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THE MANUFACTURE OF PORTLAND CEMENT FROM MARL

BY

RAYMOND E. KIRK

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PREFACE

The 1921 session of the Minnesota Legislature provided for an investigation by the University of Minnesota of the manufacture of Portland cement from marl.

The work was performed by the writer during the summer of 1922. The results are reported in this bulletin.

The writer desires to express his indebtedness to Dr. C. A. Mann, professor of chemical engineering in the University of Minnesota, under whose direction the investigation was made. Dean O. M. Leland, director of the Engineering Experiment Station of the University of Minnesota, has given helpful advice and suggestions. Dr. F. J. Alway and Dr. C. O. Rost, of the Division of Soils of the University of Minnesota, furnished useful information. The writer also wishes to thank Mr. R. A. Smith, state geologist of Michigan; Mr. Ralph W. Perry, of the Perry Testing Laboratories of Detroit, Michigan; and the chemists and operating officials of various cement plants in Michigan and Ontario for information supplied by them. He is indebted to the Hanover Cement Company and the Aetna Portland Cement Company for photographs used in this report. Mr. Charles H. Dow furnished the photographs of the Star Lake marl deposits. Standard works on the manufacture of Portland cement have been freely consulted. Proper acknowledgement has been attempted, in the text and in the bibliography, of all the sources of information utilized in this report.

R. E. Kirk

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INTRODUCTION

It is the purpose of this report to discuss the possible utilization of marl in the making of Portland cement and to point out the economic and technologic advantages and disadvantages involved in such a use. It does not pretend to give complete information about either the quality or quantity of the marl deposits of Minnesota. The conditions which seem essential for the success of any proposed plant are outlined and suggestions for the investigation of marl deposits of possible value are given.

A summary of the Portland cement industry is presented in order to show its importance.

The methods used in making Portland cement are briefly treated and the various raw materials used are mentioned. A brief consideration of the character and origin of marl is followed by statements as to its use in the making of Portland cement in other states and in Canada.

The quality and quantity of marl needed for a modern cement plant are discussed, typical analyses are given, and suggestions made as to methods of investigating marl deposits.

The problems of plant operation and design are considered and the general requirements for a marl-using plant outlined.

The chief sources of Portland cement used in the state are mentioned and the shortage within the state of calcareous raw material for Portland cement discussed.

Anyone interested in further details of the manufacture of Portland cement is referred to the standard works on the subject, especially the books by Richard K. Meade and by E. C. Eckel.

THE MANUFACTURE OF PORTLAND CEMENT FROM MARL

The Portland cement industry has developed so rapidly that the importance of Portland cement in our modern civilization has not been generally appreciated.

The following table compiled from the reports of the United States Geological Survey will give some idea of the growth and magnitude of the industry in the United States.

TABLE I

PRODUCTION OF PORTLAND CEMENT IN THE UNITED STATES

Year	Production Barrels†	Valuation	Average Price per Barrel (at Mills)
1890	335,500	$ 704,050	$2 09
1895	990,324	1,586,830	1.60
1900	8,482,020	9,280,525	1.09
1905	35,246,812	33,245,867	0 94
1910	76,549,951	68,205,800	0.89
1915	85,914,907	73,886,820	0.860
1916	91,521,198	100,947,881	1.103
1917	92,814,202	125,670,430	1.354
1918	71,081,663	113,446,334	1.596
1919	80,777,935	138,130,269	1.71
1920	100,023,245	194,439,025	2.02
1921	98,842,049	186,802,472	1.89
1922* (First 10 months)	93,850,000	....	....

* Preliminary figures.

† One barrel contains 376 pounds.

There is every reason to believe that there will be a continued growth of this industry. New uses are being discovered for Portland cement and, with added knowledge of the proper methods of concrete construction, its known uses are growing in favor. The accelerated building program expected in the next several years will call for increased amounts of cement. The good roads program of the nation and of the states means the use of more and more cement. The prejudice that once existed against concrete is fast losing its hold. As a result the demand for cement will increase.

The technologic improvements in the industry, together with the able management of many of the companies, have made this industry remarkable in that large quantities of a bulky product are produced at a relatively low cost. The growth of the industry has been aided by a careful campaign of education in the proper use of cement. The following table shows the amounts of Portland cement used in Minnesota by years since 1914. These figures were compiled from the United States Geological Survey reports on mineral resources.

TABLE II

ESTIMATED PER CAPITA CONSUMPTION OF PORTLAND CEMENT IN MINNESOTA BY YEARS

Year	Consumption (Barrels)	Per Capita (Barrels)
1914	3,125,930	1.41
1915	3,143,999	1.40
1916	3,338,560	1.46
1917	2,793,371	1.21
1918	2,164,947	0.92
1919	2,979,549	1.25
1920	3,109,243	1.29
1921	3,090,803	1.26

Since Portland cement is a bulky product, the plants have been built as close to the large consuming districts as is possible. Availability of raw materials and of fuel has also been an important factor in the location of cement plants. As a result the industry is not highly localized. Plants are found in nearly all sections of the country.

Definition of Portland cement.—The United States Government specifications[1] define Portland cement as "the product obtained by finely pulverizing clinker, produced by calcining to incipient fusion an intimate and properly proportioned mixture of argillaceous and calcareous materials, with no additions subsequent to calcination except water and calcined or uncalcined gypsum."

Portland cement has the property of hardening in air or water when mixed with a suitable amount of water and of remaining hard when immersed in water. The strong bond thus formed gives the cement its value when used in masonry or in the manufacture of concrete structures. In addition to Portland cements we have on the

[1] United States Government Specifications for Portland Cement. Bureau of Standards, *Circular* 33.

market various "natural" or "bricklayers" cements and various hydraulic cements. These cements are very valuable for certain uses but their consumption is small as compared with Portland cement.

The term Portland cement is a generic term used as descriptive of cement made according to the foregoing definition and possessing certain characteristic properties. It has no relation to the place of manufacture or the company making the cement. The term originated with the patent taken out in 1824 by Joseph Aspdin, a bricklayer of Leeds, England, on an improved cement made by grinding and burning limestone and clay. This he called "Portland cement" because the hardened cement had a yellowish gray color resembling in appearance the stone from the quarries of Portland, England.

Raw materials.—Portland cement may be manufactured from a variety of raw materials. They may be classified under two general heads:

(1) Calcareous.—Calcareous substances are those in which calcium carbonate predominates. The naturally occurring calcareous materials always contain in addition some alumina, iron and silica as clay or sand.

(2) Argillaceous.—Argillaceous substances are those in which the silica and alumina predominate. Calcium and magnesium carbonates are often present but in relatively small amounts.

The usual materials employed are listed as follows:

Calcareous	Argillaceous
Limestone	Clay
Marl	Shale
Chalk	Slate
Alkali waste	Blast-furnace slag
Cement rock	Cement rock

Cement rock is a mixture of calcareous and argillaceous materials and is placed between the two classes. Almost any combination of these materials may be used if the proper proportion is obtained. The usual combinations are:

1. Cement rock and limestone
2. Limestone and clay or shale
3. Blast furnace slag and limestone
4. Marl and clay or shale
5. Alkali waste and clay.

The following table shows the amount of Portland cement made from each group of materials.

TABLE III

PRODUCTION, IN BARRELS, AND PERCENTAGE OF TOTAL OUTPUT OF PORTLAND CEMENT IN THE UNITED STATES ACCORDING TO TYPE OF MATERIAL USED, 1898-1914

Year	Type 1—Cement Rock and Pure Limestone		Type 2—Limestone and Clay or Shale		Type 3—Marl and Clay		Type 4—Blast-Furnace Slag and Limestone	
	Quantity	Percentage	Quantity	Percentage	Quantity	Percentage	Quantity	Percentage
1898	2,764,694	74.9	365,408	9.9	562,092	15.2	....	......
1899	4,010,132	70.9	546,200	9.7	1,095,934	19.4	....	......
1900	5,960,739	70.3	1,034,041	12.2	1,454,797	17.1	32,443	0.4
1901	8,503,500	66.9	2,042,209	16.1	2,001,200	15.7	164,316	1.3
1902	10,953,178	63.6	3,738,303	21.7	2,220,453	12.9	318,710	1.8
1903	12,493,694	55.9	6,333,403	28.3	3,052,946	13.7	462,930	2.1
1904	15,173,391	57.2	7,526,323	28.4	3,332,873	12.6	473,294	1.8
1905	18,454,902	52.4	11,172,389	31.7	3,884,178	11.0	1,735,343	4.9
1906	23,896,951	51.4	16,532,212	35.6	3,958,201	8.5	2,076,000	4.5
1907	25,859,095	53.0	17,190,697	35.2	3,606,598	7.4	2,129,000	4.4
1908	20,678,693	40.6	23,047,707	45.0	2,811,212	5.5	4,535,300	8.9
1909	24,274,047	37.3	32,219,365	49.6	2,711,219	4.2	5,786,800	8.9
1910	26,520,911	34.6	39,720,320	51.9	3,307,220	4.3	7,001,500	9.2
1911	26,812,129	34.1	40,665,332	51.8	3,314,176	4.2	7,737,000	9.9
1912	24,712,780	30.0	44,607,776	54.1	2,467,368	3.0	10,650,172	12.9
1913	29,333,490	31.8	47,831,863	51.9	3,734,778	4.1	11,197,000	12.2
1914	24,907,047	28.2	50,168,813	56.9	4,038,310	4.6	9,116,000	10.3
1920*	....	......	....	......	4,038,310	2.7	....	......

* E. F. Burchard, The Cement Industry in the United States, 1914. *Mineral Resources*, 1914, Part II, U.S.G.S.; Cement in 1920. *Mineral Resources*, 1920, Part II, U.S.G.S.

Manufacture.—In the making of Portland cement we may discuss three stages, (1) grinding of raw materials, (2) burning the "clinker," and (3) grinding the "clinker."

1. Grinding of raw materials.—The raw materials are finely ground, properly proportioned, and intimately mixed. The machinery and methods used vary according to the character of the materials and the process selected. When hard materials are used preliminary crushing is often accomplished by gyratory or by jaw crushers. In nearly all plants the final reduction is attained in some form of ball mill or tube mill or a combination of these two types. Especial attention will be given later to the methods employed in plants using marl. There are two general processes of manufacture, the dry and the wet. In the first, raw materials are ground and mixed dry and introduced

into the kilns in the form of a dry powder. In the second, the materials are ground with water and brought together in a "slurry" containing enough water to allow the slurry to be pumped. This liquid is then introduced into the kilns. The merits of each of these processes will be considered.

2. Burning the clinker.—The properly proportioned mixture is now introduced into rotary kilns and heated to "incipient fusion" by means of the heat generated in the burning of powdered coal blown in with a blast of air. These rotary kilns are inclined somewhat and the material passes by gravity from the upper to the lower end, where the powdered coal burners are located. In the uppermost section of the kiln the incoming material is heated and the moisture present driven off as steam. In its progress down the kiln, the "lime carbonate" is decomposed and the carbon dioxide passes off leaving quicklime. In the "clinkering" zone the lime combines with the silica and alumina and forms the clinker. The temperature here is usually between 2,500° F. and 3,000° F. This clinker, having a size about that of a walnut, falls out of the lower end of the kiln and is cooled and passed to the clinker-grinding machinery.

The rotary kilns are lined with a refractory material and vary in length from 60 to 240 feet and from 6 to 10 feet in diameter. The longer kilns are much more efficient, especially with the "wet" process, and few, if any, new mills contemplate installing kilns less than 175 feet long.

TABLE IV*

LENGTHS OF ROTARY CEMENT KILNS IN ACTIVE PLANTS IN THE UNITED STATES, 1917-1921

Length (Feet)	Number of Kilns				
	1917	1918	1919	1920	1921†
40– 60	108	77	71	74	74
61– 99	94	90	87	87	87
100–109	84	105	98	98	91
110	83	65	55	66	56
120	88	88	95	97	99
125	194	183	166	172	164
126–149	65	63	63	63	64
150–199	73 (150–260)	63	66	73	76
200–260		15	19	23	29
	789	749	720	753	...

* E. F. Burchard, Cement in 1920. *Mineral Resources*, 1920, Part II. U.S.G.S.
† Belle W. Bagley, Cement in 1921. *Mineral Resources*, 1921, Part II. U.S.G.S.

3. Grinding the clinker.—The cooled clinker is now finely ground, usually in tube mills. The cement, now ready for use, is sent to storage or to packing machines.

TABLE V

ANALYSES OF PORTLAND CEMENT

State	Brand	Company	SiO_2	Al_2O_3	Fe_2O_3	CaO %	MgO %	Alk. %	SO_3 %
* Ala.	Red Diamond	Alabama	19.56	12.16		62.27	0.64	...	0.54
* Cal.	Golden Gate	Pacific	22.57	10.64		62.61	1.27	...	1.32
* Mich.	Peerless	Peerless	20.65	11.03		65.40	1.95	...	0.37
* Mich.	Peninsular	Peninsular	22.56	10.96		62.72	2.20	...	1.50
* N. J.	Edison	Edison	20.14	7.51	3.33	62.71	2.34	...	1.64
* N. Y.	Empire	Empire	21.98	8.20	3.70	61.83	1.43	0.84	1.18
* Pa.	Lehigh	Lehigh	22.61	9.55		62.45	2.61	...	1.45
† Ind.	Wabash	Wabash	21.78	7.31	2.65	62.35	2.88	0.47	1.78
† Ill.	Universal	Universal	23.06	8.16	2.88	62.10	1.88	0.94	1.57

* E. C. Eckel, *Cements, Limes, and Plasters.* Second edition. 1922.

† R. K. Meade, *Portland Cement.* Second edition. 1911.

THE USE OF MARL IN THE MAKING OF PORTLAND CEMENT

Many of the first Portland cement plants established used marl and either clay or shale as their raw materials. Just as good Portland cement can be made from marl as from any other calcareous material. The utilization of marl is then to be considered as a question of technology and of economic advantage.

Definition of marl.—Marl is an unconsolidated carbonate of lime deposited in the beds of present or extinct lakes in the glaciated regions of the North Central States. In many cases marl deposition is still in progress. In many other cases the lake has disappeared and the marl deposits occur in a swamp or marsh covered with peat or muck. The marl may be mixed with sand or with organic matter. Many deposits, however, are almost pure calcium carbonate. Due to its deposition in lakes the marl contains large amounts of water.

Origin.—The action of the glaciers left a large amount of finely ground calcareous material in the glaciated regions as limey gravels and limey clays. The marl comes from the leaching out of carbonate of lime from the surrounding soil by the combined action of water and carbon dioxide. The water then contains lime bicarbonate, $Ca(HCO_3)_2$, giving to water the property usually known as temporary hardness. The chemical equation showing this would be:

$$\underset{\text{Insoluble}}{CaCO_3 + H_2O + CO_2} \quad = \quad \underset{\text{Soluble}}{Ca(HCO_3)_2}$$

Deposition of marl.—The exact reason for the deposition of marl has been the subject of much discussion and investigation. All the investigators agree that the waters charged with bicarbonate of lime deposit carbonate of lime if, for any reason, carbon dioxide escapes or is removed. This action may be represented as follows:

$$\underset{\text{Soluble}}{Ca(HCO_3)_2} \quad = \quad \underset{\text{Insoluble}}{CaCO_3 + CO_2 + H_2O}$$

The discussion has to do with the causes of the escape or removal of the carbon dioxide.

Blatchley,[2] who has studied the Indiana deposits, attributes the loss of CO_2 to a decrease in pressure and an increase in temperature as the underground waters reached the lake basin.

> This spring water as it enters the lake is always colder than the water of the lake itself. The bicarbonate of lime is more soluble in cold water than in warm and a *part* of the dissolved material is therefore precipitated in the form of a fine powder soon after the cold stream enters the warmer, still water of the lake. Such precipitation of calcium carbonate from cold water as it becomes warm is seen every day in almost every household. The hard water heated in tea-kettles holds while cold a large quantity of bicarbonate of lime in solution. As it becomes warm, much, if not all of this falls and forms a coating of lime carbonate upon the bottom of the kettle. Again, if there is a large amount of carbon dioxide in the percolating waters the percentage of carbonate of lime held in solution will be increased in proportion. As the spring-water enters the lake and rises to the surface the pressure will be decreased and a part of the carbon dioxide will escape and so cause a precipitation of *another* part of the carbonate of lime according to the following formula (sic):
>
> $$CaH_2(CO_3)_2 - CO_2 = CaCO_3 + H_2O$$

Blatchley states that most of the marl lakes of Indiana are fed by underwater springs and that the larger deposits of marl in these lakes are found close to these springs. From his studies on Michigan marls Davis decided that most of the marl deposits were due to the action of certain aquatic plants such as *Chara* and *Zonotrichia.* His conclusions[3] are as follows:

> All green plants, whether aquatic or terrestrial, take in the gas (carbon dioxide) through their leaves and stems and build the carbon atoms and part of the oxygen atoms of which the gas is composed into the new compounds of their own tissues, in the process releasing the remainder of the oxygen atoms.

[2] W. S. Blatchley, *Twenty-fifth Annual Report of the Indiana Department of Geology,* p. 45. 1901.

[3] C. A. Davis, *Reports of the Michigan Geological Survey,* Vol. 8, Part 3: p. 69.

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

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

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

in which calcium bicarbonate is converted into the normal (and very slightly soluble) carbonate by the oxygen liberated in the plants, and both carbon dioxide and oxygen are set free, the free oxygen possibly acting still further to precipitate calcium monocarbonate. It is probable that the plants actually do precipitate calcium carbonate in both these ways (i.e., by abstracting carbon dioxide from the water and by freeing oxygen), but in water containing relatively small amounts of calcium bicarbonate the latter would seem the probable method.

The statement of Mr. Davis as to the "chemical" action of oxygen on the bicarbonate is open to the criticism that the action predicated might be due to the purely "physical" effect of the oxygen in decreasing the pressure of the carbon dioxide. But the influence of *Chara* in causing marl deposition can scarcely be denied by any one who has observed the luxuriant growth of *Chara* in the marl lakes.

Davis also notes that *Chara* abstract lime salts from the water and build them into their tissues. This lime is present in part as calcium silicate. There is no doubt that part of the marl has been deposited through the action of molluscs. These animals abstract lime salts from water and build it into their shells. At their death the shells sink to the bottom and aid in the formation of the marl. In some marl beds these shells are very abundant while in others no traces of shells are found.

The ideas of marl deposition may be summarized as follows: the ground water entering the lakes has lime bicarbonate $Ca(HCO_3)_2$ in solution. This is deposited as marl due to:

1. Escape of carbon dioxide owing to
   a. Decrease in pressure
   b. Increase in temperature
2. Removal of carbon dioxide by
   a. Action of aquatic plants in utilizing carbon dioxide
   b. Action of oxygen given off by aquatic plants
3. Abstraction of lime salts by *Chara*
4. Formation of shell deposits by molluscs

Undoubtedly each of these causes has contributed to the deposition of any one marl bed. The relative amounts deposited due to each cause will certainly vary greatly with the conditions of deposition.

Marl has been used in the manufacture of Portland cement in New York, Michigan, Ohio, Indiana, and Utah and in Canada. At present one plant in Indiana, one in Ohio, one in Utah, and six plants in Michigan are using marl. Reference to the table on page 4 will show the production of Portland cement from marl as compared with the production from other classes of raw materials. It will be noted that the amount of cement produced from marl has been constantly decreasing since 1899.

There are several reasons for this decrease.

Other raw materials more advantageously located with respect to markets.—Many of the marl deposits are located at considerable distances from consuming centers.

Inadequate supply of marl for continued operation of mill.—Due to lack of careful investigation many of the plants built to use marl were located at places where the supply of high grade marl was soon exhausted. Such plants boosted the totals for a few years and were then abandoned. Their failure, while due, at least in part, to lack of preliminary investigation, discouraged the building of other marl-using plants.

Obsolescence of mills.—Most of the plants designed to use marl were built between 1895 and 1905. These plants are now becoming obsolete. Much of the equipment has been completely worn out and must be replaced if the plants are to continue operations. These plants were built with the short kilns which were in universal use at that time and their fuel consumption is consequently high. Many of these plants are finding that their marl supplies, while adequate for twenty or twenty-five years, are now becoming almost exhausted. Their owners naturally hesitate to install new and modern equipment when the marl deposits left near their location are limited in amount.

With many of these plants there has been a disposition, after a period of 15 to 25 years, to shift over to the use of limestone. In some cases the limestone is shipped considerable distances. The cost of the plant has been written off by depreciation charges and the only additional equipment cost is for the machinery needed for grinding the limestone. The output of the plant can be greatly increased since ground limestone can be handled in a slurry of about 35 per cent water as compared to 45 to 60 per cent water in the marl slurries. This enables the companies to show a profit even tho the freight charges on the limestone are high. As the old equipment must eventually be replaced, such a scheme, in most cases, is possible for only a few years. In time the plant operations must be moved nearer the raw materials. In order to continue the company's trade, many companies are building new plants near limestone quarries.

Wet process not in favor.—The almost universal disfavor with which, until within the last few years, the wet process was regarded by most cement technologists, has operated against building new plants for the use of marl. The attempts to dry marl before clinkering have not been successful because of the tenacity with which the moisture is retained and the consequent cost of the large amount of fuel needed to drive off this water. For this reason the wet process is always used with marl. In more recent years the wet process has been growing in favor for reasons to be reviewed later.

Competition with limestone.—The discovery and exploitation of large deposits of limestone suitable for cement-making has caused a decrease in the use of marl. Especially in Michigan and New York the competition with limestone plants has resulted in a lessened production of Portland cement from marl.

Operations of "wild cat" companies.—The marl-cement industry has suffered greatly from the activities of unscrupulous promoters. Many companies have been organized and plants built by persons interested only in the sale of stocks. Large salaries have been paid to promoters and managers. Some plants have been built solely for the sake of possible commissions paid the manager on machinery purchased. These conditions have discouraged legitimate enterprises. Investors have hesitated to put capital into plants designed to use marl because of the poor financial history of many such plants.

MARL PLANTS IN MICHIGAN

The first Portland cement plant in Michigan was built near Kalamazoo in 1872 by the Eagle Portland Cement Company. Wet marl and clay were mixed and briquetted. These briquets were burned in stationary dome kilns with coke. This plant continued operations until about 1892.

In 1896 the Peerless Portland Cement Company built a plant at Union City. Vertical or dome kilns were installed. These were replaced in 1902 by rotary kilns. This plant is still in operation. At present, marl is brought from Spring Arbor, near Jackson, in dump cars. It is excavated in part by a dredge and in part by a drag line excavator. The plant now has nine kilns 6½x80 feet. A deposit of shale from near the plant is used with the marl. The marl carries as high as 2 to 3 per cent sand and may have 5 per cent of organic matter. The slurry as passed to the kilns carries 47 to 50 per cent of water. The operators in the raw materials department are given a bonus if the water content of the slurry is kept below 47 per cent. The clinker is burned with powdered coal—from 150 to 170 pounds of coal being used to clinker each barrel of cement.

The owners of these companies are said to be interested in a projected plant to be built at Port Huron, Michigan, to use Rogers City limestone.

The Bronson Portland Cement Company erected a plant at Bronson in 1897 and installed rotary kilns. This plant ceased operations in 1910 due to the exhaustion of its marl supply and the obsolescence of its equipment. In 1897 the Coldwater Cement Company, now the Wolverine Portland Cement Company, built plants at Coldwater and Quincy. These plants are still operating. The marl is excavated by a dredge and loaded into scows. These are towed to the bank near the mill and the marl pumped to the plant. The clay comes from a deposit near Coldwater. Altho large amounts of marl have been taken from the lake at Coldwater a considerable supply remains. At present, however, the dredge is working nearly three miles from the plant. Reserve supplies of marl are available in other lakes near by.

At these plants a moisture content of 50 per cent in the slurry is considered good operation. From 150 to 175 pounds of coal are used in burning a barrel of cement.

The plant at Coldwater has three 8x182 foot kilns and the one at Quincy seven 6x120 foot kilns.

The Newago Portland Cement Company built a plant at Newago in 1900 and 1901 designed for the use of clay and marl. The supply of each proved inadequate almost immediately and the plant has operated on limestone and shale shipped from the vicinity of Petoskey, Michigan. Because of the fact that this plant was able to use the cheap water power available at Newago it has survived despite its unfortunate location.

The Egyptian Portland Cement Company, in 1902, built a plant near Fenton in which marl and clay were to be used. This company has passed through several reorganizations and has recently resumed operations. The marl is obtained from the company's holdings on Silver Lake. It is excavated by a dredge, loaded into scows, and these are towed to the bank near the plant. The marl is then pumped to the mill. The plant now has nine kilns 6x60 feet. This company is planning to build a plant at Port Huron to use limestone shipped by boat from Rogers City. The wet process will be used.

The Aetna Portland Cement Company, located near Fenton, also uses marl from holdings on Silver Lake. The marl is handled in the same way as at the Egyptian plant. The clay is shipped from Corunna, some twenty miles distant on the Grand Trunk Railway. The slurry as it goes to the kilns carries about 48 per cent of water. The plant has two kilns 10x175 feet. About 165 pounds of coal are used to clinker one barrel of cement. The company is building a wet process plant at Bay City to use limestone brought in by boat. This new plant will supply the company's trade when the present marl supply is exhausted.

The Peninsular Portland Cement Company completed their factory at Cement City in 1901. They used marl from a near-by lake and acquired the right to exploit the marl deposits in a series of lakes several miles from the plant. Most of the clay used was shipped from Bryan, Ohio. When the marl deposits in the lake adjacent to the plant were exhausted, limestone was shipped in and used, first with clay and then with blast furnace slag. The success in operating by the wet process with limestone and slag during the season of 1921 led the officials of this company to consider utilizing their reserve supply of marl. The increased freight rates on stone offset the advantage of increased capacity of kilns. A new dredging outfit was procured and a pipe line and pumping stations were built to bring marl from the reserve supply some two miles distant. This equipment cost about $150,000 and renders available a large supply of marl. The marl is mixed with blast furnace slag. The slurry carries about 50 per cent water. About 125 pounds of coal are used on this mixture for every barrel of cement clinkered. In the spring of 1922 this plant operated for several weeks on a mixture of marl, limestone, and clay. The proportions were approximately 45 per cent marl on dry basis, 33 per cent limestone, and 22 per cent clay. This mixture could be handled as a slurry containing 40 to 45 per cent water. The marl used at this plant is of high quality, nearly all of it having well over 90 per cent calcium carbonate, dry basis. The plant is well equipped and carefully managed. It has three kilns, 9x205 feet. The company is now considering the installation of waste heat boilers.

In May, 1901, there were ten plants operating in Michigan. Of these, eight were using marl. At the same time there were six plants being built and seven projected, all of which were to use marl. Four of the plants operating on marl in 1901 are still using marl and one of them now operates on limestone. One plant built at that time and one built since are continuing to use marl. This makes a total of six plants now using marl. The reasons for discontinuing are discussed on page 9.

There is a general tendency for the new Portland cement plants in Michigan to locate where water transportation renders available the limestone screenings from the quarries in the Rogers City–Alpena region.

Despite this tendency, active investigations are now on foot looking toward the utilization of other marl deposits in Michigan. The National Portland Cement Company has been organized to use the marl deposits of Coldwater Lake near Mount Pleasant, Michigan. A large deposit of marl near Decatur, Michigan, has been carefully surveyed and sampled with the idea of its possible use in the manufacture of Portland cement.

PLANTS IN OHIO AND INDIANA

According to the state geologist of Ohio, two plants in that state are using marl: the Sandusky Portland Cement Company, operating near Baybridge, Ohio, and the Castalia Portland Cement Company, located near Castalia, Ohio.

Because of the impending exhaustion of their marl supply, the Sandusky Portland Cement Company recently dismantled its plant at Syracuse, Indiana.

About 1900 the Wabash Portland Cement Company built a plant at Stroh, Indiana, which is still in operation. The marl is loaded on cars by a floating dredge and hauled to the plant. The marl contains from 80 to 90 per cent calcium carbonate, dry basis, and has from 4 to 5 per cent organic matter. The slurry as fed to the kilns has from 53 to 56 per cent moisture. This plant has three kilns, 8½x185 feet. From 125 to 150 pounds of coal are used to burn each barrel of cement. No information was obtained as to the extent of their present marl supply.

PLANT IN UTAH

William Peterson, director and geologist of the Utah Agricultural Experiment Station, makes the following statements concerning the use of marl in Portland cement:

> We have three cement companies in the state of Utah, two of which are making cement from limestone and shale while the third one, known as the Ogden Portland Cement Company, is manufacturing cement from clay and marl. They

are located in an old flat which was an arm of the ancient lake. This particular lake is covered with a layer of marl from two to fifteen feet in thickness. The marl is not clean, but it does contain sufficient clay to make the cement. The process is to take out all the marl and dip thru far enough to pick up enough clay underneath to make the proper mixture. The plant has a capacity of 1,200 barrels per day and is making cement at a lower cost than either of the others. There are several other marl beds in the state even close to a railroad. This, however, is the only one which is being utilized at present.

PLANTS IN ONTARIO

Quite a number of Portland cement plants, using marl and clay, have been operated in Ontario. Nearly all of these plants have come under the control of the Canada Cement Company and all of them have ceased operations on marl.

Several plants operating at or near Owen Sound, Ontario, used marl from Shallow Lake. The supply of marl has been almost exhausted and these plants are all dismantled.

The Hanover Cement Company at Hanover, Ontario, operated on marl until 1920. At that time, in order to use limestone shipped from near Walkerton, they rebuilt their plant. The quarry at Walkerton, first opened and operated by the Ontario Hydro Electric Commission, has now been acquired by the company. At the time of the change to limestone most of the good quality marl had been utilized.

In nearly all the Ontario plants the impending exhaustion of the marl deposits rendered impractical the improvements in equipment needed to make the plants economically successful, and consequently they were abandoned.

Shirley Bass, chief engineer of the Canada Cement Company, Ltd., makes the following statements in a private communication:

> The Canada Cement Company ceased the operation of their marl plants in Ontario because, primarily, the mechanical equipment of their plants was extremely out of date, and secondly, the marl deposits were not of great enough extent to warrant remodelling the mills and replacing the out of date equipment with modern equipment.
>
> Regarding the economic side of operating a marl plant, the writer believes that it is quite possible for a marl plant favorably situated as regards to coal to compete with a modern limestone plant. As you well know, marl is, in the state of nature, very finely divided and needs practically no grinding in order to prepare it for the kilns. This is a great saving when compared with a limestone plant. A more serious objection to the use of marl as raw material for the manufacture of cement is the fact that the marl carries such a high percentage of water. So far as our experience goes we found that we could not handle our marl with less than 45% of water in the slurry and more often our water content would run as high as 50%. This would mean that for every barrel of cement clinker burned in the kilns about 300 lb. of water would have

to be evaporated with a very large consequent loss in fuel economy.

With the advent of the long kilns, however, this feature does not carry as much weight as it formerly did as Portland Cement clinker can be burned from a wet mix in a 200 ft. kiln for about the same number of pounds of coal per barrel as can be done with a dry process kiln. The only difference in operation conditions is that while the temperature of the kiln gases in the stack of the dry process kiln will average from 1,200 to 1,500° F., the temperature of the gases from a long wet process kiln will average not over 800° F., and frequently runs considerably less.

The writer certainly does not believe it would be advisable for anybody to build a plant to use marl as a raw material unless they had a supply of marl in sight large enough to run the plant to its full capacity for a period of at least 20 years. Marl beds of this size are not common and I should consider that anybody who finds a marl bed large enough to run a 2,000 barrel plant to its full capacity for 20 years would be a very fortunate person.

Having described briefly the plants now using marl, we shall discuss the factors to be considered in the utilization of marl in the making of Portland cement.

QUALITY AND QUANTITY OF MARL AND CLAY

Perhaps more cement plants have failed because of a low grade or inadequate supply of raw materials than for any other reason. A very thoro and systematic investigation of the deposits of both marl and clay should precede any plans for building a plant.

Quality of the marl.—The marl must carry a relatively high percentage of calcium carbonate. The higher this percentage the more desirable does the marl become. Above 90 per cent dry basis is desirable, tho plants have operated on marl with a calcium carbonate content of as low as 80 per cent. The lowest limit that can be used will depend on the character of the impurities present.

The amount of magnesium carbonate should be low. More than 3 to 4 per cent would be undesirable, especially if the clay or shale to be used carried some magnesia. Very few marls, however, carry large amounts of magnesium carbonate, even in regions where the surrounding limestones are highly dolomitic. This fact is doubtless due to the effect on the deposition of the marl of the varying solubilities of the carbonates of calcium and magnesium.

The amount of organic matter present in the marl is of vital importance. When organic matter is present the amount of water needed to give a slurry that can be handled by the machinery of the plant is greatly increased. As a consequence the kiln capacity is reduced and the fuel cost raised. The amount of water needed to form a workable slurry will vary greatly with different marls with about the same

FIGURE 1. ROAD CROSSING MARL LAKE, HANOVER, ONTARIO

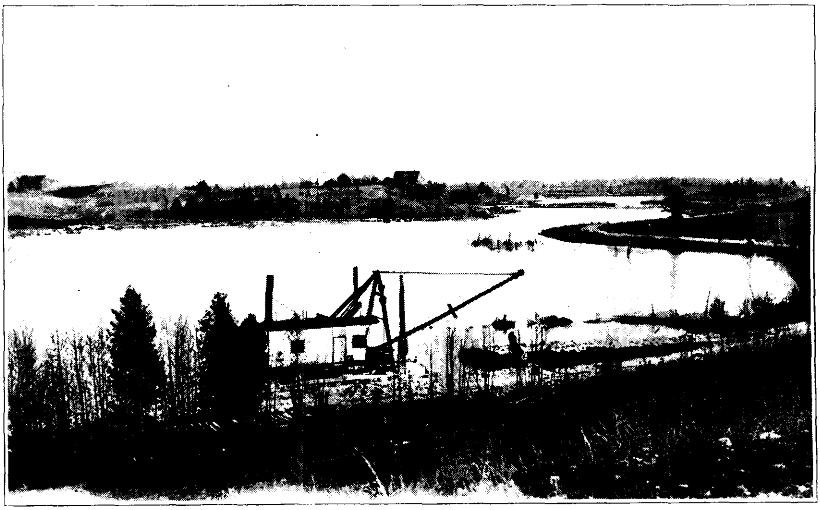


FIGURE 2. MARL LAKES OF HANOVER CEMENT COMPANY
SHOWING DREDGE

content of organic matter. It seems that the character and state of division of the organic matter is of as great importance as the amount.

It also seems probable that the physical condition of the marl itself is a factor in the amount of water needed in the slurry. No exact information is available on this point and experiment alone can tell the amount of water needed for a particular marl. This point has been quite generally overlooked in the evaluation of marls. In practice some plants have been able to operate quite effectively with amounts of organic matter over 5 per cent. Other plants find difficulty in operating with more than 3 per cent organic matter.

Sand.—The presence of sand in marl is usually considered very disadvantageous. Here, too, the physical character of the sand is a factor worthy of note. Coarse gravel can be quite readily screened out. Very fine sand, most of which will pass 100 mesh, will give little trouble. Its presence must, of course, be taken into account when the mixture is proportioned. If the sand is not so fine the proper intimacy of mixture can not be obtained. The cost of grinding sand to the desired fineness is very high. Plant practice varies as to the amount of sand that can be utilized. Some plants encounter difficulty merely because they do not vary the other ingredients of the mix to get the proper chemical relationship. In general, it may be said that the main body of a marl deposit should contain less than 2 per cent of sand. Amounts of sand up to 5 per cent can be tolerated in small areas of the deposit. Their utilization will require careful management on the part of the plant chemist. In the sampling of marl, sand layers of one or two inches in depth are often not noticed. These will cause the amount of sand in the marl bed to be higher than anticipated from preliminary investigations.

Clay.—Many marl beds have pockets of clay and in some cases rest on a layer of clay. If this clay is of the proper character for use in cement-making, its presence is an advantage. The amount of clay added at the mill must be altered as required. The clay may, however, be high in magnesium carbonate and so be disadvantageous. The amount of alkalies present should be small.

Analyses of marls.—The following table shows the analyses of some marls that have been used to make Portland cement. With some changes it has been taken from the book on cement by E. C. Eckel.[4]

[4] E. C. Eckel. *Cements, Limes, and Plasters.* Second edition, p. 312.

TABLE VI

ANALYSES OF MARLS USED IN CEMENT PLANTS

Silica SiO_2	Alumina Al_2O_3	Iron Oxide Fe_2O_3	Lime Carbonate $CaCO_3$*	Magnesium Carbonate $MgCO_3$*	Organic Matter	
1.74	0.90	0.28	88.95	3.66	4.81*	Sandusky Portland Cement Co., Syracuse, Ind.
1.78	1.21		88.43	2.72	4.23	Sandusky Portland Cement Co., Syracuse, Ind.
0.85	0.86		91.09	2.74	...	Wabash Portland Cement Co., Stroh, Ind.
0.66	0.62		94.89	0.98	2.53	Wabash Portland Cement Co., Stroh, Ind.
3.80	n.d.		91.20	3.22	1.50	Millens Portland Cement Works, South Bend, Ind.
0.19	0.05	0.07	91.57	4.04	2.25	Millens Portland Cement Works, South Bend, Ind.
0.22	0.76		92.01	2.64	4.23*	Peninsular Portland Cement Co., Cement City, Mich.
0.77	0.11		95.62	1.90	...	Newago Portland Cement Co., Newago, Mich.
1.24	0.80		90.84	2.99	4.09	Newago Portland Cement Co., Newago, Mich.
0.72	0.24	0.12	98.37	0.92	...	Newago Portland Cement Co., Newago, Mich.
0.06	0.80		98.16	...	...	Newago Portland Cement Co., Newago, Mich.
1.19	0.55	0.25	93.70	2.43	...	Wolverine Portland Cement Co., Coldwater, Mich.
1.20	0.55	0.40	91.29	0.77	...	Wolverine Portland Cement Co., Coldwater, Mich.
n.d.	n.d.	n.d.	92.63	1.74	...	Wolverine Portland Cement Co., Coldwater, Mich.
1.65	0.81		90.61	tr.	...	Bronson Portland Cement Co., Bronson, Mich.
0.40	0.20	0.20	95.48	0.63	...	Iroquois Portland Cement Co., Caledonia, N.Y.
0.42	1.08		93.45	2.11	0.86	Millens Portland Cement Co., Wayland, N.Y.
0.26	0.10		94.34	0.38	1.54	Empire Portland Cement Co., Warners, N.Y.
0.26	0.21	0.01	90.98	0.40	1.68	Empire Portland Cement Co., Warners, N.Y.
6.22	1.70	0.86	85.41	0.84	...	Montezuma, N.Y. First marl used for cement.
0.14	0.36		94.87	3.14	...	American Cement Co., Jordan, N.Y.
0.54	0.56		97.09	4.89	...	Genesee Wayland Portland Cement Co., Perkinsville, N.Y.
1.98	0.97		90.93	1.15	0.25	Buckeye Portland Cement Co., Harper, Ohio.
0.26	0.200		94.36	...	...	Castalia, Portland Cement Co., Castalia, Ohio.
1.43	0.20	0.18	90.34	4.37	3.44*	Imperial Portland Cement Co., Owen Sound, Ont.
0.46	0.44		97.16	0.63	1.12	Canadian Portland Cement Co., Marlbank, Ont.
7-12	1-3.4		72-82	2-6.25	(up to 4.5% NaCl)	Brigham, Utah (U.S.G.S. *Bulletin* 522, p. 349).

* Computed from oxides.

Quality of clay or shale.—Clay or shale should be free from sand and gravel because of the high cost of grinding such material to the fineness necessary for its reaction in the kiln. It is desirable that clays or shales carry from 60 to 70 per cent of silica altho in practice clays have been used with less than 50 per cent silica. The aluminia and iron oxides together should be from one third to one half as great as the silica. The lower limit is preferable. Magnesia and the alkalies should be low. The limits will depend on the chemical character of the marl used.

Table VII, page 20, shows analyses of clays and shales that have been used with marl in the manufacture of Portland cement.

Quantity of marl.—As deposited, marl contains large amounts of water. Very conservative estimates must be made of the amount of calcium carbonate in a marl deposit of given area. Many companies have been disappointed by finding that a bed of marl estimated to last their plant for thirty years was actually only sufficient for about five years operation. A wet marl may contain, as it rests in the lake, as high as 60 per cent water. A cubic yard of such marl may weigh about 2,000 pounds and contain only about 800 pounds of dry marl. A dry marl in a well-drained swamp or marsh may have as low as 20 per cent of water. A cubic yard would weigh around 2,600 pounds and contain a ton of dry marl. Plant operations on *wet lake marls* in Michigan would seem to justify a figure of 1.7 barrels as a conservative estimate of the amount of Portland cement which could be made from one cubic yard of marl. (Eckel uses 2 barrels per cubic yard.) We shall later see that the smallest mill that could be built with modern equipment and operated economically would be one with a capacity of about 2,000 barrels daily. This would require two kilns about 200 feet long. Such a mill, operating 300 days a year for 30 years would produce 18,000,000 barrels of cement. These would require 10,600,000 cubic yards of marl. Each acre of marl 20 feet deep would give 32,266 cubic yards of marl and approximately 320 acres of marl of this depth would be needed to supply the mill for the 30-year period. Most cement plants are either worn out or obsolete in twenty years, so the figures above could be revised for that length of time if desired. This would require approximately 240 acres of marl for successful operation for twenty years. It seems best, however, to make this estimate as conservative as possible.

TABLE VII

ANALYSES OF CLAYS AND SHALES USED WITH MARLS

Silica SiO_2	Alumina Al_2O_3	Iron Oxide Fe_2O_3	Lime Oxide CaO	Magnesium Oxide MgO	Carbon Dioxide CO_2	Water H_2O	
55.27	10.20	3.40	9.12	5.73	...	...	Clay, Syracuse, Ind., Sandusky Portland Cement Co. *Twenty-fifth Annual Report*, Indiana Dept. of Geology, 1901, p. 28.
61.70	18.00		8.40	2.91	13.30		Clay, Stroh, Ind., Wabash Portland Cement Co., 1904.
57.74	17.76		7.80	3.52	12.30		Clay, Stroh, Ind., Wabash Portland Cement Co., 1904.
56.74	19.43	4.83	7.27	3.05	10.39		Clay, Stroh, Ind. W. R. Oglesby, analyst. *Twenty-fifth Annual Report*, Indiana Dept. of Geology, 1901, p. 112.
67.89	29.89		1.42	2.16	...	20.50	Range of composition—Coldwater shale, Union City, Mich., Peerless P. C. Co.
59.20	23.33		0.00	0.26	...	10.00	Range of composition—Coldwater shale, Union City, Mich., Peerless P. C. Co.
57.26	18.12	6.53	1.25	1.49	6.19		Range of composition—Coldwater shale, Coldwater, Mich., Wolverine Portland Cement Co.
61.25	21.59	8.30	1.50	2.31	8.32		Range of composition—Coldwater shale, Coldwater, Mich., Wolverine Portland Cement Co.
54.94	12.14	4.88	9.13	3.65	...	12.44¶	Drift clay, Livington Co., Mich., Standard Portland Cement Co.
49.75	13.06	5.31	10.86	4.28	15.07		Lacustral clay, Chelsea, Mich. Analysis by E. D. Campbell.
49.34	14.50	5.37	9.75	4.77	15.55		Lacustral clay, Fenton, Mich. Analysis by E. D. Campbell.
62.55	17.46	5.08	2.30	1.67	5.55		Lacustral clay, Milbury, Ohio. Analysis by E. D. Campbell.
61.03	18.10	6.65	1.29	0.53	9.21		Lacustral clay, Bryan, Ohio. Analysis by Dean and Potter.
59.22	20.82		...	3.09	...	...	Clay, Montezuma, N.Y.
65.68	24.08		2.01	1.75	...	...	Clay, Jordan, N.Y., American Cement Co.
40.48	20.95		25.80*	0.99‡	...	8.50¶	Swamp clay, Warners, N.Y., Empire Portland Cement Co.
42.85	13.51	4.49	22.66*	6.92‡	...	...	Swamp clay, Warners, N.Y., Empire Portland Cement Co.
62.50	20.20	7.50	0.80	1.80	...	...	Clay, Canavangus, N.Y., Marengo Portland Cement Co., Caledonia.
45.21	19.08	6.74	19.94*	3.27‡	...	4.17¶	Clay, Mount Morris, N.Y., Empire Portland Cement Co., Wayland.
53.50	24.20		5.15	2.15	14.1¶		Clay, Wayland, N.Y., Wayland Portland Cement Co.
47.45	19.85		17.80	0.09	0.57	...	Clay, Buckeye Portland Cement Co., Ohio.
59.10	24.01		2.20	2.00	...	...	Clay, Ohio, Castalia Portland Cement Co.
51.56	14.50	3.84	9.80	...	7.70	...	Clay, Ohio, Castalia Portland Cement Co.
48.00	16.50		7.60	2.50	...	...	Range of composition—clay near Brigham, Utah.
50.00	18.60		...	2.80	...	...	Range of composition—clay near Brigham, Utah.

* Compiled, with some changes, from E. C. Eckel, Portland Cement Materials of the United States. *Bulletin* 522, United States Geological Survey.

† $CaCo_3$ ‡ $MgCO_3$ ¶ Includes organic matter as well as water.

Overburden.—Many marl deposits have an overburden of peat or soil. If this is shallow it can be readily stripped as the marl is excavated and dropped in the lake back of the dredge. If the overburden is deep or if it carries trees and bushes the excavation costs will mount. Wherever there is an overburden the amount of organic matter in the marl as delivered to the mill will increase, due not only to the intermingling during deposition, but also to mechanical mixing during the stripping and the excavation. It is the general opinion that an overburden of more than about five feet would render the cost of excavation almost prohibitive. In most cases a large overburden is accompanied by a decided increase in the amount of organic matter in the marl.

Depth of water.—If the marl is covered by more than fifteen feet of water, the deposit can not be effectively utilized unless arrangements can be made to lower the water level of the lake. Marl at these lower levels is apt to be mixed with large amounts of organic matter.

Investigation of marl deposits.—The marl deposits should be very carefully and exhaustively sampled. They should be laid off in fifty-foot squares and soundings made at each point. If the deposit is in a swamp or marsh the points may be easily located. If the marl is under water a raft with a hole in the center should be moored at the proper points by reference to fixed points on the shore. An even better plan is to make the soundings of the marl when the lake is frozen. The lake can be readily blocked off and holes cut in the ice. The depth of water or of peat over the marl should be carefully noted. It is best to take at least three samples of marl during each sounding, one near the top, one near the middle, and one at the bottom of the deposit. In special cases more samples should be taken. Great care should be exercised to make sure that the depth of the marl has been correctly determined. If there is any evidence of lack of uniformity in the character or depth of the marl deposit, more soundings should be made and more samples taken.

Numerous devices have been used in sampling marl beds. The simplest type consists of an auger welded to the end of a section of gaspipe. Additional sections of pipe can be screwed on as the depth of the bed demands. There is danger of mixing various layers with such an instrument and so the origin of the sample may be doubtful. Another type utilizes a section of gaspipe with a slit down the side and a flange of metal so arranged that revolving the pipe causes the section to be filled with marl. Still another type has small metal cups attached to a section of gaspipe in such a way that they are filled when the pipe is withdrawn.

The sampler devised by C. A. Davis, of the United States Bureau of Mines, for use in sampling peat is perhaps the most exact tool known. It is described in *Bulletin* 16, of the Bureau of Mines, as follows:

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

The samples of marl should be immediately placed in air-tight containers and properly labeled. The samples should always be taken by a representative of the chemical laboratory making the analysis. Samples taken by interested parties or by anyone other than the analyst or his representative are often of little value. Chemical analyses are of value only as the samples are representative of the character of the entire deposit.

It is impossible to overemphasize the urgent necessity of having all of the surveying, sampling, and testing of marl deposits done thoroly and by competent men. The total cost of a thoro investigation carried out by experienced and competent analysts is small compared with the amount of money that is required to build, equip, and operate a modern cement plant. Lack of adequate knowledge may lead to serious financial loss or to complete failure. No one should invest money in a plant designed to utilize marl until a thoro investigation has been made and exhaustive tests carried out by competent and disinterested analysts. The cost of such an examination of a marl deposit might reasonably be expected to be between $2,000 and $5,000. Since a well-equipped plant could not be built and operated with a capital of less than $3,000,000, the investigational cost is relatively quite low. A number of laboratories are prepared to undertake such investigations and report on the feasibility of the projects.

PLANT OPERATION

Excavation and transportation of marl.—The method of excavating marl will vary greatly with its character and location. When the deposit is well drained a steam shovel or a drag line excavator can be used and the marl loaded into cars and transported by rail to the plant. Where the deposit is poorly drained or under water a floating dredge may be used. The marl is taken up from in front of the dredge by a "clamshell" or "orange-peel" bucket and the dredge floats in the excavation thus formed. The marl may be loaded into cars on the edge of the cut if the swamp is solid enough to support their weight.

More often the cars will need to be placed on a floating dock or even on scows which can be towed to the shore and then transported to the plant by rail. In some instances the marl is put through a mixing machine near the dredge and pumped to the mill as a slurry. Other companies transport the marl slurry to the shore in tank scows. At the shore it is pumped to the mill through a pipe line. The method of excavating and transporting marl for any particular plant should be decided upon after a careful study of the character and location of the marl. The relative costs of various methods of excavation and transportation should be taken into account as well as the condition in which the marl arrives at the mill. If the marl must be moved any great distance water transportation may be found the cheaper. From the standpoint of efficient plant operation that method of excavation and transportation is most desirable which will deliver the marl to the mill with the smallest water content. For this reason excavation of lake marls by an orange-peel dipper and transportation in cars is good practice. With all save very fluid marls the orange-peel bucket allows the water to drain off quite completely and yet retains the marl. The cars give additional opportunity for the escape of water. It should be noted that a skilled and watchful operator on the dredge can greatly reduce the amount of water in the marl as transported to the mill. Care on his part will also materially reduce the amount of sand or of organic matter taken up with the marl. Care and forethought in excavation will also aid the plant operations by insuring a greater uniformity of material. For this reason the marl should be excavated vertically from top to bottom, rather than horizontally.

FIGURE 3. EXCAVATING MARL NEAR FENTON, MICHIGAN. AETNA PORTLAND CEMENT COMPANY

FIGURE 4. LOADING MARL IN SCOWS AT AETNA PORTLAND CEMENT COMPANY

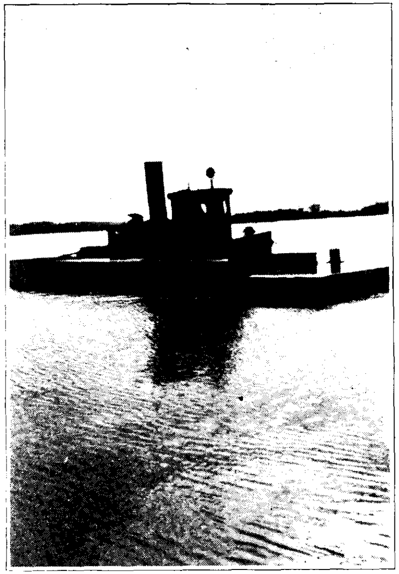


FIGURE 5. TUGGING SCOWS ACROSS THE LAKE TO THE PLANT OF THE AETNA PORTLAND CEMENT COMPANY

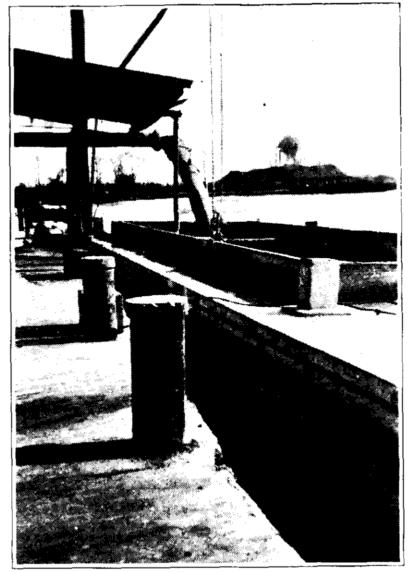


FIGURE 6. PUMPING MARL OUT OF SCOWS AT AETNA PORTLAND CEMENT COMPANY

New Egyptian Portland Cement Company's plant in the background.

The cost of excavating and transporting the marl should be relatively low. No blasting is necessary in excavating marl. Not many men are required and the maintenance cost is low as compared with quarry operations. This represents one decided advantage of marl over limestone as a raw material. It seems likely that the necessary marl and clay for a barrel of finished cement will cost only about one half as much delivered at the plant as hard limestone and shale. Exact costs are difficult to predict because of varying factors such as wages, cost of power, etc.

Excavation and transportation of clay or shale.—Clay is usually excavated and loaded onto cars by a steam shovel. Shale may need preliminary blasting before the steam shovel can handle it readily. The methods in vogue at marl plants do not differ from those used at limestone plants. The costs will be very nearly the same.

Mixing and grinding of raw materials.—The marl comes to the mill in a form that requires no preliminary grinding before mixing. It may require screening to remove stones and twigs. When pumped from the deposit or the lake shore it has already been thoroly mixed. If delivered to the plant by cars it will be passed through a pug mill to give a uniform material.

When clay is used it may be crushed through rolls and then mixed with water in a "wash mill." A more usual practice at plants using marl is to grind up the clay in a mill of the general type known as "drypan," "edge runner," or "wet pan" mills. In this type of mill the material is crushed in a pan under a pair of heavy rolls, the rolls having two motions, rotating on a horizontal axis and revolving as a whole about a fixed vertical axis.

Shale requires more preliminary crushing, before going to the edge runner mill than does clay but is handled in much the same manner.

In wet process plants using limestone the wash mill or wet pan method of handling the clay has some advantages, but for plants using marl dry grinding of the clay is advantageous, since the water content of the marl-clay mixture is more readily kept within the desired limit when the clay can be added in the dry condition.

The marl and clay or shale are now mixed in the determined proportions in a tank. Here the materials are thoroly intermixed by mechanical agitation.

The mixture is now passed to the grinding equipment. This is of the ball grinding type. Kominuters, ball mills, tube mills, or various combinations of these machines are generally used. The grinding of these soft, wet materials is relatively easy and the costs are relatively low. This represents another decided advantage in the use of marl.

The one point to be most carefully watched in the mixing and grinding department of a cement plant using marl is the water content of the slurry, as it goes to the kiln. The equipment and operations should all be those designed to produce a slurry of as low a water content as possible. Under no circumstances should it go much above 50 per cent as fuel costs in the kiln increase rapidly as the water content mounts. Because of the physical character of marl it is impossible to produce slurries therefrom with the low water content that is found in wet process plants using limestone. Such plants operate with slurries bearing as low as 30 per cent water. Many plants have attempted operation using marl when its character and their method of operation were such as to give a water content of 60 to 70 per cent. Such plants were manifestly doomed to failure when subjected to the competition of plants using better methods.

The slurry after final grinding is sent to one of a series of storage basins. As each tank is filled a sample is taken and subjected to chemical analysis. If the proper proportion of ingredients is not present the slurry may be corrected by adding the required amount of marl or clay. More often, however, the slurry is corrected by mixing the tank of material low in one ingredient with another tank high in that same ingredient. This mixing is carried out in a mixing basin of about twice the capacity of the slurry tanks. Evidently this system of handling the material going to the kilns gives an opportunity for very exact chemical control. Consequently the finished cement is very uniform in character.

Burning the clinker.—The slurry is calcined in the usual rotary kilns. The practice in burning is essentially the same whether the raw calcareous material be marl or limestone. From the figures given for water content it is evident that the production of cement from a given kiln will be less with a marl than with a limestone slurry. Evidently, too, the same kiln, using the dry process, will have an even larger production. The fuel cost per barrel of cement will also be less with the slurry of low water content and even less with the use of the dry process. This difference is much less with long than with short kilns.

The general tendency in cement technology has been towards the use of longer and longer kilns. Twenty years ago the standard length of kiln was 60 feet. The proved success of longer kilns (150 feet) at the Edison plant turned the attention of cement plant men to the advantages of the long kilns. At the present time very few new plants are equipped with kilns less than 150 feet long. Many kilns of 175 to 200 feet in length are in use and some kilns 240 and 250 feet in length are in operation. The longer kilns have given reduced fuel costs and have shown decided decreases in stack temperatures. Especially with the wet process has the use of long kilns introduced greater efficiencies. Many of the marl-using plants built with the short kilns of twenty years ago have found it impossible to continue operations with such antiquated equipment. Where the supply of marl has been sufficient to justify the installation of long kilns the plants have continued profitable operation. A plant designed to use marl should have kilns at least 175 feet long. If not equipped with waste heat boilers—and it should always be so equipped—the kilns should be not less than 200 feet long. Probably 200-foot kilns with waste heat boilers would be found the most satisfactory.

The most recent development in the Portland cement industry has been the successful introduction of waste heat boilers. These utilize the heat of the gases leaving the kilns. Otherwise this heat would be lost. This development, while of theoretical interest for many years, has been forced upon the manufacturer by the great increases in the cost of fuel during the war and the post-war periods. The results obtained in practice are such as to render it evident that any new installation should include waste heat boilers in order to meet the competition of other plants. Many old plants are installing waste heat equipment and it seems that the extraordinarily long kilns being installed by some companies could better be replaced by somewhat shorter kilns equipped with waste heat boilers.

Many plants find that waste heat boilers furnish all the power needed. Some plants even have a surplus of power to be disposed of outside of their own establishments. Waste heat installations are especially advisable in plants using the wet process. Altho the stack temperatures are lower than in the dry process, the specific heat of the stack gases is higher, due to the large amounts of steam present.

Fuel.—The usual fuel is powdered coal. Most of the marl-using plants must ship in their coal. This adds greatly to the cost. The proposal is often made that powdered peat be used to fire the kilns. The marl beds occur in close juxtaposition to the peat bogs. In fact the swamp marls often carry an overburden of peat. In Michigan, about twenty years ago, a company was organized and a plant projected to use peat. Little else is known of this attempt. It evidently was not a success as the plant changed over to the use of powdered coal.

The high cost of coal and the increased freight rates have again brought this proposal to the minds of cement mill technologists. No adequate experimental basis exists for designing a plant to use peat. Doubtless such a plant would have to pass through the experimental stage and be remodeled in the light of the knowledge so obtained before it would be a commercial success. However, powdered peat has been used for steam-raising purposes. The excavation and drying of the peat also present many difficulties.

TABLE VIII

PORTLAND CEMENT BURNED BY DIFFERENT FUELS IN 1919 AND 1920*

Fuel	1919				1920			
	Number of Plants	Number of Kilns	Barrels of Cement	Percentage of Total	Number of Plants	Number of Kilns	Barrels of Cement	Percentage of Total
Coal	90	596	65,877,185	81.6	96	629	81,265,667	81.2
Coal and crude oil	3	32	6,985,271	8.6	1	24	6,676,029	6.7
Coal and gas..	2	9			1	6		
Crude oil......	14	73	6,634,775	8.2	16	79	9,495,798	9.5
Crude oil, coal, and gas......	1	5	1,280,704	1.6	2	9	2,585,751	2.6
Natural gas...	1	5			1	6		
	111	720	80,777,935	100.0	117	753	100 023,245	100.0

* E. F. Burchard, Cement in 1920, *Mineral Resources*, 1920, Part II. United States Geological Survey.

The proposal has also been made to utilize the producer-gas from a peat fired producer-gas furnace to burn the clinker. Here, too, no adequate experimental basis is known for the design and construction of such a plant. The present experiments of the Bureau of Mines with peat in a producer-gas furnace may be of value in the future. Cement kilns have been fired with natural gas where a plentiful supply was available.

It should be said that the use of peat as a fuel for producing cement from marl would be very desirable from the standpoint both of cost and utilization of natural resources. Commercial companies can not, however, be expected to undertake such a project until they can see their way clear to successful and continuous operation and consequent financial success.

Fuel consumption.—The fuel consumption is related directly to the length of the kilns, the stack temperatures, and the amount of water in the slurry. The quality of the coal is also a factor worthy of note. Most plants use a good West Virginia soft coal with not to exceed 10 per cent ash. (See Table IX.) Where the kilns are long enough that the stack temperatures may be kept between 700° and 800° F., a marl slurry of about 50 per cent water will require from 125 to 150 pounds of such coal for each barrel of cement. The use of waste heat boilers will enable the recovery of at least enough energy from the stack gases to furnish the power for the other operations of the plant.

Clinker-grinding and packing.—The operations in these departments are the same whether marl or limestone is used and no attempt will be made to discuss them in detail.

Storage.—Any Portland cement plant must provide adequate storage to ensure its customers a continual supply of cement. The consumption of cement is seasonal in character. When construction and road-building are in full swing, the demand for cement is strong. When severe weather curtails these operations the demand drops off. As a result a plant must have rather extensive storage facilities to enable it to continue operation when the market no longer absorbs its product. Storage space for from three to six months' output of the plant would seem desirable.

Wet process vs. dry process.—Since the use of marl in the manufacture of Portland cement necessitates the adoption of the wet process (called semi-wet in Europe), a comparison of the two processes would seem of value.

The wet process involves the mixing and grinding of the materials in the presence of water. The resultant slurry is then introduced into the kilns. This process is always used for marl and may be used for hard limestone and cement rock. It has even been used with blast furnace slag.

The dry process involves the mixing and grinding of the raw materials in as dry a condition as possible. The resultant mixture is introduced into the kilns dry. This process has been widely used for limestone and cement rock. Nearly all blast furnace slag used for making cement is handled by this process.

TABLE IX

ANALYSES OF KILN COALS*

Volatile Matter Per Cent	Fixed Carbon Per Cent	Sulphur Per Cent	Ash Per Cent	Moisture Per Cent	B.T.U. per Pound	
32.90	54.66	n.d.	10.25	2.19	.....	Westmoreland, Pa., stock used at Cayuga Cement Co., Portland Point, N.Y.
39.52	51.69	1.46	6.13	1.40	.....	West Virginia stock used by Peninsular P. C. Co., Cement City, Michigan.
41.66	52.51	1.86	5.83	...	14,352	Gas coal, Island Creek, New River field, West Va., Virginia Portland Cement Co., Fordwick, Va.
39.65	54.93	1.62	5.42	...	14,510	Gas coal, Island Creek, New River field, West Va., Virginia Portland Cement Co., Fordwick, Va.
33.87	52.85	4.51	13.27	...	12,441	St. Charles, Ky., Kosmos Portland Cement Co., Kosmosdale, Ky.
34.98	53.70	n.d.	11.32	...	12,610	St. Charles, Ky., Kosmos Portland Cement Co., Kosmosdale, Ky.
31.19	51.04	2.80	12.61	2.37	.....	West Frankfort, Ill., Cape Girardeau P. C. Co., Cape Girardeau, Mo.
31.71	49.21	1.20	12.82	5.06	.....	West Frankfort, Ill., Cape Girardeau P. C. Co., Cape Girardeau, Mo.
32.26	44.48	6.10	20.07	3.19	10,971	Des Moines, Ia. district, Hawkeye Portland Cement Co.
29.81	45.66	5.80	22.25	2.38	10,763	Des Moines, Ia. district, Hawkeye Portland Cement Co.
30.81	54.94	2.86	9.37	2.00	13,246	Pittsburgh, Kan., Ash Grove Portland Cement Co., Chanute, Kan.
29.30	53.54	3.52	11.56	2.08	12,552	Pittsburgh, Kan., Ash Grove Portland Cement Co., Chanute, Kan.
33.97	46.31	5.29	18.76	0.96	.....	Mineral, Kan., Dewey Portland Cement Co., Dewey, Okla.
34.49	45.53	5.23	19.08	0.90	.....	Mineral, Kan., Dewey Portland Cement Co., Dewey, Okla.
34.78	49.72	n.d.	13.50	2.00	.....	Henryetta, Okla., Oklahoma Portland Cement Co., Ada, Okla.
37.44	55.42	n.d.	3.74	3.40	.....	Henryetta, Okla., Oklahoma Portland Cement Co., Ada, Okla.

* E. C. Eckel. *Cements, Limes, and Plasters.* Second edition. 1922.

The first Portland cements were made by the wet process. With the extended use of the dry, hard limestones and cement rocks in this country the dry process was introduced and developed. It was a process ideally fitted to the raw materials most plentiful in the United States from the standpoint of cement mill practice as then known. The great success of this process led cement technologists in general to consider it as by far the best process. Only within the last few years has the wet process again attracted serious attention and study. The changed economic conditions and the improvements in plant design and construction, especially the lengthened kiln, have caused some companies to build wet process plants, even where limestone or cement rock was to be their raw material.

Advantages of the dry process.—The advantages of the dry process may be enumerated as follows:

1. Less fuel used per barrel of cement—no water to be driven off in the kiln. There is not such a decided advantage in this respect with kilns of 200 feet in length and longer.

2. Decreased overhead cost per barrel of cement—due to the larger amount of cement burned in the kilns each 24 hours.

3. Dry materials may be ground exceedingly fine—thus insuring intimate mixing of materials and complete reaction in the kilns of all the particles.

Advantages of the wet process.—The advantages of the wet process are as follows:

1. Complete chemical control of the character of the mix—thus giving a more uniform product. Correction of the mix may be made before burning.

2. Lower "stack" temperatures—around 800° F. being usual practice in wet process plants as compared with around 1500° F. in dry process plants. This tends to offset the increased amounts of fuel needed to drive off the water.

3. Lower costs of grinding of raw materials.

4. More intimate mixing of raw materials without the need for such fine grinding.

5. Waste heat boilers can be used to great advantage.

It is worthy of note that the majority of the plants built within the last few years have adopted the wet process. While it is impossible to predict accurately the future technologic development of the Portland cement industry, it would seem that in the future wet process plants where properly designed and constructed and especially when equipped with waste heat boilers will be able to compete on at least even terms with dry process plants.

An advantage will accrue to the wet process plants using limestone as compared to those using marl because of the smaller amount of water needed to make a workable limestone slurry. Only from 30 to 40 per cent water is needed for limestone while marl slurries are seldom below 47 per cent. This will be offset, in part at least, by the decreased grinding cost with marl and by the small cost of excavating the marl.

Plant design.—There is in existence at the present time no plant with complete modern equipment designed to use marl. As a consequence a plant intended to use marl must be designed by adapting certain features developed in the industry where other raw materials are in use. Some rearrangement and remodeling must be anticipated before such a plant can operate to its greatest efficiency. The financial arrangements of a company building such a plant must allow for some adjustments and its financial backers must expect such changes.

In a general way, the requirements which seem quite definite for a plant designed to use marl will be outlined. Attention has already been called to the planning of operations and equipment to the end of keeping as low as is possible the amount of water in the slurry. It would seem that the capacity of the mill could not well be much below 2,000 barrels daily without greatly increasing the overhead costs. While many mills have operated in the past with smaller capacities this would seem to represent the minimum capacity advisable under present day conditions. Two 10x200 foot kilns of standard construction and equipped with waste heat boilers should produce this amount of cement if well and carefully handled. The capacity of the raw-grinding and clinker-grinding machinery should be such as to insure continuous kiln operation. The general plan of the plant should be such that the materials would pass in an orderly progression from raw materials storage to finished materials storage. Mechanical transportation of all materials is essential. A bulky product like Portland cement can only be economically produced by utilizing to the utmost mechanical labor-saving devices. Electrical operation of machinery is recommended.

Shipping facilities.—The shipping facilities are of prime importance in locating a Portland cement plant. A location on two or more railway lines is desirable. Water transportation is extremely advantageous.

Plant management and operation.—Experienced and competent engineers and chemists will be needed in a plant using marl even more than in one where the practice is more standardized. A large measure of energy and initiative must be added to their knowledge. On the judgment and discretion of the staff will depend in large measure the success or failure of the plant. They must beware of impractical ideas and yet be open-minded to any possible improvements in operation. The operating officials of the plant should be responsible to the company only for results. In matters of plant operation and control they should be given a free hand.

Office organization and sales force.—The office organization is mentioned here only because some companies have been financial failures because of large overhead costs due to poor office organization or to unreasonably large salaries paid for supervision. Evidently the same principles of economy and efficiency that apply in other lines of enterprise will apply to the office organization and sales force of a Portland cement company.

Capital.—A rather large amount of capital must be available for the building and operation of a Portland cement plant. Modern machinery is expensive and its installation difficult. Building costs are still quite high and promise to remain so. Adequate supplies of raw materials must be acquired and means of transporting these materials provided. Men competent to design and construct a cement plant are scarce and high priced.

In addition to all the expense incident to construction of a plant the management must expect to finance at least one year's operation before the income from the sale of cement will be sufficient to meet even operating costs. This is because of the difficulty with which a new brand of Portland cement will be introduced to the market. Engineers and contractors are always reluctant to abandon a tried brand for a new and untried brand. As a result any new brand of cement must win its way into favor by a slow process.

It would seem reasonable to say that for a 2,000 barrel a day plant a working capital of $3,000,000 would be needed to enable the plant to be constructed and operated, and its product firmly placed on the market.

Summary.—To summarize briefly it would seem that the following conditions are essential to the successful operation of a Portland cement plant using marl and clay or shale.

1. An adequate supply of marl and of clay must be known to be available. It has been estimated that 320 acres of marl 20 feet deep would be needed to supply a 2,000-barrel mill for thirty years. Other marl beds near by would be desirable.

2. The quality of the marl must be high. Careful investigation should be made as to the character of the marl by competent analysts.

3. The plant should be designed by competent engineers and controlled and operated by experienced engineers and chemists.

4. Modern equipment should be used—long kilns and waste heat boilers should be installed.

5. The machinery and methods of handling the raw materials must be such as to keep the water content of the slurry below 50 per cent.

6. No fancy salaries should be paid to managers or salesmen and little money should be spent for promotion.

7. A capital of not less than $3,000,000 is recommended.

8. The plant must be advantageously located with respect to a market for its product, and with respect to shipping facilities. Freight rates determine quite largely the location of cement plants.

9. The plant should be located in a territory where there is no limestone suitable for use in the making of Portland cement.

In a territory where a quality of limestone suitable for use in cement is available it would not be wise to attempt operations using marl. The theory and practice of modern cement-making have been almost entirely developed in plants using limestone. The design and operation of such a plant would not present the difficulties that should be expected in a plant designed to use marl. As previously pointed out, a company considering the use of marl must expect to pass through a period of experimental development and must provide funds for a possible partial change in process or equipment.

Where a supply of suitable limestone is lacking, the character and amount of the marl deposits should be carefully investigated. Under the conditions enumerated in the preceding paragraphs a Portland cement plant using marl should be a technologic and financial success.

MARL DEPOSITS OF MINNESOTA

No adequate survey of the marl deposits of Minnesota has been made. The Division of Soils of the University of Minnesota has collected more data on marl deposits than any other agency. These data have been accumulated in connection with their work on the liming of soils with marl.

Marl deposits are known to be numerous in the state. Their quality is variable. No definite information is at hand as to their extent. It would seem likely that many fairly large deposits exist whose location is unknown. In general the marl deposits of the state are found in the central and northern counties of the state. Many peat bogs prove to be underlaid by marl. This marl may be of high quality but often is mixed with organic matter.

Table X gives a few incomplete analyses of Minnesota marls.

TABLE X

ANALYSES OF MINNESOTA MARLS*

Locality	Insoluble in Acid	Organic	$CaCO_3$	$MgCO_3$
Hill City[1]	3.78	Not determined	90.84	2.45
Coon Creek[1]	12.84	Not determined	63.60	1.90
Barrows[2]	6.80	1.57	91.63	
Benton Co. 2½ miles east of Rice[2]	17.72	1.02	82.26	
Long Lake 7 miles east of Pequot[2]	1.64	3.75	94.61	
Fergus Falls[3]	4.01	Not determined	89.74	4.48
Avon[4]	0.54	Not determined	81.84	Trace†

* All figures are on the dry basis.

† Some clay.

[1] Division of Soils, Department of Agriculture, University of Minnesota.

[2] C. H. Dow, University of Minnesota Engineering Experiment Station *Bulletin* No. 1.

[3] *Twenty-third Annual Report of the United States Geological Survey*, 1894.

[4] State Highway Department, 1921, R. E. Kirk, analyst.

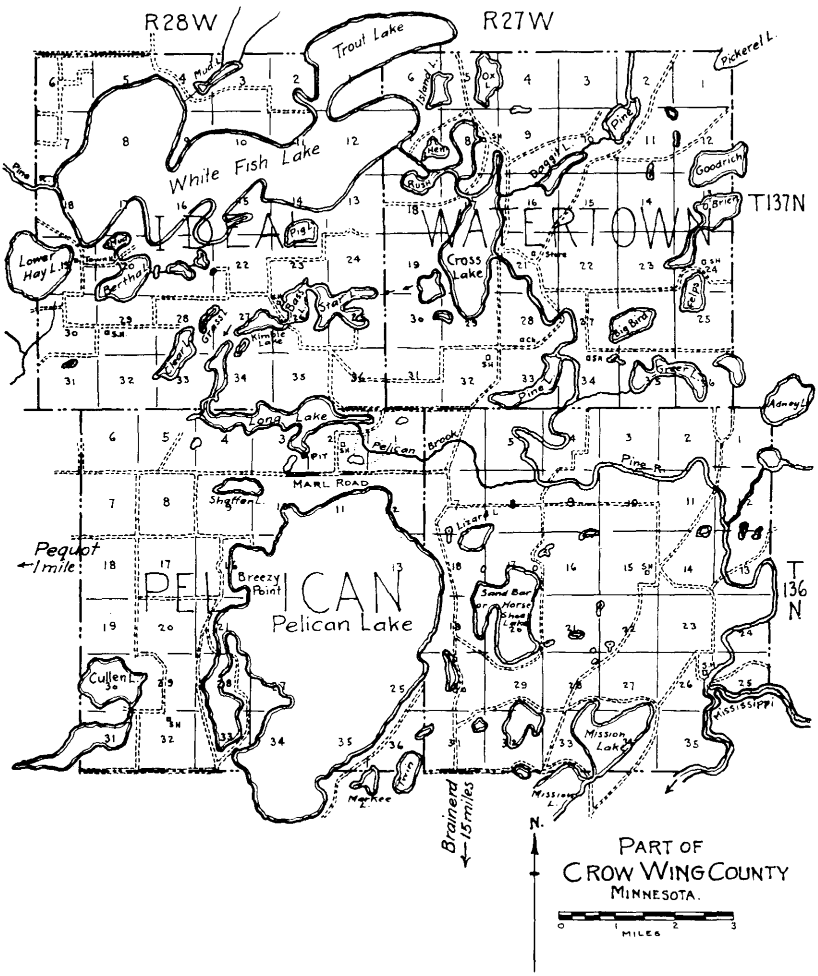
For possible use in the manufacture of Portland cement only the large deposits are of interest. Several deposits of apparently high grade marl are known which would warrant further investigation to determine their exact extent and character. Other large deposits may be found whose existence is not now known.

Dr. F. J. Alway, of the Division of Soils, reports a large deposit of marl at Hill City. Its exact extent has not been determined. The lake, with a shore line of three to four miles, contains large amounts of marl. The deposit varies from seven to fifteen feet in depth. An analysis is given in Table X. This marl bed is also worthy of consideration because of its location near a railroad.

Dr. Alway also reports a deposit at Riley Lake south of Taconite. The deposit is estimated to be about 120 acres.

A marl deposit near Bacchus has been noted by Dr. Alway and his co-workers. This bed is one-half mile wide and three miles long. The depth where explored is about twenty feet. The marl is of a high grade. The Division of Soils has opened up a marl pit on one end of this deposit. This pit is about one-half mile from the Minnesota and International Railroad. The end of the deposit near the railroad is well drained and could be worked by a steam shovel or drag line excavator. The end of the deposit farthest from the railroad is much wetter. This deposit might well be carefully investigated.

PLATE I



PELICAN LAKE VICINITY

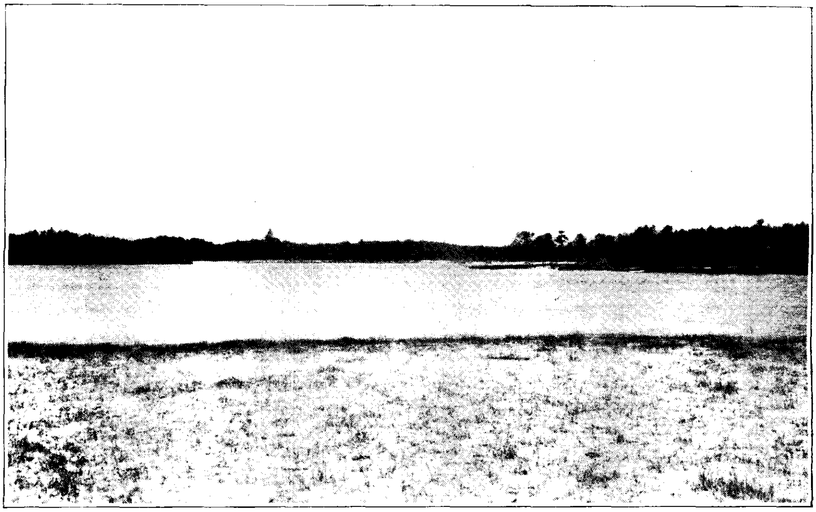


FIGURE 7. MARL DEPOSIT, STAR LAKE, CROW WING COUNTY, MINNESOTA

Lake almost filled with marl.

FIGURE 8. MARL DEPOSIT, STAR LAKE

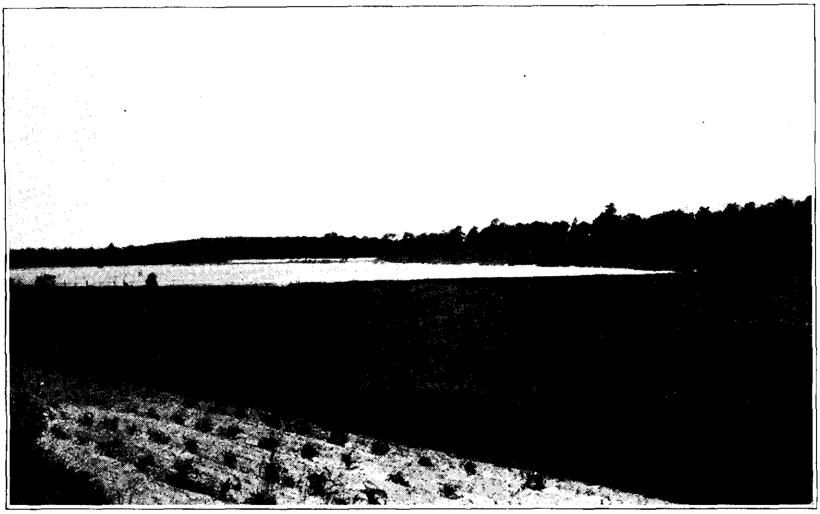


FIGURE 9. STAR LAKE. SWAMP AND PEAT BOG UNDERLAID BY MARL

Mr. J. R. Holton, of Shevlin, reports a deposit about three and one-half miles from Shevlin. He states that this deposit occurs around and in the bottom of a small lake. Surface exposures indicate that the bed is about 160 rods each way. The marl has been determined to be of good quality. It is claimed to be about twenty feet deep.

Star Lake, located in Crow Wing County about ten miles east of Pequot contains a large amount of marl. This seems to be of high quality. The near-by swamps contain deep deposits of marl. This deposit might prove worthy of careful investigation. It is of especial interest because Bass Lake and Kimble Lake, connecting lakes, also contain marl deposits. Their exact character and extent is not known. Long Lake, with an additional supply of marl, is only about one mile distant. A survey of near-by lakes and swamps might disclose still other deposits of marl. This series of deposits is located from eight to ten miles from the nearest railroad.

Marl deposits are known near Avon and between Sauk Center and Little Sauk. The writer has no definite information concerning these deposits. From the standpoint of possible use in cement these deposits should be carefully investigated. Their location near the Twin Cities would be very advantageous if they are of the requisite character and extent.

TABLE XI

ANALYSES OF CLAYS AND SHALES OF MINNESOTA

Silica SiO_2	Alumina Al_2O_3	Iron Oxide Fe_2O_3	Lime Oxide CaO	Magnesia MgO	Moisture H_2O	
50.65	10.25	4.00	10.65	4.68	1.20	Gray laminated clay, North Minneapolis, Anoka Co. (F. F. Grout, analyst).
60.49	12.62	7.80	3.87	3.68	1.94	Red drift clay, Coon Creek, Anoka Co. (F. F. Grout).
...	65.90		12.20	5.10	...	Calcareous clay, Bemidji Lake, Beltrami Co. (————).
70.29	18.71		2.02	1.35	2.15	Surface clay, Good Thunder, Blue Earth Co. (F. F. Grout).
61.32	12.27	8.00*	0.99	1.76	...	Gray shale, Cottonwood River, Brown Co. (T. M. Chatard).
63.65	17.27	4.75	0.06	1.21	2.03	Shale, Springfield, Brown Co. (F. F. Grout).
50.51	15.89	8.21	7.10	5.14	2.44	Red glacial clay, ————, Carlton Co. (A. W. Gauger).
48.79	12.08	4.60	12.10	5.54	1.26	Gray glacial clay, Wrenshall, Carlton Co. (A. W. Gauger).
53.39	14.26	13.71	3.03	1.74	9.99	Red glacial clay, ————, Cook Co. (C. P. Berkey).
56.35	18.63	6.19	0.96	2.97	2.41	Decorah shale—lower, West St. Paul, Dakota Co. (F. F. Grout).
54.66	24.04	6.53	0.45	1.08	2.35	Decorah shale—lower, West St. Paul, Dakota Co. (F. F. Grout).
50.81	20.25	5.18	4.05	2.13	2.16	Decorah shale—upper, West St. Paul, Dakota Co. (F. F. Grout).
71.53	8.07	5.63	2.36	1.74	2.30	Loess clay, Preston, Fillmore Co. (F. F. Grout).
54.90	13.94	5.15	7.36	3.28	...	Laminated clay, Albert Lea, Freeborn Co. (G. W. Walker).
57.60	14.19	2.89	7.00	3.51	...	Swamp clay—Rice Lake, Albert Lea, Freeborn Co. (A. D. Meeds).
69.92	17.39	1.68	0.60	1.11	1.10	Clay, Red Wing, Goodhue Co. (F. F. Grout).
63.32	12.68	2.66	5.08	3.94	1.83	Allurial clay, Frontenac, Goodhue Co. (F. F. Grout).
47.70	13.58	6.51	11.70	3.13	1.79	Laminated clay, Net Lake Rapids, Koochiching Co. (A. W. Gauger).
56.70	28.50	0.18	0.69	0.23	...	Clay (average), Ottawa, Le Seuer Co. (————).
58.85	7.25	4.97	9.42	3.45	...	Gray drift clay, Hutchinson, McLeod Co. (F. F. Grout).
57.20	18.23	11.04	0.72	1.02	2.48	Clay from decomposed biotite schist, Two Rivers, Morrison Co. (A. W. Gauger).
63.64	24.95	4.90	1.02	0.20	...	Clay, Brownsdale, Mower Co. (C. F. Sidener).
48.30	8.16	2.84	16.34	4.93	...	Leached silt—Red River, Grand Forks, Polk Co. (————).
53.32	8.87	4.71	9.21	6.62	1.94	Leached silt—Red River, East Grand Forks, Polk Co. (A. W. Gauger).
57.79	12.63	8.88	3.33	4.11	2.50	Red laminated clay, St. Paul, Ramsey Co. (F. F. Grout).
60.61	18.12	7.51	0.03	1.14	0.28	Decomposed gneiss, Morton, Redwood Co. (F. F. Grout).
54.43	18.15	4.20	3.98	...	...	Gray clay, Sec. 8, T. 70 N. R. 21 W. St. Louis Co. (Minn. School of Mines).
49.60	15.82	...	1.70	...	...	Red clay, Sec. 8, T. 70 N. R. 21 W. St. Louis Co. (Minn. School of Mines).
48.92	18.45	16.88	0.70	3.68	7.14	Red shale, Fond du Lac, St. Louis Co. (————).
77.89	13.55	1.83	trace	0.36	4.45	Banded "silica kaolin," Sec. 6, T. 58 N. R. 17 W. St. Louis Co. (C. F. Sidener).
60.00	11.45	3.90	6.48	4.05	2.32	Swamp clay, Meriden, Steele Co. (E. P. Harding).

* Approximation.

CLAYS AND SHALES OF MINNESOTA

A very valuable survey of the clays and shales of Minnesota has been made under the direction of F. F. Grout, of the University of Minnesota. The results of that survey are printed in *Bulletin* 678 of the United States Geological Survey. Table XI shows partial analyses of the clays and shales of Minnesota compiled from this bulletin.

LIMESTONE IN MINNESOTA

TABLE XII

ANALYSES OF LIMESTONES AND CEMENT ROCK USED IN THE MANUFACTURE OF PORTLAND CEMENT

Company	Plant	SiO_2	Fe_2O_3	Al_2O_3	$CaCO_3$	$MgCO_3$
	Limestones					
Alpha[1]	Catskill, N.Y.	1.54	1.04	0.39	96.16	1.09
Ironton[1]	Ironton, Ohio	0.92	3.70	1.16	92.78	0.97
Marquette[1]	La Salle, Ill.	4.20	0.64	2.11	90.75	1.84
Hecla[1]	Bay City, Mich.	1.76	0.62	0.62	96.06	1.51
St. Louis[1]	St. Louis, Mo.	1.00	0.35	0.65	95.00	2.00
Iola[1]	Iola, Kan.	1.16	1.72	0.58	92.59	3.36
Northwestern States[1]	Mason City, Iowa	1.20	0.32	0.56	96.50	1.10
Three Forks[1]	Trident, Mont.	8.00	1.16	3.30	83.83	2.87
Edison[1]	Stewartsville, N.J.	0.46	0.36	0.36	96.60	3.54
Alpena[2]	Alpena, Mich.	0.36	0.13		95.91	3.63
Alpena[2]	Alpena, Mich.	1.64	0.27		96.50	1.26
————	————, Pa.	3.02	1.90		92.05	3.04
Washington[2]	Concrete, Wash.	0.80	0.70		98.14	0.65
Washington[2]	Concrete, Wash.	3.41	1.78		92.50	2.30
	Chalk					
Western[2]	Yankton, S.D.	3.83	2.31		93.09	0.29
Portland[2]	Salt Lake City, Utah	6.80	3.00		89.77	0.85
	Cement Rock					
Three Forks[1]	Trident, Mont.	16.54	1.31	5.37	72.42	3.04
Allentown[1]	Evansville, Pa.	15.06	1.30	3.60	73.64	3.34
Dexter[1]	Nazareth, Pa.	11.10	1.24	4.42	77.60	4.17
Dexter[1]	Nazareth, Pa.	18.16	1.61	7.21	68.14	3.88
Edison[1]	Stewartsville, N.J.	16.16	1.25	6.98	70.38	3.90
————[2]	————, Pa.	19.08	7.92		67.07	4.06
————[2]	————, Pa.	13.80	6.08		76.08	4.51
————[2]	————, Pa.	19.62	5.68		69.78	4.90
Portland[2]	Salt Lake City, Utah	21.20	8.00		35.20[3]	1.80

[1] R. K. Meade, *Portland Cement*. Second edition, 1911.
[2] E. C. Eckel, Portland Cement Materials in the United States. U.S.G.S. *Bulletin* 522.
[3] CaO.

There are no known deposits of limestone in Minnesota of the proper character for making Portland cement and large enough in extent to warrant the building of a Portland cement plant. The amount of magnesium carbonate is above the limit which can be allowed, at present, for cement-making. Limestone to be used in the making of Portland cement must be low in magnesium carbonate since the finished cement must contain less than 5 per cent magnesium oxide. Some selected analyses of limestone and cement rocks that are used by various Portland cement companies are shown in Table XII.

Some analyses are available of low magnesia limestone but so far as is at present known the deposits so represented are small in amount. Perhaps the largest one known is that at Leroy, Minnesota. It is of course always possible that investigation might disclose an adequate supply of low magnesia limestone. The logical place one might expect to find such a deposit, if it exists, would be in certain of the southeastern counties of the state where the Plattville limestone is exposed, or in the south central counties where there are outcrops of Devonian rocks. Some selected analyses of Minnesota limestone are given in Table XIII.

PORTLAND CEMENT IN MINNESOTA

Portland cement plants in Minnesota.—The only Portland cement plant in the state of Minnesota is located at New Duluth in the Duluth industrial district. This plant is owned and operated by the Universal Portland Cement Company, a subsidiary company of the United States Steel Corporation. This plant uses blast furnace slag from the nearby plant of the Minnesota Steel Company and limestone screenings shipped in by boat from quarries in Michigan. This plant is very advantageously located with respect to rail and water transportation. It uses cheap raw materials and commands a good trade territory. The company can sell to very good advantage in the Duluth-Superior district and the Iron Range country. The plant is well built and modern and very well managed. It has four 10x150 foot kilns producing from 3,000 to 4,000 barrels of cement daily. Electrical dust collectors are used. The plant officials claim a coal consumption in the kilns of 67 pounds of coal per barrel of cement burned. This low fuel consumption is accounted for, in part at least, by the fact that the calcareous matter in the slag has already been calcined and no heat energy needs to be supplied for that purpose.

TABLE XIII

ANALYSES OF MINNESOTA LIMESTONES

Quarry	Town	County	Insoluble HCl Per Cent	Fe_2O_3 Per Cent	Al_2O_3	$CaCO_3$	$MgCO_3$
Plattville Limestone							
St. Peter's Church abandoned*[1]	Mendota	Dakota	26.66	....		45.77	24.75
Carey[1]	Spring Valley	Fillmore	1.96	....		76.44	20.45
Akre and Dahl (Old Highland)[1]	Rushford	Fillmore	6.34	....		51.50	38.98
M. C. S. Co. Composite sample[1]	Minneapolis, Johnson and 15th Ave. N.E.	Hennepin	12.50	(FeS–2.13) Al_2O_3–0.84)		70.30	13.54
Mpls. S. Co. Composite sample[1]	Minneapolis, Johnson and Central N.E.	Hennepin	9.00	1.95	1.32	80 00	6.10
Blue L. S. Co.[1]	Minneapolis, Central and 15th Ave. N.E.	Hennepin	11.90	0.71	1.04	82.06	3.72
Bielenberg, East George St. (Yellow stone)[1]	South St. Paul	Ramsey	13.54	....		55.57	29.11
Weeks and Holscher[2]	Minneapolis	Hennepin	16.22	0 90	3.16	54.53	36 00
Foley and Herbert[2]	Minneapolis	Hennepin	29.93	4.03		41.88	24.55
Eastman[2]	Minneapolis, Nicollet Island	Hennepin	14.45	1.70		75.48	6.81
A. Rau[2]	St. Paul	Ramsey	13.39	1.63 (SiO_2–8.16)	2.67	79.18	6 42
Taylors[2]	Fountain	Fillmore	9.89	1.30		86.11	0.47
M. C. S. Co.[5]	Minneapolis	Hennepin	15.38	3.50		49.68	25.18
M. C. S. Co.[5]	Minneapolis	Hennepin	10.46	1.40		81.35	4.94
M. C. S. Co.[5]	Minneapolis	Hennepin	13.19	2.70		46.15	29 98
M. C. S. Co.[5]	Minneapolis	Hennepin	11.41	1.38		77.42	6 39
M. C. S. Co.[5]	Minneapolis	Hennepin	20.40	3.40		45.76	26.44
M. C. S. Co.[5]	Minneapolis	Hennepin	36.53	4.76		39.51	15.22
M. C. S. Co.[5]	Minneapolis	Hennepin	39.05	3.20		34.92	20.55

* This rock was used in the Sibley house in 1835.

TABLE XIII—*Continued*

Quarry	Town	County	Insoluble HCl Per Cent	Fe_2O_3 Per Cent	Al_2O_3	$CaCO_3$	$MgCO_3$
M. C. S. Co.[5]	Minneapolis	Hennepin	11.76	1.96		70.33	8.92
M. C. S. Co.[5]	Minneapolis	Hennepin	18.52	0.86		78.20	0.68
St. Paul Crushed Stone Co.[5]	St. Paul	Ramsey	10.72	1.56		70.67	13.66
St. Paul Crushed Stone Co.[5]	St. Paul	Ramsey	15.82	1.92		72.67	9.67
St. Paul Crushed Stone Co.[5]	St. Paul	Ramsey	33.45	3.40		40.07	21.81
State C. S. Co.[5]	Faribault	Rice	12.45	4.46		67.43	14.87
State Hospital[5]	Rochester	Olmstead	12.28	5.20		64.88	15.99
			8.63	2.48		63.75	19.28
Buff limestone							
Representative sample[6]	....	....	8.16	2.43	2.67	79.18	6.38
Clear parts of buff limestone[6]	....	....	5.79	1.89	2.04	83.24	5.40
Dark bands of buff limestone[6]	....	....	15.84	4.00	4.93	56.47	14.21
Lower strata of buff limestone[6]	....	....	20.38	15.31	26.77	28.86	11.18
Buff limestone[6]	....	....	1.30	1.20	1.30	80.60	18.00
Buff limestone[6]	....	....	9.99	2.69	3.43	77.21	3.91
Oneota Dolomite							
Bradley[1]	Mankato	Blue Earth	....	8.6		52.62	38.78
McClure and Widell (Bridge ledge)[1]	Mankato	Blue Earh	SiO_2 7.35	0.96	4.51	48.26	38.67
Bjork[1]	Red Wing	Goodhue	6.02	....		50.00	39.79
Frontenac[1]	Frontenac	Goodhue	4.27	....		52.50	41.24
Several near[1]	Winona	Winona	11.93	....		45.83	39.42
Leatherman[1]	Elba Township	Winona	2.92	....		54.50	37.75
Coughlin[5]	Mankato	Blue Earth	14.66	1.34		48.72	33.95
Coughlin[5]	Mankato	Blue Earth	9.59	2.08		50.97	33.01
Breen Stone & Marble Co.[5]	Kasota	Le Seuer	11.12	2.06		49.54	32.34
Breen Stone and Marble Co.[5]	Kasota	Le Seuer	7.26	1.68		54.58	30.99
Hastings C. S. Co.[5]	Hastings	Dakota	2.26	1.00		56.82	40.02
Biesanz Stone Co.[5]	Winona	Winona	10.78	0.62		54.04	28.76
Biesanz Stone Co.[5]	Winona	Winona	7.50	0.84		52.79	28.20

TABLE XIII—*Continued*

Quarry	Town	County	Insoluble HCl Per Cent	Fe_2O_3 Per Cent	Al_2O_3	$CaCO_3$	$MgCO_3$
Devonian Limestone							
Bly[2]	Spring Valley	Fillmore	1.39	....		56.50	40.27
Shakopee Dolomite							
McGee[1]	Stillwater	Washington	9.26	....		50.00	40.21
Breckenridge, Stewart, and Buttar[2]	Kasota	Le Seuer	13.06	1.09		49.16	37.53
Breckenridge, Stewart, and Buttar[2]	Kasota	Le Seuer	13.85	1.49		47.90	35.23
———[3]	Ottawa	Le Seuer	7.25	1.55		58.65	29.15
———[3]	Kasota	Le Seuer	13.85	1.49		47.90	35.23
Clapp[3]	Kasota	Le Seuer	2.82	1.39		52.22	36.04†
Beatty[4]	Mankato	Blue Earth	19.88	2.43	3.72	44.68	31.59
Maxfield and Mather[4]	Mankato	Blue Earth	15.52	5.64		46.86	33.56
St. Lawrence Formation							
Tosterin[2]	Frontenac	Goodhue	2.93	0.36	0.31	54.78	42.53
Hersey, Staples, and Hall[2]	Stillwater	Washington	4.52	1.11		53.50	40.21
Hersey, Staples, and Hall[2]	Stillwater	Washington	8.54	0.78	0.64	50.22	37.39
Chas. H. Porter[2]	Winona	Winona	6.32	0.96		51.23	41.33
Mill Co.[2]	Lanesboro	Fillmore	3.45	0.37	0.33	49.66	42.06
Mill Co.[2]	Lanesboro	Fillmore	7.35	1.05		62.14	28.49
Sweeney[2]	Red Wing	Goodhue	10.94	0.55	0.34	50.68	33.61
Galena Limestone							
Hook[2]	Mantorville	Dodge	6.33	1.77		50.20	38.96‡
McDonough[5]	Mantorville	Dodge	15.71	2.34		49.38	31.12
McDonough[5]	Mantorville	Dodge	9.58	2.00		52.93	32.58

† $CaSO_4$, 6.74.
‡ Na_2O, 10.6.
[1] Oliver Bowles, Structural and Ornamental Stones of Minnesota. *Bulletin* 663, United States Geological Survey, 1918.
[2] N. H. Winchell, Final Report on the Geology of Minnesota. *Minnesota Geological Survey.* 1:195-203. 1884.
[3] *Idem.* p. 638. [4] *Idem.* pp. 450-51.
[5] Partial analyses of samples taken by State Highway Department in 1921. R. E. Kirk, analyst.
[6] Hall and Sardeson, Paleozoic Formation of Minnesota. *Bulletin of the Geological Society of America.* 3:358. 1892.

The Universal plant at Duluth produces a high grade Portland cement of standard quality. Its product is well and favorably known. Together with the plants of the same company near Chicago it supplies large amounts of cement to the Twin Cities market.

Iowa Portland cement plants.—The cement plants located in Iowa are a factor in the cement trade of southern Minnesota and of the Twin Cities. Since Iowa is well supplied with low magnesia limestone, all these plants use limestone. No attempt has been made to develop the marl deposits of Iowa.

The Northwestern States Portland Cement Company built the first plant in Iowa at Mason City. Its product is well known on the Minnesota markets.

The Lehigh Portland Cement Company operates a plant at Mason City on a tract of land adjoining the Northwestern States' holdings. The Hawkeye Portland Cement Company, at Des Moines, and the Gilmore Portland Cement Company, at Gilmore City, are the other two plants now operating in Iowa. The Western States Portland Cement Company, of Independence, Kansas, is building a plant near Davenport, and the Pyramid Portland Cement Company is completing a plant at Valley Junction, near Des Moines. In addition to the plants mentioned, companies have been organized to build plants at Rutland and at Davenport. The Globe Portland Cement Company, with offices in Minneapolis, is designing a plant to be built near Dubuque, Iowa.

Possible location in Minnesota of a Portland cement plant using marl.—Numerous factors enter into the matter of location. First of all the plant must be located near an adequate supply of raw materials. The other factors must be subordinated to this consideration. This factor could only be evaluated by careful investigation of the deposits of marl and clay.

In the second place, a location within a reasonable distance of the Twin Cities would be very desirable. This would give the plant an advantage in placing its product in this industrial center, and would also protect it from too strenuous competition with the Iowa plants on the south or the Duluth plant on the northeast. For these reasons a location to the west or northwest of the Twin Cities would be most suitable.

Finally it would be best to locate such a plant, if possible, where it could be served by more than one railway system.

1. Portland cement can be made from marl and clay, of as good quality as that made from any other raw materials.

2. Modern methods and equipment enable the wet process for the manufacture of Portland cement to compete with the dry process.

3. The use of limestone should be favored where a sufficient supply of the proper character for cement-making is available.

4. Where a supply of limestone is not available, the possibility of using marl should be given serious consideration. The conditions essential for the probable success of such an undertaking are summarized on page 34.

5. There is no evidence at hand to show that Minnesota contains deposits of limestone of sufficient extent and of the proper character to warrant the establishment of a Portland cement plant.

RECOMMENDATION

It is therefore recommended that a careful investigation be made of the larger marl deposits of the state to ascertain whether their character, extent, and location are such as to justify the erection of a Portland cement plant designed to use marl.

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