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CHAPTER VII.
MANUFACTURE OF PORTLAND CEMENT FROM MARL.

§ 1. Introduction.

The purpose of this chapter is not to give a full technical description of the process of cement manufacture. This may be found in any one of a number of large volumes written upon the subject.*

In a later chapter, prospecti from various cement plants in the State are cited and will furnish farther information. In order to connect these details and to give compact description of the process and to emphasize important points, this chapter is written.

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*See also 25th Annual Report of the State Geologist of Indiana; 22nd Ann. Proc. Ohio Soc. of Surveyors and Civil Bng., p. 18; 21st Proc. Indiana Eng. Soc., several papers; American Engineering Practice in the Construction of Portland Cement Plants, by B. B. Lathbury, 1902; A Rotary Cement Kiln for use in the Laboratory, by E. D. Campbell; Jour. Am. Chem. Soc., March, 1902; various papers, especially those by the Newberries in the Cement and Engineering News, and other pamphlets issued by the same press. Beside Lathbury and Spackman, Robert W. Hunt & Co., of Chicago, The Osborn Co. of Cleveland, and Hassan, Tagge and Dean of Detroit, may be mentioned as designers of cement plants. See also report by Prof. I. C. Russell in the 21st Annual Report of the Director of the U. S. Geological Survey.

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§ 2. Definition of terms.

The name "Portland" was derived from the name of a popular building stone used in England at the time that our present cement was given its name. The cement was thought by some to somewhat resemble this natural rock, hence was named after it.

Portland cement is an artificial mixture of calcareous matter with silicious (generally clayey) matter, which is properly proportioned and burned to a point just short of vitrification or melting. The resultant slag will, upon grinding, set with the addition of water to form a cement.

Natural cement differs only from Portland cement in that nature has mixed the calcareous and argillaceous ingredients in nearly the proper relations.

Slurry is the properly ground and mixed clay and marl or limestone suspended in enough water so that the mixture can be pumped from one reservoir to another.

The gradual perfection of Portland cement to-day is owing to the application of raw material and high grade machinery to the development of one chemical principle which is and will remain at the foundation of the cement industry, that two elements or groups, lime on the one hand, and silica or alumina on the other, when properly proportioned and intensely heated, have the power to combine with each other and then later with water such strength that after the combination once occurs, fire, water, acid or salts, have little power to disturb them or weaken their hold upon each other. The first group is calcareous. We see it purest in lime or calcium oxide, in an amorphous rock as calcium carbonate of limestone, as calcium carbonate in chalk, and in. the purest state as crystallized rock or marble. The second group is silicious. This forms a large part of the earth and is found purest in quartz sand and fire clay. When these two groups, the calcium carbonate of the marl on the one hand, and the silica and alumina on the other, are finely ground and mixed and subjected to a temperature of between 2,000 and 3,000 degrees Fahrenheit, the calcium carbonate loses its carbon dioxide becoming calcium oxide and the silica becomes soluble. When the slag is ground to powder and mixed with water the nascent compounds recombine to form a tricalcic silicate and aluminate, an insoluble, non-combustible rock which becomes harder if anything, with age.

§ 3. Historical.

Before the discovery of the principles which govern the setting of cement, the Romans and they who followed them used slaked lime and a volcanic dust called pozzuolana. It contained the above mentioned substances in the right proportions to form a fair cement.

About the year 1756, Smeaton, an English engineer, made experiments to find a mortar which could be used under water in the construction of the Eddystone lighthouse. About the year 1818 Pasley in England and Vicat in France began experimenting upon cement materials to ascertain the proportions necessary to produce an artificial cement.

"In 1824 Joseph Aspedin, a bricklayer of Leeds, discovered and patented a method of making a hydraulic cement and named it 'Portland,' from its fancied resemblance in color and texture to the oolitic limestone of the Island of Portland, well known and in great favor in England as a building stone."

§ 4. Materials for Cement.

It will not be of profit to follow the development of natural cements. They are produced by grinding and burning a rock having cement materials in nearly the right proportions mixed to some extent by nature. As the proportions always vary the product is more or less unstable, is liable to crack and warp more than Portland cement and never stands as high tensile tests. It is therefore untrustworthy in those portions of great engineering works where great soundness and durability are required. It is produced more cheaply than the Portland cement and is very satisfactory for low grades of work. It is manufactured in large quantities in the United States and supplements largely the use of the more costly Portland cement. As the State of Michigan is supplied with extensive deposits of marl and clay suitable to the production of the highest grade of artificial or Portland cement it is well to notice the different ways in which material and machinery are manipulated to produce the same result.

It is a common idea that but one or two materials may be used for the production of cement, but this is erroneous. Anywhere where lime and clay constituents can be found sufficiently near each other and pure enough, Portland cement may be manufactured. In England, much of the cement is made from chalk, which is a calcareous formation similar in composition to marl, but dry, and a dense blue clay. In the United States chalk is used so far only at Yankton, S. D. Limestone and clay are the favorite materials in most parts of the world and it is only within the past few years that marl and clay as raw materials have come into any great prominence.

Several methods of burning and mixing the raw materials are used in Europe and the United States, adapting themselves somewhat to the nature of the raw materials used.

In England, in the Medway district on the Thames, marl and clay are ground and mixed with 120 per cent to 140 per cent of water. The finer particles are then flushed off by water passed into "settle backs," where the mud settles and the clear water is drawn off. When this sediment has dried to the consistency of a paste, it is gathered up and deposited on floors where it is dried still more rapidly by waste heat from the kilns. It is then mixed with charcoal and burned in kilns. The remarkable feature about this method is the thorough manner of mixing. It is the most thorough method known as the particles of clay and calcium carbonate are suspended together in water and allowed to settle somewhat as in a natural sedimentary deposit. It requires a month to dry the material, and the method is therefore too costly in time and is giving way to more rapid methods.

Mixing by the semi-wet process is probably most widely used throughout the world. When limestone and clay are used they are mixed with about 30 per cent or 40 per cent water, by means of sludge mills or similar contrivances. The mixture is then ground, passed to a drying floor, subjected to waste heat from kilns and burned as before. The mechanical mixture of the particles is not as perfect as in the first method but the drying occupies but 20 hours.
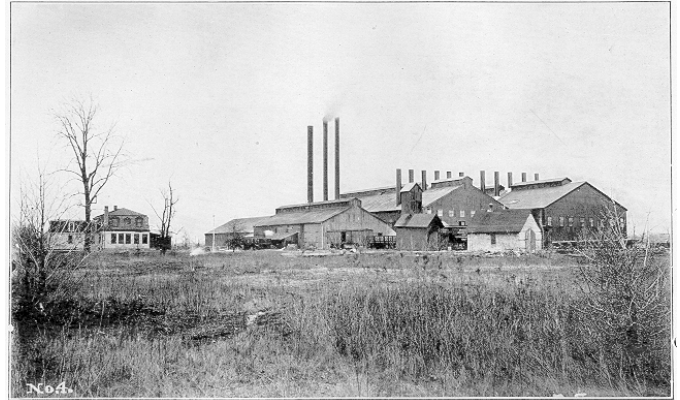
Plate IV. General exterior view of an eleven kiln plant.

Sometimes the materials are mixed nearly dry and formed into bricks which are burned as before, with coke in a kiln. This is done in the dome kiln or dry method, which has been used to some extent in our own State at Union City and Kalamazoo, and will be described later.

The method of burning differs somewhat. Where a dome kiln is used the layers of mixed cement material alternate with layers of charcoal. In the continuous kiln, charcoal and unburned and partly dried cement materials are fed in at the same time at the top arid the whole ignited at the bottom. The portion of heat not used in burning the cement at the bottom escapes upward and helps to raise the temperature of the half wet material above. In this way much more heat is said to be saved than in the dome and rotary kiln process.

Cement could be manufactured using sand to furnish the silicious elements instead of clay. Briquettes of cement made in this manner seem to have stood very good tests. Yet in practice, sand in any form is dreaded in cement manufacture, from the fact that it is so expensive to grind it to a sufficient degree of fineness for the purpose. The clay* is preferred instead because it is divided much more finely than sand, being already ground on account of the breaking down processes of nature.

It can be readily seen that the materials used and the processes relied upon vary widely in different districts although the finished product must be almost the same in all cases, as Portland cement has a narrow range of standard composition, which must be approximated in all methods of manufacture. The process used in Michigan depends mostly upon the materials at hand. The silicious element used is either a surface sedimentary, or a shale clay, depending upon which one having the best composition is at hand. The method of burning in nearly all cases is the rotary kiln process. There are few lakes or marshes that can be sufficiently drained so that the marl can be treated by the dry or semi-wet process and for this reason a more detailed description of the rotary

or wet process will be given. From the foregoing it must be clearly understood that the factories of Michigan have not only to compete with those using their own process, but also with the remainder of the manufactures by the limestone process, which alone furnishes more than half the cement produced in the United States. It must always be borne in mind that 40 to 60 per cent of the marl is water and nearly a half of the remainder carbon dioxide, a gas which is driven off in burning. The cost of handling and drying this great bulk of material must never exceed the cost of quarrying and grinding the limestone. When this happens, Michigan factories will be undersold by those of the limestone district. Besides this competitor there is the natural cement. This will take the place of Portland cement in many cases where the price of the better cement rises too high.

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*What is commonly known as clay is often very largely only extremely fine particles of quartz, mineralogically the same as common sand. L.

§ 5. Kiln process of cement manufacture.

The two methods so far employed in this State are the dome kiln and the rotary process. The former of these two processes is fast going out of use in this part of the country as it does not seem to fit the materials used as well as the rotary process. In 1872 a plant of this kind, the first cement plant in Michigan, was started at Kalamazoo. The marl beds which were used are described in Chapter VI. Another plant of this kind is erected at South Bend, Indiana, but was not in operation when visited. The process which was employed at Union City, Michigan (See Plate III), may be briefly described, as follows:

The marl was scooped up wet from the marsh and is thoroughly mixed with dry clay. The mixture, now of a doughy consistency, is pressed through a square orifice and is cut about the form and size of building bricks. These marl clay bricks are laid on flooring of T rails to thoroughly dry, when they are then ready for the burning, which is accomplished by kilns.

A kiln resembles a mammoth hollow cigar, cut off at both ends. It is built of fire-brick, and is about forty feet high by eight to ten feet in diameter. Beneath is a fireplace of about five feet to furnish a thorough circulation of air.

At the base of the kiln, above the open air space, an arched layer of these bricks is packed, a layer of lumps of charcoal, then another layer of bricks till the kiln is one-third or one-half full. The mass is then fired, and burns for about forty-eight hours; the bricks fuse into lumps of heavy, black slag, perforated by the exit of the carbon dioxide, which is expelled by the fierce heat. The whole mass shrinks and collapses and cools, and is then raked out. Then the slag is sorted by hand into two grades of cement, and is ground by mills into fine, dark brown powder which we know as Portland cement. This is an extensive process, requiring large buildings for drying, many kilns for burning (for a kiln burns only seventy-five barrels at a time) and many men to transfer and sort.

This process is not as exact as it should be. Part of the bricks are overturned and part underburned and must be sorted by hand, requiring great expense in time and labor. It has been displaced at Union City by the rotary process, and all the new factories in the State are employing the latter.

§ 6. The rotary process.

The rotary process, in order to be successful, should be carried on upon a large scale. The buildings which protect such a factory generally cover several acres (Plate IV). The prevalence of disastrous fires which have wiped out several large factories in the past year, causing great delay in the work as well as the financial loss, should emphasize the construction of durable and fire-proof buildings. The latest are being built largely of steel and cement. The machinery is so grouped (Plate V), that the raw material is transferred by machinery from one step of the process to the next, till it enters the storing bin a finished cement. The following is a brief description of the whole process, as seen at Bronson, Michigan.

The marl is scooped up by an ordinary dipper dredge and is drawn a few hundred feet to the factory on small dump cars, where it is stirred and screened and then pumped into a large funnel to measure it.

Meanwhile, the clay, which is mined several miles away and drawn to the works by rail, is elevated to the second story by machinery, is weighed by the wheelbarrowful and dumped into a hopper which drops it to a cluster of revolving millstones, which at the same time receives the semi-liquid contents of the huge marl funnel. When both have been ground and mixed with each other, this mixture drops into a second reservoir, where it is thoroughly stirred and mixed for some time by revolving paddles. From this reservoir the mixture, now termed slurry, is pumped into huge tanks, where it awaits the burning process.

Grouped with each tank is a huge cylinder about 40 feet long and four or five feet in diameter. The cylinder lies with the end that is farthest from the tank a little below the horizontal. The end opposite the tank is closed by a cupola.

The cold, wet slurry flows in at the tank end, the whole cylinder revolves, and the liquid mixture, caught on its inner surface, runs slowly towards the cupola at the further end. Here a falling stream of crude petroleum is ignited and blown by air blasts into the end of the cylinder. The solid sheet of flame penetrates six or seven feet, being under control. The slurry, slowly approaching, is first dried; then heated, and by the time it reaches the end of the cylinder is fused into liquid nodules about the size of pebbles, and falls through a slit at the base of the cylinder. Here it is received by an endless chain of wheeled trays, and, having cooled, is borne to the mills. These mills are very efficient, grinding it to a powder, ninety-nine per cent of which will pass through a sieve with 10,000 meshes to the square

inch. It is then finished cement and is stored in bins. In this process, as in the kiln process, the fine powdering and mixing of the crude material is carefully accomplished, and, by burning, the carbon dioxide is driven off and the mass thoroughly fused. This process is almost entirely accomplished by machinery. The machinery is expensive, but only requires the labor of fifty men to run the whole plant.

It is economical, as the burning is performed with exactness, and there is no charcoal to fuse with, and impair the strength of, the cement, nor is any hand sorting necessary.

In the latter case the quality of the cement and cheapness of manufacture is unrivaled.

§ 7. Preliminaries.

1. *Digging.* The raw material, marl, is in nearly all cases found in a lake or a swamp or both. In this condition it may be covered by a few inches to several feet of water, may be bare, or be covered with a surface of grass or rushes which must be "stripped" before the marl can be dug.

In many parts of the State there are extensive marshes covered with a growth of timber which must be cleared and grubbed before the marl becomes available. In such cases it is noticed that nearly all the roots follow the moist surface of upper soil which has been deposited on the marl, and do not penetrate deeply. This renders clearing much less expensive and the clearing can nearly all be done by burning. It is best in selecting sites for factories to avoid as much as possible the marl lands covered with a thick surface of swamp growth or forest. There is much marl land available in the State that does not require expensive surfacing, which should be chosen in preference to the less available territory.

The content of moisture will often vary much according to the position of the marl below or above the water line of the lake or marsh. In the same lake basin there may be marl in mid-lake containing 60 per cent to 75 per cent moisture, and at the same time marl on higher marsh land at the sides, which will not contain over 25 per cent.

The expense of surfacing is of course somewhat governed by the thickness of the bed and the depth to which it may be dug or dredged. A bed ten feet thick will be much more wasteful in digging than one thirty feet thick, for in each case the surface soil or growth is mixed with the marl in dredging, and must be burned out in the rotaries, involving cost of fuel in drying and time in handling the surface material, which is in the end burned, forming only an ash. Not only is there expense in handling and burning the material that becomes mixed with the marl from the surface, but also there must be a certain margin or remainder of the marl at the bottom of the bed which cannot be dredged on account of admixture with sand or unsuitable clay, of which the true bottom may be composed. It can then be easily seen that there is a greater proportion of the marl in a thick

bed, available for use, than there is in a thin deposit, for the waste must be the same in both cases. With the present large supply of deep beds the shallow deposits will not be immediately used. If there are but a few inches of grass and loam above the marl, no appreciable cost will be incurred, excepting to increase the organic content of the upper scoopings of the dredge. If there are several feet of dense marsh growth, sometimes as high as six, it may cost $75 an acre for surfacing,—quite a handicap.

2. *Draining.* In many lakes it is found expedient to drain by a short channel and thereby lower the water level, bringing the deeper parts of the lake within working depth of the dredge. Not every lake is located so as to be easily drained. Also it will be found, if attempt is made to so utilize marl that has laid at any great depth under water, that the quality of such marl will be much poorer, being higher in organic matter and lower in the essential calcium carbonate.

When the lake or marsh has a level of several feet above the stream or lake which empties it, it may be possible to drain it so that the semi-wet or even dry method of mixing may be used. This was to have been done at Watervale and was contemplated by the Hecla Cement Co.

3. *Dredging.* On account of the semi-fluid condition of most of the marl of the State, and its location partly in or adjacent to water, the easiest method of digging the marl has been by the ordinary steam "dipper" dredge. This is a barge or scow floating on the water and operating a large scoop or dipper, which can work to a depth of about twenty-two feet, as was claimed at Bronson. The rubbish or surface growth of a marsh is piled to one side, and the dredge makes a channel for itself as it digs the marl. It can be seen that this method is best adapted to the greater part of the marl in Michigan, which lies either under water in shallows or flats or in a marsh which is at or near water level.

Another proposed machine may come into general use. It is also built on a scow and consists of a movable crane carrying an endless chain of buckets. This chain can be lowered to greater depths by the crane and will perhaps be able to dredge to a depth of thirty feet, though, as the quality of marl decreases and the expense of power in digging will rapidly increase with great depths, it will not be found economical to dredge to the bottom of deep beds. In many factories in the State the marl is dredged and then piped to the factory.

There is one more method of transporting the marl. This is by digging or dredging and then pumping to the factory.* When the marl is pumped it must be mixed with slightly more water, which must in turn, be dried out in burning in the rotary. The increased expenditure for fuel will likely offset the cheaper transportation. The pumping plan is only considered where the marl is adjacent to the factory. Where the marl is several miles away,† a railroad must, of course, be employed, as hauling by wagon is entirely out of the question as being

too expensive. Where it is near, an overhead trolley bearing cars or a narrow guage road, in which steam or horses are the motive power, can be used.

Clay must be quarried or dug according as it is a shale or a clay. For quarrying see the account of Bronson in Part I, and elsewhere in this report. Out of 14 factories where the raw material could be located, all but one had the marl deposit within two or three miles of, or directly on the site of the factory, while but four had their clay near the factory, most of them getting it long distances away, in some cases in Ohio‡ or Indiana. The estimated cost of putting the material at the factory therefore, varied from eight cents to seventeen and one-fifth cents per barrel of finished cement, being greatest in the case of the Hecla works, who were to transfer their marl about thirty miles from bed to factory site.

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*As at the Woodstock and other plants.

†As is the case in the Hecla Plant at Bay City, 30 miles from the bed.

‡Millbury.

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§ 8. Estimates on raw material.

One factory in the State was running about 2,000 pounds of marl to the cubic yard, while it was said to require one and one-half cubic yards of liquid marl to a barrel of cement.

Now a barrel of Portland cement weighs 380 pounds. An average of 65% of this is calcium oxide; 65% of 380 equals 247 pounds of calcium oxide required for a barrel of cement.

Taking a wet marl, which has 40% moisture, and 90.3% calcium carbonate in the dry residue the available calcium oxide would figure as follows:

100% less 40% equals 60% dry matter.

90.3% of 60 equals 54.13% calcium carbonate.

100% calcium carbonate less 44% carbon dioxide equals 56% calcium oxide.

56% of 54.18 equals 30.3% of original weight as available calcium oxide.

At the above factory estimate of raw material 1½ cubic yards of marl would weigh:

1½ times 2,000 equals 3,000 pounds.

30.3% of 3,000 equals 909 pounds available calcium oxide, whereas it really furnishes but the 247 pounds necessary for the barrel of cement. This means that the deposit which was worked must have had a higher content of organic matter and moisture than we have assumed.

Notice the effect of increased per cent of moisture and decreased percentage of calcium carbonate on the percentage of available calcium oxide. Take for instance a marl 60% moisture and 75% calcium carbonate.

100% less 60% equals 40% dry matter.

75% of 40 equals 30 of original weight as calcium carbonate.

56% of 30 equals 16.8% of original weight as available calcium oxide.

In this case but 16% of the original weight of the marl as dredged and transported to the factory, contributes to the active elements of the cement. It can thus be seen that the actual supply of raw material is greater or less per acre, according to the condition in which it may be found.

No exact volume of marl to the barrel of cement can then be given, as it varies in each bed, but for a high grade marl of medium moisture, probably 10 cubic feet to the barrel would be an average. It is *estimated* in the Clare bed with 94% to 96% calcium carbonate, and 50% to 70% moisture to be from 7.5 to 12.5 cubic feet. At Zukey Lake, the Standard Portland Cement Company, with calcium carbonate 93.92%, estimates 9 cubic feet of marl to the barrel of cement.

The clay is much more compact and free from moisture. The volume of clay of the Omega Cement Company required for one barrel of cement was estimated to be 1.12 to 2.12 cubic feet, according to the per cent of calcium carbonate contained in the clay.

The question as to the requisite acreage of marl is discussed by several cement plants, and the estimated acreage varies widely, being from 262 acres to 2,000 acres. The favorite plan is to show an acreage which will run a factory of the desired size for 100 years. Several factories have been projected upon 75 or 100 acres, but have evidently given up from lack of material.
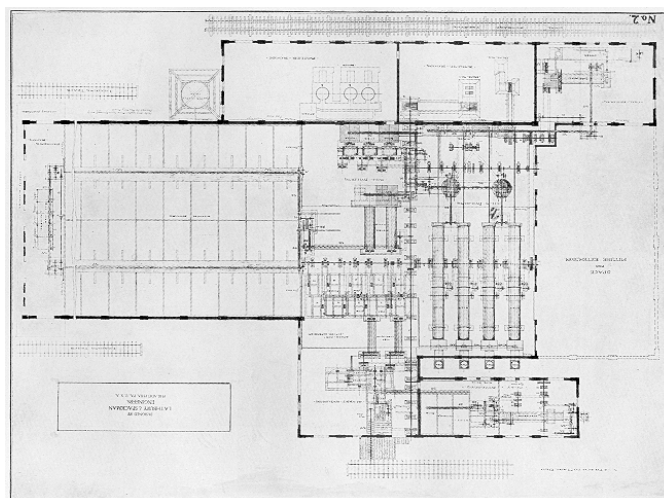
Plate V. General plan of four kiln plant with place for expansion.

§ 9. Requisites for marl deposit.

Taking the consensus of opinion as laid down in the prospectuses of the different factories built or building in the State, and the relative merits of beds as viewed in various parts of the State, the requisites of marl are as follows:

Surfacing.

There should be little or no surfacing and the water covering the marl should be as shallow as possible, not over six or eight feet. The amount of raw material in the State does not necessitate the use of beds covered with any great depth of muck or other useless matter which requires surfacing. The marl must be located on or near railroads, but better than all, on the Great Lakes. See freight rates, under shipping.

Necessary composition.

The prospectuses so far examined do not give any analyses of marl lower than 90% calcium carbonate. They vary all the way from this to 96%. It is doubtful in some cases, whether this is the highest sample found, or the average of samples in the bed. One prospectus which gave a sample analysis in its prospectus of 95.73% calcium carbonate gave in two samples taken and analyzed by two reliable chemists, when its bed was sampled as fairly as possible, 83.04 and 77.05% calcium carbonate respectively. In the majority of beds the marl varies with the depth, and when it is 90% $CaCO_3$ near the surface it is likely at 20 or 30 feet to be only 75 or 80% calcium carbonate, as explained in previous chapters.

It is very safe to say that if an average of all samples taken, whether deep or shallow, and irrespective of the choicest location, reaches 90%, the bed is safe as regards calcium carbonate. This will imply unless the bed is exceptional, that many samples will run as high as 95%.

Depth.

The depth of marl used or counted upon in the State varies from as low as 15 feet to depths which no scow of the present kind in use could possibly reach. It is fair to say that marl seems to be used anywhere from 15 to 25 feet below water level, with the restrictions as to water mentioned in the paragraph on surfacing. Low calcium carbonate means high organic matter, which is undesirable from the greater bulk of useless matter transferred to the factory to be burned.

The dangerous constituents are sulphuric acid and magnesia.

Sulphuric acid.

This does not appear to be troublesome according to the analyses seen in the various prospectuses, being given from .08% to .58%. It could go considerably above this, depending upon the amount in the clay. It is not often very troublesome in pure marls, but should be watched.

Magnesia.

This is very much more troublesome, as a strain of magnesian clay in the marl may cause it to vary dangerously. The cement prospectuses giving analyses, show from 1.41% to 1.79% magnesium oxide, which is a very safe limit.

Grain.

Some of the marls of our State are very fine and rival the finest grinding of any material by machinery. One case was noted where there was but 4% left on a 200x200 sieve, or 40,000 meshes to the square inch. This is certainly wherein marl excels all other raw materials for cement manufacture. It need hardly be said that an excess of shells or pebbly accretions somewhat increase the power necessary to grind finely and are a drawback. A marl with above 3% or 4% coarse or fine sand, must be ruled out. Effects will be noticed further on. For analyses of marls for factory purposes, see p. 32 and the descriptions of different plants.

§ 10. Clay.

We have in this State two kinds of clays, one being shale, which is often very hard to grind, but is steady in composition, and generally most free from carbonates. The other class are not of the nature of rock, but have been more recently laid down by the action of water and are not compressed. The grains are more easily separated, and grinding is effected with less cost in power. A good cement clay analysis is that of Millbury, O., being the average of 50, as given by J. G. Dean; SiO_2 61.06, Al_2O_3 18.10, Fe_2O_3 6.65, CaO 1.25, MgO .53, SO_3 1.05, organic matter and water 9.20.* The principal points about clays are the relations of silica and alumina and the proportions of lime, magnesia and sulphuric acid. If there is much lime the clay will not go as far with the same amount of marl. Hence, if it is to be carried by railroad any distance, there is the resulting disadvantage of increased cost of transportation. Organic matter and moisture are of course a dead weight. The above clay is a fairly good sample of surface clays used for cement manufacture, the same bed from which this was taken, being used by two factories in this state. A surface clay, if of the right composition, is much better because easier to dig and grind than shales. Often in the neighborhood of shale outcrops there is found a good surface clay, which is the broken down and decomposed shale, and makes a very suitable clay.
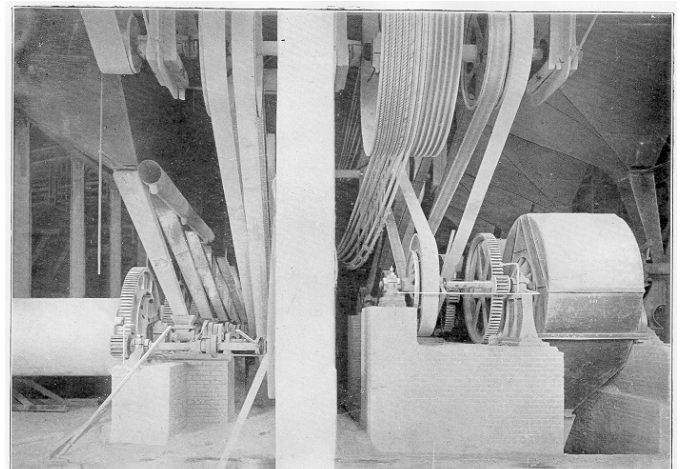
Plate VI. General interior view of slurry department.

The great body of Michigan clays are too high in magnesia and in alumina in proportion to silica.**

An average result from six factories giving their clay analyses was the following analysis:

Silica, 59.90.

Alumina, 22.76.

Magnesia, 1.47.

Sulphuric acid, 1.04 (but two out of six stated).

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*See also Prof. Fall's paper.

**See Part I of this volume, i. e., Ries' report on shales and clays of Michigan, and the analyses of shales in the descriptions of various plants.

§ 11. Admixture of raw materials.

This of course depends upon the exact amount of moisture and the percentage of calcium oxide in the marl, on the one hand, and the percentage of silica, iron and alumina in the clay, on the other. It can never be correctly determined without a careful analysis of both raw materials. A good clay is less variable than the marl. At Bronson, it was said that the clay was analyzed once a week and the marl was analyzed every day. The slurry is analyzed frequently to see if it continues in the right proportions, showing at once whether the measurement of the raw materials is carried on exactly and whether the raw material is varying much from the last analysis. If it does, one raw material or the other must be added to preserve the correct balance for the production of a cement of even composition.

Lathbury and Spackman, who write the article on cement making given below, say in their magnificent triglot on American Engineering Practice in the constructing of Rotary Portland Cement Plants:†

"A glance at the analyses of the standard brands of cements, both American and Foreign, will show a great uniformity, and it can be stated that in a good cement, the amount of the different ingredients will only vary within very narrow limits, as shown in the accompanying table.

	Minimum.	Maximum.
Silica	19%	26%
Alumina	4	10
Iron	2	5
Lime	58	67
Magnesia	0	5
Sulphuric Acid	0	2.5
Alkalies	0	2.8

Le Chatelier, after long study of the composition of cements, concluded that the two important compounds existing in the clinker were a tri-calcic silicate ($3CaO . SiO_2$), and a tri-calcic aluminate ($3CaO.Al_2O_3$). The hardened cement consists of hexagonal plates of calcium hydrate $Ca(OH)_2$ imbedded in a white mass of interlaced crystals of hydrated calcium mono-silicate ($CaO. SiO_2$ 2½ H_2O). The chief reaction which takes place during the setting of cement, according to Le Chatelier may, therefore, be represented as follows:

$$3 CaO.SiO_2 + xH_2O = Oa(OH)_2 + CaO.SiO_2.2½ H^2O.$$
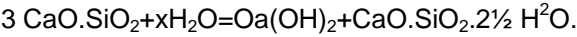
Assuming that three equivalents of lime and no more can enter into the combination with silica and alumina in a cement, then assuming magnesia to act the same as lime, the proportion of lime should not be less than that required by the formula $\frac{CaO+MgO}{SiO_2+Al_2O_3}3$ or greater than $\frac{CaO+MgO}{SiO_2-Al_2O_3-Fe_2O_3}3$

"The Messrs. Newberry in a series of researches as to the constitution of cement, determined by synthesis:

"First, that lime can combine with silica in the proportion of three molecules of lime to one of silica ($3CaO.SiO_2$) and give a product of practically constant volume and good hardening properties. With more than this proportion of lime the product is not sound.

"Second, that lime can combine with alumina in the proportions of two molecules of lime to one of alumina ($2CaO . Al_2O_3$) giving a product which sets quickly, but shows constant volume and good hardening properties. With more than two molecules of lime the product is not sound. Thus Newberry gives as the formula for a cement with the maximum amount of lime, $x(3CaO . SiO_2)+y(2CaO.Al_2O_3)$ x and y being variable factors, dependent on the relative proportions of the silica and alumina in the clay.

"In practice, cements contain a slightly less quantity of lime than the above formula requires, because of the difficulty of securing perfect mixing and burning and the danger of over liming if the formula is exceeded."

---

†Published by G. M. S. Armstrong, Harrison Building, Philadelphia.

§ 12. Mixing and raw grinding.*

The marl is dumped into a large tank or vat and is generally screened to relieve it of gross organic and foreign matter, useless to the process. As before mentioned it may arrive at the factory in little dump cars, by means of an overhead trolley or cable working from factory to bed, by horse or mule power, by scow towed in the lake, or by pumping from the dredge where it is scooped up directly to the factory by pipe. In all but the last method the marl becomes somewhat dried during transportation. The marl may be pumped into a large hopper and estimated by volume, while the clay is weighed directly, the right weight of it being added to each hopper of marl, when the two are then mixed and ground together. Sometimes the clay and marl are said to be ground separately. At Bronson, millstones were used to grind the raw materials in the wet, and at Omega they were ground as a slurry in tube mills (Fig. 15). The devices used to handle the raw materials at this stage of the process vary much. The idea should always be to handle the resulting slurry with as low a percentage of water as possible and yet make a perfect mixture of the two materials. Screw conveyors and sludge mills are used for mixing and conveying from vat to vat and to the tanks which supply the rotaries. The slurry in the tanks

must be kept in motion as it is fed out, because the more solid material settles by gravity to the bottom and would, if allowed, disturb the equality of the mixture. The expense of the raw grinding department was estimated for a 2,400 barrel plant at Lupton, as follows:

```
Raw grinding department (two shifts).
    2 millers at $2.00........................  $4 00
    4 scalemen at $1.50.......................   6 00
    1 electrician.............................   1 75
    Oil and grease............................   3 00
                                               ───────
    Total ....................................  $14 75
    125% repair account.......................   18 44
                                               ───────
    Grand total...............................  $33 19
Cost per barrel 1.4 cents.
```

Other plants, planned to manufacture from 600 to 1,000 barrels, show four to six cents cost per barrel for this step. No expense should be spared to do this step thoroughly. The whole success of the process depends upon the fineness of grinding and intimate mixing of every particle of clay and marl so that each particle of silica and alumina shall have its portion of calcium oxide ready to satisfy it. The larger the lumps of raw material left unground, the more unsatisfied and harmful material remains.
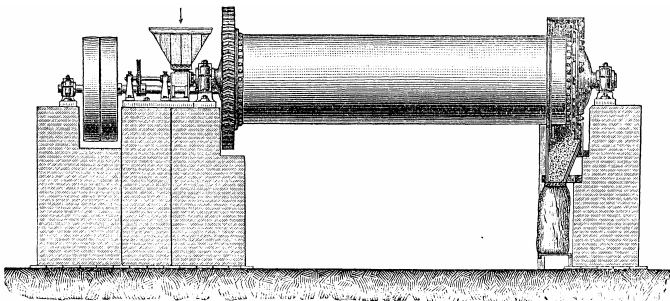
Figure 15. Tube mill.

*See Plates V, VI, and IX.

§ 13. Burning.

Every factory now going or projected in this State uses the Ransome rotary kiln process (Plate VII of Lathbury and Spackman's illustrations). It was invented by F. Ransome, an English engineer.

"It consists essentially of a revolving furnace (cylindrical in form), constructed of an outer casing of steel boiler plate lined with good refractory fire brick, so arranged that certain courses are set forward in order to form three or more longitudinal projections, finns or ledges. The cylinder is rotated slowly by means of a worm gear and wheel driven by a pulley upon the shaft carrying the worm. The cylindrical casing is surrounded by two circular rails or pathways, turned perfectly true, to revolve upon steel rollers, mounted upon suitable foundations. Gas, oil or pulverized coal may be used for fuel."

*Cement and Engineering News.

Plate VII. View of rotary.

The kilns are usually arranged in a row (Plate VIII), with the supply tanks or reservoirs back of them. The kilns lie side by side with their longest axes parallel so that the motive power may be applied over as small space as possible. In a fourteen rotary plant as at Coldwater or Quincy, there are two rows of rotaries, seven kilns each with the rows facing each other. Petroleum, gas or pulverized coal is used as fuel. This depends somewhat upon which can be delivered most cheaply at the factory. The price of petroleum, of course, is in the hands of a few and is liable to vary more or less, while coal may be had on the grounds in many parts of the State. It is therefore coming into use more generally. According to Stanger and Blount, its ultimate success is dependent upon the method of injecting the stream of coal dust into the rotaries.*

The Ransome kiln has been modified much to get around some of the difficulties encountered, and has been used with success in America, though it proved unprofitable in England. The chief trouble in the wet process, as employed in nearly all the factories in this State, is the cost of fuel. This is considerably greater than it should be when the actual heat is figured out theoretically. The weight of coal necessary to be consumed to produce clinker has been estimated as 23.28% of the weight of the clinker produced. If a portion of the heat of the waste gases is used and they are allowed to escape at 200 degrees C., the percentage is reduced to 17.1% of the weight of clinker in coal. In wet process, 40% moisture, with escaped gases at 200 degrees C., 49.3% of the heat is required to dry the mixture.*

The upper end of the kiln is metal while the lower end toward the flame is lined with magnesia or aluminum brick, to withstand the great heat. While the bricks are as nearly pure as possible, the lime of the slurry acts upon them, producing fusion to such an extent that it has been estimated! that three kilns did about the work of two, because of the break downs and delays caused from the fusing of the lining. A way is suggested and looks very feasible, of lining the fire brick with a coating of cement, packing it down so as to afford a protection to

the brick below. This method is employed at the Atlas Cement works as described by Stanger and Blount.

*Engineering News, October 24, 1901.

†A. H. Cederberg.

Analysis of kiln brick, Stanger & Blount.

Silica	55.82%
Alumina	37.98
Ferric oxide	4.02
Calcium oxide	
Magnesia	.78
Soda	.88
Potash	.37

In the furnace the slurry is first dried, then as it travels further toward the flame the different materials become oxidized. The 50 or more per cent of water is driven off in the form of steam. The organic matter is reduced to ash, the carbon being driven off in the form, of carbon dioxide. The calcium carbonate loses 46 per cent of its weight as carbon dioxide driven off as a gas. The silica and alumina are made soluble and brought into a nascent condition with the calcium oxide. If there is much sand in the slurry, it is not as easy to grind nor as likely to be ground fine, and the sand, resisting the heat, delays the point of semi-vitrification and increases the cost of burning besides being hard to grind at any stage of the process.

As the heat necessary to clinker cement material is between 2,000 and 3,000 degrees F. the blast of air coming in with the coal or petroleum and the gases driven off, must carry with them an immense amount of heat.

The amount of heat necessary to produce clinker for one barrel of cement is estimated by S. B. Newberry as follows:

Intermittent or vertical kiln (coke)	76 to	95	lbs.
Continuous vertical kiln	42 to	46	lbs.
Rotary kiln, dry material	110 to	120	lbs.
Rotary kiln, wet material (50%water)	150 to	160	lbs.

It is also estimated by Fred W. Brown, E. M.* that an additional 3 gallons of oil or 30lbs. of coal is consumed where wet material is used in a rotary kiln instead of dry. These figures tally rather closely and show the increased expense at this stage of wet marls over dry limestone as a raw material. In case the marl contains a large per cent of organic matter this is nearly as expensive as water because it calls for a large draft of cold air which must be heated to the furnace temperature in oxidizing the useless organic matter. The question is then, how to utilize the immense amount of heat which is wasted. This is roughly estimated as of 175 horse power intensity when but about 100 horse power of energy is used in clinkering the material.

*Cement and Engineering News.

Mr. Brown makes the following suggestions for improvement.

1. Recovery of heat from clinker produced.

2. Reduction of radiation of heat to a minimum.

3. Reduction of surplus air over that used in combustion to a minimum.

4. Reduction of temperature of escaping gas to a minimum.

5. Development of the efficiency of the melting chamber to a maximum.

He further recommends an induced draft to control the rate of combustion and the removal and cooling of the gases engendered in burning.

There is no doubt that this could be done and also that the hot clinker could help to heat the air entering the rotary. The idea also of using the super heated air and gases to generate steam to furnish motive power, and packing or lining the surface of the rotary to prevent undue radiation of heat is promising, but their application must hinge on the ingenuity of inventors.

There is no doubt that in many parts of the State the waste heat could be used to aid in evaporating the brine of salt wells so that salt could be produced in connection with cement.

The two weak features of wet marl as a raw material come out in the portion of the process employing the rotaries. High organic matter is said to "clog" the rotaries and if not that, it must be dried and then oxidized so that there is another expense added to the extra cost of conveying it and handling it as slurry. The increased amount of fuel necessary to accomplish this and to drive off the moisture of about 50% in the form of steam is one thing that makes the process expensive as compared with handling dry and compact limestone. It is of course counterbalanced by the extra cost of grinding limestone because the marl is already finely divided by nature.

ESTIMATES OF COST.*

A. 2,400 barrels per day.

Coal Grinding.

4 feeders at $1.50	$6 00
2 firemen at $1.50	3 00
2 general men at $1.40	2 80
8 tons coal at $1.50	12 00
Oil and grease	$25 80

Burning Department.

2 electricians at $2.00	$4 00	
2 headburners at $3.33	6 66	
24 underburners at $1.80	43 20	
100 tons slack at $1.60	256 00	
2 oilers at $2.00	4 00	
8 general men at $1.30	4 50	$328 76
		$354 56
10% repair account		35 45
		$390 01

B. 1,200 barrels per day.

Coal Grinding (one shift).

2 feeders at $1.50.............	$3 00
2 firemen at $1.50.............	3 00
2 general men at $1.40........	2 80
4 tons of coal at $1.50........	6 00
Total	$16 30

4 feeders at $1.50.............	$6 00
2 firemen at $1.50.............	3 00
2 general men at $1.40........	2 80
8 tons coal at $1.50...........	12 00
Oil and grease...........	2 00
	$25 40

*For some of these detailed estimates Mr. Hale is indebted to Mr. Cederberg.

Burning.

2 feeders at $1.50.............	$3 00
2 firemen at $1.50.............	3 00
2 general men at $1.40........	2 80
4 tons of coal at $1.50........	6 00
Total	$16 30

4 feeders at $1.50.............	$6 00
2 firemen at $1.50.............	3 00
2 general men at $1.40........	2 80
8 tons coal at $1.50...........	12 00
Oil and grease...........	2 00
	$25 40

*The Omega and Alpena factories use coal dust as will the Hecla.

The cost of burning is estimated by different factories as from 3 to 25 c per barrel, the lowest being that of Hecla cement company, which contemplates mining its own coal on the site of the factory.

One great virtue in the rotary kiln is that by careful watching the control of fuel 'being perfect the amount -of over or under burned cement may be reduced to a minimum. For a view of the clinker end of rotaries with arrangement of coal feeders, see Plate VIII.

§ 14. Clinker grinding.

When the clinker drops from the rotary it must be cooled for grinding. It may be allowed to lie until cool or the process may be hastened. A blast of cool air may be passed over it arid this air used as a hot blast in feeding coal into the kiln. For elevation of the whole process see Plate IX (Lathbury and Spackman's Plate I.)

The clinker is gathered in nodules the size of a pea to the size of the fist. When broken across, a nodule shows a steel-like lustre, said to be due to crystals of some soluble silicate. If it is a dead black it is overburned, if of a light gray it is underburned, in either case being worthless. A new scheme of cooling the cement is devised by the Atlas company, which it is said aids in "curing" the cement. It is first passed over hollow rollers through which cool air is passed. This air goes to the rotaries warmed, to feed the coal blast passing into the rotary. The clinker then falls on crushing rollers

which break up the larger lumps. These rollers are housed, and fed with a spray of water which dampens the cement and is said to satisfy the calcium oxide not taken up by the silica and alumina and so hasten at once the curing of the cement.*

The whole philosophy of the grinding process is to get a cement ground as finely as possible so that the cementing surface, which will increase with the smallness of the individual particles, will be as great as possible. For this reason the finer the flour to which the cement is reduced the more efficient the brand. The great end of manufacturers is, therefore, to obtain a cement which will be ground finely enough to pass all requirements.

For tests, see table on pp. 681 and 682 of Prof. I. C. Russell's article in the Twenty-second Annual Report of the U. S. Geological Survey, Part III and at the end of Mr. Humphrey's report.

The three different classes of machinery used for cement grinding may be described as millstone, tube mill, and rim roller.

The power consumed by the machinery of the process as reduced to the production of one ton of cement per hour is approximated by Henry Faija, as follows:

	Per ton per hour.
For millstones...................	30 to 32 I. H. P.
Ball principle....................	16 to 18 I. H. P.
Edge runner.....................	12 to 14 I. H. P.

Millstones are expensive from the fact that they must be redressed so often as to render the process too costly. They are also the most expensive of horse power.

Plates X and XI are illustrations of the Griffin mill, which seems to be the most popular type of the rim roller class.

Plate X shows a battery of Griffin mill at the Alpha Portland Cement Works, Phillipsburgh, N. J. Notice that they are mounted upon concrete foundations and as closely together as possible, for an economical application of power.

Plate XI shows a 30-inch Griffin mill arranged for dry pulverizing. This shows the interior and it is shown how the material is fed down between the roll and its ring or die. These mills deliver a finely ground and crushed grain and are used in over fifty mills in the United States.

*For detailed description see Engineering News, October 24, 1901.

The Griffin mill is undoubtedly one of the best of its class, but does not seem to have been adopted very generally in Michigan.*

Probably the best illustration of the ball principle as manufactured in this country is that represented by F. L. Smidth & Company, 66 Maiden Lane, New York, as given in Plate XII.

This principle, as far as can be learned, is adopted in most of the factories of Michigan and is well adapted to both wet and dry material. It is rather economical of power and turns out a very fine product. Greenland

chert pebbles of a very peculiar appearance are used. They are smooth, rather flat, generally ovate or elliptical in shape and have a small groove or indentation in one of their flat surfaces. They are said to withstand the wear of grinding better than anything yet found and are rather widely used for this purpose. The element of cost in this class of grinding is in replacing the pebbles which wear out and contribute to the siliceous content of the ground cement. It is claimed for this class of machine that it does its work quicker than, and turns out as fine a product with as little wear and tear and expense of power as any class of grinding machinery. It would appear that the wear on the machinery would be less than for any other class. For estimate of percentage of cost of grinding for this class of machinery, see the itemized expense of grinding clinker by this process at the close of this section.

The finer the cement is ground the more rough material it is supposed to cement together, as of course, the finer a given piece is the greater surface it will present to cement other materials together. It thus follows that the finer a cement is ground the more it can be adulterated with coarse materials, such as sand. This fact has been taken advantage of in the manufacture of what is called "silica cement." Sand is ground very finely, and mixed with Portland cement, thus going much further than the neat cement, when mixed with coarse sand. For more details see Cement and Engineering News, February, 1899.

*The illustrations were given us by the Bradley Pulverizer Company, 92 State street, Boston, Mass.

It will be of interest to mention here some experiments conducted under Prof. A. P. Hood at the Michigan College of Mines, in regard to fineness of grinding. The following are the statement of the purpose and the final results obtained by the experimenters.

1. Test A. Effect of fineness of grinding on tensile strength of briquette. The experimenter concludes that it makes little difference whether the cement is finely or coarsely ground. The finer and coarser ground being weaker as compared with the medium. This he continues is directly contrary to practice and to all current literature on the subject, and thinks perhaps if the briquettes had been molded better the results would have been different.

B. Effect of different percentages of water used in mixing Wolverine cement. Results. At seven days 15 per cent water* gives highest tensile strength. At 28 days, 20 per cent water gives highest strength.

C. Influence of different grades of sand on tensile strength. Normal sand shows highest strength. With increase of coarseness strength decreases. Standard crushed quartz shows about the average between coarse and normal sand.

D. Effect of different amounts of working of mortar. Working fourteen minutes gives highest tensile strength

with a gradual decrease with eight and two minutes working.

E. The comparative strength of four cements were in the following order: Wolverine, Lagendorfer, Bronson and Milwaukee.

The strengths of the cements increase with age, the difference between the seven day test and the twenty-eight day test showing an increase of twenty-five per cent.

Cement mortars, one part cement and one sand, the order of strength is W, B, L, M.

With one part cement and two parts sand, the order of strength is the same as above stated, and the increase of strength from the seven to the twenty-eight day test is about fifteen per cent as compared with the neat.

With one part cement and three parts sand, B has but slight advantage over W, while L and M in order are much weaker, the last named being weakest. Average increase of strength with age not appreciable at twenty-eight days.

In general, Wolverine has greatest strength for all purposes, especially when hardened under water. Bronson has next strength and is very quick setting and can be used to advantage in a damp place. It makes a strong mortar. L comes next and Milwaukee, a natural cement, has a disintegrating tendency under water with but a slight increase in strength.

*See remarks after Fall's paper, printed in the Mich. Engineer, and at the end of this report.

F. G. Test for compressive strength of the above brands.

Neat cements with compressive strength decrease in the order, W, B, L, M. Mortars: three sand, one cement, decrease in order, B, W, L, M. This test nearly checks that of tensile strength which showed B as best used in mortar. From this the experimenter concludes that tensile strength checks very well with compressive strength, so that the latter tests need not always be made.

These experiments are very interesting indeed, and are a good illustration of one very marked need in the cement business. There is imperative need of tests* along two lines: (1) To determine exactly the best methods to be used in making tests; (2) to find just what is responsible for imperfections in our cements, so that when a cement is tested in the laboratory and found to be good, that it will be sure to prove good when used in a building.

Test A of the above tests, differs radically in its conclusions from the present day practice. We would suggest a test here to supplement that, which will perhaps throw some light upon the reason why the finely ground cement did not prove as useful in giving high tensile strength. If the finer particles are fractured in-grinding to a dust, rather than worn down to

smoothness, the fractured material should give a higher strength. This idea arises from reasoning by analogy and therefore may be wrong. In a mixture of cement with coarser material, the best results are generally obtained with crushed rock, not rounded pebbles. In testing cement mortars, a crushed quartz gives the highest results for tensile strength. It would seem that there is room for experiment right here to determine if different methods of grinding produce different shaped cement particles with a resulting variation in the tensile strength.

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*Compare those reported by Prof. Russell in the 21st Annual Report of the U. S. Geol. Survey, pp. 679 to 682, and the report by R. L. Humphrey.

The cost of clinker grinding is estimated by four factories at from 7c to 12c. The grinding and the rotary departments are the ones which experience the most wear and tear and hence should have the greatest expense account. The following is a detailed statement of clinker grinding as estimated at Lupton:

ESTIMATE OF COST.

Clinker grinding department (Two shifts), 1,200 barrels.

2 electricians at $2.00..........	$4 00
2 grinding bosses at $2.00......	4 00
4 millers at $1.75............	7 00
12 feeders at $1.50............	18 00
6 tons plaster at $10.00........	60 00
Oil and grease................	3 00
Total	$96 00
10% repair account	9 60
Grand total..............	$105 60

	Cost per barrel.
2,400 barrels	8.8c

2 electricians at $2.00..........	$4 00
2 grinding bosses at $2.00......	4 00
4 millers at $1.75............	7 00
24 feeders at $1.50............	36 00
10 tons plaster at $10.00.......	100 00
Oil and grease................	4 00
Total	$155 00
20% repair account.........	31 00
Grand total..............	$186 00
Total	7.8c

Notice large cost of plaster per day. A company might manufacture its own plaster if located favorably for quarrying the raw material. For location of clinker grinders in general plan, see Plates V and IX. For interior view of coarse and fine grinding department, see Plate XIII.

§ 15. Motive power.

This is an important part. The motive power required is great and must be steady, as any breaking down of the main engines stops the whole plant, checks the grinding and cools the rotaries. To be perfectly sure that this will not occur sometimes, as at the Atlas plant, a second engine is fully prepared, so that at any time it may be hitched to the rotaries and cooling apparatus, and the vital part of the process thereby will continue. The storage tanks of slurry are sometimes made large enough to hold a supply of slurry for running the kilns forty-eight hours, so that all but the rotaries may be stopped Sunday. There are several new and interesting features to be embodied in the factories of this State relative to power and fuel. The Hecla Cement Company propose to mine their own coal near the site of the factory, thereby reducing their power estimate to 1.28c per barrel, and their burning to 3.25c per barrel. This of course, is the lowest figure given on either step of the process. Another admirable feature would be the use of water power to drive the machinery of the process. This is accomplished by the Newaygo plant. A plan now generally adopted is to transmit the power to the various parts of the process by electricity, making each portion more independent of the others and saving a large waste of power in the transmission.
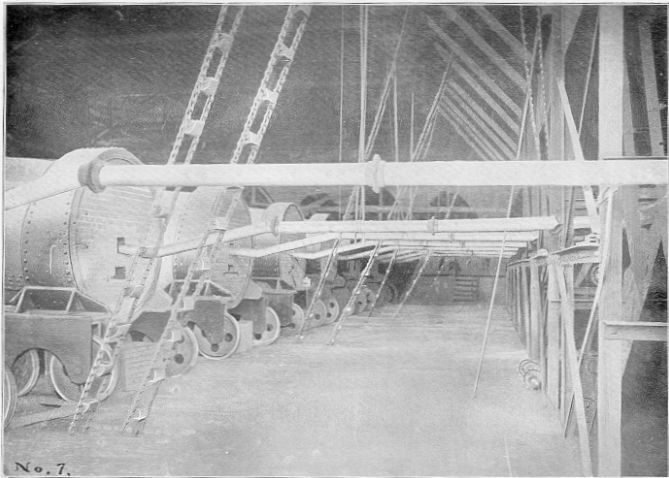
Plate VIII. Front hoods of rotary kilns and clinker elevators.
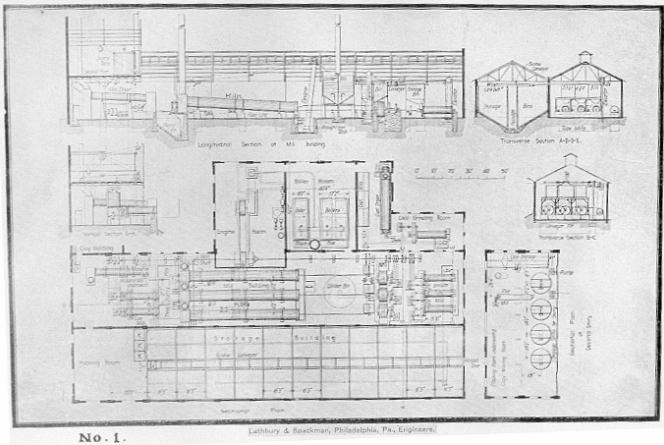
Plate IX. General plan of a three kiln plant with elevations.

ESTIMATED COST OF POWER.

The itemized statement of power for the Lupton 1,200 barrels per day, was as follows:

A.

Boiler room:		
4 firemen at $1.60............	$6 40	
50 tons of coal at $1.50........	75 00	
		$81 40

```
Engine room:
    2 chief engineers at $2.75.......    $5 50
    2 assistant engineers at $2.00...     4 00
    2 switchboard men at $2.00....        4 00
    2 wipers at $1.50..............       3 00
    Oil, etc.....................         3 00
                                                $19 50
        Total  ....................              100 90
        10% repair account........                10 09
        Grand  total.............  .             $110 99

    Cost per barrel...............        9.3c
    For 2,400 barrel plant it would be   8.2c
```

§ 16. Storage and packing.

Generally a large space should be given for the storage of cement as it is much improved by "curing." If there is any free lime not taken up and the cement is used at once in building, the satisfied compounds set, leaving the unused calcium oxide to absorb carbon dioxide and to swell, causing the cement to crack. The purpose of storage bins is to give the calcium oxide time to absorb before the setting takes place, and it also furnishes a supply for large orders, or allows the plant to run when orders are slack and do not call for rush work. The Lathbury and Spackman plans for a seven rotary plant show a storage capacity of 150,000 barrels of cement. So saying that such a plant produces on an average 500 barrels a day, this would allow it to run 300 days without orders, to fill the bins. It pays to have large storage bins as, especially in our State, the factories shut down often from one cause or another, or perhaps to make extensive changes or to enlarge the plant. This large storage prevents the cement leaving the market. It must also be remembered that the demand for cement is greatest only at certain times of the year, and the safest place to store cement is right at the factory, for nothing is so dangerous to its quality as a leaky or damp warehouse. For ground plan and cross-section of warehouse, see Plates V and IX. The interior section of storage bins under construction is also given in Plate IX. This shows the shape of the floor, which is something like an inverted A, so that the bin helps to discharge itself by the force of gravity.

COST OF PACKING.

This is not itemized by most factories, but by the Lupton Cement Company prospectus is carefully shown as follows, for 1,200 barrel plant:

```
    Regular contract rate...................    2.55c
For 2,400 barrels same rate.           .
In addition,
    1 foreman ............................    $2 00
    Paper, nails, liners, labels, paste, making
        average cost ........................    3.5c
```

§ 17. Specifications for cement.

The standard specifications for cement for the Navy Department are as follows:

The cement to be of the best quality of Portland cement, freshly ground, and delivered in canvas sacks, each sack to contain not less than 95 pounds of cement. The sacks to be carefully secured to prevent waste or loss in handling. Sacks to be returned to the contractor from time to time as they are emptied for use in the work. The cement to be delivered at the navy yard in lots of 400 bags each on or before the expiration of ten days notice in writing to deliver each lot. The first delivery to be made within ten days after the date of the contract.

Cement of which a constituent part is derived or manufactured from "slag," or which has not been used in the manufacture of concrete in heavy foundation work for more than three years prior to the time of awarding of this contract, will not be acceptable.
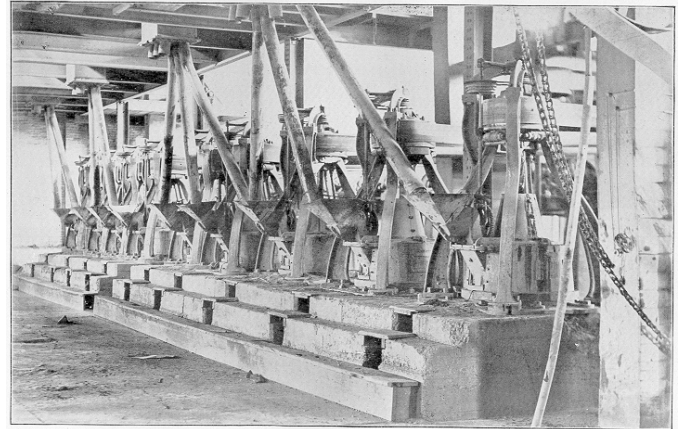
Plate X. Battery of Griffen Mills grinding clinker.
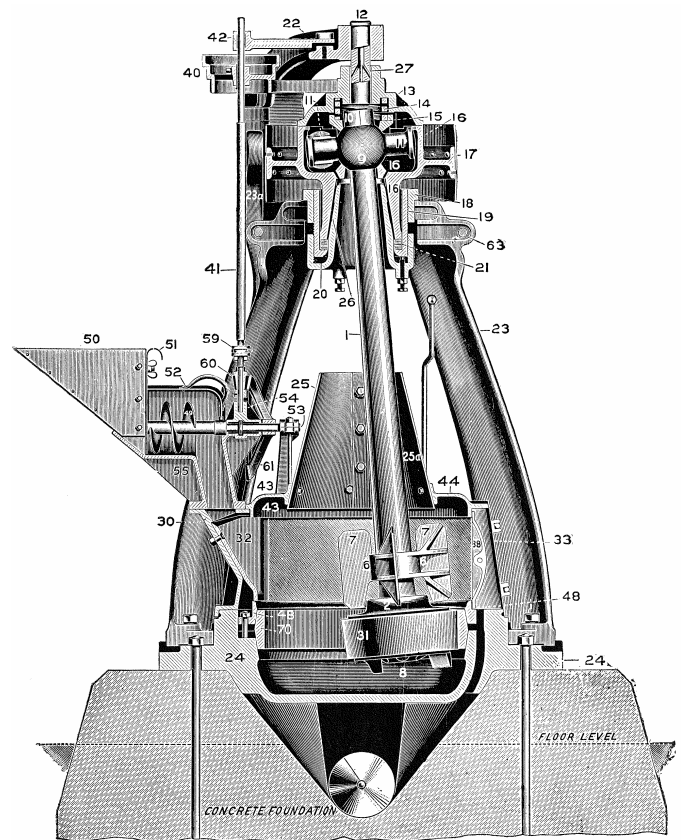
Plate XI. Cross section of Griffin Mill.

Bidders will be required to submit with their bids certified statements that no "slag" has been or will be used in the cement to be delivered under this contract; also a

certified statement of the engineer or architect of buildings or structures wherein this cement has been used in the manufacture of concrete in heavy foundation work, and has proven satisfactory in every respect for the period of three years prior to awarding of this contract. Failure to produce either of the above mentioned certified statements will be sufficient cause to reject the cement delivered by the contractors, without further test, and all rejected cement will be immediately removed from the yard by the contractor and replaced with other cement to fully meet these and all other specified requirements and tests, without cost to the government.

A certified chemical analysis of the cement to be delivered under this contract must be supplied by the contractor prior to the first delivery of said cement.

All cement as delivered will be immediately subjected to the following tests by the civil engineer in charge of the work; failure of the cement to fully meet each and all of the hereinafter described tests will cause rejection of the cement, which must be immediately removed by the contractor and replaced by other cement of a quality to meet the requirements and tests, without cost to the government:

Specific gravity and fineness—Portland cement shall have a specific gravity of not less than 3.1, and shall leave, by weight, a residue of not more than one per cent on a No. 50 sieve, 10 per cent on a No. 100 sieve and 30 per cent on a No. 200 sieve. The sieves being of brass wire cloth, having approximately 2,400, 10,200 and 35,700 meshes per square inch; the diameter of the wire being 0.0090 inches, 0.0045 inches and 0.0020 inches, respectively.

Constancy of volume—Pats of neat cement, three inches in diameter, one-half inch thick, with thin edges, immersed in water after "hard" set, shall show no signs of "checking" or disintegration.

Time of setting—It shall require at least 30 minutes to develop "initial" set; this being determined by means of needles from pastes of neat cement of normal consistency, the temperature being between 60 degrees and 70 degrees Fahrenheit.

Tensile strength—Briquettes of cement one inch square in cross-section, shall develop the following ultimate tensile strengths:

Twenty-four hours (in water after "hard" set), 150 pounds.

Seven days (one day in air? six days in water), 450 pounds.

Twenty-eight days (one day in air, twenty-seven days in water), 550 pounds.

Seven days (one day in air, six days in water) one part of cement to three parts of standard quartz sand, 170 pounds.

Twenty-eight days (one day in air, twenty-seven days in water) one part of cement to three parts of standard quartz sand, 240 pounds.

The cement depends for its quality upon the amount of soluble silica and the right proportion of lime to supply the same, alumina being also in correct proportion. The finished cement must always be within a very few per cent of a certain standard, the variation being slight. For detailed statement of same and tests applied, see R. L. Humphreys' report on cement testing*. The curing and setting properties of cement are hastened by the addition of gypsum, which counterbalances the effects of over liming. This should not be carried too far, as the sulphates are more or less soluble. It is perhaps owing to the manipulation of tests that many have begun to manifest a distrust of cement tests in general. If the tests as a whole are not conclusive as to the merits of the cement tested, they can riot be relied upon, and measures should be taken to remodel the tests, if they are at fault. Averages like the following, if fairly representative, should certainly inspire the greatest confidence in our finished product.

Average of four Michigan factories: seven days, neat 710 pounds, three parts sand 235 pounds; twenty-eight days, neat 824, three parts sand 358.

To compare with this we have the new standard specifications for the navy given above.

*For discussion of Hydraulic modulus and cement mixtures see Cement & Eng. News, Aug., Sept., 1900; June, 1901. Also pamphlet from their press by S. B. Newberry.

§ 18. Buildings.

They should be as nearly as possible fire proof and built of brick, cement or steel. The notices of loss of cement mills by fire are very frequent, and it is not alone the loss of the mill, which may be partly covered by insurance, but the loss of time and the cost of delay in rebuilding to those who have money invested and should have it earning interest on the investment. Furthermore, the cement runs out of the market and much time is lost in getting new contracts and building up the trade again. On this account, the mills that are now building, are using fire proof material as much as possible. At Lupton, corrugated steel buildings, with a supporting wall of six or seven feet of brick, are recommended. In Newaygo, cement was to be used largely. For views of plants and detailed ground plan of same, see Plates III, V and IX.

As near as can be ascertained, to October 4, 1901, the following is the condition of the cement industry in Michigan:

Eight factories are running a total of 48 rotaries, which is an average of six rotaries per factory.

Nine factories, three in addition to those mentioned, intend to put into operation 132 rotaries. There are seven other factories silent upon the subject of output,

which are incorporated under the laws of the State. There are 25 factories in the State which have issued prospectuses or become incorporated, either under the laws of this or other states.

Of 20 factories whose capitalization could be ascertained from prospectuses or other sources, the lowest capitalization was $20,000, the highest $5,000,000. The average was $1,004,500.

For statistics showing the condition of cement mills and market at any given time, consult the reports of the Michigan Commissioner of Labor.

The proposed cost of the Newaygo plant is to be about $500,000, the buildings are to cover five acres, and to hold at least 14 rotaries. The Standard Portland cement plant will be equipped with an outfit costing $350,000, and with a working capacity of 1,000 barrels per day. F. L. Smidth & Co., 66 Maiden Lane, New York, estimate the cost of buildings and apparatus for a 500 barrel plant at $125,-000 to $150,000, depending somewhat upon location. This seems much lower than the equipment of the plants which are actually building. The Elk Rapids plant cost about $200,000.

§ 19. Review.

In review of this chapter a most apparent fact is, that there will be, in the near future, severe and destructive competition in Michigan. The editor of the Cement and Engineering News is authority for the statement that in the spring of 1901, contracts were closed for Portland cement at 80 cents per barrel, f. o. b. The Michigan factories are in a comparatively limited area and must nearly all compete in the same markets. At the average estimated cost of the cement as given by the various prospectuses (68c), the addition of very high freight rates will destroy the profits and limit the area of markets. With 48 rotaries going and 132 to be running in the near future, the actual output of well established factories will be shortly trebled.

In considering these figures it must be further remembered that a factory just started must generally introduce its brand by offering it at considerable below the market price, to obtain a foothold in the market at once.

A brief enumeration of the points which will win in this competition are as follows:

The purest raw materials.

The largest plant with the strongest machinery purchasable. A. H. Cederburg estimated a decreased cost of 10c per barrel upon doubling the output.

Cheap power, either through available water power, or coal mined on site.

Most suitable location as regards raw material, fuel and market.

The more of the above requisites possessed by any one factory, the higher will be its profits.

*At present (last reading of page proof, Oct. 1902), however the price of cement has risen again and is over $2.00 a barrel, the low prices mentioned having stimulated a demand for cement in many new directions, with which the supply has not kept up. Especially in constructional work, for bridges and buildings, as well as sidewalks and cellars, a field for the use of cement has opened to which it is at present hard to set limits. L.

APPENDIX TO CHAPTER VIII.
THE DEVELOPMENT OF MARL AND CLAY PROPERTIES FOR THE MANUFACTURE OF PORTLAND CEMENT.
BY B. B. LATHBURY.

The exploitation of a marl or clay deposit involves a large amount of labor, and with it the necessity of an accurate and careful investigation of the quality and quantity of the materials, their general conditions, together with their advantages characteristic of the site from both an engineering and an economic standpoint. During the past few years, which might aptly be termed the construction period of the Portland cement industry in the State of Michigan, the investigation of such deposits have been conducted on purely scientific lines. Briefly described the method of procedure, in order to secure accuracy in the results and reliable figures upon which to base financial calculations for exhibiting the proposition as an attractive investment, is as follows:

The marl deposits should first be carefully surveyed and soundings located at convenient points over the entire deposit, from which samples of the marl should be secured, and the depths ascertained for each sounding. The most suitable time for such an investigation is the winter, when the water over the deposits, if located in a lake bed, is usually frozen. This permits meridian lines being laid out over the entire surface, thus forming squares of known size, at the corners of which holes can be bored in order to ascertain the depths and quality of the material. Field notes are usually kept of such an investigation, and the samples are carefully preserved with the number of the hole from which they are taken. The distance apart of each sounding or bore hole depends in a great measure upon the uniformity of the material and the variation in depth of the deposit, but generally speaking, on a plat laid out in measured squares, the lines of which are located, by a transit, bore holes can be made every 300 or 200 feet. The survey should then be accurately platted, a map made showing the boundaries of the deposit, together with the location and depth of all bore holes, their consecutive number on the plat, and if the deposit is under water, the depth of water over the surface of the marl.

The examination of a marl bed underlying a body of water is much more difficult and less accurate if made when there is no ice covering the surface of the water. Under such conditions, it is generally usual to survey the boundary lines of the lake, establishing stations at measured distances on the banks, and from these points, with the aid of a boat, secure samples and make soundings, in practically the same manner as a

hydrographical survey is conducted. The boat is rowed over imaginary lines between the stations on the shore, borings being made and samples taken at intervals over the deposit. If the deposit of marl occurs in a dry state or underlying a swamp, the examination is conducted by laying out meridian lines over an established survey, the borings and samples being taken from the intersection of all lines forming squares.

The next course to pursue is to submit the samples of marl to some competent testing laboratory familiar with the manufacture of cement by whom the samples should be carefully analyzed and determinations made for the following ingredients:

Calcium oxide, silica, combined oxides of iron and alumina, magnesium oxide, sulphuric anhydride, together with the loss on ignition. Determinations can be made for alkalies and other elements, but as they exist in such minute quantities, their determination will not prove of commercial value. The other ingredient to be considered is the clay or shale. Clays throughout the State of Michigan are usually found in a blue color, but when existing in connection with the marls, they usually carry a higher magnesium content than is desirable for the manufacture of Portland cement. On the other hand the suitable shales, though comparatively scarce, are notably free from deleterious elements, and better adapted for Portland cement purposes.

An examination of either the clay or shale deposits should be conducted on the same lines as those pursued for the marl investigation, analyses being made on the samples of clay in order to determine their uniformity and quality. The elements to be determined in the chemical analyses are similar in all respects to those enumerated for marl, with the exceptions of the oxides of iron and alumina should be separated. In all cases after the examination has been made, the data should be collected and a careful computation made of the quantities of suitable marl and clay occurring in each deposit. Then assuming as a conservative unit, that one square yard of marl will manufacture two and a half barrels of cement, it is readily computed the number of barrels of cement that can be manufactured from the deposit and the number of years a mill of given capacity will run.

In general, a marl of good quality should contain over 50% of calcium oxide, with not over 1½% magnesium oxide, and less than 2½% of either silica, combined iron and alumina oxide, or sulphuric acid. Although there are many marls found in the State of Michigan containing less than 50% calcium oxide having the other ingredients in proper proportions, these low lime marls usually contain a high per cent of organic matter which represents so much loss in the available quantity of marl. However, such marls can be used for the manufacture of a high grade of Portland cement, provided a suitable clay or shale is used in conjunction with them. A clay or shale of good chemical proportion should contain in general, not less than two parts of silica, to one part of combined iron and alumina, while the oxide of magnesia

should not be over 3%, and the sulphuric acid less than 2%. The clays throughout Michigan usually contain a small lime content, but this is not detrimental to their use for Portland cement mixture, provided care is exercised in correctly proportioning the two ingredients if the magnesia content is low. As a rule it will be found that clays carrying over 10% of lime will be too high in magnesia.

The quality and quantity of the marl, clay or shale deposits having been found satisfactory and the capacity of the mill been decided upon, the services of competent engineers should be engaged to prepare plans and make a final report on the property, and which report is usually used in connection with the prospectus for promoting the financial interests of the corporation.

A matter of great importance, which should be carefully investigated, before the erection of a plant, is that referring to freight rates. This question applies not only to the advantages derived from securing low rates for the shipment of cement to main distributing centers, but also to the careful consideration and selection of a site for the erection of a plant. Generally speaking, it is more desirable to erect a plant alongside of the marl deposit, but in some cases direct water and rail shipment can be made by erecting the factory some distance from the marl and clay deposit, provided a low guaranteed rate can be secured, and the haul is not too great, for the transfer of both the marl and clay from the deposits to the mill site. A plant so located possesses many undisputed advantages.

The cost of a modern rotary Portland cement plant varies largely with the character of the buildings and the mechanical equipment. A plant thoroughly up to date in mechanical equipment, using electricity for the transmission of power, and with steel frame buildings having brick sides, can usually be figured at $50,000 for each rotary kiln completely installed. Each kiln has an average capacity of about 125 barrels per day, but its daily capacity varies with the size of the kiln, skill of the operator, fusibility of the slurry burned, and general conditions of the plant. In general, therefore, it is safe to assume the cost of construction at $400.00 for each barrel of cement to be produced. This, however, does not allow a working capital, which in round figures should be 20% of the total cost of the plant. It represents, however, the entire cost and equipment of a thoroughly modern and up to date plant manufacturing Portland cement by the wet process, either from marl and clay or marl and shale, including such equipment as is needed for excavating and handling the raw material. The most economical process would necessarily embody such machinery as would eliminate manual labor and reduce the cost of repairs to a minimum. Such an equipment is contemplated in this estimate, and would include disintegrators for the marl and clay, tube mills for grinding, and pumps for handling the slurry, sufficient storage capacity for both the clay and marl ingredients, and also for the slurry mixture of the two previous to being transferred to the kilns. These storage tanks to be

equipped with suitable agitators in order that the slurry may be kept in a state of constant motion. Kilns 60 feet long by six feet in diameter to be used, equipped with pulverized coal for burning the slurry. Suitable cooling arrangements should be provided for storing and cooling the hot clinker before it is finally ground into cement; the stockhouse so designed that the bins will automatically discharge the finished cement into conveyors which carry it to the packing room, while the packing room would contain automatic packers for both barrels and bags. The plant would be thoroughly equipped with a heavy and durable elevating and conveying system in order to handle both the raw and finished materials.

Most of the plants heretofore erected have utilized shafting for the transmission of power, but experiments made in one or two mills have demonstrated the adaptability of electrical installation, doing away entirely with troublesome line shafts and cumbersome and unsightly piers upon which the shafting bearings necessarily rest.

Several of the modern plants at present under construction in the State of Michigan are installing electricity for the transmission of power. Such an installation costs about 10% more than the installation of shafting for transmitting power, but it effects a considerable saving in the floor area of the buildings, as shafting transmission of power necessarily requires buildings with larger floor space. In maintenance, the electrical equipment is probably less in cost of a cement plant than the shafting, though no accurate data is yet obtainable upon which to base a comparison.

In the matter of engines and boilers, it is desirable to use compound condensing engines with water tube boilers, and if the capacity of the plant is over 1,000 barrels per day, automatic stokers should be provided. Approximately it requires about one horse power for every barrel of cement capacity.

Electrical installation can be made with either the direct or alternating current. Between these two systems there is very little difference in the first cost of installation. The dynamos and motors for the alternating current are more costly than the same machinery built for the direct current, but the saving in the general system of wiring and connections for the alternating current about offsets the extra cost of the wiring and connections of the direct current system. While both systems are equally adapted for direct connected or belted drives, direct current installations with separate motors driving each machine have been most generally used, although there are now in operation two plants, one using alternating current and the other direct current motors, in which each machine is directly connected without the intervention of belt or shafting to the motor driving it.

Between the two systems of power transmission, that is, shafting and electricity, the latter is probably the more economical, but to offset this, it requires more skilled care and attention. Electricity, however, has one great advantage, in that it offers a more flexible plant, wherein

power can better be distributed and economy observed by the operation of any combination of machines, under all conditions.

Aside from the correct proportioning, mixing, and burning of the slurry to a proper degree of hardness, the power plant is a department upon which great care and thought should be exercised. As coal represents such a large item in the cost of production, the power plant installed should be such that the highest economy and efficiency can be obtained.

The cost of construction of a rotary plant can be reduced to $300.00 for each barrel of the capacity by the use of steel buildings covered with corrugated iron sides and roof, the omission of electrical equipment and the installation of a less costly power plant. The cost of construction can be still further reduced by the construction of frame buildings and the omission of all labor-saving devices throughout the plant which would necessitate the handling of a large part of the raw, unfinished product by manual labor. Such construction would necessarily increase the cost of production of the finished cement and thereby decrease the profits.

The preceding outlines contemplated the use exclusively of rotary kilns, but there is yet an entirely different system which can be installed, and for which the cost of erection would not exceed $200.00 for each barrel of the capacity. This refers more particularly to the installation of set kilns, together with such machinery for mixing and grinding the marl and clay or marl and shale in a semi-plastic condition, forming same into bricks which are afterwards dried and then burning the raw material in some form of a set kiln. The Dietsch and Schofer kilns, classed as the best of this type, require the expenditure of a large amount of manual labor in order to prepare the raw material, charge the kilns and handle the clinker, after it has been thoroughly burned. Small consideration is given to this method of manufacture in this country at the present time, and it has been almost entirely superseded by the rotary kiln, principally because of the increased production of the rotary kiln over the set kiln, and the opportunities offered with the rotary system of utilizing mechanical devices for handling the raw and finished products, and thus effecting a large saving in the item of labor. Assuming the capacity of a rotary plant at 1,000 barrels per day, it requires about nine months to complete the erection, and about three months thereafter, or one year after starting erection, before it is in full running order, and turning out its maximum capacity of marketable cement.

With the progress made in the Portland cement industry during the past five years, it is not a profitable venture to install less than three or four kilns on the erection of a new plant, and the plant should be so designed that the buildings can be readily increased and the capacity doubled or tripled without interfering in any way with the operation of the initial plant. The larger profits in the present condition of the cement market are to be derived from large productions.

During the construction of the plant it is absolutely important that careful consideration be given to the selection of a competent superintendent, master mechanic, electrician and chief chemist, in order that they may report for duty during the last stages of construction, and thus become familiar with the plant. These heads representing the executive force at the mill, should be men who have a thorough experience and knowledge in the manufacture of Portland cement, operating under similar conditions. Upon the skill of these men. depend in a large measure, the prospective profits to be derived from the investment. Many mistakes have heretofore been made by filling these positions at the mill with men who have had no experience in the manufacture of cement. Upon these men, working in harmony with a careful and efficient higher management, depends in a measure the success of the venture. It is generally conceded by all who have had experience in the manufacture of Portland cement that it is one of the most difficult and trying lines of manufacture. This is due to the excessive wear and tear on the machinery, due to the hard and constant use to which it is put, requiring constant watchfulness in order to detect defects and wearing parts, with skill and judgment, in remedying the same before final breakdowns occur, necessitating the shutting down of the entire plant.

The cost of manufacture varies greatly in each plant, ranging from 80 cents to $1.40 per barrel of cement produced. This variation depends on several reasons, principal among which is the general design and construction of the plant, efficiency of the entire management, daily condition of the machinery, cost of all raw materials delivered at the mill, including marl, clay, and coal, and cost of labor and size of the mill.

A brief summary of the foregoing facts would therefore tend to show that a cement proposition should be carefully handled from the earliest stages of its development, until the plant is finally erected, after which the success or failure of the venture depends in a great measure on the skill and competency of the engineers who have erected the plant and reported on the general conditions favorable to manufacture, together with the general management selected to handle the business of the company.

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The views accompanying this article are as follows:

Plate IV. General exterior view of an eleven-kiln plant.

Plate V. General plan of a complete plant having an installation of four kilns with sufficient floor space for installing the necessary grinding machinery to bring the capacity up to 1,000 barrels per day, which would only necessitate the extension of the kiln building.

Plate VI. General interior view, showing a modern slurry department in operation.

Plate VII. General view showing a modern rotary kiln 60 feet long by 6 feet in diameter.

Plate VIII. General interior view showing the front hoods of a battery of eight rotary kilns with hot clinker elevators, pulverized coal bins with apparatus and piping for forcing coal into the kilns.

Plate IX. General plan of a complete plant having an installation of three kilns, without provision for future extension.

Plate XIII. General interior view showing batteries of ball and tube mills in operation grinding Portland cement clinker.

Plate XIV. Four views as follows:

A. A modern office building with chemical and physical laboratories and a few sleeping rooms for superintendent and his assistants.

B. View showing section of a stockhouse under construction to have self-discharging bins.

C. View showing bottom of concrete slurry pits under construction, with piping and valves being set in position for handling the slurry mixture.

D. View showing a dry marl deposit with car and steel rope attached, for hauling the marl from the bed to the slurry department of the mill.

Plate XV. General exterior of a four-kiln plant.
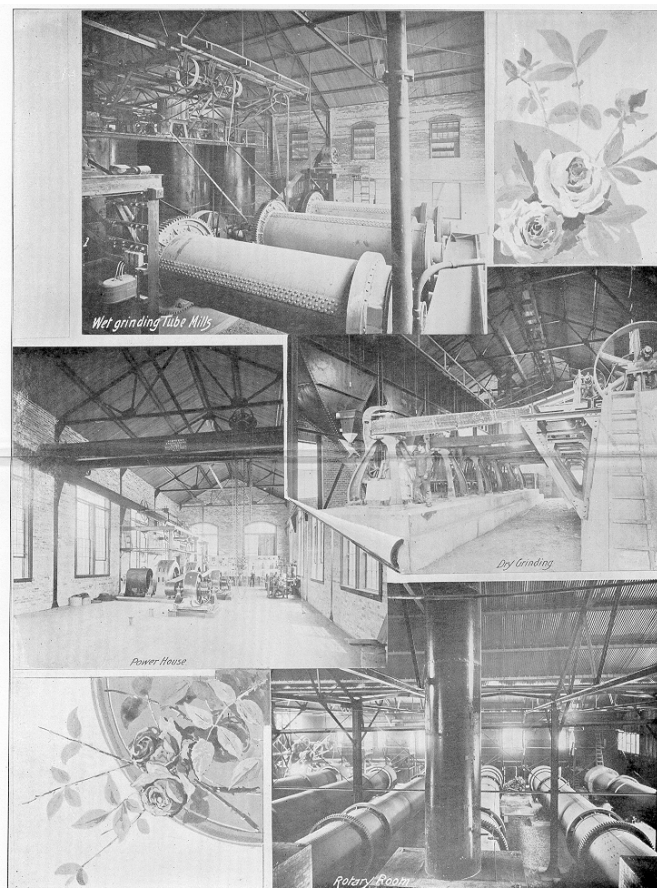
Plate XII. Views in Newaygo Cement plant, by R. L. Humphrey.
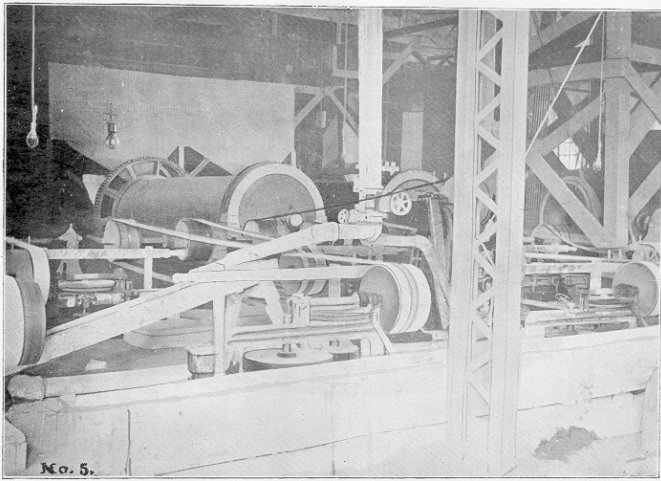
Plate XIII. General interior view showing tube mills.

Plate XV. General exterior view of a four kiln plant.

Plate XIV. A.—Office building with laboratories, etc.
B.—Stockhouse with self discharging bins under construction.
C.—Bottom of concrete slurry pits under construction.
D.—Dry marl deposit with hauling arrangement.

CHAPTER VIII.
NOTES ON THE ORIGIN OF MICHIGAN BOG LIMES.
BY A. C. LANE.

§ 1. Introduction.

It was the original intention to have this report prepared entirely by Mr. Hale, but the subject grew upon him, just as the Portland cement industry has grown in the State. Moreover, work like that which Mr. Davis, and Lathbury and Spackman have done seemed too large to be incorporated without credit to them as authors. Other information also kept coming in which deserved an incorporation, that I could myself, with less delay than any other, perform, and at the same time insert some comments on the theories of the origin of boglimes, presented by the others, that I could not very well insert into their papers.

§ 2. Origin of boglime, chemical considerations.

It must not be forgotten in discussing the origin of these fresh water lime oozes, limestone doughs, so to speak, that it is perfectly possible for more than one method of formation to produce very similar material. It is possible that the Indiana geologists may be right[1] in their conclusions as to the origin of their deposits, and Davis and Hale also right as to the origin of those boglimes they have studied. But the crucial point in discussing any theory of purely chemical precipitation is this: Is there any evidence of such saturation of ground water with calcium bicarbonate, that any loss of temperature and pressure likely to exist will cause precipitation by purely chemical means? Therein lies the importance of the tests made by and for Mr. Hale, given above[2] and we may also compare, for the hardness of spring water, analyses 52-80 of my paper on the water analyses of this State.[3] In these $CaCO_3$ varies from 0.12 to 0.40 parts per thousand,[4] yet in only five cases is it over .20
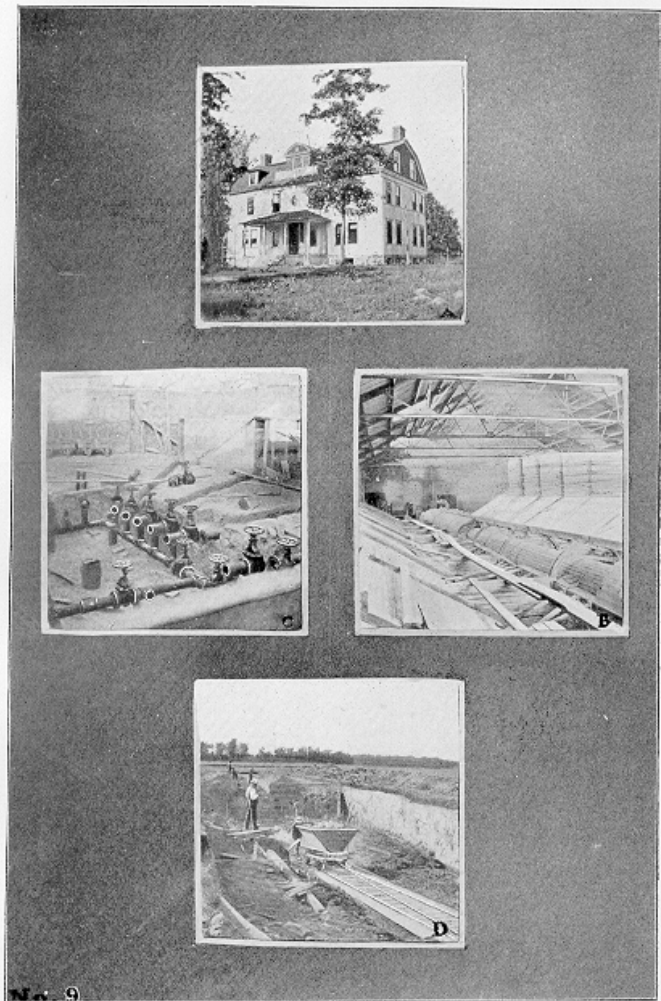
of carbonate or bicarbonate. To these analyses may be added one of the Owosso mineral water which is a natural spring, flowing from the side of the hill about 11 barrels a minute, at a temperature of 50° F.

	Parts per M.
Calcium bicarbonate	.367
Magnesium bicarbonate	.273
Iron bicarbonate	.227
Sodium and potassium chlorides	.030
Silica and alumina	.009
	.906

Mr. J. G. Dean of the Peninsula cement plant informs me that the water of Goose Lake, near the mouth of their intake yielded:

CaO	.110
MgO	.044
$(Fe, Al)_4O_3$	tr.
SiO_2	.004
SO_3	.014
CO_2	.108
$(Na,K)_2O$	.004
	.284

This implies .262 parts per thousand of calcium and magnesium carbonate, and if this is saturation for average lake conditions, then about one-third of the ground waters above referred to reach it.

Treadwell and Renter made no researches on the solubilities of calcium and magnesium carbonates together in the same solution, but as they find that calcium carbonate may exist to the extent of only .238 parts per thousand, if no free CO_2 is present, it must be near the point of saturation.

The solubilities of the carbonates are so important and the paper is so comparatively inaccessible here, and besides has a number of misprints, and misplacements of text, which Mr. Treadwell has kindly corrected for me, that I think it worth while to give the following summary in the hope that some of our cement factory chemists may feel impelled to continue an investigation, in which the survey might coöperate.

[1]Twenty-fifth Annual Report, p. 48.

[2]PP. 46 and 118.

[3]U. S. G. S., Water Supply Paper No. 30.

[4]Grams per kilogram, ounces per cubic foot nearly.

Abstract of article "Ueber die Loeslichkeit der Bicarbonate des Calciums und Magnesiums von F. P. Treadwell and M. Reuter" with 11 figures in the text. Zeitschrift für Anorganische Chemie, Vol. 17, p. 170.

It is well known that bicarbonated water gradually becomes cloudy upon exposure to the air, while calcium carbonate separates as a thin crystalline film on the surface of the fluid, and that the separation increases as the absorbed CO_2 escapes. It follows that if calcium bicarbonate was in solution, the solubility of the same stands in relation to the free CO_2. Data as to the solubility of this salt are rare in literature; indeed, its very existence has been doubted. It was accordingly of interest to investigate the existence and solubility in carbonated and non-carbonated waters of bicarbonates especially of the alkaline earths. Calcium, magnesium, and sodium bicarbonate came within the range of investigation. The method employed for the special case of the calcium salt may be briefly sketched.
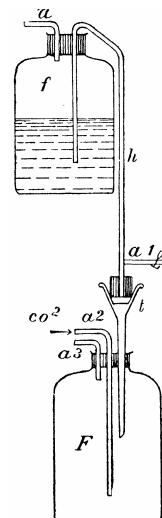
Figure 16. Apparatus for filtering bicarbonate solution.

Distilled water was saturated with CO_2 and CaO in a closed bottle, the partial pressure of the CO_2 on the fluid being one atmosphere, i. e., the gas above the water was pure CO_2.

Fig. 16 shows the apparatus used for filtering off the water from the upper bottle f, where the quicklime was to the lower F without allowing access of air and loss of pressure of carbon dioxide.

The solution, filling about the half of a large bottle, remained after filtration but without alteration of the partial pressure, clear for days,* and the *per cent of CaO does not alter in the slightest*, as is evident from the analyses below.

A part of the CO_2 above the water was replaced by air, until separation of carbonates was observable. This is the point at which the most possible CaO can be taken up, for the temperature and pressure then prevailing. By successive lessening of the partial pressure of the CO_2 the calcium was more and more separated, until finally when the partial pressure reduced to 0, no further alteration in the lime took place. The water then contained, as was shown by analyses, *calcium and CO_2 exactly in the ratio to form bicarbonate*. Accordingly an aqueous solution of calcium bicarbonate is present.

The problem was then to determine exactly at each time the partial pressure of the CO_2 resting upon the fluid as well as the per cent of CaO and CO_2 in the solution. To this end the apparatus illustrated by Fig. 17 was used.

*The experiments were performed at a constant temperature and pressure. The mean temperature of 15 degrees Celsius was chosen (59° F.), which it was possible to keep exactly only by placing the

apparatus in a room which was not subject to great variations (amounting to 1 to 2 tenths of a degree during the whole investigation).

The slight differences in the temperature could be neglected but the variations in pressure were considerable, so that all the data had to be reduced to the normal conditions of 0 degrees and 760 mm. of mercury pressure.

The bottles F_1 and F_2 contain two of the solutions to be investigated separately. The gas is drawn out through the tubes r_2. These are perforated at distances of about 2cm in their vertical parts (so as to get a fair sample of air), and outside of the neck of the bottle are bent at right angles. The horizontal parts have glass stopcocks, h_1 and h_3, and T pieces, t_1 and t_2, and n_1 and n_3 are pressure level tubes, which can also be closed by stopcocks. Mercury is the fluid that fills them. In their prolongation the tubes open into the common capillary C, which has a small funnel, n_2, above, and below is closed by a thick walled rubber pipe and clamp. The arrangement is to avoid as far as may be, the injurious space between the cocks h_1 and h_3 and the opening of the capillary pipette. If the cocks h_1, h_3 and s are closed and the other cocks open, by raising the level tubes n_1 and n_3, all of the air will be forced out of the tube system and the same will be gradually filled with mercury. When this has risen to the desired height in n_2, q_4, h_2 and h_4 are closed, and the thick tube at s is fitted over the pipette filled completely with mercury. The suction is applied at O (by a Sprengel pump) while the cocks s and h (or h_3) is opened until the globe of the pipette is full and then s is closed. It is advisable to repeat this operation two or three times. After the last time, first h_1 or h_3 is shut and the capillary of the pipette is filled with mercury by opening the clamp of q_4 a moment. The gas is now ready for analysis, which was done by Hempel's Exacter method. (Gas analytische methode, p. 45.)
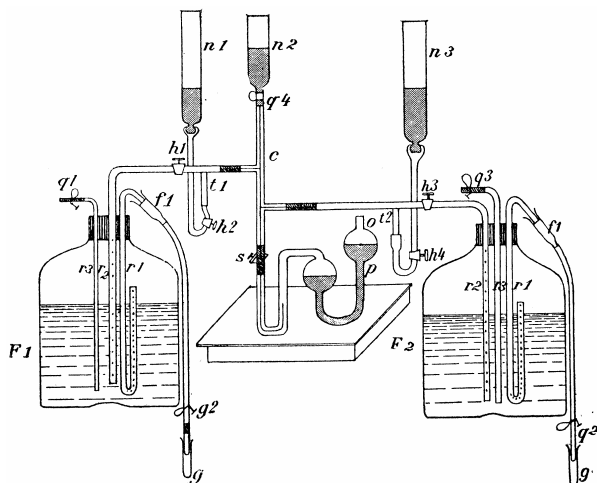
Figure 17. Treadwell and Reuter's apparatus.

The analysis of the solution falls into two parts.

a. Determination of the total CO_2.

b. Determination of CaO and combined CO_2.

Here also it is important to obtain an average sample, for it is clear that the water does not give off its absorbed CO_2 equally in each horizontal stratum. The upper

layers lose the most, the lower the least gas. Referring again to Fig. 17, the tube x goes through a perforation in the rubber cork. It is bent inside the tube and perforated in the ascending part at distances of 1cm. It works like a syphon. Any carbonate crystals possibly taken with the fluid are held back in the little filters at f. These are short glass tubes, somewhat expanded at the end, the cone of which is best packed with asbestos. Upon this goes a rubber tube, which ends in a short glass tube, over which, to prevent evaporation, a short test tube is tightly fitted. By light pressing on the clamp, q_2, any amount of water desired can be taken.
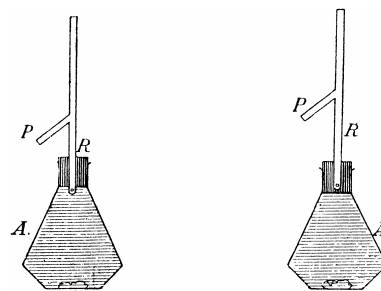
Figure 18. Bottle.

The small flask A* (Fig. 18) is exactly gaged by weighing with water filled up to a certain mark, and can be closed by a rubber cork through which goes a ⋏ shaped glass tube (E) which has a side opening a little above the end of one of the forks which is closed. To fill the flask a fine aluminum wire is put into it, the water to be tested is allowed to flow in as quickly as possible along the side, it is corked at once and the tube E raised so that the side opening is in the rubber cork, and the outer air fully excluded. The tube E is thoroughly washed with distilled water, the upper end joined to the graduated tube B and the side fork of E is connected with a reservoir of HCl (S) † by the rubber tube N, which is closed by a clamp. The rubber connections are tightly tied, then the sphere K emptied by lowering the mercury reservoir D and closing the cock L. The air which is now in B, by proper turning the cock L and raising the reservoir P again, may be driven out of the apparatus, after taking away the rubber connection to the Orsat tube. Repeating this operation several times, K is finally emptied. Now pressing the tubes E carefully into the cork so far that the side opening appears below it, the HCl finds its way into the flask A and there is a lively evolution of gas, and the mercury falls rapidly in B.** When it is about three-fourths full, the reservoir D is suddenly lowered and the cock L closed. In the meantime the Orsat tube O, full of potash (K_2O) has been connected with D and the gas is driven (noting the volume, temperature, and height of barometer) from D into it, by turning L and raising D.

Then the connection between A and B is restored and another lot of gas generated. If the gas comes too slow, the flask A may be warmed, under certain special precautions.

Finally when only a little gas is given off a few c.c. of HCl (1:2) are put into the flask A, and finally, more is added and boiled but with care that no water goes over into B.

After all the CO_2 of the expelled gas has been fully absorbed, and the amount of water vapor subtracted from the sum of the total readings, the volume of total CO_2 is thus obtained. The operation takes one-half to three-quarters of an hour.

Lime. The lime was titrated with 1-10 normal HCl, using methyl orange as indicator.

The partial pressure (amount of CO_2 in overlying atmosphere) is lessened, as was remarked at the beginning by replacing a part of the CO_2 over the fluid by air. The tubes r_2 and r_3 with their prolongations, t_1 and t_2 serve the purpose; these outside the bottles are bent at right angles and closed by rubber tube and clamp, and fit snugly into the hole of the cork, but can yet be moved up and down in the same.

The process is as follows: The ends of the rubber tube at t_1 and t_2 are taken off. The clamps q_1 opened and from t_1 and t_2 the air sucked with an air pump. If one wishes to lessen the partial pressure but slowly, the gas is replaced by air without admitting the air through the fluid. The partial pressure decreases much faster if the air is allowed to enter through the solution, after that diluting the atmosphere charged with CO_2 that rests on the surface of the water. Finally the apparatus is closed and in either case one must wait several days for equilibrium to be established.

*Treadwell "Analyse der Passugger Mineralquellen."

†This figure is omitted.

**Care is to be taken that the pressure is less than an atmosphere.

1. Calcium bicarbonate.

For the details of process of formation and filtration without change of pressure from quicklime and water charged with CO_2, reference must be made to the original Experiment 1. Solution was kept in a room of constant temperature 24 hours. The solution which stood under the pressure of one atmosphere CO_2 was analyzed four successive days and the total CO_2 and CaO found constant, to wit: 2.854 parts per thousand of CO_2 and 1.156 Ca CO_3, of which 0.509 is CO_2 equivalent to 1.872 CaH (CO)$_3$ with 1.018 CO_3.*

The lime was not quite pure, conatining in 100 ccm water, in grams:

0.0005	....	$CaSO_4$
0.0006	....	SiO_2
0.0010	....	Fe_2O_3
0.0021	....	impurity

Experiment 2 was conducted with a CO_2 pressure of 67.9 mm mercury.‡ On the surface of the solution was to be observed a faint inappreciable crystalline secretion of calcium carbonate. It follows that from the partial pressure of 70 mm (when CO_2 is 9% of the atmosphere) up, the solubility of the bicarbonate increases too slowly to be determined in this interval with present apparatus.

*The detailed figuring is as follows:

(a) CO_2, 92.67 cc. water used,

4 or 5 times repeated boiling gave	177.3 ccm. gas
After absorption with K O H.........................	42.6
CO_2	134.7
Pressure 724.7 mm. mercury temperature	10°.4 C
Reduced to standard pressure (740mm.) and temperature 0°C=	121.74
Equivalent in 100 cm. of water	131.40
Milligrams CO_2	258.4
A repetition gave	258.8

(b) Ca. In all four cases, per 100 ccm. water 22.34 cc. 1-10 normal HCl of coefficient 1.0346 was used; i. e., 23.11 cc, 1-10 HCl corrected, corresponding to 115.6 $CaCO_3$ with 50.9 CO_2 or 187.2 CaH_2 $(CO_3)_2$ with 101.8 CO_2.

100 cm. solution evaporated to dryness gave......	.1180 gCO_3
By titration above	.1158
Indicating	.0025 impurity.

A fair correspondence.

‡9.98% CO_2 in the air at t=12.50 and 726.1 mm. pressure.

Below this the separation of carbonate begins when by dilution of the CO_2 with air the pressure of CO_2 is lessened, and depends on the evaporation of the CO_2 from the water into the air. This reaction ceases when no more calcium is precipitated and the gas analyses show no increase in partial pressure. Numerous tests have shown that to determine equilibrium, the gas analysis is surest, for a slight decrease in calcium in solution corresponds to a relatively great change of partial pressure, and if two successively performed gas analyses are alike, the solubility of the bicarbonate is alike, as test 3 showed. At the beginning of the test the atmosphere above the water contained 8.94% CO_2. Air was sucked in and the gas above the water at once tested. The CO_2 was but 3.47%. After a while a second sample of the gas as well as one of the water was investigated. The CO_2 had risen to 6.23%, nearly double, while the bicarbonate has dropped off about one part per liter. After this point the CO_2 and lime remained constant.*

Ca.	Per 1000.		% CO_2	Pressure.
	Ca.	Bicarbonate.		
Experiment 2............ {	.462 .463 .439	1.872 1.876 1.776	8.94 3.47 6.23	.... 67.9
Experiment 3............ {	.433 .433	1.755 1.755	6.04 6.02	....

Treadwell and Reuter give the following other observations on the solubility of $CaCO_3$ in carbonated waters.

Grams $CaCO_3$ in liter.	Tem.	Authority.
.7003..................	0°	Lassaigne Journ. p. Chem. 44, 84.
.8803..................	10	Lassaigne Journ. p. Chem. 44, 84.
.6700..................	....	Bergmann Arch. Pharm. (1874) [3] 4 : 145.
1.8000..................	....	Bischoff Jahr. Chem. phys. geol. (quicklime).
2.8000..................	....	Bischoff Jahr. Chem. phys. geol. (quicklime).
2.5000..................	....	Marchand, 2.64, (pure) from Caro.
1.0 to 1.5..............	....	Struve, 2.64, (pure) from Caro.
3.0.....................	....	Caro inaugural dissertation.
.9832..................	21°	Warrington p = 7.483 mm.

*Details of figures are as follows:

Partial pressure P = p (percentage reduced to normal) X 7.60

Experiment 2. Zero point 2.2.	Height of mercury in barometer tube of apparatus.	Temperature in degrees centigrade.	Barometer in mm.
Initial volume.......................	58.0	12.5	726.1
After absorption of CO_2..............	127.7	12.5	726.1

Tension of water vapor at 12.50 5' = 10.8.

Initial volume stood under the pressure 726.1—(55 8 + 10.8) — 659.5.

Gas — CO_2 stood under the pressure 726.1 — (121.5 + 108) = 593.8.

Therefore percent air = 659.5 divided by 593.8 X 100 - 90.02 and percent CO_2 = 9.98.

According to these data the solubility of calcium carbonate in carbonated waters varies from 0.7003 to 3.0 grams per liter. The statements of Bischoff that the solubility of $CaCO_3$ is dependent on the purity of the material which furnishes the CaO or CO_2 can not be confirmed, but at 15°C, saturated calcium bicarbonate solutions gave, whether made of pure or impure limestone, from 1.13 to 1.17 grams per liter of $CaCO_3$. At 13.2°C. the solubility was 1.31 grams per liter for the $CaCO_3$ from common quicklime, and 1.30 grams per liter for the pure material. At a temperature of 2.8°C there was 1.45 $CaCO_3$ in the liter, showing a greater solubility at the cooler temperature. Long standing produced no increase in calcium.

A study of the solubility of calcium carbonate from an analogous point of view is presented by a work of Schloesing Compt. Rend. 74:1552. His table is as follows, but he does not describe how the partial pressure was computed:

Pressure of CO_2 in atmospheres, t = 16°.	Total $CaCO_3$ per thousand.	Total CO_2.
0.000504.	.0746	.06096
0.000808.	.0850	.07211
0.00333.	.1372	.1230
0.01387.	.2231	.2184
0.0282.	.2965	.3104
0.05008.	.3600	.40863
0.1422.	.537	....
0.2538.	.6334	1.0720
0.4167.	.7875	1.500
0.5533.	.8855	1.8460
0.7297.	.9720	2.2700
0.9841.	1.0860	2.8640

We may also add as of interest to us in this connection the following extracts from Roth's Chemical Geology.

Vol. 1, p. 44, solubility of gases and other substances in water.

Baumert found in the air absorbed by rain water (t=11.4°C; after a long rain) 1.77 volumes CO_2, 33.76 O, 64.47 N, while in atmospheric air there is but 1 vol. CO_2 to 628 of O.

Bunsen says that 1 volume water absorbs at 760 mm (atmospheric) pressure (i. e. about 1 atmosphere):

	At 10° C.	At 15° C.	At 20° C.
O	1.03250 or 1	0.02989	0.02838
CO_2	1.1847 36.4	1.0020 or 33.5	0.9014 or 31.8
N	0.01607 or 0.50	0.01478 0.49	0.11403 or 0.4

Thus more CO_2 is absorbed at low temperatures. The air free from CO_2 absorbed at 23°C consists of 34.91 volumes N and 65.09 O.

Bunsen estimates from the power of absorption the ratio of the gasts in rain water, supposing atmospheric air to be 20.951 O and 79.007 N and 0.042 CO_2, as follows:

	5° C.	10° C (50° F.)	15° C. (59° F.)	20° C.
CO_2	2.68	2.46	2.26	2.14
O.	33.97	34.05	34.12	34.17
N.	63.35	63.49	63.62	63.69

Under otherwise similar relations the amount of absorbed gas is proportioned to the pressure. Peligot found in 1857 2.4 per cent CO_2 by volume in the air absorbed by rain water.

P. 45. According to Boussingault and Levy 100 volumes of air from a soil not rich in humus and not manured for a long time, contain at least 25 times, that from humus rich soil 90 times, and that from recently manured soils as much as 250 times, as much CO_2 as atmospheric air,— the maximum in 100 volumes of air 9.74.

Pettenkofer found in the ground air of Munich down to 4 meters depth a maximum of 1.838 per cent CO_2.

P. 48. Solubility of Ca CO_3.

Fresenius: 1 part in 10,600 cold or 8,834 boiling water; Graham, 0.0343; Bineau, 0.016 to 0.02; Cruse, 0.036; Peligot, 0.020; Schloessing, 0.0131 in 1,000. If at 15°C water takes up 1 volume of CO_2 (i. e. about 0.2% by increase of pressure and lower temperature more), the amount of carbonate dissolved increases. In water saturated with CO_2 (which does not occur in nature) is dissolved in 1,000 parts of water, according to:

Bischof of chalk	9 to 10
Cossa of chalk of Luneburg (18°,740 mm)	.835
Carrara marble (7.5° to 9.5°, 753 mm)	1.181
Cossa Carrara marble (20.5—22°, 741—746 mm)	.9487
Cossa Carrara marble (26—28°, 737—742 mm	.855
Calcite 12° 754.2 mm	1.217
Iceland spar 18°, 735.1 mm pressure	.970
Precipitated $CaCO_3$ at 18° and 735.1 mm.	.950
Boutron and Boudet (several atmospheres pressure of CO_2)	1.16

According to Warrington at 13° and 747.3 mm. pressure water with 1% ammonium chloride dissolves 1.050 $CaCO_3$.

If to a solution of $CaCO_3$ in CO_2 water $MgCl_2$ is added the solution will stand weeks and can even be boiled without clouding. By continued evaporation magnesium carbonate is precipitated.

According to T. S. Hunt the solubility of $CaCO_3$ is increased also by addition of sodic or magnesic sulphate, because bicarbonates of soda respectively magnesia form.

According to Northcote, 1,000 parts of saturated salt solution contain 1.77 $CaCO_2$.

P. 50. *Magnesia carbonate* is somewhat more soluble in carbonated water than calcium carbonate. Merkell's results are:

In 1,000 parts at 50° C. under a pressure of CO_2 of:

1 atmosphere	2	3	4·5	6
1.31	1.34	7.5	9.0	13.2

Cossa 18°, 750 mm pressure, from magnesite.....	.115
Bischof, 750 mm, pressure from magnesite.......	.049
from pure magnesia............	.135

P. 51. Fresh precipitated magnesia carbonate is quite soluble in a solution of the sulphate and precipitates Ca CO_3 from solution in carbonated waters.

Vol. III, p. 417 Engel and Ville, under pressure of 1 atmosphere CO_2, the solubility varies with the temperatures, 19.°5' C. 29°.3 C. 82° C. as follows: 257.9, 219.95, 49.0; the presence of alkaline chlorides, sulphates, and carbonates and magnesia salt increases the solubility of magnesium carbonate.

Dolomite. Vol. I, p. 52 Cossa at 18° C. 750 mm. pressure, 1,000 parts of water dissolve:

of dolomite $(CaMg (CO_3))_2$................	.310
Of mesitine $FeMg (CO_3)_2$....................	.075
At 16° C, 758 mm carbonated water dissolves of $(Mg Fe_3O_{12})$..........................	.115
A. Kupffer, of dolomite	.2967
Siderite $FeCO_3$. Wagner, at 4 or 5 Atm. pressure of CO_2. $FeCO_3$......................	.725
Cossa 18°, 760 mm........................	.720
Bischof	.60755
K. von Hauer, usual pressure, iron dust of precipitate	.91

Carbonates of alkalies lessened solubility.

Iron Carbonate.

III, p. 417, J. Ville found in carbonated water..	1.39
E. Ludwig Wilhelm's quelle water............	0.9648

Schloesing worked thus: crystallized pure calcium carbonate was suspended in water and through the fluid air charged with CO_2 passed until gravimetrically no increase in calcium carbonate could be detected. But there is probably an error in calculation, for Schloesing in the strongly carbonated solution, assumes carbonate together with bicarbonate to be present. For instance, he computes:

1. $CaCO_3$ (neutral) according to special tests of solubility .... .0131 g in liter	
All calcium as carbonate.....................	.360
Difference calcium carbonate existing as bicarbonate	.3469

Accordingly he refers to the three following parts of CO_2:

CO_2 in the neutral calcium carbonate........	.00576
CO_2 in the bicarbonate.....................	.30530
CO_2 free	.09757
	.40863

Caro denies the existence of calcium in carbonate, from the following test. A solution of calcium bicarbonate with excess of CO_2 was allowed to stay exposed to the air until calcium carbonate began to form at the surface, and then the CaO and CO_2 of the clear solution determined. Caro gives the following figures : 5 cm. solution contains:

$0.00270 CaCO_3 = 0.0015176 + 0.0011924 CO_2$, or in grams per kilogram:

$0.540 CaCO_3 = 0.35352$ plus $0.23848 CO_2$.

"Total CO_2 was determined by precipitation of 5 ccm. with ammonical $BaCl_2$. The computed CO_2 is 0.0142 gr. (.142 gr. per 100 cm.).

Caro's result is thus: Combined CO_2 = 0.0011924 g., half combined and free = 0.0142 g.

The ratio of two numbers is 1 : 10, which certainly points to the presence of *calcium bicarbonate* and much free CO_2.

A series of tests, Nos. 3 to 12, showed that the three values, partial pressure in per cent at 0° C. and 760 mm. pressure, amount of calcium bicarbonate and free CO_2 decrease together so that when the first and last become zero the total CO_2 is just equal to the amount needed for calcium bicarbonate. From this the conclusion is justified that calcium bicarbonate is a permanent salt in solution, whose solubility is for the mean barometric pressure at Zurich and the temperature of 15° 0.38509 per liter. Two tables and curves are given, showing the solubility of this salt, first as a function of a partial pressure, and second, as a function of the amount of free CO dissolved. We do not repeat the curves, which can be constructed from the table below, of the original figures 5 and 6.

SOLUBILITY OF CaO IN BICARBONATED WATER AT 15° C. = 59° F. AND 760 mm. PRESSURE.

	In Air.		In Water (parts per thousand).						
Test.	% CO_2.	Pressure of CO_2.	Free CO_2.	Calcium bicarbonate.	Fixed CO_2.	$CaCO_3$.	Ca.	Total. CO_2.	CaO.
1......	100.00	760	1.872	1.872	.509	1.156	.462	2.587	.647
2......	8.94	67.9	1.574	1.872	.509	1.156	.462	2.587	.647
3......	6.04	45.9	.863	1.755	.477	1.083	.433	1.817	.606
4......	5.45	41.4	.528	1.597	.434	.986	.394	1.396	.552
5......	2.18	16.6	.485	1.540	.418	.951	.380	1.321	.533
6......	1.89	14.4	.347	1.492	.405	.921	.368	1.157	.516
7......	1.72	13.1	.243	1.331	.362	.822	.329	.967	.440
8......	0.79	6 0	.145	1.249	.339	.771	.308	.823	.432
9......	0.41	3.1	.047	.821	.223	.507	.203	.493	.284
10......	0.25	1.9	.029	.595	.162	.368	.147	.353	.206
11......	0.08	0.6	....	.402	.109	.248	.099	.214	.139
12......	....	....	....	.385	.105	.238	.095	.211	.133
13......	....	....	....	.385	.105	.238	.095	.211	.133
14......	....	....	....	.385	.105	.238	.095	.210	.133

The data given above lead to the inference that calcium bicarbonate may exist in very dilute solution.

In consequence, it was of interest to determine the electric conductivity of this salt, for Kuster says* that the bicarbonate in very dilute solutions is hydrolytically separated since its solution colors phenolphthalein feebly red. This was found true, but the result of electric tests was that "the conductivity reached no maximum, even in the greatest dilution, as is usually the case with salts that are hydrolytically broken up," and bicarbonate of potash behaved in the same way.

*Z. Anorg, Chem. 13, 127.

Calcium bicarbonate in solution with NaCl.

From Kippenberger's tests it appears that calcium carbonate is about three times more soluble in concentrated salt solutions than in water. This greater solubility is probably dependent on the formation of

double salts. Therefore it was to be expected that these double salts, like Karnallite, would be fully decomposed in dilute solution, so that the solution of calcium carbonate in dilute solutions of salt would be similar to that in pure water, and a similar behavior should be found for the bicarbonate.

Tests performed as for pure water on dilute saline solutions charged with CO_2, which contained 5 grams per liter NaCl, result as follows:

ABSTRACT OF TABLES 3 AND 4.

				0.41	0.50	3.16	6.07	11.47	16.95	%CO₂ at 0⁰ and 760 mm in gas
.082	.081	.083	.086	3 4	3.8	24.0	46.1	87.2	128.8	pressure of CO_2
.090	.089	.092	.095	.121	.182	.292	.368	.529	.539	Ca
				.133	.201	.321	.405	.582	.593	CO_2 corresponding to $CaCO_3$
.205	.203	.208	.216	.303	.456	.730	.921	.1323	1.348	$CaCO_3$
.332	.329	.337	.349	.409	.739	.1183	.1492	.2143	2.184	Bicarbonate
				.003	.027	.135	.235	.1101	1 325	Free CO_2

From this (comparing with tables 1 and 2), it is apparent that the solubility of calcium bicarbonate is but little influenced by the salt.

Figures 7 and 8 of the original paper showed the solubility as function of partial pressure, and as function of percentage of CO_2.

II. Magnesia bicarbonate.

No new principles involved. (Details of experiments omitted.)

1. Without alteration of the partial pressure (of 1 atmosphere CO_2) the CO_2 and MgO remained constant down to experiment 4, when the amount of CO_2 ceased to be enough to form bicarbonate of magnesia with the MgO present.

Fig. 9 and Fig. 10 (should be 8 and 9) showed the solubility of the bicarbonate as function of partial pressure and total CO_2 8 in mg.

The result is that magnesium bicarbonate does not exist by itself without a marked excess of free CO_2 dissolved in the water. The partial pressure needful thereto, corresponds to between 2° and 4° CO_2. If the partial pressure is less, the solution loses all of the free CO_2 with a part of the half combined and a mixture of carbonate and bicarbonate results. When the partial pressure sinks to 0 at average pressure and at 15° C, we have 0.6410 grs. magnesium carbonate and 1.9540 grs. magnesium bicarbonate per liter.

ABSTRACT OF TABLES III AND IV. (SHOULD BE V. AND VI.)*

.....	.....	.....	.....	.....	.003	.014	.021	.033	.009	.062	1.07	1.35	1.54	4.45	.547	18.86	CO_2...........
.....	.....	.....	.....	.....	.03	1.1	1.6	2.5	1.6	4.7	8.2	10.3	11.7	33 8	41.6	143.3	pressure.
.518	.511	.520	.529	.538	.545	.566	.594	.655	.788	.895	1.224	1.492	2.006	2.016	2.016	2.006	Mg.
.859	.847	.861	.877	.988	.9 2	.938	.983	1.084	1.305	1.433	2.028	2.471	3.329	3.339	3.339	3.339	MgO.
.935	.923	.939	.955	.968	.983	1.022	1.072	1.181	1.4 2	1.561	2.210	2.692	3.639	3 639	3.639	3.639	CO_2 combined.
.601	.602	.613	.569	.611	.612	.632	.659	.791	1.037	1.101	1.789	2.293	3 236	3.639	3.639	3.639	CO_2 half combined.
.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.035	.966	1.190	CO_2 free.
1.536	1.525	1.552	1.544	1.579	1.595	1.674	1.742	1.972	2.449	2.662	3.999	4.985	6.975	7.3 3	8.144	8.468	Total CO_2........
1.954	1.954	2.096	1.960	2.035	2.096	2.169	2.229	2.682	3.417	3.663	5.952	7.659	10.706	12.105	12.105	12.105	Mg bicarbonate.
.041	.616	.6 5	.702	.685	.711	.719	.771	.748	.758	.701	.857	.765	.773	.....	.....	.....	Mg carbonate.

*p. 300 of the Zeitschrift.

References to the solubility of magnesium bicarbonate are very rare. Cossa and Kippenberger assume its presence only when there is much free CO_2. Merkel is cited in Roth.

IV. Sodium bicarbonate.

To close the investigation, the presence of sodium bicarbonate in dilute solution was tested. The phenolphthalein test shows that the bicarbonate little by little gives off CO_2 and the solution becomes stronger in carbonate.

Referring to Kuster's work indicating that sodium bicarbonate, by its effect in turning phenolphthalein red, is decomposed at moderate temperatures, the effect vanishing at 0° F, it is to be remarked that solutions of bicarbonate left long standing do the same, and the effect does not disappear at 0°, which leads to the inference that it has lost CO_2, and a series of four tests show this to be true.

———————

We have given above, all the data we have been able to find on the solubilities of the carbonates for different temperatures and pressures. Now for the actual temperatures and pressures, the map figured herewith (Fig. 19), gives some data as to the mean annual temperatures by the isotherms or lines which have the same annual temperature. Upon the map are also placed the temperatures of certain flowing wells, in degrees Fahrenheit.

It appears that the temperature of ground water is usually not far from 49°, increasing according to the depth of the source quite irregularly, but at times as much as 1° in 40 feet. The farther north a place is, other things being equal, the lower the temperature. But it probably goes hardly below 45°, being more or less above that according to the amount of blanketing effect that the snow exerts, and the depth of the source.

The water of all our deep lakes is cool, and in the bottoms of the deeper lakes it will often be permanently cooler than the ground-water temperature. Hence chemical precipitation can never occur in the lake more than half the year, and it will not occur at great depths. Boglime, however, occurs more in lakes originally deep, than in lakes originally shallow. Still it appears to 'be generally true that in Michigan the marl is thicker in the shallow water at the margin, and Wesenberg-Lund reports the same to be true in Denmark. This can, however, be easily explained under either theory, that of organic or chemical precipitation. But it is curious to remark that in Indiana the geologist reports* not only a deepening of the marl towards the deeper water, but a more widespread distribution, a fact which hardly agrees with their theory of the origin of the lime.

*25th Annual Report, 1900, p. 45.

Not only will the spring water that enters the lake be cool and under pressure at the bottom so that it will not lose its carbon dioxide nor calcium carbonate there, but as it approaches the surface it is liable to be diluted with rain and surface water, which as all tests and* analyses show, are far from saturated with bicarbonates† and a dilution with only 10% of rain-water would keep in solution all the calcium carbonate of any ground water of

which we know. Mr. Hale has pointed out that marl is liable to occur most in the uppermost of a series of lakes, into which presumably less surface water would enter, and this is a distinct point in favor of the theory of chemical precipitation. But it is by no means confined to such lakes. Davis' observation, that in certain lime depositing lakes, the outflow is practically equal to the inflow, does not necessarily mean that the evaporation is too small to be noticed,‡ but merely that it is nearly balanced by subterranean springs and direct rainfall. It does, however, make it almost certain that there is enough dilution of ground water springs to prevent direct chemical precipitation.
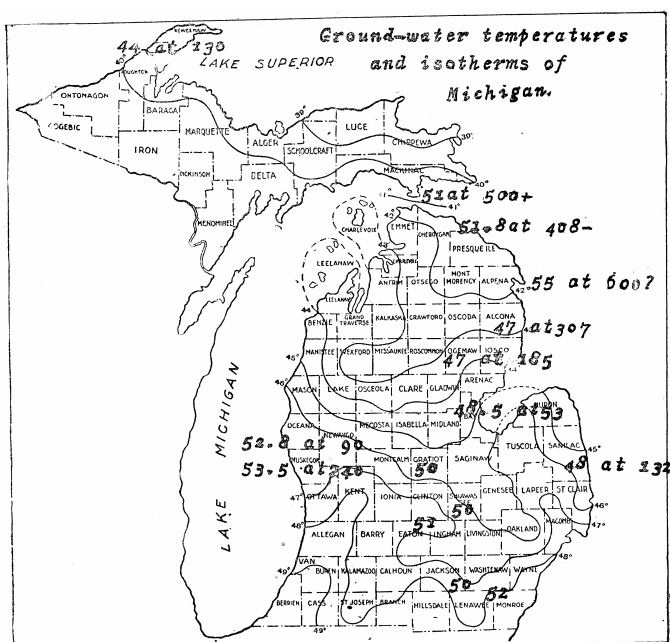

Figure 19. Reproduced from Water Supply paper No. 30, Fig. 4, with some observations on the temperatures of flowing wells.

All winter again, the water under the ice is colder than the ground water, and the escape of CO_2 is prevented. There can be no direct chemical precipitation. In the spring the influx of snow water must dilute the spring water and prevent precipitation.

Only after the hot dry weather of summer has evaporated and heated the lake to saturation point could, if ever, precipitation begin, but it seems doubtful if it could get that far.§

Considerations like the above had made the origin of the bog-limes by chemical precipitation very doubtful to me, even before Messrs. Davis and Hale made it so clear that organic life was the precipitating agent in some cases, at any rate. In fact such doubts led me to suggest to them their lines of work.

Mr. Davis' discovery of calcium succinate $Ca=O_2=(C_4H_4O_2)$, in Chara, and its lime secretions yield a new test of the origin of the fresh water limes.

Until this very peculiar salt is shown to be formed in some other way, it is a safe presumption that chara, or at

least plant life has contributed largely to lime deposits containing it. It is also found that, as Hale has remarked, organic matter always accompanies even the purest marls. Moreover, it seems to be true that in a marl analysis, in which the CaO, MgO, and CO_2 are separately and independently determined, there is never enough carbonic acid to satisfy the caustic lime and magnesia,"** even after making all allowance for the presence of calcium sulphate. While in clayey marls it might be supposed that calcium and magnesium silicates were present, in many of the purer ones the effect is too great to be thus explained, and we are forced to believe that we have the lime united to an organic acid, probably this succinic acid.

It is not uncommon in commercial marl analyses to figure from the CaO and MgO the amount of carbonates, and for many purposes this is sufficient, tout in such cases the chances are that the amount of carbonates is overestimated and the amount of organic matter underestimated some 2$.

*See also Water Supply Paper No. 31, analyses 35 to 45, and ante pp, 46 and 118.

†While as shown above rain-water selectively absorbs considerable CO_2 from the air.

‡If we look at the figures given in the "Meteorological Chart of the Great Lakes for the Season of 1899," Vol. II, No. 9, of the "Weather Bureau publications, p. 21, we see that the evaporation must be between 20 and 36 inches, and the precipitation is from 4 inches to 20 inches more.

§Yet the number of facts that must be known, accurately, evaporation, ground water supply, surface water supply, temperatures, and co-solubilities under a large range of conditions, prevent our saying absolutely that it could not occur. In fact, in such a case as the marl referred to by Mr. Hale at Corrinne, where the whole lake dries up, it must.

**For instance, the average amount of CO_2 which Prof. F. S. Kedzie found by analysis in thirty marl analyses in which CO_2 ranged from 27.13% to 44.60% was 36.28% while the amount of CO_2 required by the weights of CaO and MgO in the marl was in each case higher, the average being 38.30%, a good 2% more.

§ 3. Microscopic investigations.

Although it might seem that the subject of the origin of boglime had been pretty thoroughly threshed out, it must be kept in mind that, in view of the number of causes that are competent under proper conditions to throw down lime, no available light should be neglected. It seemed possible that a study of the microstructure of the lime with the petrographic microscope might be an aid. For comparison with them, some artifical precipitates were made for study.

(a) Microscopic precipitate by loss of CO_2 and heating.

I took a sample of water from the flowing well at the end of Hazel street, Lansing, close to the bank of Cedar river.† This well flows into the air about six feet above the usual river level and has about two feet free jet. The depth is 340 feet, but the water doubtless comes in mainly at much less depth. Within half an hour of the time of taking the water, it was heated to the simmering

point, when of course the CO_2 was practically lost. A film was seen floating on the top,—not a continuous, coating, but a lot of calcite crystals. With an enlargement of 150 diameters their crystalline character was very apparent. Hexagonal outlines were plain. They were not all simple forms, nor always the same form. Rhomb faces and hexagonal outlines were common (Fig. 20), but simple rhombohedra were not the prevalent form. In relative dimensions and habit they resemble often Fig. 21 of the Appendix to Part II of Vol. VI of our reports, or figures 11 and 13 of the calcite illustrations in Dana's System of Mineralogy. Though they are too small (about 0.02 mm) to be exactly determined, the prism or a very long scalenohedron, and the terminal rhombohedron—½ are quite probably present. The optical properties leave no doubt that they are calcite. When transmitting the ordinary ray they have much higher refraction than that of the balsam used for mounting (n=1.521), while with the extraordinary ray their index is very close to that of the balsam,—just a shade less, as it should be. (1.49) The directions of + and — extinction parallel to the diagonals of the rhomb faces are characteristic (Fig. 20). One twin with the twinning face probably—½ was observed. In mounting these crystals a second crop was formed as the water around them evaporated, considerably smaller, being half or quarter the size, and spindle-shaped, like dog-tooth spar (Fig. 20f), and the forms illustrated on Plate XI of the Appendix to Vol. VI, Part II, and Dana's figures 15 to 20.
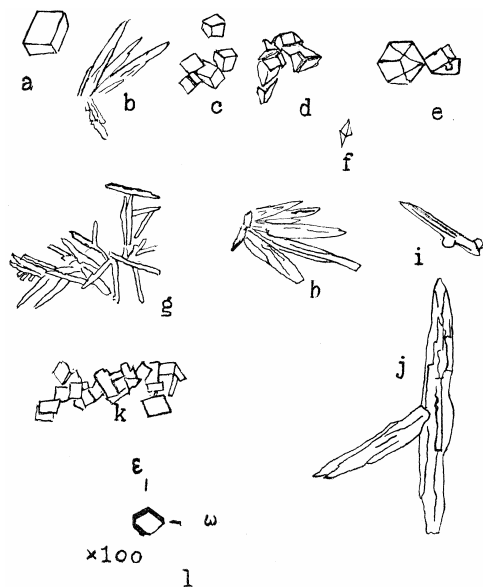

Figure 20. Crystals produced by evaporation.

No marl seen consists to any considerable degree of similar material. Had it been present in quantity, I do not think I could have failed to recognize it. It must be said, however, that every marl had been more or less dried, and therefore a certain amount of secondary chemical precipitation from the hard water of the lakes was to be expected. As a matter of fact, I noticed no material that need necessarily be ascribed even to this source.

†Temperature 50.8° F.

(b) Precipitate by evaporation.

I also allowed drops of water of the artesian well used in the Hollister block (which is 150 feet deep in white sandstone of the coal measures and probably similar in chemical character to the previous well and analyses Nos. 238 and 239 of U. S. Geol. Sur. Paper No. 31), to evaporate. In one drop the dimensions of the larger crystals are about 0.005 mm and less, about a three hundredth of a millimeter. In so minute crystals it is hard to measure angles accurately, but it appeared that a termination of the fundamental rhombohedron was combined with prismatic or acute scalenohedral faces.

In Figure 20, groups a to j were drawn by C. A, Davis from some Alma well water. I think that b and g, h, i, and j, are groups of gypsum crystals, while a, c, d, e, and k, appear to be mainly rhombohedral calcite, and f is plainly a scalenohedron. In 1 we have a crystal drawn by myself with the cameralucida with some pains to get the angles right, and the optical orientation indicated. The contrast in relief brought out by rotating the crystals immersed in balsam above a single nicol is very striking and characteristic.

(c) Chara fragments.

The calcareous Chara stems have a hollow core surrounded by a single slightly twisted row of elongate cells. The diameter is commonly about half a millimeter. The lines between the cells are continuous and produce the effect of slightly spiral ribs. This is shown in Fig. d of Plate XVI. Fragments of chara therefore, like figures b and c appear ribbed. Close to the ribs the granulation of the calcareous aggregates is very fine, while between it grows coarser,—up to 0.02 mm. The boundary between the various areas or patches of uniform polarization color appears vague or crenulated. This interdigiting effect or crenulation is especially shown in c, and sometimes needs the use of crossed nicols to bring it out. Even very small fragments show patches of different polarization colors. Sections a and e are cross-sections of chara stems drawn by Mr. B. O. Longyear and myself. Such sections are hard to prepare and seem never to occur accidentally. The other sections b to d are such as will ordinarily be found in looking at a sample of marl.

(d) Blue green algae.

The apparently calcareous pebbles which are really concretions of calcium carbonate thrown down or out by Schizothrix, have already been described by Davis. Similar pebbles are noted as occurring in the marl in certain horizons at Goose Lake, from which the Peninsular plant take their marl. The pebbles in marl referred to in the discussion of Prof. Fall's paper before the Engineering Society are probably similar, and the calcareous coating on dead branches and shells also. The "pebbles" on the southeast side of Zukey Lake at Lakelands, which turn brown on the side exposed to the light, are of the same nature.
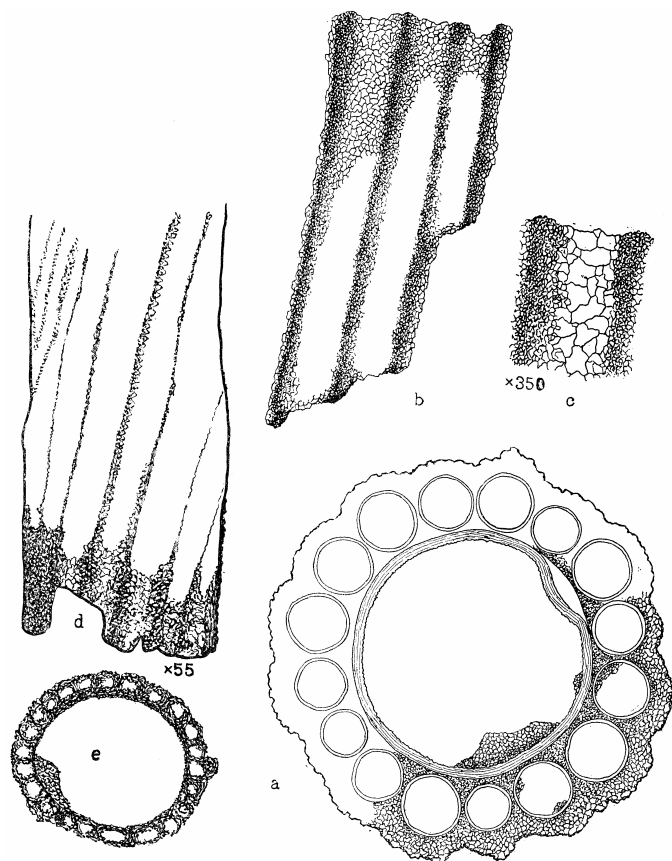
Plate XVI. Microscopically enlarged fragments and sections of Chara.

A cross-section of such a "pebble" or concretion shows a faintly radiating structure. Under the microscope I have not been able to discern this, but instead, there appears to be a cloudy aggregate of irregular calcite, not sharply crystalline nor coarse grained, not over a hundredth of a millimeter at the outside.

There is not very much that is characteristic about it, and very much of the commercial boglime deposits is precisely similar.

Near the Cottage Grove Higgins Lake resort, not only are the upper sides of pebbles overgrown with warty deposits of these algae, but the bottom sand is cemented in a layer about 3 mm thick, brown on the upper side and greenish on the lower.

(e) Shell structure.

The shells which occur in the boglimes are as Walker's list shows, mainly (bivalves) pelecypods or gastropods (snails). Whatever the genus, and whether the structure be foliated or prismatic, aragonite or calcite, the ground up shells should show, and do as a matter of fact show a fibrous structure under the microscope. Larger pieces are commonly composed of bundles of fibres, more or less opaque, owing to the interlamination of material of different refraction. The direction of extinction is usually either parallel or varies according to some law, and there is a pronounced organic structure which can hardly be mistaken, but which varies of course, according to the species. I do not think, however, that any considerable

amount of such material could escape detection under the microscope. It generally forms an unimportant part of the commercial marl or boglime deposits.

(f) Limestone flour.

What is called clay in Michigan, is, so far as the glacial clays are concerned, more properly rock flour, and contains a great deal of finely divided quartz and other minerals, being by no means merely a hydrous alumina silicate. Inasmuch as the limestones and dolomites form a large part of the subsurface or bedrock of the State, and of Canada to the northeast, the almost universal presence of lime in the clays, which are thus rendered properly marls, is quite natural. Now it is not inconceivable that, as Mr. Parmelee has suggested, in a region of limestone rocks sedimentary clay-like deposits might form, aided perhaps by the greater weight of the carbonates, in which lime would predominate to almost any extent such clays as the following analyzed by Prof. Fall, from Alcona county are very largely limestone, though in them magnesia is present in quantity, and this we should expect would be generally true. A typical till clay from the old brickyard southeast of Harrisville, Alcona county, containing some small limestone fragments, is composed as follows:

Free sand.............................	11.53	11.53	Sand.
Combined silica......................	25.71		
Oxide of aluminum....................	7.08		
Oxide of iron........................	3.99		
Organic matter, basic water..........	3.46		
Difference chiefly alkalies...........	2.60	42.84	Clayey matter.
Calcium oxide........................	1.70		
Magnesium oxide......................	6.52		
Carbon dioxide.......................	21.00	45.22	Limestone.
Sulphur anhydride....................	0.41	0.41	In pyrite or gypsum.
		100.00	

Examined under the microscope, such clays, which as we see are nearly half limestone flour, show a good deal of material which is almost indistinguishable from the alga deposits or the commercial marls. But the material is in general, more brown and opaque, contains more or less angular quartz, and almost always fragments of limestone which are over 0.01 mm in diameter,— frequently 0.05 to 0.08 and larger. Such fragments are absent in the marl, and this is the best distinction I can at present make. This is not very satisfactory. It seems quite possible that there might be quite an amount of sedimentary lime material in a bog lime, before we could separate it microscopically from materials of another origin, organic or otherwise. It seems likely that the rise in magnesia to which Hale refers is fully as sensitive a test of the admixture of clay marl in a boglime as microscopic examination. The calcareous clays become much harder when dry, and even when wet again, only very slowly break down.

§ 4. Conclusions.

It appears, therefore, that any appreciable mixture of lime sediment does not produce the quality of bog lime which is desired for Portland cement manufacture. While a continual accumulation of boglime or marl requires a continual supply of lime which is furnished in the hard water of the springs, yet the animal and vegetable life of the lakes never allows this to

accumulate to the point of chemical precipitation of the bicarbonate, but it is deposited through organic processes. In this the Characeæ play a conspicuous part, especially in the purer marls. More minute algae may have, collectively, greater and more widespread importance. In fact, microscopic examination seems to indicate this. The role of animal life is usually quite subordinate.

Notes on the microscopic examination of the different marls will be found in connection with the description of the different deposits in the next chapter.

CHAPTER IX.
LIST OF LOCALITIES AND MILLS.

§ 1. Introduction.

The object of this chapter is to give as full a list as conveniently could be made both of the Portland Cement mills actually at work and the materials that they use, and also of the plants that have been planned and materials prospected as well.

In description of the manufacturing plants, it must be remembered that the interest of the geologist is in the first place in the raw materials, and for farther discussion of the details of manufacture we must refer to Lathbury and Spackman of Philadelphia on engineering practice, the Detroit Journal of Wednesday, April 16, 1902, the nineteenth annual report of the Labor Commissioner, and professional journals like Cement, Cement and Engineering News, Stone, etc. Still we cannot thoroughly treat the raw materials without also considering the processes of manufacture to which they are adapted. We have also thought it would add considerably to the value of the report, to add a few statistics for which we have to thank the Secretary of State and the Commissioner of Labor, to whose department such matters belong. A large amount of material is derived from the printed circulars and prospectuses of the various companies, or private correspondence with the same. It is, however, almost wholly from signed reports of reputable engineers, and is duly credited. Occasional comments which may be helpful by way of comparison are added.

Alpena Portland Cement Co.

Organized Aug. 9, 1899; capital, $500,000. The officers and directors of the company are: F. W. Gilchrist, president; William B. Comstock, vice-president; George J. Robinson, secretary; A. M. Fletcher, treasurer; W. H. Johnson, auditor; John Monaghan, C. H. Reynolds, Water S. Russell, J. H. Cobb, attorney; F. M. Haldeman, superintendent. Mill located just east of Alpena on the shores of Thunder Bay. A thousand foot pier gives water transportation, and the Detroit and Mackinac R. R. also runs to the mill. This was the first mill using limestone for the calcium instead of bog lime. It is the Alpena limestone close to the mill and belongs in the

Traverse group, and corresponds somewhere nearly to the Encrinal limestone of the Hamilton of New York State. Not all of the bed is equally pure, however, and Dr. A. W. Grabau, who has made a particular study of the conditions for us, reports that the old coral reefs which occur in the bed furnish the purest calcium carbonate.* This is a very important result, for these coralline parts are easily recognized. The limestone is also used, especially the purer part, for the purification of sugar, and the report of the beet sugar chemists confirms the analyses of the local chemists, that at times the limestone is practically pure $CaCO_3$. This is one of the plants which have the advantage of using a local shale clay.

"The raw materials are very economically handled. The clay brought from the beds to the north is piled in great 'bins in the clay storage house. This house is 225 by 60 feet in dimensions and will hold clay sufficient for 60,000 barrels of cement. From the quarries to the plant, a distance of 800 feet, tracks on which are run cable cars are laid through the clay shed. Here, each car of rock, as it passes through, is weighed, analysis having been made, and the correct amount of clay is added to make a perfect cement mixture. The cars then run to the mill and their contents are dumped into the crushers.

"The materials then pass through the crushers, rolls, ball mills and tube mills automatically, being ground finer and more thoroughly mixed during each process. During the wet grinding process, water is added in the ball mills and the final and finishing mixing is done by the tube mills, which contain imported flint pebbles. The action of these against the wet mixture, produced by the revolutions of the mill, reduces it to a slurry. Then the mixture passes into correction tanks, from which samples are taken by the chemists and tests are made to guard against error. The contents of each tank are corrected before the slurry is allowed to leave it. There are 12 mixing tanks, each 14 by 16 feet high and with sufficient capacity to each hold enough slurry for 250 barrels of cement.

"This mixture carries about 33 per cent of water which makes the resultant process better. Marl and clay mixture must necessarily carry a higher degree of moisture than with the dry process. The kiln capacity is much greater where lime rock is used, as there is less water to drive out of the material before it is calcined. At Alpena the rotaries each have a daily capacity of from 140 to 150 barrels of cement as against 100 by those using marl.

"From the storage tanks the slurry is fed into the rotary kilns. The fuel used in these kilns is powdered coal, prepared by drying and grinding, and is fed into the kilns by an air blast. The kilns are taken care of by experienced burners. From the kilns the cement clinker is discharged into conveyors and carried to the clinker room to cool. Six rotaries are in constant operation and the daily capacity reaches 1,000 barrels of cement. From the clinker room the material passes to the grinding machinery, consisting of rolls, ball mills and tube mills—the chemist takes the ground cement at this

point and tests it for fineness, after which it is conveyed to the stock house, which has a capacity of 50,000 barrels, where it is allowed to season and then packed for shipment. Before shipment the chemical department makes a thorough test of the finished product for specific gravity, constancy of volume, soundness, tensile strength and setting time, and the cement is shipped only as certified by them to be in proper condition for immediate use.

"The dimensions of the various buildings are as follows: Stock house, 240 by 100 feet, making about 24,000 square feet of floor space; mixing and kiln building, 259 by 105; cement grinding room, 190 by 105. In addition to these there is a thoroughly equipped cooper shop, machine shop and round house."

Although they are not at present using the bog lime it may be of interest to give the analysis of it as well as of their shale. It comes from Middle Lake, on Sec. 29, T. 32 N., R. 9 E., about seven miles north of the mill, where the company own a thousand acres tract including also their shale clay beds.

BOGLIME.

Calcium carbonate	92.91
Magnesium carbonate	1.89
Silica	tr.
Ferric oxide	0.53
Alumina	0.21
Sulphuric anhydride	tr.
Organic matter	.80
Water, etc.	2.01
	99.87

CLAY SHALE.

CaO ($CaCO_3 = 4.48$)	2.51
MgO	.65
Silica	61.09
Ferric oxide	6.78
Alumina	19.19
Sulphuric anhydride	1.42
Water and CO_2	5.13
Potassium oxide	1.80
Sodium oxide	1.36
	99.93

Some of these shales and clays around Alpena will doubtless make good face and even paving brick.

The rocks around Alpena have been quite fully described by A. W. Grabau** in the Annual Report for 1901, and will before long be subject of a monograph by him.

*Annual report for 1901, pp. 174 to 191, especially page 178.

**See especially pages 175 to 190.

Omega Portland Cement Co.,

Organized Feb. 18, 1899; capital, $300,000; Jonesville, Hillsdale Co. The officers were: Frank M. Stewart, president; Israel Wickes, vice-president; Chas. F. Wade, secretary-treasurer; George H. Sharp, superintendent; Homer C. Lash, chemist.

The following report was prepared for us by W. M. Gregory, and was printed in the Michigan Miner for May 8, 1901, Vol. 3, No. 6.

The Omega Portland Cement Company, of Jonesville, Hillsdale County, Michigan, with a plant at Mosherville, owns extensive land tracts in Section 15, Township 5 south, 3 west. The plant stands near Cobb's Lake, on the Fort Wayne branch of the L. S. & M. S. Railway. This lake is one of a series of small lakes at the headwater of the Kalamazoo River. In the near vicinity are Hastings, Johnson, and Mosher's Lakes, and many large areas of marsh. All by actual tests and explorations have been found rich in marl deposits of an excellent quality. The immediate topography of the land in this region is rolling and hilly, this being in the locality of parallel morainal ridges deposited by the ice fronts as it retreated to the north. The clay loam forms a storage basin for the lakes—three to four miles is the average distance from the crest to crest of the valley which holds this lake chain. The valley sides are gently sloping and in places covered with sand. This region of meandering creeks, sluggish rivers and plant choked lakes was formerly considered valueless and even hindered farming interests. The discovery of marl has been the means of making a busy little village in the midst of what was once worthless soil. This is only a type of what is occurring in many places in our State. Northeast of Jonesville there are many lakes of this same character. Already at Woodstock a 600 barrel plant has been erected, and a prospective plant is in consideration at Grass Lake. Near Hanover, Moscow, Duck Lake and Addison Lake are lands rich in marl deposits. At Coldwater, Quincy, Bronson, Union City and Sand Lake extensive deposits occur and four of these places have successful plants in operation. Spencer Lake, some miles east, has also a marl bed. This region within a radius of less than fifty miles is especially favorable for extensive cement manufacture because of the abundance of marl and clay. A few words concerning the lakes in this region: They are all elliptical in shape, and on the southern shore are low morainal ridges which extend northeast to north; in many cases partly enclosing the lake. A mile is the greatest length and one-half mile is the average width. The most valuable marl deposits occur in the deepest lakes, and in fact no extensive amount occurs in any of the shallow lakes, and in such cases the sand renders the marl valueless, as some of our manufacturers have found by experience. No large inlets are known to exist in lakes with an abundance of the deposit and as a rule the outlet is plant choked. The water is in the greatest part derived from the underlying Marshall sandstone.

The plant of the Omega Company has a daily capacity of 700 barrels. The buildings are of brick and steel, and the storage house of cement concrete. The power house is 80x160 feet, containing a 750 horse-power engine, air compressors, pumps, dynamo, etc. The largest building or wet end department is 80x200 feet, and here the handling of marl and clay takes place. The marl is taken from the lake, which is 400 feet east of the mill, by a large steam dredge, and the beds of marl run to an average depth of 50 feet. The lake is one-half mile in length and one-quarter mile wide, being filled along

the shore with much plant material. At the center of this lake a depth of 40 to 60 feet is found. For convenience in handling the marl the lake has been slightly lowered by dredging the outlet.

The slimy marl taken from the lake bottom by the dredge is deposited in horse cars, skips or buckets, with a capacity of one cubic yard, and drawn to the conveyor shed, 30x130 feet, where the marl is elevated and conveyed by trolley and by automatic dump in skips dropped into the stone separator, which disintegrates the marl and relieves it of all sticks, grass and stones. In this building the clay, which is shipped in from Millbury, Ohio, is pulverized by passing through a dry pan, dried and weighed, and elevated to the mixing floor, where with the marl coming from the stone separator is mixed with the clay, forming a mud or slurry and passes to the pug mills.

The Omega Company also have a clay bed one and one-half miles northeast of the works, which matches the clay brought from Millbury, and which they use at times when weather and roads will permit of transportation economically.

<div align="center">ANALYSIS OF MILLBURY CLAY.*</div>

SiO_2	64.85
Al_2O_3	17.98
Fe_2O_3	5.92
CaO	2.24
MgO	1.40
Volatile matter	4.98

It would seem quite possible that some of the shale outcrops near Reading, or south of Jackson, would furnish suitable clay. Clay taken from the surface, if free from sand, is more apt to prove satisfactory for cement manufacture, as it is easier to mine and freer from lime than a lower strata. The manufacturer wishes a clay low in lime.

Slurry is carefully watched and tested at the Omega plant, and no trouble has been encountered through presence of sand in the marl or clay. After leaving the disintegrating pug mills, the slurry passes into vats and is pumped up to an elevated tank, where it is again screened and runs by gravity to the mixing and grinding wet tube mills, these mills being lined with wood and one-half filled with Greenland flint pebbles. After the material has passed through these mills it will all pass a sieve of 10,000 meshes without residue. The object in very fine grinding is the attainment of the most intimate admixture possible of the clay and marl, so that the heat will quickly produce incipient vitrification. Slurry is then passed into large storage tanks and from these passes by gravity as needed into vats at rear of the five 60-ton rotary kilns; these are 60 feet long and six feet in diameter: the shell being made of extra heavy boiler iron, lined with aluminate brick. The slurry is pumped from vats and forced into the end of the rotary, the rotaries being set on an incline of one-half inch to the foot. The department containing the rotaries is 80' x 100'. The rotaries are heated to about 2,900° F. by means of a gas flame generated by a continuous blast of powdered coal; the slurry while in the kilns is subjected

to temperatures varying from 1,290° F., at which CaO, SiO_2 is formed, to 3,000° F., where CaO, Al_2O_3 is formed. The calcined product of the kilns is termed clinker and has the following analysis:

SiO_2	22.24
Al_2O_3	7.26
Fe_2O_3	2.54
CaO	64.96
MgO	2.26
SO_3	.41
H_2O and CO_2	.33

The clinkers, if good, have a lava-like texture, being somewhat porous and with a greenish black bronzed color. Too much clay is shown by a tendency to give a flaky powder on cooling. An excess of lime gives a clinker of great hardness with a glassy black luster, or a fractured surface may show white specks of free lime. The excess of lime is very injurious to cement, because caustic lime expands in slaking and will disintegrate the cement mortar and produce "blowing." Too much silica will cause the clinker to crumble. Iron imparts a bluish black color and tends to produce fusion in the presence of heat.

The building where the coal is prepared for use in the kilns is 52 ft. x 68 ft. in size, and contains a preliminary crusher, dryer, preliminary pulverizer and two German tube mills for finishing the product. The coal is pulverized to pass sieve of 10,000 meshes with not over two per cent residue. On an average three cars of coal are used per day and all is prepared in this special way for use and conveyed by blast from fans into the kilns. The composition of the coal is an important factor, as an abundance of sulphur or iron pyrites is a damage to the quality of the cement, and the percentage of ash in the coal is also an important factor, and coal must be analyzed each day.

<div align="center">PITTSBURG COAL.</div>

Moisture	1.00
Vol. matter	39.37
Fixed car.	55.82
Ash	3.81
Sulphur	.92

The coal item in the expense of manufacture is a large one, and if Michigan coal could be used it might lessen the cost, but as yet its use has not been successful in this plant. After the clinkers are properly burned they pass from the rotaries to the cooling and grinding department.

The grinding mills are of the ball and tube mill patterns of German manufacture; the fine grinding of the clinker is one of the essential elements of cement manufacture. The following are some of the tests of the Omega brand:

THE OSBORN ENGINEERING CO. (INCORPORATED). CLEVELAND, OHIO. CEMENT TESTING DEPARTMENT.

Report No. 2. Records, p. 80. Reports of Tests of Omega Portland Cement. Samples received from John Laylin, City Engineer, Norwalk, Ohio. Reported to John Laylin, Sept. 6th, 1900.

Fineness, Activity, Constancy of Volume.

Brand or Mark.	Fineness.		Rate of Set.		Result of Pat Tests.		
	Per Cent Passing Sieve No. 80.	Per Cent Passing Sieve No. 100.	Initial. Hrs. Min.	Final. Hrs. Min.	Hot Test.	Cold Water.	Air.
Omega........	99.8	99.5	2-10	4-10	O K Boiling Test O K	O K	O K

Tensile Strength in Pounds per Square Inch. Results given for Tests of Sets 3 of Briquettes.

Brand or Mark.	Proport's by weight.		Per Cent of water.	Age, 24 Hours.			Age, 7 Days		
	Cement.	Sand.		Maximum.	Minimum.	Average.	Maximum.	Minimum.	Average.
Omega............................	ne at		22	384	322	361	683	550	601
"	1	3	11	....	....	....	339	263	298

We certify that the above tests were carefully made.

THE OSBORN ENGINEERING CO.,
By BERNARD L. GREEN.

It is said that 98% will pass a sieve of 10,000 meshes to the square inch, and that briquettes possess a tensile strength of 400 to 700 pounds when one week old and 500 to 800 pounds when one month old.

In the season of 1900 it produced 54,500 barrels, in 1902, 120,000 barrels.

The following are three analyses by Mr. W. H. Hess from the Cement and Engineering News for February, 1900:

	1	2	3
Silica	39.53	58.24	68.21
Alumina	11.46	20.56	18.64
Iron oxide	4.59	5.68	5.32
Calcium oxide	13.78	0.61	0.22
Magnesium oxide	5.19	9.24	9.16
Sulphur anhydride	1.62	9.91	9.12
Difference, carbon dioxide, organic matter, water, etc.	23.83	15.49	7.33
	100.00	100.74	100.00

In No. 1, which is of the surface clay type, the calcium oxide would mean 24.63 per cent of the carbonate, and similarly 19.84 magnesium carbonate, or 35.47 carbonates, which would leave from the "difference" about 7.33 for organic matter, basic water, alkalies, etc.

*Compare other analyses of this clay elsewhere given, e. g., those made by J. G. Dean at the Peninsular plant at Cement City, and those given by Prof I. C. Russell in his report in the 21st Annual of the United States Geological Survey.

Peninsular Portland Cement Co.

Organized June 24, 1899; capital, $875,000. The office of the company is at Jackson, and Jackson capital is largely interested, but the plant is in the northwest corner of Lenawee County at Wood-stock, on the L. S. & M. S. R. R., and Cement City on the Cincinnati Northern, the latter town site having been platted by the company. The officers were: W. R. Reynolds of Jackson, president; C. A. Newcomb of Detroit, vice-president; W. F. Cowham, secretary and manager; N. S. Potter of Jackson, treasurer.

The capitalization was half 7% preferred stock to be returned in 5 years. The net cost of manufacture was estimated at 80 cents.

The output when I visited it in the fall of 1901 was about 700 barrels a day. The following notes are from my visit and information kindly furnished by Mr. J. G. Dean, then chemist.:

The plant is located on the borders of Goose Lake not far from the northwest corner of Lenawee County.

The marl is dredged from the water of the lake, and forced through a pipe line into the marl tanks, where it is stirred and allowed to flow slowly into the mixers. While in transit the clay, which comes from Millbury, Ohio, is incorporated in the right proportions by an Archimedean screw. From the mixers it passes into the slurry tank, thence into the rotary roasters, in which a coal dust blast gives the heat. The coal is high in volatile matter and low in sulphur. At the lower end of the rotary it drops as a clinker and then passes into the grinder where it is reduced to powder, by being rattled with flint pebbles brought from abroad (France and Greenland). Experiments with Michigan pebbles have proven entirely unsatisfactory. The plant is producing about 700 bbls. a day with six kilns, and is beginning enlargement. The company owns a number of marl lakes in the region besides, but Goose Lake is the one which they are now using. It lies in an east and west deep trough, 60 feet or more, below the adjacent county. This trough to the east crosses the line of the Cincinnati Northern in a wide valley or open swamp, probably largely underlain by marl, and is said to extend up into Jackson County to the northeast. The outlet of the lake is to the west and the trough extends there also.

This trough appears to be not merely superficial, but to extend to the rock surface also, for in the village of Cement City half a mile north of the plant one has to put down a well but 8 to 11 feet to encounter sandstone and shale, while in the lake 60 feet below, soundings even 80 feet deep are said to be sometimes still in marl. Elk horns are said to have been found 30 feet down.

Not far north on Sec. 19, T. 4 N., R. 1 E., in a low swamp about the same distance below the high flat-topped Mils as Goose Lake there is a drilled well (t. 50° F.) flowing. It is quite likely, therefore, that as seems often the case around marl lakes there is an upward artesian pressure of the ground water. It will be noticed that this lake conforms to Hale's rule that the marl lakes tend to lie in deep depressions.

The water is also hard, as is shown by the following analysis by Dr. Hodge:

	Grains per U. S. Gallon.	Parts per thousand.	
CaO	6.410	.110	.101CaO+.079CO₃=.180CaCO₃ +.048CO₂=.092 MgCO₃
MgO	2.562	.044	
Fe₂O₃Al₂O₃............................	tr	tr	+.009CaO=.025CaSO₄
SiO₂...................................	.203	.003	
SO₃............	.800	.014	
CO₂..........	6.275	.107	
Alkalies etc...........................	.220	.004	
Residue	16.470	.282	

Now in this analysis it is noteworthy that after supposing that all SO_3 is combined with CaO and that and the MgO is combined as carbonate, there is not enough CO_2 (.107—.048=.059 instead of .079) to satisfy the calcium oxide. This perhaps indicates some organic salt of lime, for instance the calcium succinate discovered by Davis.

Another point is that the water, as will be seen by reference to Treadwell & Renter's paper, is almost or quite saturated with lime and magnesia. The sample

was taken over the marl bed, directly at the mouth of the intake ditch.

A third point of interest is the higher ratio of MgO to CaO than in marl or clay. This indicates that the water is of a residual nature, left after the deposition of the marl. The company own a clay bank about two miles west of the plant, on the north side of the hollow in which the marl lies. They have not used it for cement manufacture, preferring to use Millbury Ohio clay of the composition of Analysis 1.

(Average of 50)

	1	2	3	4	5
SiO_2	61.06	67.06	55.26	58.85	45.27
Al_2O_3	18.10	20.50	23.34	18.36	8.33
Fe_2O_3	6.65	2.52	2.52	7.16	4.84
CaO	1.29	.94	4.15	1.18	15.99
MgO	.53	tr.	tr.	1.98	
SO_3	1.05	tr.	2.00	.38	
H_2O and organic matter	9.20	8.01	11.40	8.13	
Difference, alkalies, etc.	2.12	0.97	1.33	2.96	
	100.00		100.00		

Analyses 2 to 5 are of local clays,—No. 2 from under the marsh, No. 3 a surface yellow clay probably leached of much of its lime,— No. 4, also from the top of the bank, with a low per cent of lime, while No. 5 is a partial analysis of the clay 8 feet down in the bank. A similar relation of clay analyses is very widespread and will be noticed in many other sets given in this volume. From such analyses it is probable that the ground water leaches out the carbonates unequally, preferring the magnesia, and by comparison with the following marl analysis we see that the agent which throws down the marl decidedly prefers the lime, so that there must tend to be a concentration of the magnesia in the water:

ANALYSIS OF GOOSE LAKE MARL.

CaO	51.56
MgO	1.26
SiO_2	0.22
$Fe_2O_3Al_2O_3$	0.76
Volatile matter, etc.	46.20
	100.00

The marl abounds in shells which have been determined by Mr. Bryant Walker in his paper elsewhere given, but Chara is also found in the marl. As bearing on the origin of the marl it is worth noting that at times streaks of material which dredgers would call sand or gravel are struck. This proves, however, to be pure calcium carbonate and is probably largely composed of the Schizothrix aggregates which are elsewhere described. They tend, however, to settle in the slurry and cause trouble. The marl is said to range from 10 to 42 feet thick, and the lake is half a mile wide and a mile and a half long, the deposit of marl being over 300 acres. Besides this lake other lakes in the neighborhood are owned by the same company. It is said that the average of over 200 borings ran 96.12% $CaCO_3$ and less than 1% Mg.

Peerless Portland Cement Co.

Organized Aug. 23, 1896; capital, $250,000. Oldest of the recent plants. First operated as a vertical kiln plant, as when visited by Hale and Ries, and when the view given in Plate III was taken; it has recently been remodelled to the rotary kiln.

The officers of the company are: A. W. Wright, of Alma, president; S. O. Bush, Battle Creek, vice president; J. R. Patterson, general manager; Wm. H. Hatch, secretary and treasurer; directors, the above officers, with W. T. Knowlton, Saginaw. It is a close corporation, and the stockholders are few.

The plant is located at Turtle Lake near Union City close to the line between Branch and Calhoun Counties.

Six hundred and seventy-five acres of marl land are owned by the company, and is reached by means of a little railroad. The marl is found upon the surface, and is so dry that water has to be added when it reaches the plant. The marl is almost entirely free from organic matter and is very readily worked. By means of a bucket dredge, operated on a track, the marl is dug and lifted into the dump cart.

To obtain the marl thus dry the level of Turtle Lake, "which had been twice lowered before, the last time in 1873," but still stood 22½ feet above the St. Joseph River, was lowered some 14 feet.

From the Detroit Journal of April 16, 1902, we cite the following account of the changes in the manufacturing plant:

"Intermittent vertical kilns were first installed by the company. These kilns were charged, then lighted and burned out like a limekiln. From a distance of three miles the marl was first hauled to the plant in wagons, then it was mixed with clay in a pug mill and made into bricks. These bricks were first dried in a drying kiln, then piled in the burning kilns with alternate layers of coke. After being burned the clinkers were drawn off and ground. The process was necessarily slow, as compared with that in use the present day. Two years ago another change was made in the mill and Dietch Continuous Vertical Kilns installed. In these kilns the mixture was charged at the top and the clinker drawn off at the bottom. Still progressing the company decided last fall to construct a modern cement mill and to that end hundreds of workmen have been engaged all winter in the erection of a model cement plant. Many entirely new features have been introduced into this mill, and right from the start an output of 1,200 barrels per day is confidently expected from the eight 70-foot rotaries. Two hundred thousand dollars is being expended upon this plant.

"Beds of both plastic and clay shale owned by the company are located within a mile of the mills. The shales belong to the Coldwater formation.

"The cars of marl are pulled up an elevated tramway on the track scales where the marl is weighed, and then the

clay is added before being dumped into the stone separator. From there it goes to the pug mill and then into a large tank where through return pipes the mass is kept running continuously in order to obtain a uniform mixture. It is corrected at this point by the addition of the proper amount of clay or marl determined by the chemist. From these tanks the mixture is pumped into the wet grinding tube mills and then falls into great floor tanks of concrete. In the bottom of these tanks a continuous screw conveyor forces the slurry into mammoth concrete correction tanks. These tanks are the source of just pride to the engineering force of the company. They are constructed entirely of concrete and are 22 feet deep 'by 22 feet wide and 22 feet long. The slurry in these tanks will be agitated by compressed air. The clay is prepared by being first dumped into a dryer and then ground in a Williams mill.

"The great rotary room is undoubtedly the most interesting part of the plant. Some innovations are here introduced that will materially increase the output of each rotary. The inventions are the product of advanced thought and the broadest of experiments. The rotaries are seventy feet long, being ten feet longer than the largest rotaries in any Michigan mill. The pulverized coal, to feed the rotaries, is prepared in a separate building where the most improved coal grinding machinery has been erected. The Peerless company has placed devices on the rotaries from which the waste heat from the kilns is utilized in drying the slurry before it enters the kilns. This is automatic and is said to increase the capacity of each kiln to a marked degree. The rotary room was constructed on a side hill and this has proven especially advantageous, as it saves the handling of the clinker as it leaves the kilns. Under the clinker end of the kilns has been constructed a retaining wall and in this room, 21 feet below the kilns, are the foundations for the eight automatic Wentz clinker coolers, which are being erected so that the hot clinker falls directly into them. By this device the hot air is fanned off of the clinker and driven back to aid in reducing more slurry to a calcined state.

"As the clinker drops from the coolers it is conveyed along the floor to the rolls and from there into eight Griffin mills and then into two large tube mills for the finishing process. As the cement leaves these mills it is elevated by belt and tripper arrangement to the top of the three-story warehouse and there dumped into hopper bins. These bins are two stories in height and are constructed of the best Kentucky oak, the huge pillars not depending upon the walls of the building, the construction being entirely within itself. As the cement drops from the third to the second story bins it is turned over and from there goes to the packer. The old and the new warehouses, which extend along the Michigan Central tracks, have a capacity of 100,000 barrels. It will be seen that the company is amply provided, for winter storage. At the track, coal can be unloaded and elevated to the boiler room of the plant.

"The power plant promises to be one of the finest in the state. Four Scotch Marine internally fired boilers will furnish steam for driving a 500 horse-power Hamilton Corliss engine, a Fitchburg Tandem Compound 450 horse-power, and a 300 horse-power simple engine. Rope drives will be used in part of the plant. Twenty electric motors are being installed and electrical transmission used to advantage in driving the gear of many of the machines."

Bronson Portland Cement Co.

Organized March 3, 1897; capital, $500,000. It is said that there is a mortgage of $100,000 on the plant which is said to have cost about $250,000. This is one of the well established plants of the State, and has been visited both by Dr. Ries* and Mr. Hale† and tests and a description of the process of manufacture are elsewhere given. In materials and location it is like and not far from those of the Wolverine Co.

The following are additional analyses of the Bronson clays, beside that given in Part I of this report.

REPORT OF ANALYSIS.

Date of receipt, Dec. 5th, 1900.

Composition	592 65	593 66	594 67	595 68
Silica	61.94	56.64	61.10	59.36
Alumina	11.58	12.18	13.91	12.38
Iron oxide (ferric)	3.49	3.59	3.62	3.62
Oxide of calcium	5.92	8.17	6.32	5.63
Oxide of magnesium	4.85	4.29	3.91	4.62
Sulphuric acid (anhydrid)	.18	.31	.31	.30
Organic matter				

Respectfully submitted,
(Signed) W. H. SIMMONS.
Bronson, Mich., Dec. 17th, 1900.

*This volume (VIII), Part I, pp. 42 and 43.

†Chap. VI, p. 104.

Newaygo Portland Cement Co. (Gibraltar Brand.)

Capital, $2,000,000; organized May 24, 1899. Cornerstone laid June 29, started June 5, 1901.

The officers of the Newaygo Portland Cement Company are Daniel McCool, member of American Society of Civil Engineers, president; Wm. Wright, vice president; B. T. Becker, secretary and treasurer. Directors: F. G. Bigelow, Milwaukee; H. D. Higinbotham, Chicago; George Barrie, Philadelphia, and W. Northrup, St. Louis; Clay H. Hollister, Grand Rapids, Mich.

Description by Richard L. Humphrey.*

The Newaygo Portland Cement Company's plant is located at Newaygo, on the banks of the Muskegon river, thirty-six miles north of Grand Rapids, Michigan. It is one of the finest designed and equipped plants in the State of Michigan.

The plant is electrically operated, the power being furnished by two 500 H. P. 3-phase generators, driven by eight Lombard water wheels acting under a 15-foot head.

The water is furnished by the Muskegon river. The accompanying views, Plates XII and XVIII, show the dam, race way and interior of power house.

The slurry is agitated and handled entirely by compressed air. The efficiency of this system cannot be overestimated. The centrifugal pumps usually in use are very expensive to maintain as they wear out very rapidly.

The absence of line shafting is noticeable, each machine being equipped with an individual motor, in some cases two, which enables the mill to continue in service in case of break down of one of the motors. The automatic system for controlling the compressed air is admirable.

The marl is found in a series of lakes owned by the company in Newaygo county and about five miles from the plant, known as Little Marl, Great Marl, Pickerel, Kimball, Fremont and Hess lakes.

The following is an analysis of marl taken from the Great Marl lake:

```
Silica  ....................................   1.24
Iron and Alumina  .........................    .80
Calcium carbonate  ........................  90.90
Magnesium carbonate  ......................   2.97
Organic matter by difference...............   4.09
                                            --------
                                            100.00
```

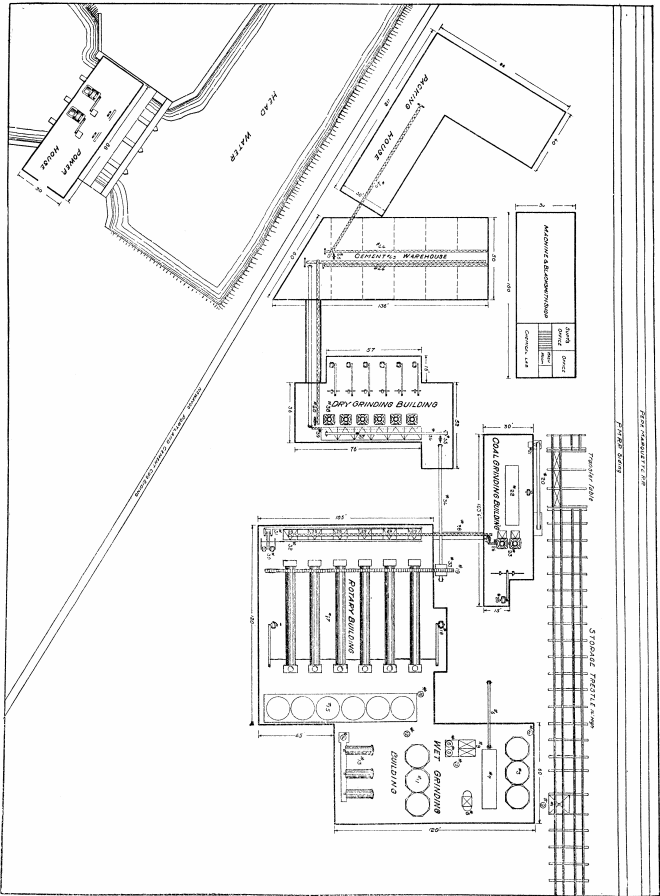*Consulting Engineer, Philadelphia, Pa.

Plate XVII. Plan of Newaygo plant.

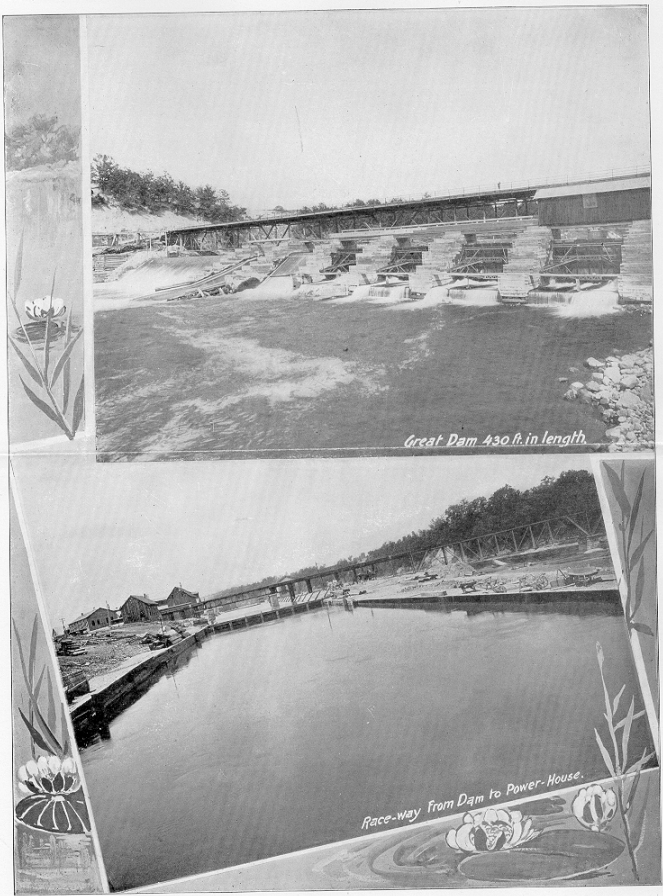Plate XVII. General view of plant.

Plate XVIII. Dam and race-way for Newaygo plant.

The composition of the marl in calcium carbonate ranges from 65 to 95 per cent.

Clay is found on the company's property along the Muskegon river opposite the plant; the following is a representative analysis of this clay:*

```
Silica  ..................................... 55.84
Iron oxide .............................  3.02
Alumina  ...............................  8.90
Lime  .....................................  9.98
Magnesia  ...............................  5.16
Loss ....................................... 13.68
                                          _____
                                           96.58
```

The cement produced by this plant is first-class in every particular, and the machinery is the best of its kind.

The following is a brief description of the plant:

The mill is on the line of the Pere Marquette railroad over which road for a mile and one-quarter the marl is hauled to the mill; the remaining three and one-half miles is over the cement company's siding.

The dredge and plant used in excavating the marl is shown on Plate XXII.

The marl is dumped into a bin [(1) on Plate XVII]. There is also storage provided, under the trestle (400 feet long), to supply the mill during the winter months.

From the bin the marl flows through a gate in the bottom, operated by a slide valve, into a machine called a separator, which drives the marl out through a perforated head in the machine, separating from the marl all foreign matter, such as sticks, stones, etc. Water is introduced at this point in quantity (about 55%) sufficient to reduce it to a slurry.

The pure marl flows through a pipe into pump (2) which pumps it by compressed air into three storage tanks (3) connected together by pipe. These tanks hold about 90 cubic yards each. From these tanks the chemist takes his samples for analysis, to determine the proportion of clay to be added. From the tanks the material, now in form of slurry, flows by gravity in a pump marked (4) which pumps it into two measuring tanks (5), these being used alternately. The clay is brought from storage and fed into a pair of rolls, then into a pug mill where water is added and it is reduced to a thin slurry. From this mill it passes into two Gates' tube mills in which it is made impalpably fine. This in turn is forced or pumped by air into a measuring tank.

The marl and clay are fed separately from the bottom of the measuring bins into a measuring hopper.

From this hopper it is pumped into three 90 cubic yard tanks (11).

The number of hoppers of marl and clay pumped into each of these tanks will depend on the composition of the marl. When the tank is full it is thoroughly agitated by air. The chemist then takes another sample. These are called correction tanks. Should the composition not be correct clay or marl is added until the desired mixture is obtained.

From these tanks the slurry or syrupy mixture of clay and marl flows by gravity into a pump (12) which forces it into the automatic feeders into the three tube mills (13), in which the material is reduced to an impalpably fine state. The tube mills discharge it into a trough running to a pump (14), which forces it into the 90 cubic yard tanks

(15) back of the kilns; there being a tank for each kiln. All tanks are continuously agitated by means of compressed air.

From the tanks it is pumped into automatic feeders from which it is fed into the rotary kilns marked (17), in which it is clinkered and is discharged into the McCasslin conveyor marked (19), which forms a continuous belt around all the rotary kilns passing in a trench underneath, then up a tower at the side of the building, overhead through the ventilator or louvre of the building and down the opposite side, where it is discharged into a cooling tower (33), and delivered by this tower onto a conveyor belt (31), which takes it to the dry grinding building and delivers it to elevator (35), by which it is elevated and deposited on conveyor belt (36) which in turn delivers it to clinker storage bins marked (37), there being one for each Griffin mill. From these bins it is fed by gravity into the Griffin mills marked (38) and pulverized to an impalpable powder; flowing from them by gravity again into a screw conveyor marked (39), by which it is delivered to elevator (40), and delivered by this elevator to either screw conveyor (41) or belt conveyor (42), either one being in reserve in case of a break down. These conveyors take the finished cement and deposit it again into a screw conveyor (43), which carries it overhead, through the cement warehouse, emptying it into any bin desired.

When the cement is shipped, it is drawn from the bottom of any one of these bins into screw conveyor (44) of which there are two, one on either side of the alleyway, conveyed by the screw conveyor to a second screw conveyor (46), which delivers it into the packing bins in the packing house, where it is either barreled or sacked by machinery, and if cars are not at hand to take it to market, it is piled in the warehouse adjoining the packing house.

The coal is either shoveled direct from a car standing on the trestle onto the conveyor belt (20), or is wheeled from storage under the trestle and dumped onto this same belt, which carries it to a coal cracker (21). From there it is elevated into a Cummer dryer (22), passes from the Cummer dryer into a second elevator, which carries it up and dumps into small bins over Griffin mills (23), where it is pulverized and then passed by a screw conveyor (26) into elevator (27), which elevates it into screw conveyor (28), by which it is carried and deposited in coal storage bins (29). From there it is fed into the rotaries by a blast of air from fan (31), driven by motor (30). These rotaries are all driven by motor (18) of which there is a duplicate kept in reserve.

In the coal grinding building the machinery is driven by motor (25), belted to a jack shaft (24), which drives both the Griffin mills. Each of the Griffin mills in the dry grinding building is driven by a separate motor, as in each of the tube mills in the wet grinding building. The agitators of each set of tanks, Nos. 3, 11 and 15, are also driven by separate motors.

The plant has been in continuous service for over one year during which time it has proved to be one of the most successful and economical in the State.

The story of the discovery of the deposits of marl is as follows:**

"A year ago Charles E. Greening, of the firm of Greening Bros., extensive nurserymen at Monroe, was on a business trip through the northern part of the lower peninsula. On May 23 he delivered an address at Newaygo, and the day following joined a fishing party at Pickerel Lake, near that village. While sitting on the trunk of a fallen tree, Mr. Greening observed that the roots of the tree were covered with a white substance resembling snow. His curiosity prompted him to taste it and he detected in it a strong flavor of lime. He sent a sample to the Agricultural College for analysis, but never heard from it.

"A few months later Mr. Greening met Prof. Fred H. Borradaile, State analyst, and gave him a sample for analysis. When the latter reported he startled Mr. Greening by urging him to go to Newaygo at once and buy up all the land containing the deposit that he could get his hands on, explaining that the substance was a most valuable specimen of marl.

"Mr. Greening hastened to Newaygo and immediately purchased about 1,000 acres of land surrounding four little lakes, the shores and bottoms of which contain unlimited deposits of marl which is said to be of a finer quality than any heretofore discovered in this country, the analysis showing 96 per cent of carbonate of lime, with little or no trace of iron. Within a short distance of the marl beds there is to be had an abundance of clay, which is an essential in the manufacture of cement.

Numerous other deposits of marl at Pine Lake, Fremont Lake, etc., exist not far off, elsewhere referred to. That of Fremont Lake is described by Mr. Hale on p. 135.

*At present, however, the company is using a clay found in connection with the gypsum at Grand Rapids whose analysis is more like that given in Part I, pp. 40 and 41. L.

**Grand Rapids Herald, May 9, 1899.

Elk Rapids Portland Cement Co.

Organized March 3, 1900; capital, $400,000. Bonds issued in 1902 to improve machinery, etc., $100,000. Original actual cost of plant about $225,000, the balance of stock being issued for land or unsold and issued as bonus with bonds, which were floated at par.

Officers: Schuyler S. Olds, president and general manager; Fitch E. Williams, vice president; Frank B. Moore, secretary and treasurer. Directors: Fitch E. Williams, attorney, Elk Rapids; M. B. Lang, merchant, Elk Rapids; Frank B. Moore, president Elk Rapids Savings Bank; Schuyler S. Olds, railroad counsel, Lansing, Mich.; Thomas A Wilson, attorney, Jackson, Mich.; C. A. Whyland, Chicago, Ill.; H. B. Lewis, manager Elk Rapids Iron Co.

Within the limits of the village of Elk Rapids the plant of the Elk Rapids Portland Cement Co. has been erected. The company own a frontage of 80 rods on the shores of Grand Traverse bay, Bee. 20, T. 9 N., R. 9 W., and the plant was built at the water's edge. The surroundings are far more picturesque than usually found accompanying a large industrial institution. In a grove of pine trees the various buildings were erected, and thrusting its arm out into the waters of the bay, a distance of 1,200 feet, is a substantial pier. At the end 16 feet of water is found, which allows the largest boats on the lakes to discharge and load. This dock is equipped with clam shell, hoisting engine, boiler, etc., and the cable dock car system for loading and conveying cargoes to and from the plant. As lake transportation is generally cheaper than rail, the company possess a decided advantage in this particular. Tracks of the Pere Marquette also run to the mills and the company uses both methods of transportation.

Thirteen and one-half acres comprise the land owned by the company, upon which the plant has been erected. Two and one-half miles south of the plant site, in the extreme northern end of Grand Traverse county, is situated the marl lands of the company. This tract comprises 350 acres of solid marl. It was formerly a shallow lake (Petobago Lake, sometimes called Tobacco Lake, Sections 5 and 8, T. 28 N., R. 9 W.), about 20 feet above Grand Traverse Bay, but the company drained off the water and the marl, is now very easy to raise and put into the dump cars of the company. This great body of marl averages, in depth, throughout its extent about 18 feet. Very little muck or organic matter lies on top of this marl bed and it goes to the mill in a very pure state. They have also recently bought some limestone lands. Within a stone's throw of the plant, clay of fine quality has been discovered. Besides this clay the company own a fine bed of shale clay (Antrim shale) on the east half of Sec. 3, T. 33 N., R. 7 W., on Pine Lake in Charlevoix County, also I am told in Lake Susan, Charlevoix County, and if needed the Watervale lands, No. 23, could be acquired.

"The buildings of the company are quite extensive and are arranged with the view of economically handling the materials as they pass from one process to another. The buildings comprise, frame coal storage building with cement floors, 50x175 feet, equipped with coal crushers, two elevators, two screw conveyors, rope drives. Concrete storage and packing buildings, 98x118 feet, concrete floors and conveyors for handling the cement. The capacity of this building is about 30,000 barrels of cement. Machine and blacksmith shop of brick, 30x50 feet; this room is very essential in a cement plant as all necessary repairs can be made in a short space of time. This shop is equipped with all of the tools and machines necessary to perform a high class of work.

"The engine and grinding rooms are in one building. This is of brick, 80x160 feet, with steel trusses, iron roof and cement floors. Steam for power is generated in two Sterling water tube boilers of 500 horse power and the

motive power consists of a 500 horsepower Russel engine, with rope drives, also a Westinghouse dynamo and engine for the lighting plant. These are separated from the clinker room by thick walls. Four Griffin mills are required to grind the clinker and in this room are clinker car conveyors, cement conveyors and elevators.

The rotary building is of brick set in cement and is 80x200 feet, with steel trusses, iron roofs, and cement floors. Here are found two pug mills, four tube mills, clay grinder, six large cement vats, ten steel slurry storage tanks, 12x16 feet each, and five Bonnet steel rotary kilns, 6x60 feet, lined with fire brick for burning cement clinker. The foundations of all machinery and all ground vats are constructed of solid concrete, resting on clay strata about eight feet below the surface of the ground. Besides these buildings there are laboratory, office, barns, boarding house and residences on the ground and owned by the company.

"To reach the marl beds the company have built a standard gauge railroad and the cars are propelled by a 35-ton locomotive. Economy in getting the raw materials to the mills has been sought and the operation expenses are very low. The road extends over the marl bed about half a mile and improved dredging apparatus is in use there.

"All of the machinery was installed with a view of increasing the plant to 10 rotaries as soon as the occasion demands. As the marl is carried to the separating machine it is weighed and then goes into the separator where all foreign matter is extracted; then the clay which has been finely pulverized is added in the quantity desired by the chemist and it goes into the pug mills and the mixing machines. After the most thorough grinding and mixing the correction tanks are reached and here the mixture is again analyzed and corrected to the proper mixture desired to make a fine grade of cement. Through the rotaries the slurry rolls and as it-leaves the far end it has been transformed into a small clinker. These clinkers are of irregular size. By means of an automatic conveyor this clinker goes to the mill to be ground into a fine powder. Test sheets are sent out with each shipment and the party receiving them knows just what he has purchased. The corps of cement makers and chemists have been carefully selected and every process of manufacture is carefully watched. A splendid system of tests has been inaugurated and any hour of the day test sheets will show just what results are being accomplished."

Wolverine Portland Cement Co.

Coldwater Portland Cement Co., organized May 25, 1898; capital, $300,000. American Construction Company, Michigan Portland Cement Company, capital $2,500,000; organized June 30, 1898.

This group of companies has had a somewhat varied financial history, but this has not prevented the steady production of cement under the "Wolverine" brand. The first company planned, the Coldwater, was a relatively modest affair with a capital stock of $300,000, $150,000 paid in with 640 acres of marsh land, a building to cost $100,000 and to have but 500 barrels capacity. Soon the plants and the capital were enlarged and the original company under the name of the American Construction Company took the contract of preparing the plant, turning in what it had done to the larger company, the Michigan P. C. Co., which issued $1,000,000 of bonds, covering the plant and lands, mainly in Coldwater and Bettrel Townships.

In recapitalizing $100 in 6% bonds were offered with every $100 of stock for $100 cash. When, therefore, in the fall of 1901 the interest failed to be paid on these bonds foreclosure proceedings began, and as a result of a compromise between the bondholders, which may be taken to represent the subscribing public, and the other creditors, prominent among which was the Construction Company, representing the promoters, the present company was formed.

The officers of the Coldwater Company were: John T. Holmes of Detroit, president; L. W. Hoch of Adrian, vice president; George M. Conner of Detroit, secretary and treasurer. In the Michigan Portland Cement Co. W. L. Holmes became president, H. H. Hatch vice president, and John T. Holmes secretary, while Mr. Hoch remained manager for a while. The officers were later changed.

This company, perhaps more than any other, brought the cement industry of Michigan into prominence by the thorough advertising they gave it in placing the large amount of stock.

They have two plants which were visited by Mr. Hale (page 105). One is at Coldwater, on the margin of Coldwater Lake,—a fourteen rotary plant, said to have cost $500,000, with a capacity of 1,500 barrels a day. The other is at Quincy, and the total capacity is said to be some 3,000 barrels. Some of the marl is said to run as high as 99% $CaCO_3$.

The following are typical analyses of the raw materials furnished by the chemist, Mr. H. E. Brown:

	Light marl (dried).	Blue marl (dried).
Calcium carbonate	93.75	91.34
Magnesium "	2.42	.77
Soluble silica	.18	.42
Insoluble "	1.01	.78
Aluminum oxide	.55	.55
Ferric "	.25	.40
Sulphur trioxide	tr.	.26
Alkalies and rest (by difference)	1.84	*5.79

	Clay, light brown upper layer.	Blue, 12ft. from surface.
Silica	60.59	57.26
Titanium oxide	.40	.82
Aluminum oxide	17.70	20.77
Ferric oxide	7.54	6.53
Magnesium oxide	1.46	2.31
Sulphur trioxide	.41	1.34
Calcium oxide		1.50
Loss on ignition	8.74	6.19
Alkalies	3.16	3.28

*Determined.

It is to be noted that all these samples are dried, the loss on ignition being to a slight extent CO_2, but mainly combined water. It will be noticed that while neither specimen of clay contains much carbonate of lime, being derived from the Coldwater shales, which are practically