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ALFRED C. LANE, STATE GEOLOGIST

VOL. VIII
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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OFFICE OF THE STATE GEOLOGICAL SURVEY,
LANSING MICH., March 31, 1903.

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 co-operation from Messrs. Lathbury and Spackman and R. 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.

TABLE OF CONTENTS.

CHAPTER I.

INTRODUCTION.

CHAPTER II.

USES OF MARL.

CHAPTER III.

THE USE OF MARL FOR CEMENT MANUFACTURE.

CHAPTER IV.

THEORIES OF ORIGIN OF BOG LIME OR MARL.

Introduction – *Continued:* Page

CHAPTER V.

A CONTRIBUTION TO THE NATURAL HISTORY OF MARL.

BY C. A. DAVIS.

CHAPTER VI.

RECORD OF FIELD WORK.

CHAPTER VII.

MANUFACTURE OF PORTLAND CEMENT FROM MARL.

APPENDIX TO CHAPTER VIII.

THE DEVELOPMENT OF MARL AND CLAY PROPERTIES FOR THE MANUFACTURE OF PORTLAND CEMENT.

BY B. B. LATHBURY.

CHAPTER VIII.

NOTES ON THE ORIGIN OF MICHIGAN BOG LIMES.

BY A. C. LANE.

CHAPTER IX.

LIST OF LOCALITIES AND MILLS.

COMPILED BY A. C. LANE.

CHAPTER X.

METHODS OF AND COMMENTS ON TESTING CEMENT.

BY RICHARD L. HUMPHREY.

LIST OF ILLUSTRATIONS.

PLATES.

FIGURES.

ERRATA.

Page 190, line 18, for Cederburg read Cederberg.
Page 277, the figure 25 is inverted.

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 his 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.

§ 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.

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

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

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*More properly bog lime. L.

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.

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*But see notes on microstructure in the last chapter.

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

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

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.

§ 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. Farr of Onekama.

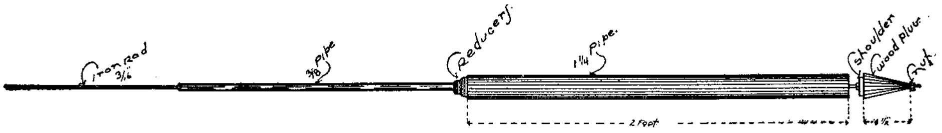

Fig. 1.—Farr's Liquid Marl sampler. For description see p. 11.

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.

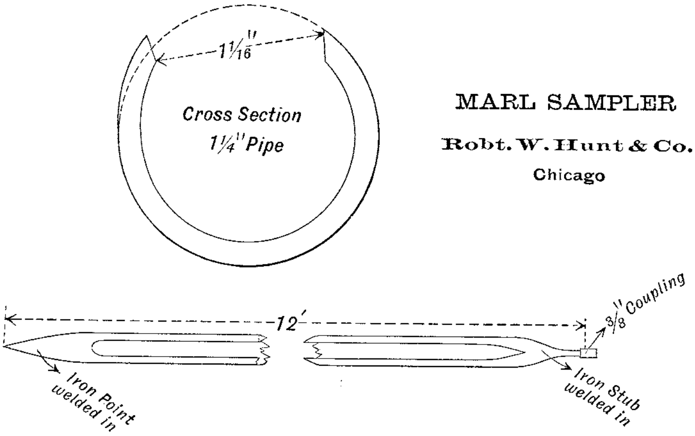

Fig. 2.—Hunt Marl Sampler.

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,

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

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.

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 hun-

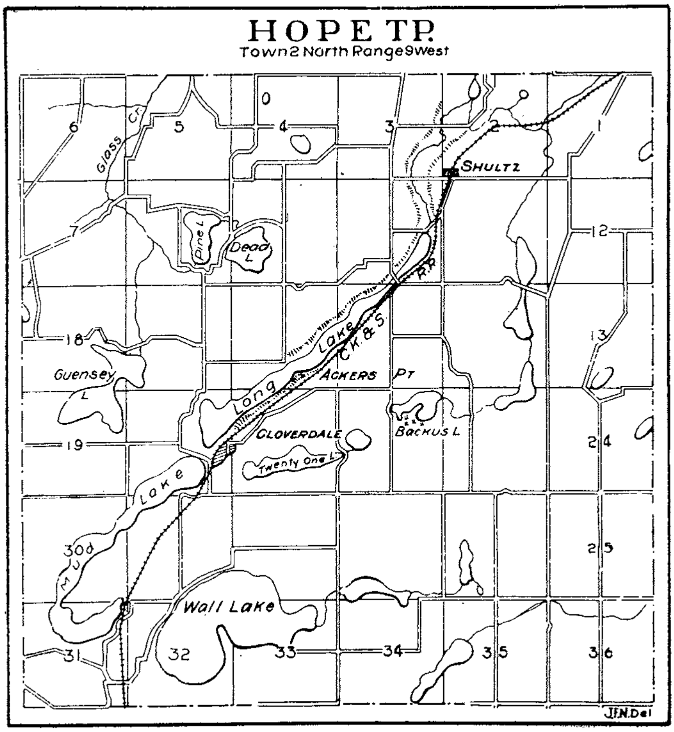

Fig. 3.—Map of Cloverdale district. By a mistake the r in Guernsey is omitted. Sec. 18. The lake on Sec. 22, is properly Balker or Horseshoe Lake, the name given being an error in the county atlas.

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

dred 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.

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.*

§ 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

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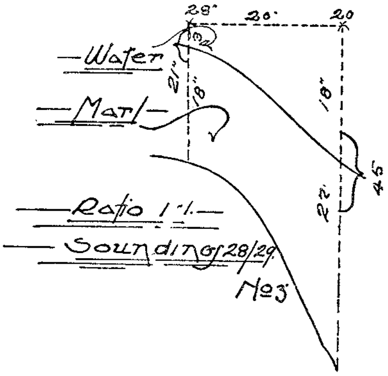
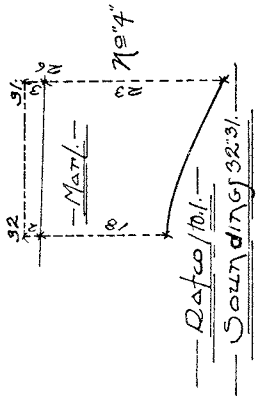
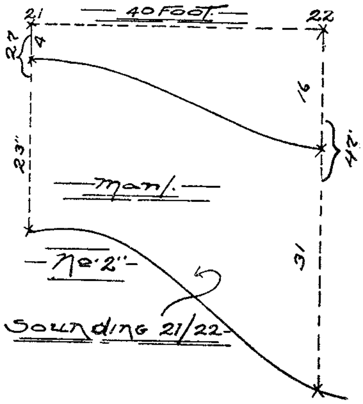
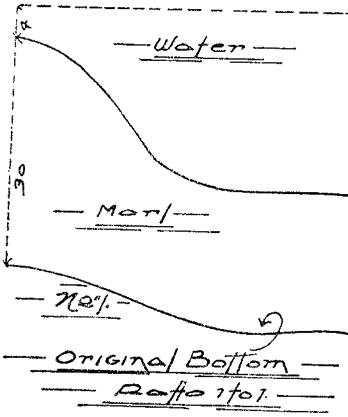
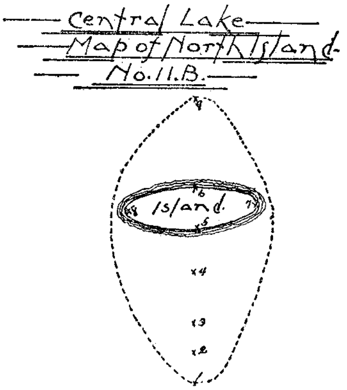
*See description of Onekama Lake.

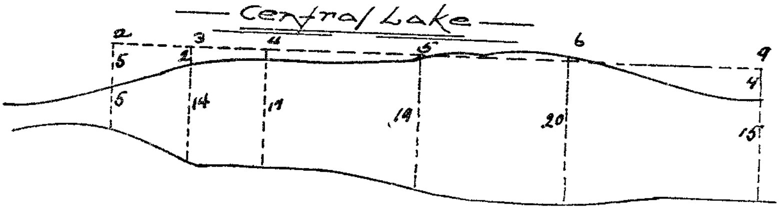


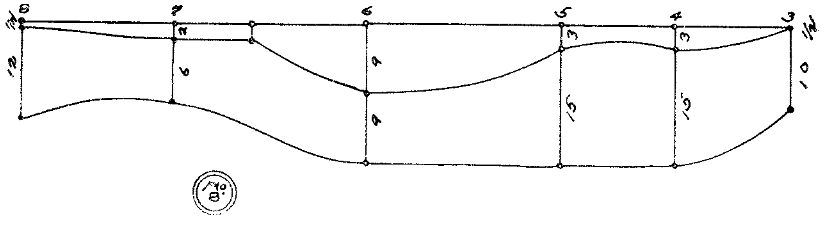












MARL SOUNDINGS, 1, 2, 3, 4, 11A, 11C.

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).

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.

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..........................			

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

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	

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*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

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

was nearly pure on top, but at bottom was scarcely more than a muck.

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.

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*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 30 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.

(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 be-

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

neath 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.*

(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

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*Compare what is said about Schizothrix. L.

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 spiles are driven, or a grading put on the ground, the presence of marl is attested. The spiles 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

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

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.

(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.

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

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

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.

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*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.*

(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

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

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.

(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

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

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.*

§ 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

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*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.

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 Reuter'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

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 4.4	80. 87.	69.6 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

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* 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.

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.

§ 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

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

glacial period from the fact that they lie in the hollows left by the glaciers, the agencies producing them must be modern as well.

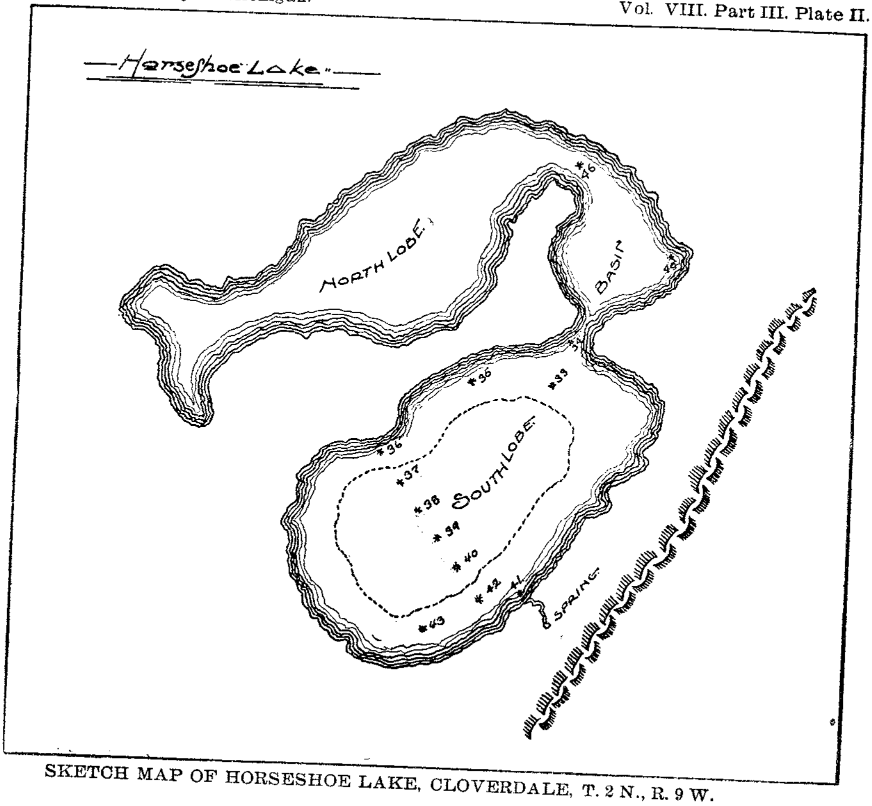
Marl has been described elsewhere as a complex compound. In the impure marl there are large percentages of insoluble matter which can readily be traced to the presence of foreign clay, sand and organic matter. It can be readily seen that these have nothing to do with the production of marl and therefore 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:

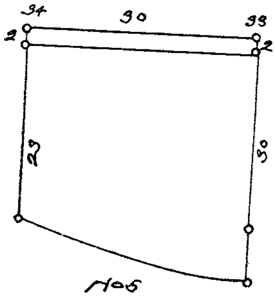
Calcium carbonate	95.231
Magnesium carbonate	.946
Ferric oxide	.536
Alumina	.159
Silica insoluble	1.205
Silica soluble	1.316
Organic matter	1.510
Water	.300
Phosphoric acid	traces.
Sulphuric acid	slight traces.
Chlorine	slight traces.
Alkalies	traces.
Total	101.203

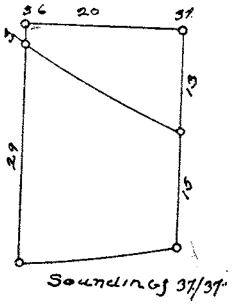
Very likely such a marl as the foregoing is as nearly as possible to purity as can be obtained. The content of organic matter is too low to be typical, while the content of soluble and insoluble silicates is a trifle high.

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

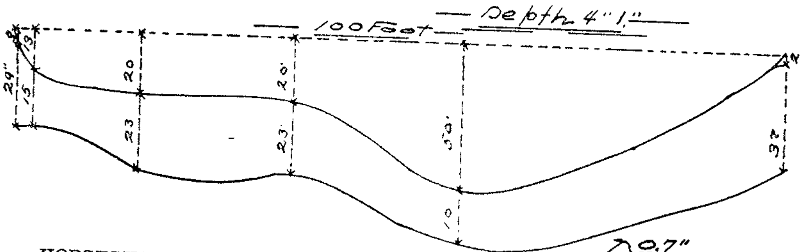


SKETCH MAP OF HORSESHOE LAKE, CLOVERDALE, T. 2 N., R. 9 W.





No. 6.



HORSESHOE LAKE, CLOVERDALE DISTRICT, T. 2 N., R. 9 WEST, WITH DIAGRAMS OF SOUNDINGS.

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.

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*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.

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. 133) 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.

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

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.

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 lukewarmness 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 downtearing 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 must 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

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

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.

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

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*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.

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.

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.

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

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

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.

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*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

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*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.

coherent and effervescing freely in acids. On dissolving it, particles of vegetable and other organic and insoluble matter are found scattered through the solution.

§ 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.*

§ 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 ap-

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*This point is considered more extensively later. L.

proached 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 dis-

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*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.

solved 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 re-solution 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,

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

†C. Wesenberg-Lund, p. 156.

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.

§ 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:

$$\mathrm{CaH_2\,(CO_3)_2} + \mathrm{O} = \mathrm{H_2O} + \mathrm{CaCO_3} + \mathrm{CO_2} + \mathrm{O}$$

$$\left.\begin{matrix}\text{calcium}\\ \text{bicarbonate}\end{matrix}\right\} + \text{oxygen} = \text{water} + \left\{\begin{matrix}\text{calcium}\\ \text{carbonate}\end{matrix}\right. + \left\{\begin{matrix}\text{carbon}\\ \text{dioxide}\end{matrix}\right. + \text{oxygen}$$

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

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

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.

§ 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.

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

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*See Plate XVI.

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 49.12	33.83
" (7).......... " (8)..........	30.52	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

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

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 give 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.

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

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*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.

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 Rilly and Sizanne, Basin of Paris." *Chara Lyelli* fruits are figured.

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 "Characee-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

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

[†] 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.

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.

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 thick-

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

ness 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.

§ 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.

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

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*25th Annual Report, State Geologist of Indiana.

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

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*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.

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.†

§ 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 in 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

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*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.

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

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*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."

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.

§ 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 Malden, 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

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*McMillan: Minn. Plant Life, 1899, p. 41. Penhallow: 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.

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.

§ 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.

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*See Plate XIX.