CEMENT RAW MATERIALS IN INDIANA

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CEMENT RAW MATERIALS IN INDIANA

BY DUNCAN J. McGREGOR

ABSTRACT

Limestone that is chemically suitable and easily accessible for cement manufacture can be found at many places in Indiana in the Mississippian limestones and to a more limited extent in the Devonian limestones. Clay, shale, and gypsum, also used in manufacturing cement, are readily available close to limestone reserves. Five areas in Indiana are most favorable for establishing cement plants: Bloomington-Spencer-Gosport, Paoli-Mitchell-Bedford, Greencastle, central Clark County, and southern Harrison County; a sixth area, east of Logansport, also may have limestone suitable for cement manufacture. Five of these areas are close to railroad lines and fuel supplies; the southern Harrison County area is favorably situated for barge transportation on the Ohio River. Reserves of mineral raw materials in 5 of the areas probably are sufficient to supply a cement plant for 50 years. Surface study does not permit an accurate appraisal of the Logansport area, but it probably also has sufficient reserves.

INTRODUCTION

Unprecedented growth and prosperity of the nation have accounted for increased demands for portland cement. This demand is reflected in new and improved uses of cement and concrete, including prefabricated and prestressed concrete and soil-cement road stabilization, in increased use of concrete on farms, in the rapid growth of plants for Ready Mix concrete and in increased use of concrete masonry units.[1] To meet these demands, cement manufacturers are increasing the size of existing plants and establishing new plant sites.

Raw materials for cement must possess the proper chemical components (lime, silica, alumina, and iron) and must have the necessary physical properties which allow for low-cost processing. These include: (1) ease of grinding, (2) uniformity of quality, (3) low water retention, (4) low volatile loss, (5) ease of blending, and (6) inexpensive quarrying.

Cement raw materials have to be inexpensive to allow a company to meet competition. Therefore, the source of raw material must be located with respect to transportation, fuel, and market facilities in such a way that raw-material cost is low in relation to the sale price of cement.

PURPOSE OF REPORT

The purpose of this report is to discuss cement raw materials briefly, to outline the source areas of cement raw materials in Indiana, and to show the relationship of these raw materials to

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[1] Concrete masonry units are block- and brick-building units that are molded of concrete and can be laid into a wall.

transportation facilities and fuel supplies. The information contained herein does not indicate specific deposits but should serve to stimulate commercial production of cement from raw materials found in Indiana.

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THE PORTLAND CEMENT INDUSTRY

EARLY HISTORY AND DEVELOPMENT OF PORTLAND CEMENT IN EUROPE

When man first started to construct buildings, he sought a material that would bind stones together to form a solid mass. Muds and limy clay mixtures probably were the first cements used by man. The Babylonians and Assyrians used clay to bind burned bricks and alabaster (gypsum) slabs for construction purposes. The early Egyptians discovered and used lime and gypsum mortars as cement in building such structures as the pyramids. The early Greeks used a mortar made by mixing volcanic tuff from the island of Santorin with lime and sand. The Romans improved on lime mortar as a cement material, and in constructing the public buildings of the Imperial City, they discovered a cement that was superior to lime mortar because it would harden under water. This hydraulic cement was made by mixing lime and volcanic ash which was procured near the Italian town of Pozzuoli, now a suburb of Naples. Pozzolan cement gets its name from this town. Many structures that still exist give evidence of the superiority of the Pozzolan cements over lime mortar.

The art of making hydraulic cement seems to have disappeared during the Middle Ages. In 1756 the manufacture of hydraulic cement was rediscovered. John Smeaton was commissioned by the British Parliament to reconstruct a lighthouse that had burned off the coast of Plymouth, England. He found by intensive investigation that if clayey limestone were burned carefully, it would make a lime which could be slaked and which would hold up under the attack of tides, waves, and wind. By using some of the same methods employed by the Romans, Smeaton found that proportioned mixtures of volcanic ash and clayey limestone when burned at higher temperatures produced a cement that possessed hydraulic properties, resisted attack of sea water, and had a quick set. It was this kind of cement that was used in constructing the Eddystone lighthouse in 1759. This structure stood for 126 years before replacement was necessary.

James Parker in 1796 patented a process in which burned limestone containing clay was ground to a powder. He called his product "Roman Cement"; this was the first natural cement to be manufactured.

Before the turn of the 19th century materials used for cement were procured as found in nature. In 1810 Edgar Dobbs took out an English patent for cement manufacture in which he artificially mixed chalk or pure limestone with clay, molded this mixture into bricks, and then burned the bricks and ground them to powder.

Credit for the discovery of portland cement is given to Joseph Aspdin, who in 1824 was granted an English patent for portland cement. His specifications are as follows (Bogue, 1955, p. 10-11):

> My method of making a cement or artificial stone for stuccoing buildings, waterworks, cisterns, or any other purpose to which it may be applicable (and which I call *Portland Cement*) is as follows: I take a specific quantity of limestone, such as that generally used for making or repairing roads, and I take it from the roads after it is reduced to a puddle, or powder; but if I cannot procure a sufficient quantity of the above from the roads, I obtain the limestone itself, and I cause the puddle or powder, or the limestone, as the case may be, to be calcined. I then take a specific quantity of argillaceous earth or clay, and mix them with water to a state approaching impalpability, either by manual labor or machinery. After this proceeding I put the above mixture into a slip pan for evaporation, either by the heat of the sun or by submitting it to the action of fire or steam conveyed in flues or pipes under or near the pan until the water is entirely evaporated. Then I break the said mixture into suitable lumps, and calcine them in a furnace similar to a lime kiln till the carbonic acid is entirely expelled. The mixture so calcined is to be ground, beat, or rolled to a fine powder, and is then in a fit state for making cement or artificial stone. This powder is to

be mixed with a sufficient quantity of water to bring it into consistency of mortar, and this applied to the purposes wanted.

Aspdin named his cement for the Isle of Portland, which lies off the British Coast, because the cement resembled in color the stone quarried there. Aspdin probably did not have in mind the use of portland cement for monolithic construction. His product was to be used as a stucco or veneer to be applied over brick or stone surfaces.

The first portland-cement plant that operated on a commercial scale was built by Aspdin at Wadefield, England. Some of the cement manufactured at this plant was used in 1828 in the construction of the Thames River tunnel. In 1848 a plant was built by J. D. White at Kent, England. This plant prospered, and in succeeding years the cement industry grew and expanded not only in England but also in Belgium and Germany. Portland cement was first shipped to the United States in 1868. Tramp steamers used the European portland cement as ballast, and thus the manufacturers were able to ship it at very low freight rates.

HISTORY AND DEVELOPMENT OF PORTLAND CEMENT IN THE UNITED STATES

The construction of canals in America early in the 19th century created the first large-scale demand for cement in the United States. In 1818, shortly after the completion of the Erie Canal, Canvass White discovered a rock deposit near Fayetteville, Onondaga County, N. Y., from which natural hydraulic cement could be made. Later other deposits were found in the Rosendale district of New York (1832), the Louisville district of Indiana and Kentucky (1826), and the Lehigh Valley of Pennsylvania (1850).

In spite of the increased manufacture of portland cement in Europe during the 19th century, natural cements rather than portland cements were used in the United States until 1871. In that year David O. Saylor started production of portland cement at Coplay, Pa. At the Centennial exhibition in Philadelphia in 1876, samples of Saylor's product and that made by Shinn at Wampum, Pa., compared favorably with the imported portland cement from Europe.

While Saylor and Shinn were perfecting their product in Pennsylvania, Thomas Miller and his two sons started a firm in South Bend, Ind., for manufacturing portland cement. They used a piece of rotating sewer pipe as a kiln, and the resulting clinker was ground in a coffee mill. The use of the sewer pipe probably was the first experimental rotary kiln used in America.

In 1880 about 42,000 bbl. of portland cement was produced in the United States. Ten years later production of portland cement amounted to 335,000 bbl., and it has increased steadily until today the United States manufactures and uses more than three times as much portland cement as any other country in the world.

One reason for this large increase is the advance in technology. Formerly, vertical kilns were used and were allowed to cool after each burning; this resulted in waste of fuel and time. F. Ransome in 1885 invented a slightly tilted horizontal kiln which could be rotated and which allowed material to move gradually from one end to the other during the burning. Because this type of kiln had a greater capacity and burned the raw material more thoroughly and uniformly, it rapidly replaced the vertical type.

Thomas Edison in 1902 introduced the first long kiln, 150 feet in length in contrast to the customary 60 to 80 feet formerly used. Some present-day kilns are more than 500 feet long. Improvements in equipment also influenced the rapid increase in production.

The distribution of portland-cement plants in the United States is determined largely by the economical availability of raw material, mainly limestone and shale. Every state except Connecticut, Vermont, New Hampshire, Rhode Island, Massachusetts, Nevada, New Jersey, New Mexico, North Carolina, North Dakota, and Delaware has at least one cement plant. Pennsylvania leads with a total of 18.

The amount of portland cement produced in the United States in 1957 was estimated to be 300 million bbl. (Trauffer, 1958, p. 107). Estimated production capacity for 1957 was 375 million bbl. (Trauffer, 1958, p. 108). At present there are 172 portland-cement plants in the United States, and several new ones are either under construction or in the planning stage.

Among the general trends in the portland-cement industry are: (1) the substitution of long kilns for short ones, (2) installation of equipment for preheating raw materials used in connection with short kilns, (3) replacement of smaller grinding units with larger ones, (4) improved methods of feeding materials into the kilns and mills, (5) increased use of closed-circuiting of secondary crushers with vibrating screens for better control over particle size of material fed to the mills, (6) increased installation of air-quenching cooling systems in clinker cooling, (7) more widespread use of instrumentation and control devices on kiln operations,

(8) improved methods of dust recovery and control, (9) increased emphasis on planned maintenance programs to minimize time lost because of breakdowns, and (10) modernization in drilling techniques and quarrying of raw materials.

HISTORY AND DEVELOPMENT OF PORTLAND CEMENT IN INDIANA

The earliest accounts of cement manufactured in Indiana were recorded by Blatchley (1901, p. 1-30), Siebenthal (1901, p. 331-389), and Logan (1922, p. 605-616).

In 1832 a flour mill at Clarksville, Ind., was converted into a cement plant by Lawson Verey. This plant was taken over by William F. Beach in 1873. Raw material was obtained by tunneling into the bank of the Ohio River. In 1884 the plant was completely destroyed by floodwaters. In 1900 at least 13 plants were actively producing natural cement along, and adjacent to, the Ohio River in Clark and Floyd Counties, Ind. The Louisville Cement Co., Speed, Ind., is the only company now producing natural cement from Indiana raw materials. The production of natural cement declined as the portland-cement industry grew.

The first portland-cement plant in Indiana was constructed at South Bend, St. Joseph County, in 1877 by Thomas Millen and sons. The raw materials were marl and clay from lake and glacial deposits in northern Indiana. This plant was the first in the United States to use this kind of material successfully as ingredients for cement. Because of dwindling markets, change of personnel, misunderstandings, and lack of experience, this plant ceased operation in 1898.

The Wabash Portland Cement Co. erected a plant at Stroh, Lagrange County, Ind., in 1900. Marl and clay procured from lake and glacial deposits constituted the source of raw material. The plant ceased operation in the summer of 1941 because of increased cost in operation.

The Syracuse Portland Cement Co. built a plant near Syracuse, Kosciusko County, Ind., in 1899 and began production in 1900 of portland cement, using marl and clay from lake and glacial deposits. The plant ceased operation in 1919 but was reopened in 1920. In 1922 the plant again was closed mainly because of lack of markets, labor problems, and the problem of securing proper raw materials.

The Indiana Portland Cement Co., with Adam L. Beck as general manager, began producing portland cement at Limedale near Greencastle, Putnam County, Ind., in July 1919. Mississippian limestones and shales were the source of raw materials. On July 1, 1925, the Lone Star Cement Corp. (then known as the International Cement Corp.) purchased the plant from A. L. Beck. The plant continued to operate under the name Indiana Portland Cement Co. until February 1929; at that time the name was changed to Lone Star Cement Co., Inc. On November 1, 1936, the plant name was changed to the Lone Star Cement Corp.

The plant at Limedale uses the wet blending process in manufacturing cement. Products are marketed under the brand names of Lone Star and Incor. Total plant capacity is about 2,600,000 bbl. per year (Trauffer, 1956, p. 177).

The Lehigh Portland Cement Co., founded in 1897, erected the first mill at Mitchell, Ind., in 1901 and 1902 (Young, 1955). The first cement from this mill was shipped in 1902. A second mill was built in 1905, and the first cement was shipped from it in 1906. The first mill was closed in 1929 and torn down and scrapped in the 1930's. A completely new plant is in the planning stage and probably will be completed by 1960. Limestone and shale are produced from company-owned quarries. The company markets the product under the brand name Lehigh. The plant uses the dry process in manufacturing portland cement and has an annual capacity of 1,700,000 bbls. (Trauffer, 1956, p. 177).

The Louisville Cement Co. had its beginning in 1830 when two French brothers, the Tarascons, put into operation a flour mill at the falls of the Ohio River at Louisville, Ky. Flour was ground 3 days a week, and natural cement was ground the other 3 days.

Several changes in name were made prior to 1866, but in that year the firm was incorporated as the Louisville Cement and Water Power Co. In 1868 land was purchased in Clark County, Ind., and in 1869 a plant was built for manufacturing natural cement. In 1869 the corporation name was changed to the Louisville Cement Co., a Kentucky corporation. Also in 1869 the Louisville Cement Co. purchased the mill owned and operated by Sabene and Gilmore at Watson, Ind. A fire completely destroyed the original Tarascon mill at the falls of the Ohio in 1892. In that same year James B. Speed was elected president of the Louisville Cement Co. A mill site was selected near the natural-cement plant at Speed, Ind., and plans were drawn for a portland-cement plant. In 1906 the first portland cement was produced at Speed.

The company owns and operates its own limestone quarry. Products are marketed under the brand names of Speed and Brixment. The plant uses the dry process of cement manufacture and produces about 2½ million bbls. of cement per year (Trauffer 1956, p. 177).

The Illinois Steel Co. erected its first mill in Indiana at Buffington near Gary in February 1903 (Hadley, 1945). The first cement was produced in November 1904. The mill was leased to the Universal Portland Cement Co., a subsidiary company of the United States Steel Corp., on Ooctober 1, 1906, and conveyed by deed to Universal on December 30, 1922. This plant was closed on March 30, 1929, and has not been operated since.

In 1906 a second mill was built by the Illinois Steel Co. and was completed by the Universal Portland Cement Co., which leased the property on October 1, 1906. Production began in October 1907. Part of this plant is now in operation producing Atlas Lumonite cement.

A third mill was constructed by the Universal Portland Cement Co. in June 1910, and production began in October 1911. On December 30, 1922, all Buffington plant property was conveyed by deed to the Universal Portland Cement Co.

On January 10, 1930, the Atlas Portland Cement Co. was sold to the United States Steel Corp., of which the Universal Portland Cement Co. is a subsidiary. The Universal Atlas Cement Co., a subsidiary of United States Steel Corp., was formed in that same year.

The Universal Portland Cement Co. and the Atlas Portland Cement Co. were pioneers in cement making. These companies pioneered the use of blast-furnace slag as a raw material of cement. Jasper Whiting of Boston initiated the experimental research and engaged John Gasta Berquist, a chemist, as his assistant. On August 20, 1895, U. S. Patent No. 544,706, which is now expired, was issued to Whiting. The claims were as follows (Hadley, 1945, p. 288):

> 1. The method of manufacturing cement from slags which consists in chilling molten slag in water, drying and grinding the product, and adding thereto caustic soda or its equivalent in a dry state.
>
> 2. The method of manufacturing cement from slags which consists in chilling molten slag in water as it comes from the furnace, drying and grinding the slag, and adding thereto slaked lime and caustic soda both in a dry state and in the proportions substantially as set forth.
>
> 3. A cement composed of blast furnace or other slag in a dry pulverized form and caustic soda in a dry state, in substantially the proportions set forth.
>
> 4. A cement composed of blast furnace or other slag in a dry pulverized form and caustic soda and slaked lime in a dry state and substantially in the proportions set forth.

The final result of Whiting's research was the establishment of a cement department within the Illinois Steel Co. in 1895 with Whiting as its head and Berquist as plant superintendent.

Raw materials now used by the Buffington plant are slag from blast furnaces of the United States Steel Co. and limestone imported from quarries near Rogers City, Mich.

Construction of Buffington harbor began in the spring of 1925 and the harbor was dedicated on June 9, 1927. This private harbor made possible the receiving of raw materials by vessel and the shipping of cement to all ports in the Great Lakes region.

Hadley (1945, p. 134) said that the name of the Buffington plant carries a personal note. The late Eugene J. Buffington, when he was president of the Illinois Steel Co., was active in getting the great steel center in Indiana at the foot of Lake Michigan named "Gary" in honor of Judge Elbert H. Gary of the United States Steel Corp. When the steel company's new cement plant was erected in the vicinity, Judge Gary returned the compliment by suggesting that this location should be called "Buffington."

The Universal Atlas Cement Co. markets its products under the brand name Atlas. The plant uses the dry process of cement manufacture and has an annual capacity of approximately 10 million bbl. per year (Trauffer, 1957, p. 149).

PORTLAND CEMENT ASSOCIATION

A meeting of cement producers in Philadelphia in 1902 resulted in the establishment of the Association of Portland Cement Manufacturers (Hadley, 1945, p. 177). In 1904 the word American was included, and in 1916 the name was changed to Portland Cement Association. Headquarters for the association was in the Conway Building, 111 West Washington Street, Philadelphia. In 1925 the association raised funds to erect a 5-story reinforced concrete structure at 33 West Grand Avenue, Chicago, and the building was occupied in 1926.

The Portland Cement Association dedicated in 1950 a new research and development laboratory building erected at Skokie, near Chicago. Frank T. Sheets, president of the association, said (Portland Cement Association, 1950, p. 2): "The Association's work consists of four principal parts: scientific research in the fields of portland cement and concrete; development of new and improved cement-using products and methods; promotion, educational work and technical service to extend the uses of portland cement and to improve concrete quality; and accident prevention work to encourage safety in the plants of its member companies."

The association is a national nonprofit unincorporated organization designed to improve and extend the uses of portland cement and concrete. It is voluntarily supported by its 67 member companies on the basis of their cement shipments.

A district office of the Portland Cement Association is at 611 Merchants Bank Building, Indianapolis, Ind.

THE NATURE OF CEMENTING MATERIALS

PORTLAND CEMENTS

DEFINITION OF PORTLAND CEMENT

The American Society for Testing Materials (1955, p. 1 and 5) defines portland cement as follows:

> . . . the product obtained by pulverizing clinker consisting essentially of hydraulic calcium silicates, to which no additions have been made subsequent to calcination other than water and/or untreated calcium sulfate, except that additions not to exceed 1.0 per cent of other materials may be interground with the clinker at the option of the manufacturer, provided such materials in the amounts indicated have been shown to be not harmful by tests carried out or reviewed by Committee C-1 on Cement. . . . Air-entraining portland cement [ASTM Designation: C 175-55] is the product obtained by pulverizing clinker consisting essentially of hydraulic calcium silicates, to which no additions have been made subsequent to calcination other than water and/or untreated calcium sulfate, except that there shall be interground with the clinker an addition meeting the requirements of the Specifications for Air-Entraining Additions for Use in the Manufacture of Air-Entraining Portland Cement (ASTM Designation: C 266).

TYPES OF PORTLAND CEMENT

Five basic types of portland cement are recognized in the United States (ASTM Designation: C 150-55, 1955, p. 1):

> Type I.—For use in general concrete construction when the special properties specified for types II, III, IV, and V are not required.
>
> Type II.—For use in general concrete construction exposed to moderate sulfate action, or where moderate heat of hydration is required.
>
> Type III.—For use when high early strength is required.
>
> Type IV.—For use when a low heat of hydration is required.[2]
>
> Type V.—For use when high sulfate resistance is required.[2]

Three types of air-entraining portland cement are made also (ASTM Designation: C 175-55, 1955, p. 5):

> Type IA.—For use in general concrete construction when the special properties specified for types IIA and IIIA are not required.

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[2] Cements conforming to the requirements for type IV and type V are not usually carried in stock. In advance of specifying their use, purchasers or their representatives should determine whether these types of cement are, or can be made, available.

Type IIA.—For use in general concrete construction exposed to moderate sulfate action, or where moderate heat of hydration is required.

Type IIIA.—For use when high early strength is required.

COMPOSITION OF PORTLAND CEMENT

The essential chemical components of portland cement are the oxides of calcium (CaO), silicon (SiO_2), aluminum (Al_2O_3), and iron (Fe_2O_3) and a small percentage of sulphur trioxide (SO_3), which is added after calcination to control the set of the finished product. Other constituents found in small amounts are magnesium oxide (MgO), sodium oxide (Na_2O), potassium oxide (K_2O), titania (TiO_2), sulphur (S), phosphorous pentoxide (P_2O_5), and manganese oxide (Mn_2O_3). Potassium oxide and sodium oxide commonly are referred to as "the alkalies" in portland cement.

Lime, silica, alumina, and ferric oxide generally constitute about 95 percent of the total oxides. Magnesia commonly is present in amounts of 2 to 3 percent and is limited to a permissible maximum of 5 percent. Sodium, potassium, and titania generally total between 1 and 2 percent.

The complex composition of cement is caused by partial melting of the raw mix that forms both liquid and solid solutions. When these solutions cool to phase equilibrium, the compounds formed are dependent on the proportions of the various oxides present and on the temperatures of the original melt and the temperature of crystallization.

Chemical analysis and compound composition of present-day portland cement are shown in table 1.

CHEMICAL REQUIREMENTS FOR PORTLAND CEMENT

Chemical requirements for portland cement are shown in table 2, which was compiled from ASTM Designation: C 150-55, 1955, p. 2, and Designation: C 175-55, 1955, p. 6.

PHYSICAL REQUIREMENTS FOR PORTLAND CEMENT

Physical requirements for portland cement are shown in table 3, which was compiled from ASTM Designation: C 150-55, 1955, p. 3, and Designation: C 175-55, 1955, p. 7.

THE MANUFACTURE OF PORTLAND CEMENT

Portland cement is made by combining argillaceous and calcareous materials which have been finely ground and mixed. Grinding and mixing may be done dry (dry process) or in water (wet process). The proportions of the mixed raw materials must

Table 1.—*Chemical analysis and compound composition (in percent) of portland cement*
[Modified from Blanks and Kennedy, 1955, p. 28.]

	Type I Standard		Type II Moderate heat		Type III High early strength		Type IV Low heat		Type V Sulphate resistance
	Range	Ave.	Range	Ave.	Range	Ave.	Range	Ave.	Ave.
Oxide analysis:									
Lime (CaO)	66-62	64	65-62	63	67-63	65	65-58	60.5	64
Silica (SiO_2)	23-19	21	24-20	22	22-18	20	26-22	24	26
Alumina (Al_2O_3)	8-5	6.5	6-4	5	7-4	5.5	6-3	5	2.5
Ferric oxide (Fe_2O_3)	4-2	2.5	6-3	4	4-2	3	6-2	4.5	1.5
Magnesia (MgO)	4-1	2.5	4-2	3	4-0.6	2.3	4-1	3	2.5
Sulphur trioxide (SO_3)	2.5-1	2.1	2-1	1.5	3-2	2.5	2-1	1.7	2
Ignition loss	2-0.6	1.3	2-1	1.1	2-0.8	1.5	2-1	1.1	1.3
Insoluble residue	0.08-0.01	0.02	0.05-0.01	0.02	0.07-0.01	0.02	0.03-0.01	0.02	0.02
Compound composition:									
$3CaO \cdot SiO_2$		48		43		57		20	39
$2CaO \cdot SiO_2$		27		30		20		52	33
$3CaO \cdot Al_2O_3$		12		7.5		11		6	4.5
$4CaO \cdot Al_2O_3 \cdot Fe_2O_3$		8		12		7		14	16

Table 2.—*Chemical requirements for portland cement*
[From American Society for Testing Materials, 1955, p. 2 and 6]

	Type							
	I	IA	II	IIA	III	IIIA	IV	V
Silicon dioxide (SiO_2), min., percent	....	....	21.0	21.0	....	....	....	....
Aluminum oxide (Al_2O_3), max., percent	....	....	6.0	6.0	....	....	....	*
Ferric oxide (Fe_2O_3), max., percent	....	....	6.0	6.0	....	....	6.5	*
Magnesium oxide (MgO), max., percent	5.0	5.0	5.0	5.0	5.0	5.0	5.0	4.0
Sulfur trioxide (SO_3):								
When $3CaO$-Al_2O_3 is 8 percent or less, max., percent	2.5	2.5	2.5	2.5	3.0	3.0	2.3	2.3
When $3CaO\cdot{+}Al_2O_3$ is more than 8 percent, max., percent	3.0	3.0	....	....	3.0	3.0	....	....
Loss on ignition, max., percent	3.0	3.0	3.0	3.0	3.0	3.0	2.3	3.0
Insoluble residue, max., percent	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75
Tricalcium silicate ($3CaO\cdot SiO_2$),[1] max., percent	....	....	50.	50.	....	....	35.	50.
Dicalcium silicate ($2CaO\cdot SiO_2$),[1] min., percent	....	....	....	....	....	....	40.	....
Tricalcium aluminate ($3CaO\cdot Al_2O_3$),[1] max., percent	....	....	8.	8.	15.	15.	7.	5.

* The tricalcium aluminate shall not exceed 5 percent, and the tetracalcium aluminoferrite ($4CaO\cdot Al_2O_3\cdot Fe_2O_3$) plus twice the amount of tricalcium aluminate shall not exceed 20 percent.

[1] Expressing chemical limitations by means of calculated assumed compounds does not necessarily mean that the oxides are actually or entirely present as such compounds.

The percentages of tricalcium silicate, dicalcium silicate, tricalcium aluminate, and tetracalcium aluminoferrite shall be calculated from the chemical analysis as follows:

Tricalcium silicate = (4.07 X percent CaO) — (7.60 X percent SiO_2) — (6.72 X percent Al_2O_3) — (1.43 X percent Fe_2O_3) — (2.85 X percent SO_3)

Dicalcium silicate = (2.87 X percent SiO_2) — (0.754 X percent $3CaO\cdot SiO_2$)

Tricalcium aluminate = (2.65 X percent Al_2O_3) — (1.69 X percent Fe_2O_3)

Tetracalcium aluminoferrite = 3.04 X percent Fe_2O_3

Oxide determinations calculated to the nearest 0.1 percent shall be used in the calculations. Compound percentages shall be calculated to the nearest 0.1 percent and reported to the nearest 1 percent.

Table 3.—*Physical requirements for portland cement*
[From American Society for Testing Materials, 1955, p. 3 and 7]

	Type							
	I	IA	II	IIA	III	IIIA	IV	V
Fineness, specific surface, square centimeters per gram: (alternate methods)[1]								
Turbidimeter test								
Average value, min.	1,600	1,600	1,700	1,700	....	....	1,800	1,800
Minimum value, any one sample	1,500	1,500	1,600	1,600	....	....	1,700	1,700
Air permeability test:								
Average value, min.	2,800	2,800	3,000	3,000	....	....	3,200	3,200
Minimum value, any one sample	2,600	2,600	2,800	2,800	....	....	3,000	3,000
Soundness								
Autoclave expansion, max., percent	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Time of setting (alternate methods):[2]								
Gillmore test								
Initial set, min., not less than	60	60	60	60	60	60	60	60
Final set, hr., not more than	10	10	10	10	10	10	10	10
Vicat test (Method C 191)								
Set, min., not less than	45	45	45	45	45	45	45	45
Air content of mortar, prepared and tested in accordance with Method C 185, max., percent by volume, less than	12.0	19±3	12.0	19±3	12.0	19±3	12.0	12.0
Compressive strength, pounds per square inch: The compressive strength of mortar cubes, composed of 1 part cement and 2.75 parts graded standard sand, by weight, prepared and tested in accordance with Method C 109, shall be equal to or higher than the values specified for the ages indicated below:								
1 day in moist air	....	....	....	....	1,700	1,100	....	....
1 day in moist air, 2 days in water	1,200	900	1,000	750	3,000	2,200	....	....
1 day in moist air, 6 days in water	2,100	1,500	1,800	1,400	....	....	800	1,500
1 day in moist air, 27 days in water	3,500	2,800	3,500	2,800	*	....	2,000	3,000

Table 3.—*Physical requirements for portland cement*—Continued
[From American Society for Testing Materials, 1955, p. 3 and 7]

Tensile strength, pounds per square inch:[2]								
The tensile strength of mortar briquets composed of 1 part cement and 3 parts standard sand, by weight, prepared and tested in accordance with Method C 190, shall be equal to or higher than the values specified for the ages indicated below:								
1 day in moist air	....	....	....	....	275	....	....	....
1 day in moist air, 2 days in water	150	....	125	....	375	....	....	....
1 day in moist air, 6 days in water	275	....	250	....	....	....	175	250
1 day in moist air, 27 days in water	350	....	325	....	*	....	300	325

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[1] Either of the two alternate fineness methods may be used at the option of the testing laboratory. However, in case of dispute, or when the sample fails to meet the requirements of the Blaine meter, the Wagner turbidimeter shall be used, and the requirements in Table 3 for this method shall govern.

[2] The purchaser should specify the type of setting-time test required. In case he does not so specify, the requirements of the Vicat test only shall govern.

* The purchaser should specify the type of strength test required. In case he does not so specify, or in case of dispute, the requirements of the tensile strength test only shall govern. The strength at any age shall be higher than the strength at the next preceding age. Unless otherwise specified, the compressive and tensile strength tests for types I and II and IA and IIA cement will be made only at 3 and 7 days. If, at the option of the purchaser, a 7-day test is required on type III cement, the strength at 7 days shall be higher than at 3 days. Unless otherwise specified, the strength tests for type IIIA cement will be made only at 1 day and 3 days. The strength at any age designated herein shall be higher than the strength at any preceding age.

be kept constant within narrow limits because any wide variance in proportions may result in an inferior cement.

When the raw materials are correctly proportioned, finely ground, and thoroughly intermixed, the resultant mixture is fed into the kiln and is heated. Water and carbon dioxide are driven off before the clinker temperature zone is reached. Increased temperature causes chemical reactions to take place between the various components of the raw mix. New compounds are formed, some of which melt to fuse the raw material partially into a clinker. When cool, the clinker is mixed with a specified amount of gypsum, and the mixture is ground to a fine powder. This powder is the commercial portland cement.

PREPARATION OF KILN FEED

Crushing and grinding.—Preparation of the raw materials begins with crushing followed by grinding. Primary crushing is done with jaw, gyratory, hammermill, or roll crushers. The kind of primary crusher used is determined by (1) the crushability of the rock, (2) the moisture content of the rock, (3) the reduction ratio required by secondary crusher, and (4) the rate of desired production.

Secondary crushing is done by the same type of crushers used in primary crushing except for modifications in design necessitated by smaller particle size and more desired uniformity in secondary crusher feed.

Grinding is important in preparing kiln feed because the establishment of maximum particle size and particle size gradation to assure proper fusion and combination of the raw materials to form the clinker is dependent upon this operation. Grinding, like crushing, is accomplished in one stage or more. The primary grinders are generally ball mills (applicable to any mill using steel balls of various sizes as the grinding media). Secondary grinders are generally compartmented tube mills (long cylinders loaded with steel balls as the grinding media). The function of secondary grinding is to establish proper fineness of the various raw materials prior to their entering the kiln.

Dry process.—In the dry process all crushing and grinding are done while the materials are in the dry state. At the beginning of crushing, some raw material is of suitable fineness for kiln feed. This fine material impairs grinding efficiency in subsequent stages of grinding because of the improper ratio between particle size and grinding media size. Such inefficiency is avoided by use of compartmented secondary grinders, care in the selection of ball sizes, and use of air classifiers. Before it is ground, the raw material commonly is passed through driers.

Two methods are employed in the dry process for proportioning cement raw materials—namely, continuous proportioning and the two-stage blending operation (Dahl, 1947, p. 92). In the continuous proportioning operation the crushed raw materials move in separate lines toward a common junction to form one continuous flow. This material when reduced to proper size constitutes the kiln feed. The raw material also can be conveyed to silos, which are filled consecutively and emptied simultaneously. These procedures permit more thorough blending of the raw material prior to its entering the kiln. In the two-stage blending operation the flow of raw materials is the same except that the silos are tapped selectively on the basis of chemical composition. The resulting mixture is conveyed to other proportioning silos, where further blending is accomplished.

A mill is referred to as operating in a closed circuit when an air classifier (separator) is used in the grinding circuit. The air classifier is used during grinding to solve the problem of the most desirable particle size. In the air classifier a draft of air carries away the fine particles for kiln feed and leaves the coarse material to be circulated back to the grinding operation.

Grinding done without the use of an air classifier is termed an open-circuit grinding operation. In open-circuit grinding a material passes through the mill only once.

The use of air classifiers improves grinding efficiency in that (1) particle-size distribution of the ground raw material is closer to ideal kiln feed, (2) the average size and maximum size of the material retained on any mesh sieve can be reduced to a specified mesh fineness, and (3) the percentage of very fine particle sizes produced is reduced to a minimum.

Wet process.—Certain raw materials used for cement manufacture are high in water content, and drying of these materials prior to grinding is expensive. Therefore during the grinding operation additional water is added to produce a mixture containing 30 to 48 percent water. This is the wet process of cement manufacture.

Proportioning of raw materials is done by the two-stage blending operation. The ground raw materials are stored in silos, which are tapped selectively according to the chemical composition desired in the kiln feed.

Before the clinker can be made, the water content of the slurry must be driven off in the kiln. Because of the high water content, more fuel to evaporate the water is required, and attempts have been made to develop various defluidizers, some of which have been successful. The cost of installing these devices, however, frequently exceeds the cost of fuel required for drying the raw material. The trend now is to utilize the heat formerly lost in the stacks for drying. In order to assure fuel economy the cement industry uses many types and methods of drying the slurry prior to clinker formation.

Grinding is done in closed circuit when rake or spiral classifiers or vibrating screens are used in conjunction with a primary ball mill. Also a closed circuit is one in which rake or spiral classifiers operate with secondary ball mills but are supplemented by a bowl classifier. The rake and bowl classifiers in the wet process are comparable to the air separator in the dry process. The only difference is that water is used instead of air to classify the raw material.

Wet process versus dry process.—The main objective in both processes of cement manufacture is operational economy. Factors to be considered before deciding on either a wet-process or a dry-process plant are: (1) fuel cost, (2) availability of water at the plant, (3) power supply, (4) water content of raw material to be used, (5) uniformity of kiln feed, and (6) need of dust-collecting devices in region where plant is to be built.

Greater fuel economy and shorter, less expensive kilns are two advantages of the dry-process plant. Wet-process advantages include better blending of raw materials for kiln feed, fewer dust problems, and application of flotation methods which permit the use of raw materials that otherwise would be useless.

Plate 1 is a flow chart showing the dry and wet processes of portland-cement manufacture.

THE BURNING OPERATION

In most American operations the raw mix either in the form of a dry powder or a slurry is fed at a uniform rate into the upper end of a rotary kiln, 100 to 500 feet long and 8 to 15 feet in diameter. The kiln is set at an angle of about 2½ degrees from the horizontal, and as the kiln rotates, the raw mix moves slowly toward the lower end. The kilns generally are heated by powdered coal, fuel oil, or gas. The fuel is introduced in the lower end of the kiln, and thus the temperature is higher in the lower end and

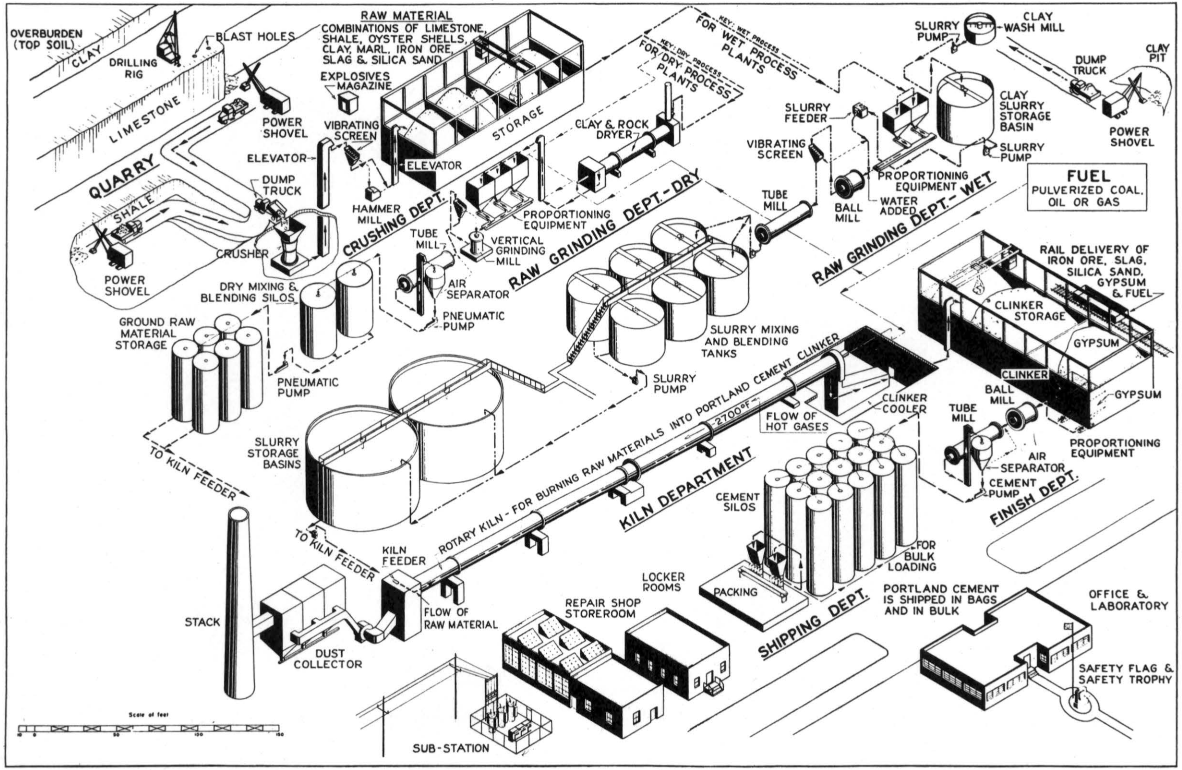

CHART SHOWING DRY AND WET PROCESSES OF PORTLAND CEMENT MANUFACTURE.
COURTESY OF PORTLAND CEMENT ASSOCIATION.

decreases toward the upper end. Maximum temperatures are between 1,400 and 1,500 degrees centigrade (2,552 to 2,732 degrees Fahrenheit).

Much water is required in the closed-circuit wet process, where rake and bowl classifiers are used. Dewatering basins or thickeners (large diameter and shallow, concave-bottomed tanks) have been fashioned to solve this water problem. One thickening basin or more may be used. A slurry (suspension of finely ground solids in water) of raw material is continuously fed into the thickeners. By sedimentation processes the particles settle and are drawn off from the bottom of the basin while the clear water overflows and is returned to the system.

Control of slurry viscosity is important. The slurry viscosity should be low enough to permit easy handling. A slurry that has excessive viscosity may cause difficulty in grinding by plugging screens in pumps and in pipes through which the slurry flows to the thickeners and in using mechanical and air agitators for thorough mixing of tank contents. The amount of water required for proper slurry viscosity depends upon the physical and chemical characteristics of the raw material, especially if the raw material consists of marls or shells.

In the wet process flotation can be used to separate the undesirable from the desirable constituents. This permits the use of some raw materials that otherwise could not be used for cement manufacture.

The open-circuit grinding method also is used in the wet process. When this method is used, the crushed raw material is fed into grinding mills at a rate that will produce the desired mean particle size in one pass. This material then is blended to constitute the kiln feed.

When the raw mix first enters the kiln, it is heated slowly. Water is driven off first, and farther along in the kiln the organic matter burns away and carbon dioxide (CO_2) is released from the carbonates. Some sulphate is decomposed, and sulphur trioxide (SO_3) is formed; the chlorides and alkali salts are in part volatilized at higher temperatures. The potash formed by volatilization may be extracted from stack dust and sold commercially. Because of volatilization, the weight of the original raw mix is reduced by about one-third.

In the higher temperature zones of the kiln about 20 to 30 percent of the raw mix is converted to liquid. Some of the chemical reactions of clinker formation take place in this liquid. New chemical compounds are formed, and the compounds of the original raw material disappear. The character of the cement is dependent upon the new compounds formed by the reaction of the several components in the raw mix.

If the temperature in the clinker zone of the kiln is too low, reactions will not progress sufficiently. Thus the clinker becomes underburned and appears dull and chalky. The clinker probably will be unsound and will not have normal strength. If the temperature in the clinker zone of the kiln is too high, the clinker is more molten, becomes harder, and causes an unnecessary waste of fuel. A properly burned clinker is one that is small (size of marbles), rounded, and black or gray-black and that shows many small crystals.

CLINKER COOLING AND TREATMENT

When the clinker drops from the kiln, water or air is used to control clinker cooling. The way in which the clinker is cooled affects the ease of grinding, color, and compound formation.

After the clinker has cooled, it passes to the finish department for grinding. The clinker is generally small in maximum diameter and commonly does not require crushing. The ease of clinker grinding is influenced by chemical composition; the way in which it was burned, cooled, and stored; its moisture content; and the temperature at which it is ground.

As the clinker passes into the mill, gypsum is added as a retarder to control the time of set. The amount of gypsum added varies with the amount of tri-calcium aluminate present in the clinker. Other additives, such as grinding aids and air entraining agents, may be admixed with the clinker in the final grinding operation.

The finished cement commonly is stored in vertical reinforced concrete silos that are constructed in rows arranged in a rectangle. Most silos are built with hopper bottoms to permit ease of cement flow without hand shoveling. Silos are rated as holding so many barrels of cement per foot of height.

Portland cement is packed in bags of 94 pounds net weight, and shipments are made in barrels, each of which weighs 376 pounds net.[3] Thus 1 barrel of cement is equivalent to four 94-pound bags

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[3] The European practice is to measure quantity of cement by the hundredweight and the short ton. Many companies in the United States favor the elimination of the barrel (376 lb.) terminology to indicate cement quantity and the adoption of the hundredweight and the short ton. Effective March 1, 1957, Canadian statistics are recorded in tons instead of in the 350-lb. Canadian barrels. This change in Canada may hasten the acceptance of the ton measure in the United States (Trauffer, 1958, p. 114).

of cement. Shipments also are made in bulk by railroad hopper-bottom cars, ships, and trucks.

POZZOLANIC CEMENT

Pozzolanic cement is one of the oldest cementing materials known. This cement is made from siliceous and aluminous mineral raw materials, which have no cementitious qualities as such, but which will react when combined with lime and water at ordinary temperatures to form cementitious compounds. Pozzolans may be the minerals found in nature, natural materials which require some beneficiation, or artificially formed mineral substances. Naturally occurring pozzolans include clays and shales, opaline materials, volcanic ash, tuffs, and pumicites.

Considerable interest exists in the use of pozzolans with portland cement. During the early period of experimentation some unsatisfactory experiences with pozzolans in portland-cement concrete retarded the use of these materials. However, when the proper proportions were determined and were used, the quality of concrete improved. Some improvements in the quality of concrete were: (1) workability, (2) lower heat of hydration and thermal shrinkage, (3) increased water tightness, (4) more resistance to cracking, (5) reduced alkali-aggregate reactions, and (6) lower susceptibility to dissolution and leaching. In addition, the cost of the concrete was lower.

Seemingly the only safe way to determine the suitability of a pozzolan is to try the material in concrete mixes from which test specimens are made. This procedure is time consuming and costly. However, the use of analytical equipment can provide reliable information as to the complex chemical and mineralogic composition of pozzolans. Spectrographic and chemical analyses yield the oxide content, from which potential compounds can be computed. Petrographic analysis shows the relationship between mineral components and indicates any alteration of minerals. X-ray diffraction and differential thermal analyses show the mineralogic content of the fine-grained mineral and amorphous components. Differential thermal analysis also indicates the endothermic and exothermic reactions as heat input is increased. The interpretation and correlation of these data with performance records are most useful in predicting pozzolanic quality.

NATURAL CEMENT

Natural cement is manufactured from raw materials found in nature which contain compounds of calcium and silicon and which produce hydraulic calcium silicate when burned below fusion. The chief difference between natural and portland cements is found in the grinding and burning of the raw materials. Raw materials used for natural cement are calcined at temperatures sufficient to dissociate the carbonates and expel the carbon dioxide, but not high enough to cause fusion. Thus, when a raw material is calcined at low temperatures, all components do not react to form new compounds. About 20 to 25 percent of the material in natural cement is inert and not in combination.

Finished natural cements vary in composition primarily in the amount of magnesium present. Much of the magnesium is present as magnesia, and if it is hydrated during mortar mixing or in the manufacturing process, the magnesium hydroxide formed adds to the plasticity and workability of the concrete or mortar mixture. Concrete made with natural cement is tough, resists sulphate attack, and has low heat of hydration.

ALUMINOUS CEMENT

Aluminous cements differ from portland cement in that the principal constituents are calcium aluminates instead of calcium silicates. Low-grade bauxite and limestone are the raw materials commonly used in making aluminous cements. The raw material is heated, and the lime reacts with the alumina to form the calcium aluminate compounds. Rate of cooling is important as it influences the setting time and rate of hardening of the finished product and also the grinding ability of the clinker. Aluminous cement is sulphate resistant and attains high early strength. The cement is used in making refractory concrete, heat-resistant concrete, corrosion-resistant concrete, and overnight concrete and in sealing rock or concrete against internal flow of water.

BLENDED CEMENT

Portland cement generally is the chief constituent of a blended cement. Blended cement is made by mixing portland cement with slag, natural cement, or pozzolanic material, such as fly ash. The mixing may be done during the finished grinding, before grinding, or at the concrete mixer. The amount of the added material ranges from 15 to 20 percent.

Blended cement is used to (1) lower heat of hydration, (2) increase sulphate resistance, (3) promote easier workability, (4) restrict or eliminate expansion that may occur when high-alkali cements are used in combination with hydrous silicate aggregates.

Although many blended cements have low initial strength, the strength commonly improves with time to equal or exceed that of portland cement.

SLAG CEMENT

Portland blast-furnace slag cement is a mixture of portland cement, granulated slag, and gypsum. The granulated slag is produced as a byproduct from the blast furnace. The composition is essentially calcium silicates and calcium aluminosilicates which have been developed at the same time with iron in the blast furnace. The slag is produced by rapid chilling of the molten mass in water, steam, or air. Care must be exercised in selecting the slag, as certain chemical and physical properties are desirable. Slowly cooled slag possesses little or no hydraulic value, whereas quickly cooled slag possesses maximum hydraulic values; this property is important in portland blast-furnace slag cement. Chemical composition of slag also affects the hydraulic value.

As an activator is required to obtain full-strength value from the slag, and as hydrated lime derived from the hydration of portland-cement constituents is one of the best activators, the composition of portland cement also affects the hydraulic value of slag.

Properties of portland blast-furnace slag cement in general are similar to portland cement. Some significant differences exist because of differences in hydration. Comparison of the physical properties of portland blast-furnace slag cement with portland cement shows that the former (1) develops higher strength at later age, (2) is more resistant to exposures to various active solutions, (3) has a lower specific gravity, (4) has a lower permeability, which improves water tightness, and (5) possesses in general better workability.

MASONRY CEMENT

The term masonry cement is commonly applied to any cement that can be mixed with fine sand and water to produce a smooth, plastic, cohesive mortar. Recently the term has been used for specially formulated mixtures of portland-cement clinker, limestone, gypsum, and air-entraining agents. Portland-cement manufacturers package the mixture in ready-to-use bags. These mortars are being used to cement together masonry units such as brick, tile, concrete block, cut stone, and field stone.

OIL-WELL CEMENT

Oil-well cement is any portland cement that is suitable for use in cementing oil wells. These cements are classified as (1) regular or unretarded and (2) slow-setting or retarded. The latter differs from the former in that special retarders other than gypsum have been added to control setting time. These retarders reduce the rate of cement hydration and thus cause the setting time to be delayed while the cement slurry is placed in deep wells.

Oil-well cement is used (1) to prevent water or gas from infiltrating the oil-bearing rock, (2) to prevent blowouts from high pressures encountered in drilling, (3) to stop the flow of water or gas into a well, (4) to seal off certain rock intervals, (5) to correct errors in casing perforation, (6) to plug back or reduce hole depth, (7) to repair leaks in casings, and (8) to plug abandoned wells.

SPECIAL CEMENTS

Special cements are manufactured to meet a specific need. Such cements include (1) white portland cement, a low ferric oxide and magnesia cement which possesses nonstaining qualities and which is an ideal base when color pigments or special colored aggregates are used, (2) colored cement, (3) antibacterial cement which contains an antibacterial agent that helps to prevent cement deterioration in food-processing plants, and (4) waterproofed cements.

SOURCES OF CEMENT RAW MATERIALS

In general, any raw material that will give the proper chemical composition when calcined may be used in manufacturing portland cements. Economically, however, occurrence of such raw materials is limited. Figure 1 shows diagrammatically the raw materials from which lime, alumina, silica, iron oxides, and fuel are derived. Typical analyses of some raw materials of portland cement are shown in table 4.

The misconception is current that the closer a raw material approaches 100 percent purity the better the material is for cement manufacture. Actually, the farther a raw material departs from the proper composition the more expensive the manufacturing process becomes because more mixing and finer grinding may be required to give a uniform feed to the kiln. Thus, a pure limestone is less desirable than an argillaceous limestone provided the impurities are not of a type or in an amount that is prohibitive.

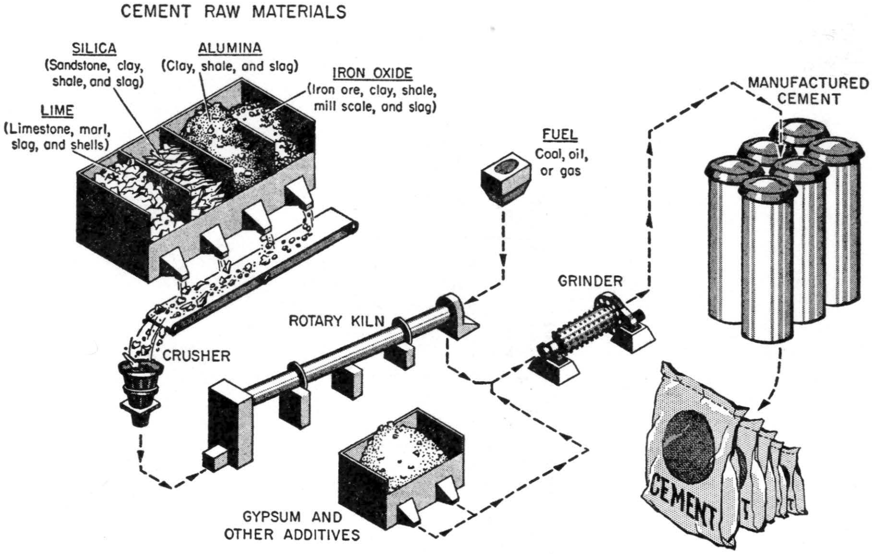

Figure 1.—Chart showing sources of raw materials for cement manufacture.

If a manufacturer of cement has a choice of raw materials, the decision as to which source to use is dependent upon weighing all the cost of chemical and physical properties as they affect the manufacturing process against the cost of quarrying, transportation, and fuel.

CALCAREOUS CONSTITUENTS

All limestones chemically contain calcium carbonate. Soft limestone such as travertine and chalk may require less than half as much energy to reduce mechanically as hard massive crystalline limestone.

Chert is a common impurity in limestone. Its presence in the quarry increases operating cost by causing rapid wear on drilling and crushing equipment. Chert increases wear throughout the crushing system and is more difficult to grind than limestone. It may be ground at high relative cost, but its particles commonly will remain larger than the limestone particles. Differential hardness of various components contributes to the lack of homogeneity in the finished product and excessive amounts of free lime. Kiln feed may be of the right chemical composition and still produce a hard-burning mix which is difficult to control owing to oversize particles. Chert increases production costs from the quarry to the finished product if it is present in large amounts. Silica sand

Table 4.—*Typical analysis (in percent) of portland-cement raw materials*

Raw material	$CaCO_3$	CaO	$MgCO_3$	MgO	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	MnO	Na_2O	K_2O	S	P_2O_5	CO_2	Ignition loss
Limestone	94.6		1.37		2.53	.74	.56	.037	.038			.28	.044	42.2	
Natural cement rock	60.6		19.2		14.1	3.99	.92	.16	.043			.60	.069	35.9	
Marl	84.0		3.6		7.7	2.9	1.8								
Shale		.38		2.47	64.0	17.1	5.97	.77	.037	1.22	3.70	.33	.093	.34	4.74
Clay		.25		.95	62.0	21.4	5.12	.87	.030	.27	3.07	.079	.099	1.5	6.44
Blast-furnace slag		44.3		8.00	35.3	12.0	.20		.39			.60			

of large particle size has the same effect as chert particles if it is present in limestone.

Limestone may contain magnesium, and if it is uniformly distributed, as much as 3 percent magnesia may be tolerated. Magnesia (MgO) as periclase is slow to hydrate and may cause expansion in concrete. However, periclase may not crystallize out of the glass phase of clinker formation if cooling is rapid. Gypsum and pyrite seams in limestone may cause sulfate and iron content to be excessive. Gypsum also interferes in wet-grinding operations. Clay minerals in limestone contribute to the necessary alumina and silica and are desirable in limited amounts.

ARGILLACEOUS CONSTITUENTS

The argillaceous constituents supply silica, iron oxide, and alumina to react with lime to form cementitious compounds. Alumina and iron oxide provide flux for the reaction. Alumina decreases heat hydration and contributes to the early strength of concrete. Free silica in the clay-size range is commonly present.

Materials used for argillaceous constituents include (1) residual clays formed from the decomposition of older rocks, (2) alluvial clays, (3) marine clays, (4) shales, (5) phyllites, and (6) schists.

Residual clays are not likely to be homogeneous. These deposits range in composition from laterite to slightly decomposed rock in which the original crystal structure is preserved. Both extremes are unsatisfactory. In bauxite, alumina is high and silica is insufficient, and thus additional constituents are required. Kaolin is refractory and is deficient in silica. Intermediate states of decomposition may be suitable as a source of argillaceous constituents. However, slightly decomposed rock may be difficult to grind, and alkaline oxides may still be present in the unaltered feldspars. Clays of this type are generally unsatisfactory as a source of cement raw material. Such clays may be used, however, if other sources are not economically feasible.

Alluvial deposits that are suitable for use with limestone may exist. These deposits may have a natural water content which requires careful consideration in process design. Grinding generally is not necessary as particle size is small. Alkaline content may be high but can be utilized with a low-alkali calcium carbonate. The material requires drying if it is to be used in a dry-process plant.

Marine clays commonly contain illite. The amount of free silica, mica, and other residual minerals varies greatly. At the time of clay deposition calcium carbonate may be precipitated, and if the amount is high, the ratio of silica to alumina may be low because less free silica (chert is an exception) is deposited from sea water when calcium carbonate and clay are laid down. Marine clays low in K_2O and Na_2O are rare. Marine clays contain abundant surface moisture and water of crystallization. They require little grinding and have to be dried in a dry-process plant. If montmorillonite is abundant in the clay, the water requirement in a wet process may be increased as much as 10 percent to produce a pumpable slurry. This also increases fuel cost.

Shales, slates, phyllites, and schists are successive stages of metamorphism of an argillaceous sediment. Grinding ability decreases with an increase in metamorphism. As the clay is altered by increased metamorphism, water of crystallization decreases, and the moisture necessary to produce a pumpable slurry may increase as much as 30 percent. A tendency toward increased alkali content results from increased metamorphism. Wolfe (1955, p. 132) believes that alkaline oxides (Na_2O and K_2O) lower the melting point and contribute markedly to the expansion and disruption of concrete when used with aggregate that contains opal. Na_2O and K_2O decrease the resistance of concrete to freezing and thawing.

MINOR CONSTITUENTS

If two mineral raw materials do not produce a suitable chemical mix, other materials must be added. Silica is the most common additive. Silica-to-alumina ratio generally is too low in calcareous materials. Silica is added as sand or in any other form, but it is desirable to have a material that can be ground easily.

Commonly an iron oxide (Fe_2O_3) is added. A pure form is desirable, as silica combined with iron is difficult to pulverize. Of the three oxides, magnetite, hematite, and limonite, hematite is the most desirable. Magnetite is less desirable than hematite because it is in a partially reduced state. Because limonite is hydrated, a greater bulk weight of it is required than of hematite.

If alumina is present it counteracts the iron oxide. A factor of 1.3 times the alumina content minus Fe_2O_3 content gives the amount of Fe_2O_3 to add (Wolfe, 1955, p. 188). Iron oxides lower fuel consumption, increase the ease of calcining, lower the heat hydration, and lessen the destructive action on kiln refractories.

In finished cement, iron oxide reduces expansion and contraction, adds strength, and increases resistance to freezing and thawing.

Gypsum is added as a retarder of set. The retarding effect is almost proportionate to the amount of gypsum used, if the amount is not more than 3 percent. More than this optimum amount of gypsum weakens cement.

GEOLOGY OF CEMENT RAW MATERIALS IN INDIANA

LIMESTONE

The limestone analyses cited here represent the minimums and maximums of each chemical component. The percentages are based on numerous analyses of limestone samples collected from each limestone formation over a wide geographic area. It must not be assumed that high magnesium content as shown in the maximum column condemns the use of any limestone as a source of raw material for cement manufacture. High magnesium content is commonly present in thin rock units, and when these units are mixed with the higher calcium limestones of adjacent units, the resultant mixture is likely to meet cement specifications.

In some localities selective quarrying can be employed to eliminate high-magnesium rock. If, for instance, an entire quarry wall of limestone were blasted down together, the resulting rock mixture might not be suitable for cement manufacture, but proper ledging and separation of rock types would produce a raw material that would meet specifications for cement manufacture.

The combination of chemical suitability and practical availability of limestone for cement manufacture exists at many places in the Mississippian limestones in Indiana and to a more limited extent in the Devonian limestones (tables 5, 6, and 7). Cement plants in Indiana using local limestone as their principal raw material are located in Clark County, where the Sellersburg and Jeffersonville Limestones (Devonian) are used; in Lawrence County, where the Harrodsburg, Salem, and lower St. Louis Limestones (Mississippian) are used; and in Putnam County, where the Ste. Genevieve Limestone (Mississippian) is used.

DEVONIAN LIMESTONES

KENNETH LIMESTONE

The Kenneth Limestone (table 6) is gray to tan, dense, cherty, and irregularly bedded and ranges from 30 to 40 feet in thickness. The chemical range of calcium and magnesium carbonate, alumina, total ferric oxide, and silica is as follows:

Table 5.—*Ordovician, Silurian, and Devonian rocks in southern Indiana, in part*

System	Series		Member, Formation, Group	
Devonian	Upper		New Albany Shale (lower part)	
	Middle	Erian	Beechwood Member 0-10 ft.	Sellersburg (North Vernon) Limestone 1-26 ft.
			Speed and Silver Creek Lithofacies 0-26 ft.	
		Ulsterian	Jeffersonville Limestone 26-46 ft.	
			Geneva Dolomite 0-35 fet.	
Silurian	Niagaran		Louisville Limestone 0-52 ft.	
			Waldron Shale 0-15 ft.	
			Laurel Limestone 27-55 ft.	
			Osgood Formation 10-30 ft.	
	Albion		Brassfield Limestone 0-12 ft.	
Ordovician	Cincinnatian		Elkhorn Formation 0-50 ft.	
			Whitewater Formation 0-80 ft.	Richmond Group
			Saluda Limestone 6-50 ft.	
			Liberty Formation 50 ft.	

Table 6.—*Silurian and Devonian rocks in northern Indiana, in part*[1]

System	Series		Formation
Devonian	**Upper**		**New Albany Shale (lower part)**
	Middle	**Erian**	**Sellersburg (North Vernon) Limestone 10-15 ft.**
		Ulsterian	**Jeffersonville Limestone 60-90 ft.**
			Pendleton Sandstone 0-15 ft.
			Kenneth Limestone 30-40 ft.
Silurian	**Cayugan**		**Kokomo Limestone 45-60 ft.**
	Niagaran		**Huntington Dolomite 90-150 ft.**
			Liston Creek Limestone 50-72 ft.
			Mississinewa Shale 90-120 ft.

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[1] The ascending sequence Mississinewa-Liston Creek-Huntington follows the usage of Cumings and Shrock (1928, p. 53), but it is probable that dolomite beds which have been called Huntington are present throughout the Niagaran section at various places in northern Indiana (Patton, 1949, p. 12-13).

	Minimum percent	*Maximum percent*
$CaCO_3$	53.7	95.2
$MgCO_3$	.47	41.8
Al_2O_3	.16	.52
Fe_2O_3	.12	1.41
SiO_2	.95	12.2

JEFFERSONVILLE LIMESTONE

The Jeffersonville Limestone (table 5) is divided into a basal brown coralline dolomitic limestone, a middle gray to brown dense to crystalline fossiliferous limestone, and an upper tan crystalline massive limestone. The middle limestone in the northern part of

Table 7.—*Mississippian rocks in Indiana*

System	Series	Member, Formation, Group	
Mississippian	Chester	Kinkaid Limestone 2-35 ft.	
		Degonia Sandstone 10-35 ft.	
		Clore Limestone 10-35 ft.	
		Palestine Sandstone 5-40 ft.	
		Menard Limestone 25-50 ft.	
		Waltersburg Sandstone 30-60 ft.	
		Vienna Limestone 5-15 ft.	
		Tar Springs Formation 40-90 ft.	
		Glen Dean Limestone 27-60 ft.	
		Hardinsburg Formation 25-45 ft.	
		Golconda Limestone 15-50 ft.	
		Big Clifty Formation 25-40 ft.	
		Beech Creek Limestone 8-35 ft.	
		Elwren Formation 20-50 ft.	
		Reelsville Limestone 0-10 ft.	
		Sample Formation 16-42 ft.	
		Beaver Bend Limestone 1-20 ft.	
		Bethel Formation 5-30 ft.	
		Paoli Limestone 0-38 ft.	
		Aux Vases Formation 0-9 ft.	
	? Meramec	Levias Member 25-60 ft.	Ste. Genevieve Limestone 70-120 ft.
		Rosiclare Member 1-40 ft.	
		Fredonia Member 30-70 ft.	
		St. Louis Limestone 90-300 ft.	
		Salem Limestone 20-80 ft.	
		Upper Harrodsburg 34-44 ft.	Harrodsburg Limestone 60-80 ft.
		Lower Harrodsburg 30-44 ft.	
	Osage	Edwardsville Formation 40-200 ft.	Borden Group 465 770 ft.
		Floyds Knob Formation 0-15 ft.	
		Carwood Formation 115-125 ft.	
		Locust Point Formation 120-140 ft.	
		New Providence Shale 190-290 ft.	
	Kinderhook	Rockford Limestone 0-4 ft.	
		New Albany Shale (upper part)	

the outcrop region is thinly laminated and dolomitic and contains many small calcite crystals.

The Jeffersonville Limestone ranges from 26 to 46 feet in thickness at the outcrop. Chemical composition varies widely from locality to locality and from bed to bed. The chemical range of calcium and magnesium carbonate, alumina, total ferric oxide, and silica is as follows (Patton, 1953):

	Minimum percent	*Maximum percent*
$CaCO_3$	50	98
$MgCO_3$	1	42
Al_2O_3	0.03	1.2
Fe_2O_3	.07	0.55
SiO_2	0.15	9.0

High-calcium Jeffersonville Limestone can be found only in selected beds and in restricted areas in Indiana (pl. 2).

SELLERSBURG LIMESTONE

In Clark County the Sellersburg Limestone (table 5) is divided into a basal blue-gray crystalline fossiliferous argillaceous limestone (Speed Lithofacies), a middle drab-gray argillaceous massive fossiliferous limestone (Silver Creek Lithofacies) and an upper gray hard coarsely crystalline fossiliferous limestone (Beechwood Member). The Sellersburg Limestone ranges from 1 foot to 26 feet in thickness.

The Speed Lithofacies ranges in thickness from a few inches to 21 feet, the Silver Creek Lithofacies from less than 1 foot to 26 feet, and the Beechwood Member from a few inches to 10 feet. The chemical ranges of calcium and magnesium carbonate, alumina, ferric oxide, and silica for each of the facies and for the member are as follows (Patton, 1953):

Speed Lithofacies

	Minimum percent	*Maximum percent*
$CaCO_3$	77	93
$MgCO_3$	3	16
Al_2O_3	.53	1.9
Fe_2O_3	.44	1.19
SiO_2	1.9	

Silver Creek Lithofacies

	Minimum percent	*Maximum percent*
$CaCO_3$	50	70
$MgCO_3$	15	30
Al_2O_3	2	5
Fe_2O_3	1	1.5
SiO_2	7	16

Beechwood Member

	Minimum percent	*Maximum percent*
$CaCO_3$	80	98
$MgCO_3$	0.5	20
Al_2O_3	0.1	0.4
Fe_2O_3	0.25	4.0
SiO_2	1	3

Rock of the Silver Creek Lithofacies is used in Clark County in manufacturing natural cement and mortar.

MISSISSIPPIAN LIMESTONES

HARRODSBURG LIMESTONE

Approximately the upper 40 feet of the Harrodsburg Limestone (table 7) is gray, crystalline, massive, and fossiliferous. The chemical range of calcium and magnesium carbonate, alumina, ferric oxide, and silica is as follows (Patton, 1953):

	Minimum percent	*Maximum percent*
$CaCO_3$	95	95 or more
$MgCO_3$	0.5	1
Al_2O_3	0.2	0.3
Fe_2O_3	0.25	0.3
SiO_2	1.5	2.5

SALEM LIMESTONE

The Salem (table 7) is soft granular fossiliferous massive crossbedded limestone. Impure zones of brown fine-grained silty argillaceous dolomitic limestone are present. The Salem Limestone ranges from 20 to 80 feet in thickness. The chemical range of calcium and magnesium carbonate, alumina, ferric oxide, and silica is as follows (Patton, 1953):

	Minimum percent	*Maximum percent*
$CaCO_3$	78	95
$MgCO_3$	2	22
Al_2O_3	0.5	1.0
Fe_2O_3	0.1	1.0
SiO_2	1	6

ST. LOUIS LIMESTONE

The St. Louis (table 7) is blue-gray argillaceous thin-bedded partly dolomitic and cherty limestone. It ranges from 90 to 300 feet in thickness. Thick homogeneous sections of St. Louis Limestone are rare. The chemical range of calcium and magnesium carbonate, alumina, ferric oxide, and silica is as follows (Patton, 1953):

	Minimum percent	*Maximum percent*
$CaCO_3$	50	90
$MgCO_3$	2	40
Al_2O_3	0.2	2
Fe_2O_3	0.2	2
SiO_2	3	10

STE. GENEVIEVE LIMESTONE

The Ste. Genevieve Limestone (table 7) is divided into a basal tan or gray crystalline to dense oolitic thin-bedded to massive limestone (Fredonia Member), a middle gray thin-bedded oolitic partly shaly and sandy limestone (Rosiclare Member), and an upper light-colored thin-bedded to massive dense to crystalline oolitic limestone (Levias Member). The oolitic beds of the Fredonia and Levias are a major reserve of high-calcium limestone.

The Ste. Genevieve Limestone ranges from 70 to 170 feet in thickness. The Fredonia is 30 to 115 feet thick, the Rosiclare 1 foot to 40 feet thick, and the Levias 25 to 60 feet thick. The chemical range of calcium and magnesium carbonate, alumina, ferric oxide, and silica for each member is as follows (Patton, 1953):

Fredonia Member

	Minimum percent	*Maximum percent*
$CaCO_3$	85	98
$MgCO_3$	0.5	1.2
Al_2O_3	0.1	0.5
Fe_2O_3	0.07	0.5
SiO_2	1.5	3.0

The Fredonia member has a higher proportion of high-calcium limestone than the two other members of the Ste. Genevieve Limestone. In less pure zones there may be as much as 8 percent magnesium carbonate.

Rosiclare Member

	Minimum percent	*Maximum percent*
$CaCO_3$	70	93
$MgCO_3$	1	6
Al_2O_3	0.6	0.8
Fe_2O_3	0.1	1
SiO_2	5	7

In some zones silica content may reach 50 percent, and alumina may be present in amounts as high as 4.5 percent.

Levias Member

	Minimum percent	*Maximum percent*
$CaCO_3$	65	99
$MgCO_3$	0.25	30
Al_2O_3	0.1	6
Fe_2O_3	.034	1.78
SiO_2	0.5	6.5

SHALE AND CLAY

MISSISSIPPIAN SHALES

BORDEN GROUP

In northern Indiana the Borden Group (table 7) has not been divided into formations, and samples are referred to as undifferentiated Borden rocks. The rocks are siltstones, gray to green in color, and may contain lenses of brown to gray micaceous sandstones. In the upper part a few thin limestone beds may be present.

In southern Indiana the Borden Group is broken down into five formations (table 7). The oldest formation is called the New Providence Shale, and rocks of this formation are overlain successively by rocks of the Locust Point, Carwood, Floyds Knob, and Edwardsville Formations. Of these formations only the New Providence and Locust Point are suitable as possible raw material for cement.

The New Providence Shale is consistent laterally in its lithology. It is composed dominantly of shale and siltstone throughout its outcrop area. The formation ranges from 190 to 290 feet in thickness. The Locust Point Formation is commonly a massive fine-grained siltstone but may contain locally a few interbedded sandstones. The formation ranges from 120 to 140 feet in thickness.

A detailed discussion of the Borden Group of formations was published by Stockdale in 1931.

BETHEL FORMATION

The Bethel Formation (table 7) commonly is composed of massive friable crossbedded sandstone and ranges from 5 to 30 feet in thickness. The formation, however, is known to grade both vertically and laterally from a sandstone to a shale.

PENNSYLVANIAN SHALES

Chemical analyses of some Pennsylvanian shales are given in table 9.

MANSFIELD FORMATION

The Mansfield Formation (table 8) commonly is a massive coarse-grained crossbedded variegated sandstone. It may contain a few thin lenticular coal beds and locally as much as 20 to 30 feet of shale. The formation ranges from 50 to 300 feet in thickness.

BRAZIL FORMATION

The Brazil Formation (table 8) is composed of an alternating sequence of sandstone, shale, and coal. The formation ranges from 75 to 90 feet in thickness.

LINTON FORMATION

The Linton Formation (table 8) contains beds of sandstone, shale, coal, and a few thin limestones. It ranges from 40 to 60 feet in thickness.

PLEISTOCENE CLAY

The deposits of marl in northern Indiana generally are associated with lake clays, and a mixture of the two has been used in manufacturing portland cement. The clays are earthy, fine grained, and may contain some organic matter. Chemical analyses of two lake clays from northern Indiana are shown in table 10.

MARL

Numerous lakes in the northern three tiers of counties in Indiana contain an earthy form of calcium carbonate mixed with organic material, sand, clay, and other minor impurities. This kind of deposit is called marl. A detailed discussion of marl de-

Table 8.—*Pennsylvanian rocks in Indiana, in part*

System	Series		Member	Formation
	Mid-Continent	Appalachian		
Pennsylvanian	Missouri	Conemaugh	Murphy's Bluff Sandstone Vigo Limestone	Shelburn Formation 210-300 ft.
	Des Moines		Maria Creek Limestone	
			Busseron Sandstone	
		Allegheny		Dugger Formation 90-120 ft.
			Coal VII	
			Universal Limestone	
			Coal VI	
			Alum Cave Limestone	Petersburg Formation 90-120 ft.
			Coal V (Petersburg)	
			Coal IVa	
			Coal IV (Linton)	Linton Formation 40-60 ft.
			Coal IIIa	
			Coal III (Seelyville)	Staunton Formation 50-70 ft.
	Atoka	Pottsville	Coal II (Silverwood)	Brazil Formation 75-90 ft.
			Minshall Limestone	
			Minshall Coal	
			Upper Block Coal	
			Lower Block Coal	
	Morrow			Mansfield Formation 50-300 ft.

Table 9.—*Chemical analyses (in percent) of some Mississippian and Pennsylvanian shales*

Sample No.	County	Location	Rock unit	Thickness (feet)	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	MgO	Na_2O	K_2O	Ignition loss	MnO	P_2O_5	S	CO_2	H_2O (−)	H_2O (+)
1	Clark	Center Clark Military Grant 128	Borden Group, New Providence Shale	9	58.8	19.2	7.53	.75	.05	2.45	.76	4.62	6.02	.061	.062	.12	.17	1.50	4.23
2	Clay	NE¼NE¼ sec. 25, T. 13 N., R. 7 W.	Brazil Formation	8	59.6	16.2	8.92	1.12	.47	1.34	.20	2.78	8.89	.12	.11	.66	2.40	1.08	5.28
3	Clay	SW¼NE¼ sec. 2, T. 13 N., R. 7 W.	Brazil Formation	12	61.4	18.8	5.48	.78	.18	1.52	.23	3.00	8.44	.12	.092	.37	1.54	1.20	5.33
4	Dubois	NE¼SE¼ sec. 2, T. 2 S., R. 5 W.	Brazil Formation	5	62.0	21.4	5.12	.87	.25	.95	.27	3.07	6.44	.030	.099	.079	1.50	1.12	3.74
5	Fountain	SW¼SW¼ sec. 32, T. 22 N., R. 7 W.	Upper part of Borden Group[1]	30	63.6	17.0	5.69	.78	.92	2.21	.93	4.30	5.00	.039	.10	.20	.83	.90	3.07
6	Jackson	NE¼NE¼ sec. 27, T. 5 N., R. 3 E.	Borden Group[1]	28	63.2	16.4	7.26	.84	.13	2.20	1.10	4.21	5.47	.065	.11	.16	.90	.95	3.46
7	Lawrence	SW¼NW¼ sec. 12, T. 3 N., R. 2 W.	Shale from lower part of Chester Series?	14	61.8	16.7	4.27	.79	1.76	1.67	.10	2.56	9.79	.017	.084	1.6	1.13	2.76	4.30
8	Montgomery	SE¼SW¼ sec. 20, T. 19 N., R. 5 W.	Borden Group[1]	25	69.6	13.8	5.20	.80	.34	2.02	1.39	3.10	3.77	.026	.11	.27	.48	.53	2.49
9	Morgan	NE¼NE¼ sec. 34, T. 13 N., R. 1 E.	New Providence Shale	35	64.0	17.1	5.97	.77	.38	2.47	1.22	3.70	4.74	.037	.093	.33	.34	.70	3.37
10	Morgan	NE¼NE¼ sec. 35, T. 13 N., R. 1 E.	New Providence Shale	25	56.3	19.2	7.05	.73	2.13	2.38	.88	4.32	6.84	.066	.096	.035	2.05	1.00	3.75
11	Parke	NE¼SW¼ sec. 20, T. 15 N., R. 8 W.	Staunton Formation	19	62.8	18.8	4.86	.84	.11	1.84	1.12	3.52	5.33	.046	.13	.061	.56	.38	4.33
12	Putnam	Center sec. 19, T. 13 N., R. 4 W.	Mansfield Formation	35	59.8	19.2	5.55	.80	.27	1.23	.17	2.66	10.4	.069	.087	.44	1.60	1.78	6.58
13	Putnam	NW¼SE¼ sec. 19, T. 13 N., R. 4 W.	Mansfield Formation	20	65.1	17.2	5.30	.62	.40	1.03	.12	2.16	7.96	.057	.15	.69	1.0	.54	5.20
14	Vermillion	SE¼NW¼ sec. 36, T. 17 N., R. 9 W.	Brazil Formation	8	62.8	17.7	5.18	.84	.55	2.03	1.13	3.35	5.70	.052	.14	.014	.61	.88	4.20

[1] Formation not determined.

Table 10.—*Chemical analyses (in percent) of two Pleistocene lake clays*

Sample No.	County	Location	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	MgO	Na_2O	MnO	P_2O_5	S	CO_2	$H_2O(-)$	$H_2O(+)$	K_2O	Ignition loss
1	Marshall	SE¼NW¼ sec. 9, T. 34 N., R. 3 E.	44.3	12.2	4.46	.49	12.7	3.98	.64	.064	.11	.029	12.8	2.28	3.39	2.89	18.5
2	Lake	NE¼SW¼ sec. 31, T. 36 N., R. 9 W.	57.7	12.3	5.18	.52	4.90	3.65	.70	.053	.081	.28	5.63	1.56	3.43	3.49	10.9

posits in Indiana was written by W. S. Blatchley and George H. Ashley (1901, p. 31-321).

Marls are earthy, soft, and porous. When marl is wet the color ranges from off white to dark brown. After marl has been exposed to air, the color may change to blue gray or light gray. The amount of impurities determines the color of marls.

Marl deposits are found on the bottom of existing lakes, ponds, or marshes and in the former basins of extinct lakes. Marls commonly rest upon clay and sand or gravel and may be covered by peat or muck. Marl deposits range from a few acres to several hundred acres in extent and from a few inches to more than 40 feet in thickness. Although many deposits of marl are 20 feet or more thick, the distribution of these deposits generally is limited.

The glacial drift of northern Indiana contains many pebbles of limestone. Solution of these limestone pebbles by meteoric waters supplies the necessary lime for growth of organic life generally abundant in lakes. The death of these organisms and the accumulation of their limy residues may account for many marl deposits. Meteoric waters flowing through the glacial drift and dissolving the limestone pebbles may because of temperature and pressure changes cause the calcium carbonate to precipitate and accumulate in the lake bottoms. Some plants and animals secrete calcium carbonate, which may fall to the lake bottom and form marl. Probably no one explanation fully accounts for the formation of marl deposits.

Calcareous marl may be used for the same purposes as limestone. The first portland-cement plants in Indiana used marl. The principal objection to its use as a cement raw material is the large amount of absorbed water. To eliminate most of this water would require a large expenditure of money for fuel. Economic factors must be evaluated in locating a cement plant, and such considerations as fuel consumption commonly are determining factors. The marls of Indiana are irregularly distributed and erratic in thickness. They are not considered as cement raw material for economic rather than for geologic reasons.

Chemical analyses of 10 marl samples from Indiana lakes are shown in table 11.

GYPSUM

Gypsum is a mineral that is added to portland cement as an additional safeguard in controlling the time of set. Gypsum is the hydrated form of calcium sulphate ($CaSO_4 \cdot 2H_2O$). Pure gypsum

Table 11.—*Chemical analyses (in percent) of marls from northern Indiana*

Sample No.	Name of pit	County	Location	Thickness (feet)	SiO_2	Fe_2O_3	Al_2O_3	TiO_2	CaO	MgO	Na_2O	K_2O	H_2O (—)	H_2O (+)	CO_2	C	Organic	S	SO_3	P_2O_5	H
1	Eddy Lake	Marshall	SE¼SE¼ sec. 29, T. 32 N., R. 2 E.	11.0	2.63	1.67	.69	.028	47.8	0.98	—[1]	—	.63	2.28	38.7	2.40	2.95	1.08	.47	.017	.10
2				3.0	13.9	1.15	1.96	.10	39.1	2.15	.12	.40	.62	2.15	33.9	1.77	2.18	.47	.32	.023	.05
3	Cass Lake	Lagrange	SW¼NW¼ sec. 5, T. 37 N., R. 8 E.	9.5	1.47	1.67	.45	.019	48.6	1.27	—	—	.83	2.50	39.7	2.24	2.76	.43	.20	.020	.18
4				9.0	8.78	.80	1.60	.037	43.0	2.73	.086	.24	.42	2.52	36.3	2.72	3.34	.19	.47	.020	.07
5				4.5	.48	1.52	.98	.037	47.6	1.76	—	—	.53	2.84	38.6	3.57	4.39	.29	.16	.029	.17
6				10.5	.50	.40	.19	.009	50.0	2.05	—	—	.40	2.28	41.1	2.46	3.02	.092	.094	.010	.08
7	Mud Lake	Elkhart	NE¼SE¼ sec. 15, T. 38 N., R. 5 E.	12.1	1.64	.26	.34	.019	50.3	2.05	—	—	.28	1.66	41.7	1.06	1.30	.15	.099	.008	.05
8	Pleasant Lake	Steuben	NE¼NE¼ sec. 23, T. 36 N., R. 13 E.	19.1	.26	.53	.14	*[2]	51.3	.88	—	—	.33	1.87	41.2	1.42	1.75	.84	.52	.008	.05
9	Shaeffer	Steuben	SW¼SW¼ sec. 20, T. 38 N., R. 11 E.	15.0	.72	.18	.28	.019	50.7	1.76	—	—	.31	1.95	41.6	1.77	2.18	.098	.079	.010	.04
10				6.5	4.69	0.66	1.60	.074	48.0	1.17	—	—	.39	2.23	38.1	2.26	2.78	.23	.15	.014	.08

[1] A dashed line in the analytical tables indicates that no determination was made.

[2] Not detected.

contains 32.5 percent CaO, 46.6 percent SO_3, and 29.9 percent H_2O. The pure mineral is commonly white, but it may be various shades of gray brown, red, or pink, depending upon the nature of the impurities. Gypsum is soft and can be easily scratched with the fingernail. Gypsum is softer and lighter than limestone or calcite.

Relatively thick beds of gypsum are found in the lower part of the St. Louis Limestone in southwestern Indiana. Gypsum is mined at an average depth of 500 feet below the surface in Martin County. Individual gypsum beds are variable in thickness; most of them do not exceed 25 feet. In general, 3 major gypsum beds exist, each separated vertically by 40 to 50 feet of limestone and dolomitic limestone.

The National Gypsum Co. and the United States Gypsum Co. are now mining gypsum near Shoals, Martin County, Ind. (pl. 2). Sufficient tonnage of gypsum can be obtained from these two mines to meet the requirements of a cement producer. Bundy (1956) and McGregor (1954) discussed the occurrence of gypsum in Indiana.

IRON OXIDE

Some kind of iron-bearing material is used in all common types of portland cement. In Indiana iron deposits are found in the lower part of the Mansfield Formation. These deposits occur locally and range from a few inches to more than 30 feet in thickness. The iron-oxide content may vary greatly over short distances. Most deposits are confined to hilltops and generally have a soil overburden 10 to 20 feet thick. X-ray powder photographs show that goethite is the predominant iron mineral (Bundy, 1956, p. 10).

The iron oxides occur in sandstone and shale as cementing material, concretions, bands along bedding planes, veins, irregular open-space fillings, and replacements of plants.

Chemical analyses of 4 samples that contain iron oxide are shown in table 12. Samples 1 and 2 are from the same outcrop. Sample 1 represents the lowermost part and sample 2 the uppermost part of the outcrop. Samples 1, 2, and 3 were taken from outcrops containing iron minerals in the form of concretions and cementing material. Sample 4 consists of sandstone containing iron oxides as cementing material along bedding planes.

The iron deposits of Indiana have an irregular and local distribution and probably would be unfavorable to expensive mining installations. Although the deposits may contain iron oxides in

Table 12.—*Chemical analyses (in percent) of iron-oxide deposits*
[After Bundy, 1956, p. 16.]

Sample No.	County	Location	Rock unit	Thickness (feet)	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	MnO	P_2O_5	SO_3	CO_2	H_2O and organic material lost at 1,000° C.
1	Martin	NW¼SE¼ sec. 1, T. 3 N., R. 3 W.	Mansfield Formation	7.5	56.8	2.3	34.2	.28	.21	.85	.04	.35	5.5
2	Martin	NW¼SE¼ sec. 1, T. 3 N., R 3 W.	Mansfield Formation	5.5	69.3	2.6	23.0	.23	.22	.44	.04	.20	3.7
3	Martin	SW¼SW¼ sec. 1, T. 3 N., R. 3 W.	Mansfield Formation	11.0	75.5	.55	20.3	.18	.15	.37	.06	.30	2.9
4	Greene	NW¼SE¼ sec. 25, T. 7 N., R. 5 W.	Mansfield Formation	10.0	84.2	2.1	10.9	.13	.21	.21	.04	.30	2.1

the amount required for portland-cement manufacture, cement producers probably will continue to purchase elsewhere the iron oxides they require.

Bundy (1956) and Shannon (1907) discussed the iron deposits in Indiana in more detail.

SLAG

Blast-furnace slag, a byproduct in the manufacture of steel, may be substituted in part for the raw materials used in the production of portland cement. Slag contains the essential oxides of silicon, aluminum, iron, and calcium that are necessary in making portland cement. When slag is used, the fluxing stone should be high-calcium limestone and not a dolomite with its commonly high magnesium content. The manufactured product except for its lower lime content is similar in composition to other portland cements. The manufacturing process is the same as that for other portland cements. The slag is mixed with limestone and provides part of the lime, silica, alumina, and iron oxides which would otherwise come from other sources.

The Universal Atlas Cement Co. at Buffington, Ind., uses blast-furnace slag from the United States Steel Corp. as raw material for manufacturing portland cement. Limestone is transported by lake freighter from the quarries near Rogers City, Mich., to Buffington Harbor on the south shore of Lake Michigan near Gary, Ind.

Chemical analyses of blast-furnace slags are given in table 13.

FACTORS AFFECTING AVAILABILITY OF CEMENT RAW MATERIALS

The information on cement raw materials in Indiana has come from quarries, strip pits, and natural rock exposures. Most quarry sites were not chosen through geologic exploration but were opened because of an artificial cut or natural rock exposure. Modern operators carefully explore the extent, availability, and character of the rock by diamond core drilling. The cores commonly are analyzed both chemically and physically to determine the various properties of the rock.

Geologic investigation can aid the exploration work which precedes the choosing of a site for a quarry and can help to solve the ultimate problems encountered in establishing a cement mill. A knowledge of regional geology, such as chemical composition, origin and present conditions, distribution and extent, and altera-

Table 13.—*Chemical analyses (in percent) of blast-furnace slags*
[Modified from Chichilo and Whittaker, 1953, p. 2.]

Type of Slag	SiO_2	Al_2O_3	CaO	MgO	S	Fe_2O_3	FeO	MnO	Metallic Fe removed
Finely ground	34.92	10.64	48.82	2.35	1.34	0.88	—	1.39	0.24
Dry granulated	35.3	12.00	44.30	8.00	0.60	—	0.20	0.39	—
Lightweight	38.2	9.18	40.70	9.56	1.09	—	0.20	0.39	—
Air-cooled	33.65	13.91	43.8	5.40	2.11	—	0.34	0.97	—
Granulated	33.61	11.76	39.31	5.04	1.67	—	1.24	0.66	—
Ferro-manganese	28.16	14.07	34.73	10.77	1.75	—	—	6.61	—

tion and decay of a rock unit, helps to restrict prospecting to those areas in which raw material suitable for cement may be expected. Although predictions can be made as to thickness and type of overburden, character of the bedrock surface, depth of weathering, and ground-water conditions, these features should be more thoroughly investigated by drilling or test pitting.

Nongeologic factors, such as transportation facilities, fuel, markets, and population centers, commonly control the location of a cement mill. Therefore geologic factors are not always the most important ones to be considered.

OVERBURDEN

GLACIAL DRIFT

Thickness of glacial drift north of the Illinoian glacial boundary (fig. 2) cannot be predicted accurately. In general the drift is thinner in southeastern Indiana than in southwestern Indiana. Drift thickness generally increases from the Ohio River northward. Limestone-quarry operators in southeastern Indiana commonly strip from 5 to 17 feet of glacial drift and soil from the underlying bedrock. Drift thickness in general is 15 feet or more between the Illinoian and Wisconsin glacial boundaries (figs. 2 and 3).

North of the Wisconsin glacial boundary, limestone is near the surface only in valleys where stream erosion has reduced the thickness of drift or where a preglacial bedrock hill stood high at the time of glaciation and consequently was covered by only a thin veneer of drift. Drift thickness generally ranges from 100 to more than 250 feet.

BEDROCK

Although sandstone and shale may be used to some extent in cement manufacture, they are generally regarded as overburden that must be removed where they lie over limestone. New Albany Shale must be removed in quarrying the Jeffersonville and Sellersburg Limestones. If shale is more than a few feet thick, heavy charges are required to aid in its removal.

Limestones of Chester age are overlain by sandstones or shales. Chester limestones except the Paoli crop out in rugged upland regions, and quarry operators in order to exploit them generally skirt the hillside to avoid excessive rock overburden.

The ultimate solution to excessive rock overburden is underground quarrying. The Ste. Genevieve Limestone is being quarried underground near Marengo, Crawford County, Ind.

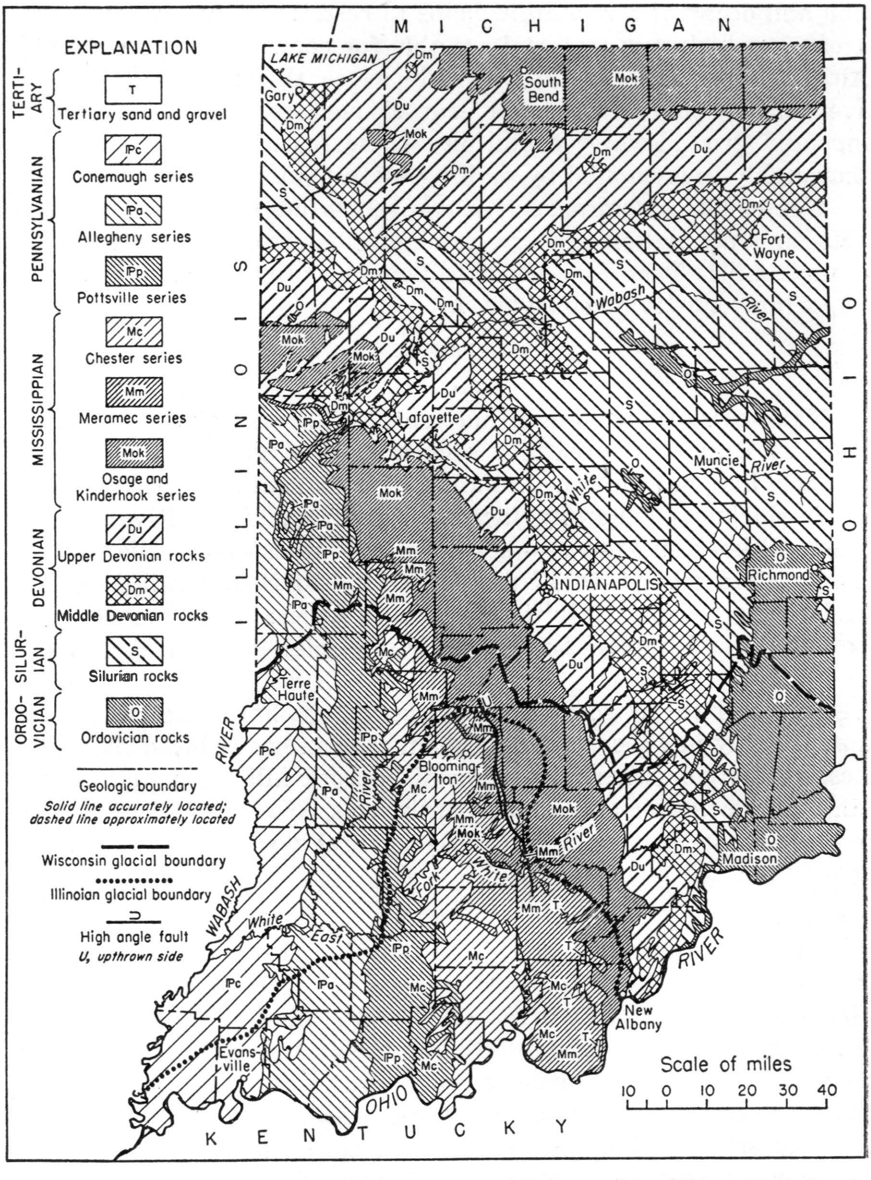

Figure 2.—Generalized bedrock distribution map of Indiana. After Wayne, 1956, fig. 6.

Underground quarries were operated in the early 1900's in Clark County. The Silver Creek Lithofacies of the Sellersburg Limestone was mined by means of room and pillar method. The stone was used as raw material in manufacturing natural cement.

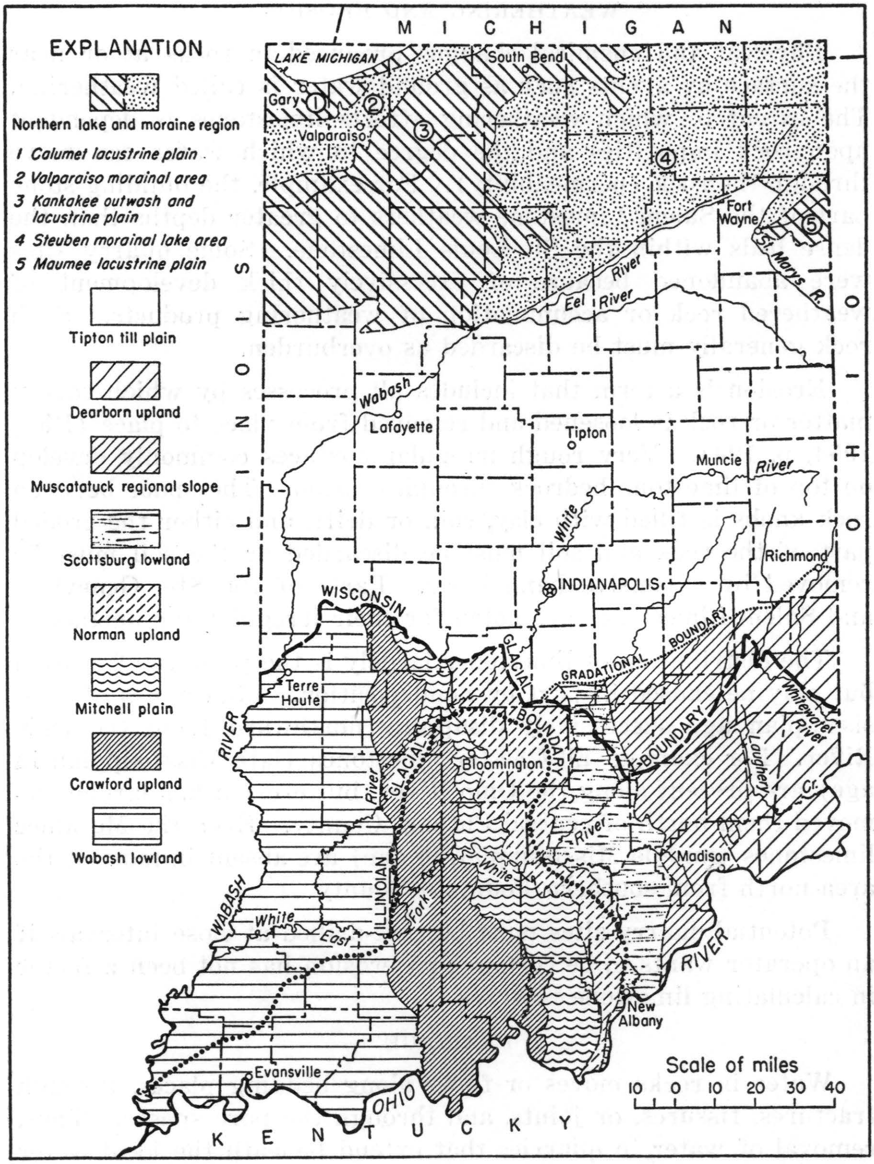

Figure 3.—Map of Indiana showing physiographic units. After Wayne, 1956, fig. 3.

The distribution of bedrock beneath the glacial drift cover is shown in figure 2.

WEATHERING AND EROSION

Physical and chemical changes produced in rocks at or near the surface by agents such as ground water is called weathering. The extent to which weathering affects limestones is dependent upon rock impurities and the degree to which water can move through the rock (permeability). For example, the building-stone part of the Salem Limestone weathers to greater depths than the dense beds within the St. Louis Limestone. Some quarry sites were abandoned because of excessively thick development of weathered rock or accumulation of weathering products. Such rock generally must be discarded as overburden.

Erosion is a term that includes all processes by which earthy matter or rock is loosened and removed from place to place (Rice, 1954, p. 124). Very rough irregular surfaces commonly develop on top of limestone bedrock through erosion. The space between rock knobs is filled with clay, soil, or drift, and either the eroded part of the rock and soil must be discarded or the soil must be removed by expensive hand labor. Parts of the Ste. Genevieve and Salem Limestones are noted for their irregular top surfaces.

The distribution of limestones largely is the product of erosion but may be caused in part by nondeposition. Limestones of Mississippian age successively disappear northward from the Ohio River. For example, all Chester limestones (late Mississippian in age) are present along the Ohio River, but erosion has largely removed them north of central Putnam County. Even the Meramec limestones (middle Mississippian in age) are absent in most of the area north from southern Fountain County.

Potential quarry sites must be core-drilled at close intervals if an operator wants to be certain that erosion has not been a factor in calculating limestone reserves.

DRAINAGE

Water in rocks moves or flows along bedding places, through fractures, fissures, or joints, and through the pore spaces. Thus, removal of water in quarries that extend beneath the local water table is an expense to the operator. The water problem is one that an operator always must consider in deepening a quarry. At least one pump must be used to remove water from a sump in the lowest part of the quarry floor. Small operators, in deepening their quarries, may encounter more water than they can remove economically, and therefore they must extend their quarries laterally.

FAVORABLE REGIONS FOR CEMENT PLANTS

Factors to be considered in establishing a cement plant are: source of raw material, transportation, fuel supplies, and market area. Generally the raw materials are within short distances from the plant site. As limestone constitutes the largest tonnage used, the mill commonly is built near the limestone source, and shale, fuel, iron oxide, and gypsum are brought in from the nearest sources.

The thickness of limestone and the topography are factors that must be evaluated in blocking out limestone tonnage. Thickness of limestone can be determined from cores, and the nature of the land surface is shown by a topographic map. A conservative estimate of limestone tonnage can be made by using the formula $\frac{A \times B \times C}{D} = E \times F$ in which "A" is the area in square feet, "B" is the thickness of limestone, "C" is the weight of a cubic foot of solid limestone in pounds (163), "D" is the number of pounds in a ton (2,000), "E" is the tons available for the area specified, and "F" is a conservative factor (60 percent) that takes into account topographic features such as drainage, ridges, valleys, and slope. For example, if the land area is 1 acre (43,560 sq. ft.), and the thickness of limestone is 50 feet, then $\frac{43,560 \times 50 \times 163}{2,000}$ will equal 177,507 tons per acre. This figure times 60 percent would give the estimated tonnage of limestone available, which is 106,504.2 tons per acre.

About 653 pounds of raw materials are used in making 1 barrel of portland cement which weighs 376 pounds. A plant whose annual production is 2,000,000 barrels would require 1,306,000,000 pounds or 653,000 tons of raw material per year. About 75 percent of this total weight is assigned to limestone. Therefore, the limestone requirement would be .75 x 653,000 or 489,750 tons.

Based on the above formula and data, 1 square mile (640 acres) underlain by 50 feet of limestone would yield about 68,162,688 tons. A cement plant whose annual production is 2,000,000 barrels would have a limestone reserve that would last 139 years.

The relationships of raw materials to railroads and fuel supplies (pl. 2) suggest that the following regions in Indiana are most favorable for establishing cement plants: Bloomington-Spencer-Gosport, Paoli-Mitchell-Bedford, Greencastle, central Clark County, southern Harrison County, and Logansport.

The reserves of limestone in the first 5 regions probably are sufficient to supply a large cement plant for at least 50 years.

Surface studies do not permit an accurate appraisal of the Logansport region, but it must fall within the range of probability. Confirmation of reserves in any of the regions will require careful exploratory drilling.

BLOOMINGTON-SPENCER-GOSPORT REGION

The Bloomington-Spencer-Gosport region lies with the Mitchell Plain and Crawford Upland physiographic units (Malott, 1922) (fig. 3). The Illinoian glacial boundary extends through the central part of the region.

The Mitchell Plain is well developed west of Bloomington, Ind. This generally level plain is locally very irregular because of sinkholes and rugged areas along stream channels. Sinkholes range from slight sags and water-tight depressions to huge basins 50 feet or more deep. In the eastern part of the plain sinkholes are not as numerous, and the topography is gently rolling without distinct gullies along small streams. However, some of the larger streams have cut below the general plain level and developed rocky, steep-sided, gorgelike valleys. In the western part of the plain the surface becomes more dissected and merges with the rugged topography of the Crawford Upland.

The Crawford Upland is a dissected plain. The ridge tops are broad and rounded, hill slopes are relatively gentle, and valleys are broad. Streams rise in the hills and commonly disappear in sinkholes when they reach the valleys. The regional slope is westward at about 20 feet per mile. Bedrock dips to the west at about 25 feet per mile.

Salem, St. Louis, and Ste. Genevieve Limestones (table 7) constitute the bedrock of the Mitchell Plain. Chester formations are encountered in the western part of the Bloomington-Spencer-Gosport region. The shales and sandstones of Chester age resist erosion and thus produce the rugged areas of the Crawford Upland. Maximum relief on the Mitchell Plain is 90 feet, whereas maximum relief in the Crawford Upland is about 200 feet. Outliers of Chester rocks commonly rise 150 feet or more about the sinkhole terrane of the Mitchell Plain. These features appear as rounded knobs or broad, elongated, unconnected ridges.

The upper surface of the limestone commonly is undulatory. The low spaces generally are filled with red clay soil, and the thickness is extremely variable.

Overburden in this region consists of glacial drift, red clay soil, and shales and sandstones of Chester age. The glacial drift north of the Illinoian boundary ranges from a few feet to 50 feet in thickness. Erosion has removed much of the drift from the higher areas, and the material has accumulated in the valley bottoms. Soil cover ranges from 3 to 15 feet in thickness. The thickness of the shales and sandstones is variable, and where it is excessive, underground quarrying may be feasible. The lower limestones in the Chester Series and some of the shales and sandstones, however, may be suitable for cement raw material.

Chemical and spectrographic analyses of stratigraphic sections in the Bloomington-Spencer-Gosport region are shown in tables 14 through 18.[4]

PAOLI-MITCHELL-BEDFORD REGION

The Paoli-Mitchell-Bedford region lies within the Mitchell Plain and Crawford Upland physiographic units (Malott, 1922) (fig. 3). The Mitchell Plain, named by Beede (Malott, 1922, p. 94), is a sinkhole terrane that was developed principally upon the St. Louis and Ste. Genevieve Limestones. The western part of the Paoli-Mitchell-Bedford region is in the more rugged topography typical of the Crawford Upland. High, steep ridges and narrow, winding valleys are the prevailing surface features. The regional slope is westward at about 20 feet per mile. Bedrock dips westward at about 25 to 30 feet per mile.

The St. Louis Limestone is noted for sinkholes. Some of these become plugged with debris and form small ponds or marshes. The upper surface of the Harrodsburg, Salem, St. Louis, and Ste. Genevieve Limestones may be exceedingly undulating, and the low spots are filled with red clay soil. Chester formations are found in the eastern part of the Paoli-Mitchell-Bedford region. Shales and sandstones are characteristic of the Chester Series, and they have little resistance to solution. Chester rocks commonly are found as outliers and appear as knobs and ridges that rise as much as 150 feet above the comparatively level sinkhole plain underlain by the St. Louis and Ste. Genevieve Limestones.

Drainage in the region is both surface and underground. Lost River, a westward-flowing stream, disappears southeast of Or-

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[4] Chemical and spectrographic analyses shown in tables 14 through 34 were made from chip samples of measured stratigraphic sections. Chip samples were obtained by breaking uniformly sized rock chips from the outcrop in such a way as to include representative material in a continuous sequence from the bottom to the top of a rock unit. Where the lithology of one rock unit grades into that of another unit, a single sample was taken. However, most samples represent a single lithology.

Chemical methods were used to obtain carbon dioxide (CO_2), total sulfur (S), and phosphorus pentoxide (P_2O_5). Spectrographic methods were used for all other determinations.

In the table of analyses the unit numbers correspond to those of the measured stratigraphic sections. All results are expressed as weight percentages.

Table 14.—*Chemical and spectrographic analyses (in percent) of samples from the Bloomington Crushed Stone Co. quarry, Monroe County, Ind. (SE¼SW¼ sec. 27, T. 9 N., R. 2 W.)*

Unit	Thickness (feet)	Rock unit	$CaCO_3$	$MgCO_3$	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	MnO	S	P_2O_5	CO_2
25	4.0	Soil										
24	11.6	Bethel[1]										
23	2.3	Paoli	96.3	.73	2.16	.11	.14	—	.039	.019	.055	43.2
22	5.3	Paoli	95.4	.71	2.67	.27	.43	—	.031	.01	.016	43.7
21	4.4	Paoli	96.7	.65	1.85	.12	.14	—	.029	.004	.007	42.8
20	1.6	Paoli	86.8	.88	9.98	.92	.39	.046	.026	.004	.011	41.3
19	1.3	Aux Vases[2]										
18	2.8	Aux Vases[2]										
17	10.7	Ste. Genevieve, Levias Member	96.5	.78	1.80	.31	.13	—	.020	.008	.007	42.7
16	1.4	Ste. Genevieve, Levias Member	57.3	30.5	6.13	1.57	2.40	.086	.044	.42	.028	41.4
15	3.4	Ste. Genevieve, Levias Member	94.9	.85	2.81	.59	.28	.045	.021	.024	.028	42.6
14	0.1	Ste. Genevieve[2]										
13	1.9	Ste. Genevieve, Levias Member	97.1	.59	1.44	.24	.13	—	.018	.006	.028	44.4
12	5.0	Ste. Genevieve, Levias Member	96.3	.80	1.89	.36	.13	—	.015	.027	.007	43.4
11	1.9	Ste. Genevieve, Levias Member	75.0	.61	23.0	.60	.22	.064	.012	.046	.014	34.0
10	2.7	Ste. Genevieve, Levias Member	95.3	.72	3.03	.32	.11	—	.014	.013	.008	43.1
9	2.8	Ste. Genevieve, Rosiclare Member[1]										
8	1.0	Ste. Genevieve, Fredonia Member	97.1	.83	1.07	.32	.15	—	.016	.014	.012	42.7
7	2.5	Ste. Genevieve, Fredonia Member	96.3	.72	2.41	.18	.13	—	.012	.014	.006	42.8
6	2.3	Ste. Genevieve, Fredonia Member	93.5	.78	4.54	.45	.14	.069	.010	.011	.005	41.9
5	2.0	Ste. Genevieve, Fredonia Member	97.6	.85	.88	.26	.14	.051	.013	.022	.004	43.9
4	4.1	Ste. Genevieve, Fredonia Member	93.0	.84	4.76	.68	.17	.068	.010	.029	.008	41.7
3	1.9	Ste. Genevieve, Fredonia Member	98.4	.67	.49	.089	.15	.037	.013	.007	.003	44.2
2	2.8	Ste. Genevieve, Fredonia Member	97.9	.55	1.15	.048	.13	.032	.013	.001	.006	44.1
1	4.3	Ste. Genevieve, Fredonia Member	90.9	.75	7.00	.56	.18	.055	.010	.008	.040	40.7

[1] Not sampled.

[2] Not analyzed.

Table 15.—*Chemical and spectrographic analyses (in percent) of samples from abandoned quarry of the Bloomington Crushed Stone Co., Monroe County, Ind. (SW¼NW¼ sec. 28, T. 9 N., R. 1 W.)*

Unit	Thickness (feet)	Rock unit	$CaCO_3$	$MgCO_3$	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	MnO	S	P_2O_5	CO_2
7	4.5	Soil										
6	7.0	Harrodsburg (upper part)[1]										
5	8.6	Harrodsburg (upper part)	97.0	.96	1.39	.20	.20	—	.019	.14	.067	42.8
4	10.2	Harrodsburg (upper part)	94.8	3.32	1.23	.28	.16	—	.024	.095	.082	43.6
3	10.2	Harrodsburg (upper part)	94.4	2.34	1.89	.44	.40	—	.030	.33	.061	42.1
2	8.5	Harrodsburg (lower part)	89.1	6.67	2.43	.96	.42	.030	.032	.24	.040	42.4
1	11.0	Harrodsburg (lower part)	61.3	22.6	10.8	3.12	1.25	.11	.033	.43	.059	38.3

[1] Not sampled.

Table 16.—*Chemical and spectrographic analyses (in percent) of samples from the Stinesville quarry section, Monroe County, Ind. (NW¼SW¼ and NE¼SE¼ sec. 20, T. 10 N., R. 2 W.)*

Unit	Thickness (feet)	Rock unit	$CaCO_3$	$MgCO_3$	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	MnO	S	P_2O_5	CO_2
8	5.0	Soil										
7	3.7	St. Louis	49.7	28.3	15.3	3.68	1.24	.17	.015	.21	.037	36.8
6	4.7	St. Louis	97.1	1.20	1.21	.17	.13	—	.0080	.030	.005	43.4
5	6.9	Salem	95.7	1.26	2.44	.31	.110	—	.0074	.038	.008	43.0
4	1.1	Salem[1]										
3	11.9	Salem	97.8	1.11	.69	.090	.12	—	.0073	.022	.009	43.6
2	16.0	Salem	97.5	1.13	.99	.065	.087	—	.0062	.029	.013	43.3
1	22.8	Salem	97.9	1.04	.70	.052	.11	—	——	.021	.011	43.4

[1] Not sampled.

Table 17.—*Chemical and spectrographic analyses (in percent) of samples from abandoned quarry of the France Stone Co., Owen County, Ind. (NE¼ sec. 30, T. 10 N., R. 3 W.)*

Unit	Thickness (feet)	Rock unit	$CaCO_3$	$MgCO_3$	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	MnO	S	P_2O_5	CO_2
7	4.2	Soil and glacial drift										
6	2.0	Ste. Genevieve, Levias Member[1]										
5	14.5	Ste. Genevieve, Levias Member	90.8	.98	7.04	.53	.11	.024	—	.009	.014	39.5
4	14.7	Ste. Genevieve, Levias Member	92.5	1.97	4.17	.72	.12	.034	—	.019	.014	41.6
3	14.1	Ste. Genevieve, Levias Member	95.6	1.12	2.42	.56	.12	.022	—	.024	.014	42.4
2	4.9	Ste. Genevieve, Levias Member	92.0	1.48	3.92	1.27	.38	.048	.018	.31	.030	40.6
1	10.4	Ste. Genevieve, Rosiclare Member[1]										

[1] Not sampled.

Table 18.—*Chemical and spectrographic analyses (in percent) of samples from the Dunn Limestone Co. quarry, Owen County, Ind. (NE¼NW¼ sec. 10, T. 10 N., R. 3 E.)*

Unit	Thickness (feet)	Rock unit	$CaCO_3$	$MgCO_3$	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	MnO	S	P_2O_5	CO_2
10	11.6	Soil and glacial drift										
9	11.9	St. Louis[1]										
8	7.0	St. Louis	67.3	19.3	9.28	2.08	.86	.12	.018	.077	.040	39.4
7	0.4	St. Louis[1]										
6	10.8	Salem	89.5	4.38	4.70	.59	.32	.039	—	.041	.013	41.6
5	0.9	Salem	79.1	3.30	13.3	2.70	.86	.24	—	.041	.014	36.2
4	2.7	Salem	74.2	18.6	5.18	.91	.56	.053	—	.029	.015	41.9
3	8.0	Salem	96.7	.88	1.99	.12	.14	—	—	.035	.007	42.6
2	6.0	Salem	97.3	.81	1.51	.097	.11	—	—	.030	.007	43.0
1	4.3	Salem	96.5	1.70	1.22	.12	.27	—	—	.025	.007	43.4

[1] Not sampled.

leans, Ind., and flows by an underground channel with a devious course for a distance of 12 to 15 miles and again rises to flow as a surface stream.

Overburden in this region consists of red clay soil and the shales and sandstones of the Chester Series. Soil cover ranges from 5 to 15 feet in thickness. Where Chester rocks are encountered, the thickness ranges from a few feet to 100 feet.

Chemical and spectrographic analyses of stratigraphic sections in the Paoli-Mitchell-Bedford region are shown in tables 19 through 25.

GREENCASTLE REGION

The Greencastle region lies within the Crawford Upland physiographic unit (Malott, 1922), which is covered by Illinoian and Wisconsin drift (fig. 3). Between the Illinoian and Wisconsin boundaries the drift may be as much as 100 feet thick, but in some areas the drift may be only 10 to 15 feet thick. North of the Wisconsin boundary the drift increases to as much as 150 feet in thickness in the northern part of Putnam County.

The region, in general, is part of an undulating or gently rolling plain broken by stream dissection. The major streams and their tributaries have in many places eroded through the drift and exposed rocks of Meramec and Chester age (middle and late Mississippian) (table 7). In the western part of the region outliers of Pennsylvanian rock also are present.

Along the major streams and their tributaries the relief is rough and may be as much as 90 feet from the stream valley to the top of the bluff. The valley slopes may be precipitous.

The regional surface slope is westward at about 20 feet per mile. The dip (inclination) of the bedrock also is about 20 feet per mile to the west.

Post-Mississippian erosion developed rugged surfaces and in some places completely or partially removed the rock suitable for cement material. Thus a potential quarry site in this region must be core-drilled at close intervals if the operator is to be certain that this erosional surface does not drop below his expected quarry level somewhere on his property.

Chemical and spectrographic analyses of stratigraphic sections in the Greencastle region are shown in tables 26 through 29.

CENTRAL CLARK COUNTY REGION

The central Clark County region lies within the Scottsburg Lowland (Malott, 1922), which is covered by Illinoian drift (fig.

Table 19.—*Chemical and spectrographic analyses (in percent) of samples from the Calcar quarry, Orange County, Ind. (SE¼SE¼ sec. 6, T. 1 N., R. 1 E.)*

Unit	Thickness (feet)	Rock unit	$CaCO_3$	$MgCO_3$	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	MnO	S	P_2O_5	CO_2
18	5.0	Soil										
17	1.5	Beaver Bend[1]										
16	13.4	Bethel[1]										
15	30.2	Paoli[1]										
13-14	4.3	Aux Vases	42.6	18.4	34.8	2.13	.98	.14	.023	.12	.026	28.4
10-12	8.4	Ste. Genevieve, Levias Member	94.6	.69	3.68	.61	.12	.032	—	.020	.011	41.9
9	11.9	Ste. Genevieve, Levias Member	98.8	.48	.40	.10	.035	—	—	.016	.004	43.7
8	5.2	Ste. Genevieve, Levias Member	86.4	11.2	1.22	.31	.35	.024	—	.010	.012	44.0
7	9.5	Ste. Genevieve, Levias Member	84.4	12.5	1.76	.49	.27	.028	—	.028	.022	43.5
6	9.6	Ste. Genevieve, Levias Member	79.8	17.7	1.52	.28	.15	.023	—	.037	.008	44.0
5	6.9	Ste. Genevieve, Levias Member	98.0	.65	.83	.26	.046	—	—	.030	.004	43.5
3-4	6.3	Ste. Genevieve, Rosiclare Member	86.1	5.44	6.84	.82	.22	.034	—	.082	.022	40.5
1-2	9.3	Ste. Genevieve, Fredonia Member	98.3	.86	.44	.16	.043	—	—	.017	.007	43.9

[1] Not sampled.

Table 20.—*Chemical and spectrographic analyses (in percent) of samples from the Cave Stone Co. quarry, Orange County, Ind. (NW¼SE¼ sec. 29, T. 2 N., R. 1 W.)*

Unit	Thickness (feet)	Rock unit	$CaCO_3$	$MgCO_3$	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	MnO	S	P_2O_5	CO_2
9	6.5	Soil										
8	15.0	Ste. Genevieve, Levias Member[1]										
7	7.6	Ste. Genevieve, Levias Member	86.8	8.03	3.51	.69	.43	.046	.014	.017	.015	42.4
6	4.6	Ste. Genevieve, Levias Member	96.8	1.01	1.61	.30	.097	——	.006	.007	.011	43.4
5	5.8	Ste. Genevieve, Levias Member	93.5	2.62	2.66	.48	.20	.036	.0074	.008	.009	43.0
4	7.7	Ste. Genevieve, Levias Member	89.6	7.45	1.95	.30	.20	——	.0063	.020	.005	43.6
3	4.8	Ste. Genevieve, Rosiclare Member	72.4	5.56	19.4	1.12	.38	.10	.0087	.028	.025	33.8
2	0.5	Ste. Genevieve, Rosiclare Member	56.5	2.39	34.2	4.47	1.07	.33	.010	.42	.054	24.1
1	5.3	Ste. Genevieve, Fredonia Member	97.4	1.04	.95	.33	.061	——	.078	.012	.004	43.8

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[1] Not sampled.

Table 21.—*Chemical and spectrographic analyses (in percent) of samples from the Radcliff and Berry quarry, Orange County, Ind. (SW¼SE¼ sec. 24, T. 3 N., R. 1 W.)*

Unit	Thickness (feet)	Rock unit	$CaCO_3$	$MgCO_3$	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	MnO	S	P_2O_5	CO_2
21	6.0	Soil										
18-20	14.9	Paoli	94.6	.80	3.38	.90	.15	.038	.018	.019	.011	42.2
17	3.0	Aux Vases	48.0	32.2	14.9	2.25	1.76	.089	.034	.50	.026	38.6
15-16	8.8	Ste. Genevieve, Levias Member	95.4	.91	2.55	.76	.14	.029	—	.050	.006	42.6
13-14	8.0	Ste. Genevieve, Levias Member	97.4	.66	1.44	.24	.067	—	—	.007	.004	43.6
11-12	8.2	Ste. Genevieve, Levias Member	93.8	3.89	1.64	.24	.091	—	—	.004	.012	43.2
10	8.6	Ste. Genevieve, Levias Member	90.0	6.85	2.08	.36	.12	—	—	.017	.005	43.2
9	9.4	Ste. Genevieve, Levias Member	89.1	7.92	2.21	.26	.10	—	—	.020	.006	43.4
2-8	11.6	Ste. Genevieve, Rosiclare and Fredonia Members	94.8	.69	3.59	.56	.098	.032	—	.022	.007	42.4
1	15.2	Ste. Genevieve, Fredonia Member	98.8	.80	.13	.048	.047	—	—	.011	.003	44.3

Table 22.—*Chemical and spectrographic analyses (in percent) of samples from the Lehigh Cement Co. quarry, Lawrence County, Ind. (S½ sec. 30, T. 4 N., R. 1 E.)*

Unit	Thickness (feet)	Rock unit	$CaCO_3$	$MgCO_3$	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	MnO	S	P_2O_5	CO_2
17	10.0	Soil										
16	10.0	St. Louis[1]										
15	12.0	Salem[1]										
14	7.2	Salem	81.6	15.0	2.42	.33	.20	.029	—	.061	.006	43.3
13	5.5	Salem	86.0	11.2	1.91	.22	.16	.027	—	.25	.007	43.2
12	6.0	Salem	96.4	.84	2.33	.097	.11	—	—	.21	.009	42.3
11	4.2	Salem	89.2	.88	9.19	.081	.13	—	—	.12	.008	39.2
10	16.0	Salem	78.4	18.0	2.39	.39	.27	.034	—	.074	.013	43.3
9	4.7	Salem	96.8	.92	1.63	.086	.32	—	—	.19	.009	43.0
8	2.8	Salem	85.3	10.8	2.29	.62	.38	.032	—	.12	.041	42.5
7	4.3	Salem	88.6	8.66	1.65	.27	.32	.026	—	.13	.016	43.3
6	2.8	Harrodsburg	93.3	3.06	2.05	.49	.57	.029	—	.46	.022	42.4
5	5.2	Harrodsburg	89.7	4.94	3.32	.98	.46	.039	.023	.23	.058	41.9
4	4.4	Harrodsburg	96.8	1.01	1.08	.31	.26	.024	.028	.25	.035	42.6
3	upper 11.9	Harrodsburg	96.9	1.76	.70	.18	.27	—	.018	.13	.041	43.5
3	lower 12.0	Harrodsburg	97.3	1.39	.73	.13	.20	—	.016	.18	.033	43.0
2	12.1	Harrodsburg	93.8	1.85	2.11	.38	.32	.028	.020	1.1	.066	40.6
1	5.5	Harrodsburg	94.2	1.37	2.52	.74	.55	.036	.038	.28	.044	42.2

[1] Not sampled.

Table 23.—*Chemical and spectrographic analyses (in percent) of samples from the Oolitic Ground Limestone Co. quarry, Lawrence County, Ind. (SE¼SE¼ sec. 16, T. 5 N., R. 1 W.)*

Unit	Thickness (feet)	Rock unit	$CaCO_3$	$MgCO_3$	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	MnO	S	P_2O_5	CO_2
7	5.0	Soil										
6	7.4	Salem	97.0	1.24	1.14	.13	.25	—	.0069	.040	.013	43.5
5	1.3	Salem	83.7	8.62	5.65	.84	.61	.072	.014	.045	.058	41.2
4a	11.6	Salem	97.0	1.15	1.34	.095	.16	—	.0082	.037	.013	43.4
4b	8.9	Salem	95.3	1.14	2.65	.15	.23	.025	.014	.026	.030	43.1
3	6.3	Harrodsburg	91.7	2.27	3.37	1.03	.59	.055	.0091	.35	.11	41.3
2	4.5	Harrodsburg	97.5	1.19	.76	.13	.22	—	.014	.058	.044	43.3
1	2.3	Harrodsburg	95.6	1.43	1.42	.29	.69	.032	.030	.39	.085	43.0

Table 24.—*Chemical and spectrographic analyses (in percent) of samples from the P. M. and B. quarry, Lawrence County, Ind. (NW¼NE¼ sec. 33, T. 6 N., R. 1 W.)*

Unit	Thickness (feet)	Rock unit	$CaCo_3$	$MgCO_3$	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	MnO	S	P_2O_5	CO_2
18	5.0	Soil										
8-17	34.0	St. Louis[1]										
6-7	18.2	Salem[1]										
5	11.9	Salem	94.3	3.41	1.41	.14	.24	—	.0068	.037	.005	43.2
4	13.7	Salem	97.2	1.46	.91	.066	.13	—	.0055	.033	.007	43.3
3	5.7	Salem	97.6	1.21	.70	.044	.18	.040	.0052	.050	.008	43.4
2	18.6	Salem	98.0	1.14	.51	.037	.089	—	.0058	.049	.011	43.4
1	7.8	Salem	97.7	1.11	.76	.046	.17	—	.0066	.028	.014	43.5

[1] Not sampled.

Table 25.—*Chemical and spectrographic analyses (in percent) of samples from the Springville quarry, Lawrence County, Ind. (SE¼SE¼ sec. 29, T. 6 N., R. 2 W.)*

Unit	Thickness (feet)	Rock unit	$CaCO_3$	$MgCO_3$	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	MnO	S	P_2O_5	CO_2
27	5.4	Soil										
26	8.6	Beaver Bend	94.6	1.07	2.38	.55	1.10	—	.078	.024	.024	41.8
25	1.6	Beaver Bend[1]										
21-24	26.1	Bethel[1]										
20	11.8	Paoli	95.8	.96	2.24	.51	.21	—	.038	.033	.019	42.4
19	4.6	Aux Vases	63.3	8.48	24.0	1.97	1.18	.12	.033	.20	.038	31.2
18	3.2	Ste. Genevieve, Levias Member	94.0	.98	3.11	1.01	.34	.036	.010	.029	.011	42.0
17	11.9	Ste. Genevieve, Levias Member	97.4	.59	1.35	.25	.12	—	.0093	.011	.004	43.0
16	4.5	Ste. Genevieve, Levias Member	88.7	7.07	2.70	.55	.48	.037	—	.009	.013	43.0
15	6.0	Ste. Genevieve, Levias Member	97.2	.77	1.26	.17	.086	—	—	.004	.014	42.9
14	4.5	Ste. Genevieve, Levias Member	92.2	3.74	2.85	.65	.25	.037	—	.034	.014	42.1
13	15.0	Ste. Genevieve, Levias Member	94.0	3.42	1.84	.34	.12	.027	—	.013	.009	43.3
12	8.0	Ste. Genevieve, Levias Member	94.9	.70	3.08	.84	.23	.036	—	.12	.011	42.0
11	2.7	Ste. Genevieve, Rosiclare Member	68.2	1.52	22.0	2.96	1.16	.14	—	.31	.041	30.4
10	7.0	Ste. Genevieve, Fredonia Member	99.2	.38	.28	.090	.031	—	—	.019	.005	43.6
9	5.7	Ste. Genevieve, Fredonia Member	67.6	22.0	8.56	.86	.37	.054	—	.064	.017	41.4
8	1.7	Ste. Genevieve, Fredonia Member	25.4	.3	73.7	.19	.075	—	—	.012	.034	12.0
7	12.8	Ste. Genevieve, Fredonia Member	95.9	.52	3.12	.16	.073	—	—	.011	.038	42.4
6	23.9	Ste. Genevieve, Fredonia Member	91.2	4.44	3.16	.66	.23	.037	—	.073	.020	42.2
5	2.4	St. Louis	92.0	2.66	4.13	.54	.14	.031	—	.019	.014	41.9
4	3.7	St. Louis	75.0	6.49	17.4	.46	.17	.034	—	.035	.013	36.8
3	1.9	St. Louis	92.5	1.96	4.43	.43	.14	.036	—	.040	.010	41.9
2	5.1	St. Louis	83.1	12.5	3.26	.46	.18	—	—	.079	.023	42.7
1	9.5	St. Louis	83.7	6.33	8.26	.84	.27	.046	—	.068	.051	40.1

[1] Not sampled.

Table 26.—*Chemical and spectrographic analyses (in percent) of samples from the State Farm quarry, Putnam County, Ind. (NW¼SW¼ sec. 17, T. 13 N., R. 4 W.)*

Unit	Thickness (feet)	Rock unit	$CaCO_3$	$MgCO_3$	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	MnO	S	P_2O_5	CO_2
27	7.0	Soil and glacial drift										
26	2.0	Sample[1]										
25	1.0	Beaver Bend[1]										
24	6.0	Bethel[1]										
19 23	20.0	Paoli ?	92.8	.98	4.47	.87	.32	.048	.030	.081	.011	41.5
14-18	13.8	Ste. Genevieve	96.5	.67	2.19	.17	.21	.027	.014	.051	.008	43.3
10a-13	16.2	Ste. Genevieve	93.1	.76	4.84	.39	.34	.036	.010	.13	.022	41.7
8-10	16.1	Ste. Genevieve	94.2	.62	3.98	.41	.27	.038	.0094	.090	.019	42.2
3-7	17.6	Ste. Genevieve	96.0	.73	2.59	.23	.17	.024	.025	.043	.022	42.8
1-2	3.2	St. Louis[1]										

[1] Not sampled.

Table 27.—*Chemical and spectrographic analyses (in percent) of samples from the Manhattan Stone Co. quarry, Putnam County, Ind. (NW¼SW¼ sec. 24, T. 13 N., R. 5 W.)*

Unit	Thickness (feet)	Rock unit	$CaCO_3$	$MgCO_3$	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	MnO	S	P_2O_5	CO_2
9	6.5	Soil										
8	9.5	Ste. Genevieve[1]										
7	5.0	Ste. Genevieve	96.0	.50	2.62	.24	.38	.034	.028	.004	.023	43.2
6	5.3	Ste. Genevieve	96.3	.40	2.47	.26	.34	.033	.022	.086	.010	41.1
5	7.5	Ste. Genevieve	94.9	.77	3.27	.59	.25	.036	.017	.060	.007	42.9
4	11.7	Ste. Genevieve	93.5	.59	4.51	.79	.34	.042	.013	.14	.009	42.0
3	14.7	Ste. Genevieve	94.0	.72	4.11	.70	.22	.034	.0097	.093	.017	42.1
2	10.3	Ste. Genevieve	86.6	6.64	5.18	.59	.38	.029	.014	.090	.018	42.1
1	5.0	Ste. Genevieve	88.9	.78	8.49	.96	.30	.040	—	.080	.060	39.4

---

[1] Not sampled.

Table 28.—*Chemical and spectrographic analyses (in percent) of samples from the Ohio and Indiana Stone Co. quarry, Putnam County, Ind. (Junction of secs. 19, 20, 29, and 30, T. 14 N., R. 4 W.)*

Unit	Thickness (feet)	Rock unit	$CaCO_3$	$MgCO_3$	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	MnO	S	P_2O_5	CO_2
12	5.0	Soil										
9-11	16.2	Ste. Genevieve[1]										
7-8	8.1	Ste. Genevieve	90.2	.71	7.96	.38	.23	.041	.011	.039	.032	41.0
4-6	11.3	Ste. Genevieve	95.7	.70	2.70	.36	.27	.036	.011	.057	.017	42.5
1-3	17.9	Ste. Genevieve	93.6	.75	4.67	.26	.21	.028	.0081	.047	.021	42.1

---

[1] Not sampled.

Table 29.—*Chemical and spectrographic analyses (in percent) of samples from the Russellville Stone Co. quarry, Putnam County, Ind. (NW¼SE¼ sec. 8, T. 16 N., R. 5 W.)*

Unit	Thickness (feet)	Rock unit	$CaCO_3$	$MgCO_3$	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	MnO	S	P_2O_5	CO_2
14	15.0	Soil										
9-13	11.0	St. Louis	82.9	3.36	9.95	1.73	.88	.10	.033	.20	.018	39.2
8	1.9	St. Louis	62.5	15.3	18.2	1.31	1.50	.11	.044	.21	.035	35.2
7	2.3	St. Louis	87.3	1.79	8.19	1.08	.51	.085	.024	.12	.030	40.5
6	3.2	St. Louis	56.5	26.6	11.8	1.73	2.20	.12	.054	.20	.026	38.5
5	6.6	Salem	97.1	.71	1.50	.12	.31	——	.024	.052	.070	43.7
4	3.4	Salem	87.2	1.11	9.94	.63	.52	.052	.022	.21	.080	39.4
3	0.2	Harrodsburg	36.4	3.38	42.3	12.3	2.92	.67	.023	1.0	.059	16.8
2	3.2	Harrodsburg	84.0	1.28	11.4	1.58	.60	.11	.022	.18	.050	37.3
1	8.0	Harrodsburg	89.1	2.55	6.22	.70	.82	.052	.029	.30	.061	41.1

3). This lowland is one of the flattest regions in the State. The major streams and their tributaries have eroded through the drift and soil and exposed Devonian limestone and shale. The major streams have abrupt banks that rise 100 feet above the flood plain. The regional slope is westward about 23 feet per mile. The bedrock also dips toward the west from 25 to 30 feet per mile.

Overburden in this region consists of glacial drift, soil, and Devonian shales. The thickness of overburden is variable and ranges from a few feet to as much as 50 feet.

The Jeffersonville Limestone (table 6) principally is a high-calcium limestone in deposits near the Ohio River but becomes more dolomitic, particularly in its lower and middle parts, in deposits to the north. The Silver Creek Lithofacies (table 6) does not extend appreciably north of Clark County, and the Speed Lithofacies (table 6) is absent at the Ohio River but increases in thickness northward at the expense of the Silver Creek. This change ultimately gives rise to a middle Devonian section that is largely usable for portland cement.

Chemical and spectrographic analyses of stratigraphic sections in central Clark County are shown in tables 30 and 31.

SOUTHERN HARRISON COUNTY REGION

The southern Harrison County region lies within the Crawford Upland and Mitchell Plain physiographic units (Malott, 1922) (fig. 3). The topography is moderately undulating, cut by few streams, but pitted with sinkholes. The underlying bedrock is conducive to underground drainage. The western part of this region, in addition to sinkholes, has isolated or somewhat disconnected steep ridges that make it rugged. The eastern part of this region is hilly, and the surface is cut by several streams. The bluffs along the Ohio River rise 360 feet above the flood plain. Valleys of tributary streams of the Ohio have steep slopes and are precipitous in many places. The regional slope is westward at about 23 feet per mile.

The underlying bedrock formations are principally the St. Louis and Ste. Genevieve Limestones of Meramec age (table 7). Along the west edge of the region lower Chester rocks are found as outliers that remain as erosional remnants. Overburden consists of soil and Chester shales and sandstone but is not considered a serious detriment in selecting a quarry site. Thickness of overburden probably ranges from 5 to 15 feet.

Table 30.—*Chemical and spectrographic analyses (in percent) of samples from abandoned quarry of the Sellersburg Stone Co., Clark County, Ind. (SE½W¼ Grant 90, Clark Military Survey)*

Unit	Thickness (feet)	Rock unit	$CaCO_3$	$MgCO_3$	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	MnO	S	P_2O_5	CO_2
18-20	12.0	Soil and glacial drift										
17	5.0	New Albany[1]										
16	3.8	Beechwood	90.9	4.15	3.82	.20	.38	—	.064	.073	.15	42.0
15	0.2	Silver Creek?	55.7[2]	17.4	14.4	2.73	4.65	.13	.078	1.4	9.2	25.9
14	5.5	Silver Creek	53.7	29.0	11.5	2.33	2.26	.13	.075	.29	.042	38.8
13	1.0	Speed?	66.9	15.4	11.4	2.92	1.23	.16	.056	.33	.042	37.5
12	upper 3.0	Silver Creek	60.5	19.0	13.5	3.19	1.58	.23	.066	.51	.047	36.7
12	lower 6.1	Silver Creek	61.6	17.4	14.1	3.26	1.39	.21	.060	.51	.064	35.8
11	1.8	Speed	82.9	5.08	7.21	1.61	.61	.065	.041	.33	1.8	38.0
10	5.6	Jeffersonville	88.4	5.81	2.97	.19	.53	—	.045	.36	.48	41.5
9	5.6	Jeffersonville	92.2	3.58	3.41	.092	.18	—	.033	.034	.11	42.0
5-8	10.3	Jeffersonville	92.1	3.81	2.38	.68	.45	.034	.022	.31	.009	42.1
4	10.0	Jeffersonville	95.4	.98	3.24	.083	.14	—	—	.078	.004	42.1
2-3	11.3	Louisville	65.4	15.0	14.5	3.22	.81	.12	.024	.42	.010	36.5
1	11.1	Louisville	66.6	13.9	14.5	3.22	.70	.12	.025	.25	.008	36.5

[1] Not sampled.

[2] Includes $Ca_3(PO_4)_2$ expressed as $CaCO_3$.

The possibility of barge transportation of products and some raw materials may cause some companies to regard this region near the Ohio River favorably.

Chemical and spectrographic analyses of stratigraphic sections in the southern Harrison County region are shown in tables 32 and 33.

LOGANSPORT REGION

The Logansport region lies within the Bluffton Plain physiographic unit (Wayne, 1956) (fig. 3). This plain is flat and slopes gently to the north. Glacial drift constitutes the surficial material, and this drift is underlain by Silurian and Devonian limestones and dolomites. Streams have cut through the drift and have exposed bedrock along their courses. The nearly flat upland topography commonly is broken by incised steep-walled stream valleys.

Overburden in the Logansport region is thin only in the valleys of major streams and at a few places in the upland plains area. In some places preglacial and glacial erosion removed much of the bedrock suitable for cement use. In other places bedrock stood as buttresses against erosional agencies and consequently was covered by a relatively thin layer of drift. Little indication exists of the high bedrock surfaces that may be present beneath the drift cover. Drift cover in the Logansport region ranges from a few feet to more than 100 feet in thickness.

The Logansport region (pl. 2) is mentioned here because the Kenneth Limestone (Devonian in age) is known to be 25 feet thick and analyzes more than 95 percent calcium carbonate (table 34). However, the extent of the Kenneth Limestone beneath the drift cover is not known, and therefore the reserves cannot be estimated as in the other five regions. The underlying Kokomo Limestone (Silurian age) (table 4) is a dolomite and cannot be considered a source of cement raw material. Extensive core drilling is necessary to prove or disprove this region as a potential source of limestone for cement.

Cumings and Shrock (1928, p. 109, 124, 131) mentioned a section between Logansport and Georgetown, Ind., in which the Huntington Formation is nearly a pure limestone. Although thickness and extent of the Huntington were not stated, it may be worthy of further exploration as a source of cement raw material.

Table 31.—*Chemical and spectrographic analyses (in percent) of samples from the Louisville Cement Co. quarry, Clark County, Ind. (Grant 132 and SW Grant 131, Clark Military Survey)*

Unit	Thickness (feet)	Rock unit	$CaCO_3$	$MgCO_3$	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	MnO	S	P_2O_5	CO_2
14	5.0	Soil										
13	3.1	Beechwood	91.5	3.39	4.12	.13	.26	—	.060	.082	.15	41.9
12	7.8	Silver Creek	53.2	25.5	15.8	3.24	1.22	.13	.044	.51	.038	36.9
11	6.1	Silver Creek	60.6	19.2	14.1	3.99	.92	.16	.043	.60	.069	35.9
10	4.4	Speed[1]	83.0	5.45	7.96	1.82	.66	.080	.042	.38	.48	38.6
8-9	12.3	Jeffersonville	91.7	4.27	2.44	.21	.32	.022	.043	.20	.41	42.0
6-7	8.6	Jeffersonville	91.9	3.81	2.66	.64	.46	.030	.022	.34	.008	42.6
3-5	11.0	Jeffersonville	94.7	1.75	2.25	.43	.30	.027	.017	.20	.006	42.5
2	3.7	Jeffersonville	92.7	1.98	4.47	.11	.18	—	.013	.075	.003	41.8
1	3.5	Louisville	75.6	4.54	16.9	1.36	.45	.091	.011	.20	.004	35.2

[1] Average for two samples.

Table 33.—*Chemical and spectrographic analyses (in percent) of samples from a section measured near New Boston, Harrison County, Ind. (NW¼SE¼ sec. 1, T. 6 S., R. 4 E.)*

Unit	Thickness (feet)	Rock unit	$CaCO_3$	$MgCO_3$	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	MnO	S	P_2O_5	CO_2
21	4.0	Soil										
20	9.3	Salem	75.5	11.56	9.81	1.64	.88	.090	—	.11	.018	38.3
19	13.7	Salem	92.0	1.56	4.42	.53	.94	—	—	.38	.035	41.1
18	14.3	Salem	75.5	16.3	5.72	1.02	.88	.058	—	.24	.030	41.2
17	11.4	Salem	79.6	13.2	4.72	.90	.97	.052	—	.059	.045	42.0
16	20.0	Salem	68.1	23.4	5.58	1.22	1.14	.058	.027	.049	.038	42.2
15	6.6	Salem	87.8	4.99	4.88	.89	.85	.047	.023	.17	.064	41.0
14	4.2	Harrodsburg (upper part)	42.9	19.7	25.9	7.30	1.60	.59	.017	.40	.056	24.7
13	1.2	Harrodsburg (upper part)	69.7	10.0	16.2	1.98	.99	.10	.017	.13	.033	35.4
12	8.6	Harrodsburg[1] (upper part)										
11	4.5	Harrodsburg (upper part)	87.1	2.11	9.41	.31	.49	.031	.014	.085	.028	41.0
10	4.7	Harrodsburg[1] (upper part)										
9	3.2	Harrodsburg[1] (upper part)										
7-8	28.2	Harrodsburg (upper part)	87.2	1.82	9.23	.62	.59	—	—	.086	.039	39.3
6	0.3	Harrodsburg[1] (upper part)										
5	4.2	Harrodsburg (lower part)	87.5	4.02	6.94	.48	.47	.036	.022	.048	.049	41.3
4a	3.3	Harrodsburg (lower part)	45.8	6.05	44.5	1.75	.79	.010	.018	.034	.050	20.9
4b	1.0	Harrodsburg (lower part)	80.9	3.81	13.8	.40	.53	.033	.023	.088	.030	37.4
4c	1.9	Harrodsburg (lower part)	43.2	2.92	37.4	11.5	2.03	.86	.017	.021	.11	17.6
3	11.0	Harrodsburg (lower part)	89.3	1.48	7.90	.46	.32	.039	.025	.015	.033	40.9
2	8.2	Harrodsburg[1] (lower part)										
1	11.2	Harrodsburg (lower part)	85.3	1.15	12.1	.56	.28	.042	.028	.018	.058	39.3

[1] Not sampled.

Table 32.—*Chemical and spectrographic analyses (in percent) of samples from abandoned quarry near New Amsterdam, Harrison County, Ind. (NE¼NE¼ sec. 12, T. 5 S., R. 2 E.)*

Unit	Thickness (feet)	Rock unit	$CaCO_3$	$MgCO_3$	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	MnO	S	P_2O_5	CO_2
16	1.0	Soil										
14-15	9.3	Paoli[1]										
7-13	15.6	Paoli	95.0	2.34	1.92	.37	.15	—	—	.021	.005	43.4
5-6	3.3	Ste. Genevieve, Levias Member	96.2	.70	2.58	.24	.072	—	—	.020	.010	43.2
1-4	13.8	Ste. Genevieve, Levias Member	98.4	.50	.63	.13	.057	—	—	.017	.004	43.0

[1] Not sampled.

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Shales suitable for cement manufacture are not known to be present in the Logansport region. The closest known sources of argillaceous material are Borden siltstone and shale from the Lafayette region and the New Albany Shale from the vicinity of Remington.

Table 34.—*Chemical and spectrographic analyses (in percent) of samples from the Cass County Stone Co. quarry, Cass County, Ind. (NW¼SE¼ sec. 28, T. 27 N., R. 1 E.)*

Unit	Thickness (feet)	Rock unit	$CaCO_3$	$MgCO_3$	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	MnO	S	P_2O_5	CO_2
10	3.0	Soil										
9	8.9	Kenneth	86.9	.47	12.2	.16	.12	.017	.0087	.023	.004	39.3
8	6.0	Kenneth	95.2	.65	3.63	.18	.13	.020	.0064	.023	.002	42.7
7	5.3	Kenneth	92.5	.76	6.10	.30	.15	.026	.0059	.056	.002	40.5
6	5.4	Kenneth	87.5	3.45	8.16	.20	.14	.020	.014	.058	.002	40.6
5	6.5	Kenneth[1]										
4	4.5	Kokomo	53.7	41.4	1.82	.52	1.41	.03	.072	.006	.013	45.1
3	18.7	Kokomo	55.9	41.8	.95	.23	.57	——	.075	.008	.007	46.5
2	15.9	Kokomo	55.7	40.3	2.17	.66	.58	——	.041	.027	.010	45.4
1	9.3	Kokomo	55.7	41.6	1.34	.36	.44	——	.032	.012	.008	46.2

[1] Not sampled.

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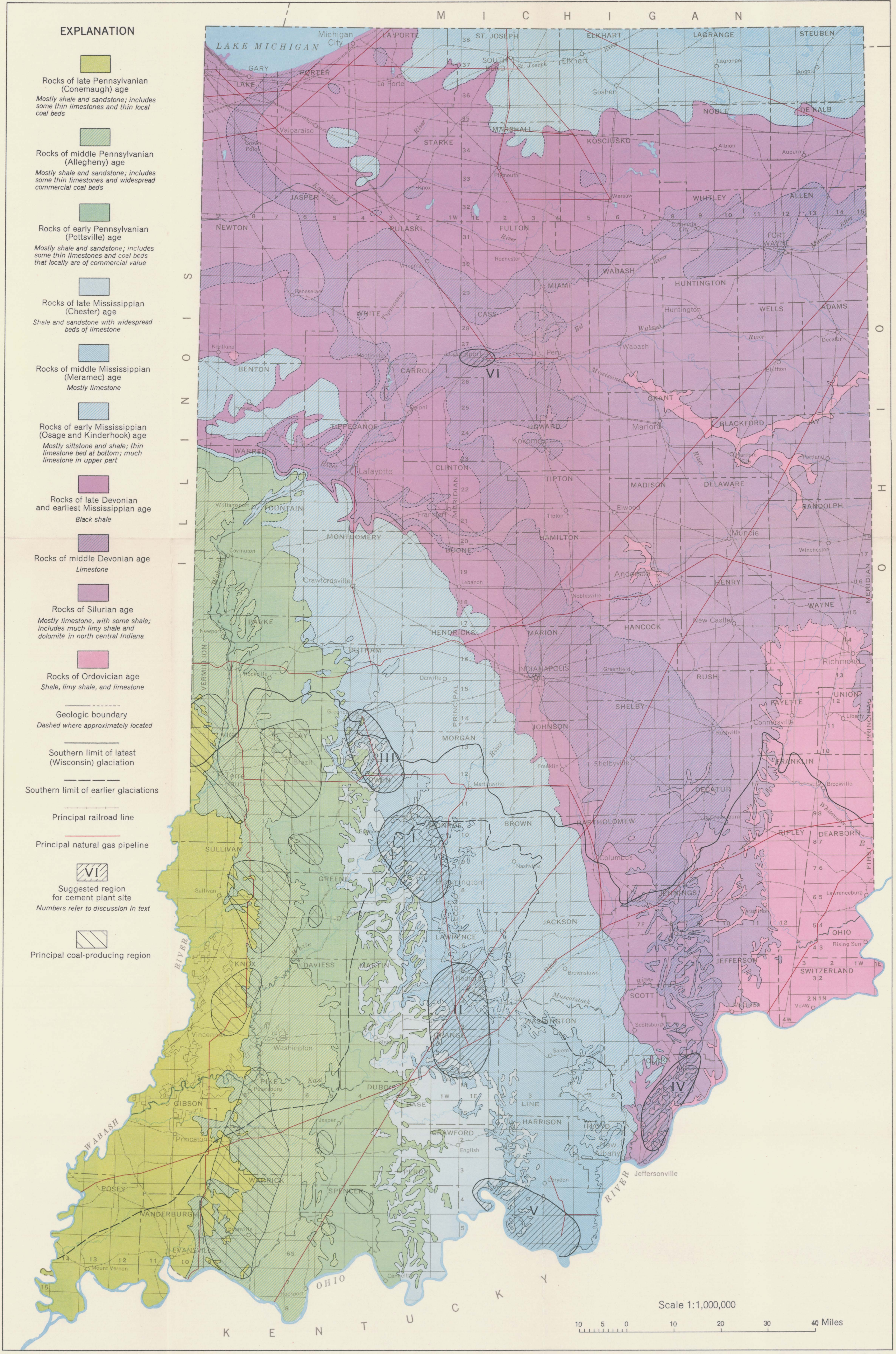
DEPARTMENT OF CONSERVATION
E. KENNETH MARLIN, DIRECTOR

GEOLOGICAL SURVEY
CHARLES F. DEISS, STATE GEOLOGIST

BULLETIN 15, PLATE 2



EXPLANATION

- Rocks of late Pennsylvanian (Conemaugh) age — *Mostly shale and sandstone; includes some thin limestones and thin local coal beds*
- Rocks of middle Pennsylvanian (Allegheny) age — *Mostly shale and sandstone; includes some thin limestones and widespread commercial coal beds*
- Rocks of early Pennsylvanian (Pottsville) age — *Mostly shale and sandstone; includes some thin limestones and coal beds that locally are of commercial value*
- Rocks of late Mississippian (Chester) age — *Shale and sandstone with widespread beds of limestone*
- Rocks of middle Mississippian (Meramec) age — *Mostly limestone*
- Rocks of early Mississippian (Osage and Kinderhook) age — *Mostly siltstone and shale; thin limestone bed at bottom; much limestone in upper part*
- Rocks of late Devonian and earliest Mississippian age — *Black shale*
- Rocks of middle Devonian age — *Limestone*
- Rocks of Silurian age — *Mostly limestone, with some shale; includes much limy shale and dolomite in north central Indiana*
- Rocks of Ordovician age — *Shale, limy shale, and limestone*
- Geologic boundary — *Dashed where approximately located*
- Southern limit of latest (Wisconsin) glaciation
- Southern limit of earlier glaciations
- Principal railroad line
- Principal natural gas pipeline
- VI — Suggested region for cement plant site — *Numbers refer to discussion in text*
- ▨ Principal coal-producing region

Base modified from U. S. Geological Survey Base map of Indiana, 1953.

Geologic boundaries modified from Indiana Geological Survey Atlas Map 9, 1956.

MAP OF INDIANA SHOWING AVAILABILITY OF FUELS, GENERALIZED GEOLOGIC BOUNDARIES, AND SOURCE AREAS OF CEMENT RAW MATERIALS

By Duncan J. McGregor and Haydn H. Murray

1958