Blind islands are met with often in these lakes. They are small shallows in the deep water of mid lake. There are large flowing springs along the shores of the lake. These springs deposit iron upon the stones and vegetation at their borders^ but the marl in the lake below them appears to be unaffected by iron coloring. One spring at the south end gave marked smell and taste of sulphur and was valued highly for its medicinal properties.

At its southeast corner the lake is bounded by a sandy ridge containing gravel with fossils and granite boulders. Beyond this ridge, perhaps 200 yards to the east, is a deep hole or smaller lake, about 200 feet across. This is fed by intensely irony springs and empties by a deeply cut creek into the larger lake. The sudden fall gives about ten feet of water fall for turning light machinery. The creek is very interesting. Its bottom is composed of marl which continues up its steep bank 20 or 30 feet. About half way to the top of the ridge upon the sides the marl is shown on the uprooted stumps of large forest trees.

Between the two bodies of water mentioned is a kettle not as deep, but with sides so steep that there was some speculation as to whether the Indians had not dug it out to make their mound which was on the ridge to the east. Upon examination a crude marl was found in the bottom of this kettle under a few feet of loam, showing that it, with the low ground adjoining, had been under water. It looked as though the three, the larger lake, the hole and the kettle between had once been one and that the creek bed was once but a connecting channel.

A bed of clay was examined on the farm of Mr. Shanklin some little distance from the lake. The clay bed was covered by 2 or 3 feet of red and yellow ochre, which had at one time been dug for paint. An augur was used and the ochre and clay bed beneath penetrated to the depth of 10 or 12 feet. The samples brought up showed a fine clay which reacted feebly with acid, but was in most cases mixed with sand, which seemed to run through the bed somewhat in layers, there being found several samples entirely free from grit.

Little Whitefish Lake, two or three miles from Whitefish Lake, was visited briefly and a few soundings made at the south end. Here there was a swamp at the southeast corner which was probed to a depth of 15 feet without striking anything but silt. The marl upon this side seemed slightly red or brownish in cast, but at the west side it was much whiter. The marl was (28 ft.) deeper upon the points or shallows running out from the shores and of the prevailing consistency. North of the marsh and jutting almost into the lake was a bluff showing 25 to 30 feet of clay which was nearly like rock, of light color and was calcareous.

§ 4. Lime Lake and vicinity.

The lakes about to be described are near Cedar Springs in the northern part of Kent County. The country through which our guide led us showed very distinctly the effects of the glacial action. Steep hills, waterways, creeks and small lakes produced a very undulating surface. The first fact worthy of notice was very strikingly illustrated in the examination of road cuts in several side hills. These hills were generally coarse sand which was thoroughly seeded with small pebbles and boulders. At varying distances up their sides, clay strata projected slightly, or their exposed surfaces were worn down and hidden by sand and gravel from above. These clay banks are typical of half the clay in Michigan. In color it is light or ashy gray. Its texture or grain is ruined by the admixture of fine sand. Upon addition of acid it effervesces more freely than many samples of marl because it contains so high a percentage of carbonates of calcium and magnesium. Upon a further examination of the bank or hill the carbonated condition of the soil is found to continue not only in the clay, but also in the loose and apparently pure sand as, upon contact with acid, the surfaces of the sand grains freely effervesce.

Parallel with the stratum of clay are often found small ledges or boulders of a matrix of coarse sand in which are cemented small pebbles. The upper surface is even as if smoothed by the leveling action of water, although the rock, as it has now become, is fifty feet above the level of a stream and buried in a hill. The lower surface of this rock or tufa is uneven and jagged. Upon the addition of acid to this rock it also, as in the case of the sand and clay, bubbles with escape of gas, and the particles of sand and the pebbles fall apart showing that the matrix or binding element is not the insoluble sand, but the very soluble carbonates.*

A comparative test for hardness was made upon the springs and creeks of this region during the trip and all were found to be very hard. Lime as a carbonate was found to permeate very thoroughly the soils of the whole district, and the soil mixing effect of glacial action was very marked.

*A similar recent sandstone occurs beneath the clay bed at Harrietta. L.

Lime Lake.

The first lake visited in this region was Lime Lake. An old kiln was still to be seen marking the place where marl from the lake had once been burned for lime. The lake as a whole made a very sharp and deep indentation or circular hole in the plain of the surrounding country. The shallows on its shores formed a white but narrow margin ending in an abrupt terrace and very deep water toward the center of the lake. The shallows, the dry land of the valley, and the broad entering valley of a small creek, formed a solid body of very white marl from fifteen to twenty-seven feet in thickness. Shells, large and small, constituted nearly the entire body of marl even at the greatest depth and they preserved their form perfectly. This is certainly one instance, at least, in which shells can furnish nearly if not all the excuse for the origin of marl.

Several samples of marl taken a few feet below the surface, upon drying, turned from nearly white to a pronounced red. This was very likely due to the oxidation, upon exposure to air, of the ferrous or nearly colorless iron to the ferric state in which the color is red. The valley opening into the lake from above was very large and probably once formed an old glacial valley. It connects Lime Lake with several higher ones and is a pure marl bed with but slight covering of surface soil.

Twin Lakes.

These lakes were remarkable for their great contrasts with each other. They had no visible union, but they were said to connect with each other by an underground channel. The lower one was shallow and sandy, the upper one was a hole between huge banks which, in cuts made by washouts, were almost identical in nature with the sand hills before described. Its banks or bluffs, fifty feet high, descended with but a step for a shore line, directly into water, making no shallows whatever. So abrupt was the descent to the bottom that one standing on shore could shove a pole out of sight in the water without touching bottom. The lake is said to be one hundred and seventy feet deep, according to the measurements of the Fish Commission. The springs emptying into the lake formed a glistening scum of iron. This lake is a very good example of the hundreds of holes made by glacial action and without which we could not have the conditions necessary for the formation of marl.

§ 5. Fremont District.

Fremont Lake and the town of Fremont are situated on the Pere Marquette railroad in the northern part of Sheridan Township, Newaygo County. The country surrounding the lake is rather level and the lake makes but a slight indentation in the surface. In sharp contrast to this the lakes in the hilly country before examined seemed to depend for the depth and extensiveness of their deposits upon the comparative depth at which their basins were sunk below the level of the surrounding country. Fremont Lake has a very shallow basin and it therefore differs entirely from the regions before mentioned.

The map of Fig. 8 represents Fremont Lake or the portion of its basin covered by water. The dotted line encloses that portion most available for cement purposes. The depths of marl soundings are shown by the figures. The drawings together with the accompanying analyses were kindly loaned us by Mr. John Cole.

The lake examined closely on the side toward the town shows marl shores covered partly with sand. The shallows which are very extensive extend out toward the center of the lake as long, parallel peninsular shallows. The change from shallows to deep water is very abrupt, even between the peninsulas. These abrupt changes are very similar to those at Cloverdale. The soundings in this lake show the shallow marl toward deep water. Soundings of eighteen and twenty feet are found toward the center as contrasted with thirty-four feet at the inside edge. There is a blind island in the center of the lake which brings within reach much valuable marl.

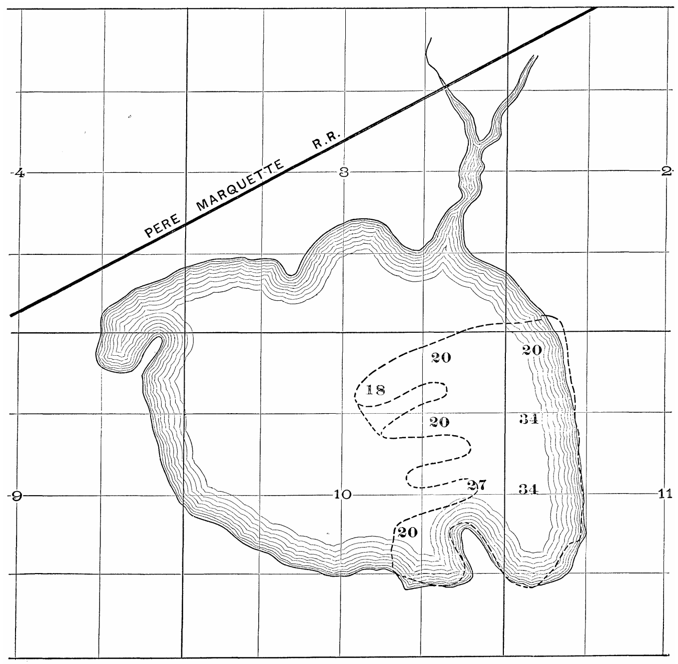


Figure 8. Fremont Lake, Newaygo County.

The lake is to be the site of a fourteen-rotary cement plant to be run by power transmitted from the other factory to be built at Newaygo.

The peninsulas above mentioned are covered with from one to three feet of water, the marl has no covering of organic matter and supports a thick growth of the cylindrical rush known as marsh-rice which is so prevalent as to be almost characteristic of marl beds.

The analysis of the sample of marl by Prof. Delos Fall of Albion was as follows:

Silica	2.28%
Aluminum and iron oxide	1.60
Lime	88.25
Carbonate of magnesium	1.40
Organic matter and undetermined	6.47
Carbonate of lime after the removal of organic matter	94.85

Beneath this marl lies a blue clay which was analyzed to determine whether it would be of proper composition to mix with clay in the manufacture of cement. It was found that the clay directly underlying the marl contained over seven per cent magnesium oxide, which was considered unsafe. The startling fact from a scientific point of view is the sudden variation in content of magnesia in the marl and in the clay immediately beneath it. 1.40% magnesium carbonate equals .7% magnesium oxide and the proportion of the oxide in the marl to the oxide in the clay beneath is then, as .7 to 7. For this reason either a totally different agent or the same agent, with greatly varying power, must have controlled the deposit of magnesia in the marl and that beneath it in the clay of Fremont Lake.

Mr. Cole showed me another clay from a different part of the country, which was to take the place of that just mentioned. It appears as a dense blue shale and the following is the analysis as given to me by Mr. Cole (chemist not known):

Silica	42.94%
Alumina (Al_2O_3)	12.94
Oxide of iron	5.73
Calcium oxide (CaO)	12.93
Magnesia	2.97
Loss by ignition	18.94
Alkalies (sulphuric acid, etc.)	4.07

There were said to be numerous hard water springs in the vicinity. A drive well near the station was examined and showed very hard water. A well bored near the lake failed to strike anything but marl till at a depth of thirty feet it penetrated a limy clay. The clays of this region are very calcareous.

§ 6. Muskegon District.

Bear Lake just north of the mouth of the Muskegon River, was visited and probed for marl. It appeared after investigation that Bear Lake was but the old mouth of a river. Muck and silt to the depth of 35 feet was found, but no marl, excepting at one place. Near its outlet was a streak of clay at right angles to the outlet and to the mouth of the Muskegon River. This clay was found to run under the lake and above it. and beneath the silt was a foot or two of genuine marl. Several soundings were made at the mouth of a creek emptying into the lake and also in the rushes at the head of the lake. The bottom was in every case a foundation of fine sand covered by many feet of silt.

The Muskegon River flats were said to contain marl and several samples were submitted to me by Prof. McClouth of the Muskegon High School, but nearly all of them showed an intimate mixture of clay, sand or muck with the marl demonstrating nicely what has usually appeared, that marl generally loses its individuality and becomes an admixture of marl with sand, clay or muck in the neighborhood of running water.

§ 7. Benzie County.

Benzie County contains a number of marl lakes, several of which are drained by the Platte River.

Also a company was formed to work the marl in Herring Lakes, five miles south of Frankfort. These two lakes are connected by a stream which has a waterfall of 15 feet. This is to be obviated by cutting a canal through a bend in the creek partly draining the upper lake. This lake contains a deposit of marl about 30 feet in depth. It is fed by numerous springs, which form a network of creeks. To the east the lower lake is very deep and is connected with Lake Michigan by a short channel which is to be deepened for the entrance of large lake boats.

The bluffs of clay about Frankfort were examined for a cement clay, but none was found. Some clay was quite free from grit, but all was highly calcareous. On a farm north of Frankfort there was a sink hole, some 300 feet from the lake. There was no visible drainage, but upon the bluff opposite the hole there was a seepage of water from between the clay and the sand lying above, showing that the water might in part be held in and turned lakeward by a dense underlying stratum of clay. This may also explain the drainage of some marl lakes which have perfectly fresh water but no visible outlet. Crystal Lake was examined but showed no signs of marl. It had a very gradually increasing depth and pebbly beach like Lake Michigan and was unlike most marl lakes in formation and slope. The Lake Michigan bluffs, which are here very high opposite the lake, suddenly sink to within 15 or 20 feet of its level. The sharp well-defined channel with abrupt banks on each side seemed to show a former connection between the two lakes. A comparative test of hardness of water showed them about alike.

In Frankfort River, south of the town, there is a large elbow or basin formed by the river bottoms which broadens into a large marsh to the south. This marsh looks as if it could easily have been a shallow basin or lagoon. It is said that several thousand acres are underlain with 2 to 3 feet of marl. That examined was under 2 to 3 feet of muck and was very white.

§ 8. Harrietta.

In the trip from Frankfort to Cadillac the clay banks of Harrietta were passed.* It was near this point, the highest in that part of the State, that marl was reported as lying in a creek and upon its banks. Marl is deposited everywhere regardless of elevation.

*See Part I, p. 53.

§ 9. Escanaba.

The country about Menominee is largely limestone. A lake in Sec. 6, T. 24 N., R. 26 W., is said to be marly. No marl lakes were popularly known around Escanaba.

At Escanaba a light prospecting outfit was made consisting of the following:

40 feet of ⅜-in. pipe, cut in 4-foot lengths.

Couplings for the above.

1½-in. common wood augur bit welded to short piece of ⅜-in. pipe.

1 alligator wrench.

This could be loaded into a sack, strapped up and checked from one station to another.

It is found that for soundings in deep water for marl ½-inch pipe is the safest, although the smaller ⅜-inch pipe is lighter and can be raised or lowered in the marl easier, but is liable to bend out of shape and tear out at the couplings.

A 2-inch bit is a good medium size. A larger one requires too much work to raise it through the marl. A smaller one does not hold the marl in its coil. For practical purposes this is the most serviceable outfit for the average marls of Michigan. But in the Upper Peninsula marl was found too hard to penetrate by this means and in the Lower Peninsula marl and mud are sometimes too soft to be held in the worm of the augur. For all round sampling we find the outfit at Cloverdale very good though bulky. At Little Lake, the junction of the Chicago and Northwestern and the Munising R. R., Marquette County, Upper Peninsula, several lakes were examined. Their water showed in comparison as 2.7 to 11-13 as contrasted with that of Lake Michigan. This was quite soft and bore out the result of investigations at Cloverdale. The lakes were in a low, level country themselves, had very low banks, and nothing but seepage springs. Upon sounding they gave depths of marsh silt varying from 12 to 25 feet upon a fine sand and gravel bottom.

§ 10. Munising.

At Munising no marl lake was found in the immediate vicinity. I was informed by the superintendent of the road of a marl lake once discovered in sinking a shaft. The boring was carried through 20 or 30 feet of muck, when the drills passed through about 30 feet of marl and then into sand and rock again. The well filled and the liquid marl was pumped up as it constantly filled the hole and prevented progress. Finally the upper layer of denser muck sank like a flap till it shut out the liquid marl and the boring was completed, no ore being found.

§ 11. Wetmore.

At this village there was a large creek fed by a mass of boiling springs in its bottom. This bottom consisted of a very dense white marl covered by a few inches of silt. When the augur penetrated with the greatest difficulty and was pulled out with a specimen, a new spring boiled up in the puncture of the crust made. This point is near the divide of the Upper Peninsula upon the side which drains into Lake Superior. The creek is bounded on either side by somewhat low hills. The marl obtained was half way in consistency between marl and limestone. It was rather granular, though the particles themselves examined under microscope cannot be distinguished from those of dried marl. The marl is an almost pure white and very heavy considering its volume in comparison with ordinary marl. The creek is said to drain several lakes nearly upon the divide.

§ 12. Manistique.

Here lime kilns were visited. The whole country is limestone and there are no lakes or flowing springs or wells in the immediate vicinity. The limestone itself is over 30% $MgCO_3$ but burns well, making a good lime. A sample of marl from a dried up lake-bed some 30 miles distant was shown me. Its analyses revealed 95% $CaCO_3$ and it seemed one of the purest samples seen in my trip, being, with the exception of a little darkening organic matter, pure white. The analyses showed 'but traces (slight) of MgO and this too in a country noticeably abounding in magnesian limestone. The lake-bed from which this came showed a basin-shaped depression of about 37 acres filled with purest marl from a shore depth of 1 to 2 feet constantly increasing to a center depth of 29 feet. This is a good example of a completed lake.

§ 13. Corinne.

A spring creek was examined and a small bottle of water taken.* Most of the bottom of the creek was underlain as at Wetmore with a very hard granular marl 2 to 3 feet deep with clay beneath and one or two feet of muck on top. There were no indications that this had been a lake bed in very recent times, though the ground which formed a small swamp had very likely been under water for differing lengths of time. A lake about three miles farther south was visited and had a peculiar history. It was said that it increased in size during the spring months, but in summer, July and August, it suddenly disappeared and it was wondered if it found some crevice in the marl and suddenly emptied itself. It is probable that the lake filled up from spring rains and then gradually dried and by summer it had got so shallow that when steady hot weather came the thin sheet of water left evaporated quickly and the shore line advanced very suddenly. When the lake was visited in late July it had 3 or 4 feet of water upon it and was one great shallow of marl one mile or more long and a quarter mile wide. The marl was the purest seen, but was so dense and granular that the augur did not penetrate over five feet. The marl, however, formed rather dense layers. As the augur penetrated it it would sink easily for a foot or two and then strike an almost impenetrable layer which seemed like sand, but the specimen obtained would be very hard marl. It is probable that this stratified condition or layering of different density is caused by the sudden drying and baking given the crust during the annual drying of the lake. The lake was in an extensive forest bottom and I was informed that it was fed only from the surface waters which collected in the wetter portions of the year.

I could hear of no marl in the region of Trout Lake, but near St. Ignace there were deposits of marl and dolomite. No marl could be located in the neighborhood of Mackinaw City. Little Traverse Bay had marl underneath the sand as shown by driving of spiles for piers.

At the straits and for many miles inland the immense area covered by limestone scraped bare of glacial drift perhaps shows where the lime of our marl once originated no matter how subsequently deposited in the lakes. The immense number of small, smoothly rounded limestone pebbles show that a great body of lime must have at one time been washed away by the action of water, being removed in the form of either a fine sediment or a solution.

*Sample of water taken from large spring. See (No. 2).

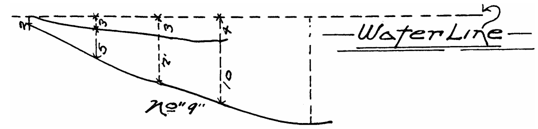


Figure 9. Section showing soundings at Duck Lake.

§ 14. Grand Traverse region.

The district about Traverse City was next visited. The marl upon a low basin on the asylum grounds was examined and found to contain an underlining of marl about 2 or 3 feet deep. Here it became evident as at Frankfort that an originally greater depth of water lying over the marl did not imply a greater depth of marl, but rather the opposite. This is considering the water level of Michigan as a whole. This, together with the thin bed at Frankfort and others very near the water level of Lake Michigan, showed unusual thinness. In this case a large basin had been grown over with muck and covered with debris to the depth of 4 to 5 feet and only showed where a large ditch had been dug. The marl was very hard and dense, very white.

The lakes about Interlochen were next visited. Duck Lake had been dammed to allow the floating of logs so that the marl being under greater depth of water was more difficult to examine. The effects of sand washing over the marl were very noticeable in this lake, probably on account of the increase of water depth. No marl was found in the immediate vicinity of the opening of any spring or creek into the lakes. In the bay or lagoon on the east side, made by the peninsula, water and marl were shallow enough to permit of sounding with the result of a gradual increase in depth of marl from shore to center. (Fig. 9.) Hard sand prevented a like test upon the opposite shore. The marl was in no case exposed close to shore excepting on the shore of the peninsula, which was very low and overgrown with trees and may have been but recently lake bottom, though upturned stumps showed no traces of marl. Upon the point itself there was a shallow coating of marl which increased but slowly at greater depths of water. The deep marl extended to a greater depth than 20 feet of sounding pipes and lay to the east of the peninsula where it joined mainland. Upon the west shore of the lake there was a coating of sand with no marl in or about the outlet. There is marl in the deepest parts of the lake. Lake rice reeds in 6 feet of water were coated with marl deposit. No Characeæ were visible. This was long known by the logging men, who in raising the weights let down to pull rafts, brought to the surface the gray mud. In general this lake as viewed seems to be a very marked case of the washing of sand from shores onto marl. The marl was undisturbed, was at the center and upon the peninsula where it thinned toward shore.

The lake opposite Duck Lake, into which Duck Lake emptied, showed nothing but sand, shallow sand shores and seepage springs.

§ 15. Central Lake.

Central Lake, also called the Intermediate Lake, being one of a series or chain, extends for some distance along the coast and very nearly at a level with Lake Michigan. The bold terraced shores and the sharply contoured hills that run down at right angles to the course of the lake are very striking to the eye. These contain a mixture of every kind of soil from pebble to fine clay. The lake itself can scarcely be called more than a river, though the ratio of fall is so slight that it has no perceptible current. Below the village of Central Lake sand is in some cases washed over the marl. But its presence underneath the lowland was shown in a startling manner. It was desired to raise the bed of the railroad which passed within 30 or 40 feet of the water's edge, and to do this a heavy grading of sand and gravel was loaded into the lowland. One night this suddenly sank with the land supporting it about 20 feet. There is no doubt the semi-liquid marl beneath the lowland was forced by the greatly increased weight of the grading out into the lake, when the land above with railroad and all sank to solid bottom.

The lake was examined mostly about midway and from there to the south end. The first series of soundings was made on the east side, out a hundred feet in shallow water, from a steam launch and from there in, and then along a slight creek about 200 feet in. The accompanying diagram (Fig. 10) will show relation of water, marl and land level. It will be seen that the large woods which had but a few inches of muck covering gave a very steady depth of marl. This marl while it contained no real sand or grit was very intensely granular and of a very brownish tinge. I should say that it had little organic matter, much iron and was decidedly different in grain from that usually met.

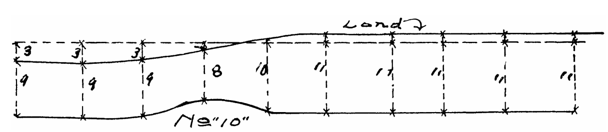


Figure 10. Central Lake, Antrim County. See also Plate I.

The marl also showed well at points and beyond one of these to the south we examined the marl islands in the south lobe of the lake.

These are very interesting as they are islands of solid marl nearly in a center line and about ½ mile apart.

North Island* is very small, has upon it but few trees, is 30 or 40 feet long, 20 feet wide, and has its longest axis from east to west.

Soundings were made first from the south, approaching from the median line of the lake to the small strip of dry land forming North Island. The following is a table of soundings on and about North Island (see Fig. 11 and Diagrams 11, 11A and 11B of Plate I):

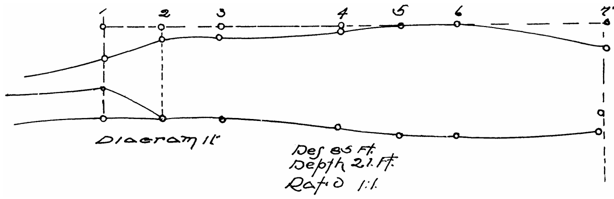


Figure 11. Section across North Island, Central Lake. See also Plate I.

No. of sounding.	Depth of water.	Depth of marl.	Location.
1	5	5	50 ft. S.
2	2	14	40 ft. S.
3	2	14	30 ft. S.
4	6 in.	17	10 ft. S.
5	Dry land	19	On S. shore.
6	Water's edge	20	North shore.
7	Dry land	21	East end.
8	Dry land	21	West end.
9	Water, 4 ft.	15	25 ft. N.

The regularity of increase and decrease in depth of marl, the steady variation in the relation of true bottom, marl, and water depths, is very striking and has been met with in but few other lakes.

The island was about 40 feet long by 10 feet wide at the center and was oval shaped. A shallow of weeds extended north and south about 50 feet at right angles to the greatest length of the island, making an oval-shaped island, surrounded by an oval-shaped belt of shallows, the ovals being at right angles to each other. The island itself was barely above the water's edge and was solid marl except for an inch or two of loam on top. Several trees grew on the dry ground which could be crossed easily on foot as the marl island seemed quite solid, which is not usual with marsh islands of this kind.

*See Plate I, Diagram 11B.

Upon the shores, especially the north shore, the light shells had been sifted at the water line by the action of the waves, so that the shore was a mass of shells of all sizes from a pin-head to an inch in diameter, and also intermixed with the shells were pebbly accretions something like those forming the coarse grained marl beneath the woods to the north, before mentioned.

Here it is very easy to see how shells could be broken into fine particles and merge with a bed of marl, losing their former identity. Several large clam shells were noticed lying just under the water's surface, upon the marl. These crumbled when grasped between the fingers though they had once been very strong hard shells. It is very easy to see that if this is the condition of a large clam shell, the more delicate shells would be crushed by a much smaller pressure.

South Island,—considerably larger and lying ½ mile south—was next examined.

It was one or two hundred feet long, oval-shaped and with its axis north to south, or at right angles to that of North Island, but in a line with the axis of the shallows of North Island. From the south end of South Island, shallows run to the south end of the lake. These shallows, the deeper channels on each side and the approaches to South Island on all sides, are all solid marl of fair quality with no surfacing of muck or silt whatever.

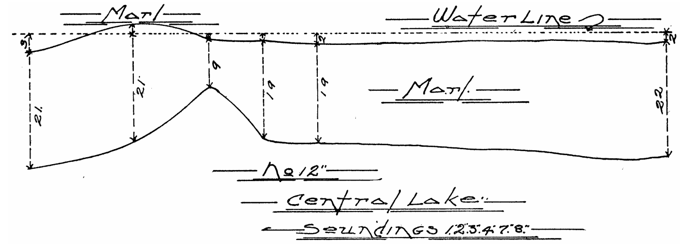


Figure 12. Section across South Island, Central Lake.

The soundings taken about South Island and on to the south end of the lake are as follows:

No.	Depth of water.	Depth of marl.	Location.
1	1	9	Close on S. E. shore S. Is.
2	1	19	10 ft. S. No. 1. Away from shore.
3	2	19	10 ft. S. E. No. 2.
4	2	22	70 ft. S. E. of 3.
5	5 ft.	20	Mid-channel S. E. of lake.
6	1	27	At extreme S. end of lake.
7	3	21	West side of island.
8	Light muck 2 in.	21	Center of South Is.

By consulting this table and the figure (12) accompanying it, it will be seen that the outcropping of the island of marl is produced not by an added depth of marl, but by a rise in the true sand bottom of the lake. This rise in level is sharp but uniform, the depth of marl being greater if anything away from the island. It helps to solve no problem concerning the formation of marl excepting to show that the marl behaves like any thick layer either of chemical deposit or sediment. It lies like a thick sheet over projections such as this, making them less pronounced than they would be without the covering.

Also notice that the soundings of South Island are deeper than those of North Island, not on the Island, but immediately around it. The island is larger and judging from the size of the trees and thickness of the muck, has been first exposed by the slowly receding waters and has probably had somewhat more of the marl washed off of the higher parts on account of its longer exposure to wave action of the lake and leveling influence of water. The two series of soundings show a gradual increase of depth of marl from the north to the south end of the lake, where in tall pipe-stem reeds and one foot of water, the deepest sounding of marl (27 feet) in the lake was made. These two series as compared with that made in the woods and immediately west are deeper and show a whiter, more finely divided marl toward the south where in the deeper parts it loses almost entirely its granular character and brownish trace of oxides of iron.

The north end of the lake a mile and a half or more north of Central Lake was visited and a brief attempt made to examine the conditions there. They were strikingly different. While at the south end there was no sign of muck or any organic covering, here there was found everywhere 2 to 8 feet of very fine river silt. Beneath this was 6 to 10 feet of marl, the deepest having a bluish tinge.

The striking features of the lake were the granular appearance of a few beds, the gradual change in depth of marl and lack of sudden irregularities in bottom. Perhaps the whole can be traced to the slight fall of level of the lake, there never having been any current to disturb the original bottom of the marl deposited upon it. There is but 3 feet fall in eight miles in this chain of lakes.

There are many good springs of hard water flowing into the lake. The samples, 8 to 11 inclusive, represent the waters of this region (p. 46).

A mound spring examined, of which there are said to be several, is very peculiar, seeming to be formed by the water issuing from a side hill with a sloping clay bank, down which the water finds its way to pile up for itself a mound, and to boil from the top of this. The mound, four or five feet high by six broad, consisted to the depth sounded, about 10 feet, of a sandy bog iron ore mixed with clay below, making it withstand the seepage of water, and above with muck . The water itself carried up with it as a fine sediment a marly clay. (See Analysis 28, page 21.)

This mound spring may be of interest perhaps as showing what a limy water will form upon being stopped and allowing to deposit upon issuing from a spring. No pure marl was found in the vicinity. A very interesting fact was its absence.

The clays of the vicinity were next examined.

The hills west of the town were in some cases strewed with glacial boulders and were more largely of sand and gravel than those on the east. On the east side was a brickyard that showed very nicely the thorough mixture that the clays of the vicinity had undergone. The clay as dug for use was somewhat moist and capable of being picked. A lump upon drying and examination showed a very fine grain, and was full of carbonates. On slicing a section of clay the different color of the fine layers gave it a highly streaked or stratified appearance, and these layers were rumpled and bent almost like the grain of curly maple, showing that the bed must have undergone great disturbance after being laid down. An inspection of the whole cut showed an upper layer of sand, a fine much rumpled layer of fine dark clay, then beneath this a fine bluish sand, hardly distinguishable from clay at first sight.* The whole hill looked as if it had been scraped together by some great power, and just before the mixture of layers became intimate, and they lost their identity, the movement ceased. This was the one of the lowest of a series of low hills, the highest of which was at an elevation of between 100 and 200 feet above the village.

The clay hills above Mr. Crow's farm were next visited. It was found that the clay anywhere near the level of the lake showed a strong heavy admixture of carbonates, but the shales higher up in the hills were freer from them. On the farm in question clay entirely free from carbonates was found, but mixed with shaly pebbles, which were very heavy in iron and somewhat gritty. There is no doubt that in the hills about the town a genuine shale of fair quality for cement manufacture could be found.

*The same contortion of the clay laminae may be noted at Clippert and Spaulding's yard in Lansing (Part I, page 56), and at the location described by Dr. C. H. Gordon, in the Annual Report for 1902. It appears to be due to a readvance of the ice sheet, after the clay had been laid down just in front of it. L.

§ 16. East Jordan and vicinity.

The marl lying at the head of the south arm of Pine Lake* and about the mouth of the East Jordan, in the large valley once forming a continuation of the lake, was next examined. The bed was reached by steamer from Charlevoix. At Charlevoix, where the railroad crossed the outlet of the lake, marl was noticed nearly worn away by washing of the water and in most cases buried by sand, but is seen in streaks, where it is exposed on the bottom. Its only significance is its presence in this part of the lake in a very thin layer.

Along the shores of the south arm of the lake layers of marl of a few feet in thickness were seen cropping out under the banks washed away sharply by the action of the waves.

The general appearance of the valley examined was very similar to that of Central Lake. Sharp hog-back ridges from high hills ran down somewhat parallel to each other and at right angles to the length of the valley, which is clearly the result of glacial action. A series of soundings were made to determine the manner in which the marl was deposited. So far as found the marl lay in the form of a basin showing 2 feet at the edges to 20 feet in the center, the center of the basin corresponding somewhat to the center of the valley. Upon the whole the marl lacked the granular appearance found at Central Lake, but was not of as uniformly great thickness and was covered with from 5 to 10 and 15 feet of muck and swamp growth and in most places with heavy forest growth or its remains.

The disturbing action of a current of water was here noticed, for at the mouth of the river and at the head of the lake the marl was covered with many feet of silt and mixed more or less with sand.

As a rule the whole of this bed was underlain with blue clay. A large area of land suitable for tillage, forming a rather dry tableland with the old deeper channel of the lake surrounding it, was covered with a light muck, 1 to 3 feet of marl and then very tough reddish or blue clay. In the above instance if marl has any value as fertilizer it should, upon the admixture of muck, marl and clay, produce splendid crops, as was already shown in one or two instances where the land was utilized. It is a significant fact worthy of notice for its bearing upon the origin of marl that these clays at or below the level of marl beds are nearly always heavily impregnated with carbonates. One sounding that showed well the condition upon the table-land was as follows: One or two inches of surface soil, 2 feet marl, 3 feet tough red clay, 15 feet black clay, water and gravel bottom.

*See reference in Davis' paper.

Upon the whole the marl of this section lay in a basin shaped depression nearest the water, but spread in a thin layer over nearly the whole valley. It is covered with forest or thick layers of muck in most instances and in others mixed with the debris of silt and sand brought down by the rapidly flowing river. It is, therefore, scarcely available for cement manufacture, but may some day be used to mix with and make more tillable the tough clays of the valley.

The clays of this region, however, were of greatest interest. They were of two somewhat distinct types. Those before mentioned were a fine-grained sediment laid down at or below the level of the marl. Black, blue and red were distinct colors noticed. They were all very tough and dense. In a drive taken 8 or 10 miles south and on the west side of the valley the clays of every color and condition from fresh sediment to a heavy shale in place were examined.

Those examined rather low down the bluff nearer the valley, always showed carbonates and more or less admixture of grit, probably brought down by water. As we ascended in the cuts, clay in various stages of weathering from an almost compact shale to completely disintegrated soil could be seen. The color also varied, being of a yellowish or greenish tinge. These were in a number of places quite free from carbonates, but the shales were always coarser grained and would, while being more compact, dig and grind hard.

Finally an old mine shaft, where an attempt had been made to find coal, was visited. A heavy black, coarse-grained shale had been pierced by a shaft to a depth of 75 feet. The shale was nearly like rick and cropped out at the surface, breaking up and seaming where exposed to the weather. It reminded me very strongly of the Coldwater shale visited in the southern part of the State.* In the seams the shale was reddened by oxidized iron and it was said that occasionally pockets of iron pyrites were found in it, although none could be seen at the time.

A brickyard was then visited on the east side of town which contained strata of different colored clay and sand, much as at Central Lake, except that the level of the layers was not disturbed. All this clay, however, showed the presence of carbonates in very large quantity.

*It is, however, the Devonian black shale. L.

§ 17. Manistee Junction.

Lakes about Manistee Junction were next visited. This part of the country shows very well the condition of the lakes and the outline of country prevailing in a large part of the marl districts of the north part of the State, to-wit: an almost level pine plain in which suddenly occur drops below the level of the surrounding country without the slightest warning, much like a hole upon a level plain.

A small lake was examined. This was circular in form and contained the deepest marl (20 feet) at upper end. This marl was bare of muck and covered only by water. Upon the west side a test was made of a shelf like those found in other lakes, these shelves probably corresponding to the bare shelves found about Central Lake and East Jordan, which marked the recession of the ice. Near the shore were ten feet of marl and shallow water, while out 12 feet there were 12 feet of water and muck. At the lower end the conditions were the opposite of those at the upper. Here were found 26 feet of muck, beneath which were 4 feet of marl. Fine sand was the bottom in every case where soundings were made. The quality of marl was poor, being much mixed with organic material and sand. Notice the parallel case of Central Lake where silt and fine muck deposit shifted toward the outlet, marl being thinner. The water of this lake and others visited in this vicinity was tinged deep brownish red, lacking the remarkable clearness of most intensely marly lakes.

Long Lake next visited was cut deeper into the surrounding country. The marl did not show upon the water's margin which was of compact sand, but farther out, away from the shore, was a fair quality of marl and a good extent of shallows. Soundings were not made as no way could be devised to get upon the water.

Calhoun Lake could not be reached in its deep parts where the marl, if any, was located. A marsh near here drained by a creek and practically dry showed good marl 15 feet thick, below one foot of muck. It was as usual in the form of a basin. No distinctive marks could be found to separate it from numerous marshes in which marl has not been found.

Marl was also reported in hills between Reed City and Clare. This appeared to be a high clay country and rolling, quite distinct from the sand plains.

§ 18. Rice Lake.

This lake is situated in Newaygo County, Town 11 North, Range 12 West. The greater part of the marl examined belongs to Messrs. John H. Kleinheksel, Henry Beers, and Dr. M. Veenboer. The above map was prepared by Prof. Kleinheksel, who accompanied me during the survey of the bed.

The lake abruptly breaks the level of the pine barrens and on account of the present condition of its bottom affords especial advantages for the study of its marl. From the appearance of the large lowland or marsh the water has not for some time occupied the whole depression indicated on the map by the double traced outer line "A," and a later limit is well defined by the presence of a thick growth of scrub oak which encloses the area covered by the recent lake. This older water line is shown by the outer single line marked "B," and the more recent one by the inner line "C." Between these two shore lines, the old and the new, is found a considerable thickness or accumulation of marl ranging from two to twelve feet and lying under an overgrowth or accumulation of solid land some six or seven feet in thickness. This land is covered as before mentioned by a thick growth of scrub oak.

By a system of large ditches the lake is still further drained till it has shrunk within the inside shore line to its present limits as marked on the map* (Fig. 13).

With the above understanding, the first notable fact revealed by the numerous and carefully located soundings is that as far as could be discovered, the center of the marl basin is not exactly under the center of the water basin, nor the present lake. The center of the marl basin is very clearly shown to be in the northeast quarter of the southeast quarter of Section 10. Around this deepest portion the gradually decreasing depths group themselves. The sounding of twenty feet in the above-mentioned section forbids an increase of depth toward the water as do the soundings of twelve feet and twenty-two feet in the quarter section adjoining it on the right. The soundings made up the center of the present lake still further deny the presence in mid lake of any marl center. The fact is then established that in the case of this lake the greatest body of marl does not lie beneath the deepest portions of the lake. Furthermore the marl as sounded extends in its location toward the large north and east lobes of the lake as marked by the line of bluffs forming the original depression.

*The original U. S. Land-office Survey in 1838, was made in January, and no lake was recognized. The re-examination in 1854, sketched in a rather small lake. In hardly any two maps has the lake the same shape.

The next point of interest is the rapidity with which the surface has overgrown and sealed up the present deposit. This deposit is covered by some three to five feet of tangled roots of marsh growth, forming a layer which jars for yards around with the weight of one's tread. This growth, though light and easily penetrated, is thick and must have nearly all formed in the few years since the lake has been drained. It leads us to beware how we judge of the age of a marl bed or the length of time since it has ceased depositing by the depth of its covering or surface.

The material underlying the marl was in all cases found to be a fine lake or quartz sand, such as has been met with in the majority of lake soundings. One peculiar feature here was that just as the augur passed from the marl into the sand, it brought up a greenish layer which contained little sand, and was a grade between organic matter and marl. This is the foundation upon which the marl started its growth, and should be of the utmost importance in the study of the method by which it is laid down.

Haying noted the surroundings of the marl, the final matter of consideration is the marl itself. The marl which was studied most closely in regard to quality was taken toward the center of the marl basin in deeper soundings. Though the examination carefully covered two quarter sections, the quality of the marl throughout remained surprisingly uniform. From the accompanying analyses by Prof. Frank Kedzie of the Michigan Agricultural College, and those selected by Prof. John Kleinheksel and analyzed by Prof. Delos Fall of Albion, it will be seen that the marl is rather high in insoluble matter and low in carbonates. Of this insoluble matter a small and constant part is quartz sand met with in many marl lakes and seemingly independent of the sand washed in by drainage. The organic matter though high is steadier than in most lakes, remaining the same through all the deep soundings. The analyses by Prof. Kedzie, Nos. 1 and 2, are at surface and 35 feet deep respectively. The variation in organic matter and magnesia is slight. These analyses illustrate the fact that the deeper parts of the bed vary but slightly, probably owing to the distance from hills and surface washings of all kinds.

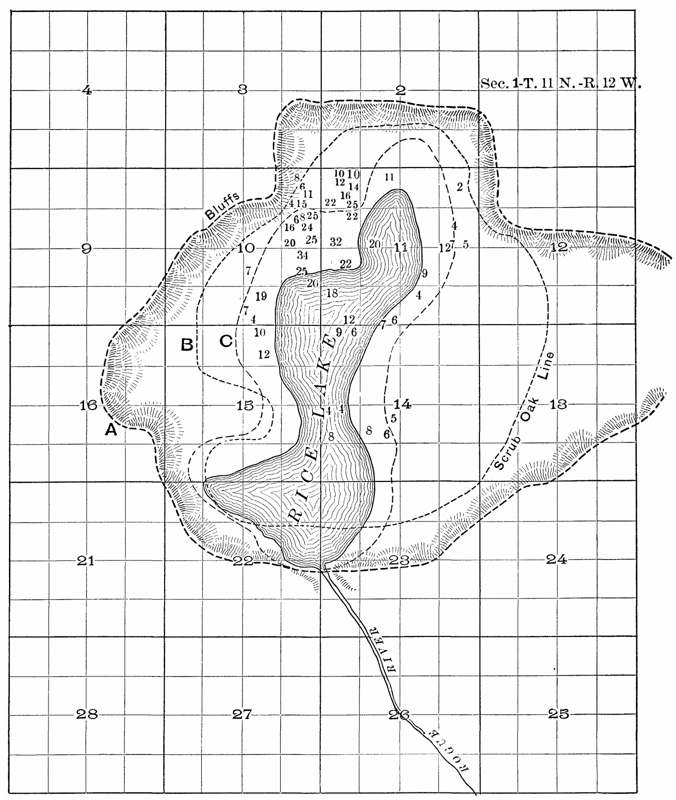


Figure 13. Rice Lake.

Following are the results of analyses:

Agricultural College, Nov. 25, 1899.

	No. 1
Insoluble matter	6.66
Oxides of iron and aluminum	1.34
Calcium oxide (equivalent to 71.66% Ca CO_3)	40.12
Magnesium oxide	1.10
Carbonic acid gas	32.50
Organic and undetermined	18.28

(Signed) FRANK S. KEDZIE.

Agricultural College, Nov. 14, 1899.

	No. 2
Insoluble matter	4.36
Oxides of iron and aluminum	2.36
Calcium oxide (equivalent to 76.82% calcium carbonate)	43.01
Magnesium oxide	.97
Carbonic acid gas	34.24
Organic and undetermined	15.05
	100.00%

(Signed) FRANK S. KEDZIE.

Albion, Mich., June 22, 1900.

Prof. J. Kleinheksel, Holland, Mich.:

	No. 3	No. 4
Silica, SiO	2.84*	8.67†
Alumina, Al_2O_3	2.76	3.55
Iron oxide, Fe_2O_3	none	trace.
Carbonate of lime, $CaCO_3$	79.55	65.67
Carbonate of magnesium, $MgCO_3$	none	none.
Sulphuric acid, as SO_3	3.15	2.50
Organic matter, etc.	11.70	19.58
	100.00	99.97

DELOS FALL.

*This is a marl containing over 5% of clay and running rather low in carbonate of lime. After the organic matter is excluded the percentage of carbonate of lime amounts to 90.09.

†This is a sandy marl. Excluding the organic matter there is 81.65% of carbonate of lime.

§ 19. St. Joseph River and tributaries.

In and about the mouth of the St. Joseph River there are beds of marl. Very small creeks have in the meadows surrounding them, small beds 1 to 3 feet thick of marl. Hickory Creek and Paw Paw River, which has a large marsh near its outlet, have marl along their course.

§ 20. Onekama.

Portage Lake (Fig. 14), on which is situated the Town of Onekama, is about eight miles north of Manistee and opens by a short but very navigable channel into Lake Michigan. It is surrounded by high hills, on all sides and on account of the deep depression made by the lake the springs which issue from beneath the hills are numerous and large. One spring contained a considerable percentage of sodium carbonate, but the marl in the immediate vicinity in which the spring emptied showed no unusual trace of alkaline salts. This is only another illustration of the fact that the agency at work in the deposit of the marl has a power of discrimination, refusing certain salts from the water and depositing others. Such was shown to be the case of the sulphur and iron springs mentioned in the description of Big Whitefish Lake. Portage Lake is fed entirely by a network of springs and spring creeks and the water is very clear.

The shallows of the lake are not all marl. Strips of marl from three to four feet in thickness alternate with sandy beach around the whole lake, but the deepest marl and that which engaged our attention lay to the north and northwest shores toward Lake Michigan. It lay in a lobe of the smaller lake forming its northwest corner and reaching beyond the water up to the low sand hills bordering on the Great Lake. It is only thought necessary to mention certain features which will illustrate the general ideas already gathered as to the location of marls.

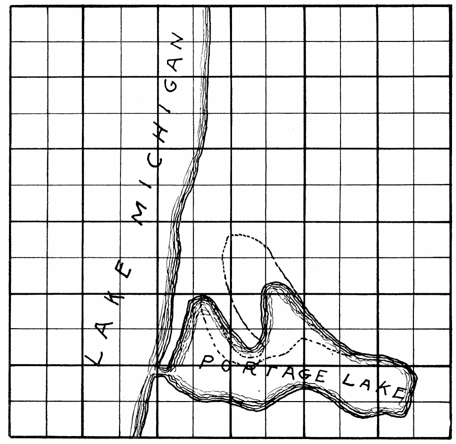


Figure 14. Portage Lake, Manistee County.

As before stated the deeper marl was confined to the large lobe or lagoon of the lake. Lines of soundings were run in different directions and the following conclusions reached: The marl decreased in depth with increase in depth of water toward the center of the lake. There was also an increase of content of organic matter as the center of the lake was approached. In the lobe above mentioned, considered as a whole, the marl deepened rather evenly toward the center of the whole basin. Here the marl was 21 to 22 feet thick with little or no surface covering. As the parallel lines of soundings approached the borders of the basin the depth of marl decreased rather evenly to 19, 17, 15 and 13 feet. The last named depth remained nearly constant as far as followed through the thick undergrowth to the northwest toward Lake Michigan.

The marl on the whole was little contaminated with foreign matter such as sand and clay. There was a very small content of the fine quartz sand often found in deposits. The ditches and small creeks emptying into the lake over the bed had carried down sand which had mixed with the marl in their immediate vicinity. The marl was deposited upon a fine pepper and salt sand which formed the lake bottom. In the marl basin or lagoon before mentioned soundings revealed a peculiar condition. The bed contained a small layer of intervening organic matter alternating with the marl. The material was well preserved and seemed to consist of driftwood and marsh growth pressed firmly into a layer a foot or so in thickness. The layer was about fifteen feet below the surface of a firm pure marl deposit.* Its presence might indicate that the marl had ceased to deposit for a time, and with the return of favorable conditions had again deposited, burying the layer of drift and marsh growth which had accumulated.

A large part of the lobe examined was not under water at the time. A part of it had recently been covered by water before a new outlet into Lake Michigan had been dredged for the lake. When it was drained the surface of the marl had been left dry. This left the marl more or less dense and dry and as a consequence there was nothing but a slight growth of grass and the consequent "surface" was only a few inches to a foot in thickness. This was a great contrast to Rice Lake which had been drained about the same length of time, but was left very wet. The marsh growth had become luxuriant and the "surface" is from three to five feet of marsh growth. Beyond the dry portions of Portage Lake and forming the fringe of real marsh was the portion which had always remained wet. Here the growth of soil and roots reached five feet or more. From these comparisons it can readily be seen that it is impossible to judge the age of a marl bed from the depth of surface growth covering it.

Sixty-nine soundings were made varying from 13 to 22 feet. The bed covered about 125 acres, not including a large area along the shores containing marl from seven to ten feet. The marl is of fair quality and its variation in quality is shown by the following analyses:

	No. 1.
SiO_2	2.81
Al_2O_3 and Fe_2O_3	.65
CaO as $CaCO_3$ (47.89)	85.63
MgO as $MgCO_3$ (1.47)	3.08
Phosphorus	.014
Total organic matter	6.96%

	No. 2.
Silica	3.64
Oxides of iron and aluminum	1.35
Calcium oxide	45.37
Magnesium oxide	.63
Carbon dioxide	35.86
Organic and undetermined	11.85

Submitted by A. W. Farr.

Samples No. 3 and No. 16, or Nos. 1 and 2 above, were taken at the respective depths of three and sixteen feet by the owner, Mr. Farr, and the latter was evidently mixed with sand as a careful examination of the whole basin showed no such amounts of sand, the sand being in all cases, excepting in the presence of flowing water, fine quartz sand and in small quantity. The remaining samples show a fair marl with no harmful compounds in proportions too large for manufacture.

*This may indicate a lower level for Lake Michigan at one time. L.