

Specialty Sand Resources of Indiana

BULLETIN 42-F



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Specialty Sand Resources of Indiana

By DONALD D. CARR

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Specialty Sand Resources of Indiana

By DONALD D. CARR

Introduction

Specialty sands are sands that can be used for special purposes either because of their high chemical purity or because of their particular distribution of grain sizes. Specialty sands are sometimes called industrial sands or high-silica sands. The geologic occurrence and areal distribution of sands having these special chemical and physical properties are restricted. In Indiana, for example, sands and gravels for aggregate or road construction can be found in nearly every county, but specialty sands can be found in only a few areas.

Because specialty sands have limited occurrence, they can demand a higher unit price than sand and gravel used for general purposes. And because some specialty sands must be shipped long distances, the transportation cost may exceed the raw material cost by several times. Processing in some form is generally necessary to improve either the chemical purity or grain-size distribution. Unconsolidated sands, weakly cemented sandstones, or pebble conglomerates may be used as raw material for specialty sands. If sandstones or conglomerates are used as a raw material, the rock must be disaggregated into discrete grains before further processing.

Specifications for specialty sands are generally exact, but some specifications depend on the material that is available at a reasonable cost. Foundry sands and sands requiring a high chemical purity generally follow precise specifications, but even these specifications are subject to change by negotiation between producer and consumer.

Acknowledgments

Information about specifications for specialty sands was provided by

the following companies: Halliburton Co., Hardy Sand Co., Harrison Steel Co., Indiana Glass Sand Co., Manley Sand Div. of the Martin Marietta Co., Ottawa Silica Co., and Simmons Industries. I gratefully acknowledge the cooperation of these companies and their permission to publish this information.

Unless otherwise stated, all chemical analyses were performed by the Geochemistry Section of the Indiana Geological Survey. All samples were collected and sieve analyses performed by the Industrial Minerals Section.

History of Development and Present State of Development and Economy

The demands by fledgling glass and foundry industries for specialty sands in Indiana were well established by the middle 1800's. Small foundry shops were widely located in principal cities across the state; one of the largest glassworks in the United States was at New Albany in Clark County.

A major expansion of the glass industry in Indiana occurred during the latter part of the 1800's when low-cost fuel became available from the Trenton gasfield in northeastern Indiana. By 1905, 71 glassworks were in operation in Indiana, and these produced about one-third of the total United States production (Burchard, 1907, p. 361-362). Indiana, however, still lacked sufficient reserves of glass sand and had to import more than 99 percent of its raw sand materials.

A spirited search for high-silica sand deposits in the early 1900's resulted in an optimistic forecast of a large glass industry in Indiana. Nineteen counties were reported to have commercial quantities of glass sand (Barrett, 1914, p. 41-59). Sands were produced from the dunes area near Lake Michigan; the Linton Formation (Carbondale Group; pls. 1 and 2) in Parke County; the Mansfield Formation (Raccoon Creek Group; pls. 1 and 2) in Fountain, Putnam, and Martin Counties; the Bethel Formation (West Baden Group; pls. 1 and 2) in Clark, Floyd, Harrison, and Crawford Counties; the Pendleton Sandstone (middle Devonian rocks; pls. 1 and 2) in

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Hamilton and Madison Counties; and sandstone of Silurian or Devonian age in White County.

Specifications imposed on glass sands near the turn of the century were not as stringent as today, so that many sand deposits qualified for glass-making purposes. Often the only specification placed on the sand was that it be "pure white sand." In the early 1900's, however, technologic advancement in the glass industry brought more exacting chemical and physical specifications to glass sands and disqualified many Indiana sand deposits for glass manufacture. At the same time, abundant high-quality glass sand deposits in nearby states and the dwindling supply of low-cost gas from the Trenton Field drove the marginal glass sand operations out of business and put the glass sand industry in Indiana to sleep.

The glass sand industry in Indiana reawoke in March 1964 when the Indiana Glass Sand Co. began production of a high-silica sand from the Bethel Formation (in a deposit formerly called the Ohio River Formation) in southeastern Harrison County. Aided by the Indiana Geological Survey's reports of high-silica sand in the Bethel Formation (Pinsak, 1956; Wayne, 1960), the company undertook an intensive exploration program that led to the opening of its main quarry and plant about 2½ miles east of Elizabeth. This efficient and attractive plant is one of the most modern producers of high-silica sand. In addition to glass sand, the Indiana Glass Sand Co. produces silica flour for filler, scouring powder and other abrasives, stone-sawing sand, sand for manufacturing porcelains, foundry and refractory sands, high-quality masonry sand, and sands for other uses.

Foundry sand production has shown a steady growth and has followed closely the rise and decline of the national economy. High sand production occurred during war years and periods of rapid economic growth when demands for castings were high. Low production occurred during periods of national economic recession.

During recent years the number of foundry sand producers in Indiana has been reduced from many small, widely scattered producers to a few large producers (fig. 1). Indiana's natural molding



Figure 1. Map of Indiana showing counties that produced foundry sand in 1918 and counties that produced foundry sand in 1968. Data for 1918 from Hole and Barrett, 1919, p. 202-205.

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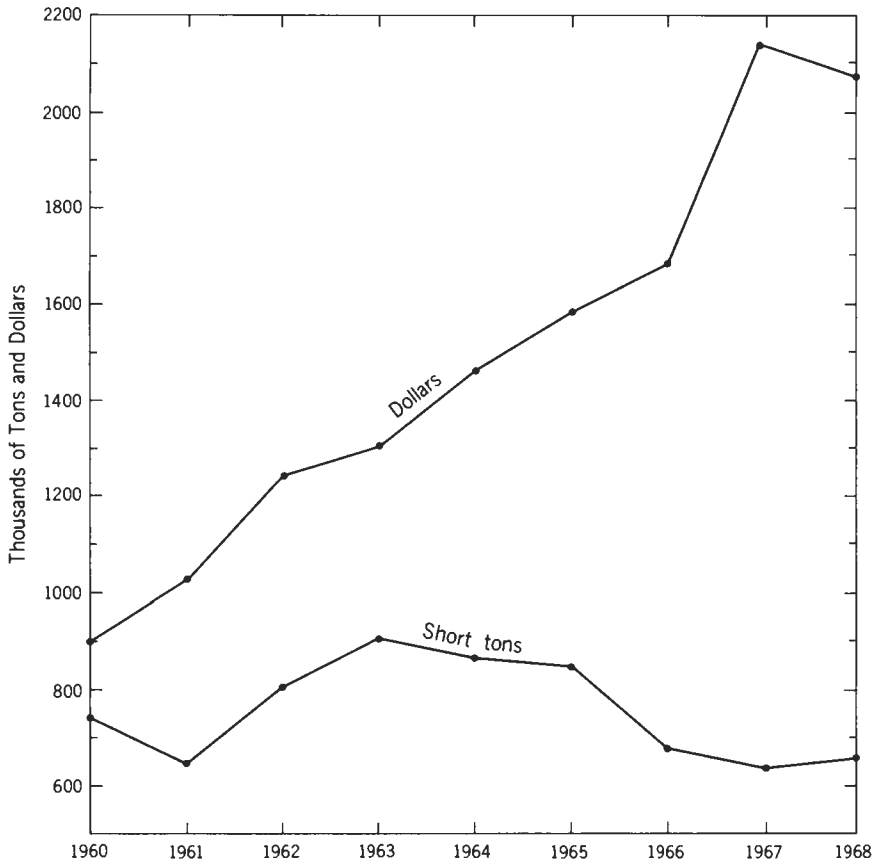


Figure 2. Specialty sand production and dollar value in Indiana, 1969-68. Data from U.S. Bureau of Mines Yearbooks.

sand industry flourished during the 1920's and 1930's. During 1926, Indiana ranked second in state production of molding sand (Logan, 1930, p. 6). As foundries became larger and the demand for sand increased, most foundries turned to using clean sands to which they would add specified amounts of different bonding materials. This trend toward preparing molding sand brought about the demise of the natural molding sand industry in Indiana; the last plant in Spencer County closed in September 1966.

Although annual production of specialty sands in Indiana has fluctuated in recent years, dollar value has increased significantly

(fig. 2). This marked increase in dollar value has resulted partly from inflation, but mainly from increased production of higher priced sands. The demand for specialty sands should continue to grow partly because of an expanding national economy and partly because of an increased use of silicon, silicone, ceramics, and glass that will require large quantities of high-silica material.

Uses of Specialty Sand

Specifications for different uses of specialty sands are expressed generally in terms of chemical content and grain size or grain-size distribution, although the shape of the grains may be important for some specifications. There is no uniform designation of grain size; however, most grain sizes are expressed in terms of U.S. Standard sieves. Table 1 compares different grain-size scales.

ABRASIVES

Most abrasive sand presently produced in Indiana is used for sand-blasting and stone sawing, but some silica sand is ground to flour for use as scouring powder. Sands for other abrasive uses do not constitute an appreciable market at present.

BLASTING SAND: Blasting sand is used extensively in the foundry to remove sand from castings and to clean burrs or scale from forgings. Sandblasting promotes machinability of metals and produces a surface on which industrial coatings can adhere more easily. It is extensively used for stone cleaning and cutting, paint removal, glass cutting, and polishing. Blasting sand is used for cleaning all types of products from heavy iron castings to delicate space-age electronic components. Approximately 1,179,000 short tons of blasting sand valued at \$6,679,000 was produced in the United States in 1968 (U.S. Bureau of Mines Yearbook).

Blasting sand must have hard durable grains. Quartz is most frequently used for sandblasting, but ground chert in lesser amounts finds some market. Only limited quantities of other rocks and minerals, such as garnet, pumice, volcanic ash, and emery, are used.

Table 1. Grain-size scales for clastic sediments

Tyler sieve numbers	U.S. Standard sieve series					Wentworth size classification
	Sieve No.	Openings				
		inches	mm	mm-fraction	microns	
	Use wire squares in inches	10.079	256			Boulder gravel
	2.520	64			Cobble gravel	
					Pebble gravel	
5	5	0.157	4			
6	6	0.132	3.36			
7	7	0.111	2.83			
8	8	0.0931	2.38		Granule gravel	
9	10	0.0787	2.00			
10	12	0.0661	1.68			
12	14	0.0555	1.41		Very coarse sand	
14	16	0.0469	1.19			
16	18	0.0394	1.00		1000	
20	20	0.0331	0.840		840	
24	25	0.0280	0.710		710	
28	30	0.0232	0.590		590	
32	35	0.0197	0.500	1/2	500	
35	40	0.0165	0.420		420	
42	45	0.0138	0.350		350	
48	50	0.0117	0.297		300	
60	60	0.0098	0.250	1/4	250	
65	70	0.0083	0.210		210	
80	80	0.0070	0.177		177	
100	100	0.0059	0.149		149	
115	120	0.0049	0.125	1/8	125	
150	140	0.0041	0.105		105	
170	170	0.0035	0.088		88	
200	200	0.0029	0.074		74	
250	230	0.0024	0.0625	1/16	62.5	
270	270	0.0021	0.053		53	
325	325	0.0017	0.044		44	
400	400	0.0015	0.037		37	
			0.0313	1/32	31.3	
			0.0156	1/64	15.6	
			0.0078	1/128	7.8	
			0.0039	1/256	3.9	
					Clay	

Special requirements determine whether grains of blasting sand should be angular or rounded (table 2). Angular grains will cut faster and leave a rougher surface. Rounded grains generally will not cut as fast as angular grains but will leave a smoother surface, which is desirable for some work. Grades of blasting sand vary between different producers and depend largely on the character of the natural deposit. These grades are given particular names by some companies. Grain-size distribution is important in determining which sand will be most effective for a particular blasting requirement (table 3).

SCOURING POWDER: Scouring powders require a pure silica flour (table 2). A white color, uniform particle size, and angularity of grains are desirable.

STONE-SAWING SAND: Stone-sawing sand must consist of hard durable grains that are well sorted and free of material that will discolor the stone (table 2). Because angular or rounded grains appear to work equally well, which grain size is used depends on the individual preference of the quarry operator. Size of the sand grains is generally within the range of 30 to 100 mesh.

A large quantity of stone-sawing sand is consumed in Indiana's dimension limestone belt in Lawrence and Monroe Counties, where more than 60 percent of the domestic dimension limestone is produced. Stone-sawing sands used in the dimension limestone industry are crushed cherts, popularly called "chat" from Missouri (Boone Formation), silica sand from Illinois (St. Peter Sandstone), and more recently silica sand from southern Indiana (Bethel Formation).

GLASS AND CHEMICAL

Sands used for glass, porcelain, and chemical products must meet extremely high chemical and physical specifications (table 2). Chemical purity and grain size are so important that processing is always necessary to beneficiate the product. For these reasons, glass, porcelain, and chemical sands have the highest unit value of the specialty sands.

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Table 3. Approximate grain-size distribution and typical uses of blasting sand
[Modified from Society of Automotive Engineers, Manual SP-124, p. 9]

	Percentage retained on U.S. Standard sieve size (square openings)							Typical uses
	8	10	14	20	30	50	Less than 50	
Fine:								
Grade 1	0.0	0.0	0.0	0.0	1.5	78.5	20	Blasting soft metal castings for "satin" finish. Used occasionally for plastics and for glass cutting.
Grade 2	0.0	0.0	0.0	5.0	43.0	48.0	4.0	Blasting soft metal castings.
Grade 3	0.0	0.0	25.0	49.0	23.0	3.0	0.0	Blasting castings, for enameling, and for lettering stone.
Grade 4	0.0	0.0	36.0	51.0	11.0	2.0	0.0	Blasting for metallizing and for stone cleaning.
Grade 7	1.0	10.0	45.0	32.0	10.0	2.0	0.0	Blasting for metallizing, for general cleaning of scale, castings, and stone, and for paint removal.
Grade 7 Special	1.0	12.5	47.0	36.0	3.5	0.0	0.0	Blasting for metallizing, for general cleaning of scale, castings, and stone, and for paint removal.
Coarse:								
Grade 10	8.0	40.0	37.0	12.0	1.5	1.5	0.0	Heavy blasting, for paint removal and corrosion removal.

Table 4. Specifications for the chemical composition of glass sand
based on ignited samples
[From Ries, 1949, p. 973]

Quality	SiO ₂ minimum (pct)	Al ₂ O ₃ maximum (pct)	Fe ₂ O ₃ maximum (pct)	CaO + MgO maximum (pct)
First quality, optical glass - -	99.8	0.1	0.020	0.1
Second quality, flint glass containers and tableware - -	98.5	0.5	0.035	0.2
Third quality, flint glass - - -	95.0	4.0	0.035	0.5
Fourth quality, sheet glass, rolled and polished plate - -	98.5	0.5	0.060	0.5
Fifth quality, sheet glass, rolled and polished plate - -	95.0	4.0	0.060	0.5
Sixth quality, green glass containers and window glass -	98.0	0.5	0.300	0.5
Seventh quality, green glass - -	95.0	4.0	0.300	0.5
Eighth quality, amber glass containers - - - - -	98.0	0.5	1.000	0.5
Ninth quality, amber - - - -	95.0	4.0	1.000	0.5

GLASS SAND: Quartz sand is the major raw material used in manufacturing glass and makes up 52 to 65 percent by weight of the mix (Bates, 1969, p. 101). Glass sands must be uniformly graded without an excess of coarse or fine particles. Midwest and eastern glass producers use sand that will pass a 30-mesh sieve with a maximum of 2 percent passing a 140-mesh sieve (Murphy, 1960, p. 764). Specifications for the chemical composition of glass sand are given in table 4.

Specifications for glass-melting sand used for glass fibers are variable from one plant to another, but one report (Olson, 1970, p. 15) states that a maximum of 0.1 percent Fe₂O₃ and 0.3 percent Al₂O₃ by weight is allowable.

PORCELAIN SAND: Specifications for sand used in manufacturing porcelain are similar to those of glass sand (table 2).

SILICON CARBIDE AND SODIUM SILICATE SAND: Sands used for chemical

purposes, such as the production of silicon carbide and sodium silicate, must pass chemical specifications similar to those required for glass sand (table 2).

Sand grains for silicon carbide production generally must pass a 20-mesh sieve with a maximum of 15 percent passing a 50-mesh sieve. Grain sizes of less than 100 mesh are not desirable. Sodium silicate production requires sand that will pass a 20-mesh sieve with a maximum of 5 percent passing a 100-mesh sieve. Actual requirements for grain size are generally negotiable between the customer and the producer.

METALLURGICAL

Metallurgical pebble, used in producing metallic silicon alloys, must be a silica material with grain size ranging from about 3/8 inch to 6 or 8 inches (table 2). Chemical requirements are a maximum of 0.4 percent Al_2O_3 , a maximum of 0.3 percent base oxides, and not a trace of phosphorus and arsenic (Murphy, 1960, p. 766).

REFRACTORY

Refractory sands must have chemical and physical properties that will allow them to withstand the high temperatures resulting from contact with molten metal (table 2), and they must be low in minerals that would sinter and impart undesirable properties to the molten metal. The sands must possess a particle-size range that will allow them to be formed or molded into desired shapes. In addition, the sand particles must be rounded and sorted to a degree that will give a high permeability and allow steam and gases to escape when the molten metal is poured into the mold.

MISCELLANEOUS

Many special uses of sand stress physical size of the grains rather than chemical composition. In many areas, consumers obtain these sands from the nearest local source, usually an aggregate-processing plant.

ENGINE SAND: Engine sand is used to increase the traction of locomotives.

tive drive wheels and requires dry, free-flowing quartz sand of fine- to medium-grain size. Only small amounts of soft particles and debris can be tolerated (table 2). The grain size that is used most often depends on the size that is available from a local source; however, fine-grained sands are preferred because they adhere better to the rails. A size gradation sometimes used in Indiana for engine sand corresponds to Indiana Highway Specification 14, No. 2 (Indiana State Highway Commission, 1969, p. 415).

FILTERING SAND: Filtering sands and gravels are used to remove sediment and bacteria from water-supply systems and should be composed largely of well-sorted round to subround quartz grains (table 2). Filter beds are generally built in layers so as to achieve a porosity of 35 to 40 percent. Grain sizes range from $\frac{1}{4}$ inch to $3\frac{1}{2}$ inches for the lower courses and from $\frac{3}{32}$ to $\frac{1}{4}$ inch for the upper courses (Murphy, 1960, p. 770).

Requirements for gravels used as sewage-trickling media are similar to other filtering sands except that a coarser material is desired (table 2). Usual specifications permit a 1-inch limit between the upper and lower size limits, so that a specification may call for sizes 1 to 2 inches, $1\frac{1}{2}$ to $2\frac{1}{2}$ inches, or 2 to 3 inches (American Society of Civil Engineers, 1937, p. 10).

Sands used to remove sludges from water, such as from industrial wastes, are much finer and like other filtering sands must be well sorted (table 2). One specification for a fine sand requires a maximum of 15 percent passing a No. 50 sieve and not less than 95 percent passing a No. 8 sieve. The specification for base sand requires that 15 percent pass a No. 8 sieve and not less than 95 percent pass a No. 4 sieve (American Society of Civil Engineers, 1937, p. 39).

HYDRAULIC FRACTURING SAND: Hydraulic fracturing sand is widely used in oilfields and gasfields to increase permeability within a producing formation. Sand in a fluid medium is pumped under pressure into the producing formation, and the rock is thereby broken apart. The fluid medium is then removed under low pressure; the sand remains behind in the newly opened fractures. The sand acts as a prop to keep the fractures open so that oil and gas can move more easily.

Specifications differ between companies that offer fracturing services and even within the same company according to local requirements. To reduce transportation costs, sand is generally obtained from the nearest supply, even though it may not meet all specifications.

The most frequently used size of fracturing sand has a minimum of 98 percent grains passing a 20-mesh sieve with a maximum of 5 percent passing a 40-mesh sieve. Particle sizes range from No. 4 to No. 70 sieve (table 2). Fracturing sands should be composed of greater than 98 percent silica and less than 0.5 percent clay, silt, and soft particles. Rounded sand grains of uniform size are preferred because they flow better in the fluid medium, pack better in the fractures, and give a greater permeability; however, sands composed of subround to angular grains are sometimes used.

Geologic and Geographic Occurrences of Specialty Sands in Indiana

Certain rock units in Indiana are considered more promising than others for special-purpose sands because they have a high silica content or special distribution of grain sizes and because they lie near the surface and can be mined easily. The most promising special-purpose sand deposits are discussed briefly below.

QUATERNARY SYSTEM

Large quantities of sand and gravel were deposited in Indiana either directly or indirectly because of Pleistocene glaciation. (See Carr and Webb, 1970.) Many of these sands are suitable for special purposes because of their high silica content or grain-size distribution.

Beach and dune sands, found extensively in northwestern Indiana near Lake Michigan, are presently being used for such special purposes as core sand, engine sand, mortar sand, blasting sand, molding sand, and furnace sand (figs. 3 and 4). At one time dune sand was used in making bottle glass and refractory brick.

Composition of beach and dune sand near Lake Michigan has been reported to be greater than 90 percent quartz (Cressey, 1928, p. 31-



Figure 3. Mining dune sand, Crisman Sand Co., Porter County.



Figure 4. Processing and drying dune sand, Manley Sand Div., Martin Marietta Corp., LaPorte County.

Table 5. Grain-size distribution and chemical composition (in percent) of dune sands near Lake Michigan
[Data from Bieber and Smith, 1952, p. 15-19]

Sample type	Sieve sizes (Tyler series)						SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	MgO	CaO	Na ₂ O	TiO ₂	ZrO ₂
	28	48	80	100	200	Less than 200								
Michigan beach sand ¹	0.45	21.57	69.78	7.14	0.41	0.65	91.9	3.8	0.53	0.41	1.4	0.38	0.085	0.0073
Tolleston Beach sand ²	0.68	90.38	7.54	1.08	0.29	0.02	91.4	4.7	0.50	0.26	0.8	0.38	0.071	0.0032
Calumet Beach sand ³	2.51	87.02	7.48	1.15	1.15	0.69	86.7	5.0	1.40	0.79	3.0	0.32	0.28	0.0068
Glenwood Beach sand ⁴	0.21	53.56	34.98	4.94	5.79	0.52	89.7	6.2	0.82	0.21	0.6	0.55	0.20	0.0079

¹Michigan beach sand collected from Producers Core Sand Co. pit, LaPorte County, SW¼NW¼ sec. 22, T. 38 N., R. 4 W.

²Tolleston Beach sand collected from Box Sand Co. pit, Porter County, NW¼NE¼ sec. 3, T. 36 N., R. 7 W.

³Calumet Beach sand collected from Crisman Sand Co. pit, Porter County, NE¼SE¼ sec. 1, T. 36 N., R. 7 W.

⁴Glenwood Beach sand collected from Lake County, NW¼NW¼ sec. 16, T. 35 N., R. 9 W.

Table 6. Chemical analyses of dune sand in Lake, Porter, and LaPorte Counties

Composition	Number of samples tested	Mean ¹ (pct)	Range	
			Maximum (pct)	Minimum (pct)
SiO ₂ ----	9	88.8	90.8	86.1
Al ₂ O ₃ ---	9	4.6	6.2	3.8
Fe ₂ O ₃ --	9	0.73	1.4	.50
MgO ----	9	0.37	.79	.16
MnO ----	—	—	—	—
CaO ----	9	1.2	3.0	0.4
Na ₂ O ---	9	0.41	.6	.31
K ₂ O ----	—	—	—	—
TiO ₂ ----	9	0.13	.28	.07

¹The mean is the arithmetic average value expressed in weight percentage.

32). Variation in composition of the sands is known to exist, however, because different areas correspond to different levels of Lake Chicago, the ancient glacial lake that eventually developed into present-day Lake Michigan. These different lake levels have been called Glenwood, Calumet, Tolleston, and Michigan phases, and the dune sands associated with these different lake levels exhibit differences in grain-size distribution and in chemical composition (table 5). Chemical analyses of dune sand from Lake, Porter, and LaPorte Counties indicate that the average SiO₂ content is less than 90 percent (table 6). These sand grains are subround to round, generally with a modal frequency between 48 and 100 mesh (table 5), and an American Foundrymen's Society grain fineness of 45 to 70 (Bieber and Smith, 1952, p. 20). Some dune sands near Lake Michigan and in the Kankakee area in Illinois contain a high percentage of feldspar, many of them greater than 20 percent (Willman, 1942, p. 29-31; Hunter, 1965, p. 17).

Other areas in Indiana contain sizable deposits of loess- and wind-deposited sands (Wayne, 1958), some of which are suitable for commercial use as special-purpose sands. The Hardy Sand Co. of Evansville mined a natural molding sand, consisting of wind-deposited sands, silts, and clays, for about 50 years in Spencer County near the Ohio River; it ceased mining these deposits in September 1966.

PENNSYLVANIAN SYSTEM

A characteristic feature of Pennsylvanian sedimentation in the Illinois Basin was the widespread deposition of sandstones. Pennsylvanian sandstones compose about 33 percent of the total Pennsylvanian sedimentary rock in southeastern Illinois (Potter, 1963, p. 13). Pennsylvanian rocks crop out in western and southwestern Indiana (pl. 1), and one of the sandstones is presently being used as a special-purpose sand. The Pennsylvanian sandstones most prospective for special purposes are described below.

MANSFIELD FORMATION: Sandstones make up about 60 percent of the Mansfield Formation (Gray, 1962, p. 12) and crop out from Warren County in west-central Indiana to the Ohio River in southern Indiana. Sandstones from this formation are used currently only for foundry sands, but in the past they were used for refractory materials and for glass manufacture.

The thickest sandstones of the Mansfield are those categorized as cross stratified (Gray, 1962, p. 18). These sandstones are generally medium to fine grained, but coarse-grained sandstones and pebble conglomerates are found in places. Individual cross-stratified beds average about 17 feet in thickness. A sieve analysis of a Mansfield quartzose sandstone, similar to one presently being used as foundry sand, is given below.

*Sample taken from a unit 40 feet thick in the E $\frac{1}{2}$ NW $\frac{1}{4}$ sec. 35,
T. 13 N., R. 6 W., Clay County, 4.5 miles east of Brazil
1 mile south of U.S. Highway 40*

[Modified from Greenberg, 1960, p. 12 and 21]

Sieve No. (U.S. Standard)	Percentage by weight retained on sieve
20 -----	0
40 -----	<1
60 -----	38
100 -----	51
140 -----	7
200 -----	2
Less than 200 -----	3



Figure 5. Sandstones of the Mansfield Formation exposed in the Harrison Steel Co. quarry about 1 mile southwest of Attica in the NW¼SE¼ sec. 13, T. 21 N., R. 8 W., Fountain County. These sandstones are crushed and used for molding sand.

Chemical analyses of Mansfield sandstones collected by the Indiana Geological Survey for high-silica evaluation are summarized in table 7.

Mansfield sandstones are used by the Harrison Steel Co. in Attica (Fountain County) for molding sand (fig. 5). After crushing, these sandstones produce a high-quality molding sand with an American Foundrymen's Society grain fineness of about 65.

A particularly high-quality quartz pebble conglomerate of the Mansfield was quarried southwest of Shoals and used as a refractory material until 1967. The coarseness of this deposit was unusual because most Mansfield deposits are much finer. Similar deposits have been reported near Buddha, Mitchell, and Williams in Lawrence County and at several places in Martin County (Indiana Geological Survey, 1957, p. 21). A sieve analysis and chemical analyses of the SiO_2 content of both the unprocessed and processed sand are given below.

*Sample collected from General Refractories, Inc., quarry in the
NE¼NE¼ sec. 3, T. 2 N., R. 4 W., and SE¼SE¼ sec. 34,
T. 3 N., R. 4 W., Martin County*

Sieve No. (U.S. Standard)	Percentage by weight retained on sieve
0.5 -----	0
0.185 -----	17.4
8 -----	15.1
20 -----	26.0
40 -----	18.5
60 -----	5.9
100 -----	4.4
200 -----	6.7
Less than 200 -----	6.0

SiO₂ composition (percentage by weight)

Unprocessed sample (pit run) -----	96.4
Processed sample -----	99.3

Table 7. Chemical analyses of sand from the Mansfield Formation in Indiana

Composition	Number of samples tested	Mean ¹ (pct)	Range	
			Maximum (pct)	Minimum (pct)
SiO ₂ ----	48	96.3	98.2	86.4
Al ₂ O ₃ ---	50	2.6	9.4	1.2
Fe ₂ O ₃ --	51	0.66	3.8	0.08
MgO ----	52	0.05	0.10	0.02
MnO ----	40	0.003	0.02	0.001
CaO ----	42	0.08	1.0	0.01
Na ₂ O ---	40	0.12	0.94	0.01
K ₂ O ----	19	0.38	1.8	0.14
TiO ₂ ----	52	0.24	0.45	0.13
ZrO ₂ ----	30	0.035	0.08	0.004

¹The mean is the arithmetic average value expressed in weight percentage.

Table 8. Chemical analyses of sand from the Linton Formation in Indiana

Composition	Number of samples tested	Mean ¹ (pct)	Range	
			Maximum (pct)	Minimum (pct)
SiO ₂ ----	4	90.6	96.3	84.0
Al ₂ O ₃ ---	4	6.1	11.0	2.1
Fe ₂ O ₃ --	4	1.52	2.7	0.66
MgO ----	4	0.32	0.62	0.02
MnO ----	4	0.013	0.02	0.003
CaO ----	4	0.32	0.77	0.05
Na ₂ O ---	4	0.23	0.41	0.10
K ₂ O ----	2	0.32	0.36	0.28
TiO ₂ ----	4	0.27	0.47	0.16
ZrO ₂ ----	4	0.015	0.03	0.008

¹The mean is the arithmetic average value expressed in weight percentage.

OTHERS: Other middle and upper Pennsylvanian sandstones cropping out in southwestern Indiana may serve as special-purpose sands when the demands for specialty sands increase. Sandstones of the Staunton, Linton, Petersburg, Dugger, and Shelburn Formations and of the Merom Sandstone Member (Mattoon Formation) in general have

Table 9. Chemical analyses of sand from the Merom Sandstone Member in Indiana

Composition	Number of samples tested	Mean ¹ (pct)	Range	
			Maximum (pct)	Minimum (pct)
SiO ₂ ----	2	87.7	87.8	87.6
Al ₂ O ₃ ---	3	6.3	7.0	5.2
Fe ₂ O ₃ --	3	1.32	1.8	0.98
MgO ----	3	0.23	0.25	0.20
MnO ----	3	0.01	0.008	0.007
CaO ----	3	0.08	0.09	0.08
Na ₂ O ---	3	0.69	0.9	0.38
K ₂ O ----	2	1.25	1.3	1.2
TiO ₂ ----	3	0.41	0.48	0.38
ZrO ₂ ----	3	0.03	0.04	0.03

¹The mean is the arithmetic average value expressed in weight percentage.

a silica content of more than 85 percent and some of more than 96 percent (Greenberg, 1960, p. 52). Grain size varies considerably between the different units, but of the sandstones tested by the Indiana Geological Survey, the Linton and the Merom contained the coarsest grains, the Shelburn contained the finest grains, and the Staunton, the Petersburg, and the Dugger contained intermediate-size grains (Greenberg, 1960, p. 30).

Chemical analyses of sandstones of the Linton and Merom collected by the Indiana Geological Survey for high-silica evaluation are summarized in tables 8 and 9.

MISSISSIPPIAN SYSTEM

Sandstones of Mississippian age are primarily restricted to the Borden Group (Valmeyeran Series) and the Stephensport and West Baden Groups (Chesterian Series) in Indiana (pl. 2).

Rocks of the Borden Group consist mainly of siltstones and shales that range in thickness along the Indiana outcrop from about 750 feet in central Indiana to about 400 feet in southern Indiana. Scattered thin to medium beds of fine-grained sandstones are found within this clastic sequence, but they generally lack sufficient thickness or chemical purity to make them desirable as special-purpose sands.

Sandstones of the Chesterian Series, which make up 25 percent of the total Chesterian rocks along the south edge of the Illinois Basin (Potter, 1963, p. 13), crop out in western and southwestern Indiana. Some of these sandstones have a chemical content and a grain-size distribution that make them suitable for special purposes. The most prospective of these sandstones are discussed below.

BIG CLIFTY FORMATION: Sandstones of the Big Clifty (formerly called the Cypress Sandstone) range from 25 to 40 feet in thickness and crop out extensively in southern Indiana from Owen County to the Ohio River. These sandstones are generally buff to gray, massive bedded, and relatively resistant to erosion (Murray and Patton, 1953, p. 12). A sieve analysis of Big Clifty sandstone is given below.

*Sample taken from a unit 18 feet thick in the NW¼SE¼ sec. 9,
T. 1 S., R. 1 W., Orange County, about 2.3 miles southwest of
Youngs Creek and 140 feet north of a gravel road
[Modified from Greenberg, 1960, p. 13 and 20]*

Sieve No. (U.S. Standard)	Percentage by weight retained on sieve
20 -----	0
40 -----	7
60 -----	14
100 -----	43
140 -----	19
200 -----	10
Less than 200 -----	7

Chemical analyses of Big Clifty sandstones collected for high-silica evaluation by the Indiana Geological Survey are summarized in table 10.

Table 10. Chemical analyses of sand from the Big Clifty Formation in Indiana

Composition	Number of samples tested	Mean ¹ (pct)	Range	
			Maximum (pct)	Minimum (pct)
SiO ₂ ----	16	95.6	97.2	90.1
Al ₂ O ₃ ---	16	2.6	4.8	1.7
Fe ₂ O ₃ --	16	0.33	0.82	0.13
MgO ----	16	0.05	0.13	0.03
MnO ----	16	0.002	0.006	0.001
CaO ----	16	0.23	1.2	0.08
Na ₂ O ---	16	0.12	0.28	0.06
K ₂ O ----	10	0.47	0.77	0.30
TiO ₂ ----	16	0.34	0.5	0.18
ZrO ₂ ----	16	0.06	0.13	0.01

¹The mean is the arithmetic average value expressed in weight percentage.

Sections containing Big Clifty sandstones that were examined by the Indiana Geological Survey for high-silica content were described by Murray and Patton (1953) and Greenberg (1960). Coring in 1965 by the Indiana Flood Control and Water Resources Commission in

sec. 22, T. 4 S., R. 1 E., Crawford County, revealed near-surface sandstones of the Big Clifty about 35 feet thick. One sample, representing 34.8 feet, was analyzed and found to contain 97.0 percent by weight SiO_2 . The economic potential of these sandstones is enhanced by their proximity to the Ohio River.

SAMPLE FORMATION: The Sample Formation is principally shale or siltstone with lenses of sandstone that attain a thickness of 10 to 30 feet (Murray and Patton, 1953, p. 12). In one area, half a mile south of New Amsterdam in Harrison County, a composite sandstone body made up of the Sample and Bethel Formations reaches a thickness of about 60 feet (Amos, 1971). Numerous exposures of the Sample can be found in southern Indiana, especially along the bluffs overlooking the Ohio River in Crawford County. Sand from the Sample may be suited for some special uses, but it is generally finer than that desired for most glass manufacture. A sieve analysis of a sandstone unit of the Sample Formation is given below.

*Sample taken from a unit 17 feet thick in the SE $\frac{1}{4}$ NW $\frac{1}{4}$ sec. 1,
T. 4 S., R. 1 E., Crawford County, 0.75 mile west of the
old town of Leavenworth in the high bluffs along the
Ohio River*

[Modified from Greenberg, 1960, p. 12 and 20]

Sieve No. (U.S. Standard)	Percentage by weight retained on sieve
20 -----	0
40 -----	3
60 -----	6
100 -----	50
140 -----	21
200 -----	6
Less than 200 -----	12

Chemical analyses of sandstones of the Sample Formation collected for high-silica evaluation by the Indiana Geological Survey are summarized in table 11.

Table 11. Chemical analyses of sand from the Sample Formation in Indiana

Composition	Number of samples tested	Mean ¹ (pct)	Range	
			Maximum (pct)	Minimum (pct)
SiO ₂ ----	4	95.8	96.7	93.8
Al ₂ O ₃ ---	4	2.2	2.6	1.8
Fe ₂ O ₃ --	4	0.51	0.55	0.47
MgO ----	4	0.05	0.05	0.04
MnO ----	4	0.005	0.006	0.004
CaO ----	4	0.55	2.0	0.05
Na ₂ O ---	4	0.05	0.05	0.05
K ₂ O ----	1	0.2	0.2	0.2
TiO ₂ ----	4	0.25	0.36	0.12
ZrO ₂ ----	4	0.07	0.12	0.02

¹The mean is the arithmetic average value expressed in weight percentage.

BETHEL FORMATION: Scattered deposits of poorly consolidated sands overlying the Salem and St. Louis Limestones in upland areas of Washington, Clark, Floyd, and Harrison Counties were designated the Ohio River Formation, but they are now considered to belong to the Bethel Formation (Sedimentation Seminar, 1969, p. 9-10; Shaver and others, 1970, p. 13). These sands were used for a short time in the late 1800's for manufacturing glass; they also have been used as mortar and filtering sands. In 1964 the Indiana Glass Sand Co. established a processing plant near Elizabeth in Harrison County (figs. 6 and 7) and has been processing this sand for glass-sand materials, silica flour, and a variety of special purposes.

The Bethel sand is characteristically white to red, fine to medium grained (median grain size is 0.26 mm), well sorted, round to angular, and poorly cemented (Pinsak, 1956, p. 27-37). Grain size varies little throughout the deposit; 80 percent by weight of the samples tested fell between .420 mm and .177 mm (Wayne, 1960, p. 12). Sand produced by the Indiana Glass Sand Co. has an American Foundrymen's Society number of about 45. Although the sandstone is 10 to 40 feet thick at most places in Indiana, test drilling indicates that the sandstone unit is greater than 80 feet thick in some places of Harrison



Figure 6. High-silica sand processing plant, Indiana Glass Sand Co., Elizabeth, Harrison County.



Figure 7. Sandstones of the Bethel Formation exposed in the Indiana Glass Sand Co. quarry, Harrison County.

Table 12. Chemical analyses of sand from the Bethel Formation in Indiana

Composition	Number of samples tested	Mean ¹ (pct)	Range	
			Maximum (pct)	Minimum (pct)
SiO ₂ ----	32	97.8	99.3	94.6
Al ₂ O ₃ ---	36	1.42	3.8	0.54
Fe ₂ O ₃ --	36	0.39	1.20	0.066
MgO ----	36	0.05	0.14	0.03
MnO ----	29	0.001	0.003	0.0001
CaO ----	24	0.05	0.06	0.01
Na ₂ O ---	24	0.05	0.10	0.05
K ₂ O ----	3	0.20	0.20	0.20
TiO ₂ ----	36	0.12	0.35	0.033
ZrO ₂ ----	24	0.018	0.03	0.0051

¹The mean is the arithmetic average value expressed in weight percentage.

County (Wayne, 1960, p. 11). Chemical analyses of samples of Bethel sand collected by the Indiana Geological Survey for high-silica evaluation are summarized in table 12.

DEVONIAN AND SILURIAN SYSTEMS

Rocks of Devonian and Silurian age in Indiana (pl. 1) consist principally of limestones, dolomite, and shale. A white sandstone, however, believed to be of middle Devonian age crops out near Pendleton in Madison County and is known as the Pendleton Sandstone. No Silurian sandstones thick enough to merit high-silica evaluation have been found in Indiana.

The Pendleton Sandstone was described in the first annual report of the Indiana Geological Survey as a soft, white sandstone, which tested to be excellent for manufacturing glass (Cox, 1869, p. 7). This sandstone was used later as glass sand by the Indianapolis Glass Works, and it was even quarried for a short time for building stone. The quarry at Pendleton is now filled with water and is part of the city park. The sandstone averages about 10 feet in thickness near Pendleton, but one measured section indicated a thickness of 15 feet (Cox, 1879, p. 60). A sieve analysis of sandstone 9 feet thick exposed in the falls of Fall Creek in the Pendleton city park is given below.

Sieve No. (U.S. Standard)	Percentage by weight retained on sieve
40 -----	8.6
50 -----	11.1
80 -----	11.7
100 -----	4.9
140 -----	38.4
200 -----	20.4
Less than 200 -----	4.9

ORDOVICIAN SYSTEM

Rocks of Ordovician age crop out in southeastern Indiana (pl. 1) and consist principally of shale and limestone. No deposits of high-silica sand suitable for special uses are known to exist. The St. Peter Sandstone, widely exploited as a source of high-silica sand in the Middle West, underlies Indiana but at depths that make it uneconomical to produce at present.

Near Kentland, in northwestern Indiana, an isolated outcrop of St. Peter and other Ordovician rocks is the site of the Newton County Stone Co. quarry, which produces crushed limestone and agricultural limestone. The St. Peter is exposed on the quarry wall in a near-

Table 13. Chemical analyses of sand from the St. Peter Sandstone in Indiana

Composition	Number of samples tested	Mean ¹ (pct)	Range	
			Maximum (pct)	Minimum (pct)
SiO ₂ ----	2	99.4	99.6	99.1
Al ₂ O ₃ ---	2	0.26	0.27	0.24
Fe ₂ O ₃ --	2	0.02	0.02	0.02
MgO ----	2	0.06	0.1	0.01
MnO ----	—	—	—	—
CaO ----	2	0.10	0.15	0.05
Na ₂ O ---	2	0.1	0.1	0.1
K ₂ O ----	—	—	—	—
TiO ₂ ----	2	0.03	0.03	0.02
ZrO ₂ ----	2	0.02	0.03	0.01

¹The mean is the arithmetic average value expressed in weight percentage.

vertical attitude and is highly distorted. The force that raised these Ordovician rocks to such an anomalous position has been variously attributed to faulting, volcanism, or meteoritic impact.

St. Peter sandstone is light gray and medium grained and averages 35 feet in thickness where it has been sampled for high-silica evaluation by the Indiana Geological Survey; however, these beds may not extend laterally or vertically as continuous units. Chemical analyses of St. Peter sandstones are summarized in table 13.

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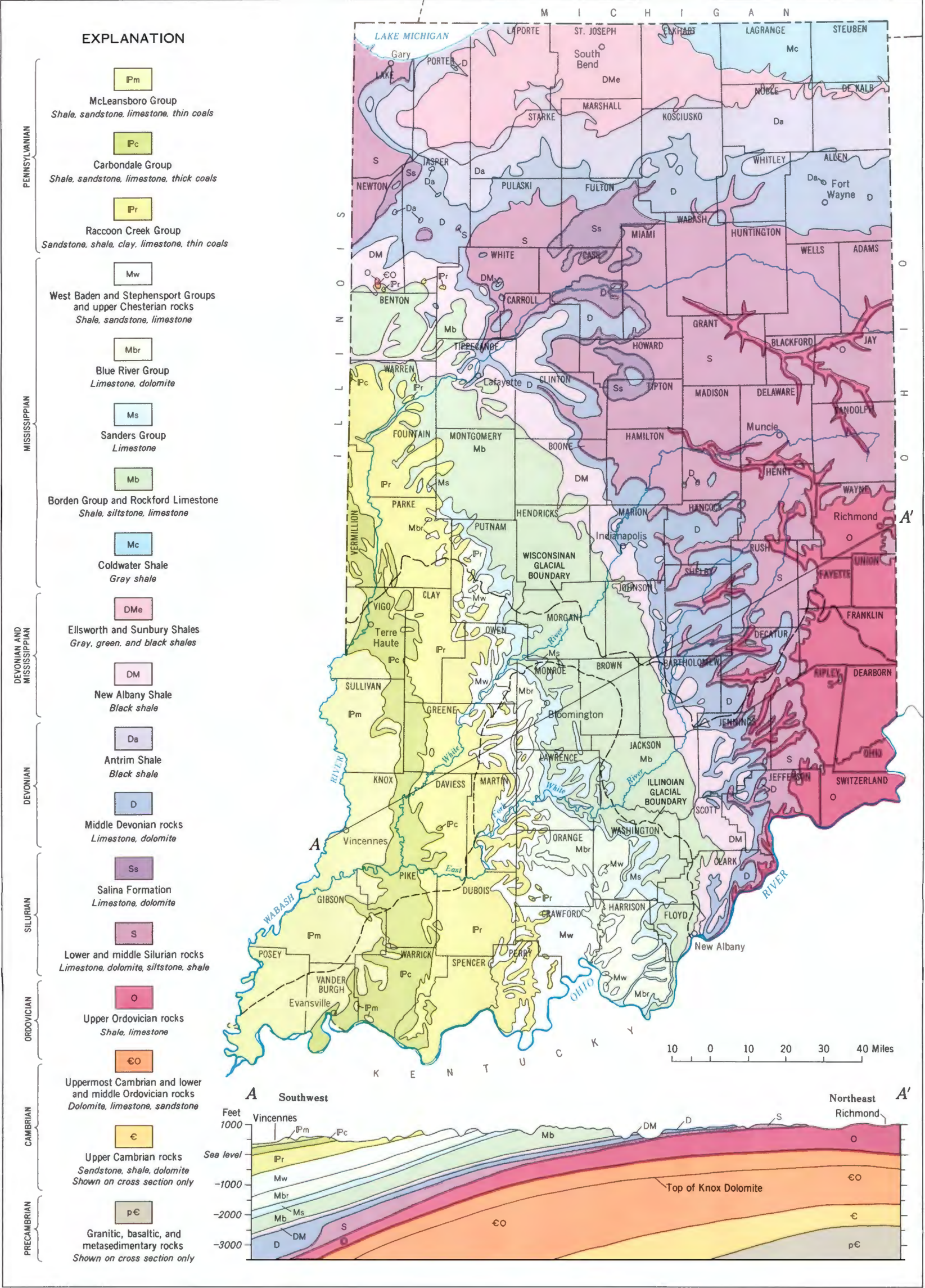
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OVERSIZED DOCUMENT

**The following pages are oversized and
need to be printed in correct format.**



MAP OF INDIANA SHOWING BEDROCK GEOLOGY

Adapted from Regional Geologic Map Series, Indiana Geological Survey. Drafted by Roger L. Purcell

System	Bedrock map units	Map symbol		Formation or member		Thickness of sand (ft)
QUATERNARY	Recent*					10-70
	Pleistocene*					
PENNSYLVANIAN	McLeansboro Group	IPm		Mattoon Formation	Merom Sandstone Member**	10-70
				Bond Formation Patoka Formation		
				Shelburn Formation**		10-30
	Carbondale Group	IPc		Dugger Formation**		10-60
				Petersburg Formation**		10-50
				Linton Formation**		10-60
	Raccoon Creek Group	IPr		Staunton Formation**		10-75
				Brazil Formation		
				Mansfield Formation**		10-350
MISSISSIPPIAN	Stephensport Group and West Baden Group and upper Chesterian rocks	Mw		Glen Dean Limestone Hardinsburg Formation Golconda Limestone		
	Blue River Group	Mbr		Big Clifty Formation**		10-40
	Sanders Group	Ms		Beech Creek Limestone Elwren Formation Reelsville Limestone		
	Borden Group and Rockford Limestone	Mb		Sample Formation**		10-30
				Beaver Bend Limestone		
				Bethel Formation**		10-80
DEVONIAN AND MISSISSIPPIAN	Sunbury Shale and Ellsworth Shale	Me				
	New Albany Shale	DM				
DEVONIAN	Antrim Shale	Da				
	Middle Devonian rocks	D		North Vernon Limestone Jeffersonville Limestone		
				Pendleton Sandstone**		1-15
				Geneva Dolomite		
SILURIAN	Salina Formation	Ss				
	Middle and lower Silurian rocks	S				
ORDOVICIAN	Upper Ordovician rocks	O				
	Middle Ordovician rocks*	EO				
	Lower Ordovician rocks*			St. Peter Sandstone**		
CAMBRIAN	Uppermost Cambrian rocks*					
	Upper Cambrian rocks*	C				

*Bedrock map units not shown on map (pl. 1).

**Sands and sandstones discussed in this report.

GEOLOGIC COLUMN SHOWING STRATIGRAPHIC
POSITION AND GEOLOGIC AGE OF SANDS AND SANDSTONES
THAT MAY BE SUITABLE FOR SPECIALTY SANDS

Table 2. Physical and chemical specifications of special-purpose sands

Sand uses	Physical properties			Chemical properties			
	Size range of particles (U.S. Standard)	Roundness of particles	Desirable degree of sorting	Percentage range SiO ₂	Percentage range Al ₂ O ₃	Percentage range Fe ₂ O ₃	Others
Abrasives:							
Blasting	4 to 100	Round or angular	Well sorted	High	Low	Low	Low in debris
Scouring powder	Silica flour; 99 percent less than 200 sieve	Angular or subangular	Well sorted	High	Very low	Very low	Very low; whiteness important
Stone sawing	30 to 100	Round or angular	Well sorted	High	Low	Low	Low in soft particles and materials that stain
Glass and chemical:							
Glass ¹	30 to 140	Round to angular	Moderately well sorted	Very high	Low	< 1	< 0.5 percent
Porcelain	30 to 140	Round to angular	Moderately well sorted	Very high	Low	< 1	Low
Silicon carbide	20 to 100	Round to angular	Moderately well sorted	> 99.0	Low	Low	Low
Sodium silicate	20 to 100	Round to angular	Moderately well sorted	> 99.3	< 0.25	< 0.35	Low
Metallurgical:							
Metallurgical pebble ²	3/8 in. to 8 in.	Round to angular	Moderately well sorted	Very high	< 0.4	< 0.2	Base oxides, < 0.3 percent; phosphorus and arsenic not per- mitted
Refractory: ³							
Core	30 to 140	Round to angular	Moderately well sorted	High	Low	Low	Low in debris
Furnace bottom	3 to 200	Round to angular	Moderately sorted	High	Some desirable	—	—
Ganister mix	50 to 200	Round to angular	Moderately sorted	High	Some desirable	—	—
Molding	70 to clay	Round to angular	Moderately sorted	Variable	Variable	—	—
Refractory pebble	40 to 2 in.	Round to angular	Moderately sorted	High	< 0.4	< 0.4	Opaline silica, < 0.5 percent; CaO, < 1.0 percent; alkalies, < 0.5 percent; TiO ₂ , very low
Miscellaneous:							
Engine	16 to 100	Angular to subangular	Well sorted	High	Low	Low	Low in debris
Filtering ⁴							
Water filtering	3/32 to 3½ in.	Round to subround	Well sorted	High	Low	Low	—
Sewage trickling	1 in. to 3 in.	Round to subround	Well sorted	High	Low	Low	—
Sludge filtering	4 to 50	Round to subround	Well sorted	High	Low	Low	—
Hydraulic fracturing	4 to 70	Round	Well sorted	> 98	Low	Low	Clay, silt, and soft- particle content < 0.5 percent

¹Ries, 1949, p. 972-973.²Murphy, 1960, p. 764-765.³Murphy, 1960, p. 766-769.⁴American Society of Civil Engineers, 1937, p. 10, 39.