Mississippi State Geological Survey

ALBERT F. CRIDER, DIRECTOR.

BULLETIN No. 1

Cement and Portland Cement Materials of Mississippi

By ALBERT F. CRIDER

NASHVILLE
BRANDON PRINTING COMPANY
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STATE GEOLOGICAL COMMISSION.

His Excellency, James K. Vardaman .... *Governor*

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Dr. William N. Logan .... *Assistant Geologist*

Dr. Calvin S. Brown .... *Assistant Geologist*

LETTER OF TRANSMITTAL.

JACKSON, MISS., July 20, 1907.

To Governor James K. Vardaman, Chairman, and Members of the Geological Commission:

GENTLEMEN—I submit herewith my report on Cement and Portland Cement Materials of Mississippi.

Very respectfully,

ALBERT F. CRIDER,

Director.

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ACKNOWLEDGMENTS.

In the preparation of this report the author is under many obligations to Drs. William N. Logan and Calvin S. Brown, of the State Survey, for collecting samples of limestones and clays, and for other valuable assistance.

The credit of the chemical analyses, unless otherwise stated in the report, belongs to Dr. W. F. Hand, State Chemist, Agricultural College.

The author is indebted to Mr. D. L. Mitchell, of Biloxi, Miss., for reading the manuscript and offering valuable suggestions.

In the discussion of the technology and manufacture of cements the various works of Mr. E. C. Eckel, of the United States Geological Survey, have been freely used.

CEMENT AND PORTLAND CEMENT MATERIALS OF MISSISSIPPI.

By Albert F. Crider.

INTRODUCTION.

The growth of almost every line of the mining industry in America in the last decade has been most phenomenal. The mineral production of the United States for 1905, the latest year for which complete official returns are available, was $1,623,877,120. Of this amount $921,024,019 was contributed by the non-metallics, and $702,453,101 by the metallics.

The value of Portland cement products is surpassed only by iron, gold, copper, coal, oil and stone. In its importance to the advancement of the present civilization it is surpassed only by iron, coal and oil. Its per cent of increase in production and consumption since 1890 is greater than any mineral mined in the United States.

Until 1905 the amount of Portland cement imported into the United States was greater than the amount exported. In 1891 the amount of production was 454,813 barrels, and the amount imported was 2,998,313 barrels. In 1905 the amount imported had been reduced to 896,845 barrels, and the amount exported was 897,686 barrels.

Some sections of the United States have not been able to secure all the cement they could use, and there is an increasing demand for our cement in foreign countries, especially in the Central and South American States, and the West Indies. But before we need to exploit fields outside of the United States for our cement we must create a surplus over and above the amount consumed at home. But with the increase in production due to the erection of new plants and the enlargement of the old ones comes new demands for cement as a structural material from every section of the country.

No section of the United States is advancing quite so rapidly as the South. The advance in the manufacture of cements has not kept pace with the progress in other lines of industry, and for this reason the South offers practically an open field to the cement manufacturer. And in no section of the South is this more evident than in Mississippi where, at present, there is not a single cement plant. The object of this report is to point out the geographical distribution, the available amount and the quality of cement materials, and call attention to the economic advantages offered for the erection of cement plants within the State.

EARLY HISTORY OF THE PORTLAND CEMENT INDUSTRY.

Portland cement was first made in 1824 by Joseph Aspdin, a bricklayer in Leeds, England. The name "Portland" was chosen because of the resemblance of the cement to the oolitic limestone of Portland, England. The limestone is extensively used in England as a road metal and building stone.

The first cement was made by taking a specific quantity of road scrapings from roads repaired with the oolitic limestone and reduced to a powder and calcined. The calcined material was then combined with a specific quantity of argillaceous earth or clay, mixed with water, and the mixture placed in a pan and heated until all the water was evaporated. After this the mixture was broken into small lumps and calcined in a furnace similar to a lime kiln till the carbonic acid was entirely expelled. It was then cooled and reduced to a powder which had the power of setting when mixed with water.

Aspdin's original patent did not specify the percentages of limestone and clay in the mixture, and he also omitted to state that the mixture should be burned until incipient vitrification is attained. In the absence of machinery for grinding the hard limestone, he was forced to calcine it before it was mixed with the clay.

From this crude beginning has developed one of the greatest industries of building material of modern times.

PRESENT CONDITION OF THE INDUSTRY IN THE UNITED STATES.

The Portland cement industry has had a more marvelous growth than any other large industry of this era. It came at a most opportune time in the development of the country. It has prolonged the life of lumber and supplemented iron and steel. It has become one of the leading and most substantial products for general construction work where strength, durability and economy are required. It is used alone, or as a reinforcement in the construction of bridges, business and dwelling houses, aqueducts, sewers, pavements, large foundation walls and dikes such as the Galveston wall, docks, wharves and levee work; besides in many minor ways, such as in making fence posts, telegraph poles, railway ties, monuments, and in various other lines of construction work.

The output of Portland cement in the United States in 1890 was only 335,500 barrels. In 1900 it had reached 8,482,020. The most rapid growth of the industry was between 1900 and 1905. Preliminary figures in 1906, announced by the United States Geological Survey, show that 46,463,424 barrels were produced, valued at $52,446,186. This is even a greater increase in output and in value than that of the previous year.

The following table shows the amount and value of Portland cement produced in the different States where this article was manufactured in 1903, 1904 and 1905:

TABLE I.

PRODUCTION OF PORTLAND CEMENT IN THE UNITED STATES IN 1903, 1904 AND 1905, BY STATES.†

[BARRELS.]

STATE.	1903.			1904.			1905.		
	Number of works	*Quantity.*	*Value.*	*Number of works*	*Quantity.*	*Value*	*Number of works*	*Quantity*	*Value*
Alabama (*a*)	1	....	....	1	....	....	1	....	....
Arkansas*	1	....	....	1	....	....	1	....	....
California	3	631,151	$1,019,352	3	1,014,558	$1,446,909	3	1,225,429	$1,671,816
Colorado	1	258,773	436,535	1	490,294	638,167	1	786,232	1,172,027
Georgia (*a*)	1	....	....	1	....	....	1	....	....
Illinois	5	1,257,500	1,914,500	5	1,326,794	1,449,114	5	1,545,500	1,741,150
Indiana	3	1,077,137	1,347,797	4	1,350,714	1,232,071	6	3,127,042	3,134,219
Kansas	1	1,019,682	1,285,310	2	2,643,939	2,134,612	4	....	....
Kentucky (*b*)	....	....	....	1	....	....	1	....	....
Michigan	13	1,955,183	2,674,780	16	2,247,160	2,365,656	16	2,773,283	2,921,507
Missouri (*b*)	2	825,257	1,164,834	2	....	....	2	3,879,542	4,164,974
New Jersey	3	2,693,381	2,944,604	3	2,799,419	2,099,564	3	3,654,777	2,775,768
New York	11	1,602,946	2,031,310	11	1,362,514	1,257,561	11	2,111,411	2,044,253
Ohio	8	729,519	998,300	7	910,297	987,899	8	1,312,977	1,390,481
Pennsylvania	17	9,754,313	11,205,892	17	11,496,099	8,969,206	18	13,813,487	11,195,940
South Dakota (*c*)	1	....	....	1	....	....	1	....	....
Texas (*c*)	2	....	....	2	....	....	3	....	....
Utah (*c*)	1	....	....	1	....	....	1	....	....
Virginia	1	538,131	690,105	1	864,093	774,360	1	1,017,132	1,033,732
Washington	....	....	....	....	....	....	1	....	....
West Virginia (*a*)	1	....	....	1	....	....	1	....	....
Total	76	22,342,973	$27,713,319	81	26,505,881	$23,355,119	89	35,246,812	$33,245,867

†Mineral Resources of the United States, 1905, U. S. Geological Survey, p. 926. *Shut down.

(*a*) Total amount combined and given with Virginia.

(*b*) Total amount combined and given with Kansas.

(*c*) Total amount combined and given with Colorado.

New plants are reported to be in process of construction or completed in the following States:

Iowa, 2 plants.
Oregon, 1 plant.
Wisconsin, 2 plants.
Tennessee, 1 plant.
Alabama, 2 plants.
Georgia, 1 plant.

The total number of Portland cement plants in the United States at the present time approaches the one hundred mark.

CEMENT INDUSTRY IN THE SOUTH.

Of the whole number of plants in the United States there are but 8 in the South producing cement, and about 4 new plants under construction. According to the latest official report the South produces less than 4 per cent of the total amount of Portland cement manufactured in the United States. This, added to the fact that the South is growing more rapidly than any other section of the country, gives a promising outlook for the development of the cement industry. There should be a large number of plants located in various sections of the South to equalize the output in the United States; at least a sufficient number to supply the local demands.

At present Mississippi is dependent upon the cement plants of Alabama and other States for cement. There is a wide field in Mississippi for the development of this important industry. With an abundance of excellent raw materials favorably located, as at Vicksburg where coal is cheap and with railway and water transportation, there is no reason why Mississippi should not enter the field as a cement-producing State and supply a large amount of the increasing demand in the middle South. The erection of a plant in this undeveloped territory would be a paying investment, and would ultimately cheapen the product to the consumers.

It has been reported by government authorities that the construction of some of the locks of the Panama Canal will require about 92,000 carloads of cement. This amount equals about one-fourth of the output of all the cement plants in the United States for 1905. There is an ever increasing demand for cement in the United States as shown by the fact that during 1905 over 35,000,000 barrels were used, besides 896,845 barrels shipped in from other countries. While the Panama Canal trade may appeal to some of the factories of the United States, there is not a sufficient number of plants in the South at the present time to supply the increasing local demand.

CLASSIFICATION OF CEMENTS.*

Cements may be classified under two general heads, Simple cements and Complex cements.

SIMPLE CEMENTS.

Simple cements are those in which the setting properties are similar to the original raw material. Under this class come (1) hydrate cements and (2) carbonate cements.

(1) *Hydrate Cements.*—Hydrate cements include those cements in which the water of combination from certain rocks has been driven off by heat not exceeding a temperature of 400° Fahrenheit, and which upon the reabsorption of water produce an artificial rock similar to the original.

The hydrate cements are "Plaster of Paris," "Keene's cement," "Parian cement" and "Cement plaster." They are all manufactured from gypsum and differ from each other only in the addition of relatively small amounts of clay, limestone, sand and other materials; or by slight variations in the methods of manufacture.

(2) *Carbonate Cements.*—Carbonate cements are formed from limestone by dissociating and driving off the carbon dioxide (CO_2) and the water of combination by the application of heat at a temperature between 1,382° F. and 1,652° F., leaving behind "quicklime" or unslaked lime (CaO). "Quicklime" on being treated with water expands and gives off heat, forming the hydrated calcium oxide or slaked lime ($Ca\ H_2O$).

The cementing qualities are imparted to the hydrated calcium oxide on the reabsorption of carbon dioxide from the air, forming the original calcium carbonate or limestone. Only the outer portions of the walls are thoroughly recarbonated, since the reabsorption of the carbon dioxide can only take place where the material is exposed

*In the treatment of this subject the writer has followed E. C. Eckel in Limes, Cements and Plasters.

to the air. The products of carbonate cements are calcium and magnesian limes. It requires a higher degree of temperature to dissociate a relatively pure limestone than one containing a high per cent of magnesium, and the resulting quicklime slakes more readily and has a quicker set. The magnesian limes have a slower set, but attain a higher degree of strength.

COMPLEX CEMENTS.

In the manufacture or in the use of complex cements certain chemical changes take place forming new compounds which impart the setting properties to the cement. In this class come natural cements, Puzzolan cements, hydraulic limes, and Portland cement. In all of these the cementing quality is imparted by calcium oxide in the presence of silica and alumina approaching a tri-calcic silicate. There are, however, certain natural or added impurities in the limestone and clays or shales to form various lime silicates and silico-aluminates. The most common impurities formed in limestones, clays and shales are iron, magnesia, alkalies and sulphur. Calcium sulphate is added to some cements to retard the set. The impurities act as a flux upon the body of the materials and greatly reduce the temperature of incipient fusion.

Natural Cement.

Natural cement is produced by burning an impure limestone containing from 15 to 40 per cent of silica, alumina and iron oxide. In addition to these ingredients it usually contains a small per cent of alkalies, sulphur trioxide and water.

The temperature required for burning hydraulic limestone is about the same as that obtained in burning lime, or between 900° to 1,300° F. All the combined water and most of the carbon dioxide are driven off and the lime and magnesia combine with the iron oxide, silica and alumina. The fluxing properties, such as soda and potassium, aid in decomposing these ingredients. The burned product shows little or no free lime.

The burned mass or clinker is ground to a fine powder, which has the power of setting when placed under water.

Natural cements differ from common lime in possessing hydraulic properties and refusing to slake before grinding. They differ from

Portland cements in not being a mechanical mixture of raw materials possessing definite chemical constituents. They have a specific gravity which ranges from 2.7 to 2.9; while Portland cement has a specific gravity from 3.0 to 3.2. Natural cements are burned at a lower temperature, have a quicker set, and a much lower ultimate strength than the true Portland cements.

Magnesia is found in comparatively large quantities in the raw materials used in the natural cement plants in the United States. It does not, however, possess any hydraulic properties within itself, and could be easily exchanged for lime without affecting the quality of the cement. The hydraulic properties are imparted to the limestone by the clayey materials, the silica, and the iron oxide.

The following are analyses of natural cement rock now in use in American and European natural cement plants:

TABLE 2.

ANALYSES OF NATURAL CEMENT ROCK USED IN AMERICAN AND EUROPEAN PLANTS.*

	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	CO_2	H_2O	S
Rosendale, N. Y.	10.90	3.40	2.28	29.57	14.04	0.61	37.90	n.d.	n.d.
Milton, N. D.	14.00	6.70		37.60	n.d.	0.58	n.d.	n.d.	1.45
Defiance, Ohio	42.00	7.00	7.10	9.91	5.81	n.d.	14.18	14.00	......
Copley, Pa.	18.34	7.49		37.60	1.38	n.d.	31.06	3.94	......
Balcony Falls, Va.	17.38	7.80		34.23	9.51	n.d.	30.40	n.d.	n.d.
Milwaukee, Wis.	17.00	4.25	1.25	24.64	11.90	n.d.	32.46	n.d.	......
Mankato, Minn.†	16.00	5.85	2.73	22.40	14.99	n.d.	34.11	n.d.	n.d.
Fort Scott, Kan.	17.26	2.05	5.45	34.45	5.28	n.d.	32.87	n.d.	n.d.
Utica, Ill.	17.01	3.35	2.39	32.85	8.45	1.81	34.12		......
Louisville, Ky.	9.80	2.03	1.40	29.40	16.70	n.d.	41.49	n.d.	n.d.
Belgium	15.75	3.95	1.00	43.10	0.49	0.50	35.21		n.d.
England	18.00	6.60	3.70	39.64	0.10	n.d.	29.46	1.30	n.d.

Puzzolan Cement.

The process of making Puzzolan cement was known to the ancients, and was named from its use at Puzzolano, Italy.

It is produced from an uncalcined mixture of slaked lime and a silico-aluminous material, such as volcanic ash, or blast-furnace slag. The process is simply a mechanical mixture of the two materials.

*Cements, Limes and Plasters, E. C. Eckel, 1905, pp. 204–217.
†Alkalies 0.76.

The ingredients are thoroughly mixed and ground to a fine powder, which will set under water. The per cent of lime and slag used in the mixture is about 35 parts of slaked lime to 100 parts of slag. Puzzolan cements are of a lighter color, have a lower specific gravity and a much lower set than Portland cements.

Portland Cement.

There are at present many different kinds of cements manufactured and sold as Portland cements. Some of these are made by burning a natural magnesian, argillaceous limestone and grinding it to a powder. According to the best authorities, however, on the manufacture of cements, these would be excluded from the list of true Portlands. The following definition,* perhaps, comes near fulfilling all the conditions of the best Portland cements:

"By the term Portland cement, is to be understood the product obtained by finely pulverizing clinker produced by burning to semi-fusion an intimate artificial mixture of finely ground calcareous and argillaceous materials, this mixture consisting approximately of three parts of lime carbonate (or an equivalent amount of lime oxide) to one part of silica, alumina, and iron oxide. The ratio of lime (CaO) in the cement to the silica, alumina, and iron oxide together shall not be less than 1.6 to 1, or more than 2.3 to 1."

From the above definition it is evident that all cements produced by burning argillaceous limestones without grinding the mixture before burning are excluded from the list of true Portland cements.

To burn the materials to a semi-fused mass requires a temperature of something like 3,000° F. This can only be obtained in kilns made especially for this purpose.

The chemical changes which take place in the kiln are, first, the expulsion of the mechanically held water, which is driven off at a temperature of 212° F.; second, the dissociation of the lime carbonate at about 1,300° F., setting free carbon dioxide and sulphur trioxide third, at about 2,600° F. and above, clinkering takes place, the silica and alumina are decomposed, and the lime oxide, silica, alumina and iron oxide combine, forming silicates, aluminates and ferrites of lime in definite proportions.

*Cements, Limes and Plasters, E. C. Eckel, p. 297.

The semi-fused mass when finely pulverized wili set under water. The specific gravity of Portland cement is from 3.0 to 3.2.

The chemical composition of Portland cement varies within certain limits. The first Portlands manufactured in England were low in lime oxide. Some of the earliest brands ran as low as 50 per cent in lime. The best brands now manufactured in the United States have a general average of about 62 per cent of lime oxide. In an investigation of 81 analyses of American brands, the maximum amount of lime oxide was about 65.44 per cent, and the minimum amount 58.07 per cent. The amount of silica varied from about 19 per cent to 24 per cent, with a general average of about 21.75 per cent. The amount of alumina and iron oxide together varied from 6 per cent to 13.5 per cent with a general average of about 10.5 per cent. The amount of magnesia varied from a trace to 3.5 per cent. The greatest amount of alkalies was 2.25 per cent. The amount of sulphur trioxide varied from a fraction of 1 per cent to 2.786 per cent.

TABLE 3.

ANALYSES OF AMERICAN PORTLAND CEMENTS.*

	1	2	3	4	5	6	7	8	9	10	11	12
Silica (SiO_2).........	20.14	22.48	20.80	22.04	21.20	19.92	21.96	22.00	22.00	22.50	20.25	24.00
Alumina (Al_2O_3).....	7.51	6.52	7.39	6.45	6.05	9.83	9.29	9.74	7.74	8.35	13.44	7.50
Iron oxide (Fe_2O_3)...	3.33	4.46	2.61	3.41	3.33	2.63	2.67		4.61	4.25		2.40
Lime oxide (CaO)....	62.71	62.93	64.00	60.92	58.07	60.32	60.52	62.34	59.50	62.35	63.60	62 00
Magnesia (MgO)......	2.34	1.48	n.d.	3.53	2.80	3.12	3.43	2.54	0.90	.....	1.03	2.50
Alkalies (K_2O, Na_2O).	.....	.....	.....	.....	2.20	.....	.....	.....	1.20	.....	.....	.....
Sulphur trioxide (SO_3)	1.64	1.30	n.d.	2.73	.....	1.13	1.49	1.40	0.80	1.75	0.41	1.50

1. Edison Portland Cement Co., New Jersey.
2. Catskill Portland Cement Co., New York.
3. Empire Portland Cement Co., New York.
4. Empire Portland Cement Co., New York.
5. Buckeye Portland Cement Co., Ohio.
6. American Portland Cement Co., Pennsylvania.
7. Atlas Portland Cement Co., Pennsylvania.
8. Lehigh Portland Cement Co., Pennsylvania.
9. Western Portland Cement Co., South Dakota.
10. Texas Portland Cement Co., Texas.
11. Alabama Portland Cement Co., Alabama.
12. Michigan Portland Cement Co., Michigan.

*Cements, Limes and Plasters, E. C. Eckel, 1905, pp. 577 to 579.

RAW MATERIALS OF PORTLAND CEMENT.

The principal constituents which enter into the manufacture of Portland cement are lime, silica, alumina and iron oxide. These materials are found widespread in nature and occur in various combinations, especially in sedimentary rocks. It is from these rocks the necessary constituents are found for making Portland and natural cements. Lime is found in argillaceous limestones, hard pure limestones, chalks, marls, oyster shells, alkali waste and blast-furnace slags. Silica, alumina and iron oxide are found principally in clays, shales and slates, although they all frequently occur in greater or less quantities in limestones. A limestone may vary in composition from pure calcium carbonate ($CaCO_3$), calcite, to a rock containing an increasing amount of clay or sand, until the name limestone is nc longer applicable. There is a regular gradation from a pure limestone to a pure clay or sand. It is possible, therefore, to find a rock in nature, in small quantities at least, which would contain the exact proportions of lime, silica, alumina and iron oxide for a Portland cement. It is hardly probable, however, that such a rock would occur in large quantities.

ARGILLACEOUS LIMESTONE.

A limestone containing a relatively large amount of clayey material in chemical combination with lime is called an argillaceous limestone. It has been formed at the bottom of an open or inland sea by calcareous remains of small invertebrate organisms, in the presence of sediments carried by streams from the shore. The purest limestones are formed at too great a distance from the shore to receive any accumulation of sediments. Owing to the constant agitation of the water near the shore sandstones and clays have but little or no organic remains. The argillaceous limestones, therefore, represent an intermediate stage between the pure limestones and the non-calcareous near-shore deposits.

There is no definite rule for determining when a limestone shall be called "argillaceous." The argillaceous limestone in the "Lehigh district" of Pennsylvania and New Jersey has been called "cement rock," because it has been the most important source of cement in this country. Until as late as 1903 two-thirds of the Portland cement manufactured in the United States was made from the "cement rock" of the Lehigh district, mixed with pure limestone. This district is still producing 38 per cent of the Portland cement of the United States.

The quality and composition of some of the argillaceous limestones now used by American cement plants are here given:

TABLE 4.

ANALYSES OF ARGILLACEOUS HARD LIMESTONES, "CEMENT ROCK," LEHIGH DISTRICT.*

Silica (SiO_2)	18.30	15.97	17.32	19.62	16.77	15.73	19.06
Alumina (Al_2O_3)	6.11	7.53	9.11	5.68	6.50	7.92	4.44
Iron oxide (Fe_2O_3)	1.85	2.24					1.14
Lime carbonate ($CaCO_3$)	36.38	34.34	38.59	39.08	41.37	39.62	38.77
Magnesium carbonate ($MgCO_3$)	2.13	3.93	2.05	2.35	n.d.	1.81	2.02
Carbon dioxide (CO_2)	28.96	32.80	32.55	33.25	n.d.	33.08	32.66

ANALYSES OF ARGILLACEOUS LIMESTONES FROM WESTERN UNITED STATES.†

Silica (SiO_2)	21.02	6.80	20.06	7.12	14.20
Alumina (Al_2O_3)	8.00	3.00	10.07	2.36	5.21
Iron oxide (Fe_2O_3)	.....	.....	3.39	1.16	1.73
Lime carbonate ($CaCO_3$)	62.08	89.80	63.40	87.70	75.10
Magnesium carbonate ($MgCO_3$)	3.80	0.76	1.54	0.84	1.10

It will be seen by a study of the above analyses that in order to bring the argillaceous limestones to the proper composition of Portland cement (75 to 77 per cent of lime carbonate) they require the addition of a purer limestone.

HARD PURE LIMESTONE.

Pure limestone has the composition of calcite ($CaCo_3$), corresponding to the composition, calcium oxide, 56 per cent; carbon dioxide, 44 per cent. The theoretically pure limestone is rarely met with in nature in large quantities. The most common impurities found in limestones are magnesia, silica, alumina, iron, alkalies and a few minor materials.

Magnesia may be carried in solution and introduced into the limestone when it is being formed, or subsequently forming a mag-

*Cements, Limes and Plasters, E. C. Eckel, 1905, p. 329.

†Bulletin 243 U. S. Geological Survey, 1905, p. 32.

nesian limestone. The calcium carbonate is replaced by the magnesium carbonate. Limestones in which the calcium carbonate and the magnesium carbonate are united in equal molecular proportions are called dolomites, having a formula $CaCO_3$, $MgCO_3$, and are composed of 54.35 per cent calcium carbonate, and 45.65 per cent magnesium carbonate. Magnesia in Portland cement is an inert material and limestones containing more than 5 or 6 per cent of it should be avoided.

Where the impurities in the limestones are chiefly clayey materials, silica, alumina and iron oxide, the chemical composition of the raw material is of the greatest importance to the cement manufacturer, and should be carefully studied. Where the silica is present in limestones in the form of free sand or chert nodules it will not easily enter into combination with the calcium carbonate, and is, therefore, largely an inert material. If, however, silica and alumina are combined in the form of clay, shale or slate they readily combine with the calcium carbonate under the action of heat.

A cement manufacturer having a limestone with a high per cent of calcium carbonate must select a clay with a high silica-alumina ratio. If, however, he has a limestone with a low per cent of calcium carbonate great care must be used in selecting a clay with a low silica-alumina ratio.

"For this reason it may be taken as a safe rule that when a limestone carries less than 90 per cent of lime carbonate it should give a value between 2.25 and 3.00 for the ratio $\frac{SiO_2}{Al_2O_3 + Fe_2O_3}$. These are comfortable limits, and will give the manufacturer considerable latitude in his choice of a clay to mix with it."*

CHALK.

Chalk is a white limestone so soft that it can be easily scratched with the finger nail. Where pure it is composed of fine sediment of calcium carbonate derived chiefly from shells of foraminifera. Like other forms of calcareous deposits it varies from a rather pure calcium carbonate to a chalky limestone containing silica, alumina, magnesia, iron and other impurities, requiring little additional material to make

*Cements, Limes and Plasters, E. C. Eckel, 1906, p. 315.

it suitable for Portland cement manufacture. The range in composition of chalky limestones used in American cement plants is here given:

TABLE 5.

ANALYSES OF CHALK USED IN AMERICAN CEMENT PLANTS.

Silica (SiO_2)	12.50	9.88	5.33	12.13	2.22
Alumina (Al_2O_3) }	2.76	6.20	3.03	4.17	.92
Iron oxide (Fe_2O_3) }				3.28	.18
Lime (CaO)	45.20	43.19	50.53	42.04	54.08
Magnesia (MgO)	0.50	0.52	0.55	0.44	0.10
Carbon dioxide (CO_2)	36.06	34.49	50.30	33.51 }	42.50
Water	1.36	5.72	n.d.	n.d. }	

The most extensive calcareous formation in Mississippi is the Selma chalk or "rotten limestone" which is more than 900 feet thick in Lowndes, Noxubee, Oktibbeha, Clay, Monroe and Chickasaw counties, and thins to about 300 feet in Alcorn County. Under the discussion of the Selma chalk are numerous analyses, some of which are inferior to and some better than the ones given above.

FRESH-WATER MARL.

Marl, such as is used in cement manufacture, is a chemical deposit of almost pure carbonate of lime which has been deposited in inland seas and lakes by streams or springs carrying lime carbonate in solution. Marls differ from hard limestones in that they are masses of granular, incoherent deposits containing land shells and shell fragments.

Workable deposits of marl are chiefly confined to that part of the United States which was formerly covered by glacial deposits. Most of the lakes of northern United States and Canada are due to the damming of streams, and to the uneven distribution of the glacial deposits. The streams of that region carry a large per cent of lime carbonate in solution and deposit it on the sides and bottoms of the enclosed lakes. These marl deposits are still in process of formation.

Marl is in composition, as shown by the following analyses, a comparatively pure lime carbonate, and is correspondingly low in silica, alumina and other impurities. Where used in cement manufacture it requires the addition of a large amount of clay to bring it to the proper mixture.

TABLE 6.

ANALYSES OF MARLS USED IN AMERICAN CEMENT PLANTS.*

Silica (SiO_2)	1.74	1.78	0.19	0.06	1.19
Alumina (Al_2O_3)	0.90	1.21	0.05	0.80	0.55
Iron oxide (Fe_2O_3)	0.28		0.07		0.25
Lime (CaO)	49.84	49.55	51.31	55.00	52.50
Magnesia (MgO)	1.75	1.30	1.93	.....	1.16
Alkalies (K_2O_3, Na_2O)	.....	.....	.....	.....	1.84
Sulphur trioxide (SO_3)	1.12	1.58	0.14	0.05	tr.
Carbon dioxide (CO_2)	46.01	40.35	42.40	43.22	42.51
Organic matter		4.23	2.25	.....	n.d.

OYSTER SHELLS.

Oyster shells are composed almost entirely of lime carbonate, and as such they could be used in the manufacture of Portland cement. At present, however, they are not so used by any plant in the United States.

In regions where oyster canning is carried on extensively oyster shells form an important waste product which is usually disposed of for making shell roads. Where suitable clay can be obtained they might form an important source of Portland cement material.

The oyster shells from Biloxi, Mississippi, as shown by the following analysis, could be used in the manufacture of Portland cement. Good clay can be obtained on Tchouticabouff River.

TABLE 7.

ANALYSIS OF OYSTER SHELLS FROM BILOXI.

Silica (SiO_2)	5.30
Alumina (Al_2O_3)	.73
Iron oxide (Fe_2O_3)	.57
Lime (CaO)	50.25
Magnesia (MgO)	.45
Sulphur trioxide (SO_3)	.25
Volatile matter (CO_2)	41.39
Moisture	.60

ALKALI WASTE.

In the manufacture of caustic soda there is a large per cent of waste material in the form of lime carbonate which is sufficiently pure for use as a Portland cement material.

The possibility of using the waste product depends on the process used in the alkali plant. In the Leblanc process pyrite is used,

*Cements, Limes and Plasters, E. C. Eckel, 1905, p. 342.

which combines with the lime and forms a large percentage of lime sulphide which renders the resulting waste unfit for use in Portland cement manufacture. In the ammonia process of making caustic soda pyrite is not used and the precipitated waste is largely a mass of lime carbonate. The amount of sulphur, magnesia and other impurities found in the waste depends largely on the character of the limestone used. Where a pure limestone is used the waste forms a cheap source of lime for Portland cement.

The following analyses were made from the waste obtained at alkali plants using the ammonia process:

TABLE 8.

ANALYSES OF ALKALI WASTE.*

Silica (SiO_2)	0.60	1.75	1.98	0.98
Alumina (Al_2O_3)	3.04	0.61	1.41	1.62
Iron oxide (Fe_2O_3)			1.38	
Lime (CaO)	53.33	50.60	48.29	50.40
Magnesia (MgO)	0.48	5.35	1.51	4.97
Alkalies (K_2O, Na_2O)	0.20	0.64	0.64	0.50
Sulphur trioxide (SO_3)	n.d.	n.d.	1.26	n.d.
Sulphur (S)	n.d.	0.10	n.d.	0.06
Carbon dioxide (CO_2)	42.43	41.70	39.60	n.d.
Water and organic matter	n.d.		3.80	n.d.

SLAG.

Slag is a by-product obtained from blast furnaces. In refining metallic ores, especially iron, limestone is most commonly used as a flux. In heating the gangue the lime unites with the silica, the alumina and other materials present in the gangue forming fusible silicates. In the high heat to which it is subjected the limestone gives up a large per cent of lime carbonate which in the slag is changed to the oxide. Slags generally contain from 30 to 40 per cent of lime oxide. Dolomite and highly magnesian limestones render the slag unfit for cement manufacture.

Where slag of the proper composition can be obtained in sufficient quantities it may be combined with a pure limestone in the manufacture of Portland cement.

TABLE 9.

ANALYSIS OF SLAG USED IN GERMAN PORTLAND CEMENT PLANTS.*

	Per cent
Silica (SiO_2)	30 to 35
Alumina (Al_2O_3)	10 to 14
Iron oxide (FeO)	00.2 to 01.2
Lime (CaO)	46 to 49
Magnesia (MgO)	00.5 to 03.5
Sulphur trioxide (SO_3)	00.2 to 00.6

*Bulletin 243, U. S. Geological Survey, E. C. Eckel, 1905, p. 37.

*Bulletin 243, U. S. Geological Survey, 1905, p. 38.

CLAY.

Clays have in their composition alumina and silica with impurities of iron, magnesium, sulphur, alkalies and other minor impurities. The proportion of these ingredients varies from the hydrous silicate of alumina, kaolinite, to the lean sandy clays with barely enough alumina in them to bond them.

The value of a clay for use in the manufacture of Portland cement depends on its comparative freedom from impurities. The best clays are those having a greasy, unctuous feel and free from sand. Some clays like those found in the Lafayette formation contain a high per cent of free silica which is not in chemical combination with iron, alumina or lime, and should, therefore, be avoided. Such clays may be well suited for common brick, but ill suited for making cement. A clay which is free from all impurities is hard to find in nature. Residual and transported clays, such as occur in association with the limestones of Mississippi, are apt to contain a large amount of insoluble material, which is inert in the kiln. The purest clays in the State are those found in the Cretaceous and Tertiary formations.

Fortunately for the cement manufacturer clays with a low percentage of impurities may be used. A study of a large number of analyses of clays now used in American cement plants shows a general average of about 61 per cent of silica, the lowest not below 53 per cent, and the highest not above 75 per cent. "The alumina* and iron oxide together should not amount to more than one-half the percentage of silica, and the composition will usually be better the nearer the ratio $Al_2O_2 + Fe_2O_3 = \frac{SiO_2}{3}$ is approached."

The average amount of magnesia in 87 analyses of clays and shales now used in American cement plants is 2.21 per cent. Alkalies and iron pyrite should be as low as possible.

SHALE.

Shale is a product resulting from a mixture of residual materials derived from the decay of all kinds of rocks which have been disintegrated by mechanical and chemical agencies, carried off and deposited by streams along their channels and at their mouths, and

*Cements, Limes and Plasters, E. C. Eckel p. 354

subsequently hardened by rock pressure. The chemical composition of shale is essentially silica and alumina, while iron oxide, lime, magnesia, sulphur and alkalies are of frequent occurrence.

SLATE.

Slates are shales and clays which have been formed by lateral compression developing cleavage planes which may or may not be parallel to the planes of deposition.

Clays, shales and slates may be used in the manufacture of Portland cement. Slates require more power to pulverize them and are, for that reason, less used than clays and shales. As a waste product in slate quarries slate can be obtained very cheaply, and where limestone is accessible it would form a desirable material in Portland cement mixture.

METHODS OF PORTLAND CEMENT MANUFACTURE.

The methods of Portland cement manufacture have been greatly improved in the United States in the last decade. Heavy machinery must be installed for crushing the raw materials to an impalpable flour. The enormous cost of erecting a cement plant is largely attributable to the heavy machinery and the fireproof kilns.

The processes involved in the manufacture of Portland cement may be divided as follows:

Preparing and grinding the raw materials.
Burning.
Grinding the clinker.

PREPARING AND GRINDING THE RAW MATERIALS.

One of the essential differences between Portland cement and natural cement is in the preparation of the mixture before burning. The raw materials for a true Portland are intimately mixed in definite chemical proportions and thoroughly ground before burning. In natural cement the stone is burned as it comes from the quarry, without previously being ground and mixed. The chemical proportions in a Portland cement can, therefore, the more easily be kept within certain narrow limits.

Dry Process.

In the dry method of preparing the mixture for the kiln it is necessary to drive off the mechanically held water from the raw materials. The amount of water contained in the raw materials depends upon the character of the rocks and the condition of the weather.

All freshly quarried limestones contain more or less hydroscopic or mechanically held water in addition to the chemically combined water. Very compact limestones, such as the oolitic limestones of Tishomingo County, carry from ½ to 3 and possibly 4 per cent of water in rainy seasons.

The percentage of water in porous chalky limestones, such as the Selma chalk, will, doubtless, in rainy seasons, run as high as from 10 to 15 per cent. The amount of water in chalks will vary in different geological formations, and in different parts of the same formation.

Clays and shales are more porous than limestones, and hence carry a greater percentage of water. The amount of water carried will depend on the region, the season, the natural drainage, and the porosity of the material. It has been estimated that the total amount of hydroscopic and chemically combined water in clays may range from 6 to 42 per cent.

Where the raw materials are to be finely ground the mechanically combined or hydroscopic water is first removed by some method of drying. In some plants the clays or shales are dried by storing the materials in large sheds. This, however, requires extra shed room, and likewise, additional handling. In most plants it has been found more economical and quicker to dry the raw materials by artificial heat. The materials are usually partially reduced before drying.

Before the introduction of the rotary kiln the materials were dried in drying tunnels and on drying floors.

The most economical and efficient dryer now in use at the large Portland cement plants of the United States is some type of the rotary dryer, constructed in a manner similar to the rotary kilns. At one plant an ordinary rotary kiln is used for drying the raw materials.

In the rotary dryer the materials are introduced into the upper end of the dryer by means of a chute. The combined rotary motion imparted to the dryer and the action of gravity gradually move the materials to the lower end where they fall on an endless belt and are conveyed to the crushers. In passing through the dryer the materials come in contact with heat and are thoroughly dried.

Dry heat is forced into the dryer at the lower end and moves in an opposite direction to the motion of the raw materials. It thus completely envelopes the raw materials and drives off the water of moisture which partially saturates the dry air.

At the Edison Portland cement plant of New Jersey, a vertical tower-dryer is used for drying the argillaceous and pure limestones used for making cement. The crushed rock is conveyed to the top of the stack, and by means of the baffle system of screens, which partially retard the speed of the fall, descends through the rising gases of combustion, and is thoroughly dried. The dryer has a capacity of 3,000 tons per day, the same as the crusher plant. A piece of rock will pass through the dryer in 26 seconds, reducing the percentage of moisture from 3 or 4 per cent to about 1 per cent. The raw materials are conveyed from the dryer to the crushers and reduced and mixed preparatory to burning. The mixing may be accomplished either before or after grinding. The coarse materials are first crushed in a Gate's crusher, Blake's crusher, or in rolls. All of these mills, working upon different principles, reduce the materials so they that can be handled by Huntingdon, or Griffin mills, comminuter or ball mill.

Any one of the four latter mills will reduce the materials so that they will pass through a 30-inch mesh. The reduction previous to burning is usually completed in a tube mill where 90 to 95 per cent of mixture should pass through a 100-mesh sieve.

In soft materials, such as are found in Mississippi, the entire crushing before grinding could be accomplished economically by a combination of ball mills and tube mills, or by comminuter and tube mills. In the use of chalky limestone the entire process of reduction may be accomplished in tube mills.

The cost of drying depends on the amount of moisture in the raw materials, the type of dryer used, and the cost of fuel. It has been estimated that the most improved dryer will evaporate seven or eight pounds of water per pound of coal.

Wet Process.

The wet process of manufacturing Portland cement is best adapted to plants located in the northern States and in Canada, where the raw materials used are frequently fresh-water marls and clay. The marl usually occurs in swamps which are covered with water in wet seasons, and often frozen over in winter. Such plants, therefore, can run only a portion of the year.

The marls and clays are usually excavated from the pits by means of steam shovels. In some plants the marl is thoroughly mixed with water in the pit and pumped to the mill through pipes. The marl is screened before mixing with the clay to remove pebbles, sticks and roots. The clay in some plants is dried and pulverized before mixing in order to determine more easily the per cent of the mixture. The materials are mixed in the proportion of about 75 per cent of marl and 25 per cent of clay. The mixture is ground in wet mills of the disc type and finally reduced in wet tube mills.

The slurry from the tube mills contains from 30 to 40 per cent of solid matter, and 60 to 70 per cent of water. From the tube mills the slurry is pumped to large tanks and analyzed. If it contains the proper percentages of marl and clay, it is conveyed to the rotary kiln and burned.

The daily output of a 60-foot rotary kiln, using the wet process, is from 80 to 120 barrels, as compared with 160 to 180 barrels of a dry mixture. The difference is due to the great amount of water to be removed in the wet process. The cost per barrel in a wet mixture is 30 to 50 per cent greater than in the dry process.

PREPARING SLAG FOR CEMENT.

In iron-producing districts true Portland cement may also be made from a mixture of blast-furnace slag and pure limestone. The slag contains a sufficient amount of silica and alumina for the mixture. In addition it usually carries from 30 to 40 per cent of lime. By the addition of a pure limestone the proper percentages of a Portland cement are obtained.

In American cement plants the two materials are ground separately and then mixed in proper proportions. The mixture is then finely pulverized in tube mills and conveyed to rotary kilns and burned.

Where a good quality of slag and limestone can be obtained, the cost of making cement is reduced to a minimum. The process requires but little skilled labor and a relatively cheap plant.

Burning.

After the raw materials are carefully mixed and ground they are burned to a semi-vitrified mass called clinker, in kilns specially designed for the purpose.

The first kilns used in the manufacture of Portland cement were the stationary, intermittent, upright kilns, similar to those now generally in use in burning lime. They have some advantages over the more modern kilns. The original cost of construction is smaller, and less fuel is required. But in this country, where fuel is comparatively cheap, the object to be attained is as large an output as possible. For this reason, therefore, the rotary kiln has become very popular, and in all the modern, up-to-date plants they have displaced the upright kilns. The upright kilns are still in use in Europe.

The rotary kiln is a steel cylinder from 5 to 7 feet in diameter, and from 60 to 150 feet long. It is lined with the best fire brick to withstand the enormous heat necessary to burn the raw materials.

The kiln is inclined at about one-half inch to the foot. The mixture to be burned is fed into the upper end. The rotation of the kiln and the action of gravity gradually force the material through the kiln. In passing through it comes in contact with intense heat generated by the combustion of fuel gases, driving off the water and the carbon dioxide, and forming a chemical combination of lime, silica, alumina and iron oxide. The resulting mass falls out at the lower end of the kiln as clinker.

The fuel is fed into the kiln at the lower end just above the opening through which the clinker falls out. If coal is used as a fuel it is first finely crushed and thoroughly dried, and by means of an automatic feeder is forced into the kiln.

Fuels.

Coal.—The most common fuel used in the manufacture of Portland cement is bituminous coal. A coal high in volatile matter and low in ash has been found to be more desirable than coals containing a high per cent of carbon, such as anthracite and semi-bituminous coals.

A coal which contains more than 2 per cent of sulphur should not be used.

The following table gives the analyses of coals now used in different Portland cement plants in the United States:

TABLE 10.

ANALYSES OF KILN COALS.*

Volatile matter	32.90	38.10	31.38	35.41	35.26	39.52	39.37	31.87	37.44	38.00
Fixed carbon	54.66	53.24	58.23	56.15	56.33	51.69	55.82	51.05	53.72	51.72
Sulphur	n.d.	n.d.	n.d.	1.30	1.34	1.46	0.42	n.d.	n.d.	n.d.
Ash	10.25	8.06	9.42	6.36	7.06	6.13	3.81	5.22	5.50	5.38
Moisture	2.19	0.60	1.03	2.08	1.35	1.40	1.00	11.86	3.334	4.90

Before the coal is used in the kiln the large lumps and nut coal are first crushed and reduced to slack in an ordinary crusher. It is then taken to the dryer where all the hydroscopic or mechanically held water is driven off. This is most economically done in a rotary dryer, in much the same way as the raw clay and the limestone are dried. Care should be taken in drying the coal not to raise the temperature high enough to drive off any of the volatile combustible gases.

After the coal has been dried it is crushed and pulverized so that at least 85 per cent of it will pass through a 100-mesh sieve. The finer the coal is pulverized the more thorough is the combustion, and the better the results in the kiln. A poor coal, if finely pulverized, will give better results than a higher grade of coal coarsely ground. For this reason it is desirable to get the run of the mines, the original cost of which is cheaper, requires less crushing, and is as good as the hard lump coal.

The cost of coal as a fuel depends on the production-cost, the quality of the coal, the kind of kilns used, and the degree of fineness to which it is crushed before using.

From 200 to 300 pounds of coal are used in the power plant and in the kilns in the manufacture of a barrel (380 pounds) of Portland cement.

The cost of crushing, drying and finely pulverizing the coal, conveying it to the kilns, allowing for repairs, and interest on a four-kiln plant, will vary from 20 to 30 cents per ton, or about 3 to 5 cents

*Cements, Limes and Plasters, E. C. Eckel, 1905, p. 513.

per barrel of cement. In the average plant using coal as a fuel, about one-third of the total cost of the cement may be chargeable to fuel. The question of cheap fuel should, therefore, be an important factor in determining the location of a Portland cement plant.

Oil.—Oil was formerly used in Pennsylvania Portland cement plants as a fuel in rotary kilns; but its use has been abandoned for coal. Oil is used in some of the wesern plants where good heating coals cannot be obtained at reasonable prices.

It is claimed that from 11 to 14 gallons of oil, used in a rotary kiln, will burn one barrel of cement. On this basis, 1 gallon of oil is equivalent to about 20 pounds of coal.

Natural gas.—In sections of the country where there is natural gas it is found to be a very economical fuel. The gas is fed into the kiln by means of a large gas burner. It is found to be as good a fuel as coal and requires much less labor and storeroom to feed it to the kiln.

Producer gas.—At present there are three cement plants in the United States using producer gas as a fuel. Only one of these has been successful in obtaining an economical fuel consumption.

It has been shown by experiments carried on by the United States Geological Survey Coal-testing Plant at St. Louis, that the best quality of producer gas is obtained from bituminous coals and lignites. This gas can be ignited in internal combustion engines for the development of power, with a fuel economy of more than 50 per cent. A number of bituminous coals were converted into producer gas and burned in gas engines with a gain in power of 2.6 per cent more than when coal was burned under a common boiler in the production of steam power.

It was further shown that gas of a higher quality can be obtained from lignites and low grade coals than from the best Pennsylvania and West Virginia bituminous coals. The gas obtained from a ton of lignite, and burned in a gas engine, produced as much power as a ton of the best bituminous coal burned under a common boiler.

In his investigations of the lignites of Mississippi Dr. Calvin S. Brown, assistant geologist of the State Survey, has shown that there are a large number of workable veins of lignite in the State. It is quite possible, therefore, that a high quality of producer gas could be made from the lignites of Mississippi, and a more economical power produced than can be obtained by using Alabama, Kentucky and Illinois coals.

TABLE 11.

ANALYSES OF MISSISSIPPI LIGNITES.

Moisture	13.61	12.51	13.50	8.72	14.61	14.90
Volatile matter	37.14	41.40	39.66	34.64	38.51	39.21
Fixed carbon	42.10	33.93	36.50	22.84	39.10	35.57
Ash	7.15	12.16	10.34	33.80	7.78	10.32
Total	100.00	100.00	100.00	100.00	100.00	100.00
Sulphur	2.64	2.77	4.10	2.76	1.28	0.56
Moisture	15.22	13.04	14.60	13.20	12.26	11.61
Volatile matter	42.38	36.68	30.59	40.16	37.43	34.61
Fixed carbon	34.91	35.62	35.21	31.24	41.91	42.47
Ash	7.49	14.66	11.60	15.40	6.37	11.31
Total	100.00	100.00	100.00	100.00	100.00	100.00
Sulphur	0.91	0.48	1.83	1.20	0.94	2.66

GRINDING THE CLINKER.

As the burned clinker emerges from the rotary kiln it has a temperature ranging from 300° F. to 2,500° F., or about 13 per cent of the total amount of heat utilized in the kiln. Before it can be crushed the clinker must in some way be cooled.

A number of devices have been invented to cool the clinker in the most rapid and at the same time in the most economical way. In some plants the hot clinker, on its journey from the kiln to the storage room, is subjected to a spray of water, the evaporation of which absorbs the heat of the clinker. In this method of clinker-cooling none of the heat of the clinker is utilized. Since the amount of heat carried off in the clinker is so great, efforts have been made to utilize the heat of the cooling clinker. This has been the most successfully done by the two-stage rotary cooler.

The principle on which the cooling is done is here summarized from a description of the cooling system at the main Atlas cement plant, by Stanger and Blount in Proc. Inst. Civil Engineers, Vol. 145, pp. 57–68, 1901.

The hot clinker from the kiln falls into a rapidly revolving cylinder about 30 feet long and 3 feet in diameter, otherwise similar in construction to the rotary kiln. At the end of the cylinder opposite the kiln is admitted a blast of cool air which passes through the cylinder, cools the clinker, and is admitted into the kiln in a highly heated condition. At the end of the first cylinder the clinker passes through a crusher which is kept cool by a spray of water. The clinker passes from the crusher through a second cylinder, 60 feet long and 5 feet in diameter. From the second cylinder the clinker is conveyed to the crushers.

In burning the raw materials at a high temperature the clinker thus formed is a very hard semi-vitrified mass which must be pulverized to a fine flour before it can be called cement. The best Portland cements are now ground so that from 90 to 95 per cent will pass a 100-mesh sieve. The process requires a great amount of power and heavy machinery.

It is estimated by Mr. E. C. Eckel that, in a Portland cement plant using the dry process of manufacture, it requires about the same amount of power and similar machinery to crush the clinker as that used in crushing the raw materials. "It must be remembered that for every barrel of cement produced, about 600 pounds of raw material must be pulverized, while only a scant 400 pounds of clinker will be treated; that the large crushers required for some raw materials can be dispensed with in crushing clinker, and that the raw side rarely runs full time."*

RETARDER FOR QUICK-SETTING CEMENTS.

A small amount of calcium sulphate, usually in the form of crude gypsum or plaster of Paris, is necessary in the manufacture of Portland cement to retard the quick-setting, high-limed clinker produced in the rotary kilns. The amount used in most American plants varies from 2 to 3 per cent. Used in large quantities it may even accelerate the set and greatly weaken the cement. The calcium sulphate should be intimately mixed with the cement, and that this may be thoroughly done it is usually put in and ground with the clinker.

PORTLAND CEMENT MATERIALS OF MISSISSIPPI.

GENERAL GEOLOGY.

Cement materials of Mississippi consist of hard limestones, chalk, clays and shales. Inasmuch as the chalk of this State is a comparatively hard rock it will be treated as a limestone.

Limestone, the principal ingredient necessary in the manufacture of Portland cement, is found in four geologic periods of the State,

*Limes, Cements and Plasters, 1906, p. 531.

widely differing from each other in age and location. In each period shales or clays overlie the limestones. The four periods will be described in the order here given.

(1) Devonian.
(2) Carboniferous.
(3) Cretaceous.
Selma chalk.
(4) Tertiary.
Vicksburg limestone.

Devonian.

Along the Tennessee River, and for a distance up all the streams flowing into the Tennessee from the State of Mississippi, are beds of limestone representative of the Lower Devonian. The line of separation of the Devonian and Carboniferous rocks has not been mapped in Mississippi. The Devonian rocks are represented by a dark gray limestone and interbedded shales, with an occasional stratum of fine-grained standstone. The limestone contains a high per cent of insoluble matter which occurs in chemical combination and not in the form of free silica or sand.

The following section of the Devonian on Yellow Creek, Tishomingo County, was obtained by the writer:*

Section of Devonian on Yellow Creek.
Sec. 22, T. 1 N., R. 10 E.

	Feet
Thin-bedded, impure limestone at base, changing gradually to a bluish limestone at top of cliff	95
Compact blue limestone, non-fossiliferous	40
Dark gray limestone containing numerous Devonian fossils	10
Dark pure limestone to water's edge	5

On the north bank of Yellow Creek, near its mouth, the limestone is overlain by thin strata of aluminous sandstone and shale.

A reproduction of the outcrop near the mouth of Yellow Creek is found on Whetstone Creek near Short postoffice.

Section on A. L. Bugg's Land, near Mouth of Whetstone Creek.†

	Feet
Angular chert, flint and hornstone	100
Dark blue shale containing iron pyrite; very fossiliferous in lower part	30
Thin-bedded, fine-grained, shaly limestone, with thin bands of fine-grained sandstone or whetstone varying from a fraction of an inch to 12 inches in thickness	20

*Geology and Mineral Resources of Miss., U. S. Geol. Surv. Bull. No. 283, p. 9.
†Ibid p. 10.

It is quite probable that the dark blue limestone which is found at the mouth of Bear Creek is the uppermost member of the Devonian.

The Devonian of this State includes shale and limestone suitable for hydraulic and Portland cements.

TABLE 12.

ANALYSES OF DEVONIAN LIMESTONE FROM TISHOMINGO COUNTY.

	1	2	3	4
Insoluble matter (SiO_2)	54.201	35.281	42.00	48.18
Alumina (Al_2O_3)	1.064	1.914	1.98	3.43
Iron oxide (Fe_2O_3)	0.903	1.581	6.02	3.13
Lime (CaO)	23.247	32.603	23.25	39.47
Magnesia (MgO)	0.788	0.630	0.27	3.19
Carbonic acid	15.572	27.643	*24.10	5.06
Organic matter and water	3.752		0.40	0.40
Potash	0.473	0.348	......	......
Sulphur trioxide	......	......	1.50	2.23

1, 2. Dr. E. W. Hilgard, analyst.
3, 4. Dr. W. F. Hand, analyst.

Carboniferous.

The Carboniferous rocks in Mississippi include beds of limestone, shale, chert and sandstone extending in age from the Ordovician to and including the Mississippian. Oolitic limestone suitable for the manufacture of Portland cement is found near the top of the Carboniferous rocks in Mississippi, and is the equivalent of the St. Genevieve limestone of western Kentucky, and the famous building stone of Bedford, Indiana. In Alabama this rock is quarried for burning lime and building stone.

The oolitic limestone is dark gray to white, and is made up almost exclusively of small, rounded concretions called oolites. It is practically free from impurities. A thickness of 30 feet or more is exposed in the bluffs on Bear Creek as far south as Mingo.

The distribution of the oolitic limestone and accompanying shales is confined to that part of Tishomingo County lying north of Mingo, along Bear Creek and its tributaries, and in one locality on Macky's Creek. In the hills to the west the Paleozoic rocks are covered by later deposits of Cretaceous and Lafayette.

On the west side of Cypress Pond, about 1 mile north of west of the steel bridge across Bear Creek near Mingo, on land now belonging to Mr. William Southward, the limestone forms a bluff 30 to 35 feet high. Its thickness below the surface has not been determined. The

*Volatile matter.

limestone is overlain by a bed of dark blue shale which weathers to a tough blue clay. The top of the limestone along the pond has about the same elevation as the base of the shale bed in the section at the steel bridge given below, so that the two may be taken together as one continuous section, the one at the bridge being a continuation upward of the Cypress Pond section.

Limestone outcrops in many of the branches flowing into Cypress Pond, and is frequently struck in wells on the west side of Bear Creek. Still farther north, on the Allsboro and Iuka road, the oolitic limestone outcrops in sections 22, 26 and 27, T. 4 N., R. 11 E. The oolitic limestone near Mingo is overlain by a bed of shale 23 feet thick, separated by a thin stratum of impure limestone 8 inches thick.

The following is a section of the bluff at the steel bridge near Mingo:

Section of the Bluff at the Steel Bridge near Mingo.

Residuary soil and Lafayette at the surface.........	x feet
Heavy-bedded limestone about.....................	20 feet
Compact, blue shale.............................	15 feet
Thin ledge of impure limestone, upper 3 inches studded with fossils..................................	8 inches
Thinly laminated blue shale with an occasional fragment of impure dark limestone, water's edge.....	8 feet

The lowest shale bed is thinly laminated and contains more or less fine sand between the laminæ. The upper bed is more thickly laminated and freer from impurities.

The composition of the above limestones and shales is given below:

TABLE 13.

ANALYSES OF CARBONIFEROUS LIMESTONES AND SHALE, TISHOMINGO COUNTY.

	1	2	3
Silica (SiO_2).................................	1.57	10.91	54.46
Alumina (Al_2O_3)................................	1.94	8.17	14.92
Iron oxide (Fe_2O_3).............................	1.69	5.00	12.50
Lime (CaO).....................................	52.75	47.06	2.56
Magnesia (MgO).................................	.36	0.16	0.00
Volatile matter (CO_2)...........................	40.80	27.00	13.30
Sulphur (SO_3)...................................	.32	0.85	.85
Moisture..	.15	1.10	2.30
	99.48	100.25	100.89

1. Limestone from Cypress Pond near William Southward's house.
2. Limestone from Mingo bridge, Bear Creek.
3. Shale from Mingo bridge, Bear Creek.

CRETACEOUS.

TUSCALOOSA CLAYS.

The Tuscaloosa clays are well displayed in northeastern Mississippi. They have been more carefully studied in Tishomingo County, where they occur in thick deposits over large areas. These clays overlap the Carboniferous and Devonian limestones and in some cases outcrops of limestone and clay occur in the same section.

The following analyses are characteristic of the clays of Tishomingo and Itawamba counties:

TABLE 14.

ANALYSES OF TUSCALOOSA CLAYS OF MISSISSIPPI.*

	Silica (SiO_2)	*Alumina* (Al_2O_3)	*Ferric oxide* (Fe_2O_3)	*Lime* (CaO)	*Magnesia* (MgO)	*Sulphur trioxide* (SO_3)	*Moisture*	*Loss on ignition*
Pink clay, 6 miles north of Iuka, Tishomingo County	†38.11	36.42	11.73	.60	.14	Tr.	.87	11.96
White clay, 6 miles southeast of Iuka, Tishomingo County	†66.85	20.54	3.77	.21	.18	Tr.	.59	8.00
White potter's clay, 5 miles south of Iuka, Tishomingo County	†68.65	18.99	2.77	.20	.20	Tr.	1.09	7.34
White clay, 5 miles south of Iuka, Tishomingo County	‡80.07	11.46	.57	.12	.37	n.d.	X6.81	.60
Tuscaloosa clay, 15 miles south of Iuka, Tishomingo County	†80.03	12.00	1.68	.24	.26	Tr.	.48	4.82
Tuscaloosa clay, 12 miles south of Iuka, Tishomingo County	§90.877	2.214	.126	.140	Tr.	n.d.	X6.93	......
White potter's clay, 14 miles southeast of Fulton, Itawamba County	†59.12	27.44	4.39	.34	.28	Tr.	.54	7.40
White potter's clay, 14 miles southeast of Fulton, Itawamba County	†62.58	27.58	1.57	.40	Tr.	Tr.	.77	6.77
Tuscaloosa clay, 14 miles southeast of Fulton, Itawamba County	†71.53	14.46	4.14	.62	.55	n.d.	2.17	5.91

SELMA CHALK.

The Selma chalk of Mississippi includes a great thickness of chalky limestone commonly known as "rotten limestone" of Cretaceous age. In Bulletin No. 283, U. S. Geological Survey, the writer describes the Selma chalk as "a mass of loosely semi-cemented lime carbonate, the

*Bull. 283 U. S. Geological Survey, Crider, pp. 51–55.
†W. F. Hand, State chemist, analyst.
‡J. Blodgett Britton of Philadelphia, Pa., analyst.
§Dr. E. W. Hilgard, analyst.
XWater and organic matter.

upper division of which is of exceptional purity. Where it is typically exposed along the larger streams it bleaches to a white appearance and is called the 'white chalk' bluffs. To the casual observer the entire formation has much the same appearance, but it may be separated into three natural divisions, based primarily on chemical analysis, (*a*) the transition beds at the base, (*b*) the 'blue rock,' or more clayey unweathered portion, and (*c*) the rotten limestone, or chalk, including the upper portion of the formation.

"(*a*) The lowest division contains a large amount of free sand which was washed into the Selma sea from the Eutaw and the older land surface to the east. This forms the transition beds from the extremely sandy strata of the Eutaw to the deep-sea deposits of lime carbonate which characterizes the Selma chalk. The amount of sand is greatest at the base and becomes less and less upward until it finally disappears entirely." This lower portion would not be suitable for cement on account of the great amount of free sand it contains. Fortunately, however, the sandy portion is confined to the lower division of the formation and can be easily avoided in using the overlying limestone for cement.

"(*b*) The middle division contains a relatively large amount of clay and when freshly dug is of a bluish color. It is found in the deep wells and recognized by the drillers as 'blue rock.' The great amount of clay in the lime carbonate renders the rock impervious to water. The fine supply of artesian water stored in the underlying Eutaw sands is held in place and prevented from escaping upward by means of the 'blue rock' of the Selma.

(*c*) "The uppermost division contains a greater amount of lime carbonate and much less clay than the 'blue rock' and likewise a smaller amount of free silica than the lowest division. Some of the analyses of this chalk show 98 per cent of calcium carbonate.

"In places a hard crystalline limestone, somewhat silicified, forms a capping to some of the hills of the Selma. Hard flint rock and a thin strata of sandstone are reported in a deep well-boring at Livingston, Ala."

The Selma in Mississippi corresponds to the formation of the same name in Alabama. The white chalk bluffs along Tombigbee, Warrior and Alabama rivers may be seen in numerous places in Dallas, Hale, Sumter and Green counties, Alabama. It is all of the same geologic age, and once known it may be easily recognized.

THICKNESS.

The Selma attains its greatest thickness in central Alabama, where it is reported to be 1,200 feet. It decreases in thickness to the east, disappearing entirely in the eastern part of the State. East of Montgomery the three divisions are mapped as one formation. In western Alabama it has a thickness of 925 to 950 feet, while in Oktibbeha County, Mississippi, it has a thickness of about 800 feet. From this point northward the formation continues to thin and finally disappears entirely near Camden, Tennessee. The area of the State underlain by the Selma is shown by the light green on the map. The region is known as the "prairies" and may be easily recognized by the dark rich loams at the surface. The disintegration of the Selma forms one of the richest soils in the State. In Alabama the Selma area forms one of the richest cotton belts in the South and is known as the "Black belt."

In comparatively recent geologic times the entire area of the Selma was covered by the Lafayette, a thin deposit of sandy loam. The greater part of the Lafayette has been carried away by the streams. In the inter-stream areas however, and on the more level lands near the streams, there are still small patches of Lafayette which have suffered but little erosion since its deposition. In consequence of this fact there are two distinct and widely different soils which are found in this region. These are the "post oak" and the "prairie" soils. The Lafayette in this area has a maximum thickness of about 13 feet.

The "post oak" soils are usually found on the higher inter-stream areas where there has been least erosion. The soil is poor and produces a scrubby growth of post oak and black jack. In the early settlement of the region the "post oak" land was first cleared, but at present it is mostly used for grazing.

The "prairie soils" are found on the rolling lands from which the Lafayette has been entirely removed so that the rich black loam, formed by the disintegration of the underlying Selma limestone, is at the sufrace. The "prairie soils," therefore, are residual soils *in situ*, and form the most fertile lands of eastern Mississippi.

In places all the Lafayette and even the residual soil of the Selma have been removed by erosion, leaving the white chalky limestone of the Selma at the surface. On looking for the outcropping Selma it may be more readily found along the streams, on the steep hillsides and in the railroad cuts.

Inasmuch as this is to be the final report on the cement materials of the State for some time, space will be taken to describe a large number of outcrops of the Selma limestone, much of which is very similar in appearance. A fair series of analyses has been made of the limestone from different localities, giving some idea of the value of the Selma for cement. It must be understood, however, that at no locality has the Selma been found to contain all the constituents necessary in the manufacture of either hydraulic or Portland cement. It becomes valuable as a cement product when used in connection with clay. All the limestone found in the Selma area is not of value for cement because of the lack of good clay near it. Only those outcrops, therefore, which are near good clay outcrops can profitably be utilized for cement. The clay in the geologic section immediately overlying the Selma, known as the Porter's Creek, is suitable for mixing with the limestone. The possibility of using this clay will be taken up under the head of Porter's Creek clay.

DISTRIBUTION.

That part of the State embraced within the area represented on the map by the light green color is underlain by the Selma chalk. The limestone does not show at the surface over the entire area shown on the map owing to the covering of sandy loam and residual soil which, over the greater part of the area, completely covers the limestone. This covering is comparatively thin, as is shown in wells, railway cuts, along the streams and on many hillsides where the atmospheric waters have carried away the soil covering, leaving the Selma limestone exposed at the surface.

Corinth and Vicinity.—The town of Corinth is built in the valley of a small stream which flows into Tuscumbia River. On the west side of the town is a low range of hills which rise 30 to 40 feet above the valley. About $\frac{1}{8}$ of a mile west of the station on the Southern Railway, is a cut through a small ridge showing from 5 to 8 feet of surface sandy loam, with an equal thickness of Selma limestone, which extends to the bottom of the cut. The Selma at this place can hardly be called a limestone. It is the "blue rock" which occurs near the bottom of the formation, and is more properly a compact calcareous clay which can be broken into rectangular blocks. There are small needle-like crystals of selenite in the cracks and on exposed surfaces. The thickness of the Selma at Corinth is less than 100 feet.

TABLE 15.

ANALYSIS OF SELMA LIMESTONE FROM CORINTH.

Silica (SiO_2)	25.40
Alumina (Al_2O_3)	6.88
Iron oxide (Fe_2O_3)	8.62
Lime (CaO)	26.37
Magnesia (MgO)	.58
Volatile matter (CO_2)	23.70
Sulphur trioxide (SO_3)	0.64
	92.19

The above analysis shows a high per cent of silica, which is characteristic of the lower beds of the Selma. Higher in the formation the percentage of lime steadily increases, while the siliceous material decreases correspondingly. Purer limestone is found in the railway cuts west of Corinth.

The Selma may be found underlying the surface covering for 6 to 10 miles west of Corinth, and for 3 miles east. It gradually thins to the east and finally disappears completely in the low north and south range of hills 3 miles east of town.

At the western end of the 90 foot cut on the new line of the Illinois Central Railway, 3 miles east of Corinth, the blue limestone of the Selma extends to the bottom of the cut. At the eastern end it forms a thin stratum and finally disappears completely. The lowest member of the Selma is underlain by a bed of oxidized, calcareous, sand-bearing fossils.

The Selma is exposed in almost every cut of any size along the Southern Railway from Corinth to the Tennessee State line. A few hundred yards west of Wenasoga, 12 feet or more of bluish calcareous clay are exposed in the railway cut. At this point the Selma is much thicker than it is at Corinth. At the little town of Chewalla, across the line in Tennessee, it was penetrated in a well at a depth of 350 feet. There is quite a thickness of overlying transported soil, so that the limestone is at least 300 feet thick.

The Selma is encountered in digging wells at Danville, Rienzi and Thrasher, but these towns are near the eastern edge of the Selma, which, as is shown by the well records, contains more or less sand. These towns are located on the Mobile and Ohio Railway, which follows along the second bottoms of the Tuscumbia River, and consequently there are no outcrops of the Selma at the surface.

Booneville and Vicinity.—In the deep cut on the Mobile and Ohio Railway, in the town of Booneville, the typical Selma limestone is exposed. There is a thick covering of sandy loam (Lafayette) overlying the limestone in the vicinity of Booneville. Many of the wells obtain their supply of water from the base of the Lafayette. The compact nature of the Selma prevents the water from penetrating it. There are many small springs found at the contact between the Lafayette and the underlying Selma.

The following record of the Booneville Waterworks Company's well, furnished by Mr. A. W. Hurley, driller, will give some idea of the thickness of the Selma at this place:

Section of Booneville Waterwork's Well.

	Feet
13. Surface red clay	18
12. Selma "blue rock"	52
11. Bluish green sandy clay with shells	3
10. Blue sand containing water	40
9. Hard rock	1
8. Blue sand containing water	7
7. Blue hard rock	1½
6. Clay ("soapstone") } 5. Sand } 4. Clay ("soapstone") } 3. Sand }	188
2. Hard rock at 307 feet	1½
1. Gray sand containing green sand grains	35
Total depth of well	347

From the above record it will be seen that the limestone at Booneville is 52 feet thick. One-fourth of a mile east of this town it is only 25 feet thick, and ¾ of a mile east it cuts out entirely. It outcrops in the hills west of the town and is encountered in all the deep wells as far west as Jumpertown. The Mobile and Ohio Railway follows, approximately, the eastern limit of the Selma between Booneville and Tupelo. The eastward extension of the Selma at Booneville is due to the fact that the divide between the waters of Tuscumbia and

Tombigbee rivers have suffered but little erosion. South of the divide the headwaters of Tombigbee River have carried away a large amount of the Selma and caused the contact between the Selma and the underlying Eutaw green sands to swing westward in the vicinity of Wheeler, Baldwin and Guntown.

At Guntown the lowest beds of the Selma are exposed in the railway cut just north of the station. There is a compact ledge of fossiliferous limestone about 2 feet thick underlain by a bed of green sand which extends to the bottom of the cut. This doubtless corresponds to strata No. 11 in the Booneville section. There is a strong southward dip of the Selma as shown in the railroad cut at Guntown. The main body of the Selma lies west of Guntown. The basal members here, as at all other places where they are exposed, contain too much sand to be used in the manufacture of Portland cement.

Tupelo and Vicinity.—The town of Tupelo is built in the valley of Old Town Creek, a large tributary to Tombigbee River. In the lower portions of the town the alluvial soil is 20 feet thick. The hills to the east have a thin covering of Lafayette. To the northwest the Lafayette and residual Selma form the fertile farming lands. The only evidence of the presence of the Selma here is found in the wells which extend below the surface soils. Below is a record of an average artesian well in Tupelo:

Well Record at Tupelo.
R. B. McVay, Driller.

	Feet
Surface soil	20
"Blue rock" with some sand (Selma)	100
Blue limestone (Selma)	130
Fine gray sand, water-bearing	10
Clay ("soapstone")	4
White sand, water-bearing	10
Clay ("soapstone")	20
Fine white sand, thickness undetermined.	

The above record shows 230 feet of Selma limestone. The upper 100 feet of "blue rock" is reported as containing some sand. This is perhaps a calcareous green sand or else it is a horizon in the Selma not yet discovered at the surface. The latter theory is hardly probable, however, since so great a thickness would not have escaped detection in the detailed work done on the formation in Alabama and along the Tombigbee River in Mississippi.

The first cut on the Mobile and Ohio Railway south of Tupelo exposes the Selma from the surface to the bottom of the cut. All the deep cuts from here to Verona penetrate the surface soils and reach the Selma. It also outcrops on the sides of the wagon road and in the open field about 2½ miles south of Tupelo. In other places along the road between Tupelo and Verona, and in numerous places west of Verona, the Lafayette has been removed by erosion, exposing the Selma. On the more level lands the residual soil of the Selma forms the well known "prairie soil." During the rainy season the constant kneading of the "prairie soil" by wheels of vehicles and horses' feet forms a tough plastic clay which, when once recognized, may never be mistaken. Even if there is no outcrop of the Selma near, the "prairie soil" indicates that the Selma is but a few feet, or perhaps a few inches, below the surface.

A sample of the Selma collected from the roadside about 2½ miles south of Tupelo shows the following analysis.

TABLE 16.

ANALYSIS OF SELMA LIMESTONE 2½ MILES SOUTH OF TUPELO.

Silica (SiO_2)	22.76
Alumina (Al_2O_3)	4.56
Iron oxide (Fe_2O_3)	6.46
Lime (CaO)	34.31
Magnesia (MgO)	.05
Volatile matter (CO_2)	28.25
Sulphur trioxide (SO_3)	.43
Moisture	2.10

Fine exposures of the Selma are found on Coonewah Creek about 5 miles west of Tupelo. It is overlain in places by 6 to 10 feet of yellow clay. The Selma continues westward to within 3 or 4 miles of Pontotoc. In southeastern Pontotoc County it is reported to be 750 feet thick.

A sample of Selma collected by W. N. Logan from a point 1 mile west of Tupelo, on the Tupelo and Pontotoc road, shows the following analysis:

TABLE 17.

ANALYSIS OF SELMA LIMESTONE 1 MILE WEST OF TUPELO.

Silica (SiO_2)	14.84
Alumina (Al_2O_3)	15.59
Iron oxide (Fe_2O_3)	4.50
Lime (CaO)	32.89
Magnesia (MgO)	.41
Volatile matter (CO_2)	27.10
Sulphur trioxide (SO_3)	3.30
Moisture	1.08
	99.71

The thickness of the Selma as shown in the wells at Verona is about the same as it is in Tupelo. The following is a record of one of the wells in Verona:

Well Record at Verona.
R. B. McVay, Driller.

	Feet
Surface soil	21
Light colored Selma	80
Blue limestone, Selma	160
Gray sand, water-bearing	10
Compact, sticky sand	30
Gray sand, water-bearing	15
Black clay, "soapstone"	20
Fine gray sand, water-bearing	x

The entire thickness of the Selma here is 240 feet. No sand is reported from the upper 80 feet as in the well at Tupelo. The well is located in the lowest part of the town near the station. The Selma comes to the surface in places just west of town.

Okolona and Vicinity.—One of the best exposures of the Selma limestone in the northern and central portions of the Selma area is found in the town and vicinity of Okolona. In a few places the Lafayette sandy loam is present, but from the greater portion of the area it has been removed, leaving large patches of exposed limestone known as "bald prairies." The limestone has become white by reason of long exposure to sun and rain. In this respect it resembles the "white chalk" exposed in the bluffs along Noxubee and Tombigbee rivers.

The numerous outcrops of the Selma in southeastern Chickasaw and western Clay counties have been carefully described by Dr. Hilgard.*

The country is dotted with outcrops of the Selma along Chookatonkchie, Houlka, Oka Tibbeha or Tibby creeks, and on the eastern slope of Pontotoc Ridge, projections of which extend southward between the above mentioned streams. The limestone in northwestern Clay County has been penetrated in wells at a depth of about 500 feet.

A sample of the limestone from the railroad cut at the Mobile and Ohio station, Okolona, was burned in a forge for a period of 15 min-

*Agriculture and Geology of Mississippi, pp. 79-81.

utes. The rock was heated to a white heat and slaked by pouring water on it. It immediately broke down into a beautiful white lime. The following analyses were made of this limestone:

TABLE 18.

ANALYSES OF SELMA LIMESTONE FROM OKOLONA.

	1	2
Silica (SiO_2)	8.80	8.70
Aluimna (Al_2O_3)	2.86	0.00
Iron oxide (Fe_2O_3)	4.08	6.00
Lime carbonate (CaO)	45.51	45.62
Magnesium carbonate (MgO)	.36	1.72
Volatile matter (CO_2)	31.11	34.40
Sulphur trioxide (SO_3)	.38	1.11
Moisture	6.35	1.10

The following analysis of the same limestone was made by Dr. E. W. Hilgard.*

Insoluble matter (mostly silica) (SiO_2)	10.903
Alumina (Al_2O_3)	1.957
Peroxide of iron (Fe_2O_3)	1.421
Lime (CaO)	†45.791
Magnesia (MgO)	‡0.877
Carbon dioxide (CO_2)	35.725
Alkalies (K_2O, Na_2O)	0.568
Organic matter and water	2.840

The eastern edge of the Selma south of Tupelo follows, approximately, the boundary between Itawamba and Lee counties southward to the Monroe County line. From here to Columbus it is almost a due north and south line, rarely extending more than 3 miles west of Tombigbee River. Outcrops are frequent from the eastern to the western borders of the formation.

Starkville and Vicinity.—In the eastern half of Oktibbeha County the Selma limestone is characteristically developed. A few small patches of the Lafayette still remain on some of the divides. The rest of the surface is formed by the residual loam of the "prairie soil," and the white rock of the Selma.

One to ten feet of Selma limestone may be seen in almost every cut along the Illinois Central Railway from Starkville to West Point.

Similar outcrops occur along the Mobile and Ohio Railway from Starkville to Artesia.

*Geology and Agriculture of Mississippi, 1860, p. 101.

†Equals lime carbonate ($CaCO_3$) 81.77.

‡Equals magnesium carbonate ($MgCO_3$) 1.84.

The thickness of the Selma in the city well at Starkville is about 750 feet, with 50 feet or more exposed in the hills to the north.

The character of the limestone collected from various localities in Oktibbeha County is shown by the following analyses:

TABLE 19.

ANALYSES OF SELMA LIMESTONE FROM OKTIBBEHA COUNTY.

	1	2	3	4	*Average*
Silica (SiO_2)	2.89	2.33	3.03	2.55	2.70
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	1.53	1.72	1.92	1.96	1.78
Lime carbonate ($CaCO_3$)	94.10	94.35	93.60	94.07	94.03
Magnesium carbonate ($MgCO_3$)	1.84	1.82	1.64	2.12	1.85
Water (H_2O)	.36	.44	.42	.52	.44

By a proper admixture of clay with any of the above samples of limestone the product would make an excellent Portland cement. The per cent of lime carbonate is high with a corresponding low per cent of iron oxide, alumina and magnesium carbonate.

The following samples of Selma limestone, collected by W. N. Logan from Oktibbeha County, were analyzed with the following results:

TABLE 20.

ANALYSES OF SELMA LIMESTONE FROM OKTIBBEHA COUNTY.

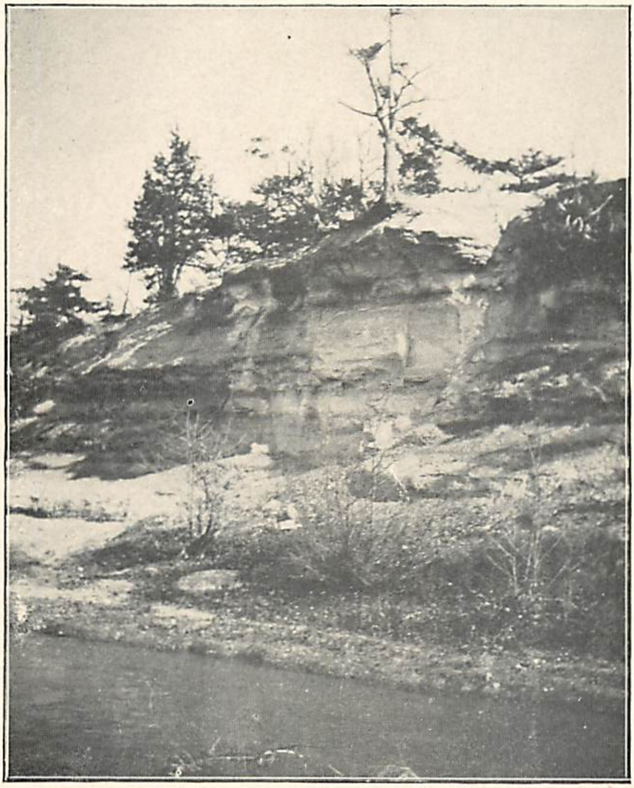
	1	2	3	4	5	6
Silica (SiO_2)	29.98	25.27	9.84	20.60	17.03	18.82
Alumina (Al_2O_3)	5.45	4.81	.19	7.63	21.00	.23
Iron oxide (Fe_2O_3)	5.60	10.35	2.58	4.62	3.33	2.80
Lime (CaO)	31.62	32.85	38.65	21.81	29.29	40.02
Volatile matter (CO_2)	24.50	25.60	42.05	23.15	28.20	34.02
Magnesium oxide (MgO)	.14	.84	.18	.81	0.00	.96
Sulphur trioxide (SO_3)	.21	.62	2.05	.25	.72	2.53
Moisture	1.50	.40	.94	.85	.75	1.15

1. Agricultural College.
2. Near Osborn.
3. Reynolds farm, 1 mile west of Starkville.
4. Howard Brick Yard, Starkville.
5. Howard Brick Yard, Starkville.
6. Mayhew road, 1 mile east of Agricultural College.

The occurrence of Selma limestone in southern Monroe, Lowndes, Noxubee and Kemper counties has been described in detail by the writer in Bulletin 260, U. S. Geological Survey, 1904, pp. 510-521. A large number of samples from these counties were collected and analyzed in the U. S. Geological Survey laboratory.

Macon and Vicinity.—The limestone at and near Macon deserves special mention on account of the large amount of material in sight,

Plate I.



SELMA CHALK BLUFF, MACON.

the ease with which it could be quarried, the nearness to deposits of clay and the facilities offered for transportation.

The bluff on Noxubee River at the mouth of Macon Creek, near the town of Macon, is about 40 feet high, and extends more or less unbroken to the mouth of the Noxubee River. The entire bluff, except 5 or 10 feet of surface soil, is formed of the Selma limestone. Other outcrops occur along all the principal streams flowing into the Noxubee River, and in the railway cuts as far south as Scooba.

The limestone, viewed from a distance, appears to be a homogeneous mass of white chalk. On close examination, however, it is found to have an amygdaloidal structure, as if small fragments of limestone had been cemented into a compact mass. There are few joints or stratification lines visible. Occasional concretions of iron pyrite ranging from the size of a buckshot to a hen's egg occur imbedded in the limestone. After long exposure to the weathering agents the sulfide of iron changes to the oxide, leaving rusty iron stains on the rocks.

The following analyses were made of the limestone from the bluff at Macon:

TABLE 21.

ANALYSES OF SELMA LIMESTONE FROM MACON.

	1	2
Silica (SiO_2)	9.09	13.03
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	7.47	7.43
Lime carbonate ($CaCO_3$)	80.99	76.71
Magnesium carbonate ($MgCO_3$)	.00	.36
Water	1.08	.95
Sulphur trioxide (SO_3)	0.00	.64

1. W. S. McNeil, U. S. Geol. Survey, Analyst.
2. W. F. Hand, State Chemist, Agricultural College, Analyst.

A sample of limestone was collected from the ridgeland 3 miles north of Macon and analyzed in the laboratory of the U. S. Geological Survey with the following results:

TABLE 22.

ANALYSIS OF SELMA LIMESTONE FROM 3 MILES NORTH OF MACON.

(W. S. McNeil, Analyst.)

Silica (SiO_2)	8.52
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	6.60
Lime carbonate ($CaCO_3$)	83.88
Magnesium carbonate ($MgCO_3$)	.00
Water	1.00

Still another sample of the Selma was collected from Prairie Rock, 12 miles east of Macon. This rock is much harder than the ordinary Selma and breaks with a metallic ring. It has been used to some extent for building roads near Prairie Rock, but it soon breaks down into soil under the action of the weathering agents. A sample of this limestone was analyzed in the laboratory of the U. S. Geological Survey with the following results:

TABLE 23.

ANALYSIS OF SELMA LIMESTONE FROM PRAIRIE ROCK.

(W. S. McNeil, Analyst.)

Silica (SiO_2)	1.13
Alumina (Al_2O_3) Iron oxide (Fe_2O_3)	.68
Lime carbonate ($CaCO_3$)	98.36
Magnesium carbonate ($MgCO_3$)	Tr.
Water	.40

In southwestern Lowndes County excellent Portland cement materials are found along the divide between Tombigbee and Noxubee rivers.

On Mr. J. B. Brook's land near Crawford, much of the overburden has been removed, leaving the white Selma chalk at the surface. The limestone from this place contains about the proper proportions of lime carbonate, alumina and iron oxide for Portland cement. There is a small amount of magnesia, but not enough to injure it. To make a suitable cement this limestone must be mixed with a clay containing a low per cent of silica.

TABLE 24.

ANALYSIS OF SELMA LIMESTONE FROM CRAWFORD.

(Analysis furnished by J. B. Brooks.)

Silica (SiO_2)	8.88
Alumina (Al_2O_3) Iron oxide (Fe_2O_3)	5.94
Calcium carbonate ($CaCO_3$)	79.73
Magnesia ($MgCO_3$)	1.22
Loss	1.88

A residual clay of the Selma limestone from the same locality was analyzed with the following results. This clay, while it is a fairly good one, contains a rather high per cent of iron oxide and alumina to use with the limestone.

PLATE II.

RESIDUAL CLAY AND LAFAYETTE OVERLYING SELMA CHALK, MACON.

TABLE 25.

ANALYSIS OF CLAY FROM CRAWFORD.

Silica (SiO_2)	69.10
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	17.10
Calcium carbonate ($CaCO_3$)	1.60
Magnesium carbonate ($MgCO_3$)	.72
Loss	9.18

The Selma limestone may be seen along many of the streams, and in the railway cuts between Macon and Scooba. As a general thing there is only a thin covering of overburden on the ridges and slopes.

Five miles east of Shuqualak, Noxubee River has cut into the Selma limestone and formed a bluff on the east bank 50 feet high. A sample of this limestone collected by the writer* and analyzed in the laboratory of the U. S. Geological Survey, gave the following results:

TABLE 26.

ANALYSIS OF SELMA LIMESTONE 5 MILES EAST OF SHUQUALAK.

(W. S. McNeil, Analyst.)

Silica (SiO_2)	8.06
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	5.94
Lime carbonate ($CaCO_3$)	84.61
Magnesium carbonate ($MgCO_3$)	.06
Water	1.32

The high percentage of silica in the Selma at Wahalak, Bodea Creek and Scooba, indicates a change from the deep sea in which the Selma was deposited, to the more shallow waters which received the more siliceous deposits of the Ripley and the Porter's Creek formations.

The following analyses† of Selma limestone were made in the laboratory of the U. S. Geological Survey:

TABLE 27.

ANALYSES OF SELMA LIMESTONE FROM KEMPER COUNTY.

(W. S. McNeil, Analyst.)	1	2	3
Silica (SiO_2)	16.48	10.60	20.00
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	6.97	5.90	8.92
Lime carbonate ($CaCO_3$)	74.34	82.47	68.91
Magnesium carbonate ($MgCO_3$)	.67	Tr.	Tr.
Water	.67	.82	1.06

1. Two and one-half miles east of Scooba.
2. Seven miles east of Sucarnochee.
3. One and one-half miles south of Wahalak.

*Bull. 283, U. S. Geol. Survey, p. 216.

†Bull. 243, U. S. Geological Survey, pp. 206 to 219.

AVAILABLE CLAYS IN AND ADJACENT TO THE SELMA AREA.

As above stated, a mixture of clay with a pure limestone is necessary in the manufacture of Portland cement. The amount of clay varies with the amount of lime carbonate in the limestone. A pure limestone like that from Prairie Rock (see page 52) requires about one part of clay to two parts of limestone, while the limestone from near Wahalak requires the addition of a purer limestone.

There are two possible sources of clay for Portland cement in the Selma area and adjacent to it. These are (*a*) residual Selma clays; (*b*) Porter's Creek clay.

Residual Selma Clays.

Highly plastic clays, resulting from the decomposition of the Selma limestone, occur to greater or less extent over the entire Selma area. Where disintegration is complete the residual Selma clays are low in lime carbonate and comparatively high in alumina and silica. In the absence of any other clays they may be used with the limestones in making cement. In fact, the Alabama Portland cement plant at Demopolis, Alabama, uses the residual clay which occurs along Tombigbee River. The limestone used at this plant is comparatively low in lime carbonate and, therefore, requires only a small amount of clay to reduce the lime to the proper percentage.

TABLE 28.

ANALYSES OF SELMA LIMESTONE USED AT THE ALABAMA PORTLAND CEMENT PLANT, DEMOPOLIS, ALABAMA.

	1	2
Silica (SiO_2)	12.50	9.88
Alumina (Al_2O_3) Iron oxide (Fe_2O_3)	2.76	6.20
Lime carbonate ($CaCO_3$)	80.71	77.12
Magnesium carbonate (MgO)	1.05	1.08
Sulphur trioxide (SO_3)	1.62	n. d.
Water	1.36	5.72

1. R. S. Hodges, analyst.
2. Sen. Doc. No. 19, 58th Congress, 1st Session, p. 22.

No analysis of the clay used at the above mentioned plant is available. The following is an analysis of the residual Selma clay from Uniontown, Alabama:

TABLE 29.

ANALYSIS OF RESIDUAL CLAY FROM UNIONTOWN, ALABAMA.

(R. S. Hodges, Analyst.)

Silica (SiO_2)	69.57
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	19.04
Lime (CaO)	0.37
Ignition	9.68

TABLE 30.

ANALYSES OF RESIDUAL SELMA CLAYS FROM MISSISSIPPI.

	1	2	3	4	5	6	7
Silica (SiO_2)	63.63	75.95	72.32	65.30	56.97	63.35	67.60
Alumina (Al_2O_3)	10.34	9.62	8.74	12.63	15.09	13.70	12.55
Iron oxide (Fe_2O_3)	8.25	5.08	7.44	12.18	10.40	7.90	7.60
Lime (CaO)	3.75	1.25	1.55	1.50	1.00	0.80	.80
Magnesia (MgO)	.50	.74	.47	.63	0.54	0.60	.78
Volatile matter (CO_2)	7.77	2.52	5.58	2.27	10.90	6.50	5.00
Sulphur trioxide (SO_3)	.34	.34	.51	0.25	0.34	0.34	.17
Moisture	4.25	3.50	3.45	4.75	2.95	6.02	5.50

1. West Point.
2. West Point.
3. West Point.
4. Starkville.
5. Agricultural College.
6. Agricultural College.
7. Agricultural College.

Porter's Creek Clay.

Immediately above the Selma limestone, south of Houston, the Porter's Creek clay outcrops in a belt 2 to 15 miles wide. North of Houston the Ripley and Clayton limestones intervene between the Selma and the Porter's Creek formations. It is known as the "Flatwoods" country, and in places is characterized by low flat land resembling the broad bottom of a large river. The Porter's Creek clay is a dark gray clay which has a tendency to break into rectangular blocks when exposed to the sun. It contains small flakes of mica, which in places have been segregated into small dikes.

Excellent exposures of the Porter's Creek formation occur throughout the State where the Lafayette has been removed. The Mobile, Jackson and Kansas City Railway has made deep cuts into the clay at Walnut, Ripley, and along the divide between Houston and Maben. The Southern Railway, from West Point to Winona, cuts into the Porter's Creek in the hills between Maben and Pheba.

A sample of the residual Porter's Creek from 1 mile west of Starkville was analyzed with the following results:

TABLE 31.

ANALYSIS OF RESIDUAL PORTER'S CREEK CLAY, FROM 1 MILE WEST OF STARKVILLE.

Silica (SiO_2)	75.60
Alumina (Al_2O_3)	7.00
Iron oxide (Fe_2O_3)	8.24
Lime (CaO)	1.20
Magnesia (MgO)	.67
Volatile matter (CO_2)	3.91
Sulphur trioxide (SO_3)	.25
Moisture	2.97

The following analyses of the Porter's Creek clays were made from different localities in the State:

TABLE 32.

ANALYSES OF PORTER'S CREEK CLAY.

	1	2	3
Silica, (SiO_2)	57.25	71.47	61.62
Alumina (Al_2O_3)	6.17	9.45	8.87
Iron oxide (Fe_2O_3)	18.95	6.97	16.29
Lime (CaO)	1.05	.40	.91
Magnesia (MgO)	.95	.63	.69
Volatile matter (CO_2)	7.75	5.04	7.77
Sulphur trioxide (SO_3)	.21	.13	.28
Moisture	7.59	5.65	4.50

1. Residual clay from near Macon.
2. Residual clay from Wahalak.
3. Porter's Creek clay from Winston County.

The Illinois Central Railway from Starkville to Ackerman crosses the Porter's Creek formation, showing deep cuts of laminated grayish clay.

Again, on the Mobile and Ohio Railway, between Scooba and Lauderdale, occurs the same characteristic clay which has been traced across Alabama, Mississippi, western Tennessee and Kentucky.

A sample of the Porter's Creek clay from the town of Scooba was analyzed in the laboratory of the U. S. Geological Survey* with the following results:

TABLE 33.

ANALYSIS OF PORTER'S CREEK CLAY FROM SCOOBA.

(W. S. McNeil, Analyst.)

Silica (SiO_2)	61.92
Alumina (Al_2O_3)	19.47
Iron oxide (Fe_2O_3)	2.81
Magnesia (MgO)	1.98
Soda (Na_2O)	.50
Loss on ignition	12.29

*Geology and Mineral Resources of Miss., U. S. Geol. Survey, Bull. No. 283, p. 55.

It will be seen from the above analyses that the Porter's Creek clay is an excellent quality of clay for use in making cement.

JACKSON FORMATION.

Heretofore no attention has ever been paid to the calcareous marls of the Jackson formation for Portland cement. During the course of the present survey, experiments have been made using the marl for cement. Samples were collected from two of the most important places where the marl comes to the surface, and analyzed. The formation was so called from the typical exposures in the bank of Pearl River at Jackson. It underlies a large area of central Mississippi, just north of the Vicksburg limestone area. It comprises what is known as the "central prairie" region. The marl outcrops in comparatively few places owing to the overlying surface formations and residual soil. The surface of the country is not so broken as the region to the north and also to the south.

The materials composing the formation are principally calcareous, clayey marls, and unconsolidated limestones, clays and sands. The sandy portion is confined to about the uppermost 50 feet of the formation. The remaining 300 feet are marls and clays. The marls are easily recognized by the great amount of shells which they contain.

Throughout the entire Jackson area where the marls are near the surface they have undergone a chemical change. In the two analyses of Table 34a the nature of the change is apparent. No. 1 is an analysis of a partly weathered Jackson marl; No. 2 is the analysis of the clay derived from the marl. There has been a loss of lime carbonate in the marl and a porportionate gain of silicon dioxide and aluminum oxide in the clay. These changes have been brought about by weathering. The weathering of the marl, therefore, accounts for the presence of the green plastic clay which is found over the entire Jackson area from which the overlying Lafayette and yellow loam have been removed.

DISTRIBUTION.

Yazoo City.—Perhaps the best exposure of the Jackson calcareous marls in the State is found in the bluff at Yazoo City. This formation is exposed in the bluff for a distance of about 10 to 12 miles north and 15 miles south of the city. The following is a section of the bluff at the city reservoir:

Section of the Bluff at Yazoo City.

	Feet
Yellow loam brick clay	10–12
Gray calcareous Loess, which stands in perpendicular walls	100
Lafayette pebbles	12
Jackson marls, containing Zeuglodon bones and other Jackson fossils	180

A sample of the marl taken from this place was analyzed with the following results:

TABLE 34.

ANALYSIS OF JACKSON MARL-CLAY, YAZOO CITY.

Silica (SiO_2)	40.90
Alumina (Al_2O_3)	13.50
Iron oxide (Fe_2O_3)	5.55
Lime (CaO)	14.62
Magnesia (MgO)	.88
Volatile matter (CO_2)	19.25
Moisture	4.00

The above analysis was made from the surface and represents the transitional stage between the more highly calcareous marl and the plastic residual clay.

Jackson.—The Jackson marls are exposed in the bank of Pearl River between the wagon bridge and the Alabama and Vicksburg Railroad bridge. A continuation of the exposure is found extending up Town Creek. Other exposures are found in the bed of Moody's Branch near the city waterworks' stand-pipe, and in the railway cut ¼ mile north of the Asylum station. The Jackson clays, underlain by calcareous marls, are found in the deep cut on the Illinois Central Railway 1 mile south of Jackson. At the latter place the marl weathers to a slightly pinkish clay, which possesses a jointed structure. The clay contains in places small patches of very fine sand. The quality of the unweathered marl and the clay from this place is shown in the following analyses:

TABLE 34a.

ANALYSES OF JACKSON MARL AND CLAY 1 MILE SOUTH OF JACKSON.

	1	2
Silica (SiO_2)	35.72	59.82
Alumina (Al_2O_3)	13.79	12.24
Iron oxide (Fe_2O_3)	5.38	6.10
Lime (CaO)	17.00	2.90
Magnesium oxide (MgO)	1.99	1.68
Sulphur trioxide (SO_3)	0.12	2.11
Volatile matter (CO_2)	17.91	7.55
Moisture	5.85	6.08

VICKSBURG FORMATION.

The Vicksburg formation outcrops in a narrow belt of territory in Mississippi from 1 to 12 miles wide, extending across the State in an approximately northwest, southeast direction. The accompanying geological map of the State shows the area underlain by the Vicksburg and its relation to the Jackson marls on the north and the Grand Gulf group on the south.

The Vicksburg and the Jackson in Mississippi are mapped as two distinct formations, while in Alabama they are described together under the term St. Steven's limestone. The Vicksburg is the equivalent of the upper, and the Jackson of the lower part of the St. Steven's limestone.

The character and composition of the St. Steven's limestone has been described by Dr. E. A. Smith in Bulletin No. 243, pp. 77–81, U. S. Geological Survey. The large number of analyses of this limestone made in the laboratory of the Alabama Survey shows that it is well adapted to the manufacture of Portland cement. It carries from 75 to 95 per cent of calcium carbonate, with very little magnesium carbonate.

In Mississippi the Vicksburg formation includes thin beds of fine grained non-magnesium limestone from 1 to 4 feet thick, alternating with highly calcareous marl beds more or less indurated in places and bearing a rich fauna of Oligocene age. Some of the ledges of limestone make excellent building stone and lime, but owing to the great amount of interbedded marl and surface material, quarrying the limestone has been found to be unprofitable.

The alternating nature of the limestone and marl is shown in the following section of the bluff at Vicksburg,* between the city and the National Cemetery:

Section of the Bluff in Vicksburg.	*Inches*
22. First stratum of limestone from top, overlain by Loess.	10
21. Gray to yellowish marl	9
20. Heavy-bedded limestone	46
19. Indurated marl	34
18. Thin, calcareous, plastic clay	2
17. Indurated marl	6
16. Clay similar to No. 10	2
15. Indurated marl	5

*Bull. 283, U. S. Geol. Survey, p. 38.

Section of the Bluff in Vicksburg—Continued.

		Inches
14.	Clay	4
13.	Hard limestone	18
12.	Clay and marl from $\frac{1}{3}$ to 2 inches thick	15
11.	Indurated marl	21
10.	Limestone	18
9.	Gray marl	18
8.	Limestone	18
7.	Marl	3–6
6.	Hard limestones	52
5.	Marl	6
4.	Limestone	27
3.	Marl	17
2.	Limestone	20
1.	Marl	45

In the above section there are 17 feet and 5 inches of hard limestone, and 16 feet and 8 inches of marl and clay. The impracticability of using the hard limestone without using the marl and the clay is at once apparent. One of the special features in the study of this formation has been to determine the possibility of utilizing the marls in combination with the limestone in the manufacture of Portland cement.

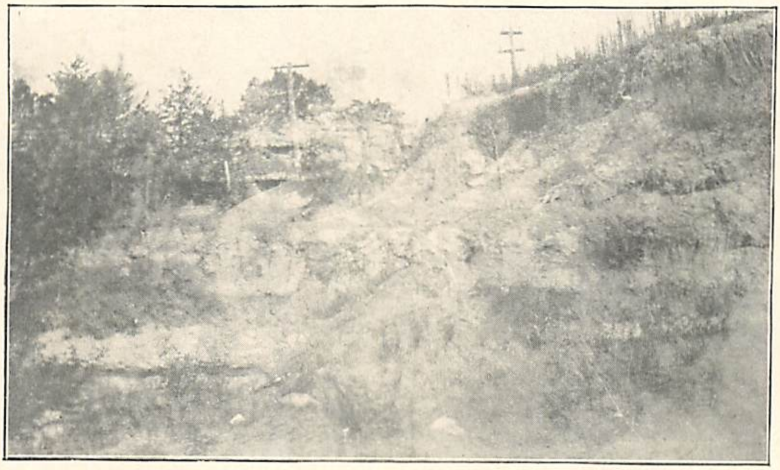
A large number of analyses of the marls from different localities show that they contain no large amounts of injurious properties, and can be used for cement as they come from the quarry. The marls and the clays supply the silica and alumina for Portland cement and are therefore of equal value to the limestone. In fact, by taking a general average of the analyses of the limestones and the interbedded marls we obtain the desired mixture for a Portland cement, without the addition of other materials.

In the central and the eastern parts of the State the Vicksburg formation is more homogeneous than it is in the western area. In Smith County the Vicksburg is a soft porous limestone which is known as the "chimney rock." It is quarried for chimneys and foundation pillars by sawing it into any desired shape with a large saw. On exposure to the air it hardens and lasts for 30 to 40 years. The "chimney rock" is one of the purest forms of the Vicksburg limestone.

DISTRIBUTION.

Vicksburg.—The typical locality of the Vicksburg formation is in the bluff in and near the city of Vicksburg. In the bluff overlooking

PLATE III.



BLUFF AT VICKSBURG SHOWING VICKSBURG LIMESTONE.
(Photo by W. N. Logan.)

the Mississippi River just below the oil mill, ½ mile south of the confluence of the Yazoo and the Mississippi rivers, the following exposure of the Vicksburg formation was observed. The limestone outcrops on the river for a distance of 800 feet. On the slope facing the river between the oil mill and the city the limestone underlies a thin veneer of soil. It is exposed in the branches and in a few places along the track of the Yazoo and Mississippi Valley Railway from the oil mill to the National Cemetery. The top of the Vicksburg forms a bench-like terrace which extends back to the foot of the Loess bluff.

Section of Vicksburg Limestone at the Oil Mill, 2½ Miles South of Vicksburg.

	Feet
9. Loess in the bluff back from the river	100
8. Marl	2
7. Ledge of hard limestone	3
6. Bed of soft marl	3
5. Ledge of limestone	5
4. Marl stratum	5
3. Ledge of hard limestone	5
2. Hard limestone	3
1. Bed of compact marl	5
Water's edge.	

The thickness of the exposure in the above section is about one-third of the entire thickness of the Vicksburg formation.

Analysis of each stratum from Nos. 1 to 7 inclusive was made with the following results. The numbers of the analyses correspond to the numbers in the above section.

TABLE 35.

ANALYSES OF VICKSBURG LIMESTONE AND MARLS FROM VICKSBURG.

	1	2	3	4	5	6	7	*Average*	8
Silica (SiO_2)	32.45	6.43	7.39	25.27	5.58	13.62	3.10	13.41	7.08
Alumina (Al_2O_3)	2.12	.31	1.02	4.50	1.00	3.00	.25	1.74	.61
Iron oxide (Fe_2O_3)	2.05	2.00	2.48	5.37	2.18	2.75	1.62	2.63	2.50
Lime (CaO)	34.20	50.25	47.50	29.50	49.97	40.37	50.63	43.20	50.44
Volatile matter (CO_2)	26.65	39.00	38.65	24.10	39.26	33.66	41.00	34.62	37.22
Magnesium oxide (MgO)	.38	1.36	1.45	1.99	1.01	1.72	.99	1.29	1.07
Sulphur trioxide (SO_3)	.08	.36	.51	2.76	.30	.98	.60	.79	0.38
Moisture	1.60	.61	1.10	3.95	.82	2.75	.60	1.63	0.40

No. 8 is a limestone from Steel's Bayou, Vicksburg.

A small fragment of limestone from each ledge including Nos. 2, 3, 5 and 7 was pulverized and the mixture analyzed with the results given in No. 1 below. A similar analysis was made from a mixture of the marls with the results given in No. 2.

TABLE 36.

ANALYSES OF VICKSBURG LIMESTONE AND MARLS FROM VICKSBURG.

(Dr. A. M. Muckenfuss, Analyst.)

	1	2	*Average*
Silica (SiO_2)	4.95	24.97	14.96
Alumina (Al_2O_3)	.56	6.49	5.46 (Alumina and Iron oxide)
Iron oxide (Fe_2O_3)	2.47	1.36	
Lime (CaO)	50.11	33.97	42.04
Carbon dioxide (CO_2)	39.30	26.38	32.84
Magnesia (MgO)	1.13	1.60	1.37
Alkali (K_2O)	0.15	0.70	.43
Sulphuric acid (SO_3)	0.25	1.00	.63
Phosphoric acid (P_2O_5)	0.03	0.07	.06
Insoluble matter, volatile (organic)	0.84	2.24	1.54
Moisture	0.20	0.82	.51

The value of the Vicksburg limestone as a Portland cement rock is shown by comparing the general average of the above analyses to the analyses of actual cement mixtures given in the following table. The amount of combined impurities in the Vicksburg limestone is smaller than that in the actual mixtures given below:

TABLE 37.

COMPOSITION OF ACTUAL MIXES USED IN AMERICAN CEMENT PLANTS

Silica (SiO_2)	14.77	12.85	15.18	11.8	13.52	13.46	13.85	12.62	14.94	12.92
Alumina (Al_2O_3)	4.35	4.92	6.42	8.2	6.56	n.d.	7.20	6.00	2.66	4.83
Iron oxide (Fe_2O_3)		1.21							1.10	1.77
Lime (CaO)	43.03	42.76	42.97	41.8	42.07	41.25	41.40	42.26	42.34	42.30
Magnesia (MgO)	1.74	1.02	n.d.	0.8	2.07	n.d.	n.d.	2.67	2.21	2.08
Carbon dioxide (CO_2)	35.61	34.71	n.d.	n.d.	35.31	34.86	36.42	36.10	35.68	35.49
Water	n.d.	n.d.	n.d.	n.d.	n.d.			n.d.	n.d.	n.d.

The Vicksburg outcrops at intervals in the bluff from the city of Vicksburg to the town of Redwood or beyond; the limestone occurs beneath a thick Lafayette and Loess overburden which attains a maximum thickness of about 175 feet.

In the hills south of Vicksburg the Grand Gulf clays are found on the hillsides and in the bluffs beneath the Loess and Lafayette. In places it is a highly plastic gray clay interbedded with aluminous sandstone. From five miles south of Vicksburg, on the old Roche land, a sample of Grand Gulf clay was analyzed with the following results*:

ANALYSIS OF CLAY 5 MILES SOUTH OF VICKSBURG.

Silica (SiO_2)	58.50
Alumina (Al_2O_3)	19.04
Ferric oxide (Fe_2O_3)	1.93
Lime (CaO)	1.48
Magnesia (MgO)	1.66
Sulphur trioxide (SO_3)	Trace
Moisture	3.19
Loss on ignition	8.26

*Bull. 283, U. S. Geol. Survey, p. 68

PLATE IV.

LEDGE OF VICKSBURG LIMESTONE, CLINTON.

Byram.—The Vicksburg formation outcrops in the hills northwest of Byram. One mile north of the station the rock is exposed in the railway cut. From the little hill to the west of this exposure the hard limestone was used formerly for making lime.

Hard ledges of limestone interbedded with beds of indurated marl are exposed in the banks of Pearl River from about ¼ of a mile below to 2½ miles above Byram. In places the same ledge may be seen in the bank of the river only a few feet above the water for a distance of ½ mile. There is a gentle fold in the rocks with the axis extending in an approximately east and west direction (see Plate V).

Samples of the limestone and marl from the bank of the river at Byram were analyzed with the following results:

TABLE 38.

ANALYSES OF VICKSBURG LIMESTONE AND MARL FROM BYRAM.

	Limestone	*Marl*
Silica (SiO_2)	2.28	26.42
Alumina (Al_2O_3)	2.42	8.25
Ferric oxide (Fe_2O_3)	2.19	5.20
Lime (CaO)	50.55	27.77
Magnesia (MgO)	1.40	1.44
Volatile matter (CO_2)	40.87	26.00
Sulphur trioxide (SO_3)	.30	2.00
Moisture	.31	3.00

About 2½ miles north of Byram on the east bank of Pearl River the following section is exposed:

*Section of Vicksburg Formation 2½ Miles North of Byram.**

	Inches
Gray rotten limestone containing grains of glauconitic sand	24
Harder gray limestone	24
Indurated brown marl	24
Hard, compact, gray limestone	16
Soft yellow marl	14
Very hard gray limestone	10
Gray marly clay	8
Compact limestone	20
Indurated white to gray marl	20
Ferruginated sandy limestone	72
Green-sand marl base of exposure	60

Plain.—The Vicksburg limestone outcrops in the first cut south of Plain, on the Gulf and Ship Island Railway. The exposure here as at

*Unpublished notes obtained by the writer while employed on the U. S. Geol. Survey.

Vicksburg is composed of alternating beds of limestone and marl. At the top of the formation is a plastic, calcareous red clay, which is formed from the decomposition of the limestone and the marl. Samples of each stratum in the cut were analyzed with the following results:

TABLE 39.

ANALYSES OF VICKSBURG LIMESTONE AND MARLS FROM NEAR PLAIN.

							Average
Silica (SiO_2)	7.57	1.85	4.95	12.52	14.11	17.53	9.76
Alumina (Al_2O_3)	1.23	1.37	0.00	4.75	2.87	1.42	1.94
Iron oxide (Fe_2O_3)	5.50	1.75	4.25	5.50	6.60	15.15	6.46
Lime oxide (CaO)	46.33	52.12	47.50	39.75	39.78	29.87	42.56
Magnesium oxide (MgO)	0.02	0.49	1.16	0.81	0.40	0.02	.48
Volatile matter (CO_2)	38.54	41.87	39.25	34.50	34.33	27.45	35.99
Sulphur trioxide (SO_3)	.09	.....	.25	.....	.17	.....	.17
Moisture	.27	.25	1.25	1.56	1.62	5.25	1.70

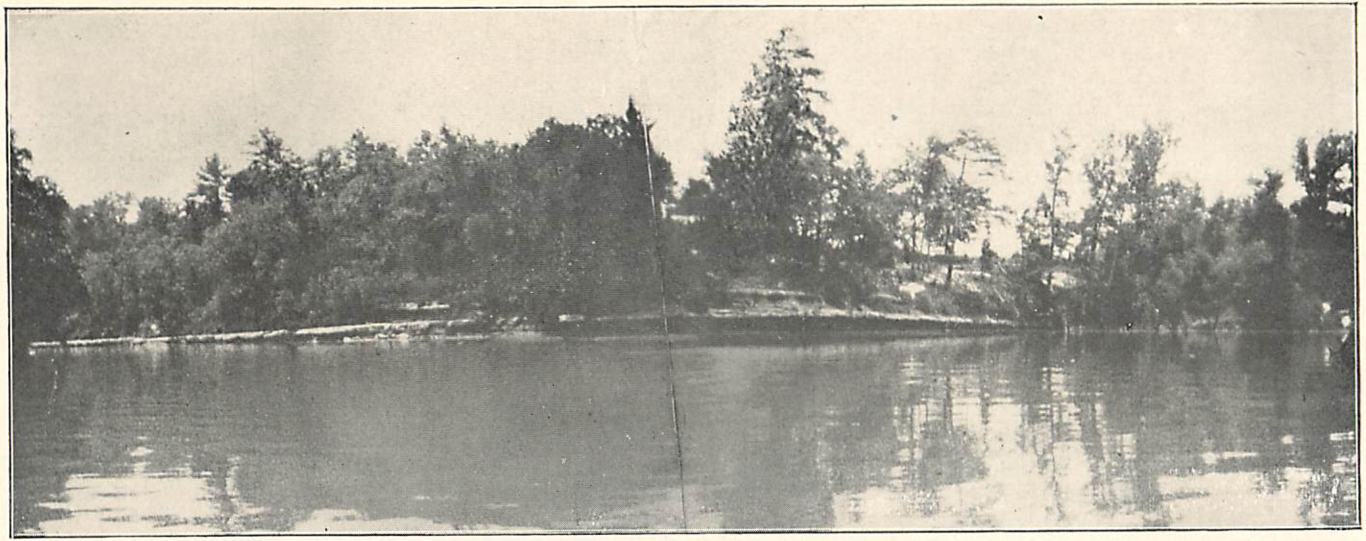
The Vicksburg limestone can be easily traced by the outcrops in the hills from the exposure in the railway cut south of Plain westward to Pearl River, and eastward to Brandon. At no place is there a great thickness exposed, rarely more than 20 feet, and frequently much less.

Brandon.—The Vicksburg limestone is exposed at the railway station at Brandon and for ¼ mile to the west. Another exposure is found at the old Yost lime kiln site, 1 mile east of the station.

The most complete exposure of the Vicksburg, east of Pearl River, is found at the old Robinson quarry, about 4 miles southeast of Brandon. The formation is made up of hard ledges of crystalline limestone alternating with beds of calcareous marl of about equal thickness. This rock was quarried for some time by a firm in Jackson. It was crushed and used in the foundation of the new State Capitol. Work was discontinued because of the great amount of useless marl which had to be removed to get the rock. The analyses as given below show that the marl and limestone could all be used in making Portland cement.

This material is easily quarried as there is little or no superincumbent matter. A spur from the main line of the Alabama and Vicksburg Railway has been built from Rankin to the quarry, thus giving an easy outlet for the material.

Plate V.



VICKSBURG LIMESTONE ON PEARL RIVER, BYRAM.

TABLE 40.

ANALYSES OF VICKSBURG LIMESTONE FROM ROBINSON QUARRY, 4 MILES SOUTHEAST OF BRANDON.

Silica (SiO_2)	4.22	4.55	5.56	1.58	16.88
Alumina (Al_2O_3)	.75	.00	1.09	4.40	5.70
Iron oxide (Fe_2O_3)	4.37	4.25	4.01	3.31	3.59
Lime oxide (CaO)	49.62	49.92	48.44	48.40	36.86
Magnesium oxide (MgO)	.09	.09	.78	1.27	.99
Volatile matter (CO_2)	40.05	39.61	38.12	39.70	33.16
Sulphur trioxide (SO_3)	.36	.72	.24	.45	.24
Moisture	.88	.95	1.61	.60	2.10

Bay Spring.—There are numerous outcrops of the Vicksburg formation between Brandon and Bay Spring, but as they are so far removed from lines of transportation it is hardly possible that the limestone will soon become of value for cement, and consequently only one of the most important outcrops will be described in this report.

On the east side of Tallahala Creek, about 4 miles west of Bay Spring, the Vicksburg limestone outcrops in the road and on the side of the hill. Above the limestone is a pink, plastic clay very similar to the clay overlying the limestone 1⅓ miles south of Plain (see preceding page). The thickness of the Vicksburg here is 65 feet.

The uppermost member of the Vicksburg is a ledge of hard bluish gray limestone, which is so much more resistant than the overlying Grand Gulf clay that it forms a marked bench along the hillside at this place. One thing noticeable about the Vicksburg limestone at this locality is the absence of marl beds alternating with harder ledges of limestone. The top of the formation is capped with a hard ledge of limestone, but all the material underneath this to the bottom of the hill is a soft, porous, white to yellowish limestone. The harder ledges of limestone were formerly used for burning lime.

On Mr. Houston's land, 2 miles west of Sylvarina, is a quarry where the soft, porous limestone is sawed out for building chimneys. The rock for 3 to 4 feet below the surface has disintegrated into a rotten mass, easily picked to pieces with a spade. Below this it is sufficiently compact to be used for building chimneys. The quarry has been worked for 17 years.

Chimneys built of this rock first disintegrate at the top. The rock is very porous; it fills with water which freezes in the winter and causes it to break. The rock has also been used for making lime and doubtless is very desirable for this purpose, since it is almost pure lime carbonate.

No detailed work has been done on the Vicksburg limestone by the present survey along the New Orleans and Northeastern, and the Mobile and Ohio railways. The hard upper ledges outcrop in the hills north and east of the town of Vossburg.

Two samples of limestone from near Nancy, Clarke County, were collected by W. N. Logan, and analyzed with the following result:

TABLE 41.

ANALYSES OF VICKSBURG LIMESTONE FROM NEAR NANCY, CLARKE COUNTY.

Silica (SiO_2)	7.31	6.77
Alumina (Al_2O_3)	13.61	4.68
Iron oxide (Fe_2O_3)	4.00	2.00
Lime oxide (CaO)	36.62	45.51
Magnesia (MgO)	.29	.64
Volatile matter (CO_2)	35.20	35.40
Sulphur trioxide (SO_3)	2.78	3.00
Moisture	1.00	1.79

"Near Red Hill,* in Wayne County, on Limestone Creek, the Mobile and Ohio Railway is cut through a considerable hill, where the limestone group of the Eocene formation is well exhibited. Limestone Creek, which runs south of the cut on the railroad and empties about 400 yards from it, into the Chickasawhay River, contains large ledges of hard, compact limestone; and southeast of the cut about 1½ miles the sandstone which appears south of the cut and not well cemented, crops out as a hard limestone, an excellent material for building purposes."

At the confluence of Limestone Creek and Chickasawhay River Dr. Harper gives the following section of the limestone:

Section of Vicksburg Limestone at the Mouth of Limestone Creek, Wayne County.

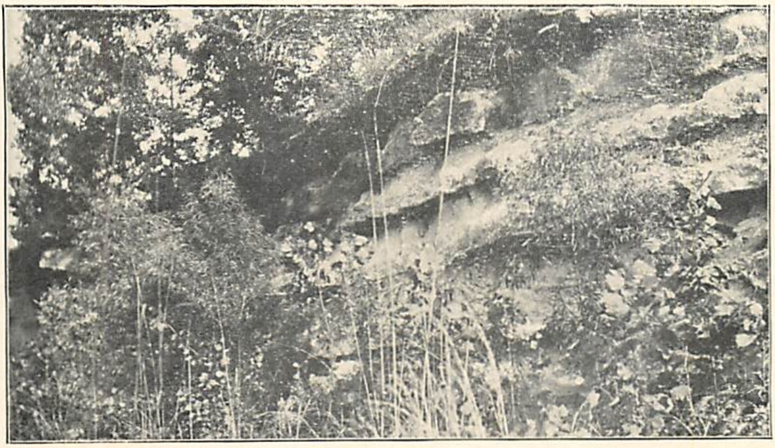
Surface soil, chiefly sand	—
Yellowish limestone	—
Calcareous sand containing Pecten	—
Calcareous marl containing Orbitoides, Ostrea, Pecten, Arca, Flabellum, Cardita, etc	—
Shell marl	—

No thicknesses are given.

Three analyses of the limestone from Red Hill, Wayne County, are given by Dr. L. Harper (†) as follows:

*Geology and Agriculture of Mississippi, 1857, L. Harper, p. 140.
†Ibid, p. 166.

Plate VI.



VICKSBURG LIMESTONE, ROBINSON QUARRY, NEAR RANKIN.
(Photo by W. N. Logan.)

TABLE 42.

ANALYSES OF VICKSBURG LIMESTONE FROM RED HILL, WAYNE COUNTY.

(Dr. L. Harper, Analyst.)

Silica (SiO_2)	6.30	15.05	9.20
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	7.20	5.35	6.65
Lime (CaO)	48.44	44.58	47.12
Carbon dioxide (CO_2)	38.06	35.02	37.03
Water	n. d.	n. d.	n. d.

Dr. E. W. Hilgard (*), in speaking of the occurrence of the Vicksburg limestone in Wayne County, says: "On the Chickasawhay, between Red Bluff and the latitude of Waynesboro, both marls and limestones crop out with frequency; the same is the case on the creeks on the east side as on Cakchey's Mill Creek and Limestone Creek, especially near the mouth of the latter, at the foot of the hill on which Dr. E. A. Miller lives—the most southerly outcrop of the calcareous Vicksburg on the Chickasawhay. The sections exhibited here in the river banks and cuts of the railroad correspond so closely to those between Yost's lime kiln and Brandon depot that the specimens can hardly be distinguished from each other when placed side by side, the only difference being the great abundance of Orbitoides in the soft white marl intervening between the strata of rock. The ledges of hard limestone (in Wayne County) are not so well defined—the rock being softer and whitish."

(*)Geology of Mississippi, Hilgard 1860, p. 146

ADVANTAGEOUS LOCATIONS FOR CEMENT PLANTS.

To build a Portland cement plant at a point remote from transportation lines is to invite financial loss. And under the present system of levying freight rates it is almost equally perilous to build a plant where there is but one transportation outlet, unless satisfactory arrangements have been made previous to the erection of the plant.

In Mississippi there are four general localities where raw materials, and good transportation facilities can be obtained.

TISHOMINGO COUNTY.

The Southern Railway from Memphis to Chattanooga passes near the northern outcrop of the oolitic limestone in Tishomingo County near where the road crosses Bear Creek. At this point it is only 8 miles to the Tennessee River. The largest boats of that river run as far as the mouth of Bear Creek. A cement plant built at this point would have an outlet to the north by boat and a railway connection to the east, west and south. Coal could be obtained by river or from the nearby Alabama fields at a minimum cost. A Portland cement plant at Mingo bridge could use the oolitic limestone and the overlying shale. Bear Creek furnishes sufficient water to run a mill by water power. The newly constructed line of the Illinois Central Railway connecting Birmingham, Alabama, and Jackson, Tennessee, with an outlet to the north and south, runs within 3 miles of this place.

STARKVILLE AND WEST POINT.

The Selma limestone and Porter's Creek clay are in proximity along the Mobile and Ohio Railway in Kemper County, along the Illinois Central in Oktibbeha County, and along the Southern in southern Clay County. The relations of these locations to transportation lines are clearly indicated on the map. The Mobile and Ohio furnishes an outlet to the north and south. The Southern line from

Greenville, Mississippi, to Birmingham, Alabama, offers an outlet to the east and west. The Aberdeen branch of the Illinois Central connects with the main line from Louisville to New Orleans at Durant, thus giving an outlet into a new territory.

Starkville and West Point offer exceptional advantages for Portland cement plants, inasmuch as limestone and clay are found near in great abundance, and the coal field of Alabama is less than 100 miles away. In fact either of these places is closer to the coal field by rail than the Alabama Portland Cement plant at Demopolis.

With a bed of limestone 800 to 1,000 feet thick underlying Noxubee. Clay, Lee, eastern Oktibbeha and Chickasaw counties, and an inexhaustible supply of clay just west of the Selma area, there is a sufficient amount of raw material to supply the Portland cement trade of the entire United States for an indefinite length of time.

Starkville and West Point afford good advantages in regard to proximity of raw material and fuel for a cement plant; and they have a fair outlet for the finished product.

COLUMBUS.

The town of Columbus has plenty of limestone near and has some advantages over West Point and Starkville in being closer to the coal field of Alabama. With the opening of the Tombigbee River to navigation cheaper rates could be had than at any other city in eastern Mississippi. Good clays can be obtained in the Tuscaloosa and the Eutaw formations in the hills east of Tombigbee River.

JACKSON AND VICINITY.

The Vicksburg limestone outcrops in the banks of Pearl River at Bryam, in the railway cut 1⅓ miles south of Plain, and again at the Robinson quarry near Rankin. All of these outcrops are on railway lines and within a radius of 14 miles from Jackson. The limestones at all of these places have been analyzed and found to be desirable materials for Portland cement. Jackson is a good distributing point with seven railway lines radiating to the north, east, south and west. Two railway lines, the Illinois Central and the Gulf and Ship Island, connect Jackson with deep water routes to the Gulf.

VICKSBURG.

Vicksburg offers more natural advantages for the location of a cement plant than any other city in the State. Raw material of limestone and marl are found in the bluffs facing the river. The Mississippi River and the Yazoo and Mississippi Valley Railway afford transportation to the north and south; the Alabama and Vicksburg Railway affords transportation to the east and west. Coal could be obtained by river from Pittsburg, by the Yazoo and Mississippi Valley Railway from Illinois and western Kentucky, and by the Alabama and Vicksburg Railway from the Alabama coal field.

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