STATE OF ARKANSAS

Arkansas Geological Survey

GEORGE C. BRANNER

State Geologist

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St. Peter and Older Ordovician Sandstones of Northern Arkansas

By

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With a Section On Their Economic Possibilities

By E. E. Bonewits

LITTLE ROCK

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LETTER OF TRANSMITTAL

Arkansas Geological Survey

LITTLE ROCK, ARK., *Aug. 15, 1930.*

HON. HARVEY PARNELL,
Governor, State of Arkansas,
Little Rock, Arkansas.

Sir:

I have the honor to submit herewith the report, "The St. Peter and Older Ordovician Sandstones of Northern Arkansas," by Dr. Albert W. Giles, which contains a section on the economic possibilities of the sandstones by Mr. E. E. Bonewits.

It has long been known that there are in northern Arkansas widespread deposits of relatively soft silica sandstones of high purity. These deposits are exposed over an area of approximately 750 square miles and have a maximum thickness of about 200 feet. Up to the present time information concerning their distribution, geology, physical and chemical characteristics and their economic possibilities has been more or less incomplete. Both in Missouri and Illinois, their quarrying constitutes an industry of some magnitude and especially for this reason it was believed advisable to make a detailed report on the geology and economic possibilities of these sandstones in Arkansas.

Dr. Giles undertook the study of these sandstones in the summer of 1927 with the assistance of Mr. Bryan Parks and Mr. Eugene Brewster. His work constitutes a valuable contribution to the knowledge of these formations in northern Arkansas, particularly the St. Peter sandstone, which has a wide distribution in Missouri, Illinois, Wisconsin, Minnesota, and Iowa. The mapping of a new member of the Everton formation which Dr. Giles has named the Calico Rock sandstone, is important economically and is an addition to the knowledge of the stratigraphy of the north Arkansas region. From a more general geologic standpoint, this report is a contribution to the knowledge of the Ordovician sandstones of central United States.

The addition of a section on the economic possibilities of the sandstones by Mr. E. E. Bonewits is an attempt to stimulate the development of a new industry or industries in Arkansas which would utilize the deposits. His conclusions are important and it is hoped they will attract attention to the industrial possibilities of the region.

Respectfully submitted,

GEORGE C. BRANNER,
State Geologist.

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ABSTRACT

Three sandstones of early middle Ordovician (Buffalo River) age are prominently developed and widely distributed in the Ozark region of northern Arkansas. They are, named from oldest to youngest, Kings River, Calico Rock, and St. Peter sandstones. The Kings River sandstone is the basal member of the Everton formation over a large area in the western and central Ozark region except at places where it is underlain by the Sneeds limestone member of the Everton. The Calico Rock sandstone is conspicuously developed in the central part of the region and lies stratigraphically below the middle of the Everton formation. The St. Peter sandstone overlies the Everton unconformably and is the most widely distributed of the three sandstones extending from northwestern Arkansas to the Mississippi Valley alluvial plain.

The sandstones are normally white or light cream colored, friable, and saccharoidal. Physically they are so similar that it is impossible in hand specimens to distinguish one from the others. The striking physical similarity that they reveal in hand specimens extends also to their larger field relations. On weathering they yield rolling uplands capped with a thin veneer of sandy and infertile soil, through which project here and there picturesque ledges, turrets, and towers, the "hoodoo rocks." They form steep slopes and precipitous bluffs with fluted surfaces on valley sides. Typically the sandstones are massively bedded and laminated. Cross bedding, usually fine, is a conspicuous feature of the sandstones. Ripples, normally of the asymmetric current pattern, are developed in the three sandstones but are most conspicuous in the Calico Rock sandstone. Dips are gentle nearly everywhere; in the western part of the region southward and farther east south-southeastward, away from the central part of the Ozark dome. The sandstones contain no fossils, but their physical features and their association with sediments of undoubted marine origin lead to the conclusion that they are of marine origin.

In size the grains composing the sandstones exhibit a large range. No samples screened left a residue on the 20 mesh sieve, and only about one-fourth of the more than 100 samples had weighable residues on the 28 mesh. The bulk of the sand of all samples found lodgment on the 35, 48 and 100 meshes. All samples had weighable quantities of "fines," grains small enough to pass 100 mesh, and three-fourths of the samples had weighable residues passing the 200 mesh. On the whole the grain size of the St. Peter as well as that of the Calico Rock and Kings River sandstones averages somewhat finer than the grain size of the St. Peter in Missouri and farther north in the Mississippi Valley, indicative of greater attrition resulting from farther transportation from the original source of the sand in the pre-Cambrian mass of northern United States and southern Canada.

Contrary to prevalent conception, the grains of the St. Peter are dominantly angular, and this is true also of the Calico Rock grains. Only 10 per cent of the St. Peter grains and 14 per cent of the Calico Rock grains are rounded or fairly well rounded, the remaining grains being subangular or angular.

Pitting is a prominent feature of the grains both of the Calico Rock and St. Peter sands. It is restricted largely to the coarser sizes. About one grain in three of the St. Peter and one grain in seven of the Calico Rock sand are pitted. Pitting develops at points of contact of adjacent grains and is attributed primarily to secondary enlargement by the addition of silica to the surfaces of the grains not in contact with surfaces of neighboring grains and hence exposed to the precipitating activity of penetrating solutions, and secondarily to chemical attrition at points of contact of neighboring grains.

Secondary enlargement is a marked feature of all samples examined both of St. Peter and Calico Rock sand. The silica precipitated on the surfaces of the grains develops crystal faces, which are clean and smooth and free from fractures, chipping, pitting and frosting. Rhombohedral faces typically terminate the grains, and prism faces are developed about the central parts of the grains. One or both forms may be present. Frequently the central part of the grain is frosted but its ends are terminated with rhombohedral faces. Some grains are completely bounded by crystal faces; other grains are partly bounded, the remaining surface being frosted. In grains larger than 100 mesh the crystal faces are due chiefly to secondary enlargement. In grains smaller than 100 mesh the crystal faces are in part secondary and in part inherited from the original source of the sand. Many of these grains and those passing 200 mesh are fragments and flakes derived from the attrition of the larger grains. The coherence of the sandstones is attributed primarily to secondary enlargement.

Frosting is a conspicuous feature of the sand grains forming the St. Peter and Calico Rock sandstones. The phenomenon is, however, restricted almost entirely to grains coarser than 100 mesh, particularly to those grains which are oblong, egg-shaped, spindle-shaped, and lens-shaped. The coarser grains with angular outlines are either not frosted or only partly frosted. On an average about 14 per cent of the grains are entirely frosted and 46 per cent partly frosted. The proportion of grains originally frosted was unquestionably very much larger, the marked decrease resulting from subsequent secondary enlargement. The frosting is attributed to the action of the wind in shifting the sand about the beach and the adjacent upland before it was deposited in the invading marine waters.

Chemically the three sandstones are remarkably similar and significantly high in silica, selected samples, unwashed, averaging about 99 per cent silica. Lime and magnesia are either absent or are present in scarcely more than traces. Iron averages under 0.2 and alumina about 0.25. The ignition loss is only 0.25.

The purity, high silica content, cleanness, toughness, and durability of the St. Peter, Calico Rock, and Kings River sands recommend them for utilization in the manufacture of high-grade glass products, for metallurgical and chemical uses, and for uses where high temperatures are encountered, particularly for steel molding purposes, for facing and annealing and for furnace linings. Their toughness, degree of angularity, and durability make the sands very satisfactory for friction and abrasive purposes. The average effective size and uniformity coefficient bring the Arkansas sands well within the range of sands successfully employed for filtration purposes. The sands can also be successfully used in paving and construction where a high grade, fine-texteured sand is desirable. And, finally, the sands are adapted to the many minor uses where high silica, clean, and durable sands are employed.

As a resource the Kings River and Calico Rock sandstones are untouched, and the St. Peter is being actively exploited in only one locality. Each of the sandstones over large areas possesses a thickness that is commercially inviting, but, unfortunately, transportation facilities are unavailable in large parts of the region. There are, however, a number of localities near or on railroads, where the sandstones are thick and extensively developed, that are recommended with a view to exploitation. It is apparent that Arkansas has an almost inexhaustible resource of high-grade sand, the exploitation of which should furnish a constant source of income for generations to come.

Note.—For abstract on the economic value of the sandstones see page 159.

THE ST. PETER AND OLDER ORDOVICIAN SANDSTONES IN NORTHERN ARKANSAS

By Albert W. Giles

ACKNOWLEDGMENTS

The writer wishes to express his appreciation of the constant interest Mr. George C. Branner, State geologist, has taken in the progress of the study, and to acknowledge the many helpful suggestions received from Mr. Branner during the course of the field and laboratory work and in the publication of the report. Acknowledgments are gratefully tendered Mr. E. T. McKnight of the United States Geological Survey, who placed the results, so far as available, of his study of the St. Peter sandstone and Everton formation in the Yellville quadrangle at the disposal of the writer. The writer desires also to express his gratitude to Mr. Bryan Parks, who assisted in the field and later made the sieve analyses of the sands; to Mr. Eugene Brewster, who assisted in the field and in the laboratory, particularly in the gravity determinations and in the microscopic study of the sand grains; and to Mr. Forrest Uhl for effective clerical assistance, particularly in making and checking the computations. Acknowledgments are also due Miss Lucille Muse and Miss Blanche Roberts for their efficient service in typing the manuscript.

COMMERCIAL VALUE OF THE SANDSTONES

Three sandstones of commercial value are found in northern Arkansas. They are, named from the oldest to the youngest, the Kings River, Calico Rock, and St. Peter sandstones. Of the three the St. Peter is by far of greatest economic importance. It is the most widely distributed of the three, it maintains a thickness that makes it commercially attractive over a great area, and it lies contiguous to transportation facilities for long distances. The Calico Rock sandstone in the area of its development is inviting from a commercial standpoint and close to transportation, but its area of development is restricted. The Kings River sandstone is widely distributed, but in the area where it is sufficiently thick to make it commercially inviting, transportation facilities are not available. The distribution, geologic features, physical and chemical properties, uses, and areas favorable for commercial development of the sandstones are described.

THE ST. PETER SANDSTONE

FIELD WORK

During the summer of 1927 the mapping of the St. Peter sandstone in northern Arkansas was continued after a lapse of several years. The project was inaugurated by the Arkansas Geological Survey and carried out under the auspices of that organization. The field party consisted of the writer and Mr. Bryan Parks and Mr. Eugene Brewster, of the department of geology of the University of Arkansas.

The geographic distribution of the sandstone had previously been mapped in the northwestern part of the State and the results published by the United States Geological Survey.[1] During the summer and fall of 1928 the Yellville quadrangle was remapped by Mr. E. T. McKnight of the United States Geological Survey, the work being carried on in co-operation with the Arkansas Geological Survey. The results, so far as available, of that part of his work pertaining to the St. Peter sandstone are incorporated in this report. The work done in 1927 involved tracing the formation eastward from the eastern limit of the Yellville quadrangle to its disappearance beneath the Mississippi Valley alluvial plain.

NAME, AGE, AND REGIONAL DISTRIBUTION

The term "St. Peter sandstone" was applied by Owen in 1847 to exposures of sandstone along the Minnesota River near St. Paul, Minnesota. This river was formerly known as the St. Peter River.[2] In Arkansas for many years sandstone of the same age was called the "Key sandstone," named for the postoffice of Key, northeast of Fayetteville, in the northwestern part of the State. In northeastern Oklahoma it has been called the "Burgen sandstone." In Missouri the older geologists referred to the St. Peter as the "Saccharoidal sandstone" or "First sandstone." It has also been known locally

[1]Purdue, A. H. and Miser, H. D., Eureka Springs-Harrison Folio, No. 202, Geologic Atlas of the United States, Washington, 1916.
Adams, G. I., Purdue, A. H., and Burchard, E. F., Zinc and Lead Deposits of Northern Arkansas. Prof. Paper No. 24, U. S. Geological Survey, 1904.
[2]Owen, D. D., Senate Executive Document No. 2, 30th Congress, 1st session, p. 169, 1847.

in Missouri as the "Crystal City," "Pacific," and "Cap au Gres" sandstone[3].

The St. Peter sandstone is of early middle Ordovician age. Table 1 shows the general stratigraphic succession of the formations of the Ordovician system in the Ozark region of northern Arkansas.

Table 1.—Ordovician Section of Northern Arkansas

Age	Standard Time Scale		Formation
Upper Ordovician	Richmond		Cason shale Fernvale limestone
Middle Ordovician	Black River		Kimmswick limestone
			Plattin limestone
	Buffalo River (Ulrich)		Jasper limestone Joachim limestone St. Peter sandstone Everton formation
Lower Ordovician	Canadian	Beekmantown	Black Rock limestone Smithville limestone Powell limestone Cotter dolomite Jefferson City dolomite

The St. Peter sandstone is widely distributed in the upper Mississippi Valley region. Much of the formation is buried beneath later formations, but it outcrops locally in the bottoms of valleys, on hill slopes, and on ridge tops. In some localities its outcrop may be traced continuously for scores of miles. Where the sandstone is buried its presence is revealed in drill cores. From much of the Ozark region of extreme northern Arkansas and southern Missouri the sandstone has been removed by erosion.

The northern boundary of the St. Peter sandstone extends through southern Minnesota and Wisconsin into northern Michigan. Its eastern limit is indefinitely known because of its burial beneath later formations, but in general it extends through eastern Michigan and Indiana into eastern Kentucky and Tennessee. Its southern boundary is generally considered as located in southern Tennessee, central Arkansas and central Oklahoma but it may extend beneath Gulf Coastal Plain sediments far south of this limit. Its

[3] Dake, C. L., The Sand and Gravel Resources of Missouri. Missouri Geol. Survey Vol. XV, 2d series, p. 105, 1918.

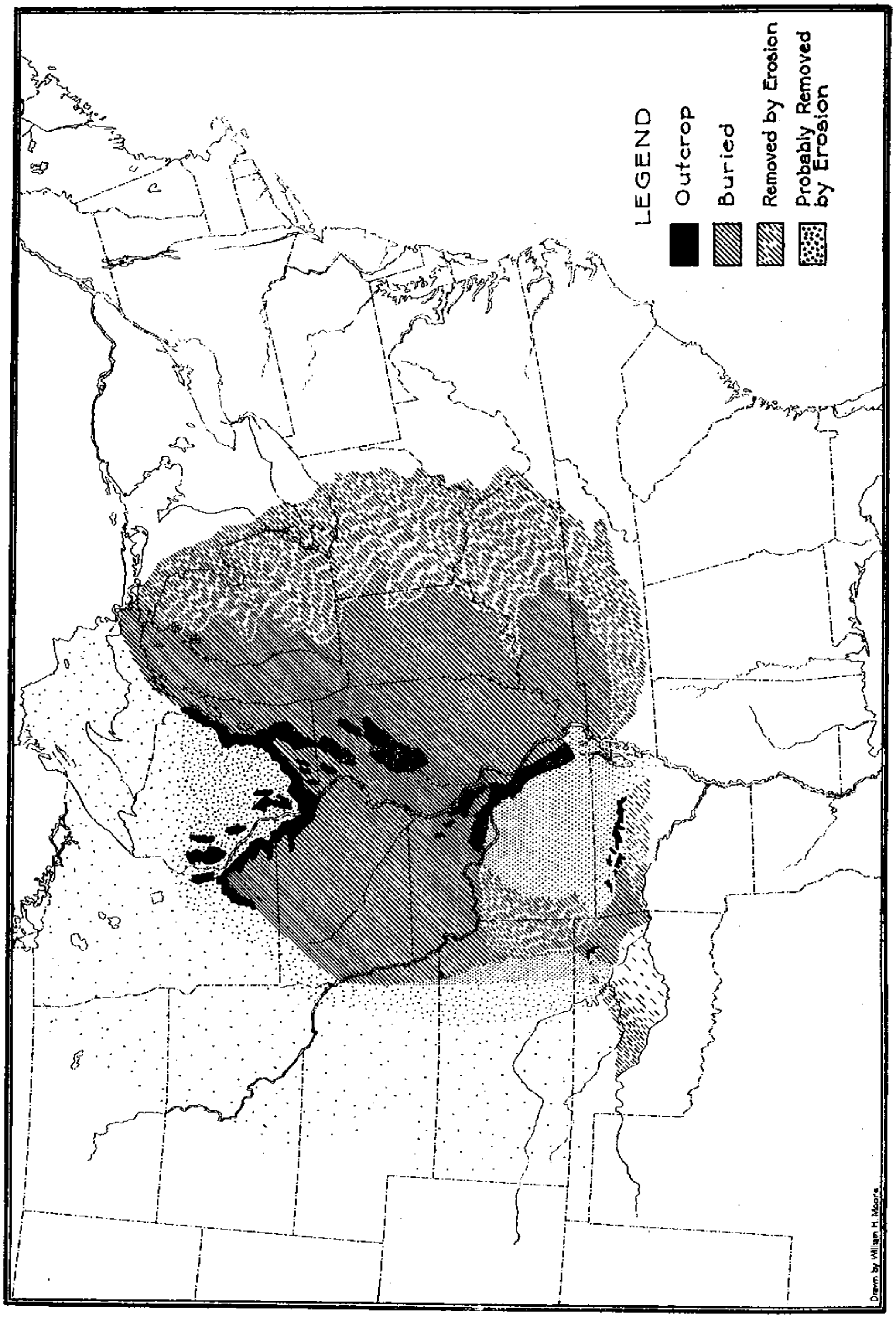

FIGURE 1.—Map showing distribution of the St. Peter sandstone in the United States.
From C. L. Dake, University of Missouri School of Mines and Metallurgy Bull. Tech. Ser., Vol. 6, No. 1, August, 1921. Arkansas surface distribution according to A. W. Giles.

western boundary extends northward from central Oklahoma through western Missouri and Iowa into Minnesota. It is believed to have extended formerly much farther westward into the Great Plains region and northward to the Canadian boundary, having been removed from these regions by erosion. Figure 1, originally prepared by Dake, shows the general distribution of the St. Peter sandstone.[4]

DISTRIBUTION IN NORTHERN ARKANSAS

The accompanying map (Pl. I, in pocket) shows the general distribution of the St. Peter sandstone in northern Arkansas. It occurs in Madison, Carroll, Newton, Boone, Searcy, Marion, Baxter, Stone, Izard, Sharp, and Independence counties, and has been reported in Lawrence County.[5]

The St. Peter sandstone does not crop out in the extreme northwestern part of Arkansas. Its most westerly known outcrop is on War Eagle Creek, northeast of Hindsville, in Madison County. The sandstone crops out also near the heads of the tributaries of Kings River south and southeast of Rockhouse, in the northeastern part of Madison County and in adjacent Carroll County. Farther east, in the Harrison quadrangle, the formation is present as inliers, its discontinuous outcrops occurring in the lower parts of the valleys of the larger streams. In the western part of the Harrison quadrangle, in Carroll County northwest of Osage, the formation is present as a long, continuous outcrop on Osage Creek. East of Harrison, in Boone County, the sandstone outcrops along Hussar and Crooked creeks and underlies a large area at Bellefonte. In the southern part of the quadrangle, in northern Newton County, the formation is again found as long, continuous outcrops in the lower parts of the valleys of Buffalo Fork and White River and their larger tributaries.[6]

Numerous outliers of St. Peter sandstone are also present farther north, both in the Eureka Springs and Harrison quadrangles, these erosional remnants indicating the former widespread extent of the formation in this region. The formation disappears entirely about the middle of the quadrangles, but it probably originally extended over the entire Eureka Springs-Harrison region to unknown limits beyond this region, but during the long interval of later Ordovician, Silurian, and Devonian erosion the formation was largely re-

[4] Dake, C. L., The Problem of the St. Peter Sandstone. Bulletin Missouri School of Mines, Vol. 6, No. 1, Plate III, 1921.
[5] Eureka Springs-Harrison Folio, p. 7.
[6] Eureka Springs-Harrison Folio, p. 7 and maps.

moved, except in small protected areas, so that in general in this region the Sylamore sandstone, St. Joe limestone, and the higher Boone limestone succeed unconformably the Everton and other formations older than the St. Peter.[7]

The St. Peter sandstone is widely distributed in the south-central and southern parts of the Yellville region, forming continuous outcrops along Buffalo River and its tributaries in southern Marion, northern Searcy, and northeastern Newton counties.

The outcrop of the St. Peter sandstone in the Mountain Home quadrangle is limited essentially to the region south of White River in northern Stone and southern Baxter counties. Its outcrop is continuous in the escarpment south of the river, and it has been traced up the valleys of Big Creek and other tributaries that flow into Buffalo River from the south and southeast. In southwestern Izard County, northeast of White River, the sandstone is conspicuous near the tops of the highest hills, such as Turkey Knob, Pilot Knob, Twin Knobs, Devils Knob, and other residuals. East of the Mountain Home quadrangle, in central Izard County, the formation is represented only on the highest peaks and ridges, the massive saccharoidal sandstone seen north of Melbourne and elsewhere belonging to a lower horizon.

The formation is well developed in the northern part of the Mountain View quadrangle. An outcrop several miles long floors the valley of Roasting Ear Creek, in northern Stone County. It caps the bluffs on both sides of White River and extends up all the tributaries of that river in northeastern Stone and southern Izard counties. Farther east in the Batesville quadrangle, along White River, the sandstone descends to water level, and its outcrop has been traced on the north side of the river to the vicinity of Guion, in southern Izard County. It is absent south of the river in this quadrangle, the steep southward dip carrying it beneath the bluffs on that side of the river. The sandstone forms broad outcrops in southern Sharp and northern Independence counties, in the northern part of the Batesville quadrangle.

The area east of the Batesville quadrangle has not been surveyed topographically, but the sandstone was traced southeastward for several miles, finally disappearing beneath the gravels and sands of the Mississippi Valley alluvial plain east of Walnut Grove, in Independence County. In this direc-

[7]Eureka Springs-Harrison Folio, pp. 7 and 18.

tion the outcrop of the formation gradually diminishes in width, becoming less than one-half mile wide at the eastern termination of its outcrop. The lack of adequate base maps, together with the wooded and rugged nature of the country, prevented an accurate determination of the boundaries of the formation both north and east of the Batesville quadrangle. The problem is further complicated by the presence of a similar sandstone below the St. Peter and separated from it by a narrow and irregular vertical interval, which in places apparently absent.

In the preceding paragraphs the outcrop of the sandstone is sketched in a general way, but the distribution of the sandstone is much more general and extensive than the tracing of its outcrop indicates. The sandstone undoubtedly persists as a continuous formation underlying the ridges between its outcrops on the valley slopes that bound the ridges. Hence the sandstone is present, though buried by later formations, in large areas in northern Arkansas. Its northward extent is terminated by older formations that appear in extreme northern Arkansas. It was originally present in this region but has been removed during the prolonged period of erosion which this region has experienced. Eastward the sandstone probably continues beneath the Mississippi River alluvial plain, and southward it continues beneath the Boston Mountains and Arkansas Valley and for an unknown distance beneath the Coastal Plain of southern Arkansas and northern Louisiana. Westward the sandstone thins and may be absent locally, but it continues far into eastern and central Oklahoma, where it is called the Burgen or the Wilcox sandstone.

THICKNESS

The St. Peter sandstone in Arkansas is very variable in thickness even within short distances. Its thickness reaches a maximum of 200 feet. The sandstone is buried in extreme northwestern Arkansas but appears south of Eureka Springs and thickens eastward, reaching its maximum thickness, 125 to 200 feet, in the Mountain View, Mountain Home, and Batesville region.

On Kings River, in eastern Madison and southern Carroll counties, the thickness of the formation ranges from 10 to 70 feet. In eastern Carroll County, on Osage Creek, its thickness is generally 30 feet but reaches 100 feet northwest of

Osage postoffice. On Crooked and Hussar creeks, east of Harrison, in central Boone County, the formation is 10 to 20 feet thick. It is only 15 feet thick near Yardelle, in northern Newton County, but farther west, on Buffalo Fork, it is thicker, reaching a maximum of 150 feet south of Compton.[8]

The St. Peter sandstone is well developed and widespread in the southern part of the Yellville quadrangle, in northern Searcy and southern Marion counties, but the study of this region, which is in progress at the present time, has not yet reached the stage where precise measurements are available. The thickness of the formation is probably not materially different from its thickness farther west, in the vicinity of Jasper, and farther east, in northern Stone County, where it varies in thickness from about 50 to 150 feet and averages about 75 feet.

In Warner Mountain, in southeastern Marion County, the St. Peter sandstone is 50 feet thick. Farther east, in Stair Mountain opposite Buffalo City, the thickness is the same. This thickness persists in Matney Knob, in southern Baxter County. In Sugar Loaf Mountain, in southwestern Izard County, the sandstone is 126 feet thick. It thins northeastward to 90 feet in Pilot Knob and maintains about this thickness in the neighboring Turkey Knob and Twin Knobs, northeast of White River, in western Izard County. On Roasting Ear Creek, in northern Stone County, and on Big Creek and other tributaries of Buffalo River, in eastern Searcy and Marion counties and southern Baxter County, the formation is 65 to 85 feet thick.

The formation is considerably thicker in the vicinity of Sylamore and eastward to Guion, in southern Izard and northeastern Stone counties. Thus, west of Boswell, on the opposite side of White River, the sandstone is 150 feet thick, and its thickness is the same across from Mt. Olive. Southwest of Perrins Ferry it is 125 feet in thickness and about the same thickness on Livingston and Sylamore creeks. Northwest of Sylamore, on the river, its thickness is 135 feet. In Rocky Bayou and at Guion the sandstone is 150 feet thick. The formation thins northward from the river, having a thickness of 100 feet on Lyons and Twin creeks and 115 feet east of Candlestick Knob. At the heads of these creeks it is generally 50 to 75 feet thick.

[8] Eureka Springs-Harrison Folio, p. 7.

BLUFF OF ST. PETER SANDSTONE THREE QUARTERS OF A MILE NORTHWEST OF WILLIAMSON, IN IZARD COUNTY

Farther east in the Batesville region, in northern Independence County, its thickness is great but variable. According to Miser it is 200 feet thick on the west slope of Pine Mountain, at least 75 feet thick 1½ miles west-northwest of Williamson, 125 feet thick in the vicinity of Cushman as shown by the log of the well at the Southern mine, and 120 feet thick near Sandtown.[9]

The variability in the thickness of the St. Peter sandstone is attributable to uneven deposition, post-depositional differential settling, the unevenness of the eroded floor upon which the sand was spread out in an advancing sea, and the erosion that has in places stripped off its stratigraphic cover and removed partly or entirely the underlying sandstone.

TOPOGRAPHIC EXPRESSION

The outcrop of the St. Peter sandstone is typically a precipitous slope (see Pl. II), the height of the bluffs in places representing the full thickness of the sandstone and in others including beds of overlying and underlying formations. These bluffs are conspicuous features along Buffalo Fork of White River north and northwest of Jasper, and on the south side of White River from Buffalo City eastward to Sylamore. The vertical faces of the bluffs are fluted in many places, and the upper edges of the sandstone at the top of bluffs are more or less rounded. Streams descending the escarpments have carved narrow, V-shaped steep gorges. (See Pl. III.) The base of the sandstone is marked in many places by springs. The water seeps downward through the sandstone and then flows along the contact of the porous sandstone and impervious underlying limestone to places of exit.

Where the sandstone underlies considerable areas it yields a thin, porous soil that is readily gullied to form a gently rolling surface. Above this undulating surface rise isolated knobs, ledges, pinnacles, towers, and turrets, some of them fantastically carved and known locally as "hoodoo rocks." They are of sufficiently frequent occurrence to be a diagnostic feature of St. Peter outcrops, but unfortunately the Calico Rock and Kings River sandstones, in the underlying Everton formation, display similar features, so that discrimination between the outcrops of these formations must in places be made by other means.

[9] Miser, H. D., Deposits of Manganese Ore in the Batesville District, Arkansas. Bulletin 734, U. S. Geological Survey, p. 17, 1922.

STRATIGRAPHIC RELATIONS

In the Ozark region of northern Arkansas the St. Peter sandstone normally overlies the Everton limestone and is succeeded upward by the Joachim limestone. The sandstone is separated from the Everton by an unconformity, but the Joachim rests with apparent conformity upon the upper surface of the sandstone.

During the interval preceding the deposition of the St. Peter sands the upper surface of the Everton was profoundly eroded and locally the formation was entirely removed, together with underlying beds. As a result the base of the St. Peter in places rests upon the upper layers of the Everton, again upon the middle or basal layers of that formation, and in places upon older formations below the Everton. Thus, at the mouth of Piney Creek, in the Eureka Springs quadrangle, the sandstone rests upon the Kings River member in the lower part of the Everton formation. In a small area on Osage Creek, in the western part of the Harrison quadrangle, central Carroll County, pre-St. Peter erosion completely removed the Everton, so that the sandstone rests upon the Powell limestone.[10]

In the Yellville region the formation underlying the St. Peter everywhere is mapped as the "Yellville formation," a term including the Cotter, Powell and Everton formations.[11] The upper surface of the "Yellville" was much eroded before the deposition of the St. Peter sands, so that the contact of the St. Peter sandstone with the underlying formations is very irregular. In Stone and Baxter counties and farther east the St. Peter rests upon the Everton formation, which was submaturely dissected previous to St. Peter deposition, so that in places the St. Peter rests upon layers in the upper part of this formation, and again upon layers in the middle or lower part of the formation. Locally, as near Melbourne, the sandstone rests upon the Calico Rock sandstone, the upper Everton having been entirely removed before the St. Peter sands were deposited.

The Joachim limestone generally overlies the St. Peter sandstone in the eastern part of the Ozark region, but west of Newton County the Joachim is not known. In this region, including Madison, Carroll and Boone counties, the St. Peter is overlain unconformably by the Sylamore member of the

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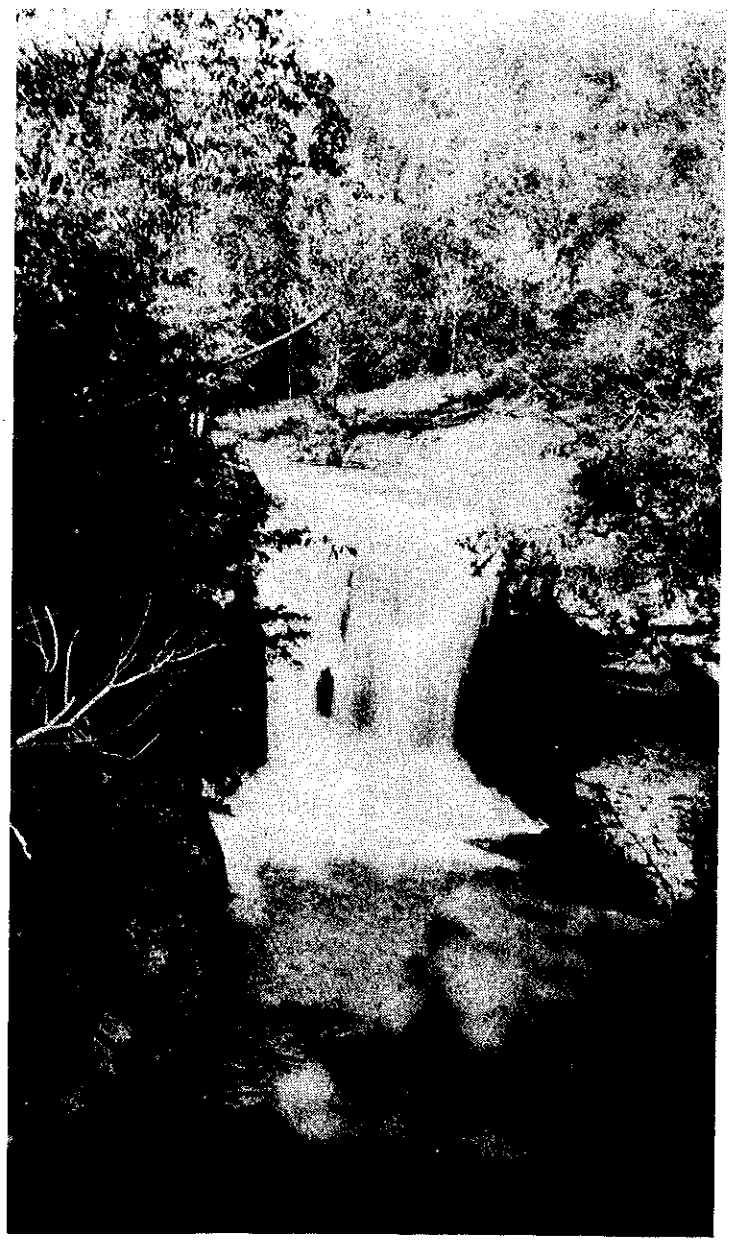
[10] Eureka Springs-Harrison Folio, p. 7.

[11] Adams, G. I., Purdue, A. H., and Burchard, E. F., Zinc and Lead Deposits of Northern Arkansas. Prof. Paper No. 24, U. S. Geological Survey, Plates IV and V, 1904.



MARBLE CITY FALLS, NEAR WILLCOCKSON, IN NORTHERN NEWTON COUNTY, ONE OF THE LARGEST WATERFALLS IN THE ST. PETER SANDSTONE

Chattanooga, by the Chattanooga shale itself, by the St. Joe member of the Boone limestone, or by higher beds of the Boone. On War Eagle Creek, in Madison County, and farther north, on Kings River, the St. Peter is overlain by the Sylamore sandstone. This relationship continues into central Carroll County. East of Harrison and at Bellefonte the Sylamore is again present, overlying the St. Peter. In the southern part of the Harrison region, in northern Newton County, the Joachim normally succeeds the St. Peter.

In the Yellville region the St. Peter is overlain in places by the Joachim limestone, and in other localities by formations younger than the Joachim. Here, as elsewhere in Arkansas, the Joachim succeeds the St. Peter conformably. Where the Joachim is absent younger formations succeed the St. Peter unconformably, locally with angular discordance. Thus, according to McKnight, on the east side of Cabin Creek the Joachim rests upon the St. Peter. Parks reports the presence of Plattin limestone in the Rush district immediately above the St. Peter sandstone.[12] In other localities the St. Joe limestone or the Sylamore sandstone lies above the St. Peter.

East of the Yellville region, on White River, Buffalo River, and Sylamore and Livingston creeks, the St. Peter is overlain by the Joachim limestone. In the Batesville area, as mapped by Miser, the Joachim also everywhere succeeds the St. Peter sandstone.[13]

CORRELATION

In Table 2 an attempt has been made to correlate the St. Peter and adjacent formations with their generally accepted stratigraphic equivalents in neighboring states. The St. Peter of Arkansas is the equivalent, of course, of the St. Peter of Missouri, Illinois, Iowa, Minnesota and other Mississippi Valley states. In northeastern Oklahoma the St. Peter has been called the Burgen sandstone, but that name has now been abandoned, since Ulrich considers the Burgen the equivalent of the St. Peter.[14] Mrs. Edson has recently prepared a correlation table of the Ordovician formations of Oklahoma and concludes that the Wilcox sandstone is the equivalent of the Burgen and St. Peter sandstones.[15] No equivalent of the St. Peter

[12] Personal communications.

[13] Miser, H. D., Deposits of Manganese Ore in the Batesville District, Arkansas. Bulletin 734, U. S. Geological Survey, 1922.

[14] Ulrich, E. O., Boulders in the "Caney" Shale. Bulletin 45, Oklahoma Geological Survey, 1927.

[15] Edson, Fanny C., Ordovician Correlations in Oklahoma. Bulletin Am. Assoc. Petroleum Geologists, Vol. XI, No. 9, pp. 967-975, 1927.

has been recognized in the Arbuckle Mountains, but it is probably present in the Arbuckle section, and Mrs. Edson concludes, "but the evidence available at present suggests that the 'Burgen' sand correlates with the 'true Wilcox' sand, with

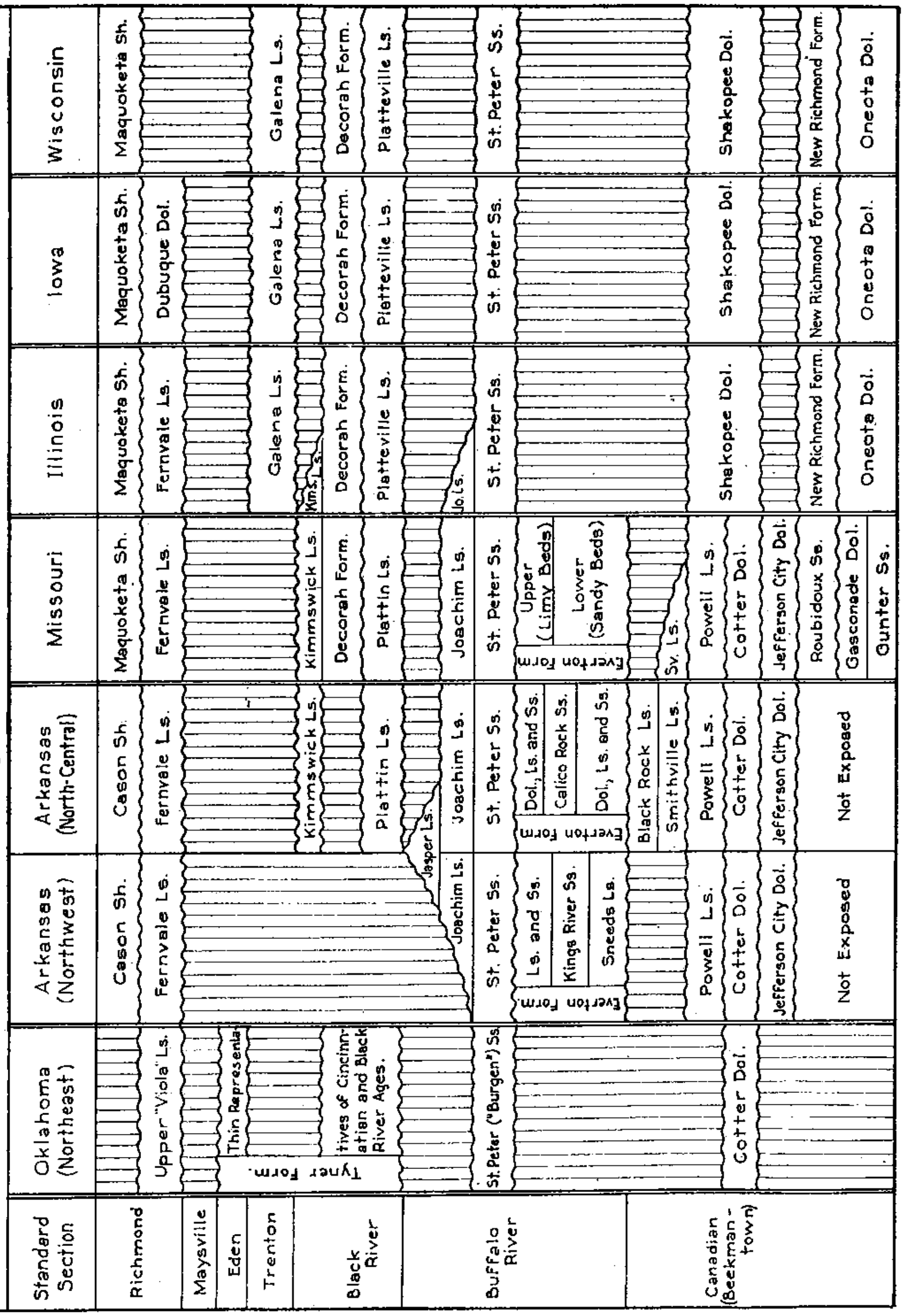


Table 2 - Correlation of St. Peter and Adjacent Formations of Arkansas with those in Nearby States.

one of the Ordovician sandstones outcropping in the Arbuckle Mountains, and that both may correlate with the widespread St. Peter sand in the upper Mississippi Valley."

The Joachim normally overlies the St. Peter conformably in Arkansas and Missouri. This formation is absent in Illinois except in Calhoun County, where it overlies the St. Peter. Elsewhere in Illinois the Platteville limestone, or its lower member, the Glenwood shale, overlies the St. Peter. In Iowa and Wisconsin the Platteville limestone normally succeeds the St. Peter upward. In northeastern Oklahoma the Tyner formation overlies unconformably the sandstone.

In Illinois, Iowa, and Wisconsin, the Shakopee formation normally underlies the St. Peter, from which it is separated by a pronounced stratigraphic break. In Missouri the sandstone is underlain normally by the upper limestone beds of the Everton. The same stratigraphic sequence is present in the Arkansas Ozarks.

FOSSILS

Fossils are very rare in the St. Peter sandstone and those found are poorly preserved. None has been found in Arkansas, although a considerable fauna has been reported from the underlying Everton.[16] Dake has found fossils (gastropods) at the top of the formation in southeast Missouri,[17] and tubular cavities *(Scolithus)* near the middle of the formation. These cavities have also been reported as occurring near the top and near the middle of the formation in Illinois.[18]

Sardeson has described 28 species of fossils of marine organisms found in southern Wisconsin near Dodgeville and St. Paul. Some came from near the top of the formation, but most of them were collected from three horizons well down in the formation, 60 feet or more below the top. Pelecypods and gastropods predominate in his collections. In addition there are three species of cephalopods, three of brachiopods, a sponge, and another form classified as a bryozoan. Sardeson describes as follows the conditions of preservation of the fossils:

> The fossils are found as casts of shells that have themselves been entirely dissolved without leaving even a stain of color or a trace of calcium carbonate in the sand. The cavities left by the shells are closed up by a consolidation of the sand in some manner, so that generally little more than smooth cleavage planes remain to define the fossils.
>
> The fossilization itself is not strange, but it reveals to us, perhaps, the reason that the St. Peter sandstone is so generally unfossil-

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[16] Eureka Springs-Harrison Folio, p. 6.

[17] Dake, C. L., The Problem of the St. Peter Sandstone. Bulletin Mo. School of Mines, Vol. 6, No. 1, pp. 195 and 26, 1921.

[18] Lamar, J. E., Geology and Economic Resources of the St. Peter Sandstone of Illinois. Illinois Geological Survey, Bulletin 53, p. 36 and footnote references, 1928.

iferous, viz: because the fossils have been destroyed since the sandstone was deposited. One might dig up many fossils without seeing them, unless care be taken to prevent the casts from being crumbled.[19]

Indefinite tracings interpreted as fucoids (sea weeds) have also been found.[20] The rarity of St. Peter fossils probably finds a partial explanation also in the scarcity of life in the shallow seas in which the sands were deposited.

MAJOR STRUCTURAL FEATURES

The St. Peter sandstone in northern Arkansas lies on the southern and southeastern flank of the Ozark geanticline. The dip of the sandstone nearly everywhere conforms to the structure of the fold. In Madison and Carroll counties and farther east the dip is from one-half to five degrees in a southerly direction. In the eastern part of the belt, from Stone and Baxter counties eastward, the dip remains about the same in amount but its direction is south-southeast and then southeast. The steepest dip observed in this eastern section was found near Sylamore, where the sandstone rapidly mounts the hills toward the northwest with dips as high as 10 degrees. Other local departures from the regional dip are not infrequent and represent small and gentle folds affecting the sandstone together with the overlying and underlying strata.

Faults are not uncommon in the Ozark Plateau of northern Arkansas, and in places the sandstone has been involved. Southeast of Rockhouse, in Madison and Carroll counties, the St. Peter has been cut and offset in five places along the southwest trace of a normal fault. Northeast of Harrison the outcrop of the formation has been offset for nearly a mile along a fault.

A plexus of faults occurs in northern Newton and northwestern Searcy counties, with east, northeast, and northwest strikes. South of Compton, in Newton County, a series of parallel faults repeatedly intersects and offsets the outcrop of the St. Peter where it has been uncovered by erosion in the valleys tributary to Buffalo Fork. North of Jasper an isolated area of St. Peter lies north of a fault, and northeast of Jasper a similar outcrop of the sandstone has the same relationship to another northeast trending fault. A long east-west trending fault is developed in the extreme northeast part of Newton County and extends eastward through northern Searcy County to the vicinity of Tomahawk. Isolated outcrops of

[19] Sardeson, F. W., The St. Peter Sandstone. Bulletin Minn. Acad. Sci., Vol. IV. pp. 64-88, 1910.

[20] Prof. Paper 24. U. S. Geological Survey. p. 21.

St. Peter are numerous along the north side of the fault, but this formation on the south side of the fault is buried beneath Boone limestone, erosion having removed the overlying formation, revealing the St. Peter on the north or upthrown side of the fault. In the vicinity of Tomahawk isolated areas of St. Peter are likewise bounded by faults of small displacement. The throw of these faults is generally less than 300 feet.[21]

North of Rush Creek, in Marion County, near the eastern boundary of the Yellville quadrangle, the outcrop of the St. Peter is bounded on the north for long distances by a northwest-southeast fault. In southern Baxter County two miles northeast of Big Flat, along a northwest trending fault on Spring Creek, the outcrop of the sandstone has been offset about one mile.

Miser has mapped a fault with northeast trend, nearly two miles long, about 2¾ miles northwest of Cushman. It cuts across an inlier of St. Peter with downthrow on the southeast side, narrowing the outcrop of sandstone on this side. The maximum displacement is 200 feet. Two short parallel faults, 250 feet apart, having an eastward trend, occur on Polk Bayou 4½ miles east-northeast of Cushman. The Joachim and Plattin limestones and the St. Peter sandstone are exposed in the belt between the faults, and the St. Peter bounds the faults on the north and south. The rocks in this belt have settled about 100 feet.[22]

The outcrop of the formation appears normally to be massive, with little or no evidence of stratification. In many places, however, weathered surfaces, when viewed from a distance, exhibit distinctly massive bedding. In fresh exposures the bedding may be marked by a faint color banding. Such exposures also may show brownish ferruginous beds and greenish mud seams marking the position of bedding planes. In general, the formation may be described as massively but not conspicuously stratified.

Some outcrops show marked cross-bedding, but this structure is neither striking nor conspicuous. The false beds are usually several feet in length, rarely steep, and never intricate in arrangement. They generally exhibit the relatively simple arrangement of water-laid sands, rather than the complexity of eolian deposits.

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[21] Eureka Springs-Harrison Folio, p. 17. Prof. Paper U. S. Geological Survey No. 24, Plate V.

[22] Bulletin 734 U. S. Geological Survey, pp. 48-49.

MINOR STRUCTURAL FEATURES

Ripple marks are comparatively rare in the St. Peter sandstone. They were found in only a few places during the recent field season. Dunkin has recently illustrated ripple marks in the St. Peter near Guion.[23] The ripples have the undulatory outline produced by wave oscillation or the asymmetric cross sections produced by water currents.

A peculiar feature of the St. Peter sandstone is the rather common occurrence in it of pipes shaped like an inverted cone, which are believed to have been formed by the solution of the underlying Everton limestone before the St. Peter sand was fully consolidated. The sand slumped in hour-glass fashion into the solution cavity and became consolidated in that position, forming a cone-shaped structure expanding upward. These pipes have been described and illustrated by Purdue and Miser.[24]

In the southern part of the Yellville region the sandstone locally develops a vertical structure. Similar structure has been noted by Dake in Missouri and Lamar in Illinois. The structure appears to represent vertical worm tubes filled with sand.

Honeycomb weathering is developed at many places in the upper portion of the sandstone. The pitted appearance resulting from this kind of weathering has been attributed to the presence of worm tubes, which cause the sandstone to weather unequally.[25]

Sun cracks, tensional features due to desiccation, are sometimes observed in the St. Peter sandstone. No examples of these features were seen during the recent field work in Arkansas. Dake comments on the general absence of sun cracks in the St. Peter, and Lamar cites examples found in quarries in Illinois.[26]

ORIGIN

Two quite different ideas have long been entertained regarding the origin of the St. Peter sandstone. Originally it was held that all sedimentary rocks were marine in origin. Later, with more intensive study of sediments, it was found that many sedimentary rocks were not marine, but accumu-

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[23] Dunkin, D. D., Mining and Preparation of St. Peter Sandstone in Arkansas. Am. Inst. of Mining and Metallurgical Engineers. Tech. Pub. No. 55, p. 2, 1928.

[24] Eureka Springs-Harrison Folio, p. 7.

[25] Prof. Paper U. S. Geological Survey No. 24, p. 21.

[26] Dake, C. L., The Problem of the St. Peter Sandstone. Bulletin Mo. School of Mines, Vol. 6, No. 1, p. 194, 1921. Lamar, J. E., Geology and Economic Resources of the St. Peter Sandstone of Illinois. Illinois Geological Survey, Bulletin 53, pp. 36-37, 1928.

lated on land areas as the result of the action of wind, glaciers, and rivers. As early as 1907 evidence was presented leading to the conclusion that the St. Peter was not marine but eolian in origin. This opinion, however, was not universally accepted. In 1917 Trowbridge, after many seasons of work in the "Driftless Area" of Iowa and neighboring States, published his conclusion that most of the St. Peter was marine in origin.[27] Dake has made the most exhaustive study of the St. Peter. After a very detailed study of the St. Peter, extending over a long period of time, he concluded that the sandstone is principally of marine origin except in some of the shore phases, that the source of the sand was the pre-Cambrian crystalline rocks and the Potsdam sandstone exposed in the Canadian shield north and northwest of the St. Peter basin, and that the sand was transported by streams from its source area to the epicontinental sea, in which it was deposited and distributed principally by waves and currents. There may also have been minor distribution of beach sand by wind into dunes and related deposits, which later were buried by the advancing sea. Dake has summarized the evidence on which his conclusions are based and a statement of them in summary form may be found in his publication on the problem of the St. Peter sandstone.[28]

Lamar has recently published the results of an elaborate investigation of the St. Peter in Illinois.[29] He states that the data obtained by his investigation tend to corroborate Dake's conclusions. Additional corroborative evidence of marine origin, he adds, is seen in seven features, as follows:

(1) Worm borings: In Chapter III worm borings are described from the middle St. Peter of the Ottawa district. Similar borings were also reported by Freeman. The borings are preserved in sandstone, doubtless deposited by water, and are probably the borings of marine worms, suggesting marine conditions during at least part of middle St. Peter time.

(2) Ripple marks: The upper and lower St. Peter in northern Illinois and the middle of the formation in Calhoun County contain ripple marks, which are described in Chapter III. These are of the oscillation type commonly developed in shallow water.

(3) Desiccation or sun cracks: In Chapter III desiccation cracks are described from the middle St. Peter in sandstone with a high clay and probably a high colloidal silica content. The presence

[27] Trowbridge, A. C., The Origin of the St. Peter Sandstone. Iowa Academy of Science, Vol. XXIV, pp. 171-175, 1917.

[28] Op. cit., pp. 221-224.

[29] Lamar, J. E., Geology and Economic Resources of the St. Peter Sandstone of Illinois. Illinois Geological Survey, Bulletin 53, 1928.

of these cracks in well-stratified sandstone in horizontal and parallel beds suggests temporary emergence and subsequent submergence of water-laid sediments.

(4) Uniform character of clay: As suggested in Chapter III the uniform character of the clay of the St. Peter is best explained by postulating a principally marine origin for this material.

(5) Relation of bedding and cross-bedding: Dake's contention that bedding in the St. Peter is far more important than cross-bedding is thoroughly confirmed from the detailed study of the St. Peter of Illinois. This is thought to favor marine origin for the bedded sandstone. Furthermore, such cross-bedding as is present in the Illinois St. Peter is generally of the aqueous rather than the eolian type.

(6) Similarity between the St. Peter sand and the New Richmond sand: A comparison of the shape, size, degree of rounding, frosting, and texture of samples of St. Peter sand and the New Richmond sand from outcrops in Illinois fails to reveal any significant difference between the two. Two unlabeled samples of these sands would be indistinguishable. The sieve analysis of a sample of New Richmond is given in the table of fineness tests (Table 10, No. 59). The presence in the New Richmond formation of interbedded limestone of marine origin suggests that the sandstone may also be marine, and that sand of the physical character of the St. Peter may accumulate as a marine deposit.

(7) Limestone and dolomite: The presence of limestone or dolomite beds in the St. Peter of Lake, Cook, and Adams counties indicates that in parts of Illinois at least some of the formation is marine in origin and suggests that parts of the sandstone elsewhere in the State may have had a similar origin.[30]

In Arkansas the St. Peter sandstone exhibits the same structural and stratigraphic features as in Missouri, Illinois, and elsewhere. The pertinent arguments, therefore, that Dake, Lamar, and others urge in favor of the marine origin of the sandstone in Missouri, Illinois, and elsewhere are equally applicable when applied to the origin of the formation in Arkansas.

It would seem that the evidence gathered by several careful students of the St. Peter points unmistakably to the marine origin of the greater part of the formation. The sands of the St. Peter were derived from older formations to the north and carried southward by streams to be deposited as sandstone layers in a sea slowly advancing northward across the interior of North America.

Little is known about the climate of North America during early Ordovician time, and any consideration of the climate of that remote time must be largely theoretical. It is

[30] Op. cit., pp. 28-29.

a reasonable assumption, however, that the area of St. Peter deposition lay in the belt of prevailing west winds demanded by the rotation of the earth, and there is little reason for assuming that either the direction or the rate of earth rotation has changed. It is also reasonable to assume that cyclonic conditions prevailed then as now, but they were probably less pronounced, for there is no evidence of the marked temperature gradient in the two hemispheres which the earth now experiences and with which the present abnormally strong cyclonic control of weather is intimately connected, particularly during the winter, when the temperature gradient is steepest. This consideration, coupled with the wide expanse of lowlands lying west of the Mississippi region during early Ordovician time, leads to the conclusion that the prevailing west winds were dry winds influenced by weak cyclonic control. As Dake points out, these winds would separate the finer materials from the sands and carry these materials eastward beyond the continental mass. This separation was facilitated by absence of vegetation, which had evolved at this early time into plants of a low order of organization and which would have experienced difficulty in clothing a surface watered by deficient rainfall. In turn the winds drifted the heavier sands into the temporary and permanent streams of the time, which also gathered sands from the rivulets developed during the heavy downpours characteristic of a dry climate. In places on the shores of the advancing sea and elsewhere over the interior region the wind drifted the sands over local areas, forming sand plains and dunes. These sands were incorporated by wave action into the layers of sandstone forming in the waters of the shallow advancing sea. Much of the sand was thus subjected to wind action, which accounts for its frosted character, and the preservation of the frosting indicates that the sand was subjected to water action for only a relatively brief period before burial by additional supplies of sands carried into the advancing waters.

GEOLOGIC HISTORY

At the close of deposition of the Everton formation the shallow sea which had been receiving sand and calcareous mud to form the Everton beds withdrew probably southward and the emerging land area was subjected to erosion.[31] This period of erosion was of sufficient duration to remove

[31] Eureka Springs-Harrison Folio, p. 18.

completely the Everton from considerable areas in the Ozark region, and to trench the formation deeply elsewhere. At the same time underground water was forming caverns in the limestone. It is probable that the entire Ozark region and much of the Mississippi Valley was land area at this time, so that streams were actively removing formations older than Everton where the Everton had not been deposited. Thus, in Illinois the older Shakopee formation, which underlies the St. Peter, was undergoing erosion at the same time that the Everton and older formations were being removed in Arkansas. During this period of erosion in Arkansas clay and sandy soils accumulated as they do today on land surfaces during the period of erosion of a region. The soil as rapidly as formed was exposed to the action of the wind, which removed the finer materials beyond the limits of the region.

This period of erosion was terminated by a readvance of the sea from the south. The waters advanced slowly and the waves removed whatever soil accumulations were encountered, the finer materials being transported by the agitation of the water far back from the shore. The coarser materials were reduced to sand and much sand was obtained from streams flowing from the north, as well as from winds sweeping the beach and dry adjacent surfaces. This sand, in part rounded and frosted, was deposited to form the sandstone layers of the St. Peter. Reworking the beach materials and depositing their burden back from the shore line the waves slowly advanced across the Ozark region and northward into the upper Mississippi Valley region, thus burying the whole interior of the United States beneath the waters of a shallow sea. The rate of deposition in such a shallow, migrating sea doubtless varied considerably, but it was greatest in the strip of sea water lying a short distance back of the advancing waves.

As the waves advanced farther and farther inland the sea waters were gradually cleared of their sand content and received instead finer calcareous materials, which were deposited as layers upon the sands to form the Joachim limestone. "Nevertheless, some quartz sand, like that in the underlying beds of heavy sand, continued to be delivered to the sea and was at places laid down with calcareous material and a small amount of magnesium carbonate, which together produced sandy limestone. At other places the sand was sufficient in quantity to form sandstone that included but little calcareous material. The paucity of fossils indicates that marine life was then meager.'"[32]

The deposition of the Jasper formation followed the close of Joachim deposition. This formation is known only in the central part of the Ozark region of Arkansas, near Jasper, in Newton County. The Jasper beds were laid down in a shallow and restricted sea, probably with southward outlet. After Jasper deposition much of the southern Ozark region appears to have been land undergoing erosion.

During the succeeding Ordovician period the eastern part of the southern Ozark region was invaded at least four times by the sea. And during the following Silurian, Devonian, and Mississippian periods the Ozark region experienced frequent incursions by the sea, alternating with long periods of erosion. During these erosion intervals formations previously deposited were partially or wholly removed from small or large areas, so that the St. Peter sandstone and older as well as younger formations may vary in thickness in small distances, and locally may be absent where they have been completely removed. These successive erosion intervals also explain why the formations overlying the St. Peter may be of various ages, from Joachim to early Mississippian, erosion having removed older beds overlying the St. Peter before the younger beds that now overlie the sandstone were deposited.

LITHOLOGIC FEATURES

COHERENCE

In general the St. Peter sandstone of Arkansas is so friable that it may readily be disintegrated by rubbing with the fingers, and pieces in a mortar easily yield to the blows of a pestle. But locally the sandstone is resistant, in fact, it is so firmly cemented as to be broken with difficulty with a hammer. Near Cave City, in southern Sharp County, the sandstone recently exposed in road improvement is so firmly resistant as to be almost a quartzite. Beds near Maxville, in southwestern Sharp County, exhibit the same character, yet adjacent beds are friable. A bed may also be hard and resistant at one place and within a short distance be friable. It is apparent that the coherence of the sandstone is variable both laterally and vertically. This is true in weathered outcrops as well as in fresh exposures. Its degree of coherence, therefore, is a feature which does not seem to be con-

[32] Eureka Springs-Harrison Folio, p. 18.

trolled by weathering. Although the sandstone is resistant in places, yet as a whole the formation is very friable, so that collection of samples for making microscopic slides, performing absorption tests, etc., where a considerable degree of coherence is desirable, is difficult.

COLOR

Fresh exposures of the sandstone are white or light cream-colored, but weathered surfaces in most places are brown, due to infiltration of iron compounds washed down the exposed surfaces from the overlying soil, or due to oxidation of minute particles of pyrite locally but very sparingly distributed through the sandstone.

Thin green bands are discernible in some exposures. This color Dake attributes to the presence of clay containing chlorite. Yellow to brown ferruginous streaks and bands are locally developed along joints and other fracture planes in the formation. Rootlets penetrating the sandstone along joints and horizontal seams from the soil above develop thin horizontal and vertical carbonaceous bands, formed by the decomposition of the organic matter.

INTERBEDDED STRATA

The formation is not everywhere entirely sandstone but here and there contains layers of other kinds of rocks. Purdue and Miser state that "a foot of sandy bluish-gray limestone in the St. Peter sandstone, 40 feet from its top, is exposed on Little Buffalo Fork, 3½ miles northeast of Jasper. It is possible, however, that this sandy limestone is the upper part of the Everton and that the underlying 30 feet of massive friable white sandstone that is calcareous in thin layers is the Kings River sandstone member, but as a similar calcareous sand near the base of the St. Peter has been seen at a few other places in this part of the Harrison quadrangle these beds are referred to the St. Peter."[33]

Parks reports calcareous sandstone overlain with shale in the upper part of the St. Peter two miles north of Rush. The shale and the limy sandstone are several feet thick.[34]

INTERSTITIAL MATERIAL

In those parts of the formation immediately adjacent to soil a small amount of organic matter has been carried into

[33] Eureka Springs-Harrison Folio, p. 7.
[34] Personal communication.

the sand layers. Elsewhere organic matter is essentially absent. Iron is present locally in the formation as minute inclusions of pyrite[35] and as hydrated oxide of iron coating the sand grains. This iron coating is secondary and may be due to oxidation of pyrite or to leaching of overlying soil and deposition of the iron oxide by downward penetrating rain-water. This is a local phenomenon and is mainly limited to the exposed portions of the sandstone subject to surface wash from above and to the layers immediately beneath ferruginous soils. Horizontal bands a few inches thick of faintly reddish-brown sandstone, the so-called "iron seams," have been discussed by Dake, who considers the iron to be of secondary origin, accumulated by oxidation at levels marking a position of a former water table, which remained stationary for a considerable period of time.[36]

Nearly all the analyses of the St. Peter sand yields an appreciable amount of alumina. The alumina is a constituent of clay present in the sandstone as "mud seams" a few inches thick, or in very small amounts as a partial coating of the grains, or as particles between the grains. In some places the clay has been introduced through infiltration from above subsequent to the formation of a soil cover which furnished the source of the clay, but generally the clay is probably to be regarded as an original constituent of the formation. The general absence of conspicuous bedding in the formation is in large part to be attributed to the absence of clay seams, which serve to make the bedding a conspicuous feature of many formations.

Lime and magnesia are revealed in scarcely more than traces in nearly every analysis. They are present as carbonates, and were introduced mainly at the time of formation of the sandstone, although a part of the material may have been introduced by underground water subsequent to the elevation of the sandstone above sea level.

CLEANNESS

Cleanliness is an important property of sands, particularly with reference to certain uses. The chief impurities are clay or silt, organic matter, iron stain, and finely divided quartz and other hard minerals. A simple method of detecting impurities is to rub a little of the sand between the hands. A

[35] Bulletin 734, U. S. Geological Survey, p. 17.
[36] The Problem of the St. Peter Sandstone, p. 139.

perfectly clean sand will not soil the fingers. If a sand is found to be dirty, the percentage of its impurity is determined by washing. A sample of sand, after being thoroughly dried, is weighed and placed in a pan of water and stirred vigorously. It is then allowed to settle, after which the water is decanted. This operation is repeated until the water, after stirring, fails to show any turbidity. The water is then poured off and the sample is thoroughly dried and weighed. The loss of weight represents the impurities removed. The following formula is applicable:

$$D = \frac{W - W'}{W}, \text{ in which}$$

D = Proportion of dirt
W = Weight before washing
W′ = Weight after washing

In samples of the St. Peter collected from unweathered outcrops the percentage of dirt is so low as to be almost or quite inappreciable when measured by the method just described. Yet much of the St. Peter sand that goes on the market is washed, the process removing a large proportion of the "fines," some organic matter, and hydrated iron oxide.

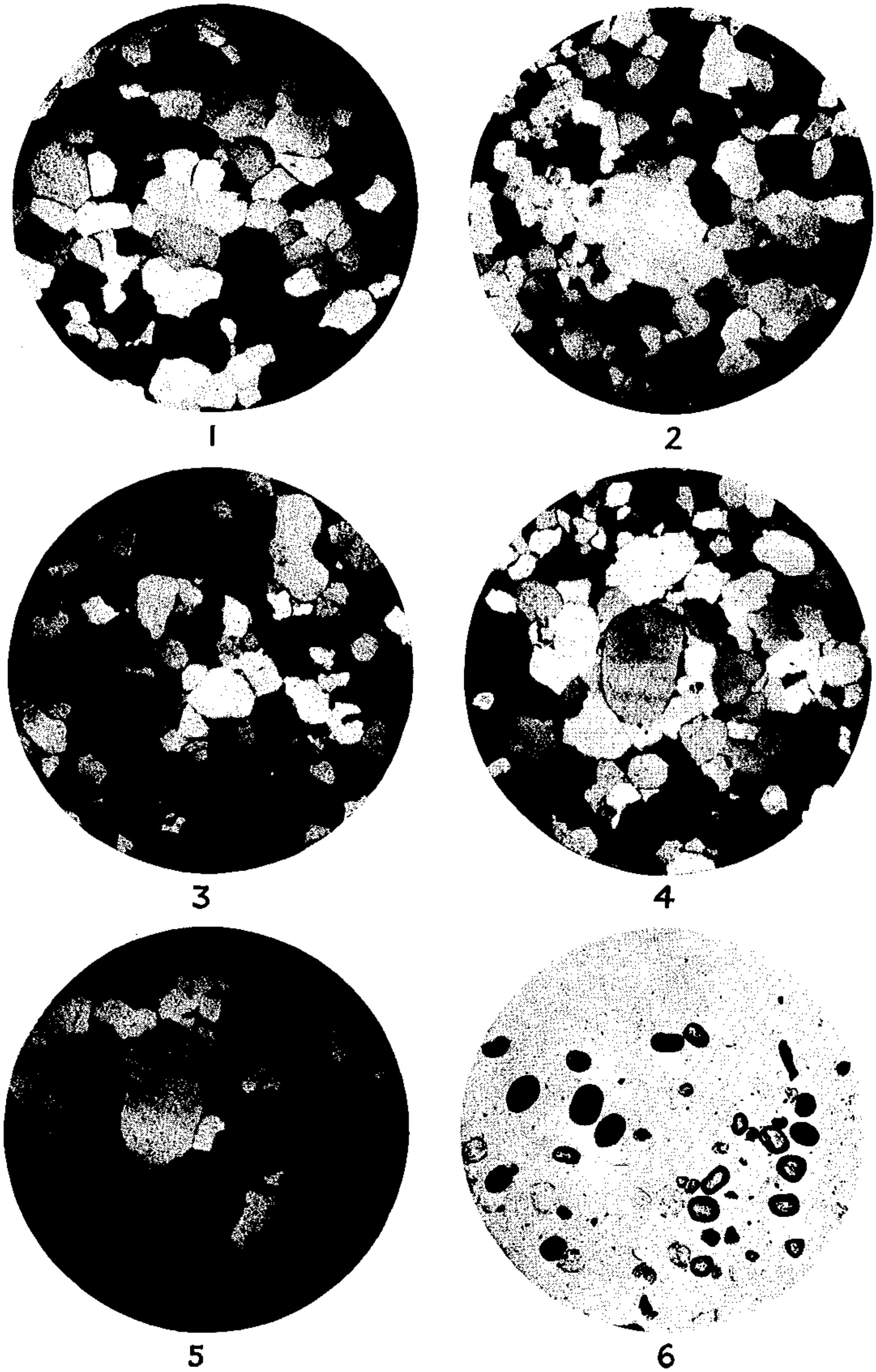
TEXTURE

GENERAL FEATURES

The texture of the sandstone has been studied megascopically and microscopically. In the microscopic study a binocular with magnification of 30 diameters was used. A number of thin sections were also cut for microscopic examination (Pl. IV), but their examination revealed little beyond the information gathered in the binocular study. The angularity of many grains is brought out in their cross-sections, as well as the indiscriminate mixing of grains of all sizes, a characteristic feature of the sandstone everywhere.

The texture of the St. Peter sandstone is variable in individual samples but monotonously uniform when the formation as a whole is concerned. Fine and coarse grains are indiscriminately mixed. Rarely do samples show grains strikingly large or uniformly small. Mechanical analyses of samples from different localities show few differences.

The sandstone is also remarkably uniform in texture from the top to the base of the formation. Locally, as at



MICROSCOPIC VIEWS OF THIN SECTIONS OF ST. PETER SANDSTONE AND OF ST. PETER SAND

No. 1, from near middle of formation, near Maxville, southwest Sharp county; No. 2, from near top of formation, south of Cave City, northern Independence county; No. 3, from near base of formation, near Maxville, southwest Sharp county; No. 4, from near middle of formation, south of Cave City, northern Independence county; No. 5, from near base of formation, near Calamine, eastern Sharp county; No. 6, heavy minerals in the St. Peter sandstone.

Guion, certain parts of the formation yield materials of more desirable sizes for certain industrial purposes, but the difference in texture between these layers and layers above and below is slight.

COLLECTION OF SAMPLES

A large number of samples collected from the formation across northern Arkansas were screened. Unfortuately, most of the samples had to be collected from surface outcrops with limited exposures, since active exploitation of the formation has been undertaken in only one locality. The samples were collected where the rock appeared fresh and unstained by surface wash and from the part of the outcrop that appeared typically to represent the texture of the rock for the locality. Trenching of the formation from top to bottom was not resorted to because of limited time at the disposal of the collector.[37] There was also the additional factor involved in the difficulty of finding complete sections of the formation and of removal of decayed and stained surfaces of the rock from the sections. The mechanical analyses therefore represent but a very limited fraction of the vertical thickness of the formation.

MECHANICAL ANALYSES

The samples collected were filed in drawers in the laboratory cabinet, each sample labeled with its field number. When ready for study the sample was crushed in a mortar with a small, light wooden mallet. Many samples, however, required no such treatment, the friability of the sandstone leading to their disintegration during their collection in the field. Each sample was next dried in an electric oven and a definite quantity of it was weighed and screened.

The sieve analyses were made with Tyler Standard screens,[38] nested in a mechanical agitator driven by an electric motor and shaken for four minutes. In Table 3 the sizes of screens used and their dimensions are given.

[37]Most of the samples were collected by Bryán Parks of the Arkansas Geol. Survey.
[38] Described in Catalogue 48, W. S. Tyler Company, Cleveland, Ohio, 1924.

Table 3.—Constants for Tyler Standard Screen Scale Sieves[39]

[Arranged According to Sieve Openings]

Sieve	Apertures Tyler Standard Screen Scale Sieves		Average Diameter of Product	
	Inches	Millimeters	Inches	Millimeters
1 in.	1.050	26.67		
			0.896	22.76
¾ in.	0.742	18.85		
			0.634	16.09
½ in.	0.525	13.33		
			0.448	11.377
⅜ in.	0.371	9.423		
			0.317	8.052
3 m	0.263	6.680		
			0.224	5.690
4 m	0.185	4.699		
			0.158	4.013
6 m	0.131	3.327		
			0.112	2.845
8 m	0.093	2.362		
			0.079	2.014
10 m	0.065	1.666		
			0.056	1.422
14 m	0.046	1.178		
			0.0394	1.000
20 m	0.0328	0.833		
			0.0280	0.711
28 m	0.0232	0.589		
			0.0198	0.503
35 m	0.0164	0.417		
			0.0140	0.356
48 m	0.0116	0.295		
			0.0099	0.252
65 m	0.0082	0.208		
			0.0070	0.178
100 m	0.0058	0.147		
			0.0050	0.126
150 m	0.0041	0.104		
			0.0035	0.089
200 m	0.0029	0.074		
			0.0022	0.056
270 m	0.0014*	0.037		

*Assumed.

[39] W. S. Tyler Co., Cleveland, Ohio, Catalogue 48, p. 37.

Table 4 illustrates the method employed for recording the results of the sieve tests and the results of the subsequent computations.

Table 4.—Results of Screen Tests and Computations in Mechanical Analyses of Sand of St. Peter Sandstone

(Sample No. 23-A; weight of sample 100 grams)

SCREEN SCALE (Ratio= $\sqrt{2}$)	TIME OF SHAKE, 4 MINUTES					
Mesh	Weight Retained	Per Cent Retained	Cum. Per Cent	Uniformity Coeff.	Effective Size	Fineness Modulus
10						
14						
20						
28	0.38	0.38	0.38			
35	3.58	3.58	3.96			
48	8.78	8.78	12.74			
65	25.76	25.76	38.50			
100	42.34	42.34	80.84			
150	15.92	15.92	96.76			
200	2.76	2.76	99.52			
Pan	0.30	0.30	99.82			
Total	99.82	99.82	99.82	1.63	0.125	1.92

Sixty-three samples of sand from the St. Peter sandstone were screened. Of this total 54 samples were selected as typical of the St. Peter sand in Arkansas. The essential facts regarding these samples are shown in Table 5, together with the locality and position in the formation where the sample was collected. The terms "base of formation" or "near base of formation," and "top of formation" or "near top of formation," appearing in Table 5 mean that the sample was collected within five feet above the base or five feet below the top of the formation, respectively. The vertical positions from which other samples were collected are indicated in the table. Figures 2, 3, 4, 5, 6 and 7 (pp. 28-33) graphically illustrate many of the analyses.

SIZES OF THE GRAINS

Range in size.—In all samples the grains were small enough to pass the 20-inch mesh. Eighteen samples contained grains large enough to remain on the 28 mesh after four minutes of shaking. All samples showed a considerable residue on the 150 mesh, and 46 samples had weighable quantities on the 200 mesh. Of the 54 samples 31 left a weighable residue in the pan, passing the 200 mesh.

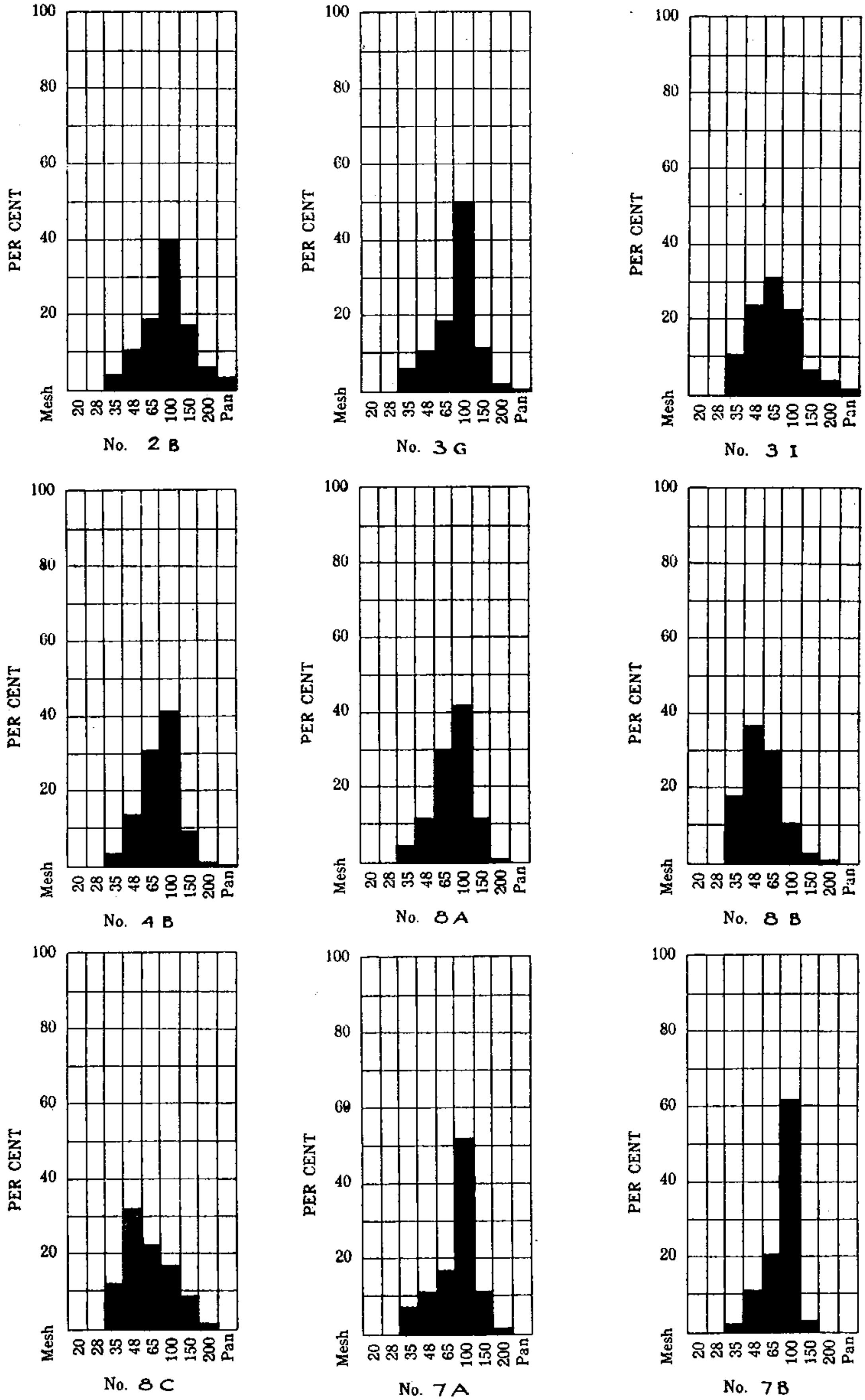


FIGURE 2.—Composition pyramids of samples of St. Peter sand from southern Sharp, northern Independence, and southeastern Izard counties.
The numbers below the diagrams are the numbers of the samples as given in Table 5.

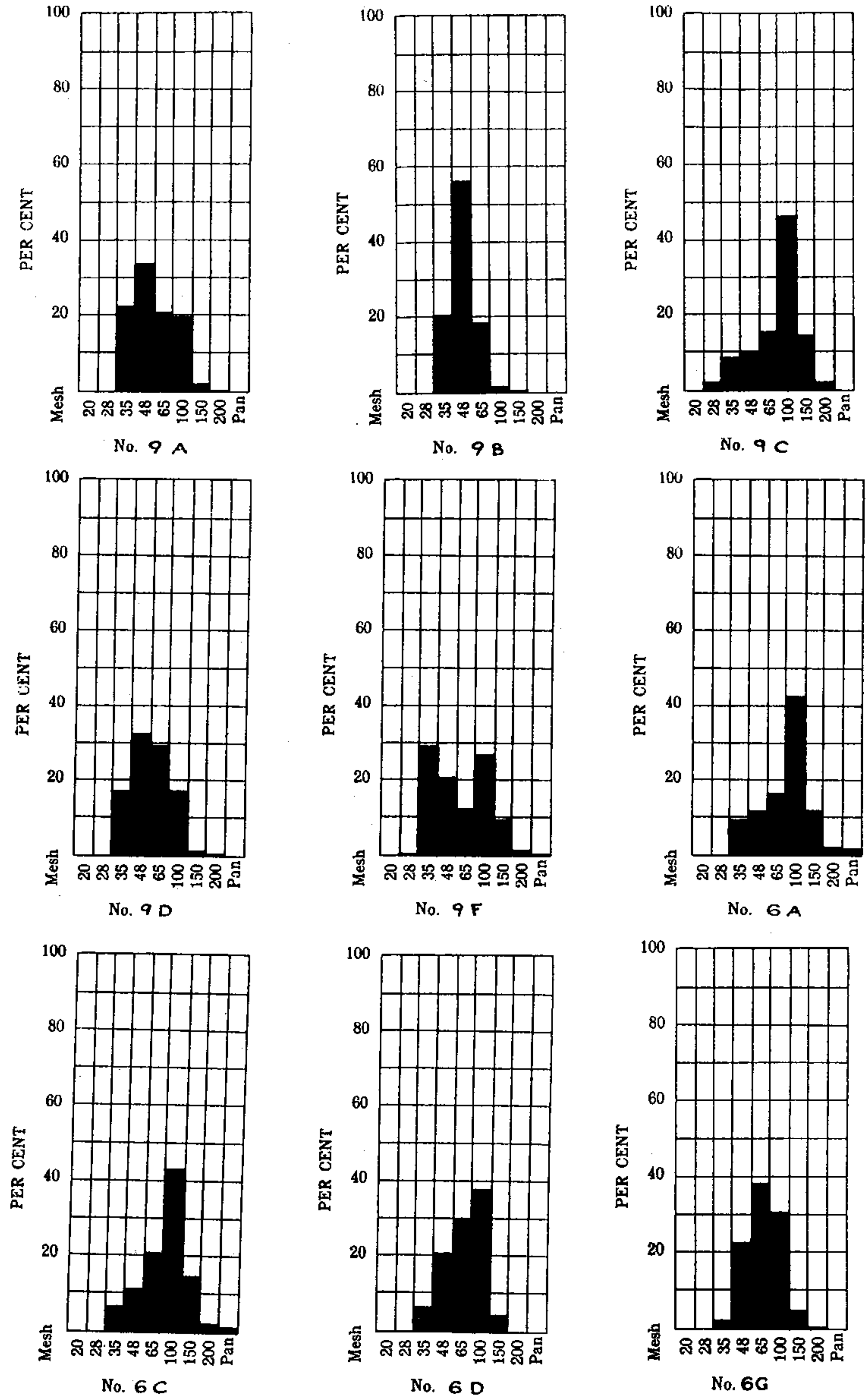


FIGURE 3.—Composition pyramids of samples of St. Peter sand from southern and southeastern Izard county.

The numbers below the diagrams are the numbers of the samples as given in Table 5.

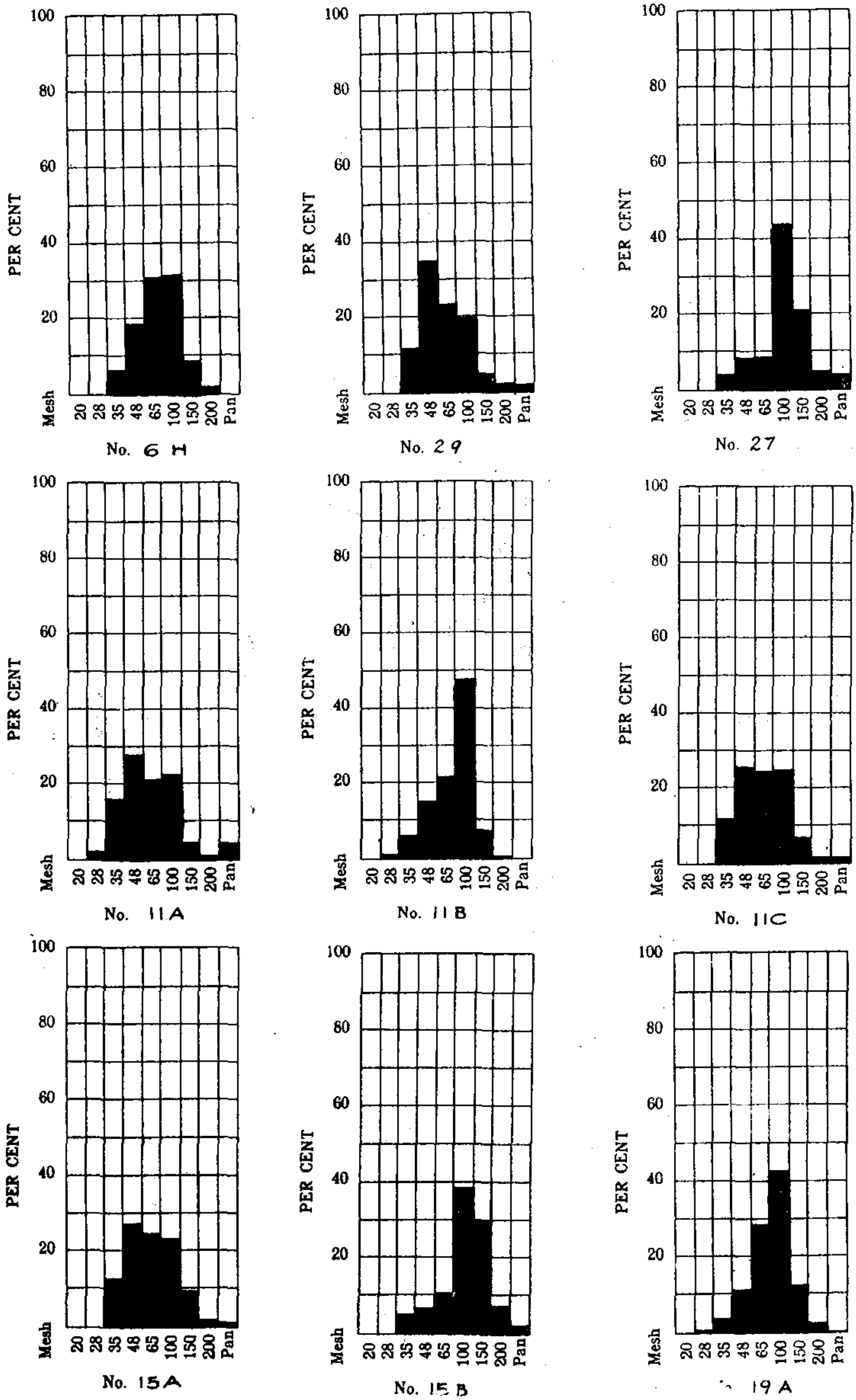


FIGURE 4.—Composition pyramids of samples of St. Peter sand from southern and western Izard, northern Stone, and southeastern and western Marion counties.

The numbers below the diagrams are the numbers of the samples as given in Table 5.

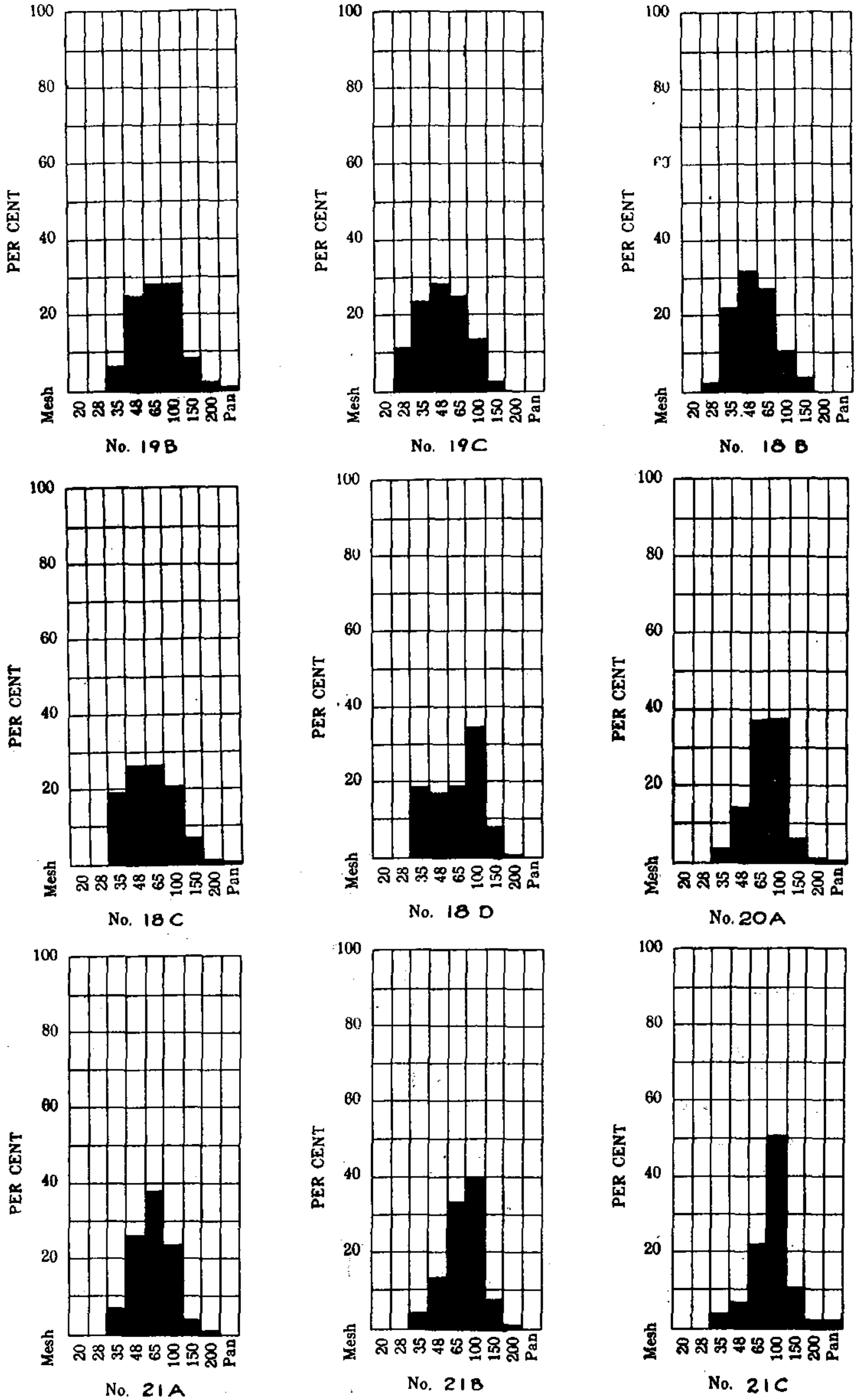


FIGURE 5.—Composition pyramids of samples of St. Peter sand from western Marion, southeastern Boone, northwestern Searcy, and northern Newton counties. The numbers below the diagrams are the numbers of the samples as given in Table 5.

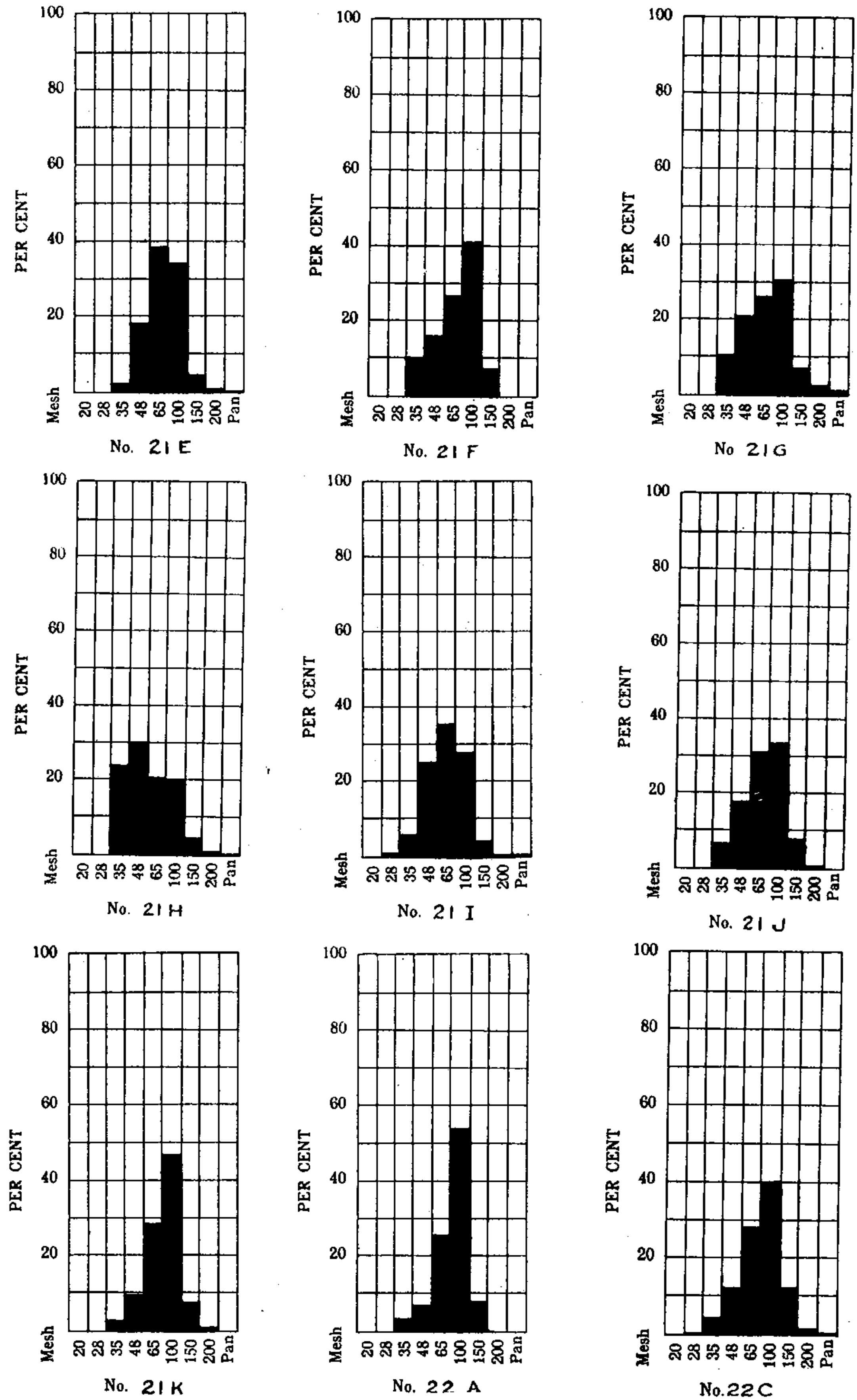


FIGURE 6.—Composition pyramids of samples of St. Peter sand from northern Newton and south-central Boone counties.

The numbers below the diagrams are the numbers of the samples as given in Table 5.

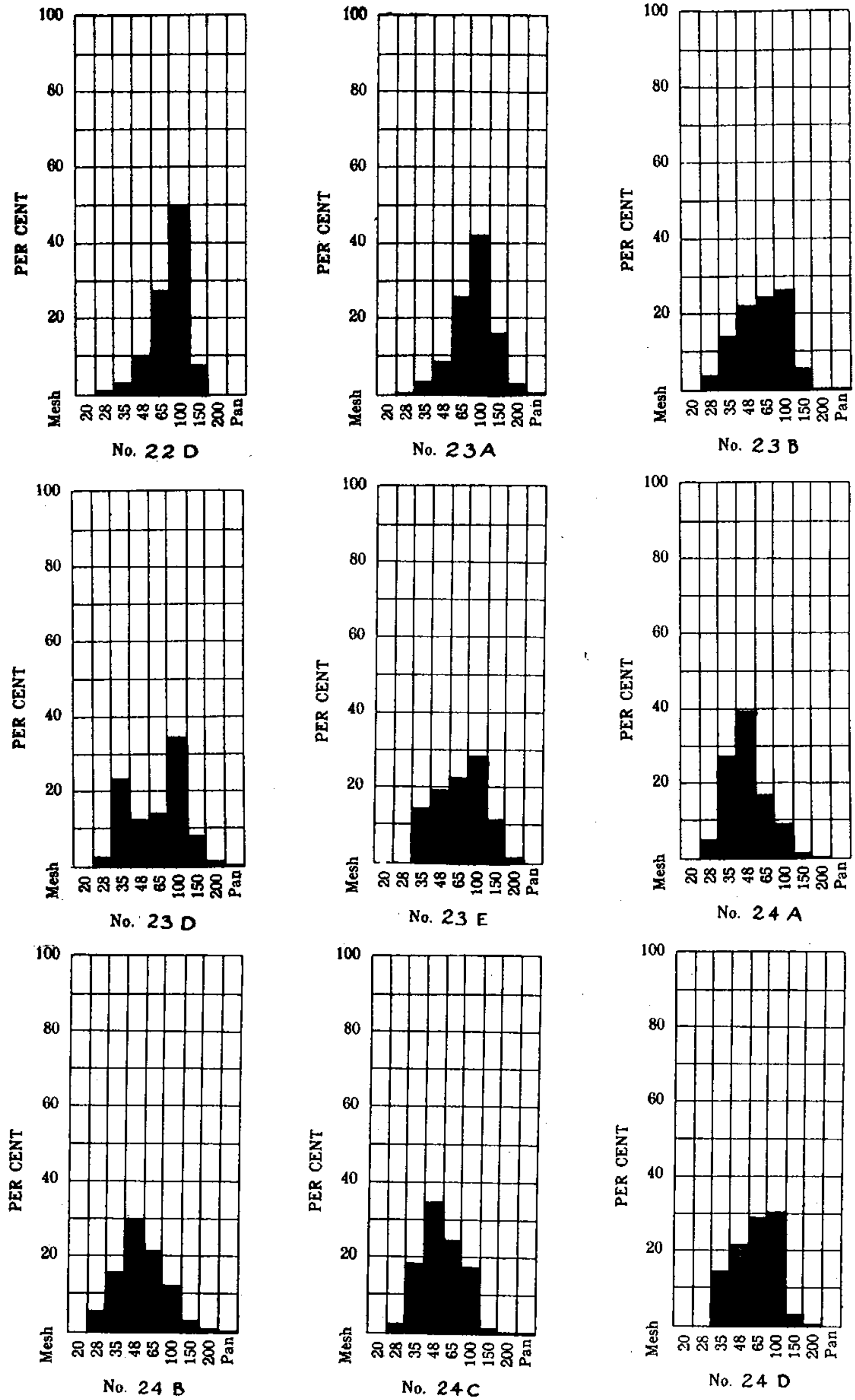


FIGURE 7.—Composition pyramids of samples of St. Peter sand from south-central Boone, southeastern, southern, and southwestern Carroll, and northern Madison counties.

The numbers below the diagrams are the numbers of the samples as shown in Table 5.

Fineness modulus.—Abrams has devised the most recent method of determining a single figure that will express the fineness of a sand.[40] This figure is called the fineness modulus. The fineness modulus of a sand is defined as the sum of the cumulative percentages computed from the sieve analysis, either by weight or by volume, divided by 100. Each of the sieves used should have an opening double that of the preceding sieve. Abrams bases his method on the products of three sieves, e.g., 48, 100, and 200. Lamar has modified Abrams' method by using the cumulative percentages of four sieves, e.g., 28, 48, 100, and 200.[41] This gives a more accurate figure than that based on the cumulative percentages of three sieves. The following example shows how the fineness modulus is calculated:

Fineness Modulus of Sample 11-B

Mesh of sieve	Cumulative percentages
28	1.20
48	22.60
100	92.60
200	100.40
100	216.80
	2.17 = Fineness modulus

Many of the samples of St. Peter sands from Arkansas were too fine to leave a residue on the 28-mesh sieve. For these samples the fineness modulus was calculated by adding the cumulative percentages of the 48, 100, and 200 mesh sieves and dividing the result by 100.

The fineness modulus of all the samples of St. Peter screened was computed and the results are given in Table 5. As this table indicates, the fineness modulus of the St. Peter sand ranges between 1.53 and 2.74, with an average of 2.17 for the 54 samples.

Based on fineness modulus the St. Peter sand of Illinois was divided into three classes by Lamar,[42] as follows:

Coarse: Fineness modulus 2.76 and larger.
Medium: Fineness modulus above 2.30 and below 2.76.
Fine: Fineness modulus 2.30 and smaller.

The results of the application of this three-fold division to the St. Peter sand of Arkansas are given in Table 6.

[40] Abrams, D. A., Design of Concrete Mixtures. Structural Materials Research Laboratory, Lewis Institute, Bulletin 1, pp. 5-7, Chicago. 1924.
[41] Lamar, J. E., Geology and Economic Resources of the St. Peter Sandstone of Illinois. Bulletin 53, Illinois Geol. Survey, pp. 157-158, 1928.
[42] Op. cit., p. 158.

Table 6.—Classification of St. Peter Sand of Arkansas Based on Fineness Modulus

Number of Samples	Fine (2.30—)	Medium (2.30-2.76)	Coarse (2.76+)
54	40	14	0
Percentage	74	26	0

A comparison of the fineness modulus of the St. Peter sand of Arkansas with results obtained in the study of the St. Peter sand of other States is given on a later page.

Percentage of fineness.—Several methods of determining the percentage of fineness of a sand have been devised. Several years ago Kümmel and Hamilton[43] suggested that the percentage of fineness may be determined by adding the percentages of sand passing the sieves of a given set and dividing the number thus obtained by the number of sieves used. This method affords an approximate means of comparing sands with each other, provided they have each been screened with the same set of sieves or with sieves of identical mesh. The percentage for each sieve is readily determined by subtracting the cumulative percentage for the sieve from the total percentage retained in the complete analysis. In Table 5 the percentage by weight of sand retained on each sieve is given. The percentage of fineness for any analysis in this table may be readily obtained by computing the cumulative percentages for each sieve, subtracting the results thus obtained from the total percentage of the analysis, adding the remainders, and dividing by the number of sieves used in making the mechanical analysis. The folowing example illustrates the method employed.

Percentage of fineness of sample 23-A

Mesh of sieve		Percentage passing	
28		99.44	
35		95.86	
48		87.08	
65		61.32	
100		18.98	
150		3.06	
200		0.30	
	7	366.04	
		52.29	= percentage of fineness

[43] Annual Report of the State Geologist of New Jersey for 1904, p. 208. New Jersey Geological Survey, 1905.

Table 7.—Percentage of Fineness of St. Peter Sand

SAMPLE NO.	PERCENTAGE PASSING EACH SIEVE							Number of Sieves	Percent-age of Fineness	HORIZON IN FORMATION	LOCALITY
	28	35	48	65	100	150	200				
2-B	99.42	95.42	85.02	66.62	26.82	9.42	3.22	7	55.13	Base	Southeast of post office at Sidney
3-G	100.00	94.36	83.66	65.06	15.06	3.50	0.90	7	51.88	110 feet below top	In front of post office at Sandtown
6-C	100.00	93.80	82.60	61.70	18.70	3.70	1.70	7	51.80	65 feet below top	Southeast of post office at Anderson
7-A	99.80	92.40	81.40	64.40	12.80	1.60	0.00	7	50.34	25 feet below top	West of Mt. Pleasant ¼ mile
8-A	100.00	95.54	83.86	54.22	12.50	0.90	0.00	7	49.60	15 feet below top	North of Cushman 1½ miles
11-A	97.72	81.72	54.32	33.12	10.56	5.92	4.22	7	41.08	Base	n Pilot Knob
18-C	100.00	81.80	55.80	29.80	8.80	1.80	0.60	7	39.91	10 feet above base	Below the school house at Everton
19-A	100.00	97.66	86.26	57.86	15.12	2.92	0.16	7	37.30	Top	East of Pyatt ¼ mile
21-C	98.80	94.90	88.10	66.10	15.30	4.70	2.30	7	52.89	10 feet below top	Little Buffalo Fork at Jasper
21-I	98.65	92.72	67.69	32.48	5.02	0.56	0.32	7	42.49	Near top	South of Willcockson 5 miles
21-K	98.78	96.03	86.37	57.76	10.55	2.46	0.90	7	50.41	Top	South of Wilcockson ¼ mile
22-C	98.95	94.54	82.64	54.42	14.70	2.76	0.44	7	49.78	25 feet below top	At Bellefonte, in creek bed
23-A	99.44	95.86	87.08	61.32	18.98	3.06	1.30	7	52.43	Middle	Southeast of Berryville 10 miles
23-D	99.19	86.19	65.93	38.73	10.29	2.45	0.90	7	43.38	Near top	At Metalton, in Piney Creek
29	98.91	87.23	52.36	28.73	9.24	4.28	2.16	7	40.42	12 feet below top	Silica Products Co., at Guion
Av.	99.31	92.01	76.21	51.49	13.63	3.34	1.27	7	47.26		

Table 7 gives the percentage of fineness of 15 samples of St. Peter sand selected from Table 5 and computed by the method just described. From the results thus obtained the average percentage of fineness, 47.26, was determined, a figure that probably represents very closely the percentage of fineness of the formation as a whole, for the samples were selected as typical of the St. Peter sand obtained at widely separated localities.

Average fineness.—Lamar has summarized the method of obtaining an average fineness figure recommended by the International Correspondence Schools of Scranton. This method may be used for comparing sand, but it is open to the objection that it is possible by selecting analyses to obtain the same fineness figure from sands of different sieve analyses.[44]

In this method the sieves used are of the meshes indicated in the example given below. The fineness figure is determined by multiplying the weight of the sand passing each sieve by the number of mesh of the sieve and dividing the total of all the sieves by 100. The 60-mesh sieve is credited with any loss occurring during the sieving operation, and the sand not passing the 20-mesh sieve is credited to a 1-mesh sieve. The following example illustrates more concretely the method here described.

Mesh of sieve		Weight of sand passing one sieve and retained on the next		
100	×	5.2		520.0
80	×	5.0		400.0
60	×	10.0		600.0
40	×	20.0		800.0
20	×	59.2		1184.0
1	×	0.5		0.5
60	×	0.1	(Loss)	6.0
			100	3510.5
			Average fineness	35.1

The average fineness figure is sometimes spoken of in commercial parlance as the fineness number.

Average grain size.—Average grain size is the term applied to the size of the average grain of a sample of sand. It is determined by calculating the average size of each mesh of a sieve having a given number of openings per linear inch and multiplying the number obtained by the amount of sand

[44] Op. cit., pp. 156-157.

retained on the given sieve expressed as a fraction of unity.[45] It is assumed that the grains retained on the 20-mesh sieve average 1-15 inch in size. This size would be expressed decimally by 0.066. Those retained on the 40-mesh sieve would range from 1-20 to 1-40 inch in size, and their average would be as follows:

$$\frac{1/20+1/40}{2} = 0.037$$

The averages for the other meshes are determined in the same way; thus for the 250 mesh:

$$\frac{1/150+1/250}{2} = 0.005$$

Ries and Rosen suggest the following illustrative example:

Table 8.—Determination of Average Grain Size of a Sand

SIEVE ANALYSIS		CALCULATION OF AVERAGE GRAIN SIZE		
Mesh	Percentage	Fraction of Unity	Average Grain Size in Inches	Product of Columns 3 and 4
20	6.84	.0684	× .066	.00451
40	6.61	.0661	× .037	.00244
60	40.09	.4009	× .019	.00762
80	8.98	.0898	× .013	.00117
100	23.82	.2382	× .011	.00262
250	12.56	.1256	× .007	.00088
Clay	1.06	.0106	× .002	.00002
			Total	.01926 average grain size

That is, $$\frac{1}{.01926} = 51$$

In other words, if all the grains in a given volume of the sand whose mechanical analysis is shown above were reduced to a uniform size, they would pass through a 51-mesh sieve.

As Lamar has pointed out, the chief sources of error in this method reside in the fact that an average screen size must be calculated and that the size retained on any sieve varies between the sizes of the mesh of the retaining sieve and of the mesh of the sieve through which it passes on to the retaining sieve.[46]

Effective size and uniformity coefficient.—It is customary to specify effective size and uniformity coefficient in connection with the purchase and use of sands for filtration.

[45] Ries, H. and Rosen, J. A., Foundry Sands of Michigan. Michigan Geological Survey Ann. Rept. for 1907, pp. 50-51, 1908.
[46] Op. cit., p. 157.

Aside from this particular use of sand the effective size and uniformity coefficient are rarely considered. The effective size and uniformity coefficient of the samples of the St. Peter sand studied have been calculated and the results are given in Table 5 (p. 28).

The effective size is measured by that opening which will just pass 10 per cent of a representative sample of sand. The uniformity coefficient is defined as the "ratio of the size of grain which has 60 per cent of the sample finer than itself to the size which has 10 per cent finer than itself."[47]

The uniformity coefficient of a sample of sand is obtained by dividing the size of opening expressed in millimeters which will pass 60 per cent of the sand by the effective size. The uniformity coefficient is intended to indicate the uniformity of the sand or the variation in the 50 per cent of sand lying between the finest 10 per cent and the coarsest 40 per cent. The closer the uniformity coefficient is to zero the more uniform the sand.

"That is, in a sand, if just 10 per cent were finer than 1 mm. and just 60 per cent finer than 2 mm., the uniformity coefficient would be 2. In other words, 50 per cent of the sample lies between 1 mm. and 2 mm. in diameter. Similarly, if 10 per cent of the sample were finer than 3 mm. and 60 per cent finer than 6 mm., the uniformity coefficient would again be 2, though the latter sand would be three times as coarse as the former. Thus, it will be seen that the uniformity coefficient does not necessarily indicate the absolute coarseness or fineness of a sand. It merely expresses a ratio of variation of size of grain. A sand with a coefficient of 5 means that 50 per cent of that sand has a variation in size of grain represented by the ratio of 1:5. A uniformity coefficient of 1, which is almost an impossibility, would mean that 50 per cent of the sand was uniform in size, with 10 per cent smaller and 40 per cent larger than this size. The smaller the uniformity coefficient, the more uniform the grain of the sand; the larger the uniformity coefficient, the less uniform the grain of the sand."[48]

The values of effective size and uniformity coefficient can be most readily determined by means of interpolation on cumulative direct plotting paper.[49]

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[47] Condra, G. E., Sand and Gravel Resources and Industries of Nebraska. Nebraska Geological Survey, Vol. III, pt. 1, p. 30, 1908.

[48] Dake, C. L., The Sand and Gravel Resources of Missouri. Missouri Geol. Survey, Vol. XV, 2d series, p. 14, 1918.

[49] This paper may be procured directly from the W. S. Tyler Co., of Cleveland, Ohio.

Table 8A.—Derivation of Cumulative Per Cent and Method of Recording Uniformity Coefficient and Effective Size as Determined by Figure 8

SCREEN SCALE RATIO= $\sqrt{2}$				TIME OF SHAKE—4 MINUTES				
OPENINGS		Mesh	Diam. of wire (inch)	Weight Rtnd.	Per Cent Rtnd*	Cum. Per Cent	Uniformity Coeff.	Effective Size
Inches	Mils.							
.065	1.651	10	.035					
.046	1.168	14	.025					
.0328	.833	20	.0172					
.0232	.589	28	.0125		0.80	0.80		
.0164	.417	35	.0122		10.88	11.68		
.0116	.295	48	.0092		20.58	32.26		
.0082	.208	65	.0072		24.78	57.04		
.0058	.147	100	.0042		32.16	89.20		
.0041	.104	150	.0026		8.06	97.26		
.0029	.074	200	.0021		1.55	98.81		
		Pan			0.75	99.56		
					99.56		1.83	0.146

*Averages of analyses of 54 samples of St. Peter sand as given in Table 5.

The following diagram (Fig. 8), plotted on standard graph paper, illustrates the method of procedure used in obtaining the values expressed by the terms effective size and

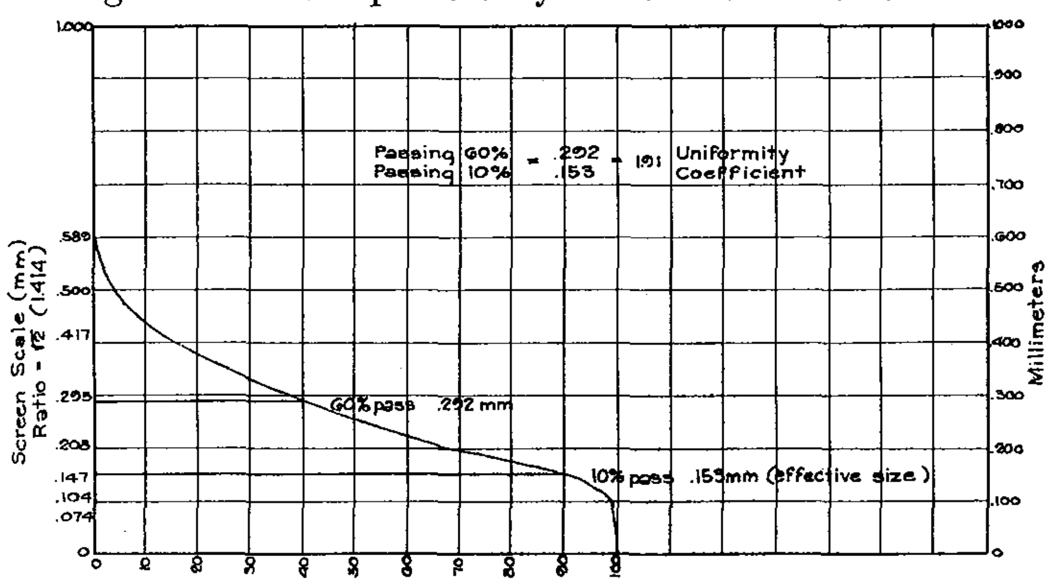

FIGURE 8.—Graph showing the derivation of uniformity coefficient and effective size of all samples of St. Peter sandstone.

The averages of analyses of 54 samples of St. Peter sand were used in plotting the graph. The results are given in Table 8A.

uniformity coefficient. The vertical ordinate (Y coordinate) indicates the weight retained on each screen expressed as a percentage. The horizontal ordinate (abscissa or X coordinate) indicates the screen sizes expressed in millimeters, each smaller division representing four units. The graph expresses the analysis in cumulative percentage. A vertical dropped from the intersection of the graph with the 90 per cent horizontal line intersects the horizontal ordinate or X axis in a point expressing the size of the sieve opening that will just pass 10 per cent of the sample of sand. The value of this point may be read directly on the horizontal ordinate or X axis and represents the effective size. A vertical dropped from the intersection of the graph with the 40 per cent line intersects the horizontal ordinate at a point expressing the size of the sieve opening that will just pass 60 per cent of the sample. The value of this point may also be read directly from the horizontal ordinate. This value divided by the effective size represents the uniformity coefficient.

As indicated in Table 5 (p. 28), the figures showing the effective size and uniformity coefficient of the 54 samples of St. Peter sand have a considerable range, indicating a lack of uniformity in the grain sie of the sand. Effective size has a range from 0.087 (sample 27) to 0.240 (sample 9-B), and an average for the 54 samples of 0.146. Uniformity coefficient ranges between 1.29, the smallest value obtained (sample 7-B) to 2.70, the largest value obtained (sample 18-B), with

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40. Interchange plate of Figure 8 and plate of Figure 13, page 121.

clusions. Hence a comparison of the St. Peter sandstone of Arkansas with the same formation of these two States is readily made and yields interesting and instructive results. In this comparison the fineness modulus, effective size, uniformity coefficient, and size of grains as revealed in many sieve analyses will be considered.

The average fineness modulus of St. Peter sand of Illinois was computed from the results obtained by Lamar and found to be 2.51, with 1.47 as the lowest and 3.08 as the highest values obtained. These figures are based on 76 samples, of which 27 samples were washed sand.[51] Lamar determined

[50] Dake, C. L., The Problem of the St. Peter Sandstone. Bulletin University of Mo. School of Mines and Metallurgy, Vol. VI, No. 1, 1921.

Dake, C. L., The Sand and Gravel Resources of Missouri. Missouri Geological Survey, Vol. XV, 2d series, 1918.

Lamar, J. E., Geology and Economic Resources of the St. Peter Sandstone of Illinois. Illinois Geological Survey, Bulletin 53, 1928.

[51] Op. cit., Table 10.

the average fineness modulus of 28 samples of washed sand from the St. Peter of Illinois to be 2.60, and the average fineness modulus of 29 samples of crude sand to be 2.63.[52]

For the St. Peter of Missouri the average fineness modulus was computed from the results of sieve analyses made by Dake and found to be 2.32. The computations were based on the residues on the 30, 50, 100, and 200 screens, which might introduce a slight difference in the results obtained when compared with the results obtained in Illinois and Arkansas, where Tyler Standard screens were used with the computations based on the residues (cumulative percentages) on the 28, 48, 100, and 200 screens. The lowest value found for the sand samples of Missouri was 1.83 and the highest was 2.83.[53] These figures are based on 27 samples, of which three were washed sand.

Table 9.—Comparison of Fineness Modulus of St. Peter Sand of Several States

State	Condition	Total Number of Samples	Smallest Fineness Modulus	Largest Fineness Modulus	Aerage Fineness Modulus
Illinois	Crude sand	29	1.47	2.97	2.63
	Washed sand	28	2.02	3.08	2.60
Missouri	Crude sand	27	1.83	2.83	2.32
Arkansas	Crude sand (except one sample)	54	1.53	2.74	2.17
Oklahoma	Crude sand	1	1.85	1.85	1.85

The average of the values obtained expressing the fineness modulus of the St. Peter sand of Arkansas was 2.17, based on 54 samples, all of which, with one exception, represented crude sand. The lowest value obtained was 1.53 and the highest was 2.74.

The fineness modulus of a single sample of St. Peter (Burgen) sandstone collected near Grand River in northeastern Oklahoma was 1.85. This indicates a fineness comparable to the St. Peter of Arkansas for this particular sample.

The general results of the comparison of the fineness modulus of the St. Peter sands of the Mississippi Valley are given in Table 9.

Dake determined the effective size and uniformity coefficient of a large number of samples of St. Peter sand collected in Missouri.[54] The results he obtained were averaged

[52] Op. cit., p. 159.
[53] Op. cit., table opposite page 126.
[54] Op. cit., table opposite page 126.

and are given in Table 10. Lamar determined the effective size and uniformity coefficient of a number of samples of the St. Peter of Illinois.[55] The average values yielded by these samples are also given in Table 10. The effective size and uniformity coefficient for all the samples of St. Peter sand of Arkansas studied were determined and their averages have also been introduced in Table 10. The average fineness modulus of the sands for these three States is also included in the table, so that it is possible to compare at a glance the effective size, uniformity coefficient, and fineness modulus for the three States.

Table 10.—Comparison of Average Effective Size, Uniformity Coefficient, and Fineness Modulus of St. Peter Sand of Illinois, Missouri, and Arkansas

State	Average Effective Size		Average Uniformity Coefficient		Average Fineness Modulus	
	No. of Samples	Averages	No. of Samples	Averages	No. of Samples	Averages
Illinois	11	0.204	11	2.04	76	2.51
Missouri	27	0.155	27	1.78	27	2.32
Arkansas	54	0.146	54	1.83	54	2.17

Table 10 emphasizes the close similarity of the St. Peter sands in Illinois, Missouri, and Arkansas. The decrease in the value of the figures from Illinois to Arkansas is clearly indicated, and is probably to be explained by the increasing fineness of the sand southward in the Mississippi Valley with constantly increasing distance from the source of supply and correspondingly greater attrition.

Table 11 presents a classification of the St. Peter sand of Illinois, Missouri, and Arkansas on the basis of the fineness modulus, in which all samples for which the fineness modulus has been determined are divided into three groups on the

Table 11.—Percentage Classification of St. Peter Sand of Illinois, Missouri, and Arkansas on the Basis of Fineness Modulus

State	Condition of Sand	No. of Samples	Fine (less than 2.30)	Medium (2.30-2.76)	Coarse (2.76+)
Illinois	Crude sand	25	8	56	36
	Washed sand	21	14	33	53
Missouri	Crude sand	24	50	42	8
	Washed sand	3	67	33	0
Arkansas	Crude sand	53	75	25	0
	Washed sand	1	0	100	0

[55] Op. cit., p. 155.

basis of size. Group 1 contains all samples with a fineness modulus below 2.30; group 2 contains all samples with a fineness modulus between 2.30 and 2.76, and group 3 contains all samples with a fineness modulus above 2.76. This table also emphasizes the greater fineness of the sand in Arkansas as compared with the St. Peter of Missouri and Illinois.

The conception that the sand grains of the St. Peter sandstone are of uniform size has long been prevalent and is still occasionally expressed. A number of years ago Dake criticised this conception, and subsequent work in Illinois and Arkansas fully substantiates his conclusions in this respect. In discussing the results of tests showing the uniformity coefficient and effective size for a large number of samples of St. Peter sand Dake concludes that "the factor of uniformity has been heretofore greatly overestimated in describing the St. Peter formation." And in comparing the results with results obtained after analysis of a large number of samples representing eight formations ranging in age from Cambrian to Tertiary Dake states "the difference is entirely inappreciable either as to average or extreme range."

Even a cursory survey of the results obtained by Lamar strikingly emphasizes the lack of uniformity in grain size of the Illinois St. Peter.[56] The averages given in Table 5 of this report indicates as great a lack of uniformity in the St. Peter sand grains of Arkansas as exists in the same formation in Illinois and Missouri.

In Table 12 a comparison of the size of grain of St. Peter sands of Illinois, Missouri, Arkansas, and Oklahoma is drawn.

Table 12.—Comparison of Size of Grains of St. Peter Sand in Illinois, Missouri, Arkansas, and Oklahoma

State	No. of Samples	Average Passing Each Sieve					Total Passing all Sieves
		28-30	48-50	100	150	200	
Illinois*	76	95.16	43.65	8.88	3.62	1.36	99.98
Missouri†	27	96.25	63.18	7.33	1.67	1.19	99.99
Arkansas‡	54	98.77	67.31	10.37	2.31	0.76	99.57
Oklahoma	2	99.99	81.23	22.57	11.01	2.74	99.99

*Includes 27 samples of washed sand.
†Includes 3 samples of washed sand.
‡Includes 1 sample of washed sand.

This table again emphasizes the absence of uniformity in the St. Peter sands, and clearly indicates the increasing fineness

[56] Op. cit., Table 10.

of the sand in proceeding southward in the Mississippi Valley. This increasing fineness is most strikingly evident in the larger volumes of the sand passing the coarser sieves, a feature persisting to the sieve of 100 mesh.

But two analyses of the St. Peter (Burgen) of northeastern Oklahoma were available for use in the table. One analysis was made by the writer, the sample having been collected near Grand River not far from the Tulsa-Fayetteville highway. The other analysis was taken from Buttram's report.[57] These analyses indicate a fineness as great as characterizes the St. Peter sand of Arkansas. It is probably unwise, however, to draw more than tentative conclusions from results of only two analyses.

SHAPES OF THE GRAINS

General features.—The shapes of sand grains are of economic importance in the utilization of a sand, and in addition they possess scientific interest, especially for the information they furnish as an aid in interpreting the history of the sand. Some samples of the St. Peter sand of Arkansas have been studied with particular reference to the shapes of the grains. The results of the study do not confirm the prevalent notion that the St. Peter sandstone is composed of well-rounded grains. In fact, the grains possess an infinite variety of shapes, ranging from angular to rounded. Many grains show no rounded surfaces whatever, others are partially rounded, the remaining surface being composed of facets at angles to one another, and rounded grains are very rarely round but instead are oblong, spindle-shaped, egg-shaped, or lens-shaped.

Degree of angularity.—Lamar has recently devised a refined method of determining angularity of sand grains, and has developed the essential mathematical procedure involved, so that the result of the method may be expressed as a single angularity figure.[58] Trowbridge and Mortimore have also recently suggested a method of determining angularity by optical comparison with a somewhat arbitrary set of standard angularity grades consisting of representative grains.[59] They recognize four degrees of rounding: rounded, fairly well rounded, subangular, and angular.

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[57] Buttram, Frank, The Glass Sands of Oklahoma. Bulletin Oklahoma Geological Survey, No. 10, p. 89, 1913.

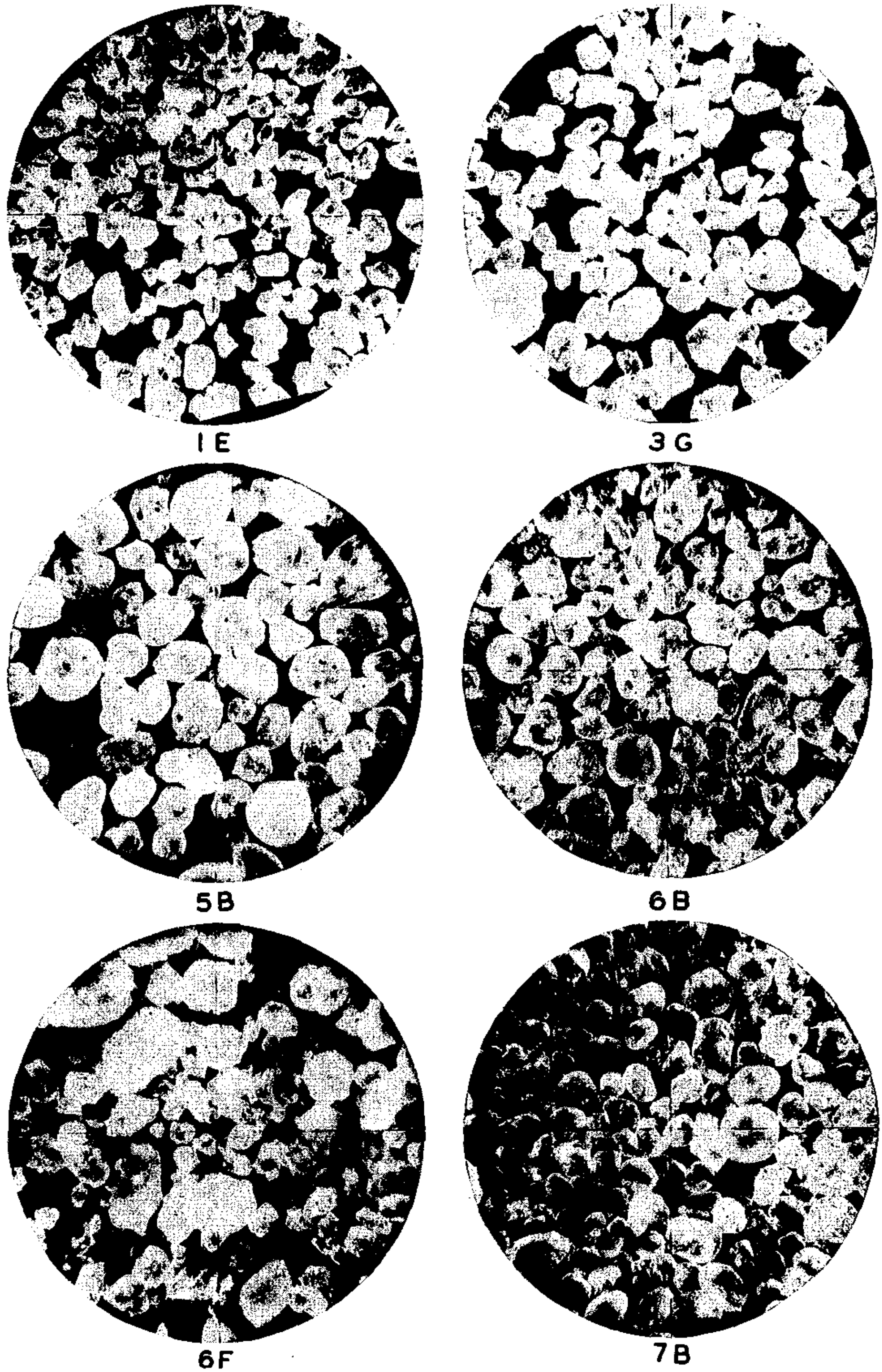
[58] Lamar, J. E., op. cit., pp. 148-151.

[59] Trowbridge, A. C. and Mortimore, M. E., Correlation of Oil Sands by Sedimentary Analysis. Economic Geology, Vol. XX., No. 5, pp. 409-423, 1925.

Table 13.—Tests of Angularity of Grains of St. Peter Sand

Sample No.	Degree of Angularity	Results of Test for Each Mesh							Rounded	Fairly Well Rounded	Subangular	Angular	Total Grains	Location of Sample	
		23	35	48	65	100	150	200						Geographic	Stratigraphic
21-K	Rounded	*	9	5	4	4	0	0	22					Marble City Falls one-fourth mile south of Willcockson, northern Newton County.	Five feet below top of formation.
	Fairly well rounded		10	13	10	12	2	3		50					
	Subangular		28	21	29	32	14	9			133				
	Angular		53	61	57	52	84	88				395			
	Total grains		100	100	100	100	100	100					600		
23-C	Rounded	0	0	0	0	0	0	0	0					On Piney Creek near Metalton, southern Carroll County.	Five feet below top of formation.
	Fairly well rounded	8	4	1	0	1	1	0		15					
	Subangular	23	43	39	38	16	15	2			176				
	Angular	69	53	60	62	83	84	98				509			
	Total grains	100	100	100	100	100	100	100					700		
9-D	Rounded	*	7	9	4	2	1	0	23					South of Sage one mile, southern Izard County.	Five feet above base of formation.
	Fairly well rounded		31	28	14	8	4	1		86					
	Subangular		46	44	49	43	30	19			231				
	Angular		16	19	33	47	65	80				260			
	Total grains		100	100	100	100	100	100					600		
		Total grains							45	151	540	1,164	1,900		
		Percentage							2.37	7.95	28.42	61.28	100		

*No residue.



MICROSCOPIC VIEWS OF ST. PETER SAND

The locations and descriptions of samples 3G and 7B are described in Table 5. The locations of the other samples are as follows: No. 1E, near top of formation, two miles southwest of Calamine on Calamine-Cave City road; No. 5B, near top of formation, in front of post office at Mobley; No. 6B, 40 feet below top of formation, one-fourth mile south of Anderson; No. 6F, near bottom of formation, 3½ miles northwest of Anderson in Little Lafferty Creek.

Following the method suggested by Trowbridge and Mortimore three samples of St. Peter sand collected at different horizons in widely separated localities were analyzed with reference to angularity. The sand was sprinkled on the surface of a microscope slide and examined under a binocular against a dark background. The magnification employed was 30 diameters. The slide was illuminated by two 100-kilowatt lamps. (See Pls. V and VI.) The samples selected were screened and the residues from the successive sieves placed in envelopes labelled with the size of the sieve and sample number. One hundred grains were arbitrarily separated from each envelope and the shape of each grain classified according to the suggested scale of standard angularity. The results are given in Table 13.

A casual inspection of Table 13 indicates that only a small proportion (less than 3 per cent) of the St. Peter sand grains are rounded, and that only about 8 per cent are fairly well rounded. Slightly more than one-fourth of the total number of grains are subangular, and considerably more than one-half (61 per cent) are distinctly angular.

Table 14 summarizes the degree of angularity of the grains according to size. With increasing fineness of grains there is a corresponding decrease in rounding of grains. Essentially all of the rounded grains are coarser than 100 mesh size, and in general the coarser the grain the more likely it is to be rounded. The same generalizations are true when applied to fairly well rounded grains. Subangularity shows a rather marked uniformity in percentage of total

Table 14.—Average Angularity by Mesh Size of St. Peter Sand

(Compiled from Table 13)

On Mesh	Rounded		Fairly Well Rounded		Subangular		Angular		Total No. of Grains
	No. of Grains	Per Cent	No. of Grains	Per Cent	No. of Grains	Per Cent	No. of Grains	Per Cent	
28	0	0.0	8	8.0	23	23.0	69	69.0	100
35	16	5.3	45	15.0	117	39.0	122	40.7	300
48	14	4.7	42	14.0	104	34.7	140	46.6	300
65	8	2.7	24	8.0	116	38.7	152	50.6	300
100	6	2.0	21	7.0	91	30.4	182	60.6	300
150	1	0.4	7	2.3	59	19.7	233	77.6	300
200	0	0.0	4	1.3	30	10.0	266	88.7	300
Total	45	2.4	151	7.9	540	28.4	1,164	61.3	1,900

grains for the coarser meshes, but the proportion of subangular grains declines rapidly below the 100 mesh. Angularity, on the other hand, shows a constant increase with increasing fineness of grains. Below the 100 mesh more than three-fourths of all grains are angular, and below the 150 mesh more than four-fifths of the grains are angular.

Broadly generalizing on the basis of the results obtained, one out of seven of the grains coarser than 100 mesh is likely to be rounded or fairly well rounded, while only one out of 50 of the grains finer than 100 mesh is likely to be rounded or fairly well rounded.

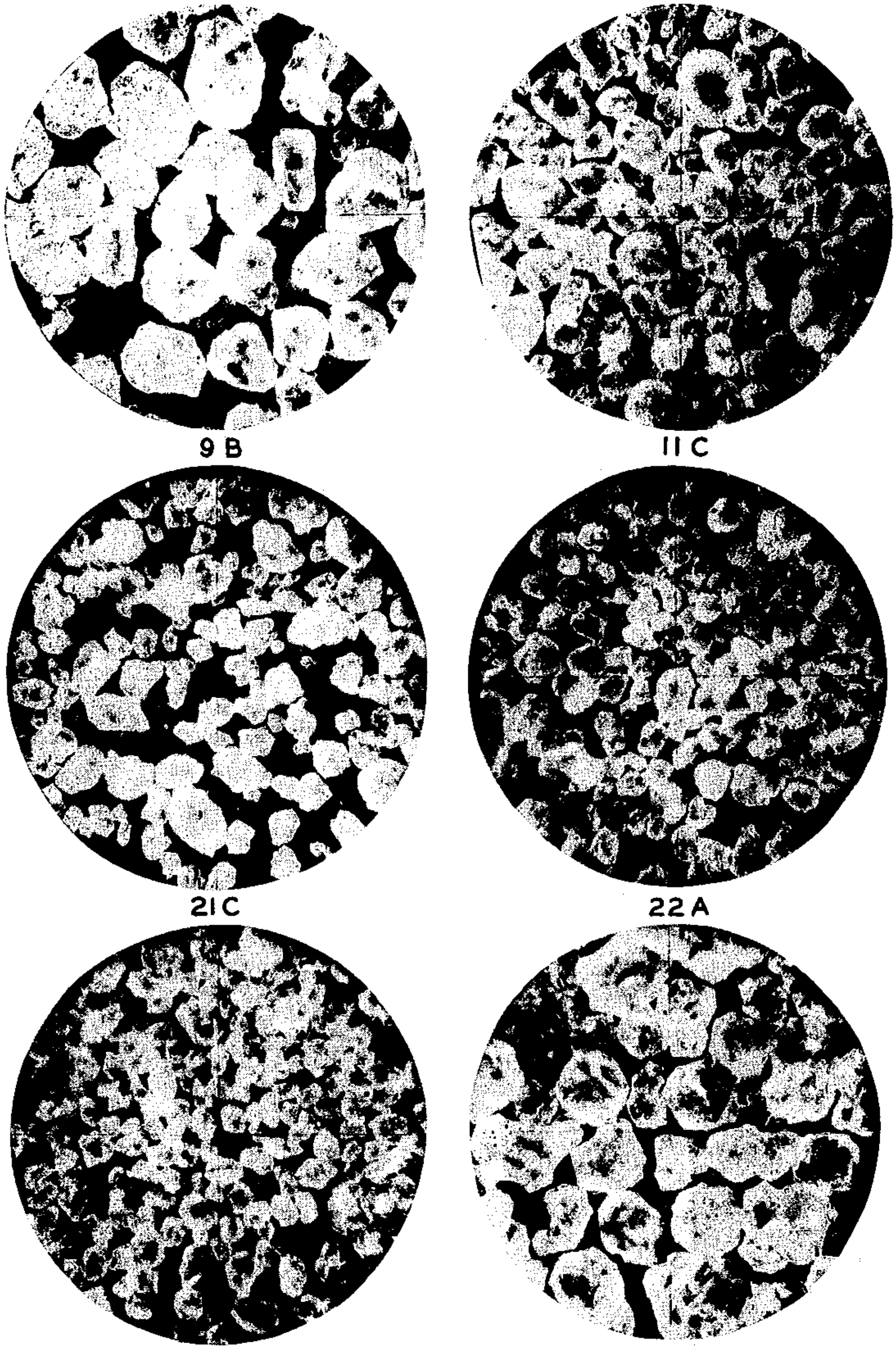
SOUNDNESS OF THE GRAINS

For most commercial purposes it is essential that the grains be nearly free from chemical decay. Incipient chemical decay reduces both tensile and crushing strength, and if the decay has gone far the sand becomes useless for many purposes. Each individual grain should be at least as resistant both to tensile and crushing strength as the cement that is used to bind the aggregate together. Samples of St. Peter sand collected from unweathered portions of the formation uniformly exhibit no traces of chemical decay when examined megascopically or microscopically. On the other hand the grains appear as fresh and unaltered as if they had been very recently deposited without experiencing previous weathering.

ABSORPTION OF MOISTURE

Absorption of moisture by a stone is particularly important if the stone is to be used in a structure exposed to the weather. Absorption tests were made on samples of St. Peter sandstone, although the rock, because of its friability, is a poor building material.

To test the absorption of the sandstone 10 samples selected as typical of the St. Peter in widely separated localities were weighed and immersed in water, where they were permitted to remain for 16 days. The degree of coherence of each sample—whether friable, resistant (firmly cemented), or quartzitic—was noted. After immersion the samples were again weighed, the increase in weight representing the degree of absorption. The volume of the sample was next determined by immersion. This was accomplished by immersing the sample in water of known volume in a beaker, marking



MICROSCOPIC VIEWS OF ST. PETER SAND

The numbers below the figures are the numbers of the samples as given in Table 5 opposite page 28.

Table 15.—Absorption Tests on St. Peter Sandstone

Sample No.	Weight of Sample (grams)		Volume of Sample (cc.)	Absorption		Degree of Coherence	Horizon in Formation	Locality
	Dry	Wet		Weight in Grams	Per Cent			
1	48.74	50.15	21	1.41	2.89	Friable	Near top	South of Willcockson ¼ mile
2	179.75	182.86	73	3.11	1.73	Resistant	Near top	At Metalton on Piney Creek
3	93.05	95.06	38	2.01	2.16	Resistant	Near top	South of Willcockson ¼ mile
4	146.05	150.20	61	4.15	2.84	Very resistant	Base	Maxville
5	154.56	157.31	64	2.75	1.77	Friable	Near top	Cave City
6	118.72	121.06	47	2.34	1.97	Very resistant	Near base	Calamine
7	162.33	168.87	75	6.54	4.02	Friable	15 feet below top	South of Willcockson ¼ mile
8	136.05	137.80	56	1.75	1.28	Very resistant	Near middle	Maxville
9	90.94	93.76	45	2.82	3.10	Very resistant	Near base	On Big Buffalo Creek 4 miles N.W. of Jasper
10	46.86	48.25	20	1.39	2.96	Friable	Top	On Cedar Creek near Metalton
Aver.	117.71	120.53	50	2.83	2.47			

the level assumed by the water, then removing the sample. After removal the sample of sandstone was suspended over the beaker for several minutes in order that as little water as possible be removed on the surface of the sample. The beaker was then filled to the level previously marked and the total volume of water measured. Even with all precautions there is some loss due to adherence of water to the surface of the sample. An unavoidable loss also occurs in measuring the volume of water before and after immersion, due chiefly to adherence of drops of water to the surface of the graduate.

After weighing and determining the volumes of the wet samples they were broken and in each sample the water was found to have thoroughly permeated the sandstone. The percentage of absorption was computed by dividing the amount of water absorbed by the weight of the dry sample. The results are given in Table 15.

It is often desirable to determine with accuracy the porosity of sandstones adapted to building purposes or likely to serve as reservoirs for oil or for water supplies in dry regions. Several methods have recently been devised for determining the porosity of such sandstones.[60]

POROSITY OF THE SAND (VOIDS)

The determination of the porosity of a sand is important, particularly in concrete work, for the greater the porosity the larger the quantity of cement needed to fill the pore spaces. Dake has summarized several methods for the determination of pore space in sand and gravel aggregates and has pointed out the causes of inaccuracies likely to be present in the results obtained by the use of each of the methods.[61] He describes the method most commonly used in the laboratory for the determination of porosity. In this method the apparatus consists of a receptacle holding a known quantity of sand: "To an opening in the bottom attach a rubber tube and connect this with a graduated glass tube containing water. The graduate

[60] Melcher, A. F., Determination of pore space of oil and gas sands. Mining and Metallurgy, No. 160, April, 1920.
Washburn, E. W., and Bunting, E. N., Determination of porosity by the Method of Gas Expansion. Journ. Am. Ceramic Soc., Vol. 5, pp. 113-129, 1922.
Melcher, A. F., Texture of oil sands with relation to the production of oil. Bull. American Association of Petroleum Geologists, Vol. 8, pp. 716-774, 1924.
Russell, W. L., A quick method for determining porosity. Bull. American Association of Petroleum Geologists, Vol. 10, pp. 931-938, 1926.
Sutton, C. E., Use of the acetylene tetrachloride method of porosity determination in Petroleum Engineering Field Studies. United States Bureau of Mines Reports of Investigations, Serial No. 2876, June, 1928.

[61] Op. cit., pp. 21-27.

must stand sufficiently above the sand box to force the water down through the rubber tube into the sand. The flow of water is controlled by a pinchcock on the hose. A fine screen over the opening in the sand box prevents the sand from passing out into the tube below. After the graduated glass tube has been filled with water, the cock is opened, and the water allowed to rise in the connecting tube just even with the bottom of the empty sand box in order that it will not be necessary to compute the water in the connecting tube. The sand box is now filled with sand, and 'stricken off' with a straight edge. If it is the porosity in loose dry sand that is desired, the sand is sifted into the box from a given height. If it is the voids in wet packed sand that is desired, the box is filled and tamped by a uniform method. In either case the water in the graduate is read. The pinchcock is then opened and the water allowed to run till it just begins to overflow the edge of the box. The cock is then closed, and the water in the graduate again read. The difference in the two readings is the water let into the pores of the sand. In other words, it is the actual volume of the voids. Expressed in formula this becomes:

$$\text{Voids} = \frac{Vw}{Vb}, \text{ in which}$$

Vw = volume of water introduced
Vb = volume of the box.

"Even by this method there are likely to be air bubbles left in the sand. In order to detect these, glass containers of various shapes and sizes were used, and it was found that a container not too deep and high and an inflow of water fast enough to stir the sand slightly seemed to eliminate the bubbles best. It was found impossible, however, to expel the air entirely. This method, because of the air bubbles, gives a figure somewhat too small, just as the fact that sand stratifies when poured into the water is likely to give a value too large." To obtain most satisfactory results it is advisable to use receptacles large enough to hold 300 cc. or, better, 500 cc. of sand.

For the determination of porosity Dake and others also recommend the specific gravity-weight method. This is probably the most accurate method of determining porosity, particularly with small samples, since by the use of the pycnometer or graduated water bottle the gravity can be determined with accuracy and the weight of the sand can also be determined accurately. Dake outlines the method of porosity determination as follows: "First determine the specific gravity in the manner already indicated. Suppose this to be 2.64. Measure out in cubic centimeters a given volume of sand, say 100 cc. Then, if there were no voids, the sand should weigh 264 grams. (The weight of 1 cc. of water is 1 gram, and sand weighs 2.64 times as much.) Weigh the sand. Because of the voids, it will weigh less. Suppose it weighs 144 grams. The difference in weight caused by the voids is 120 grams, that is, 120 grams of sand will fill the voids. Then

120 divided by 2.64 = volume of voids in cc.

(120 divided by 2.64) divided by 100 = .454 or 45.4 percent voids.

"Expressed as a formula this would be:

$$\text{Voids} = \left\{ \frac{\dfrac{(Vc \times G) - W}{G}}{Vc} \right. , \text{ where}$$

Vc = volume in cc.
G = specific gravity.
W = weight in grams.

If the measurement is made in cubic feet, the formula will be:

$$\text{Voids} = \left\{ \frac{\dfrac{Vf \times 62.5 \times G - Wlb}{G \times 62.5}}{Vf} \right. , \text{ in which}$$

Vf = volume in cubic feet.
G = specific gravity.
Wlb = weight in pounds.
62½ = weight in pounds of one cubic foot of water.

"For the sake of convenience, one cubic foot is usually taken. Then 62.5 pounds, the weight of a cubic foot of water, times 2.64, the specific gravity of the sand, is 165 pounds, the weight of a cubic foot of the sand if there were no pores. If the actual weight were 100 pounds, then 65 pounds, the deficit, is the weight of the sand which would fill the pores. Then the proportionate volume of the pores is $\frac{65}{2.64 \times 62.5} = 394$, and the percentage voids is 39.4. It will at once be noted that as the volumes are in proportion to the weights, the percentage voids can be determined by dividing the difference in weight directly by the theoretical solid weight. In the first instance 120 is divided by 264 and in the latter 65 by 165."

In the determination of the average porosity of the St. Peter sand the method just described was employed. A sample of sand obtained from Marble City Falls, in northern Newton County, was selected for the porosity determination. This sand has a gravity of 2.643. The weight of 100 cc. of the sand was found to be 147.31 grams. The difference in weight caused by the voids is:

$264.30 - 147.31 = 116.99$, then

116.99 divided by $2.643 = 44.26$ per cent voids.

In Table 16 the results of five determinations of the porosity of the St. Peter sand are given. The specific gravity of each sample and also the weight of 100 cc. of the sand are given. The averages for the five samples have been computed and are given in the table.

Table 16.—Porosity of St. Peter Sand

Sample No.	Specific Gravity	Weight of 100 cc.	Porosity (Percent of Voids)	Horizon in Formation	Locality
6-H	2.651	153.313	42.20	25 feet below top	West of Mt. Pleasant 1½ miles
18-B	2.650	162.330	38.78	15 feet above base	West of Everton ½ mile
21-K	2.643	147.310	44.26	Top	South of Willcockson ¼ mile
22-C	2.649	143.350	45.88	25 feet below top	At Bellefonte
23-C	2.652	156.230	41.08	Near top	At Metalton, on Piney Creek
Av.	2.649	152.507	42.44		

While it is probably unwise to use the results given in Table 16 as applicable to samples collected from any particular area of outcrop of the St. Peter sandstone, yet these results are based on the study of samples selected as typical and representative of the formation, and they may be considered as representing very closely the average porosity of the sand. Values obtained for particular areas should not depart notably from the averages given in Table 16.

NUMBER OF GRAINS PER UNIT WEIGHT OF SAND

The determination of the number of grains in a unit weight of sand is sometimes made, although the results are probably of greater scientific interest than of practical importance. This determination may be made by taking a quantity of the sand that is representative of the sample and then counting out a sufficient number of grains to yield an appreciable weight. Knowing the weight of the aggregate of grains and the number of grains in the aggregate, the weight of the average grain may be readily computed. From the result the average number of grains in any definite quantity of the sand of known weight, such as a gram, may be readily determined.

It is sometimes desirable to obtain the number of grains in a definite quantity of sand representing each of the various grades of sand resulting from the sieve analysis. Three samples were subjected to this determination and the results are given in Table 17.

Table 17 indicates the essential steps in making the determinations. Of the grains retained on each of the 28, 35, and 48 sieves 100 were counted out and weighed. Of the grains retained on the 65 mesh 200 were counted out under the binocular (magnification 30 $\times$) and weighed. Three hundred grains retained on the 100 mesh were counted out under the binocular and weighed, 400 of the grains retained on the 150 mesh, and 500 of the grains retained on the 200 mesh. The weight of a single grain was determined using the following formula:

$$x = \frac{a}{b}, \text{ in which}$$

x = the weight of a single grain
a = total weight of the aggregate
b = number of grains

Knowing the weight of a single grain the number of grains in a gram may be computed as follows:

$$x = \frac{a}{b}, \text{ in which}$$

x = number of grains in a gram
a = one gram
b = weight of a single grain

These computations were made for each grade determined by the screen analysis and the results, prepared in tabular form, are given in Table 17. These results were next averaged and these figures are also given in the table. Since the samples were carefully selected as typical of the St. Peter sand in widely separated localities, it is probable that the averages indicate very closely not only the average weight of the individual grains for the different grades of the St. Peter, but also indicate very closely the number of grains per gram for the different grades of the St. Peter sand.

PITTING OF THE GRAINS

Pits seen in the grains of St. Peter sand have been studied, particularly by Lamar,[62] who has discussed at some length their dimensions and origin. They occur in frosted grains and in grains that have been enlarged by the addition of silica. The pits may be frosted or unfrosted. They may occupy a large part of one side of the grain or they may be merely minute depressions; they may extend inward one-third of the diameter of the grain, or they may be so shallow as to be detected with difficulty. In shape they may vary from round to oblong, and a few are crescentic. Normal grains exhibit but one or two pits; a few grains show three, and a very few show four.

In frosted grains the pits have probably originated by solution at the points of contact with adjacent grains. The solvent action would scarcely be uniform and would therefore leave the etched surfaces developed at points of contact with the frosted appearance observed in the bottoms of many of the pits. In grains secondarily enlarged the pits have also developed at points of contact with adjacent grains, but in these cases the depressions are due to deposition of secondary silica about the points of contact, covering the frosted surfaces of the grains except at such points, and when the grains are separated the depressions remain with frosted surfaces as a part of the frosted surface of the original grain.

Tables 18 and 19 summarize the results of the study of Arkansas St. Peter sand grains with special reference to pitting of the grains.

As Table 18 indicates, only about one-third of the grains were found to be pitted. Table 19 presents in summary the results shown in Table 18. Although nearly half of the grains on the 28 mesh were found to be pitted, pitting seems to reach its best development in grains ranging in size between the 28 mesh and 35 mesh, with nearly two-thirds of the grains

[62] Op. cit., p. 46.

Table 18.—Pitting of St. Peter Sand Grains

Sample No.	Development of Pits	Results of Tests for Each Mesh							Pitted	Unpitted	Total Grains	Location of Sample	
		28	35	48	65	100	150	200				Geographic	Stratigraphic
21-K	Pitted	*	17	25	25	14	1	1	83	....	....	Marble City Falls, one-fourth mile south of Willcockson, northern Newton County.	Five feet below top of formation.
	Unpitted	....	83	75	75	86	99	99	....	517	....		
	Total grains	....	100	100	100	100	100	100	....	....	600		
23-C	Pitted	45	87	67	51	12	1	2	265	....	....	On Piney Creek near Metalton, southern Carroll County.	Five feet below top of formation.
	Unpitted	55	13	33	49	88	99	98	....	435	....		
	Total grains	100	100	100	100	100	100	100	....	....	700		
9-D	Pitted	*	83	72	68	18	6	0	247	....	....	South of Sage one mile, southern Izard County.	Five feet above base of formation.
	Unpitted	....	17	28	32	82	94	100	....	353	....		
	Total grains	....	100	100	100	100	100	100	....	....	600		
		Total grains							595	1,305	1,900		
		Percentage							31.3	68.7	100		

*No residue.

Table 19.—Average Pitting by Mesh Size of St. Peter Sand Grains

(Compiled from Table 18)

On Mesh	PITTED		UNPITTED		Total No. of Grains
	No. of Grains	Per Cent	No. of Grains	Per Cent	
28	45	45.0	55	55.0	100
35	187	62.3	113	37.7	300
48	164	54.7	136	45.3	300
65	144	48.0	156	52.0	300
100	44	14.7	256	85.3	300
150	8	2.7	292	97.3	300
200	3	1.0	297	99.0	300
Totals	595	31.3	1,305	68.7	1,900

pitted. About half of the grains finding lodgment on the 48 and 65 meshes are pitted, but with increasing fineness pitting of surfaces of the grains rapidly decreases and is nearly absent in grains below 100 mesh in size.

SECONDARY ENLARGEMENT OF THE GRAINS

The deposition of silica by underground water on the grains of the St. Peter sandstone is a noteworthy feature of the formation. Lamar has discussed this feature of the St. Peter sandstone of Illinois and states that "the addition of secondary silica is common in outcrops and in sand from wells reaching the St. Peter except in the Ottawa-Utica district, where this phenomenon is restricted primarily to weathered deposits."[63]

After studying microscopically several samples of St. Peter sand from Arkansas Dr. Littlefield states that "all the sands show some degree of recrystallization."[64] Mrs. Fanny Edson, who has also examined a number of samples of the sand from Arkansas, reports that the grains of every sample show secondary enlargement.[65]

Mr. Eugene Brewster, of the department of geology of the University of Arkansas, has made a careful study under the writer's direction of the development of crystal faces and terminations on the sand grains. The results are given in Table 20.

As Table 20 indicates, the majority of the grains of the St. Peter sand of Arkansas exhibit crystal faces. The faces are typically prismatic and rhombohedral. One form may be

[63] Op. cit., p. 49.
[64] Personal communication.
[65] Personal communication.

Table 20.—Development of Crystal Faces on St. Peter Sand Grains

Sample No.	Development of Crystal Faces	Results of Tests for Each Mesh							Present	Absent	Total Grains	Location of Sample	
		23	35	48	65	100	150	200				Geographic	Stratigraphic
21-K	Present	*	82	80	87	85	94	87	515	....	....	Marble City Falls, one-fourth mile south of Willcockson, northern Newton County.	Five feet below top of formation.
	Absent	....	18	20	13	15	6	13	....	85	....		
	Total grains	....	100	100	100	100	100	100	....	....	600		
23-C	Present	89	91	89	92	75	64	44	544	....	....	On Piney Creek near Metalton, southern Carroll County.	Five feet below top of formation.
	Absent	11	9	11	8	25	36	56	....	156	....		
	Total grains	100	100	100	100	100	100	100	....	....	700		
9-D	Present	*	49	44	51	40	45	27	256	....	....	South of Sage one mile, southern Izard County.	Five feet above base of formation.
	Absent	....	51	56	49	60	55	73	....	344	....		
	Total grains	....	100	100	100	100	100	100	....	....	600		
		Total grains							1,315	585	1,900		
		Percentage							69.2	30.8	100		

*No residue.

present without the other, but usually both are developed. The rhombohedral faces typically terminate the grains and the prism faces are developed about the central parts of the grains. In some cases, however, rhombohedral faces may be seen projecting from the sides of the grains. Grains may be completely bounded by crystal faces, or partly bounded, the remaining surface being frosted.

Some of the crystal faces may be survivals from the original source of the sand, but the amount of attrition by wind and water to which the grains were subjected before deposition makes this conjecture unlikely for any appreciable percentage of the crystal faces except on the smallest grains. This conclusion finds strong support in the almost complete absence of pitting, chipping, or frosting of the crystal faces. These faces are almost invariably as clean and smooth as the similar faces developed on large quartz crystals that have grown continuously and unimpeded.

Insufficient evidence is available to warrant a conclusion regarding the distribution of secondary enlargement throughout the formation. All samples studied by the writer and others show this feature to a marked degree, but the samples studied by the writer were necessarily collected near the outcrop. It is reasonable to assume that the upper layers of the sandstone and portions of the formation near outcrops would exhibit the feature most conspicuously, since the source of the silica is to be sought in solution in the belt of weathering by downward penetrating rainwater, the deposition of which would normally occur on the surfaces of the grains of sand encountered early after entry of the solute into the sandstone.

In Table 21 the results of the study of a large number of the sand grains with special reference to the development of crystal faces are summarized. Crystal faces are present on about two-thirds of the grains studied. These surfaces are almost invariably clean and smooth, free from chipping that might arise from abrasive action. Interfacial angles are likewise sharp and distinct and free from notching.

Table 21.—Average Development of Crystal Faces by Mesh Size on St. Peter Sand Grains

(Compiled from Table 20)

On Mesh	CRYSTAL FACES PRESENT		CRYSTAL FACES ABSENT		Total No. of Grains
	Number of Grains	Per Cent	Number of Grains	Per Cent	
28	89	89.0	11	11.0	100
35	222	74.0	78	26.0	300
48	213	71.0	87	29.0	300
65	230	76.7	70	23.3	300
100	200	66.6	100	33.4	300
150	203	67.7	97	32.3	300
200	158	52.7	142	47.3	300
Totals	1,315	69.2	585	30.8	1,900

The crystal faces are not limited to grains of any particular size, as Table 21 indicates, but are as likely to be present on the coarser grains as on the finer. More than three-fourths of the grains of one sample that failed to pass the 28 mesh showed crystal faces. And of the grains finding lodgment on the 35, 48, 65 and 100 screens more than two-thirds are outlined in part or entirely with well-developed crystal faces. The majority of the grains finer than the 100 mesh are angular, with smooth crystal faces. Many of these grains, however, are fragmentary in origin, originating from attrition of the larger grains during deposition or surviving as angular fragments during transportation from the original source of supply of the sand. In general it is reasonably clear that grains larger than 100 mesh showing crystal faces have experienced secondary enlargement, since crystal faces, clean and free from abrasion, would scarcely survive transportation by wind or water for any considerable distance. Crystal faces on grains smaller than 100 mesh may be due in some cases to survival for the small size of the grains results in greater immunity from attrition, but the smooth, even surfaces of the faces and the sharp, clear, interfacial angles indicate that secondary enlargement has been an important factor in producing the crystal faces on the surfaces of the smaller grains.

FROSTING OF THE GRAINS

The St. Peter sand is usually supposed to consist of frosted grains, and frosting is a conspicuous feature in all representative samples of the sandstone. It is easy, however, to over-emphasize this feature, as has been pointed out by Dake and Lamar, and the present investigation shows that this conception is only partly correct, even when restricted to the coarser grains of the sandstone. In general rounded grains, as the oblong, egg-shaped, spindle-shaped, and lens-shaped, are almost without exception completely frosted, but the coarse grains with angular outlines are either not frosted or only partly frosted. The fine grains are as a rule unfrosted.

Table 22 shows the results of the study of frosting of St. Peter grains. Of 1,900 grains representative of three samples studied only 261, or 13.7 per cent, were frosted; 874 grains, or 46 per cent, were partly frosted, and 765 grains, or 40.3 per cent, were unfrosted.

The results given in Table 22 were rearranged according to size of grain, and the conclusions are compiled in Table 23.

A casual inspection of Table 23 is sufficient to indicate that only 7 per cent of the largest grains of the sample which were too coarse to pass the 28 mesh is frosted, while 50 per cent is partly frosted. The proportion of frosted grains increases to the 48 mesh, then remains fairly constant to the 100 mesh, but in any case this proportion is less than one-fourth of the total number of grains. Most grains passing the 100 mesh are unfrosted, the proportion being 1 to 21.

The percentage of partially frosted grains increases up to the 35 mesh, then remains fairly constant to the 100 mesh, then slowly decreases, with nearly one-fourth of the grains on the 200 mesh showing partial frosting. The proportion of unfrosted grains shows a constant increase from about 40 per cent on the 28 mesh to 75 per cent on the 200 mesh.

As a whole, then, frosting is not as characteristic a feature of the St. Peter sand as has been supposed. In arriving at this conclusion the fact must be taken into consideration that secondary enlargement by deposition of silica would cover the frosted surfaces. The St. Peter grains show pronounced effects of secondary enlargement and it is very probable that most of the grains of larger sizes forming the St. Peter sandstone were originally largely frosted, but the finer grains were only in part frosted. The proportion of frosted grains varies considerably in different samples, a feature to be explained chiefly by the degree of secondary enlargement. Thus, in Table 22 it is at once apparent that the percentage of frosted grains of sample 23-C is considerably below the percentages of frosting that the study of the other two samples revealed.

Table 22.—Frosting of St. Peter Sand Grains

Sample No.	Degree of Frosting	Result of Tests for Each Mesh 28	35	48	65	-100	150	200	Frosted	Partly Frosted	Unfrosted	Total Grains	Location of Sample: Georgraphic	Stratigraphic
21-K	Frosted	*	19	19	14	16	3	3	74				Marble City Falls, one-fourth mile south of Willcockson, northern Newton County.	Five feet below top of formation.
	Partly frosted		32	32	49	47	29	26		215				
	Unfrosted		49	49	37	37	68	71			311			
	Total grains		100	100	100	100	100	100				600		
23-C	Frosted	7	5	5	1	2	1	1	22				On Piney Creek near Metalton, southern Carroll County.	Five feet below top of formation.
	Partly frosted	50	93	74	72	35	31	10		365				
	Unfrosted	43	2	21	27	63	68	89			313			
	Total grains	100	100	100	100	100	100	100				700		
9-D	Frosted	*	28	41	33	43	17	3	165				South of Sage one mile, southern Izard County.	Five feet above base of formation.
	Partly frosted		66	49	61	48	38	32		294				
	Unfrosted		6	10	6	9	45	65			141			
	Total grains		100	100	100	100	100	100				600		
		Total grains							261	874	765	1,900		
		Percentage							13.7	46.0	40.3	100		

*No residue

The frosting of the grains shows a broad but fairly definite relationship to angularity, which is apparent when Tables 13 and 22 are compared. In Table 13 it appears that approximately 10 per cent of the grains are rounded or fairly well rounded, and Table 22 shows that 13 per cent are frosted.

Table 23.—Average Frosting by Mesh Size of Grains of St. Peter Sand

(Compiled from Table 22)

On Mesh	Frosted		Partly Frosted		Unfrosted		Total No. of Grains
	No. of Grains	Per Cent	No. of Grains	Per Cent	No. of Grains	Per Cent	
28	7	7.0	50	50.0	43	43.0	100
35	52	17.4	191	63.6	57	19.0	300
48	65	21.7	155	51.6	80	26.7	300
65	48	16.0	182	60.7	70	23.3	300
100	61	20.3	130	43.3	109	36.4	300
150	21	7.0	98	32.7	181	60.3	300
200	7	2.3	68	22.7	225	75.0	300
Total	261	13.7	874	46.0	765	40.3	1,900

The proportion of subangular and angular grains, as indicated in Table 13, is 89 per cent, while Table 22 shows that the relative proportion of partly frosted and unfrosted grains is 86 per cent. This relationship becomes the more striking since the data used in compiling the tables were gathered in the study of the same grains, for in the study of the degree of angularity of each grain, the presence or absence of pitting, frosting, and crystal faces was noted.

The origin of the frosting of the St. Peter sand grains usually finds its explanation in persistent wind abrasion and there is little in the nature of the frosting to indicate that this view is incorrect. The suggestion that the frosting may be due to etching by underground water since the deposition of the sandstone finds little support in the evidence available. The marked secondary enlargement of the grains points to deposition rather than solution as the important process. The smoothness of the crystal faces developed on a majority of the grains indicates the absence of solution. The prevalence of frosting throughout the formation is indicative of a single primary cause in its production. And the frosting of the entire surfaces both of large and small grains, instead of its restriction to angles and small grains, points to other agency than solution by water, which is selective in its operation.

SPECIFIC GRAVITY OF THE SANDSTONE

An accurate determination of the specific gravity of a porous rock like the St. Peter sandstone is difficult to make, and the results can be considered as only approximate. In making gravity determinations of the St. Peter sandstone two methods were followed. In the first method the volumes of the ten samples given in Table 15 were obtained as described under "absorption of moisture" (see p. 45). The weights of the soaked pieces of sandstone were then divided by their respective volumes, determined by immersion and measuring the volume of water displaced. The results were found to be too low, the average gravity of the ten samples being only 2.40. The inaccuracies arose from loss of water during measuring and from inability to read accurately the lower limit of the meniscus in a 250 cc. beaker.

In the second method the specific gravity was determined by weighing the sample in air, and again when immersed in water. The general formula to be solved is $\frac{A}{A-W}$, in which A is the weight in air, and W is the weight in water. The specific gravity of 10 selected samples of the St. Peter were obtained in this way, and the results, together with the computed weights of the sandstone, are given in Table 24. These results can be regarded as only approximate because of the porosity of the sandstone, the pores of which tenaceously retain included air. The results, however, are considerably more accurate than the results obtained by following the method first described.

SPECIFIC GRAVITY OF THE SAND

Dana places the specific gravity of quartz between 2.5 and 2.8, and of quartz crystals between 2.6413 and 2.6541.[66] The St. Peter sand analyzing 97 percent or higher in silica should have a gravity close to that of quartz crystals. Determinations, however, show appreciable departure from the value assigned to pure quartz. This departure may be ascribed to several factors. First, the technique involved in the specific gravity determination of finely divided materials does not permit absolute accuracy in carrying out the operation. Sources of error arising aside from the technical procedure,

[66] Dana, E. S., A Text-book of Mineralogy. John Wiley & Sons, New York, 1877.

Table 24.—Gravity and Weight of St. Peter Sandstone

Sample No.	Gravity	Weight of 100 cc. in Pounds	Degree of Coherence	Horizon	Locality
1	2.56	160.00	Friable	Top of formation	South of Willcockson ¼ mile
2	2.47	154.38	Friable	4 feet above base of formation	North of Jasper 4½ miles
3	2.48	155.00	Resistant	5 feet below top of formation	Near Cave City
4	2.60	162.50	Very resistant	Near top of formation	Near Maxville
5	2.50	156.25	Friable	Near base of formation	On Big Buffalo Creek 4 miles north of Jasper
6	2.50	156.25	Resistant	Near base of formation	At Calamine
7	2.60	162.50	Friable	10 feet below top of formation	South of Willcockson ¼ mile
8	2.60	162.50	Very resistant	Near base of formation	Near Maxville
9	2.52	157.50	Resistant	Near top of formation	At Metalton on Piney Creek
10	2.60	162.50	Friable	Near top of formation	On Cedar Creek near Metalton
Average	2.54	158.94			

such as failure to eliminate all air from around and within the individual constituents composing the aggregate under investigation, lead to further inaccuracy. Second, all samples of St. Peter sand examined yield heavy minerals in minute quantities, and these are undoubtedly distributed throughout the whole formation. This would tend to increase the gravity above the average of quartz. Third, the presence of iron, which most analyses reveal, whether it is present as oxides or sulphides, also enhances the value of specific gravity. Clay is also generally present in minute quantities, and this lowers the gravity slightly, since clay is slightly below quartz in gravity.

Two methods for the determination of the gravity of the St. Peter sand were tried. In one method, adequately described by Dake,[67] a sample of sand was thoroughly dried and weighed. The sand was then introduced by means of a small glass funnel with a bore but little larger than the diameter of the lead of an ordinary lead pencil into a bottle with a narrow neck which was graduated into centimeters. The bottle previously had been filled with distilled water to a point where the lower boundary of the meniscus could be read on the centimeter scale. The sample of sand was then added and the lower limit of the meniscus again read, care being exercised to read the level of the meniscus to a fraction of a cubic centimeter. The difference in the two readings is the measure of the displacement resulting from the introduction of the sand. The following is the formula:

$$\text{Sp. gr.} = \frac{W}{Vt - Vw} \text{ in which}$$

W = the weight of the dry sand expressed in grams,

Vw = the volume of the water in the bottle expressed in cubic centimeters,

and

Vt = the total volume of the sand and water in the bottle expressed in cubic centimeters, whence

Vt — Vw = actual volume of sand, exclusive of voids.

In the laboratory procedure the sample was limited to 25 grams, weighed to within a milligram. The capacity of

[67] Op. cit., pp. 18-21.

the bottle was 2,000 cubic centimeters. Ten samples of sand were used, the samples being carefully selected as typical of unweathered sandstone and as representative of the formation in widely separated localities. The results ranged from a value of 2.662 to a value of 2.777, with an average value for the 10 samples of 2.698. It was felt that the results obtained were too high to represent accurately the specific gravity of typical St. Peter sand. Accordingly the following method was devised, which is the same as the use of the pycnometer, with the exception that a small water bottle of 150 cc. capacity was used, the stem of which was marked about 1½ inches below the top. The bottle was first weighed empty (A), and then filled with distilled water to the point where the lower boundary of the meniscus coincided with the mark on the neck of the bottle. This was done very accurately by using an ordinary medicine dropper. The bottle with its water content was then carefully weighed (B), after which the bottle was emptied, dried, and 25 grams of sand carefully weighed were introduced. The weight of the bottle and sand is designated C. Water was then introduced to the level of the mark on the neck of the bottle. The whole was then weighed (D). The specific gravity is determined by the following formula:

$$\text{Specific gravity} = \frac{C - A}{B + C - A - D}$$

A = weight of bottle
B = weight of bottle and water
C = weight of bottle and sand
D = weight of bottle, sand and water

With this method the results check very closely, not only when samples were run in duplicate but also when samples were carefully selected as typical of the St. Peter sand. Five determinations were made, the gravity ranging from 2.643 to 2.652, with an average of 2.649 for the five samples. This figure was taken as reasonably accurately representing the specific gravity of the St. Peter sand both in the further laboratory procedure and in the computations into which specific gravity entered as a factor. The results are given in Table 25.

WEIGHT OF THE SANDSTONE

A simple method of determining the weight of a cubic foot of stone is to weigh a cube of 1-inch dimensions and multiply the result by 1,728, the number of cubic inches in a cubic foot. This method is open to some objection because of the difficulty of trimming many rocks precisely to the dimensions of a cubic inch.

Table 25.—Weight of St. Peter Sand

Sample No.	Specific Gravity	Weight of 100 cc.	Weight per cu. ft. (lbs.)	Horizon in Formation	Locality
6-H	2.651	153.313	95.787	25 feet below top	West of Mt. Pleasant 1½ miles
18-B	2.650	162.330	101.383	15 feet above base	West of Everton ½ mile
21-K	2.643	147.310	92.076	Top	South of Willcockson ¼ mile
22-C	2.649	143.350	89.588	25 feet below top	At Bellefonte
23-C	2.652	156.230	97.647	Near top	At Metalton on Piney Creek
Average	2.649	152.507	95.296		

Another method is to determine the volume of pieces of the rock arbitrarily chosen by immersion in water, following the method described on page 47. The weights of the dry samples expressed in grams divided by their respective volumes expressed in cubic centimeters give the weight of one cubic centimeter. The weight of a cubic foot of the rock is then obtained by the following formula:

$Wpf = Wgc \times 62.513$, where
$Wpf =$ weight per cubic foot in pounds, and
$Wgc =$ weight per cubic centimeter in grams.

The weight may also be determined by multiplying the specific gravity by 62.5, the weight of a cubic foot of water. In Table 24 the weights of 10 samples of the St. Peter sandstone are given, using this method of weight determination. The results are likely to be slightly low, since the gravity determinations are somewhat low. The average specific gravity of the 10 samples is 2.54, and the average weight of a cubic foot of the St. Peter sandstone is, then, 158.94 pounds. The gravity of pure quartz is 2.65, and hence a cubic foot of pure quartz weighs 165.625 pounds. According to these determinations a cubic foot of St. Peter sandstone weighs nearly as much as a cubic foot of pure quartz, which should be true theoretically, since the St. Peter sandstone is an almost pure quartz sandstone.

WEIGHT OF THE SAND

The weight of a sand is usually expressed in pounds per cubic foot or per cubic yard and refers to dry sand unless otherwise specified. The weight is ordinarily determined by filling and weighing a box holding exactly one cubic foot. The sand is permitted to run into the box from a definite height, usually one to three feet, hence the weight obtained is that of loose sand. If the sand is compacted before weighing, the weight is correspondingly increased. If this procedure is employed in the determination of weight, the method of compacting, whether by shaking or by placing a weight upon the sand at intervals during the filling of the box should be stated.

The common laboratory method of determining the weight of a sand is to measure out 100 cc. of the sand and ascertain carefully the weight of this quantity with the analytical balance. This can be reduced to pounds per cubic foot by the following formula:

$$\text{Wpf} = \text{Wgc} \times 62.513, \text{ in which}$$

Wpf is the weight per cubic foot in pounds, and

Wgc is the weight per cc. in grams.

Dake has described the derivation of this formula.[69]

If specific gravity and voids are known, the following formula may be used:[70]

$$\text{Weight per cu. ft.} = G \times 62\tfrac{1}{2} \times \frac{(100 - V)}{(100)}, \text{ in which}$$

G = specific gravity,

V = per cent voids, and

$62\frac{1}{2}$ = weight in pounds of one cu. ft. of water, whence

$G \times 62\frac{1}{2}$ = weight of one cu. ft. of sand if perfectly solid, then

$$\frac{100 - V}{100} = \text{proportion of actual sand without voids.}$$

The following determination of the weight of a sample of St. Peter sand illustrates the application of the formula:

Sample of St. Peter sand from Marble City Falls:

Gravity = 2.643

Voids = 44.26 per cent

$$\text{Weight per cu. ft.} = 2.643 \times 62\tfrac{1}{2} \times \frac{100 - 44.26}{100}$$

$$= 92.08 \text{ pounds}$$

In Table 25 the results of the determinations of the weights of five samples of typical St. Peter sand are given. The average weight of the five samples is 95.296, which may

[69] Op. cit., p. 27.
[70] Op. cit., p. 28.

be taken as typical of the weight of the sand per cubic foot for the formation as a whole.

Saturation of sand with water, as when it is delivered from the washer, has the effect of increasing its weight. With porosities comparable to those given in the preceding samples the increase in weight may amount to as much as 20 per cent of the original weight, the increase depending directly upon the volume of the pore space.

REFRACTORINESS

No laboratory tests were undertaken to determine the refractoriness of the St. Peter sand. Pure quartz is very refractory, and since the St. Peter is almost entirely pure quartz it may be expected to possess high resistance to fusion. The St. Peter sand of Missouri and Illinois has repeatedly been used successfully in furnace and foundry practice, under high temperatures, and it is also suitable for use as furnace lining. The close physical and chemical similarity of the Arkansas St. Peter sand to the St. Peter sand of Illinois and Missouri indicate that it is as refractory as the St. Peter sand of those states and as fully adapted to uses in which resistance to high temperatures is demanded.

CHEMICAL COMPOSITION

Chemical analyses.—Chemical analyses of samples of St. Peter sand collected in Arkansas emphasize its high content of silica and its very low content of iron, lime, magnesia and alumina. Table 26 includes analyses of samples collected as typical of the sandstone in many and widely separated localities.

All the analyses given in Table 26 with the exception of those representing the sand quarried at Guion were made of unwashed sand. The averages of the samples indicate that the white Arkansas sand will run over 98 per cent silica and less than 0.40 per cent iron oxide, with alumina averaging only about 0.30 per cent or less. Washed samples will run somewhat higher in silica and lower in iron and alumina, since some of the latter may be derived from minute amounts of clay present between the grains of the sandstone which are removed in washing. Lime will average less than 0.10 per cent, and is not likely to exceed 0.20 per cent in any analysis. Magnesium carbonate as Table 26 indicates, will average below the small percentage of lime.

Table 26.—Analyses of St. Peter Sand of Arkansas

Sample No.	Ignition Loss	SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	Total	Color	Horizon in Formation	Locality
1-E	0.26	99.24	0.12	0.23	0.09	0.00	99.94	Cream	Near base	West of Calamine 2 miles
2-A	0.37	98.41	0.28	0.43	0.15	0.00	99.64	Cream	Base	East of Sidney 1 mile
3-G	0.25	99.24	0.19	0.30	0.06	0.00	100.04	Cream	110 feet below top	At Sandtown
5-A	0.29	99.28	0.10	0.18	0.07	0.00	99.92	White	Upper part	South of Mobley ½ mile
6-G	0.35	98.32	0.40	0.32	0.19	0.00	99.58	Brown	10 feet above base	Southwest of Mt. Pleasant 2½ miles
8-A	0.12	99.32	0.09	0.12	0.08	0.02	99.75	Cream	15 feet below top	North of Cushman 1½ miles
9-B	0.30	98.51	0.26	0.23	0.11	0.00	99.41	White	Near top	North of Mt. Pleasant 3 miles
11-ABC	0.34	98.39	0.30	0.29	0.02	0.00	99.34	Cream	From base (A) and from top (B, C)	Pilot Knob
18-A	0.35	99.38	0.09	0.17	0.02	Tr.	100.01	White	25 feet below top	West of Everton 3 miles
19-B	0.36	99.02	0.12	0.30	0.00	0.00	99.80	White	Near top	South of Pyatt ½ mile
21-A	0.23	99.11	0.09	0.37	0.08	0.02	99.90	White	10 feet above base	At Yardelle in creek bed
21-J	0.10	99.08	0.06	0.26	0.00	0.00	99.50	White	Top	South of Willcockson 2½ miles
22-D	0.27	99.24	0.12	0.08	0.04	0.00	99.75	Cream	25 feet below top	At Bellefonte in creek bed
23-A	0.24	99.16	0.07	0.11	0.03	0.00	99.61	Cream	25 feet below top	On Cedar Creek southeast of Berryville 10 miles
24-A	0.16	99.38	0.13	0.15	0.12	0.00	99.94	White	5 feet below top	East of Forum in Pine Creek
28	0.46	98.49	0.15	0.26	0.12	0.00	99.48	Cream	Within 5 feet of base	Mouth of Sylamore Creek
29	0.012	99.38	0.028	0.57	0.01	0.00	100.00	White	12 feet below top	Guion. Silica Products Co.
29	0.024	99.38	0.39	0.46	0.09	0.00	100.344	White	12 feet below top	Guion. Silica Products Co.
18	0.249	99.02	0.166	0.27	0.07	0.002	99.775		Base	

Analyses of Guion samples, No. 29, by Waring & Williams laboratories, Joplin, Mo.; of all other samples by Dr. W. F. Manglesdorf, Little Rock. See Table 5 for mechanical analyses of Guion sand No. 29, and samples 3-G, 6-G, 8-A, 9-B, 11-A-B-C, 18-C, 19-B, 21-A, 21-J, 22-D, 23-A, and 24-A. Samples 29 washed; others represent unwashed but selected sand.

In the sand the silica is present chiefly as quartz (SiO_2), with a very small amount combined to form clay and the relatively rare heavy minerals. The alumina (Al_2O_3) is present as clay-forming minerals of unknown identity, and the iron oxide is one of the hydrous iron oxides, as limonite ($Fe_2O_3.H_2O$), turgite ($2Fe_2O_3.H_2O$), and possibly göthite ($Fe_2O_3.H_2O$), as well as hematite (Fe_2O_3) locally. Pyrite (FeS_2) is also sparingly present and would be shown in the analysis as the oxide of iron. The lime and magnesia are present as carbonates (calcite, $CaCO_3$, and dolomite, $CaMg(CO_3)_2$). The ignition loss is very small so that little organic matter is present, and a large part of this loss is probably due to loss of water and carbon dioxide in attaining the temperature necessary to complete the test.

For most purposes for which sand is utilized a knowledge of the chemical composition is of little value, and analyses are rarely made, but "in a general way it may be said that chemical analyses yield the following information that is of value for any given sand. For glass making it is desirable to know the content of silica, iron, alumina, magnesia, and organic matter. For moulding sands, especially for steel moulding, the content of silica, alumina, iron, magnesia, lime, and alkalies should be known. For fire and furnace sands, the percentage of silica, iron, lime, magnesia and alkalies should be determined. For filter sands, the percentage of silica, iron, lime, magnesia, alkalies and organic matter should be determined. For concrete work, it may become desirable to determine the organic matter."[71]

Comparison of Arkansas sand with sand in other States. —Table 27 gives a comparison of the chemical character of the St. Peter sand of Arkansas, Missouri, Illinois, and Oklahoma. This comparison is based on the averages of a number of analyses of samples collected. Two of the 18 analyses representing Arkansas sand were run on unwashed samples. The 22 analyses of the Missouri sand, taken from Dake's report,[72] represent unwashed samples chosen carefully as typical of the sandstone in the localities where the samples were collected. The analyses of the Illinois St. Peter were taken from Lamar's report and represent washed sand.[73] The single analysis of the Oklahoma sand was taken from Buttram's

[71] Quoted from Dake, op. cit., p. 30.
[72] Op. cit., table, p. 123.
[73] Op. cit., p. 154.

report and represents a sample collected northeast of Tahlequah, in northeastern Oklahoma.[74]

Table 27.—Comparison of Chemical Characters of St. Peter Sand of Arkansas, Missouri, Illinois, and Oklahoma

State	AVERAGES OF CHEMICAL ANALYSES							
	No. of Anal.	Ig. Loss	SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	Total
Arkansas	18	0.249	99.02	0.166	0.27	0.07	0.002	99.775
Missouri	22	0.34	98.87	0.19	0.35	0.13	0.08	99.96
Illinois	5*	....	99.725	0.054	0.11	0.559	0.04	99.95
Oklahoma	1†	0.0028	99.22	0.14	0.32	0.18	Tr.	99.8628

HEAVY MINERALS IN THE SANDSTONE AND SAND

The analyses of Arkansas and Missouri sands are strikingly similar; in fact, individual analyses of samples collected in either State may differ from each other more notably in their results than do the averages for the two States. The analysis of the single sample collected in Oklahoma also agrees closely with the Missouri and Arkansas analyses. It is impossible to compare accurately the Illinois analyses with the analyses of the St. Peter sands of other States, since the Illinois analyses represent washed samples, the product ready for shipment of well-equipped plants producing large quantities of sand. Therefore the analyses of Illinois sand as given in the table should average higher in silica and lower in iron and alumina, but the difference in magnesia content is very slight and the percentage of lime runs appreciably higher in the Illinois analyses than in the analyses of the sands of the other states. The differences in the analyses, however, are so slight that it is clear that the washed product of Arkansas or Missouri St. Peter sand will average as high in silica and as low in iron and alumina as the Illinois product.

The St. Peter sandstone in Arkansas contains minor amounts of heavy minerals, which are sparingly but very uniformly distributed throughout the formation. They are present in the St. Peter sand in such relatively small amounts as to have no significant commercial bearing on the uses of the sand, but their identity is of some scientific importance, hence a number of samples were studied with particular reference to their content of heavy minerals. In isolating the heavy minerals for study they are separated from the quartz sand by the use of liquids of such gravity that the quartz

[74] Op. cit., p. 88.
*All samples from washed sand.
†"Burgen" sandstone 5 miles northeast of Tahlequah.

Table 28.—Heavy Minerals in the St. Peter and Older Sandstones

Sample No.	Formation	Heavy Minerals						Horizon in Formation	Locality
		Zircon	Tourmaline	Leucoxene	Anatase	Rutile	Apatite		
	Everton	3	2	5	5	..	..	10 feet below top	South of Willcockson 2½ miles
	Kings River	3	2	..	..	..	..	Near top	Little Clifty Creek southwest of Eureka Springs
16-B	Calico Rock	3	3	..	5	..	..	150 feet above base	At Iuka postoffice
14-A	Calico Rock	2	3	5	5	..	..	Near base	East of Calico Rock ¼ mile
13-G	Calico Rock	2	3	..	5	..	..	Near top	North of Calico Rock 1½ miles
29	St. Peter	1	4	5	5	5	..	12 feet below top	Guion, Silica Products Co.
11-A	St. Peter	3	2	5	5	..	..	Base	Pilot Knob
21-J	St. Peter	2	3	..	5	..	..	Top	South of Willcockson 2½ miles
2-C	St. Peter	1	4	5	5	..	..	15 feet below top	Near Cave City
21-K	St. Peter	2	3	..	5	..	..	Top	South of Willcockson ¼ mile
23-D	St. Peter	2	3	..	5	..	..	Near top	In Piney Creek at Metalton
19-B	St. Peter	2	3	6	..	6	6	Top	South of Pyatt ½ mile

grains float and the heavier minerals settle. The lighter quartz grains are then decanted off and the heavy mineral residue is mounted on slides and identified microscopically. Nearly all of the heavy minerals are found in the "fines," that is, they are small enough to pass the 100 mesh.

Dr. M. S. Littlefield kindly made the study for the writer of the heavy minerals found in the Arkansas St. Peter sand. For this study seven samples were selected as typical of the St. Peter in widely separated localities.

All the samples were found to contain feldspar, both orthoclase and microcline, in grains usually less than one-eighth of a millimeter in length. Tourmaline and zircon were found in all of the samples, with a small percentage of the zircon possibly representing xenotime, which is difficult to recognize with certainty. Leucoxene is present in half of the samples, and anatase in nearly every sample. Rutile was detected in two of the samples, and apatite was present in a single sample.

In Table 28 the results of the heavy mineral analyses are given, the numbers indicating the relative percentages as follows:

100-75	1
74-50	2
49-25	3
24-10	4
9- 1	5
Less than 1 per cent	6

Dr. Littlefield estimates the heavy separate to be less than 0.25 per cent of the sample in all cases. In Table 28 the heavy mineral analysis of one sample of Everton sandstone, one sample of Kings River sandstone, and three samples of Calico Rock sandstone are introduced for comparison. These determinations were also made by Dr. Littlefield.

CEMENTATION

As has already been pointed out, the St. Peter sandstone is for the most part so friable that it may be readily disintegrated by rubbing between the fingers. But locally the sandstone is sufficiently cemented that it is broken with difficulty with a hammer, and in other places the sandstone is so resistant that it resembles quartzite. In some of these situations the rock is iron-stained and it is evident that an iron compound firmly cements the grains. At other places, as south of Cave City, in southern Sharp County, the rock is white and almost quartzitic. Examination of the grains of this quartzitic phase shows that nearly all are angular with pronounced secondary enlargement. Gradation laterally and vertically from very friable through coherent to quartzitic, white sandstone may be found in the same locality, as at Maxville, in southern Sharp County. These observations should throw light upon the character of the cementation of the sandstone.

The St. Peter sandstone is generally considered to be cemented by a small amount of calcium carbonate. Its friability has been attributed to weathering, but study of fresh exposures on recently graded roads, in the quarries at Guion, and elsewhere indicates that friability is a prevailing characteristic throughout the formation. The content of iron, alumina, lime, and magnesia is so small as to be an almost insignificant proportion of the formation as a whole. Magnesia was detected in only two of the 18 analyses given in the preceding table of analyses (Table 26). Of 10 analyses made by the writer by using strong nitric acid in which pieces of sandstone had been immersed for a month only one showed more than a trace of magnesia. The analyses clearly indicate that magnesium carbonate is not the cementing substance of the sandstone.

The percentage of alumina is higher, but in four analyses conducted by the writer only a trace could be detected; the other six yielded good tests. The average for 18 analyses was 0.27 per cent (see Table 26). The alumina is probably present chiefly as clay particles between the grains, but the small quantity of clay, together with its slight resistance, cannot account satisfactorily for the cementation of the sandstone, even with its friable character.

As the table of analyses indicates, the percentage of iron oxide in samples of unwashed sand is less than that of alumina. Two analyses by the writer showed no detectable iron content and in five the iron present yielded only a trace. Its amount is so small, in connection with the prevailing white color of the formation, as to lend little support to the conception that iron in some form is in general the cementing substance of the formation.

Lime is present in very small amount, as Table 26 indicates. One analsis yielded no trace, and one only 0.01 per cent. Two of 10 analyses conducted by the writer yielded no trace of calcium, five a trace of calcium, and three gave a good lime test. The samples yielding no lime test or slight trace of lime were as coherent and firmly cemented as those samples yielding a measurable quantity of lime after analysis. The absence of lime or its presence in traces in so many samples examined leads to the belief that calcium carbonate is not the prevailing cementing substance of the sandstone.

The general coherence of the sandstone appears to be explained most satisfactorily by the secondary enlargement of the sand grains. The grains of all samples, as already pointed out, exhibit marked secondary enlargement. This is particularly true of the coarser and medium-sized grains. Secondary enlargement also satisfactorily explains the increasing resistance to crushing of the sandstone within small areas. In fact in places the sandstone may be friable and within a few feet it is almost quartzitic. The sandstone is considered as having been deposited in large part as well-rounded grains, which remained incoherent until after elevation above sea level. Underground water carried silica into the formation and precipitated it about the grains to form the glassy surfaces—crystal faces—that are a marked feature of all samples of the sand. This secondary growth has interlocked the grains, and where the deposition has continued sufficiently long the rock has become quartzitic. The silica was derived in large part from overlying formations, but a small part may have originated by solution of the smaller grains within the formation.

USES OF THE SAND

Because of its purity (over 98 per cent silica) its freedom from heavy minerals, such as magnetite, titanite, and ilmenite, the almost total absence of iron-bearing compounds and minerals possessing various colors, its friability, its composition of rounded and angular grains, and the facility with which it is graded into sizes, the St. Peter sand readily lends itself to a great variety of uses. More than 100 different uses t which St. Peter sand may be applied have been found.[75]

GLASS SAND

The bulk of the sand shipped from Arkansas is used in glass manufacture. This is also true for the greater part of

[75] Much of the material for this section of this report has been taken from two recent descriptions of the uses of sand:

Weigel, W. M., Technology and Uses of Silica and Sand. *Dept. of Commerce, U. S.* Bureau of Mines, Bulletin 266, 1927. This bulletin contains a selected bibliography of recent publications dealing with the uses, preparation, producing localities, etc., of silica and sand. For molding sand see p. 107, glass sand p. 135, filter sand p. 152, and special sands p. 159.

Lamar, J. E., Geology and Economic Resources of the St. Peter Sandstone of Illinois. Bulletin 53, Illinois Geological Survey, 1928.

the sand quarried in Missouri and Illinois. Its successful application to glass manufacture has made the St. Peter widely known as a high-grade glass sand.

Types of glass.—Glass may be classified according to its chemical composition, or on the basis of the predominating basic oxide, or by physical characteristics, which are largely controlled by the quality of the sand used. The last is the classification usually employed and the one of interest to the sand producer. The following classification includes glass of chief commercial importance:[76]

1. Lead flint glass. Requires sand of highest purity, and includes optical glass, fine cut glass, table ware, artificial gems, etc.

2. Lime flint glass. Requires sand almost as pure as for lead flint glass and includes prescription bottles, tumblers, pressed glass for table ware, novelties, etc.

3. Polished plate glass. Requires a high grade sand and includes all glass cast upon a smooth table, rolled to the desired thickness, annealed, and then ground and polished.

4. Rough plate glass. Requires a high grade sand and includes all glass cast as if to be polished, and is used for ribbed plate, rough plate, skylights, colored cathedral, wire glass, etc.

5. Window glass. Requires a less pure sand and includes all glass blown in cylinders, and then cut, flattened and polished while hot, and used for pictures, window glazing, mirrors, etc.

6. Crown glass. Requires a sand of about the same purity as rough plate glass and includes glass blown in a spherical form and flattened by the centrifugal motion of the blow pipe, and used for decorative purposes.

7. Green glass. Requires a sand of still lower purity, which may contain considerable iron oxide, and includes all of the commen kinds of glass used in the manufacture of fruit jars, bottles, carboys, glass containers, etc.

8. Amber glass. Requires sand with a fairly high content of iron oxide and is used for special purposes, as colored bottles, etc.

Chemical properties.—The presence of iron, clay, alumina, alkalies, and organic material impairs the hardness, brilliance, and transparency of glass. Iron colors the glass

[76] Linton, Robert, Glass. Mineral Industry for 1899, Vol. VIII, pp. 234-263, New York, 1900.

green, yellow, or brown and may be present in the sand as heavy minerals (for example, magnetite or ilmenite) or as hydrated or unhydrated oxides of iron coating the grains. The presence of iron in one form or the other or in both forms is very common in sand and renders the sand unsuitable for other than the cheapest kinds of glass. In making high-grade glass, lime, magnesia, clay, etc., are avoided, since absolute and certain control of the melt must be retained in order to give the desired product.

The American Ceramic Society and the United States Bureau of Standards have formulated the specifications covering chemical requirements for different grades of glass. These are given in Table 29, and the percentage tolerances recommended are given in Table 30.[77]

Table 29.—Percentage Composition of Sands of Various Qualities for Glass Sand

(Based on Ignited Samples)

Quality and Product	SiO_2, Minimum	Al_2O_3, Maximum	Fe_2O_3, Maximum	$CaO+MgO$, Maximum
1. Optical glass	99.8	0.1	0.02	0.1
2. Flint glass containers, tableware	98.5	0.5	0.035	0.2
3. Flint glass	95.0	4.0	0.035	0.5
4. Sheet glass, rolled and polished plate	98.5	0.5	0.06	0.5
5. Sheet glass, rolled and polished plate	95.0	4.0	0.06	0.5
6. Green glass containers and window glass	98.0	0.5	0.3	0.5
7. Green glass	95.0	4.0	0.3	0.5
8. Amber glass containers	98.0	0.5	1.0	0.5
9. Amber	95.0	4.0	1.0	0.5

Table 30.—Percentage Tolerance in Composition Allowed

(Based on Ignited Samples)

Quality and Product	SiO_2	Al_2O_3	Fe_2O_3	$CaO+MgO$
1. Optical glass	±0.1	±0.05	+0.005	±0.05
2. Flint glass containers, tableware	±0.5	±0.1	+0.005	±0.05
3. Flint glass	±0.0	±0.5	+0.005	±0.1
4. Sheet glass, rolled and polished plate	±0.5	±0.1	+0.005	±0.1
5. Sheet glass, rolled and polished plate	±1.0	±0.5	+0.005	±0.1
6. Green glass containers and window glass	±1.0	±0.5	±0.05	±0.1
7. Green glass	±1.0	±0.5	±0.05	±0.1
8. Amber glass containers	±1.0	±0.5	±0.1	±0.1
9. Amber	±1.0	±0.5	±0.1	±0.1

The manufacturers, however, have adopted no definite standards, and opinions vary considerably as to the neces-

[77] Bulletin 266, U. S. Bureau of Mines, p. 132.

sary composition of the sand for various kinds of glass. In general the adaptability of the sand for the desired use is first tried and if the results of the preliminary trials are successful the producer of the sand guarantees to keep his product within the specifications prescribed by the manufacturer. Chemical analyses of representative glass sands from leading producing districts are given by Weigel.[78]

Physical properties.—The shape of the sand grains has been emphasized as an important factor in determining the desirability of a sand for glass manufacture, since it is assumed that an angular sand should melt faster than sand composed of rounded grains. Careful consideration of this question has led to the conclusion that either material is satisfactory, and both kinds of sand are being employed successfully in glass manufacture.

There is also difference in opinion as to what size of sand grains is most desirable for glass making. While a fine sand melts more readily than a coarse sand, it is reported to yield a smaller volume of glass per unit volume of sand than coarse sand. If coarse and fine sands are used, the finer grains may settle to the bottom of the batch and yield a glass of uneven texture. In general neither a coarse nor a fine sand is desirable in glass manufacture. All glass sand should be screened to remove oversize particles, which may cause "stones" in the finished glass. It is generally considered that all glass sands should pass a 20-mesh sieve, and, while some manufacturers do not regard "fines" (grains that will pass through a 100 mesh screen) as objectionable, yet a proportion of fines above five per cent is likely to make the glass "seedy," and to choke the checker work of the regenerators by being carried over in the draft.[79] The fines also carry the bulk of the impurities, the heavy minerals. If the sand is washed, the excess of fines is usually removed in the washing.

The American Ceramic Society, in conjunction with the United States Bureau of Standards, has recommended the following grading of glass sand:[80]

[78] Op. cit., p. 134.
[79] Dunkin, D. D., op. cit., p. 4.
[80] Weigel, W. M., op. cit., p. 131.

Table 31.—Limiting Percentages of Different Sizes of Sand Grains for Glass Sand

Through a No. 20 screen, 100 per cent.

Through a No. 20 and remaining on a No. 40 screen, not more than 60 or less than 40 per cent.

Through a No. 40 and remaining on a No. 60 screen, not more than 40 or less than 30 per cent.

Through a No. 60 and remaining on a No. 100 screen, not more than 20 or less than 10 per cent.

Through a No. 100 screen, not more than 5 per cent.

It is also recommended that the cars in which the sand is to be shipped shall be thoroughly cleaned before loaded, and lined with paper where sand is sold for first, second, or third quality; that sand shall not be contaminated with stripping dirt or contain any crushed stones or pebbles; that all sand shall be screened, washed, and dried before shipment, except where the natural condition of the quarries will allow the production by screening only of fourth, fifth, sixth, or seventh quality sand.[81]

Examination of the chemical analyses (Table 26) and mechanical analyses (Table 5) indicates the high adaptability of the St. Peter sand of Arkansas to glass manufacture. Its high silica content, averaging over 99 per cent, its low magnesia content, averaging 0.002 per cent, its low lime content, averaging 0.07 per cent, and low iron oxide content, averaging 0.166 per cent, and low alumina content, averaging 0.27 per cent, make its use highly successful for better grades of glass.

FILTER SAND

Sand and gravel are now extensively employed for filtration purposes, particularly in obtaining supplies of pure water for municipalities dependent on streams for their water supply. The filter removes suspended matter, as organic débris, clay, silt, bacteria adhering to the organic and inorganic particles, metallic oxides, etc. In filter construction the lower layers are gravel, grading upward into the sand forming the upper layers, in the ratio of about one foot of gravel to two of sand.

Specifications differ, but Lamar summarizes their general features as follows:[82]

"1. General physical properties.—The sand shall be clean and free from organic material. It shall consist of hard, impermeable grains, either rounded or somewhat angular but

[81] Lamar, J. E., op. cit., p. 120.
[82] Idem, p. 116.

not flat, sharp, or splintery. The color of the sand is unimportant.

"2. Size of grains.—The effective size of the sand may vary from 0.3 to 0.7 but for municipal work is usually required to be between 0.35 and 0.45. The uniformity coefficient varies between 1.5 and 2.0 but is ordinarily about 1.6 for sand used in municipal filters.

"3. Chemical properties.—Filter sand should be composed principally of insoluble grains. This property is tested by allowing some of the sand to stand for 24 hours in a concentrated solution of hydrochloric acid. The loss in weight should not exceed 5 per cent and commonly a loss not to exceed 3 per cent is specified."

As a concrete example of the character of sand demanded in a large filtration project, the sand specifications for the filtration plant in Washington, D. C., may be cited:

"Filter sand.—The filter sand shall be clean river, beach, or bank sand, with either sharp or rounded grains. It shall be entirely free from clay, dust, or organic impurities and shall, if necessary, be washed to remove such materials from it. The grains shall, all of them, be of hard material which will not disintegrate and shall be of the following diameters: Not more than one-half of 1 per cent by weight shall be less than 0.13 millimeter; not more than 8 per cent less than 0.26 millimeter. At least 7 per cent by weight shall be less than 0.34 millimeter, at least 70 per cent less than 0.83 and at least 90 per cent less than 2.1 millimeters. No particle shall be more than 5 millimeters in diameter, and the sand shall be passed through screens or sieves of such mesh as to stop all such particles, and no screen or sieve shall be used containing at any point holes or passages allowing grains larger than the above to pass. The diameters of the sand grains will be computed as the diameters of spheres of equal volumes. The sand shall not contain more than 2 per cent by weight of lime and magnesia taken together and calculated as carbonates. In all other respects the sand shall be of a quality satisfactory to the Engineer officer in charge.

"The filter sand shall be placed in the filters in three layers, each layer to be about 1 foot thick, and the sand shall not be dropped from a height into final position or otherwise unduly compacted. The first two layers may be filled in to only approximate depths and the surfaces need not be smoothed. The final layer shall be brought to a true and even grade, and the surface left smooth and uniform."[83]

The St. Peter sand conforms closely in character to these specifications, and it has been widely employed for filtration purposes. The sand is hard and clean, with rounded to angular grains well mixed. The effective size of the Arkansas sand averages 0.146 (see Table 5), and the uniformity coefficient averages 1.83. In general the crude Arkansas sand is probably somewhat too fine for filtration purposes, but the washed and screened product should prove thoroughly satisfactory in filtration. Its high silica content makes the sand essentially insoluble in waters containing the solvents usually encountered in rivers and smaller streams.

SAND FOR STRUCTURAL WORK

Requirements.—Sand is utilized in many ways in construction. St. Peter sand can be successfully used for some of these purposes, but for other purposes it is too fine to be used economically. Sand used successfully in structural work has certain general characteristics. "Virtually all specifications require the sand to be clean and reasonably free from clay-coated grains, lumps of clay, flat or elongated grains, vegetable or organic matter, and pyrite, and have a minimum of clay, silt, or loam. The upper limiting size of the coarser sands is placed at ¼-inch to ⅜-inch. The material retained on a 100-mesh screen is called sand and that passing 100 mesh is called clay, silt, or loam. The material removed by sedimentation or elutriation is sometimes called silt and is usually specified not to exceed 3 per cent for all grades. Most specifications require the sand to be uniformly graded from coarse to fine, so that it will not contain an undue amount of any one size. . . . All earlier specifications and some present building codes require sand grains to be angular or 'sharp.' It has been pretty thoroughly proved, however, that although sharp grains may have some slight advantage, good concrete mortar and plaster can be made with rounded grains, hence this requirement is omitted in modern specifications."[84]

Sand used for structural work readily falls into two classes—paving and building sand.

Paving sand.—Sand in large quantities is used in the construction of sheet asphalt, asphaltic concrete, and asphalt

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[83] Mineral Resources of the United States, Chap. XIX, Pt. II, pp. 336-337, 1913.
[84] Weigel, W. M., op. cit., p. 73.

block pavements, brick pavement, concrete pavement, concrete and brick sidewalks, wooden and stone block pavements, grouting, asphaltic flooring, sand-clay roads, as a moisture blanket, and for railroad ballast.

The surface of a sheet asphalt pavement is composed of about three-fourths sand and one-fourth asphalt cement with a filler of Portland cement or rock dust. For this course the sand should be hard and durable and free from soft materials, such as clay, shale, etc. The sand may be round or angular, and for general traffic should range from 20 to 30 per cent fine (80 to 100 mesh), 30 to 40 per cent medium (40 to 50 mesh), 20 to 30 per cent coarse (10 to 30 mesh), and under 10 per cent very coarse (8 mesh). Light traffic permits a slight increase in medium size sand, and heavy traffic a slight increase in the proportion both of medium and fine.[85] Sand may be utilized in the binder course beneath the wearing surface to fill the voids between the fragments of crushed stone. For this purpose sand should be resistant and durable.

In asphaltic concrete pavements the concrete foundation may be covered, to form the wearing surface, with asphalt cement and broken stone, to which sand may be added. The sand so utilized should be durable and resistant and graded essentially, as stated in the preceding paragraph, successfully to meet the resistance of the character of traffic anticipated.

Sand is also used in the manufacture of asphalt blocks to form the wearing surface on a foundation of concrete, macadam, or gravel. The sand used is similar in durability and specifications for anticipated traffic as that used in sheet asphaltic concrete pavements.

To all of these purposes the St. Peter sand is well adapted, its range in grain size permitting grading to meet the demands of buyers and highway construction departments.

Paving bricks and wooden and stone blocks are laid on a sand bed or cushion. The sand for this bed should be "reasonably clean and free from foreign substances, although this requirement need not be as strict as for sand entering into mortar of any kind. It is usually specified that all should pass a ¼-inch screen, that not more than 5 per cent be removed by elutriation, and that it be well graded from coarse to fine. When the sand is used for a cement-mortar cushion (instead of loose sand) it should be free from lumps

[85] Lamar, J. E., op. cit., p. 102, and appended bibliography.

of clay and objectionable foreign matter. In addition to the limiting maximum size of ¼-inch grains, at least 90 per-cent should pass a No. 10 sieve. Strength tests of mortar made from the sand under standard conditions are usually required.''[86] St. Peter sand is excellently adapted to this purpose.

The cement concrete base used in the semi-monolithic type of brick pavement requires a sand of clean, resistant, durable grains, with less than five per cent clay or silt, and of such size that 35 to 70 per cent will pass the 20 mesh, and not more than 5 per cent the 100 mesh, or be retained on the ¼-inch mesh. For this use the St. Peter sand must be graded. It is doubtful, on account of its fineness, if the St. Peter sand of Arkansas is suitable for this purpose.

The sand bedding course consists of a layer of sand between one-half and one inch thick when finished, onto which the bricks making the wearing surface are laid. Sand for this purpose should not exceed one-quarter of an inch in maximum grain size. It may contain fine material passing a 20 mesh not exceeding 15 per cent by weight.

The sand-cement bedding course consists of a layer of dry sand and Portland cement mixed in the ratio of one to four. The layer when finished should be between one-half and one inch thick. The bricks are set on this sand-cement bed and the pavement sprinkled. Sufficient water enters between the bricks to wet the sand-cement bed and to cause it to set. Sand for this purpose should pass a one-fourth inch sieve, be of uniform size, and clean. It should be free from soft, friable material, shale or slate, and organic matter.[87]

For concrete pavements a sand composed of a mixture of coarse and fine grains, the coarse grains predominating, is recommended. Organic impurities, dust, clay, shale, mica, etc., are highly deleterious, even in small amounts, and make the sand unsuitable for concrete. The Bureau of Public Roads recommends the following proportion of sizes:[88]

Table 32.—Sizes of Sand Recommended for Concrete Pavements

	Per Cent
Passing ¼-inch screen	100
Passing ¼-inch screen and retained on No. 10 sieve	5-25
Passing No. 10 sieve and retained on No. 50 sieve	50-90
Passing No. 100 sieve, not more than	10
Weight removed by elutriation, not more than	3

[86] Weigel, W. M., op. cit., pp. 77, 78.
[87] Lamar, J. E., op. cit., pp. 107-108.
[88] Weigel, W. M., op. cit., pp. 76-77.

The St. Peter sand of Arkansas averages considerably finer than specifications given in Table 32.

Cinders and gravel are commonly used as a foundation for concrete and brick sidewalks. Sand may be added to form a cushion for the bricks or concrete. Any medium-grained sand that packs well is suitable for this purpose.

Grouting sand is used for making a thin cement mortar which is introduced into the joints between paving wood or stone blocks or bricks to act as a filler and binder. To be satisfactory for this use the sand should be fine-grained (to flow into narrow joints), resistant, and durable and free from soft materials. The American Society for Testing Materials recommends the following grading:[89]

Table 33.—Sizes of Sand Recommended for Grouting

	Per Cent
Total passing 10-mesh sieve	100
Total passing 20-mesh sieve, not less than	80
Total passing 200-mesh sieve, more than	5

The fineness of much of the Arkansas St. Peter sand recommends it for grouting sand.

In building sand-clay roads the surface is finished with sand and clay so mixed as to yield a compact, firm surface. If the road has a clay base, sand is added; if the base is of sand, clay is added, until the mixture yields a mixture of desired firmness. For the best results Baker states that "not less than 45 per cent nor more than 60 per cent of the sand should be finer than that caught on a standard No. 10 sieve, and coarser than that caught on a No. 60 sieve; and that caught on Nos. 20, 40 and 60 sieves should be about equal to each other."[90] The St. Peter sand of Arkansas is too fine to meet these specifications.

Sand in considerable quantities is also spread as a blanket on the surface of concrete freshly laid on sidewalks and roads to prevent cracking of the concrete as the cement sets. The sand layer is kept moist, thus preventing too rapid loss of moisture from the underlying concrete. Any sand of medium-sized grains is suitable for this purpose.

Sand is in some localities used for railroad ballast, although crushed rock or gravel is to be preferred for this purpose. The sand should be coarse, to permit free drainage, and be free from clay, organic matter, or other material that

[89] Weigel, W. M., op. cit., pp. 76-77.
[90] Baker, I. O., A Treatise on Roads and Pavements, p. 124. John Wiley & Sons, New York, 1920.

might cause the sand grains to slide, especially when wet. A clean sand of angular grains mixed with rounded grains is suitable for this use. In railroad fills and in elevating tracks sand is often used. The sand should be in part angular, and free from impurities, and sufficiently coarse to permit free drainage. To these purposes St. Peter sand is well adapted.

Building sand.—Building sands are used in engineering and architectural structures as concrete, mortar, plaster, asbestos shingles, roofing sand and roofing paper, clay brick, silica brick, sand-lime brick, terrazzo floors, facing tile and brick, and finishing sand for painted and plaster walls. The general characteristics of building sand are the same as those of paving sand and outlined on page 83.

Enormous quantities of sand are used in making concrete. The American Society for Testing Materials has summarized the specifications as follows:[91]

Fine aggregate shall consist of sand, stone screenings, or other inert materials with similar characteristics, or a combination thereof, having clean, hard, strong, durable, uncoated grains, free from injurious amounts of dust, lumps, soft or flaky particles, shale, alkali, organic matter, loam, or other deleterious substances.

They also recommend the following requirements covering size and grading of the sand:[92]

Fine aggregate shall preferably be graded from fine to coarse, with the coarser particles predominating, within the following limits.

	Per Cent
Passing ⅜-inch sieve	100
Passing No. 4 sieve	85
Passing No. 50 sieve, not more than	30
Weight removed by decantation test, not more than	3

The methods for making sieve analyses, colorimeter and decantation tests recommended by the American Society for Testing Materials are summarized by Weigel and need not be repeated here.[93] In color, freedom from impurities, silica content, hardness and cleanness of grains, the St. Peter sand is adapted to concrete work. Some of the sand is probably too fine for use in concrete preparation, and would require grading to make available the coarser sizes.

For mortar sand used in laying brick and stone the same general characteristics hold as for concrete, that is, the sand shall be clean, uncoated, and free from organic material, mica, etc., although 3 per cent of clay or silt is

[91] Weigel, W. M., op. cit., pp. 73-74.
[92] Weigel, W. M., op. cit., pp. 73-74.
[93] Weigel, W. M., op. cit., pp. 74-75.

permissible. If white joints are desired the sand should be white; for other work, or where a mortar color is used, the color of the sand is immaterial. Mortar sands should be free from soluble salts, since they come out on the surface after the walls have dried and produce a white, gray, or brown coating. The sand may be round, or it may be angular if the former frosted surfaces are preferable. The coarsest grains should have diameters less than the thickness of the mortar joints. In general practice the sand used will pass a 10 mesh and is coarser than the 100 mesh. St. Peter sand properly graded is excellently adapted to mortar preparation.

Sand is used in making lime plaster, gypsum plaster and cement plaster or stucco, the amount used depending on the character of the plaster, finish, and strength desired. The American Society for Testing Materials has tentatively adopted the following specifications for sand for gypsum plaster, and these are applicable to the sand used in making other plasters:

''Sand used for plastering in which gypsum is employed shall consist of fine granular material, naturally or artificially produced by the disintegration of rock containing not less than 80 per cent by weight of silica, feldspar, dolomite, magnesite, or calcite, and shall be free from saline, alkaline, organic, or other deleterious substances.

''It shall be graded from fine to coarse, and when dry not more than 6 per cent by weight shall be retained on a No. 8 sieve; not less than 80 per cent by weight shall be retained on a No. 50 sieve; and not more than 6 per cent by weight shall pass a No. 100 sieve. These sieves shall meet the specifications given in the Bureau of Standards' standard screen scale.''[94]

For lime plaster the sand should be well graded, coarse, and free from impurities, as well as hard and resistant. For cement plaster the sand should be dry, clean, sharp or with rough surfaces, hard and durable, and free from impurities, such as clay, silt, organic matter, soluble salts, etc. Its screening test should approach the following:

Not more than 10 per cent shall be retained on a No. 8 sieve.

Not less than 80 per cent shall be retained on a No. 50 sieve.

Not more than 6 per cent shall pass a No. 100 sieve.

Sieves shall meet the specifications of the U. S. Bureau of Standards' standard screen scale.[95]

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[94] Weigel, W. M., op. cit., pp. 75-76.
[95] Lamar, J. E., op. cit., p. 122.

The St. Peter sand can be produced in well-graded sizes, and in other respects is entirely suitable for plaster sand.

In making asbestos shingles the sand should be free from color, and ground to pass a 200 mesh sieve.

Roofs are sometimes covered with tar with which sand has been mixed. A relatively coarse sand is preferable. The washed St. Peter sand is entirely suitable for this purpose.

The finer grades of St. Peter sand, 65 to 100 mesh, are suitable as a coating for tar and roofing paper. A clean, white sand, free from impurities, is demanded for this purpose.

Sand is mixed with clay in the manufacture of clay brick to give the brick a durable surface and to prevent shrinkage and cracking during firing and cooling. The sand should pass the 28 mesh and most of it be retained on the 100 mesh. It should be clean, free from impurities, especially those that will color the brick, and from soluble salts which would cause fusion of the brick during firing or produce a coating after burning. The St. Peter sand graded to the above size is very suitable for clay brick.

The St. Peter sand when washed is also entirely satisfactory in the manufacture of silica brick. Its high silica content, low iron and alkali content, and freedom from clay, dirt, silt, etc., with its white color adapts it satisfactorily to this use. Finer sizes should be avoided.

Sand-lime brick consists of about one part of slaked lime to nine parts of sand cured in steam, the heat and vapor producing hydrated calcium silicate, which acts as the bond of the brick. A clean white sand of which about 15 per cent should pass the 100 mesh sieve is preferred. The most satisfactory sand consists both of angular and rounded grains. The St. Peter sand, if graded and washed, is fully satisfactory in the manufacture of this kind of brick.

In laying terrazzo floors a sand bed one-quarter to one-half inch thick is laid as a base, covered with tar paper, and followed by a layer of mortar composed of Portland cement and coarse sand in the proportion of one part to four. The terrazzo is then laid on this surface after it hardens. Any coarse, white, clean sand will serve for mixing with the cement.

The washed St. Peter sand in sizes from 48 to 100 mesh is suitable for facing tile and brick. The sand is coated on the surface of the tile or brick before firing. This produces a white brick. If yellow or red brick is desired, it is best to add iron oxide in amounts to be determined by experimentation. Some of the red phases of the St. Peter locally developed might be successfully utilized in producing colored facing brick or tile.

Painted walls are sometimes finished with sand to give them a rough, stone-like appearance. A clean sand of angular, subangular, and rounded grains is desirable for this purpose. The St. Peter sand is entirely suitable, because of its durability, purity, and shape of grain. Sand is also applied to plaster walls to secure a sand finish. Sand most suitable for this purpose should be fairly uniform in size of grain and in color. The St. Peter sand is desirable for this purpose and has been widely used in securing this type of finish.

HEAT-RESISTING SAND

Large quantities of sand are employed for various uses where high temperatures prevail. These uses are usually indicated in the designation of the sand, thus, molding sand, facing sand, annealing sand, brass sand, fire or furnace sand, sagger or placing sand, setting sand, and brick molding sand.

Molding sand readily falls into two classes, that with and that without natural bond. Sand of the first class contains sufficient clay, loam, or other foreign material to bond it when tamped into place around the pattern. Such naturally bonding sands are called "foundry sand," "iron molding sand," or simply "molding sand." Sand of the second class does not contain sufficient natural bonding material, and as a result, refractory clay, an organic binder, such as molasses or flour, or other substance has to be mixed with it. These sands run higher in silica and are more refractory than natural bonding sands, and hence are often called "silica sand," or "steel molding sand." These sands are used in steel molding, where high refractoriness is essential, while foundry sand is used for molding cast iron and alloys, such as brass.

Special names are given to molding sands used in different parts of the operation of molding, as follows:

Core sand—a highly refractory sand used for making the cores for molds.

Parting sand—a fine sand consisting preferably of rounded grains used for dusting the meeting faces of molds.

Facing sand—a sand which is generally fine, used to coat the inside of molds in order to give the casting a smooth surface.

Green sand—raw molding sand used in a moist condition.

Dry sand—molding sand which while damp is shaped into molds and then allowed to dry before metal is poured into it.

Loam—a mixture of clay and sand for molding large castings.

Backing or floor sand—the type of sand that makes up the bulk of the mold. It gives the mold its strength and offers escape to the gases formed at the contact of the mold and the molten metal.

The general properties that determine the value of a sand for molding purposes are: (1) bond, (2) grain shape, (3) grain size, (4) permeability, (5) refractoriness, and (6) durability.

"The binding material of a molding sand is probably its most important constituent. A well-bonded sand is soft and smooth to the touch and can be compressed in the hand. Each quartz grain should be covered with a thin film of the bonding material."[96] Clay is a common bond, as well as hydrated oxide of iron. The latter may be mixed with hydrated aluminum oxide. Either one or both make good bonding material, since either readily retains the film of water necessary. Other minerals that may be present and affect the bond are feldspar, mica, hematite, ilmenite, rutile, calcite, etc. If a sand is deficient in bonding quality, flour, molasses, oil, gluten or fire clay, etc., are added. The bonding material should be fairly evenly distributed.

Grain shape is an important property of molding sand. An angular sand in general will have greater bonding facility than a rounded sand, since the interlocking of the grains adds strength. On the other hand rounded grains are more refractory than angular grains under similar conditions. Rounded grains are in general less permeable than angular grains because of decreased pore space. Grains with frosted surfaces are more desirable than grains with smooth surfaces, since the rough surfaces afford a greater degree of adhesion than smooth surfaces.

Grain size is important, as it affects the permeability and determines the use of the sand. Coarse sand is used for heavy work and fine sand for light work and smooth castings.

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[96] Weigel, W. M., op. cit., p. 96.

Permeability is an important property of molding sand. A permeable sand permits the gases formed at the contact with the molten metal to flow through the mold without causing "blows" in the casting. Permeability depends on several factors. The grading of the sand is important. A sand of good permeability is very often not graded from coarse to fine, for difference in grain size permits closer packing of the grains, but consists of grains of fairly uniform size, representing the average texture of the sand, and enough fines or clay to make the bond. The size of the sand influences permeability in another way. In general the coarser the sand the more permeable it is, and angular sand is likely to be more permeable than rounded sand. Water in excess and bonding material in large amounts diminish permeability, for both clog pore spaces. Both should be kept at the minimum consistent with satisfactory working quality. Temperature and type of metal casts may influence permeability. High temperatures lead to fluxing, and some metals close the pores in the surface of the mold, so that sands of high permeability are demanded.

Refractoriness depends largely on chemical and mineral composition. In general sands high in silica are most refractory and sands high in alkalies are least refractory. Coarse sand is in general more refractory than fine sand, and rounded sand is in general more refractory than angular sand under similar conditions. Most naturally bonded sands contain from 75 to 90 per cent of silica. The fusion points of pure quartz lies between 1,700° C. (3,092° F.), and 1,800° C. (3,272° F.). This temperature is not attained in casting, but the maximum temperature attained in casting steel may be as high as 3,002° F. (Searle). Minerals likely to be present are hornblende, feldspar, ilmenite, tourmaline, zircon, rutile, pyrite, magnetite, titanite, anatase, xenotime, apatite, limonite, etc. Some of these fuse below the fusion temperature of quartz and if present in large amount may seriously lower the fusion temperature of the sand.

The durability of a sand determines the number of times it may be used. Rapid deterioration seems to depend largely on the bonding material present. Dehydration of the clay or limonite present as the bond, or the destruction of colloidal bond renders sand bonded with these materials unserviceable.

Numerous mechanical and chemical analyses of American molding sands have recently been published.[97] Weigel

[97] Weigel, W. M., op. cit., pp. 98-100.

has recently published a selected bibliography of recent articles on molding sand and molding sand research.[98] Lamar also gives a selected bibliography.[99] The American Foundrymen's Association has recently adopted tentative standard methods of testing.[1]

As a steel-molding and core sand the St. Peter has been widely used in the Middle West, and the Silica Products Company of Guion, Arkansas, has shipped considerable quantities of sand for this purpose. Lamar gives the following specifications of sand in commercial use for different types of castings:[2]

Steel Molding and Core Sand for Casting Car Wheels and Structural Steel

Representative sieve analysis:

	Per Cent
Sand passing through 100-mesh sieve	2.96
Sand passing through 80-mesh sieve	2.75
Sand passing through 60-mesh sieve	8.41
Sand passing through 40-mesh sieve	42.87
Sand passing through 20-mesh sieve	42.60
Sand retained on 20-mesh sieve	0.30
Fineness number	35.90

Color—not essential; usually light yellow tinge.

Shape of grains—round grains preferred, to allow for safe void between sand after it is rammed and to insure porosity and permeability.

Chemical analysis—silica content over 96 per cent preferred. Lime should be kept at minimum.

Sand for Molding Bars, Shapes, and Light Rails

Sieve analysis:

	Per Cent
Sand passing 100-mesh sieve	3.2
Sand passing 80-mesh sieve	1.2
Sand passing 60-mesh sieve	6.1
Sand passing 40-mesh sieve	39.3
Sand passing 20-mesh sieve	50.2
Fineness number	33.2

Color—unessential.

Shape of grain—rounded.

Chemical analysis:

		Per Cent
Silica	minimum permissible	98.0
Alumina	maximum permissible	1.0
Magnesia	maximum permissible	0.1
Lime	maximum permissible	0.5
Iron oxide	maximum permissible	0.5

Sand for Casting Car Couplers

Sieve analysis:

10 per cent must be retained on 20-mesh sieve.

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98 Weigel, W. M., op. cit., pp. 107-108.
99 Lamar, J. E., op. cit., pp. 129-130.
1 Transactions, Vol. 31, pp. 687-749, 1924.
2 Lamar, J. E., op. cit., p. 129.

30 per cent must be retained on 40-mesh sieve.
40 per cent must be retained on 60-mesh sieve.
80 per cent must be retained on 80-mesh sieve.
Color—prefer sands lacking high color.
Shape of grains—rounded.
Chemical analysis:

		Per Cent
Silica	minimum permissible	97.0
Soda, potash, and lime	maximum permissible	0.4
Total—alumina, magnesia, lime, soda, potash, and iron oxide	maximum permissible	2.0

St. Peter sand is not a natural bonding sand, and hence is but little used for foundry purposes where natural bonding sands are available and where high temperatures are not needed.

St. Peter sand is widely used as a facing sand and mold wash to give the surface of the castings a smooth appearance. For this purpose only fine sand is used, usually that passing the 200 mesh or finer. The sand is generally ground, since only a small proportion of the St. Peter sand is as fine as is required for this use.

For annealing purposes a fine sand, the bulk passing 100 mesh, is used. The hot surface freely sprinkled with fine sand cools more slowly. The finer grades of St. Peter sand are excellently adapted to this purpose.

Brass sand is a very fine-grained refractory sand used for making molds for casting brass, bronze, and aluminum. The finer grades of St. Peter sand are suitable for this purpose.

Fire or furnace sand is used to line furnace bottoms and walls, especially furnaces in which acid open-hearth steel and malleable iron are made. It is also used in making the bottoms of copper-refining and reverberatory copper-smelting furnaces. With a binder it is used as a lining for converters, cupolas, and ladles for holding molten metal. A high silica content is essential to obtain the necessary refractory properties. The sand should be free from fluxing materials and organic matter. A small amount of bonding material is required to hold the sand in place until the furnace lining has been fired or burned in. If bond is absent, plastic fire clay is added. A silica content above 95 per cent is usually specified, and alkalies must be at a minimum. Clay is the best bond and the least objectionable impurity. Iron oxide in small amount is also not objectionable. Desirable physical properties seem to be a graded product, all passing 10 mesh.

The fines fill voids, making the hearth more impervious and act as a bond. They also sinter more rapidly in the first firing. The sand may be either rounded or angular. The St. Peter sand is suitable for fire or furnace linings, since it is highly refractory, low in alkalies, and well graded. Bonding material, however, may have to be added to some shipments.

Sagger or placing sand is used in the manufacture of white ware and tile as a packer in the containers (saggers) in which the ware is burned. In burning white ware the sand must be free from impurities and low in fluxes and iron. Two grades of sand are desirable, coarse, between 10 and 40 mesh, and fine, between 28 and 100 mesh. Rounded grains are preferred as less likely to stick to the ware. St. Peter sand is excellently adapted to this use, because of its high silica content and hence refractory quality, and its freedom from fluxes, iron, and impurities.

In brick kilns a layer of sand is used as a cushion on which the bricks are placed to be fired. The sand desirable for this purpose should be free from impurities that might discolor the brick. It should be dry and fine enough not to indent the surfaces of the bricks. It should be high in silica and low in fluxes to prevent its fusion. The St. Peter sand is excellently adapted to this use.

Sand for brick molding is used in dusting the surfaces of the molds to prevent the brick from sticking to the molds. The sand should be refractory to withstand high temperature; hence it should run over 97 per cent silica. It should be fine enough to pass a 20-mesh sieve and the greater part of it should be coarser than 100 mesh. The grains should be round and the color white. The St. Peter sand meets all of these desirable qualities.

ABRASIVE AND FRICTION SAND

Enormous quantities of sand are used for abrasive and friction purposes. Friction sand is often referred to as engine sand. For abrasive purposes the sand may be reduced to desirable fineness by grinding, as in the manufacture of tooth paste, dental sand, scouring soaps and powders, metal polish, and scouring paste. For other uses the sand in some cases is graded, and in other cases used in the crude or washed condition. Some of these important uses are for grinding wheels, sawing and cutting stone, sand blast, banding, and burnishing.

Engine sand, sometimes called traction sand, is used to prevent the steel wheels of self propelled vehicles from slipping on wet or slippery rails. It is used by railroad locomotives, street cars, and mine locomotives. The sand should be clean and dry and contain a minimum of dust and fine particles and be free from large particles, clay lumps, clay coating the grains, or other materials that would tend to form lumps. It should feed freely through the feed pipe. An angular or subangular sand is more desirable than a sand of rounded grains, since the latter tend to roll off the rails before being caught under the driving wheels. It should be a high silica sand; most of it should pass a 20 mesh and be retained on the 80 mesh. The St. Peter sand, hard, clean and durable, is a satisfactory engine sand and has been much used in the Middle West for this purpose.

Stone-sawing sand is used as an abrasive for cutting stone. The sand should be hard, clean, and durable, and the grains of fairly uniform size, since the coarser grains support the cutting edge, leaving no work for the finer grains, the presence of which adds to the danger of impeding progress in the cutting. The grains should be quartz or other minerals at least as hard as quartz, since softer minerals are immediately crushed to powder. Sand uniformly graded to pass a 20 mesh and be retained on the 48 mesh is probably most desirable. The grains may be either rounded or angular. White sand is preferable, since there is no likelihood of staining or coloring the cutting face of the stone. The St. Peter sand, washed and graded, possesses all the properties demanded for stone-sawing material, and has been extensively used in the Middle West for this purpose.

Crude-rolled plate glass is first ground with sand to remove inequalities of the surface, two to three tons of sand being required to grind one ton of plate glass. Specifications for this sand are not strict, but it should be a subangular to rounded quartz sand free from soft minerals and impurities, such as clay and organic matter, and free from large grains that would deeply scratch the glass in grinding. A sand that will pass the 20 mesh and for the most part be retained on the 150 mesh is suitable for this purpose. The St. Peter sand meets all the requirements for this work.

Banding sand is an abrasive sand used in the second grinding of plate glass and in beveling glass. It is now largely replaced by artificial abrasives that cut more rapidly. It is a finer sand than that used in the first grinding of glass. The bulk of the sand should pass a 30 mesh and be retained on the 100 mesh, though some producers specify a sand so fine that 20 per cent is retained on the 200 mesh. The sand should be free from impurities, hard, clean, and durable. The grains may be rounded or angular. St. Peter sand has long been used as a banding sand.

Sand was formerly largely used for surfacing sandpaper, but the introduction of harder and faster cutting artificial abrasives and the use of garnet, crushed quartz, and quartzite has practically eliminated the use of sand for this purpose. Sand for this use should be angular, sharp edged, hard, and durable.

Sand is also used as the abrasive on the surface of grinding wheels. Angular sand is preferred to rounded because the grains are more firmly held by the bond, which may be shellac, rubber, or other substance. Angular sand also cuts faster than rounded. St. Peter sand is not as well suited to this use as more angular sands.

For grinding stone and marble a sand that is suitable for sawing stone is satisfactory. Sharp, angular grains are considered best, but rounded grains, through breakage and frequent use, soon become angular. The type of stone also controls to some extent the kind of sand desirable. For general purposes larger grains and pebbles should be screened out, and large amounts of fines and clay reduce efficiency. A sand with hard, tough, durable grains is most satisfactory. St. Peter sand fully meets the requirements for this use.

Friction sand other than engine sand is a fine sand placed between pulleys and belts and similar apparatus to prevent slipping by increasing friction. The finer grades of St. Peter sand are suitable for this use.

Sand-blast sand is a term applied to sand that is directed against objects by a rapidly moving air current, which carries the sand. It has a great variety of uses: cleaning and removing inequalities from rough castings, removing mill scale from sheets and bars, removing paint from old surfaces, cleaning or renovating stone and brick buildings, dressing stone, cutting glass, etching, labeling and decoration, engraving and carving designs and letters on stone and marble, preparing metal surfaces for enameling, and preparing metal surfaces for electrolytic treatment. Sand-blast sand in many places reaches the market in four grades, No. 1, through 20 mesh and retained on 48 mesh; No. 2, through 10 mesh and retained on 28 mesh; No. 3, through 6 mesh and retained on 14 mesh; and No. 4, through 4 mesh and retained on 8 mesh. Some departures from the grading for each grade is permissible. The sand should be hard, clean, tough, and durable. The grains may be either round or angular. As the sand in most plants is used repeatedly it requires frequent screening to remove dust and fines. The St. Peter sand is probably too fine to be a very desirable sand for sand-blast purposes. Lamar states that "it stands up very well as a blast-sand and is reported to give superior results."[3]

Burnishing sand is used for rolling down and burnishing gold decorations of china and porcelain. It should be clean, well rounded, and uniform, passing a 60 mesh and retained on a 100 mesh. St. Peter sand graded to this size is well adapted to use as a burnishing sand.

Polishing sand is a fine-grained, clean, tough and durable sand for smoothing the surfaces of sanitary ware, terra cotta, and other ceramic products. The finer grades of St. Peter sand are suitable for this purpose.

"Silver" or "livery" sand is used as a scouring agent for cleaning metal and other articles. The sand should be fine, hard, durable, and may be either angular or rounded. The finest grade of St. Peter sand is satisfactory for this purpose.

St. Peter sand in very fine grades, below 200 mesh or ground, is suitable, because of its high silica content and purity, for the manufacture of matches, scouring soap, metal polish, leather polish, scouring paste, dental paste, dental sand, etc.

CHEMICAL AND METALLURGICAL SAND

Sand enters into the chemical and metallurgical industry in a variety of ways. In chemistry sand is used in making sodium silicate or water glass, carborundum, silicon alloys and silicon, and for miscellaneous chemical compounds. In metallurgy sand is used for coking, enameling, as a flux, for making fused silica, glazes, pottery, refractory mortars and cements, refractory ware, and for welding.

[3] Lamar, J. E., op. cit., pp. 136-137.

In making sodium silicate or water glass both sand and diatomaceous earth are used, but the larger amount is made from sand, as it is cheaper than diatomaceous earth of the requisite purity. Only high-grade sand, comparable to a good glass sand, is suitable for sodium silicate. The sand must be low in iron and alumina, for iron salts affect the color and alumina makes the resulting silicate difficulty soluble. The sand should be clean and analyze at least 99 per cent silica, not over 1 per cent alumina, less than 0.1 per cent iron, and not over 0.5 per cent lime and magnesia combined. The sand should all pass 20 mesh and remain on 100 mesh. The St. Peter sand from the Ottawa district of Illinois has long been used for this purpose. Graded and washed St. Peter sand fully meets the requirements for the making of water glass.

A good quality of glass sand, such as the St. Peter, is usually satisfactory for the manufacture of silicon carbide or carborundum. The sand should contain from 99 to 99.5 per cent of silica and should be very low in iron. More than a trace of lime, phosphorus, and magnesia should not be present. Alumina should be small in amount, and the sand should be free from organic matter, lumps, etc. All grains should pass a 20-mesh sieve, and be retained on the 150-mesh sieve. St. Peter sand, particularly that from Illinois, has long been used for this purpose.

In making silicon for alloys, such as ferrosilicon and other compounds, the sand should be fine and of high chemical purity, running over 97 per cent in silica, and low in lime and alumina. The sand is mixed with coke, and the reaction takes place in the high temperature obtainable in the electric furnace.

Fine-grained, pure sand enters into the preparation of a number of chemical compounds of limited use. The purity of the St. Peter sand recommends it for chemical purposes.

Finer grades of St. Peter sand, because of the purity of the sand, are entirely suitable as a coking sand. This sand is sometimes added to the charge in the coke oven to combine with any bases present.

Quartz sand and ground quartz are used in the preparation of enamels for coating and finishing metal objects. The sand should be over 97 per cent silica, free from clay, and free from iron salts that might color the enamel. The finer grades of St. Peter sand and pulverized St. Peter sand are well adapted to this use.

In metallurgy a high silica sand is sometimes used as a flux in the smelting of sulphide lead and copper ores, the silica combining with the iron present to form slag. A fine sand is preferable. The finer grades of St. Peter sand are suitable for this use.

Fused silica, also called fused quartz or silica glass, is generally made from ground quartz. The finer grades of St. Peter sand and the ground sand possess sufficiently high silica content to be satisfactory for the manufacture of silica glass.

The purity of many sands now available and their cheapness have resulted in their coming into use for glazing chinaware, porcelain, pottery, stoneware, etc., displacing to a large extent crushed vein quartz. A sand possessing the properties of a high-grade glass sand is used. The sand must be low in iron compounds to prevent coloration, and have very small amounts of alumina, lime, and other oxides. The sand may be pulverized or fines passing 120 mesh may be used. The ground St. Peter sand is entirely satisfactory for making glazes.

Potter's sand is used for making white ware, table ware, wall and floor tile, chemical and electrical ware, art pottery, sanitary ware, and heavy clay products. The sand is of two general types, that used in making white ware, and that used in making dark, heavy clay ware. The first must be a high silica sand similar to a good glass sand, low in iron compounds and in easily fusible and fluxing minerals, while the second need not be so pure. For the first the sand should be free from dust, organic matter, and other impurities, and fine enough to pass a 28 mesh and be retained on a 100 mesh. For the second a similar degree of purity is not necessary, and the sand may be coarser, 10 to 40 mesh. A good grade of glass sand, such as washed St. Peter sand, is suitable for nearly all kinds of pottery.

Clean, highly refractory sand is employed in the manufacture of refractory mortars and cements, crucibles, retorts, saggers, etc. The sand must be low in iron and free from fluxing impurities, since the ware must withstand high temperatures. For mortars and cements the sand should be fine, but for retorts, saggers, and crucibles, the sand may be coarser. In all cases the sand should pass a 20 mesh sieve.

The St. Peter sand is satisfactory for use in making refractory ware.

Welding sand is sprinkled on the surfaces of pieces of iron to be welded and acts as a flux, forming the scale coating that is eliminated by hammering. A high silica sand which will pass a 28 mesh and be retained on the 100 mesh is suitable for welding. Graded to these dimensions St. Peter sand, because of its high silica content, is satisfactory for welding purposes.

ABSORBENT AND FILLER SAND

Sand is used in small quantities as an absorbent. As a filler, sand is used to a limited extent in agriculture, in the manufacture of fertilizer, rubber, paper, linoleum, paint, cements, sweeping compounds, etc.

A fine sand of well-rounded grains is used in small amounts in chemical laboratories and in industry as an absorbent for strong chemical solutions.

Sand is sometimes added to give a soil a coarser texture and freer drainage. Also a fine-grained, clean sand, such as the finer grades of St. Peter, is suitable as a filler in fertilizer to prevent its hardening and to keep it in a loose, mealy condition.

The finest grades of quartz sand, like the St. Peter or ground St. Peter sand, are used as a filler in the manufacture of paper, rubber, soaps, and linoleum.

Very finely ground quartz sand, such as the St. Peter, is used as a filler in certain paints. They give the paint a smoother working quality. White, high silica sand is suitable for this use.

Sand is used in making a number of cements, of which oxychloride cement is typical. This cement consists of sand, finely ground silica, and some organic material, such as wood flour, and a coloring pigment. The sand should be white, clean, free from clay lumps and clay coating the grains, and iron compounds, and sufficiently fine to pass a 20 mesh sieve. A good glass sand, such as the St. Peter, is satisfactory for making oxychloride cement. About the same grade and quality of sand is used in making lead cement, a mixture of sand and white lead, lime or plaster-of-Paris, and linseed oil; and in making sand cement by grinding sand and cement together. Borax cement and dental cement also contain fine-grained or ground white silica sand.

Sand is often used in making sweeping compounds to give them body and to hold the oil they contain.

MINOR USES OF THE SAND

Considerable quantities of sand are used annually for a number of miscellaneous purposes. In general the quality of these sands is not as high as St. Peter sand possesses, nor as high as demanded for most of the uses previously described.

Considerable quantities of sand are used in washing coal. Large quantities are also used in grading tennis courts, golf tees, and golf greens. Where supplies of sand at low cost are available, considerable quantities are used in sanding icy walks and streets. Medium to coarse-grained sand mixed with clay is used for horticultural purposes. Clean, white sand ranging from coarse to fine in grade is much used in school rooms and playgrounds. Coarse sand is used in large quantities, particularly in the Middle West, as a bedding for stock cars. In the lower Mississippi Valley region considerable sand is used in sand bags for construction of temporary dams and levees. A high silica sand of medium grain is used as sand baths in chemical laboratories where slow heating out of contact with the flame is desired. For all these uses the St. Peter sand is satisfactory.

MINING AND PREPARATION OF THE SAND

As a resource the St. Peter sandstone is essentially undeveloped in Arkansas. Only one plant is actively mining and marketing the sandstone. This plant, the Silica Products Company, Inc., is located at Guion, in southern Izard County, on White River. (See Pls. VII and VIII.) At this locality operations began as early as 1910, soon after the completion of the White River branch of the Missouri Pacific Railroad, but until 1921 the operations were spasmodic and ended in many failures. In that year a plant was built by the Silica Products Company and since that time its operation has been continuous and steady. The land is held under leases covering about 30 square miles of the best sandstone adjacent to the railroad. Most of the product is shipped to glassmakers.[4]

The mine of the Silica Products Company is developed in a bed 16 feet thick, the top of which is 12 feet below the top of the formation. The floor of the mine is a layer of

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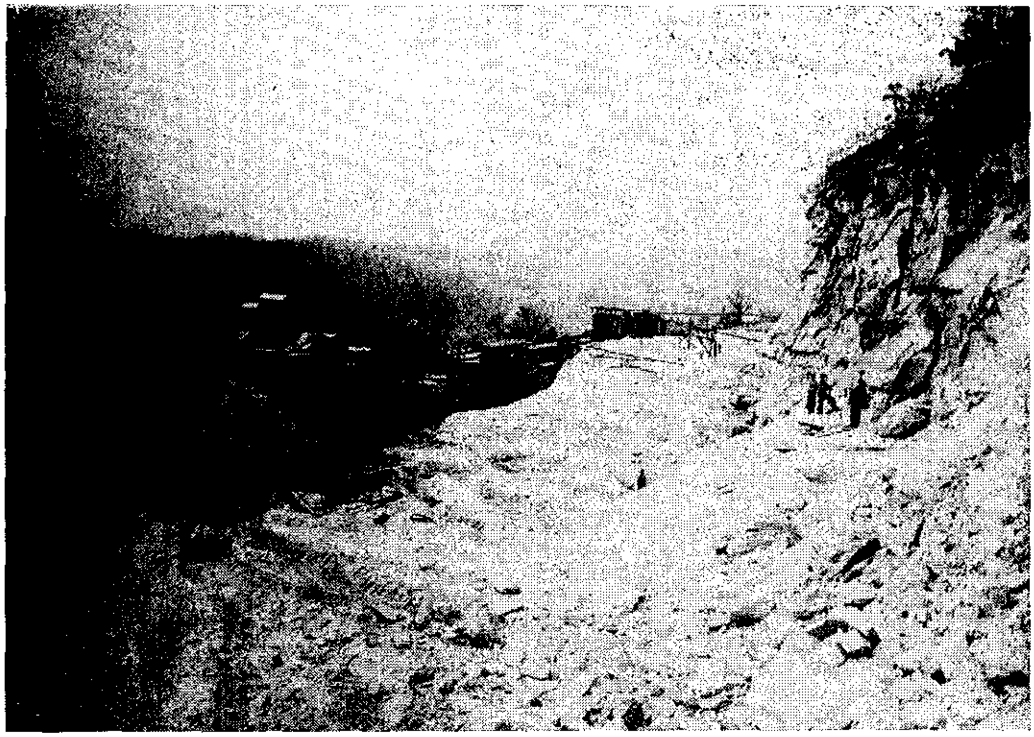
[4] Dunkin, D. D., Mining and Preparation of St. Peter Sandstone in Arkansas. Technical Publication No. 55, American Institute of Mining and Metallurgical Engineers, February, 1928.



VIEW OF ST. PETER SAND QUARRY OF SILICA PRODUCTS COMPANY AT GUION, IZARD COUNTY, ARKANSAS

VIEW OF ST. PETER SAND QUARRY OF THE SILICA PRODUCTS COMPANY AT GUION, IZARD COUNTY, ARKANSAS

St. Peter consisting of fine sand grains, which afford a hard, smooth surface with minor undulations. The roof is smooth and clean, permitting the sand beneath to be easily separated. "The general scheme leaves about 60 per cent of the sandstone in the mine as pillars to support the roof. The tunnel, or drift, was driven straight in, 16 feet high by 40 feet wide. As in coal mining, rooms are turned off this tunnel every 100 feet, the turn being narrower than room width; corresponding to the room neck in coal mining. This neck is about 25 feet wide at the beginning and gradually widens to 40 feet. The rooms are connected by crosscuts, which are 35 feet wide and are 80 feet apart. The mine has natural ventilation and numerous exits. A convenient bend in the mountain permits the rooms or drifts to be driven to the outside."[5]

In drilling and blasting and in handling the sand a number of new methods and new apparatus have been developed, which are fully described by Dunkin. The drill used is a Waugh 93 with air by-pass, manufactured by the Denver Rock Drill Manufacturing Company. The holes are drilled in horizontal series straight into the face to a depth of 12 feet, thirty-five holes constituting a complete battery. All holes are fired with fuse and in rotation, the central holes being fired first in order to afford sufficient "break" for the remainder. The round of holes yields about 500 tons.

The sand is loaded into two-ton, bottom dump cars built for a three-foot track gage. The track leads to a storage bin 100 feet long. From the storage bin the sand is removed by a hoe-type drag designed and built at the plant. The sand is then transferred by tram-car to the mill storage bin. From this bin the sand is fed to a 16-inch Blake type crusher, then to an elevator, which delivers the sand to an American process-type rotary drier mounted horizontally and equipped with two sets of slanting wings, which advance the sand as the dryer rotates. The dryer is oil-fired, the hot air from the combustion chamber passing the length of the dryer. An elevator carries the sand from the dryer to two trommels in series, each 4 by 9 feet. "There is enough oversize in the sand to keep the screens from blinding, even though these screens deliver a product that is all through 28 mesh (Tyler standard screen scale). The oversize passes to a small set of Cornish rolls and is returned to the screens. The throughs

[5] Dunkin, D. D., op. cit.

are elevated and sent to the grader, which removes the fines, so that a product can be guaranteed to contain less than 5 per cent of them. The fines pass to waste and the finished sand goes to storage bins."

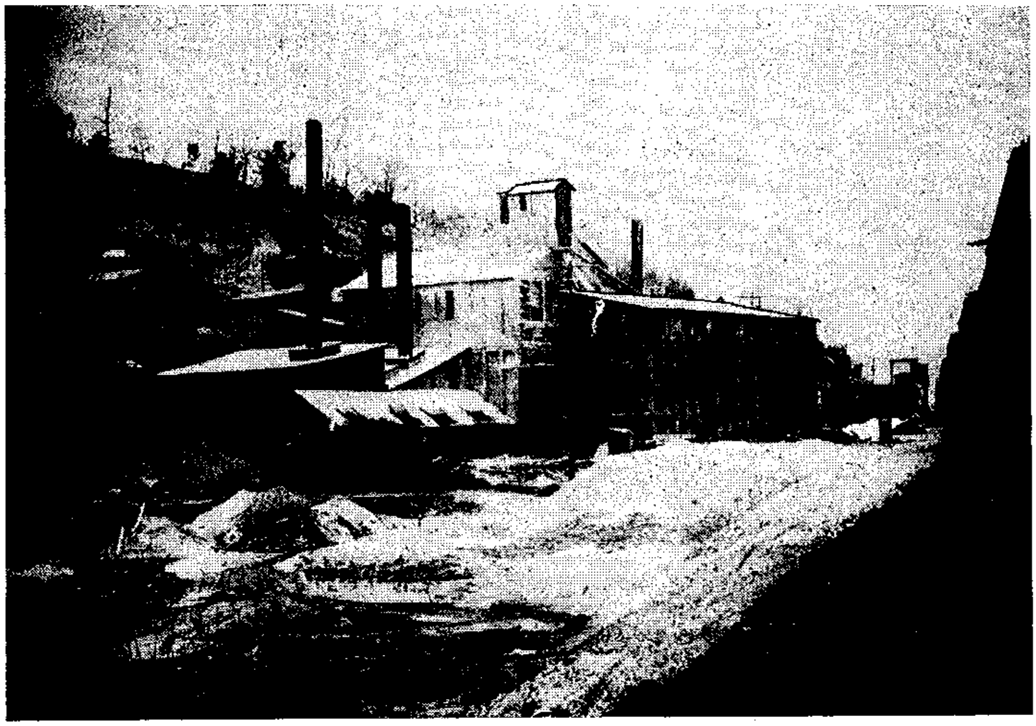
A special sand grader has been developed at the plant, the principle of which is based on differences in the coefficient of friction of different sizes of sand grains. "The machine at present consists essentially of an endless belt operating over a system of rollers, so that the slope and speed may be varied; also, different portions of the belt may have different angles of slope. The fines are discharged at the top of the belt and the coarse at the bottom, into suitable receptacles. The machine has a belt 7 feet wide and a feed slot 5 feet long. The capacity of each machine is 12.5 tons per hour. The fines will vary from 75 to 80 per cent through 100 mesh. This makes the machine very efficient as compared to the ordinary method of fine screening.

"Another design has been developed, and patent applied for, in which more than one belt or inclined plane is employed. The slope and speed of each is independent of the other and more than one separation is possible, as each belt takes the fines from the preceding one and makes a further division."

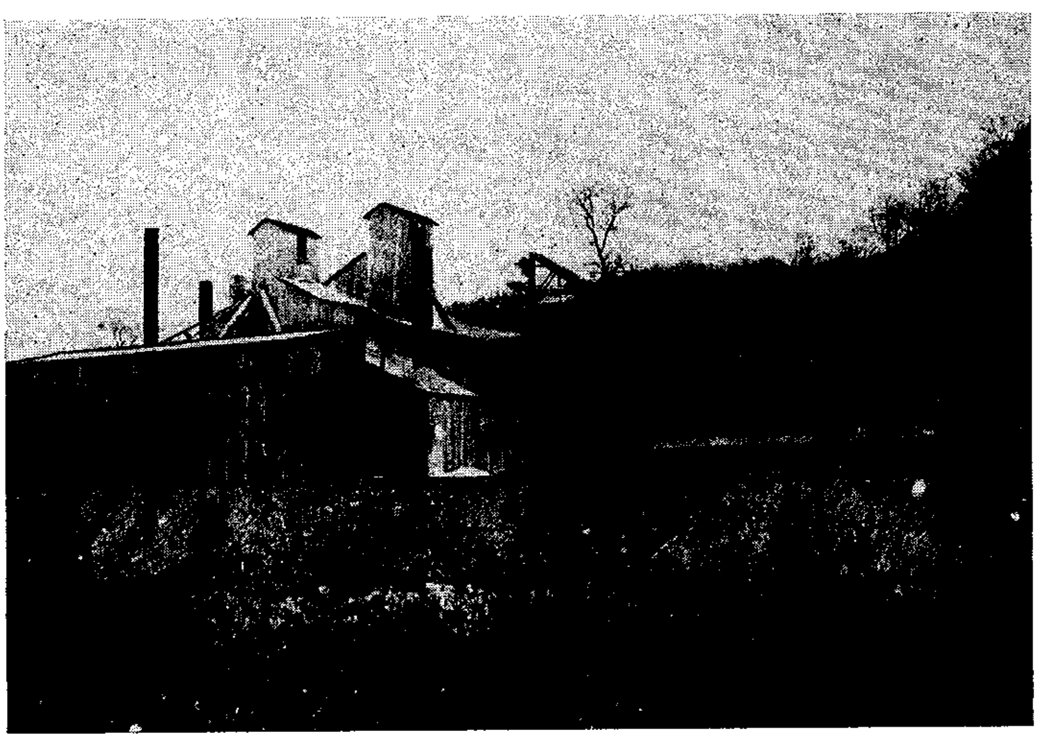
AREAS FAVORABLE FOR DEVELOPMENT

The successful and profitable development on a commercial scale of any natural resource depends upon a large number of factors. The factor first in importance is the presence of a reserve with tonnage sufficient to warrant the outlay necessary for the installation of modern equipment and to permit operations extending over a period of years commensurate with the cost of installation and cost of maintenance and operation and at the same time yielding a profit on the undertaking in proportion to the total outlay. The quality of the reserve is also a prime factor. Unless the quality is equal to that of other known reserves that are being exploited or that are known to exist the development of the resource faces almost certain failure. The success of the enterprise is dependent also on labor costs and supply, the capacity of the market for absorption of maximum output, water supply, nearness to railroad and freight rates, cost of getting product from mill to railroad, efficient operation of

[6] Dunkin, D. D., op. cit., p. 10.



VIEW OF PLANT OF THE SILICA PRODUCTS COMPANY AT GUION, IZARD COUNTY, ARKANSAS



VIEW OF PLANT OF THE SILICA PRODUCTS COMPANY AT GUION, IZARD COUNTY ARKANSAS mine and mill, efficiency of apparatus and alertness in recognition of improvement in methods and machinery, together with constant care and improvement of apparatus already installed. The success of an enterprise also depends on favorable cost of raw materials, such as gas and coal, in comparison with competitors, natural advantages which make mining or quarrying easy, the amount, character and ease of removal of overburden or other valueless material encountered in development, etc.

The presence of so many variable factors increases the difficulty of pointing out explicitly in a reserve as widely distributed and extensive as the St. Peter sandstone what areas are most favorable for profitable development on a commercial scale. There are, however, a number of areas where the sandstone is extensively developed at the surface and where it is thick and of good quality, with transportation facilities available, and with dependable water and labor supply.

The most favorable area for development lies between Guion and Sylamore, on the north side of White River. (See Fig. 9.) The White River branch of the Missouri Pacific railroad is adjacent and the sandstone bluffs overlook both railroad and river, making gravity haul feasible from the mine to the mill and railroad. The Silica Products Company has a large operation at Guion and holds extensive leases along the river. The sandstone is 100 to 150 feet thick, with almost continuous outcrop on the railroad and up the sides of the valleys of Rocky Bayou, Hidden Creek, Lyons Creek, and Twin Creeks, leading away from the river. The creeks possess gentle gradient, permitting gravity transportation from any locations on their courses. In this area the sandstone rapidly passes under thick cover, so that mining rather than quarrying is advisable. The sand is of good quality, as indicated by analyses of samples 11-A, 11-B, 11-C, and 29, given in Table 5. Chemical analyses of representative samples are given in Table 26, samples 11-A-B-C, 28, and 29.

The sandstone is well developed on the south side of White River, extending several miles up both North and South Sylamore creeks, maintaining a thickness of 125 feet. (See Fig. 9.) Screen analyses of the sandstone in closely adjacent localities are given in Table 5, samples 15-A, 15-B and 27. Chemical analyses are given in Table 26, samples 28 and 29. The location on the side of the river opposite to

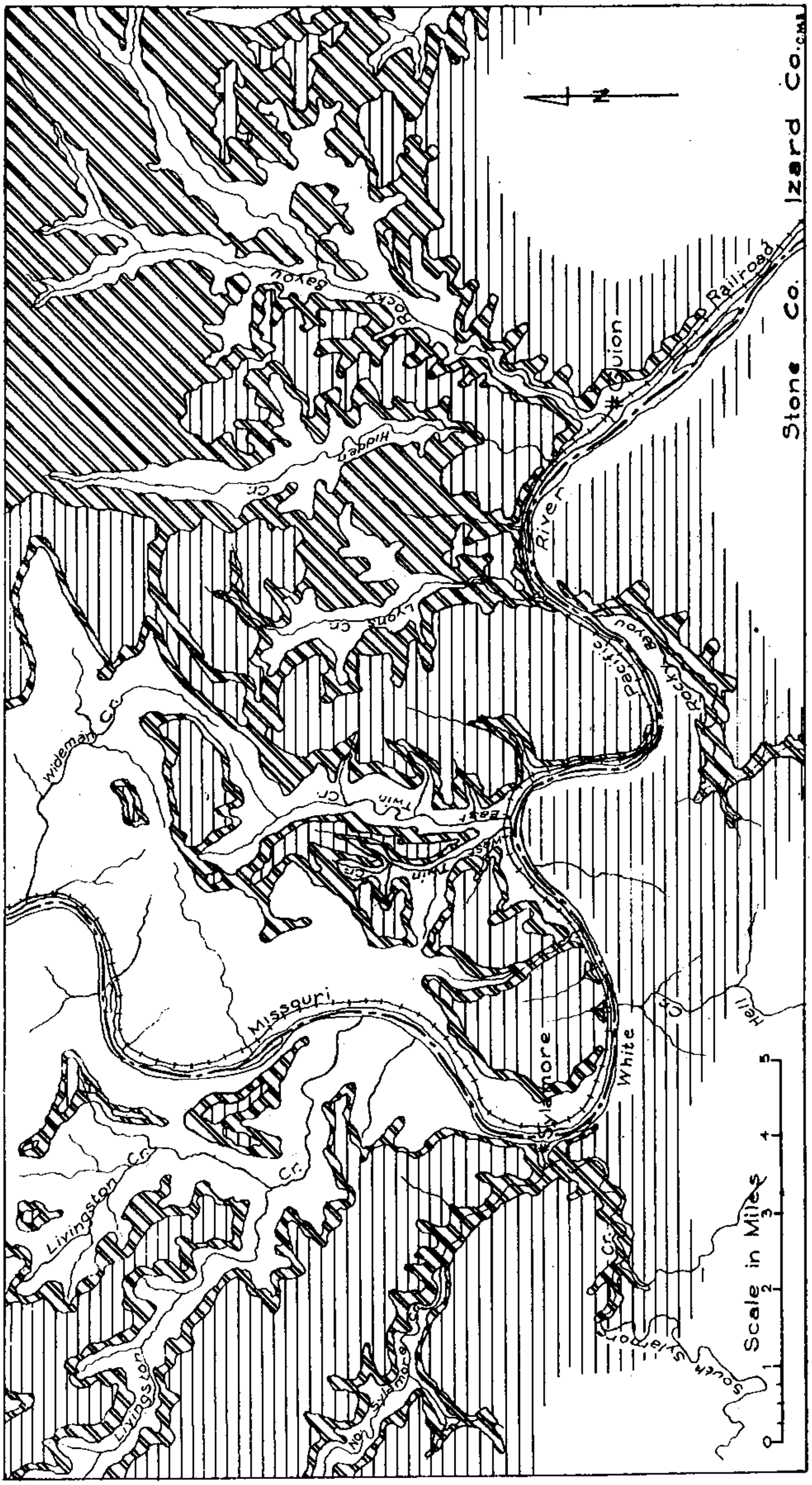


FIGURE 9.—Sketch map showing distribution of St. Peter sandstone on White River in southern Izard and northern Stone counties.

the railroad might be considered a deterrent factor in any proposed development, but the product could be transferred directly from the mill across the river by aerial tram to a spur track.

From Mt. Pleasant eastward to Cave City and southeastward to Sandtown there is a large area, 50 square miles or more, where the St. Peter sandstone is the surface formation. (See Fig. 10.) This is the largest area of surface outcrop of the St. Peter in Arkansas. The formation in this area is from 75 to 200 feet thick and has an average thickness of 100 feet. Representative analyses typical of the sand are given in Table 5, samples 2-B, 3-G, 3-I, 7-A, 7-B, 8-A, 8-B, 8-C, 9-A and 9-B. Chemical analyses of representative samples are given in Table 26, samples 2-A, 3-G, 8-A and 9-B. Unfortunately this area lies several miles from a railroad, hence there is little prospect of its immediate development. The construction of a railroad up Polk Bayou and Sullivan Creek is practicable and would furnish an outlet for manganese ore found in this area, as well as for the sand.

Southwest of Mt. Pleasant the St. Peter sandstone occupies the lower parts of the valleys of East and West Lafferty creeks. (See Fig. 10.) The sandstone here is 75 feet or more in thickness and analyses are favorable, as indicated in Table 5, samples 6-A, 6-C, 6-D, 6-G, 6-H and 7-A. Chemical analyses are given in Table 26, samples 6-G and 8-A. These outcrops, however, lie two miles or more from the railroad.

The extensive exposure of the St. Peter sandstone in northeastern Searcy, northern Stone, and southern Baxter counties is of little immediate commercial significance, for its distance from a railroad precludes its exploitation. The thickness of the sandstone ranges from 50 to 100 feet and averages about 75 feet.

At Pyatt, in western Marion County, a sandstone 25 feet or more in thickness is well developed just above water level. It is here included with the St. Peter, although it may be older. Mechanical analyses are given in Table 5, analyses 19-A, 19-B and 19-C. Chemical analyses are given in Table 26, sample 19-B. Physically the sandstone differs in no essential respects from the typical St. Peter as developed elsewhere. Its thickness, good quality, and accessibility to transportation facilities are favorable factors that invite investigation relative to possible commercial development.

Sandstones are well developed on Clear Creek south,

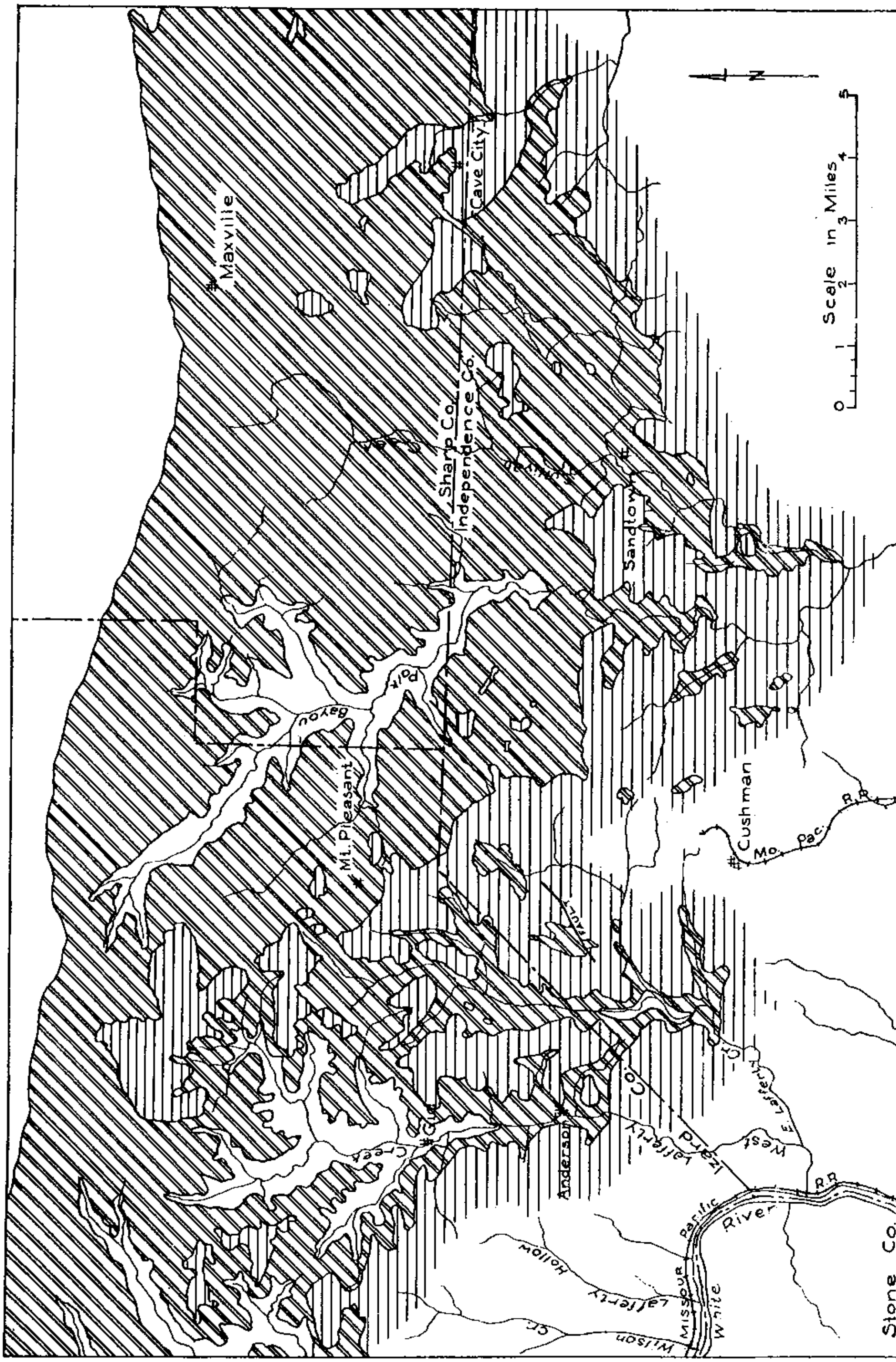


FIGURE 10.—Sketch map showing distribution of St. Peter sandstone in southeastern Izard, southern Sharp, and northern Independence counties.

north, and northwest of Everton, in southeastern Boone, southwestern Marion, and northwestern Searcy counties, with a thickness of 50 to 150 feet. This valley is penetrated by the Missouri and North Arkansas railroad and for a distance of 10 miles south and northwest of Everton the outcrop of the sandstone closely parallels the railroad on either side. At Olvey, northwest of Everton, the railroad passes over the sandstone for a distance of nearly a mile. This area undoubtedly possesses commercial possibilities with accessible transportation. Mechanical analyses are given in Table 5, samples 18-B, 18-C and 18-D. A chemical analysis of sample 18-A collected three miles west of Everton is given in Table 26.

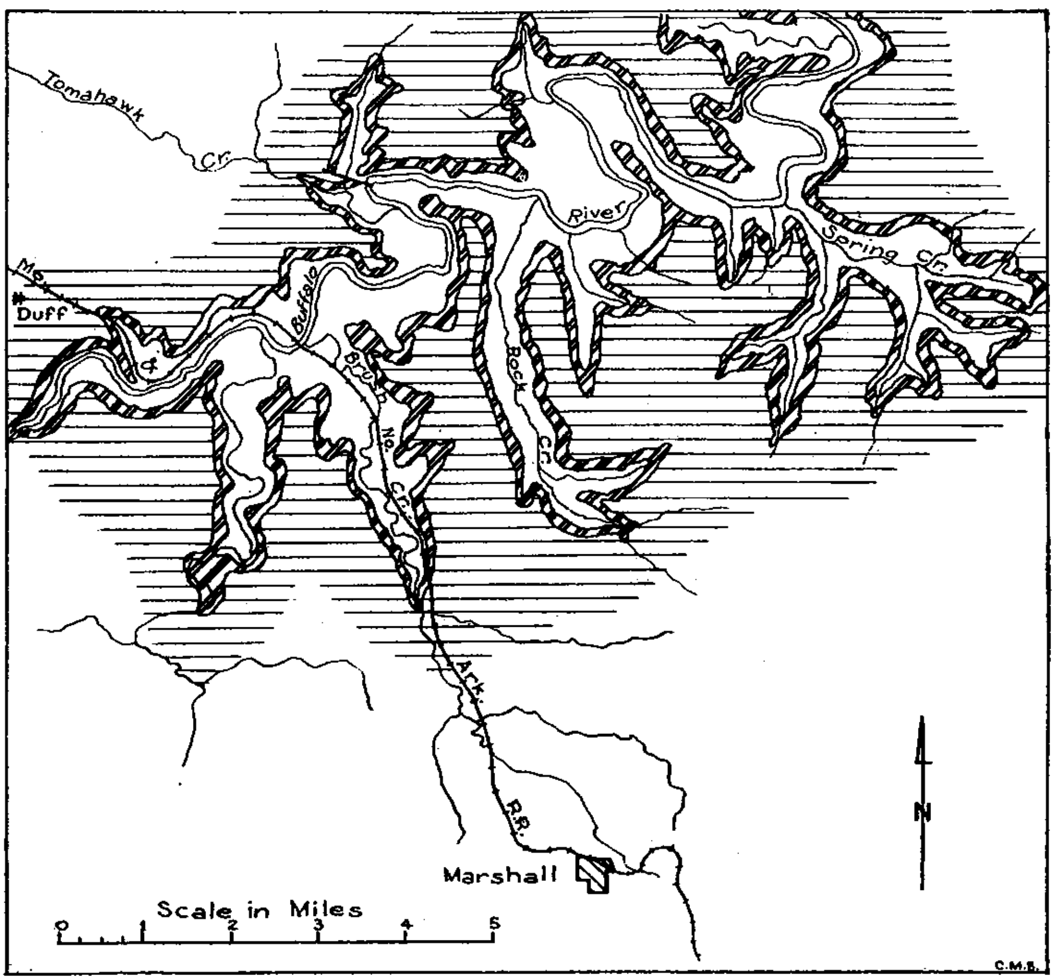


FIGURE 11.—Sketch map showing distribution of St. Peter sandstone on Buffalo River in northern Searcy County.

Southeast of Duff, in northern Searcy County, the outcrop of the sandstone lies on either side of the valley just above the level of the Missouri and North Arkansas railroad and continues to the White River Valley. (See Fig. 11.) Similarly, the outcrop parallels the railroad on both sides of Brush

Creek for a distance of three miles from White River towards Marshall. The extent of the outcrop in this region and its accessibility to transportation would seem to warrant the prospecting of the St. Peter relative to possible development.

In northern Newton County the St. Peter outcrops for long distances on White River, Buffalo Fork, and Little Buffalo Fork and their tributaries. The sandstone is of as high grade here as elsewhere (see analyses of samples 21-A-K, Table 5, and samples 21-A and 21-J, Table 26). It possesses a minimum thickness of 15 feet, but in most places its thickness is considerably greater, amounting to 150 feet south of Compton. The nearest railroad is 10 miles or more distant, so that the area affords no immediate prospect of development.

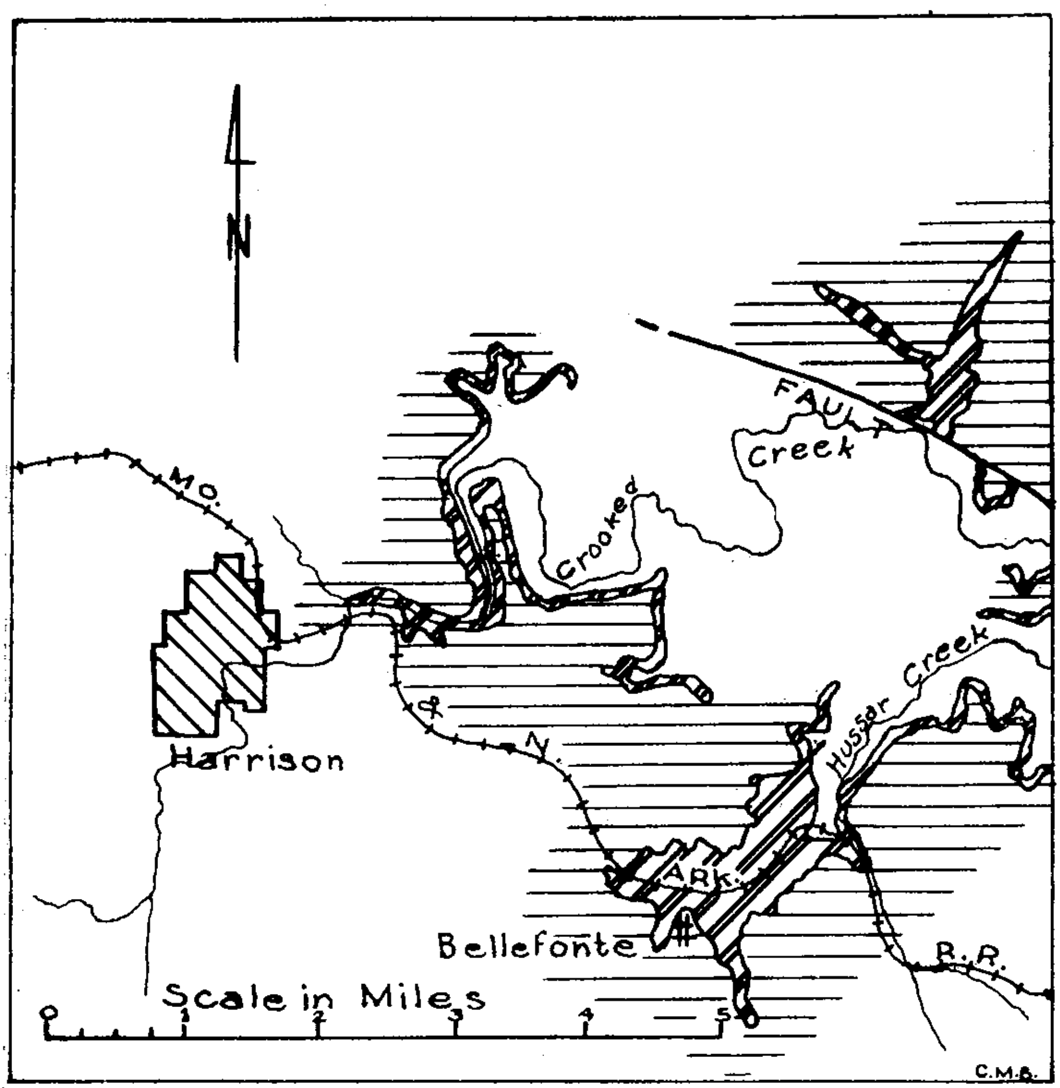


FIGURE 12.—Sketch map showing distribution of St. Peter sandstone in the vicinity of Harrison and Bellefonte.

At Bellefonte, southeast of Harrison, the St. Peter sandstone underlies an area two miles long and one mile wide (see fig. 12). This area is traversed by the Missouri and North Arkansas railroad. The formation here is only 10 to 20 feet thick, but its accessibility warrants prospecting. Screen analyses are given in Table 5, samples 22-C and 22-D. Chemical analyses are given in Table 26, sample 22-D.

One mile east of Harrison the railroad parallels the outcrop of the St. Peter for one-half mile. The formation here underlies a much smaller area than in the vicinity of Bellefonte. Its thickness is reported to be about the same as at Bellefonte. Although the sandstone is thin and the area small, yet prospecting is warranted because of its accessibility. The analysis of sample 22-A collected from this outcrop is given in Table 5.

There are a number of other localities where the St. Peter is inviting from a commercial standpoint. It is present with broad outcrop northwest of Osage postoffice in the valley of Osage Creek in eastern Carroll County. In southwestern Carroll County and northeastern Madison County the sandstone outcrops for miles on Kings River and its tributaries. The sandstone in these localities, however, is so far from transportation facilities as to preclude the possibility of commercial development in a strongly competitive field until cheap transportation becomes available.

PRODUCTION AND RESERVE

Figures giving the total annual production of St. Peter sand in Arkansas are not available. The Guion plant of the Silica Products Company has been in operation for a number of years with a large production. The sand has also had some slight local use in road work, building construction, etc., but as a resource it is essentially untouched and undeveloped. As such it represents a large, almost inexhaustible resource, capable of yielding sand for an indefinite period in the future, suitable for nearly all purposes where a high silica, clean sand is demanded. The sand is in every way comparable and equal in quality to the Missouri and Illinois St. Peter sand, which has long been exploited and which annually is produced in enormous tonnage. The result of the present study indicates that on the whole the Arkansas sand is somewhat finer than the Illinois and Missouri sand, yet by grading it can be utilized for the same purposes as the sand from those states. The St. Peter sand is excellently adapted to certain construction purposes, glass manufacture, molding use, and other uses described in the preceding section, and it should have a ready market and constantly increasing demand for use in these directions.

Development should proceed in areas where railroad transportation is available and where facilities for mining and handling the sand can be conveniently located. These areas have been described in the preceding section. Careful study of the texture, thickness, and quality of the sand over a considerable area should be undertaken before installation of a plant. Core drilling is advisable in areas under consideration for development. The sand should be handled in plants fully equipped with washers, crushers, and screens to insure highest quality attainable to meet severe competition. There is no tangible and valid reason why the St. Peter sand of Arkansas, if properly prepared, should not enter into successful competition with high silica sands produced elsewhere in the United States.

THE CALICO ROCK SANDSTONE

FIELD WORK

During the mapping of the St. Peter sandstone in northern Arkansas in the summer of 1927 a sandstone was found that is extensively and conspicuously exposed in eastern and southern Baxter County, northern Stone County, and eastward in Izard, western Fulton and western Sharp counties. This sandstone was mapped independently of the St. Peter sandstone. Its thickness and its wide areal distribution warrant a description of its geological features and a discussion of its economic importance.

NAME, AGE, AND REGIONAL DISTRIBUTION

The Calico Rock sandstone is named for the town of Calico Rock, on White River, in the western part of Izard County. The sandstone conspicuously outcrops in the river bluffs east and west of the town.

The Calico Rock sandstone is of early middle Ordovician age. It is older than the St. Peter sandstone and is stratigraphically a part of the Everton formation, which underlies the St. Peter sandstone.

The regional distribution of the Calico Rock sandstone is indicated on Plate IX. The formation outcrops over a large area in the southern part of the Mountain Home quadrangle and east of that quadrangle north of Melbourne. Good exposures of the sandstone are numerous on the main highway from Melbourne to Oxford, in northern Izard County. North of Oxford the sandstone outcrops in a narrow belt that extends nearly to the Missouri line. East of Melbourne and Sage the sandstone underlies the surface of a large area extending nearly to Evening Shade. South of Evening Shade the northeast boundary of the sandstone extends southeastward to the vicinity of Maxville, in southwestern Sharp County, and northwestward to the vicinity of Violet Hill, and thence to Oxford. This boundary has not been mapped in detail, but its general course is indicated in Plate IX.

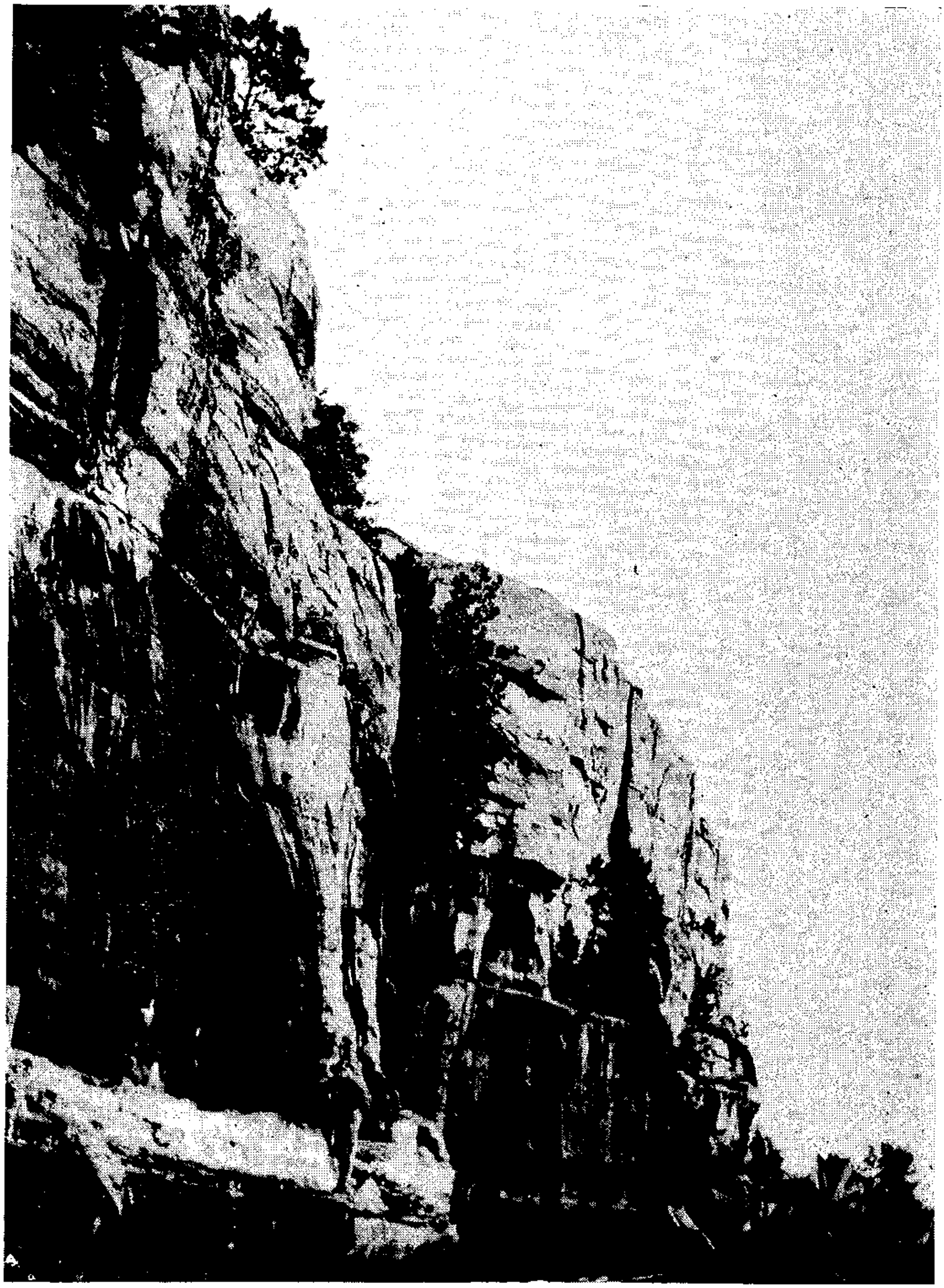
The Calico Rock sandstone underlies a large area north of White River. The sandstone rises above water level at

Mt. Olive, in southern Izard County, and forms almost continuous massive bluffs on both sides of the river from Mt. Olive to Norfolk, in south-central Baxter County, a distance of nearly 30 miles. These bluffs extend for long distances up tributary valleys draining into the river from the north and south. South of the river the sandstone floors the upland, forming a sandy belt with a width of three to four miles extending from the vicinity of Boswell, in southern Izard County, northwestward nearly to Big Creek, in southeastern Marion County. North of the river the upland is floored with the sandstone for a distance of five miles or more away from the river. The northern boundary of this sandstone area extends from Wild Cherry southwestward to the mouth of North Fork. Southeast of Mountain Home and west of North Fork a large outlier of the formation has an area of about five square miles. The total area underlain by the Calico Rock sandstone in the Mountain Home quadrangle is nearly 100 square miles, and east of the Mountain Home quadrangle the sandstone is the surface formation over an area of equal size.

The sandstone as a distinct lithologic unit does not persist west of Big Creek, in extreme southeastern Marion County. Sections measured at Buffalo and on Warner Mountain failed to reveal the presence of the sandstone, but on Matney Knob, six miles east of these sections, the sandstone is 65 feet thick.

THICKNESS

The Calico Rock sandstone is variable in thickness but will average about 100 feet in Izard, Fulton and Sharp counties. West of Calico Rock, in the river bluff, it is 72 feet thick. A well at Pineville, three miles north of Calico Rock, penetrated 60 feet of sandstone underlain by magnesian limestone. On the east side of Knob Branch, in southern Izard County, the sandstone is 100 to 125 feet thick, and it has about the same thickness at Mt. Olive, where it passes beneath the river toward the southeast. North of Melbourne it is 50 to 60 feet thick, and it is of about the same thickness in the vicinity of Wild Cherry, in southern Fulton County. It is thickest at Iuka, in western Izard County, ranging from 125 to 150 feet. From Iuka it thins southward and westward with a thickness of 65 feet in Matney Knob, in southern Baxter County, and about 75 feet in Sugar Loaf Mountain, in northern Stone County.



BLUFF OF CALICO ROCK SANDSTONE ON THE MISSOURI PACIFIC RAILROAD HALF A MILE SOUTHEAST OF CALICO ROCK

TOPOGRAPHIC EXPRESSION

The topographic expression of the Calico Rock sandstone is identical with the topographic expression formed by the erosion of the St. Peter sandstone. It forms conspicuous bluffs with fluted surfaces on White River above and below Calico Rock and precipitous cliffs on the sides of the valleys draining into White River (Pl. X). Where the formation underlies the surface erosion has carved the sandstone into rolling and sandy uplands, here and there with conspicuous cliffs, ledges, towers, turrets, and crags, which are readily mistaken for outcrops of St. Peter sandstone.

STRATIGRAPHIC RELATIONS

The stratigraphic relations of the Calico Rock sandstone are indicated in Table 2. The sandstone lies in the lower part of the Everton formation, early middle Ordovician in age, and is separated from the St. Peter sandstone by an interval that varies rapidly, even within short distances. This interval between the Calico Rock and St. Peter sandstone is occupied by beds of massive, white, coarse-grained sandstone alternating with thin to massive, blue to gray magnesian beds with a few dove-colored layers, upper Everton in age. The sandstone layers are lithologically identical with the Calico Rock and St. Peter sandstones. These sandstone and limestone beds occupy the same relative position that the upper layers of the Everton formation occupy farther west, in the Eureka Springs-Harrison region, and lie conformably on the Calico Rock sandstone and unconformably beneath the St. Peter sandstone.

The interval between the Calico Rock and the St. Peter sandstone, occupied by the upper Everton beds, varies from more than 400 feet to 0. This variation is due to erosion preceding the deposition of the St. Peter sand, which resulted in the removal of the upper Everton beds in whole or in part. Thus, in Candlestick Knob, in southern Izard County, the Calico Rock sandstone is 300 feet below the St. Peter; in Sugar Loaf Mountain, 10 miles to the northwest, in northern Stone County, it lies 275 feet below the St. Peter; and between these two places, east of the head of Livingston Creek, the interval between the two sandstones is about 100 feet. In Pilot Knob the interval is about 325 feet, but in the adjacent Turkey Knob, in southern Izard County, it is only 60 feet. East of Calico Rock 410 feet of Everton beds overlie the

Calico Rock sandstone, the top of the Everton having been removed by erosion. Five miles west of Melbourne the interval is 280 feet. North of Melbourne the two sandstones apparently come together, making a continuous outcrop of sandstone for many miles.

According to Miser the Calico Rock sandstone overlies beds of Everton age which are not identified as Sneed's limestone, the basal member of the Everton formation. (See Table 2, p. 12.) [7] These beds are an alternatin of blue and gray limestone and some coarse sandstone. In a section west of Calico Rock measured by the writer and Brewster an unconformity between these beds and the overlying Calico Rock sandstone is suggested, which made it somewhat difficult to locate precisely the basal bed of the Calico Rock sandstone.

FOSSILS

The Calico Rock sandstone is as devoid of fossils as the St. Peter sandstone. Although much of the area underlain by the sandstone was traversed and outcrops were examined at many places, no fossils were found.

STRUCTURAL FEATURES

Throughout most of its extent the Calico Rock sandstone possesses a gentle dip of from 1° to 5° per mile toward the south-southeast. The formation locally exhibits steeper dips, as at Mt. Olive, where the sandstone rapidly rises above the level of White River. Here the dip is as high as 10°. In places the formation, with overlying and underlying beds, has been thrown into broad but gentle folds. Thus, in tracing the formation northwestward from Mt. Olive to Calico Rock the sandstone repeatedly rises above water level until it outcrops in the river bluffs only to descend again to water level or below. On Piney and Mill creeks, east of Calico Rock, the formation is intersected by an east-west fault. South of the fault the sandstone either does not appear or its outcrop is much diminished in width.

Cross-bedding is a common feature of the sandstone, and ripples are conspicuous in nearly every exposure. They are a much more prominent feature of the Calico Rock sandstone than of the St. Peter sandstone. The ripples are almost entirely of the asymmetric current pattern. The layers of the sandstone are massive to thin bedded. Massive beds may be several feet in thickness. Beds a foot or less in thickness

[7] Miser, H. D., personal communication.

are much more numerous than in the St. Peter; in fact, thin and flaggy sandstone beds are a much more conspicuous feature of the Calico Rock sandstone than of the St. Peter sandstone.

ORIGIN AND GEOLOGIC HISTORY

Although fossils are absent the association of the sandstone with overlying and underlying strata of marine origin points to the marine origin of the formation. The ripples have the characteristic cross-sections produced by water currents and wave oscillation, and the cross-bedding is of the marine rather than the eolian or fluvial type. The sands with frosted surfaces show the effects of wind action, but the locus of this action was the beach facing the waves of an advancing sea.

The deposition of the Powell limestone, underlying the Everton, was terminated by uplift of northern Arkansas, elevating the area above the sea everywhere. Following a period of erosion the land was again depressed beneath the sea. In the Calico Rock region lime mud and quartz sand were delivered to this sea. Following this period of deposition there is some evidence that the sea withdrew again and the Calico Rock region experienced erosion for a short time, terminated by a readvance of the sea. Quartz sand in quantity was delivered to this sea by streams flowing probably from the north. This sand now constitutes the Calico Rock sandstone. The rounded and frosted surfaces of many of the grains indicate that the sand was actively carried about by the wind before falling into the control of the waves of the slowly advancing shore line. Wave action was vigorous, for the absence of fine material from the sandstone indicates that such material was kept in suspension until it had been wafted outward in the sea, beyond the limits of the distribution of the sandstone.

As the shore advanced and the waters deepened somewhat calcareous mud was deposited on the Calico Rock sands to form the overlying Everton limestone layers. But the deposition of calcareous material was interrupted from time to time by the pouring into the sea of quartz sand to form the sandy layers that alternate with the limestone layers.

LITHOLOGIC FEATURES

COHERENCE

In general the Calico Rock sandstone, like the St. Peter, is so friable that it is readily disintegrated with the fingers.

Locally, however, it may be so resistant that it is broken with difficulty with a hammer. This variability in coherence may affect the formation laterally or vertically. Certain beds may be resistant for short distances, or certain parts of the formation may be resistant through a considerable thickness. But as a whole the sandstone is so friable that it readily disintegrates before the attack of wind and weather. As a result streams draining the outcrop are clogged with sand. And again the friability of the sandstone is seen in the rapid grinding to sand beneath the wheels of traffic of ledges extending across roads.

COLOR

Fresh exposures of the sandstone are white or light cream color, but surfaces exposed to weathering are a dull brown, due to wash of iron compounds downward from the surface or to the oxidation and hydration of minute quantities of iron compounds distributed through the sandstone. On the whole the marked brown coloration of exposed surfaces of the sandstone is a more conspicuous feature than in the St. Peter sandstone. Bands of green color are not as noticeable in the Calico Rock sandstone as in the St. Peter. But yellow to brown ferruginous streaks are locally developed along joints and other fractures in the sandstone, as in the St. Peter. Organic matter has darkened the rock bordering penetrating rootlets, and immediately beneath the soil organic matter has leached down to a depth of a few inches in the sandstone.

INTERBEDDED AND INTERSTITIAL MATERIALS

Wherever examined the sandstone is remarkably uniform throughout the exposure. In this respect it closely resembles the St. Peter sandstone. The successive sandstone layers rarely show a conspicuous clay or shale parting and where these are present, as on the main highway south of Oxford, it is not clear that the parting has not been introduced by downward penetrating rainwater from the soil above. The general absence of interstitial materials is indicated in the analyses (Table 50). The very low alumina content points to the almost complete absence of clay, the commonest and most widely distributed interstitial material in sedimentary rocks. The iron content is even lower.

CLEANNESS

The Calico Rock sandstone appears as clean in fresh exposures as the St. Peter sands. When rubbed between the hands it fails to leave an appreciable coating. When a sample of the fresh sand is stirred in water it produces no appreciable turbidity. Freedom from organic matter, clay, etc., is a remarkable feature of the sandstone, which in this respect resembles other high silica and pure sands.

TEXTURE

General features.—The texture of the Calico Rock sandstone has been studied microscopically and megascopically. A binocular with a magnification of 30 diameters was used in the microscopic examination. No thin sections were prepared. The texture of different samples is different, but as a whole the sandstone is very uniform. The results of the sieve analyses in Table 35 emphasize this feature of the texture of the sandstone. Fine and coarse grains compose all samples examined under the binocular. Samples collected from any horizon in the sandstone are so similar in texture to samples collected higher up or lower down in the formation that no differentiating characters can be discriminated. Likewise samples collected from one locality differ in no essential respects from samples collected from other localities.

Collection of samples.—Nearly 50 samples were collected by Parks as representative of the Calico Rock sandstone. As the formation at no place has been developed commercially, the samples had to be taken from outcrops on roads and streams. In some places recent grading for road construction facilitated the collection of samples from unweathered layers, but in most places it was necessary to chip off the surface of the rock to a depth of several inches in order to get samples of the unweathered and unstained sandstone. These samples furnished the basis of the laboratory study. The samples necessarily represent a very limited range vertically and horizontally, but the sampling so thoroughly covered the area underlain by the sandstone that in the aggregate they represent very accurately the general character of the rock.

Mechanical analyses.—The laboratory procedure involving the samples of Calico Rock sandstone was the same as that described for the St. Peter samples. (See p. 25.) The analyses were made with Tyler Standard screens, the constants of which are given in Table 3. The separation was made in a mechanical agitator electrically driven. Thirty-eight samples of the Calico Rock sandstone were selected as typical of the formation and screened. The following example is the result of a typical analysis and illustrates the method of recording the analyses and resulting computations:

Table 34.—Mechanical Analysis of a Typical Sample of Calico Rock Sandstone

Sample 16-B. Weight of Sample, 100 grams. Time of Shake, 4 Minutes.
Screen Scale (Ratio=$\sqrt{2}$)

Mesh	Weight Retained	Per Cent Retained	Cum. Per Cent	Uniformity Coeff.	Effective Size	Fineness Modulus
35	17.27	17.27	17.27			
48	29.95	29.95	47.22			
65	17.78	17.78	65.00			
100	27.85	27.85	92.85			
150	5.73	5.73	98.58			
200	0.42	0.42	99.00			
Pan	0.29	0.29	99.29			
Total	99.29	99.29	99.29	2.10	0.151	2.39

The results of the mechanical analyses, together with locality where the sample was collected and the position of the sample in the formation, are given in Table 35. The results have been averaged in order to obtain a general survey of the size of the grains of the formation as a whole, and these results are also given in Table 35. The analyses of the samples are graphically illustrated as composition pyramids in Figures 14, 15, 16, and 17.

The terms "base of formation" and "near base of formation," "top of formation" and "near top of formation," appearing in the table, mean that the sample was collected within five feet of the base or the top of the formation, respectively. The vertical positions from which the other samples were collected are indicated in the table.

SIZES OF THE GRAINS

General features.—In making the mechanical analyses it was found that none of the samples of the Calico Rock sandstone contained grains large enough to remain on the 20 mesh sieve, but that 10 of the 37 samples of the sandstone analyzed contained grains large enough to remain on the 28 mesh sieve after four minutes of shaking. The bulk of the sand of the samples, however, is fine enough to pass the 28 mesh but most of it remains on the 100 mesh. All samples contain fine grains passing the 100 mesh in weighable quantities. All samples had weighable quantities on the 150 mesh, and all but three on the 200 mesh, and 11 samples had a weighable residue in the pan, passing 200 mesh.

From the results of the analyses as given in Table 35 the fineness modulus, percentage of fineness, effective size, and uniformity coefficient were computed.

Fineness modulus.—The fineness modulus is the sum of cumulative percentages computed from the sieve analyses divided by 100. Each sieve used has an opening double that of the preceding sieve. The sieves used in the present computation were the 28, 48, 100 and 200 mesh. If the sand was too fine to leave a residue on the 28 mesh sieve the fineness modulus was determined by adding the cumulative percentages of the 48, 100, and 200 mesh sieves and dividing by 100. The fineness modulus was determined for each of the analyses of the samples of Calico Rock sand, and the results are given in Table 35. The average fineness modulus for all samples was found to be 2.30, the values ranging between 1.66 (sample 10-F) and 2.74 (sample 10-B).

Percentage of fineness.—To determine the fineness of Calico Rock sand 12 samples were selected as typical of the formation in as many localities. The results are given in Table 36. The method of computation is described elsewhere.

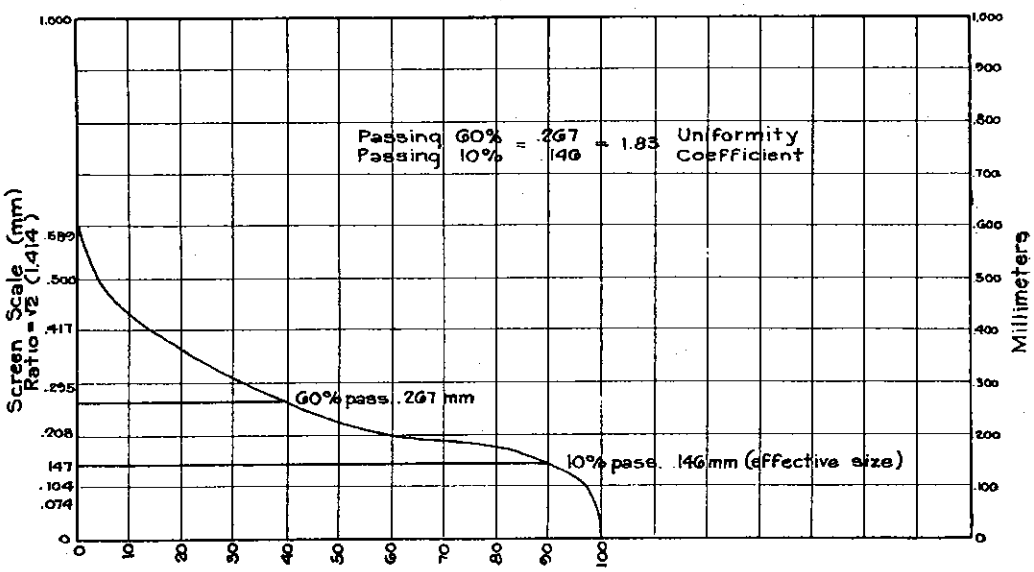


FIGURE 13.—Graph showing the derivation of uniformity coefficient and effective size of all samples of Calico Rock sand.

The screen sizes in millimeters are indicated on the horizontal axis, and the cumulative percentages on the vertical axis. The averages of analyses of 37 samples of Calico Rock sand as given in Table 35 were used as the basis for determining the cumulative percentages and plotting the graph. (See also Figure 2.) The results are given in Table 36A.

The percentages by weight retained on seven screens were used in order to insure uniform results that could be compared with the results obtained in the analysis of the St. Peter sand. The average percentage of fineness of the 10 samples of Calico Rock sand was found to be 42.27.

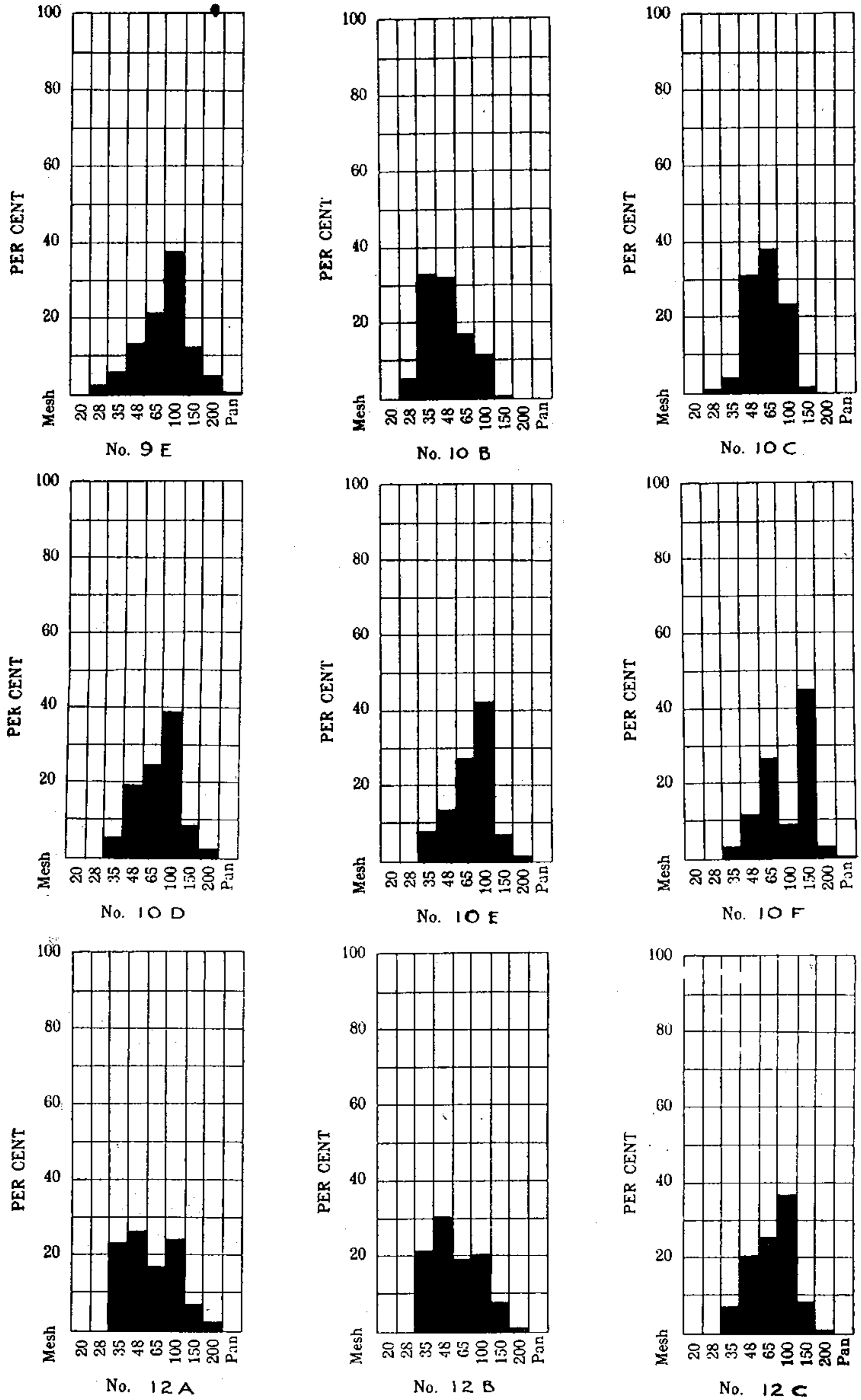


FIGURE 14.—Composition pyramids of samples of Calico Rock sand from central Izard county.

The numbers below the diagrams are the numbers of the samples as given in Table 35 (p. 120).

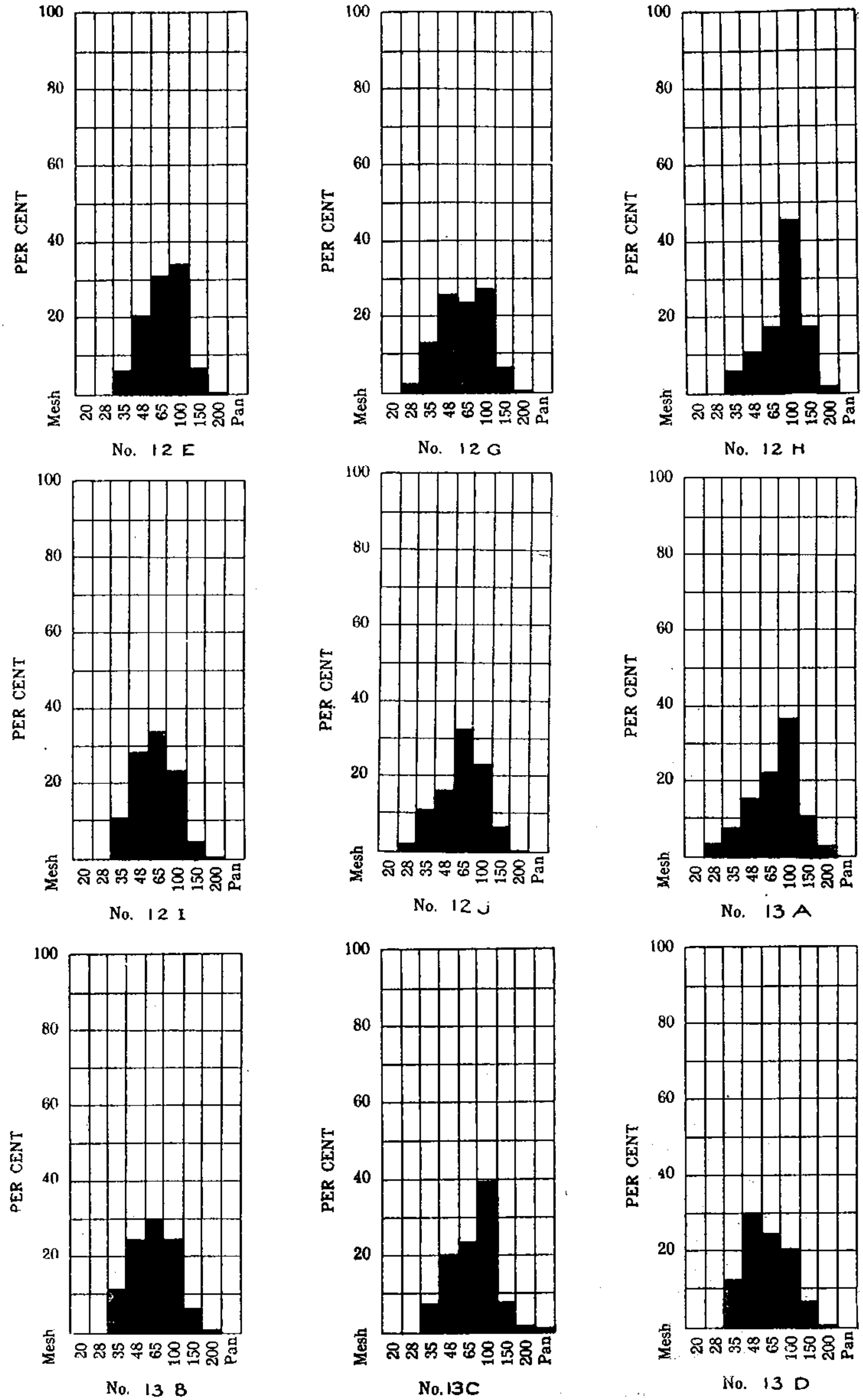


FIGURE 15.—Composition pyramids of samples of Calico Rock sand from northern Izard county.

The numbers below the diagrams are the numbers of the samples as given in Table 35 (p. 120).

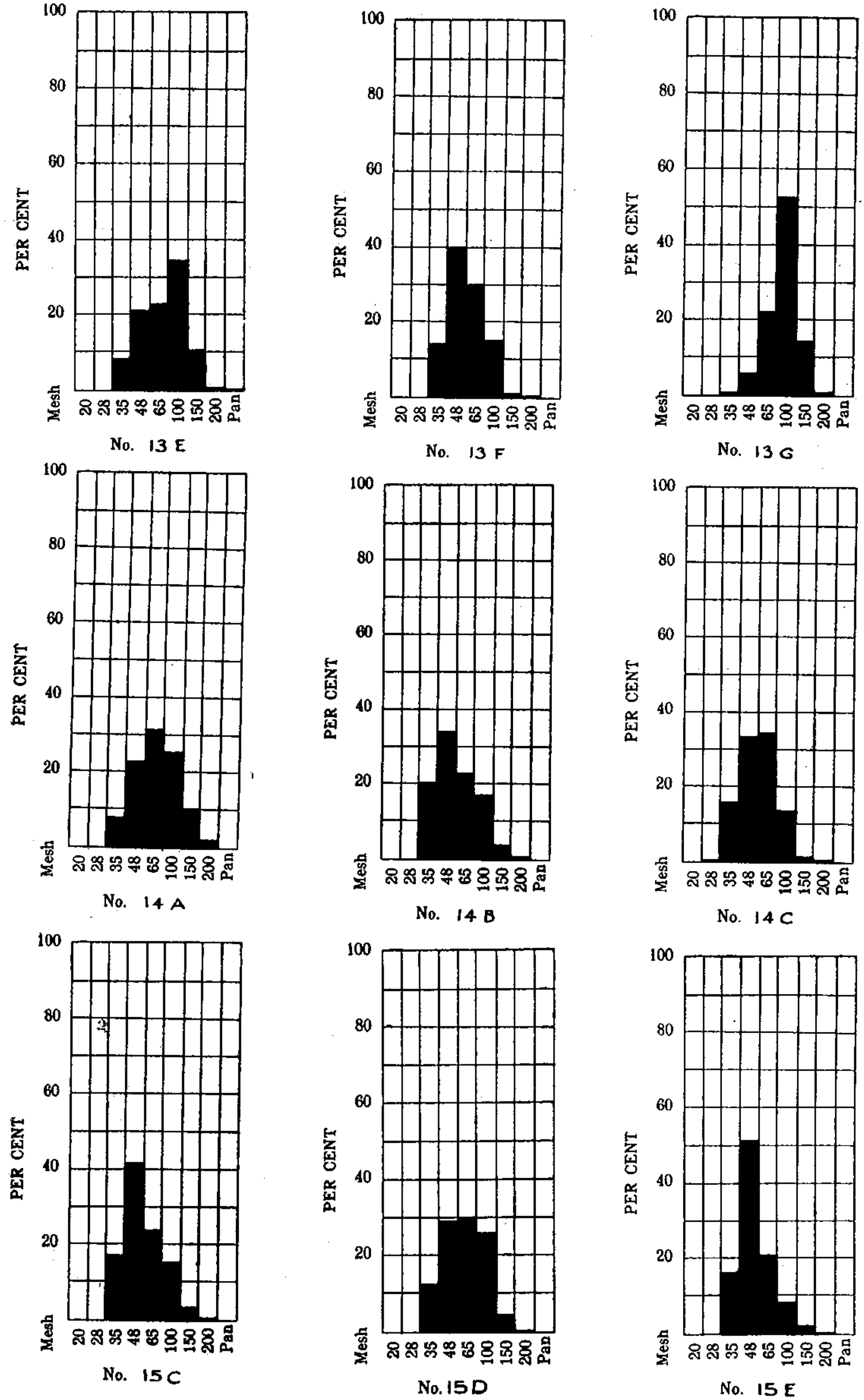


FIGURE 16.—Composition pyramids of samples of Calico Rock sand from western Izard and northern Stone counties.

The numbers below the diagrams are the numbers of the samples as given in Table 35 (p. 120).

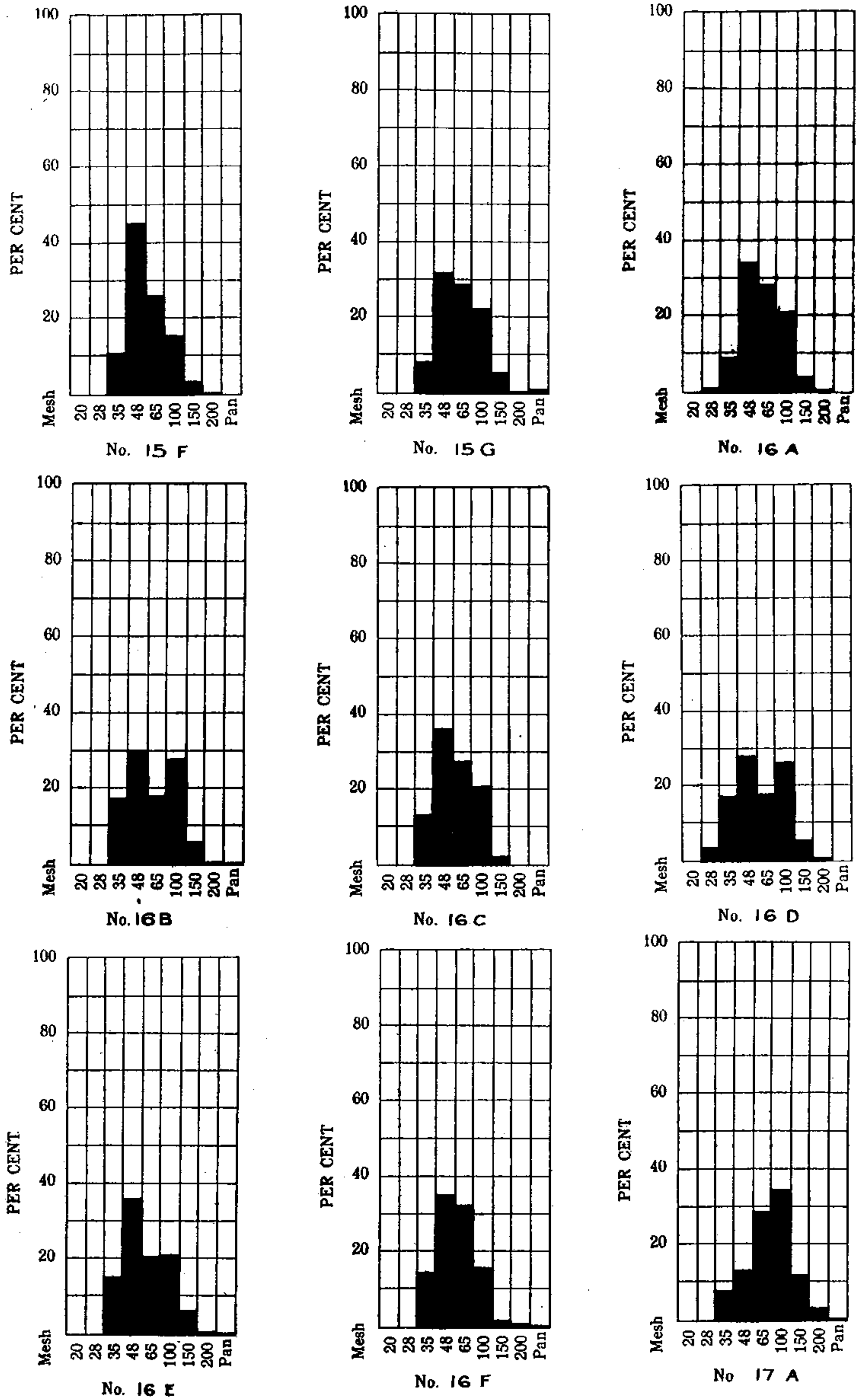


FIGURE 17.—Composition pyramids of samples of Calico Rock sand from western Izard, eastern Baxter, and south-central Marion counties.

The numbers below the diagrams are the numbers of the samples as given in Table 35 (p. 120).

Table 36.—Percentage of Fineness of Calico Rock Sand

Sample No.	PERCENTAGE PASSING EACH SIEVE							No. of Sieves	Percentage of Fineness	Horizon in Formation	Locality
	28	35	48	65	100	150	200				
9-E	97.16	90.16	77.16	56.08	18.48	5.98	0.28	7	49.33	Near top	North of Sage 2 miles
10-B	96.26	63.26	30.66	13.00	1.00	0.00	0.00	7	29.17	Near top	Northwest of Melbourne 2 miles
10-F	100.00	96.60	84.80	57.80	48.60	3.60	0.60	7	56.01	Near base	Foot of Pilot Knob
12-E	98.53	92.31	72.10	41.19	7.16	0.66	0.16	7	44.59	Below middle	East of Brockwell ½ mile
12-J	89.88	78.68	62.56	30.44	7.10	0.50	0.00	7	38.45	Below middle	At Brockwell
13-C	99.86	92.18	72.52	49.20	10.05	1.87	0.64	7	46.62	Near middle	West of Brockwell 7 miles
13-E	98.86	90.36	68.66	45.73	11.52	1.24	0.44	7	45.26	Near top	On Piney Creek
14-A	99.44	91.34	68.72	37.22	12.08	2.04	0.00	7	44.41	Base	East of Calico Rock ¼ mile
14-B	99.48	79.30	45.30	22.26	4.94	1.14	0.00	7	36.06	Middle	East of Calico Rock ¼ mile
14-C	99.90	83.72	50.06	15.60	1.88	0.40	0.00	7	35.94	Top	East of Calico Rock ¼ mile
15-G	99.64	91.20	59.10	30.50	7.96	2.42	1.34	7	41.74	Top	West of Calico Rock 3 miles
16-B	99.29	82.02	52.07	34.29	6.44	0.71	0.29	7	39.70	150 ft. above base	At Iuka
Av.	98.19	85.93	61.98	36.11	11.43	1.71	0.31	....	42.27		

Effective size and uniformity coefficient.—The effective size and uniformity coefficient of all samples of Calico Rock sandstone that were screened have been computed. This procedure was carried out by reducing the cumulative percentages to the form of a graph and determining the effective size and uniformity coefficient by interpolation, following the method described on page 39. The method employed is illustrated in figure 13, which represents the average graph for all anlayses of Calico Rock sand. The result therefore represents the average effective size and the average uniformity coefficient of all samples of Calico Rock sand. The effective size and uniformity coefficient for each mechanical analysis of Calico Rock sandstone are given in Table 35.

Table 36A.—Derivation of Cumulative Percentages and Method of Recording Uniformity Coefficient and Effective Size as Determined by Figure 13 (p. 121)

SCREEN SCALE RATIO = $\sqrt{2}$				TIME OF SHAKE—4 MINUTES				
OPENINGS		Mesh	Diam. of wire (inch)	Weight Re-tained	Percent Re-tained*	Cum. Per Cent	Uniform-ity Coeff.	Effective Size
Inches	Mils.							
.065	1.651	10	.035					
.046	1.168	14	.025					
.0328	.833	20	.0172					
.0232	.589	28	.0125		0.73	0.73		
.0164	.417	35	.0122		12.04	12.77		
.0116	.295	48	.0092		26.45	39.22		
.0082	.208	65	.0072		25.57	64.79		
.0058	.147	100	.0042		26.03	90.82		
.0041	.104	150	.0026		7.60	98.42		
.0029	.074	200	.0021		1.15	99.57		
		Pan			0.16	99.73		
					99.73		1.91	0.153

*Averages of analyses of 37 samples of Calico Rock sand as given in Table 35.

The effective size of all samples of Calico Rock sand screened was found to range between 0.107 (sample 10-F) and 0.199 (sample 15-E), with an average of 0.153 for the 37 samples. The uniformity coefficient ranges between 1.38 (sample 13-G) and 2.74 (sample 10-B), with an average of 1.91 for the 37 samples.

Comparison with the St. Peter sand.—Table 37 emphasizes a very marked physical similarity of the Calico Rock and St. Peter sands. The results of the screen tests are so

Table 37.—Comparison of Mechanical Analyses of St. Peter and Calico Rock Sands

Formation	AVERAGES OF SIEVE TESTS										Fineness Modulus	Effective Size	Uniformity Coefficient	Percentage of Fineness	
	No. of Samples	On 28	On 35	On 48	On 65	On 100	On 150	On 200	Pan	Total				No. of Samples	Results
St. Peter	54	0.80	10.88	20.58	24.78	32.16	8.06	1.55	0.75	99.57	2.17	0.146	1.83	15	47.26
Calico Rock	37	0.73	12.04	26.45	25.57	26.03	7.60	1.15	0.16	99.73	2.30	0.153	1.91	12	42.27
Difference	....	0.07	1.16	5.87	0.79	6.13	0.46	0.40	0.59	0.16	0.13	0.007	0.08	....	4.99

similar that the averages of only three screen sizes show a difference greater than 1 per cent. On the 35 and 48 screens the Calico Rock sand left slightly larger residues, and on the 100 mesh the St. Peter sand averaged more than 6 per cent higher than the Calico Rock sand.

The average fineness modulus of the Calico Rock sand is but 0.13 percent higher than the average for the St. Peter sample. The fineness modulus of all samples of St. Peter sand screened ranges between 1.53 and 2.74, as indicated in Table 5. The fineness modulus of the Calico Rock samples ranges between 1.66 and 2.74 (see Table 35). In Table 38 a further comparison is drawn indicating that the samples of Calico Rock sandstone approach an average much more closely than the St. Peter samples. Of the St. Peter samples 74 per cent have a modulus below 2.30, whereas only 43 per cent of the Calico Rock samples are as fine as this. On the other hand more than half of the Calico Rock samples have a modulus between 2.30 and 2.76, while only one-fourth of the St. Peter sands are as coarse as this.

Table 38.—Comparison of Fineness Modulus of St. Peter and Calico Rock Sands

Formation	Total No. of Samples	Fine (—2.30)		Medium (2.30–2.76)		Coarse (2.76+)	
		No. of Samples	Percentage	No. of Samples	Percentage	No. of Samples	Percentage
St. Peter	54	40	74	14	26	0	0
Calico Rock	37	16	43	21	57	0	0

The effective size of the two sands shows a remarkably small difference (0.007), and the uniformity coefficient of the Calico Rock sand is but slightly higher (0.08) than that of the St. Peter sand.

The percentage of fineness determined by the Kümmel-Hamilton method indicates that the Calico Rock sand is as a whole but slightly coarser than the St. Peter sand. The percentage of fineness of 15 samples of St. Peter sand averaged 47.26, while 12 samples of Calico Rock sand averaged 42.27. While this difference is slight, it is in agreement with the results obtained expressing the average fineness modulus, effective size, and uniformity coefficient of the two sands.

It would be very difficult to find two sands as closely similar in grain size as the sands of these two formations.

Table 39.—Angularity Tests of Calico Rock Sand

Sample No.	Degree of Angularity	Results of Tests for Each Mesh							Rounded	Fairly well Rounded	Subangular	Angular	Total Grains	Location of Sample	
		28	35	48	65	100	150	200						Geographic	Stratigraphic
16-B	Rounded	*	13	7	8	1	1	2	32					South of postoffice at Iuka, in northwestern Izard County.	Above base of formation 150 feet.
	Fairly well rounded		12	18	16	8	5	4		63					
	Subangular		36	37	23	44	37	26			203				
	Angular		39	38	53	47	57	68				302			
	Total grains		100	100	100	100	100	100					600		
13-C	Rounded	*	15	7	4	2	1	0	29					West of Brockwell 7 miles in west-central Izard County.	Near middle of formation.
	Fairly well rounded		8	11	13	9	3	4		48					
	Subangular		23	30	27	9	5	15			109				
	Angular		54	52	56	80	91	81				414			
	Total grains		100	100	100	100	100	100					600		
15-F	Rounded	*	6	7	3	1	2	0	19					On top of river bluff west of Calico Rock, in western Izard County.	Top of formation.
	Fairly well rounded		18	13	14	4	6	4		59					
	Subangular		43	37	27	31	26	13			177				
	Angular		33	43	56	64	66	83				345			
	Total grains		100	100	100	100	100	100					600		
		Total grains							80	170	489	1,061	1,800		
		Percentage							4.5	9.5	27.1	58.9	100		

*No residue.

SHAPES OF THE GRAINS

General features.—Because of its scientific interest and economic importance in the utilization of sand the shape of the grains in samples of Calico Rock sand were studied. Like the St. Peter, the sand under the binocular closely resembles crushed rock salt or fragments of crushed glass. The results of the study of this material show that both small and large grains are indiscriminately mixed and that the grains possess an infinite variety of shapes, ranging from rounded to angular with quadrilateral, triangular, rectangular and irregular outlines. Some grains are wholly angular, particularly the smaller grains; others are partially rounded, the remaining surfaces being composed of facets at angles to one another; and only a very small percentage is entirely rounded. The latter are very rarely perfectly round, but instead they are in most cases oblong or egg-shaped, more rarely spindle-shaped or lens-shaped, or very rarely semilunar.

Degree of angularity.—Following the method suggested by Trowbridge and Mortimore, three samples of Calico Rock sand collected at different horizons in different localities were analyzed with reference to angularity. The examination was made under a binocular against a dark background, using a magnification of 30 diameters. The slide was illuminated by means of two 100-kilowatt lamps. The samples selected for study were first screened and the residues from the successive sieves placed in envelopes labeled with the size of the sieve and sample number. In none of the samples was there a residue left on the 28 mesh. One hundred grains were arbitrarily separated from each envelope, and the shape of each grain classified according to the suggested scale of angularity. The results are given in Table 39.

Table 39 shows that less than 5 per cent of the grains of Calico Rock sand are rounded, and that only about 10 per cent are fairly well rounded. Slightly more than one-fourth of the total number of grains are subangular, and nearly 60 per cent of the total number of grains are angular. (See Pl. XI.)

Table 40 summarizes the degree of angularity of the grains according to size. With increasing fineness of grains there is a corresponding decrease in rounding and fairly well rounding of grains. Seven-eighths of the rounded grains are coarser than 100 mesh, and nearly three-fourths of the fairly well rounded grains are coarser than 100 mesh. For the coarser meshes the proportion of subangular grains remains fairly constant, but the percentage decreases rapidly for grains finer than the 100 mesh. Angularity, on the other hand, shows a constant increase with increasing fineness of grains. Three-fourths of the grains passing the 100 mesh are angular.

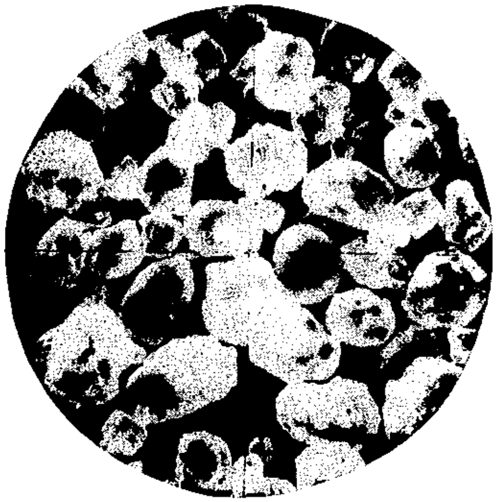
Table 40.—Average Angularity by Mesh Size of Calico Rock Sand

(Compiled from Table 39)

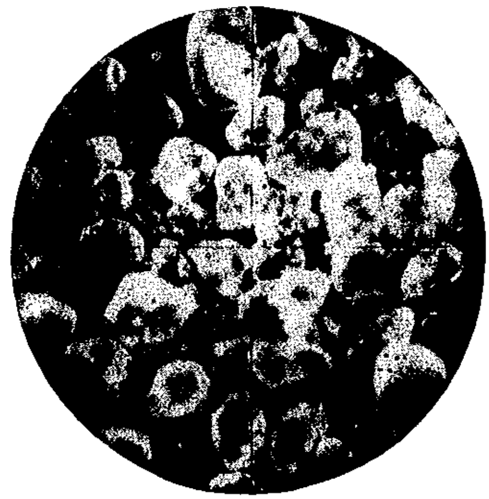
On Mesh	Rounded		Fairly Well Rounded		Subangular		Angular		Total No. of Grains
	No. of Grains	Per Cent	No. of Grains	Per Cent	No. of Grains	Per Cent	No. of Grains	Per Cent	
28	0	0.0	0	0.0	0	0.0	0	0.0	....
35	34	11.3	38	12.7	102	34.0	126	42.0	300
48	21	7.0	42	14.0	104	34.7	133	44.3	300
65	15	5.0	43	14.3	77	25.7	165	55.0	300
100	4	1.3	21	7.0	84	28.0	191	63.7	300
150	4	1.3	14	4.7	68	22.7	214	71.3	300
200	2	0.7	12	4.0	54	18.0	232	77.3	300
Total	80	4.5	170	9.5	489	27.1	1,061	58.9	1,800

In general considering the results as a whole one out of six grains coarser than 100 mesh is likely to be rounded or fairly well rounded, while only one out of 19 grains finer than 100 mesh is likely to be rounded or fairly well rounded.

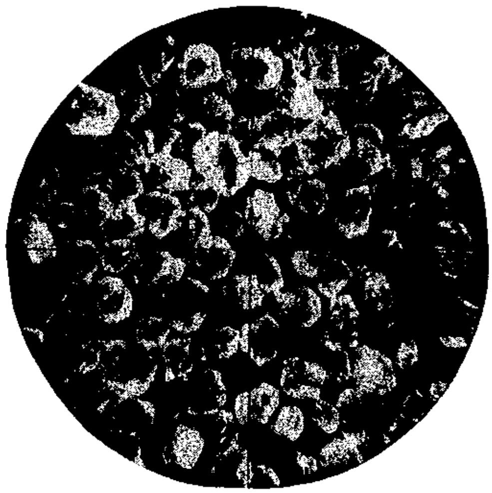
Comparison with the St. Peter sand.—The relative degree of angularity of the St. Peter and Calico Rock sands may be readily obtained by comparing Tables 13 and 39. The relative proportion of rounded grains of the Calico Rock sand is nearly twice that of the St. Peter sand, and the percentage of fairly well rounded grains is considerably larger. The proportion of subangular grains is nearly the same in both sands, but the percentage of angular grains in the St. Peter sand is appreciably larger than in the Calico Rock sand. The larger percentage of rounded and fairly well rounded grains in the Calico Rock sand is in part due to the rounding of the coarser grains, but a part of the difference finds explanation in the rounding of a larger proportion of Calico Rock grains ranging from the 100 to the 200 mesh. Table 41 is introduced in order that the degree of angularity of the St. Peter and Calico Rock sands mesh by mesh may be readily compared.



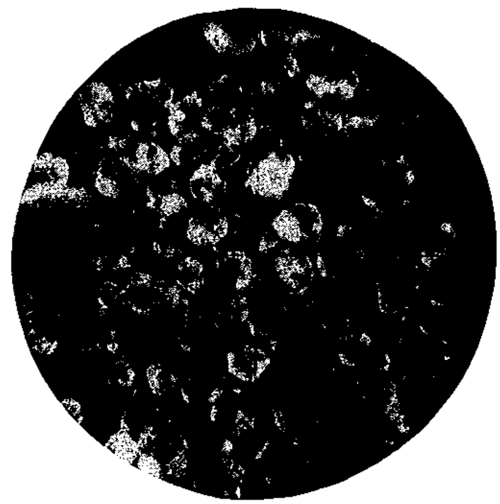
8 D



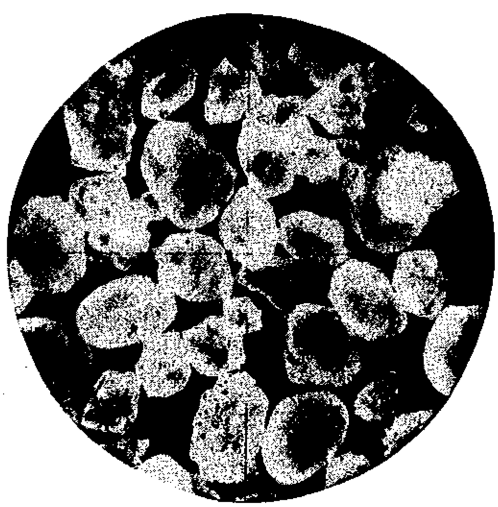
12 B



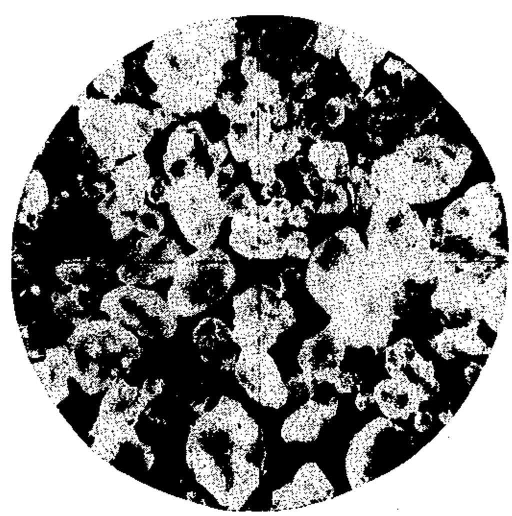
12D



12J



14A



15E

MICROSCOPIC VIEWS OF CALICO ROCK SAND

The numbers below the figures are the numbers of the samples as given in Table 35, opposite page 120.

No. 12D from near top of formation, one-half mile south of Brockwell; No. 8D from 16 feet below top of Calico Rock sandstone, north bluff of White River, five-sixths mile west of Calico Rock.

Table 41.—Comparison of the Degree of Angularity of the St. Peter and Calico Rock Sands

On Mesh	Rounded				Fairly Well Rounded				Subangular				Angular				Total No. of Grains	
	St. Peter		Calico Rock		St. Peter		Calico Rock		St. Peter		Calico Rock		St. Peter		Calico Rock			
	No. of Grains	Per Cent	No. of Grains	Per Cent	No. of Grains	Per Cent	No. of Grains	Per Cent	No. of Grains	Per Cent	No. of Grains	Per Cent	No. of Grains	Per Cent	No. of Grains	Per Cent	St. Peter	Calico Rock
28	0	0.0	0	0.0	8	8.0	0	0.0	23	23.0	0	0.0	69	69.0	0	0.0	100	....
35	16	5.3	34	11.3	45	15.0	38	12.7	117	39.0	102	34.0	122	40.7	126	42.0	300	300
48	14	4.7	21	7.0	42	14.0	42	14.0	104	34.7	104	34.7	140	46.6	133	44.3	300	300
65	8	2.7	15	5.0	24	8.0	43	14.3	116	38.7	77	25.7	152	50.6	165	55.0	300	300
100	6	2.0	4	1.3	21	7.0	21	7.0	91	30.4	84	28.0	182	60.6	191	63.7	300	300
150	1	0.4	4	1.3	7	2.3	14	4.7	59	19.7	68	22.7	233	77.6	214	71.3	300	300
200	0	0.0	2	0.7	4	1.3	12	4.0	30	10.0	54	18.0	266	88.7	232	77.3	300	300
Totals	45	2.4	80	4.5	151	7.9	170	9.5	540	28.4	489	27.1	1,164	61.3	1,061	58.9	1,900	1,800

SOUNDNESS OF THE GRAINS

Megascopic and microscopic examination of the Calico Rock sand shows that it is free from decay or other alteration. Traces even of incipient decay were not found in fresh samples. The grains appear as fresh and unaltered as the St. Peter sand grains. Apparently the sand was deposited as fresh and firm quartz grains and subsequent changes have not altered this character of the grains except in places where the rock has been exposed to the action of the weather.

POROSITY OF THE SAND (VOIDS)

The importance of determining the porosity of a sand, particularly sand to be used in construction has already been emphasized in connection with the discussion of the porosity of the St. Peter sand. In order to reach a definite conclusion regarding the porosity of the Calico Rock sand five samples were selected as representative of the formation in localities where the formation is typically developed and their porosity determined. In this determination the specific gravity-weight method was used, as recommended by Dake and others and as described elsewhere in this report.

The following example ilustrates the procedure. The specific gravity of sample 12-J, collected below the middle of the formation at Brockwell, was determined to be 2.680. The weight of 100 cc. was found to be 151.572. The difference in weight caused by the voids is:

$268.00 - 151.572 = 116.428$, then

$116.428 \div 2.68 = 43.4$ per cent voids

Table 42.—Porosity of Calico Rock Sand

Sample No.	Specific Gravity	Weight of 100 cc.	Porosity (Per Cent of Voids)	Horizon in Formation	Locality
12-J	2.680	151.572	43.4	Below middle......	At Brockwell
13-E	2.613	150.478	42.4	Near top................	On Piney Creek
14-A	2.699	147.595	45.3	Base........................	East of Calico Rock ¼ mile
15-G	2.686	145.716	45.7	Top..........................	West of Calico Rock 3 miles
16-C	2.654	151.388	42.9	Near middle..........	West of Pineville ½ mile
Aver.	2.666	149.350	43.94		

The results of the five determinations are given in Table 42. Both gravity determinations and weighings of samples were checked to insure greater accuracy. The average porosity computed from the results of the five determinations is 43.94, slightly higher than that of the St. Peter sand, which is 42.44 (Table 16, p. 53).

PITTING OF THE GRAINS

Many of the grains of the Calico Rock sand show one or more pits, but the present study seems to indicate that pitting is not so characteristic of the Calico Rock sand as of the St. Peter sand. The pits are found on both frosted and unfrosted grains. They are more numerous on the surfaces of rounded and fairly well rounded grains, but they were seen also on the surfaces of subangular and even angular grains. Pits are rare in grains finer than 100 mesh. In dimensions and shape they resemble very closely the pits developed on the St. Peter sand grains. Not more than two were observed on a single grain. Their origin has doubtless been similar to the origin of the pits observed on the St. Peter grains, which were ascribed primarily to secondary enlargement of the sand grains by the addition of silica. More rarely the origin of the pits is due to solution at a point of contact of two neighboring grains.

**Table 44.—Average Pitting by Mesh Size of Calico Rock Sand Grains*

(Compiled from Table 43)

On Mesh	Pitted		Unpitted		Total No. of Grains
	No. of Grains	Per Cent	No. of Grains	Per Cent	
28	0	0.0	0	0.0	....
35	86	28.7	214	71.3	300
48	77	25.7	223	74.3	300
65	63	21.0	237	79.0	300
100	30	10.0	270	90.0	300
150	7	2.3	293	97.7	300
200	4	1.3	296	98.7	300
Totals	267	14.8	1,533	85.2	1,800

Tables 43 and 44 summarize the results of the study of Calico Rock sand grains with reference to pitting of the grains. As Table 43 indicates, only one grain out of seven on an average is pitted. In Table 44 the results are rearranged, and they emphasize the marked decrease in pitting with increasing fineness of grain, the phenomenon being essentially absent in grains passing 100 mesh. A comparison of Tables 43 and 44 with Tables 18 and 19 emphasizes the much greater prevalence of pitting in the St. Peter sand than in the Calico Rock sand, an average of more than twice as many grains of the St. Peter being pitted than of the Calico Rock.

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*Table 43 on page 136.

Table 43.—Pitting of Calico Rock Sand Grains

Sample No.	Development of Pits	Results of Tests for Each Mesh							Pitted	Unpitted	Total Grains	Location of Sample	
		28	35	48	65	100	150	200				Geographic	Stratigraphic
16-B	Pitted	*	26	26	16	15	5	2	90	....	....	South of postoffice at Iuka, in northwestern Izard County.	Above base of formation 150 feet.
	Unpitted	....	74	74	84	85	95	98	....	510	....		
	Total grains	....	100	100	100	100	100	100	....	....	600		
13-C	Pitted	*	26	21	16	6	2	1	72	....	....	West of Brockwell 7 miles, in west-central Izard County.	Near middle of formation.
	Unpitted	....	74	79	84	94	98	99	....	528	....		
	Total grains	....	100	100	100	100	100	100	....	....	600		
15-F	Pitted	*	34	30	31	9	0	1	105	....	....	On top of river bluff west of Calico Rock, in western Izard County.	Top of formation.
	Unpitted	....	66	70	69	91	100	99	....	495	....		
	Total grains	....	100	100	100	100	100	100	....	....	600		
		Total grains							267	1,533	1,800		
		Percentage							14.8	85.2	100		

*No residue.

SECONDARY ENLARGEMENT OF THE GRAINS

As has been pointed out in the text on the shapes of the grains of the St. Peter sandstone, the deposition of silica by underground water on the surfaces of the grains is a noteworthy feature of the formation in all areas where the sandstone has been studied. The physical similarity of the Calico Rock sandstone to the St. Peter would lead naturally to the study of the sand grains composing the Calico Rock sandstone in order to discover whether secondary enlargement is as characteristic of that formation as of the St. Peter.

Dr. Littlefield and Fanny Edson, after studying samples typical of the Calico Rock sandstone, report that the grains show some degree of crystallization.[7] In some samples the recrystallization is very marked.

Mr. Brewster, of the department of geology of the University of Arkansas, has also made a careful study of the sand grains of samples typical of Calico Rock sandstone with particular reference to the development of crystal faces and terminations on the sand grains. The results of his study are given in Table 45.

As Table 45 indicates, five out of six grains exhibit crystal faces. The manner of development of the crystal faces is in general the same as described for the St. Peter grains. Rhombohedral faces typically terminate the grains, and the prism faces are developed about the central parts of the grains. Both may be present, or only one form may be present. Frequently the central part of the grain is frosted but its ends are terminated with rhombohedral faces. Some grains are completely bounded by crystal faces; other grains are partly bounded, the remaining surface being frosted.

The crystal faces are clean and smooth and free from fractures, chipping, pitting, and frosting. In a few cases the boundary below the subsequently deposited silica forming the crystal face and the original surface of the grain is discernible. In partly frosted grains the boundary between the crystal faces and the frosted surface is sharp, defining abruptly the limit of the surface favorable for deposition.

In general the crystal faces are best seen on grains larger than 100 mesh. An examination of the material passing 200 mesh leads to the conclusion that this material consisted of flakes and minute fragments of larger grains, apparently broken off from the larger grains at the time of deposition

[7] Personal communications.

Table 45.—Development of Crystal Faces on Calico Rock Sand Grains

Sample No.	Development of Crystal Faces	Results of Tests for Each Mesh							Present	Absent	Total Grains	Location of Sample	
		28	35	48	65	100	150	200				Geographic	Stratigraphic
16-B	Present	*	77	75	71	87	88	89	487			South of postoffice at Iuka, in northwestern Izard County.	Above base of formation 150 feet.
	Absent		23	25	29	13	12	11		113			
	Total grains		100	100	100	100	100	100			600		
13-C	Present	*	75	82	82	87	93	78	497			West of Brockwell 7 miles, in west-central Izard County.	Near middle of formation.
	Absent		25	18	18	13	7	22		103			
	Total grains		100	100	100	100	100	100			600		
15-F	Present	*	81	79	81	94	88	83	506			On top of river bluff west of Calico Rock in western Izard County.	Top of formation.
	Absent		19	21	19	6	12	17		94			
	Total grains		100	100	100	100	100	100			600		
		Total grains							1,490	310	1,800		
		Percentages							82.8	17.2	100		

*No residue.

of the sandstone. Secondary enlargement of these grains is not evident. Grains ranging in size from 100 to 200 mesh are in part fragments and in part whole grains. Secondary enlargement of these grains is not so apparent, and crystal faces present are probably in part inherited from the original source of the sand. Crystal faces on grains larger than 100 mesh are to be attributed for the most part to secondary enlargement.

Table 46.—Average Development of Crystal Faces by Mesh Size on Calico Rock Sand Grains

(Compiled from Table 45)

On Mesh	Crystal Faces Present		Crystal Faces Absent		Total No. of Grains
	No. of Grains	Per Cent	No. of Grains	Per Cent	
28	0	....	0	....	....
35	233	77.67	67	22.33	300
48	236	78.67	64	21.33	300
65	234	78.00	66	22.00	300
100	268	89.33	32	10.67	300
150	269	89.67	31	10.33	300
200	250	83.33	50	16.67	300
Totals	1,490	82.78	310	17.22	1,800

The results set forth in Table 45 are rearranged and presented in Table 46 in order to illustrate clearly the relation of the development of crystal faces to grain size. The general results brought out in Table 46 indicates an increase in the proportion of grains on which crystal faces are developed with decreasing size of grain. Three-fourths of the grains larger than 100 mesh have well defined crystal faces, and more than five-sixths of the grains between 100 and 200 mesh show crystal faces. In general it is reasonably clear that grains larger than 100 mesh showing crystal faces have experienced secondary enlargement, since crystal faces, clean and free from abrasion, would scarcely survive transportation by wind or water for any considerable distance. Crystal faces on grains smaller than 100 mesh may be due in some cases to survival, for the small size of the grains results in greater immunity from attrition, but the smooth, even surfaces of the faces and the sharp, clear interfacial angles indicate that secondary enlargement has been an important factor in producing the crystal faces on the surfaces of the smaller grains.

An idea of the relative importance of recrystallization in the St. Peter and Calico Rock sands may be obtained by comparing Tables 20 and 21 with Tables 45 and 46. Of all St. Peter grains studied 70 per cent showed crystal faces as compared with 83 per cent of the Calico Rock sand grains. Of 1,200 Calico Rock grains coarser than 100 mesh, 971 showed distinct crystal faces, while 954 St. Peter grains out of 1,300 coarser than the 100 mesh were found to have well developed crystal faces. It is quite apparent on the whole that, as compared with the St. Peter sand grains, a slightly larger proportion of the Calico Rock sand grains show crystal faces and that secondary enlargement is somewhat more pronounced in this sandstone than in the St. Peter.

FROSTING OF THE GRAINS

Frosting is a conspicuous feature in all representative samples of the Calico Rock sand, but it is restricted almost entirely to the coarser grains, and particularly to grains that are oblong, egg-shaped, spindle-shaped, and lens-shaped. The coarser grains with angular outlines are either not frosted or only partly frosted.

Table 47 shows the results of a study of three samples of Calico Rock sand with especial reference to frosting of the grains. Of 1,800 grains representative of the three samples 278, or 15 per cent, were frosted; 844, or 47 per cent, were partly frosted; and 678, or 38 per cent were unfrosted.

The results given in Table 47 have been rearranged according to size of grain, and the conclusions are compiled in Table 48. Of the 278 grains found to be frosted, 229 are coarser than the 100 mesh. Of this total the proportion of frosted grains on the 35, 48, and 65 mesh is about the same, and the proportion on the 100 mesh decreases to about one-half of the total on any one of the larger meshes. Of the grains passing the 100 mesh, one in six on the average is frosted.

The percentage of partially frosted grains shows a very uniform decrease of about five per cent to the 65 mesh; then it increases to the 100 mesh and remains fairly constant through the smaller meshes. The small size of the grains that find lodgment on the smaller meshes raises the question whether their frosted appearance may not be due in part to etching as a result of solution.

Table 47.—Frosting of Calico Rock Sand Grains

Sample No.	Degree of Frosting	Results of Tests for Each Mesh 28	35	48	65	100	150	200	Frosted	Partly Frosted	Unfrosted	Total Grains	Location of Sample: Geographic	Stratigraphic
16-B	Frosted	*......	24	24	30	12	11	9	110	......	......	......	South of post-office at Iuka, in northwestern Izard County.	Above base of formation 150 feet.
	Partly frosted	......	46	46	36	67	58	56	......	309	......	......		
	Unfrosted	......	30	30	34	21	31	35	......	......	181	......		
	Total grains	......	100	100	100	100	100	100	......	......	......	600		
13-C	Frosted	*......	24	18	17	12	4	8	83	......	......	......	West of Brockwell 7 miles, in west-central Izard County.	Near middle of formation.
	Partly frosted	......	40	37	42	34	42	40	......	235	......	......		
	Unfrosted	......	36	45	41	54	54	52	......	......	282	......		
	Total grains	......	100	100	100	100	100	100	......	......	......	600		
15-F	Frosted	*......	20	22	19	7	12	5	85	......	......	......	On top of river bluff west of Calico Rock, in western Izard County.	Top of formation.
	Partly frosted	......	67	53	44	51	46	39	......	300	......	......		
	Unfrosted	......	13	25	37	42	42	56	......	......	215	......		
	Total grains	......	100	100	100	100	100	100	......	......	......	600		
		Total grains							278	844	678	1,800		
		Percentages							15.44	46.89	37.67	100		

The proportion of unfrosted grains shows a fairly constant increase from 26 per cent on the 35 mesh to 48 per cent on the 200 mesh.

It is apparent from the study of Tables 47 and 48 that frosting affects only a part of the grains of the Calico Rock

Table 48.—Average Frosting by Mesh Size of Calico Rock Sand Grains

(Compiled from Table 47)

On Mesh	Frosted		Partly Frosted		Unfrosted		Total No. of Grains
	No. of Grains	Per Cent	No. of Grains	Per Cent	No. of Grains	Per Cent	
28	0	....	0	....	0	....	....
35	68	22.67	153	51.00	79	26.33	300
48	64	21.33	136	45.33	100	33.34	300
65	66	22.00	122	40.67	112	37.33	300
100	31	10.33	152	50.67	117	39.00	300
150	27	9.00	146	48.67	127	42.33	300
200	22	7.33	135	45.00	143	47.67	300
Total	278	15.44	844	46.89	678	37.67	1,800

sandstone and is largely limited to the surfaces of the larger grains. It is apparent also that frosting is a variable feature in the formation, for sample 16-B, Table 47, has a considerably larger proportion of frosted grains than the other two samples, and in sample 13-C the proportion of frosted and partly frosted grains falls considerably below the percentages indicated for the other two samples. It is impossible to draw conclusions as to what proportion of the grains were originally frosted. The marked secondary enlargement which the grains have experienced since their deposition has masked the surfaces of the grains to such an extent that no certain conclusions can be drawn relative to the prevalence of frosting that once existed in the sandstone. The origin of the frosting is attributed to the action of the wind in shifting the sands about the beach and adjacent upland previous to deposition of the sand in the invading marine waters.

The frosting of the Calico Rock sand may be readily compared with the frosting of the St. Peter sand by consulting Tables 22 and 23 and Tables 47 and 48. In general the Calico Rock has a somewhat higher percentage (about 2 per cent) of frosted grains (Table 47) than the St. Peter sand (Table 22), but the percentage of partly frosted grains is about the same in both formations.

The same grains were used in compiling the data for angularity, pitting, crystal faces, and frosting, so that it is possible to compare the successive tables in which the data are recorded and to draw logical conclusions on the relationships revealed as a result of the comparison. As in the case of the St. Peter, the frosting of the Calico Rock grains shows a fairly definite and constant relationship to angularity, which may be readily observed by comparing Tables 39 and 47. Out of 1,800 grains 250, or 14 per cent, were found to be rounded or fairly well rounded, and 278, or 15 per cent, to be frosted. The proportion of subangular and angular grains, as indicated in Table 39, is 86 per cent, while Table 47 shows that the relative proportion of partly frosted and unfrosted grains is 85 per cent.

SPECIFIC GRAVITY OF THE SAND

In the determination of the specific gravity of the Calico Rock sand the same method was employed as that used for determining the specific gravity of the St. Peter sand. A small water bottle (150 cc.) was used, the stem of which was marked about 1½ inches below the top. The bottle was first weighed empty (A) and then filled with distilled water to the point where the bottom of the meniscus coincided with the marker on the neck of the bottle. The bottle with its water content was then weighed (B). The bottle was next dried and 25 grams of sand introduced. The weight of the bottle and sand was then determined (C). Water was next introduced to the level of the marker on the neck of the bottle. The bottle, water, and sand were then weighed (D). The specific gravity of the sand wes determined by the following formula:

$$\text{Specific gravity} = \frac{C-A}{B+C-A-D}$$

A = weight of bottle
B = weight of bottle and water
C = weight of bottle and sand
D = weight of bottle, sand and water

Five determinations were made, the results of which are given in Table 49.

To test the accuracy of this method of determining gravity a check determination was made with two samples. The results follow:

Sample No.	First Determination	Second Determination	Difference
13-E	2.6070	2.6130	0.0060
16-C	2.6501	2.6540	0.0039

As Table 49 indicates, the highest determination was 2.699 and the lowest 2.613. The average specific gravity of the Calico Rock sand as determined by this method is 2.666,

Table 49.—Weight of Calico Rock Sand

Sample No.	Specific Gravity	Weight of 100 cc.	Weight per cu. ft. (lbs.)	Horizon in Formation	Locality
12-J	2.680	151.572	94.825	Below middle	At Brockwell
13-E	2.613	150.478	94.087	Near top	On Piney Creek
14-A	2.699	147.595	92.291	Base	East of Calico Rock ¼ mile
15-G	2.686	145.716	91.175	Top	West of Calico Rock 3 miles
16-C	2.654	151.388	94.735	Near middle	West of Pineville ½ mile
Av.	2.666	149.350	93.423		

which agrees closely with that of pure quartz, 2.654. The figure 2.666 was taken as representing the average specific gravity of the Calico Rock sand, both in the further laboratory procedure and in the computations into which specific gravity entered as a factor.

WEIGHT OF THE SAND

The weight of five samples of Calico Rock sand was determined in order to obtain a satisfactory index of the weight of the sand of the whole formation. The samples were selected as representative of the sandstone where it is typically developed in a number of different localities. The gravity and porosity of the samples had already been determined (Tables 42 and 49). The computation was based on the formula used in the earlier part of this report devoted to the St. Peter sandstone. The formula is repeated here for convenience in reference:

Wpf. = Wgc$\times$62.513, in which
Wpf. = weight per cubic foot in pounds,
Wgc. = weight per cc. in grams.

The weights of the five samples are given in Table 49, and the average of the weights (93.423 pounds) may be taken as typical of the weight of the sand per cubic foot for the formation as a whole.

REFRACTORINESS

No tests were conducted on the Calico Rock sand to determine its refractoriness. But the high silica content and the exceedingly low content in fluxing compounds (Table 50) indicate that the sand is highly refractory; in fact, it is as refractory as the St. Peter sand, which the Calico Rock sand so closely resembles physically and chemically. The sand is excellently adapted to those uses in which resistance to high temperatures is demanded.

COMPARISON WITH THE ST. PETER SAND

The close physical similarity in grain size and grain shape of the Calico Rock sand to the St. Peter sand is maintained in all other textural features. The Calico Rock sand grains are as fresh and unaltered in appearance and structure as the St. Peter grains. The average porosity of the Calico Rock sand was found to be 43.94 (Table 42) which is but slightly higher than the average result (42.44) obtained for the St. Peter sand (Table 16).

Pitting is undoubtedly of greater prevalence in the St. Peter sand than in the Calico Rock sand, more than twice as many grains on an average of the St. Peter sand being pitted than of the Calico Rock sand grains. In both sands pitting is restricted almost entirely to the coarser sizes, as emphasized in Tables 18 and 19 and 43 and 44. Secondary enlargement is a somewhat more conspicuous feature in the Calico Rock sand than in the St. Peter sand. This generalization is true of the coarser as well as the finer grains of the two sandstones, as is apparent when Tables 20 and 21 are compared with Tables 45 and 46. Frosting is also present on the surfaces of a larger number of Calico Rock than of St. Peter grains. The proportion is only about 2 per cent higher in the Calico Rock sand, and the percentages of partly frosted grains is about the same in both formations. The results of the study are tabulated in Tables 22 and 23 and 47 and 48.

The specific gravity of the Calico Rock sand (2.666) is slightly higher than that of the St. Peter sand (2.649) the difference amounting to 0.017. The results obtained from the individual determinations are given in Tables 25 and 49. The average weight per cubic foot of Calico Rock sand was found to be 93.423 pounds, which compares closely with the average weight of a cubic foot of St. Peter sand, which was found to be 95.296 pounds. The results of the individual determinations and the averages are given in Tables 25 and 49. The similarity in physical and chemical properties indicates that the Calico Rock sand is as highly refractory as the St. Peter sand.

Table 50.—Analyses of Calico Rock, Kings River, and Everton Sands

Sample No.	Ignition Loss	SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	Total	Color	Horizon	Locality
9-E	0.41	98.68	0.24	0.24	0.21	0.00	99.78	Light cream	Near top of formation	North of Sage 2 miles
12-E	0.32	98.91	0.21	0.29	0.04	0.02	99.79	White	Below middle of formation	East of Brockwell ½ mile
13-C	0.11	99.24	0.11	0.23	0.00	0.00	99.69	White	Near middle of formation	On main road halfway between Brockwell and Calico Rock
14-A-B-C	0.42	98.76	0.08	0.20	0.00	0.01	99.47	White	Base, middle and top of formation	East of Calico Rock ¼ mile
15-G	0.09	98.99	0.20	0.28	0.06	0.01	99.63	White	Top of formation	West of Calico Rock 3 miles
16-A-B-C-D-E	0.19	99.39	0.10	0.12	0.02	0.00	99.82	White	Base, middle and top of formation	Iuka-Pineville area. Composite of 5 samples
Average	0.26	99.00	0.16	0.23	0.06	0.0066	99.70			
25-A-B	0.24	99.24	0.11	0.19	0.00	0.00	99.78	White	Near top of formation	Little Clifty Creek southwest of Eureka Springs
30-B	0.32	98.84	0.19	0.05	0.14	0.00	99.54	White	Near bottom of formation	South of Willcockson 2½ miles

Samples 9E, 12E, 13C, 14ABC, 15G, and 16ABCDE are Calico Rock sandstone.
Sample 25AB is Kings River sandstone.
Sample 30B is Everton sandstone.
Samples represent unwashed but selected sand.

CHEMICAL COMPOSITION

Chemical analyses.—The results of six analyses of the Calico Rock sandstone made by Dr. William F. Manglesdorf are given in Table 50. The small amount of organic matter, water of hydration, and carbonates in this sandstone is shown by the ignition loss, which averages only 0.26 per cent with a total of only 1.54 per cent for the six analyses. Three analyses revealed no magnesia, and in the other three magnesia was present in scarcely more than a trace. Two analyses revealed no lime, and only one analysis showed lime in appreciable amount. Both alumina and iron oxide are present in small amounts in every analysis, the alumina slightly exceeding the iron in amount. The alumina is probably present as clay particles between the grains and would largely be eliminated by washing. The iron is probably present in the form of hydrated oxide as flakes between the grains and as coatings on the grains. The average of the silica content for the six analyses (98.995) is remarkably high considering that the samples were collected within a few inches of weathered outcrops of the sandstone. These analyses indicate that this sand is comparable in purity with the highest grade high silica sands in use in the United States.

Table 51.—Comparison of Chemical Characters of St. Peter and Calico Rock Sands

Formation	Averages of Chemical Analyses							
	No. of Anl.	Ig. Loss	SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	Total
St. Peter	18	0.247	99.02	0.166	0.27	0.07	0.002	99.775
Calico Rock	6	0.26	99.00	0.16	0.23	0.06	0.0066	99.70
Differences	....	0.013	0.02	0.006	0.04	0.01	0.0046	0.075

Comparison with the St. Peter sand.—In Table 51 the results of six analyses of Calico Rock sand are compared with the results of 18 analyses of St. Peter sand. While the number of analyses of Calico Rock sand is much smaller than the number of St. Peter analyses, yet the samples were selected as typical of the Calico Rock sand and hence additional analyses would little affect the general averages given in Table 51. From the marked physical similarity of the St. Peter and Calico Rock sands analyses of samples of the two formations should be expected to have closely comparable results. The table emphasizes the chemical similarity of the two sands. The silica, iron and lime content of each of the formations when compared is found to be almost identical. The volatile matter and alumina of the St. Peter average slightly higher than in the Calico Rock sand, and the magnesia is slightly lower in the St. Peter. It is apparent that the marked physical similarity of the St. Peter and Calico Rock sands is also reflected in as marked chemical similarity.

Heavy minerals.—Analyses of the heavy minerals of the Calico Rock sandstone have been made by Dr. Littlefield, and the results are given in Table 28. Zircon, tourmaline, and anatase were found in every analysis, and leucoxene was reported in one analysis. Microcline and orthoclase, usually less than one-eighth millimeter in size, were also present in all samples. Rutile and apatite reported in the St. Peter were not found in the Calico Rock samples. Otherwise the two sands are very similar in their heavy mineral content. The results of the heavy mineral analyses are given in Table 28, along with the results obtained in the study of the St. Peter, Everton, and Kings River, so that a comparison of the heavy mineral content of these sandstones may be readily made. These minerals are almost entirely limited to the fines, that is, to grains small enough to pass a 100-mesh sieve.

CEMENTATION

Friability is a marked lithologic feature of the Calico Rock sandstone and indicates either a lack of sufficient cementing material or the presence of a weak cement. Where the sandstone is brown and iron-stained, as it is on the surfaces of outcrops, the rock is firm and coherent, but the fresh white sandstone is almost invariably incoherent. The presence in quantity of cements that are encountered in studying the cementing materials of sedimentary rocks is not revealed in the analyses. Lime and magnesia are found only in traces, and the low volatile content indicates a remarkable percentage of carbonate. Iron oxide and alumina are found in only very small quantities. None of these is apparently present in sufficient quantity to give the sandstone the degree of coherence it possesses.

The coherence of the sandstone is believed to be most satisfactorily explained by the pronounced secondary enlargement that the majority of the grains exhibit. The development of rhombohedral terminations and prism faces occupying the spaces between the grains remaining after original deposition serves to bind the grains together sufficiently to give the sandstone the small degree of coherence it possesses. This does not preclude the possibility that small amounts of lime, alumina, magnesia, and iron compounds may serve as a cement, but their cementing capacity, owing to their small amounts, is believed to be inferior to secondary enlargement in maintaining the coherence of the sandstone. The angularity of the finer grains, leading to interlocking as a result of long-continued pressure, both horizontal and vertical, may be a factor in effecting the small degree of coherence the sandstone possesses.

USES OF THE SAND

The remarkable physical and chemical similarity of the St. Peter and Calico Rock sands has already been discussed. This similarity is so close as to indicate very definitely that the Calico Rock sand is excellently adapted to the same uses to which the St. Peter sand has long been successfully applied and which have been described in detail in a preceding section. The purity and high silica content of the Calico Rock sand recommends it for utilization in the manufacture of high-grade glass products. The average effective size and uniformity coefficient (Table 35) of the Calico Rock sand adapts it to filtration purposes. Its high silica content recommends the sand for steel molding purposes, for facing and annealing, and for furnace linings, and other uses where high temperatures are encountered. Its purity, toughness, durability and degree of angularity excellently adapt the sand to friction and abrasive purposes. It should find application in the various chemical and metallurgical uses for which high silica sands are successfully employed. The Calico Rock sand can be used with success for various paving purposes, such as in the construction of asphalt, concrete, block and brick pavements and as a grouting sand. The Calico Rock sand is also excellently adapted to building purposes, as plaster sand, mixing of mortar, roofing sand, clay and silica brick and sand-lime brick, and finishing sand. The coarser sizes can be used in the making of concrete. The sand can also be successfully employed in the many minor uses where high silica and very pure sands are needed.

AREAS FAVORABLE FOR DEVELOPMENT

Although the Calico Rock sandstone is a thick formation underlying a large area in Izard and adjacent counties, only

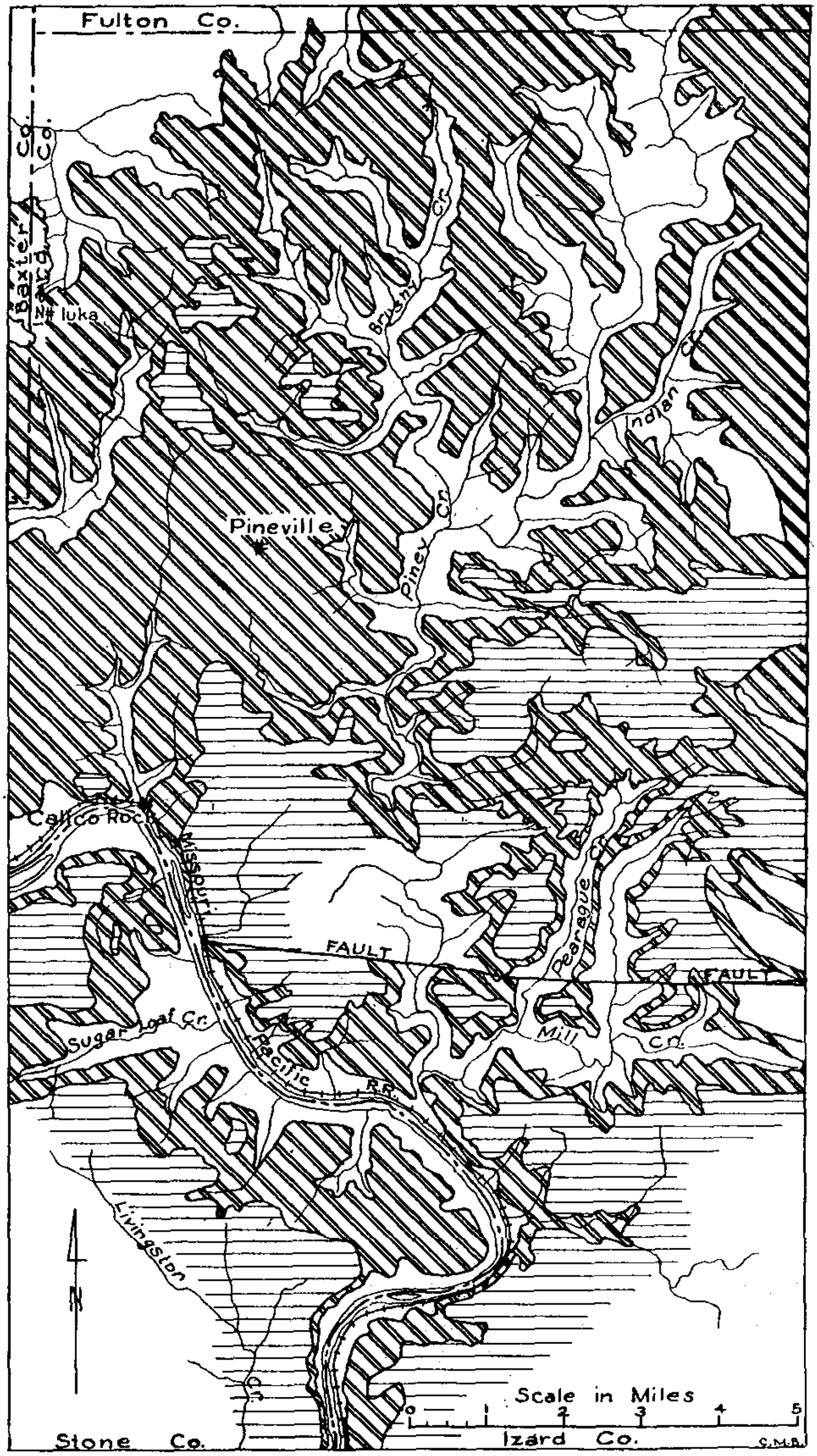

FIGURE 18.—Sketch map showing distribution of Calico Rock sandstone in the vicinity of Calico Rock, in southern Izard and northern Stone counties.

a small area of the formation is available for development at the present time. This area extends along the Missouri Pacific railroad west of Calico Rock for 15 miles and east of Calico Rock for 12 miles (see figs. 18 and 19). Transportation facilities are available, and water is abundant. In this area the formation is thick, ranging frm about 60 to nearly 100 feet. The sandstone is very uniform in quality and texture throughout its thickness and is in every way suitable for

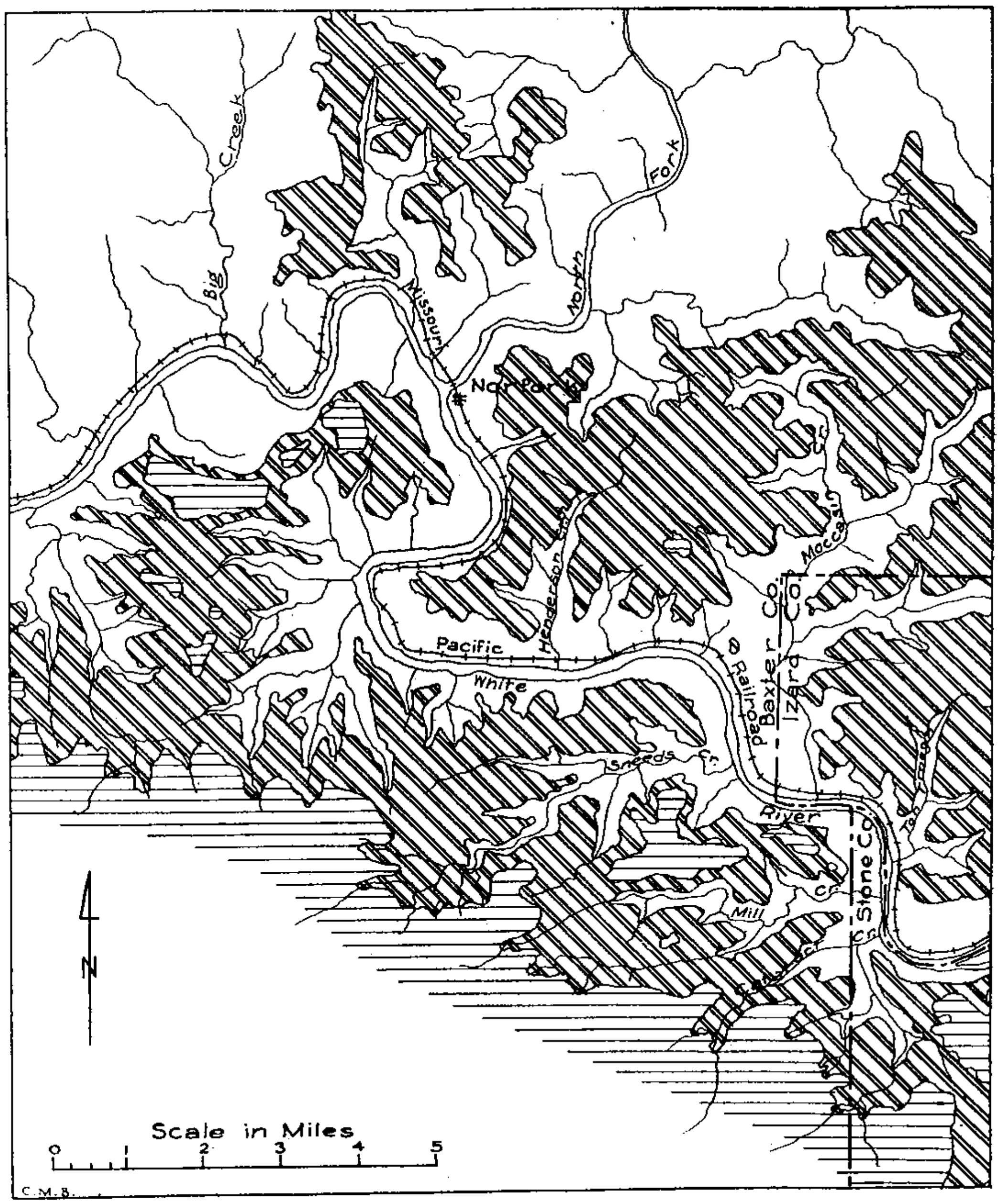

FIGURE 19.—Sketch map showing distribution of Calico Rock sandstone in western Izard and southern Baxter counties.

development. Mechanical analyses are given in Table 35, samples 14-A, 14-B, 14-C, 15-F, and 15-G. Chemical analyses are given in Table 50, samples 14-A-B-C, and 15-G.

The sandstone is extensively developed from Iuka through Pineville to Brockwell, in western Izard County, but this area is so far from transportation facilities that it possesses no immediate promise, although the formation could be reached by spur track to Iuka, where it possesses its greatest thickness. Mechanical analyses of samples collected in this area are given in Table 35, samples 12-E, 12-G, 12-H, 12-J, 13-A, 13-B, 13-C, 13-D, 13-E, 13-F, 13-G, 16-A, 16-B, 16-C, 16-D, and 16-E. Chemical analyses are given in Table 50, samples 12-E, 13-C, and 16-A-B-C-D-E.

The sandstone also underlies a large area south of White River south of Calico Rock. Any development in this area must provide for transportation across the river to the railroad. Mechanical analyses of representative samples are given in Table 35, analyses 15-C, 15-D, and 15-E.

THE KINGS RIVER SANDSTONE

DISTRIBUTION AND CHARACTER

The Kings River sandstone is the oldest of the saccharoidal sandstones of commercial value in the Arkansas Ozark region. It is more widely distributed than the Calico Rock sandstone, but less widely distributed than the St. Peter sandstone. It is persistent over a large area, but it is in most places so thin as to offer little or no possibility of commercial development. It is everywhere remarkably similar physically and chemically to the Calico Rock and St. Peter sandstones. The geologic features, general distribution, physical and chemical properties, and commercial significance of the Kings River sandstone will be briefly considered.

GENERAL GEOLOGY

The geology of the Kings River sandstone in the Eureka Springs-Harrison region, where the sandstone is best developed and best known has already been described.[8] The geological work now in progress (1928) in the Yellville area by the United States Geological Survey and the Arkansas Geological Survey will extend present knowledge of this sandstone over essentially the entire area of its development in northern Arkansas.

Origin of name.—The Kings River sandstone is named for Kings River, which flows northward east of Eureka Springs, draining northeastern Madison County and central and southern Carroll County.

Age.—The Kings River sandstone is a part of the Everton formation and is therefore early middle Ordovician in age.

Regional distribution.—The Kings River sandstone is widely distributed in the central and southern parts of the Eureka Springs region, but in most places it is buried beneath later formations. It outcrops in the valleys of streams which have cut their channels through the overlying cover of later rocks. It is found "at every place in the Eureka Springs quadrangle where this horizon of the formation is exposed. In fact, it is the only part of the formation found along Little

[8] Eureka Springs-Harrison Folio, No. 202, U. S. Geological Survey, 1916.

Clifty Creek and its tributaries, on Big Clifty and Keels creeks, in Williams Hollow, and at many places on Kings River and Rockhouse and Piney creeks."[9]

The sandstone is also widely distributed in the central and southern parts of the Harrison and Yellville regions, and it extends eastward into the area south of Mountain Home in eastern Marion and southern Baxter counties. In the Harrison quadrangle the sandstone is well exposed on Buffalo Fork and on Osage Creek.

Thickness.—The Kings River sandstone is thickest in the area south of Eureka Springs, in southeastern Benton, northern Madison, and southwestern Carroll counties, where its thickness ranges from 2 to 40 feet, averaging about 25 feet. Farther east its thickest outcrops are on Buffalo Fork of White River south of Compton, in northern Newton County, and on Osage Creek, in southeastern Carroll County, where in places it is 4 to 12 feet thick. In many places on these streams, however, it is only 1 to 2 feet thick, a thickness it maintains over much of the Harrison quadrangle. In the Yellville area and farther east the Kings River is likewise thin, so that it differs in no appreciable respect from the saccharoidal layers interbedded with limestone layers overlying the sandstone.

Topographic expression.—The sandstone is sufficiently thick on the streams draining the area south of Eureka Springs to form conspicuous and continuous steep-faced bluffs, which resemble closely the bluffs produced by the Calico Rock and St. Peter sandstones. In this area it weathers into rolling uplands, with here and there crags, turrets, and towers in every way similar to those features resulting from the weathering of the St. Peter and Calico Rock sandstones. Elsewhere the sandstone is so thin that it does not give rise to noticeable topographic features.

Stratigraphic relations.—The stratigraphic relations are indicated in Table 2. Except in the southern part of the Harrison quadrangle and in the adjacent part of the Yellville quadrangle, the basal member of the Everton, the Sneeds limestone, is absent, so that in most places in the Eureka Springs, Harrison, Yellville, and Mountain Home quadrangles the Kings River sandstone is the basal member of the Everton, resting unconformably upon the Powell limestone. It is probable that where the Sneeds limestone is present it is uncon-

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[9] Eureka Springs-Harrison Folio, p. 6.

formable beneath the Kings River sandstone.[10] The sandstone is succeeded upward conformably by the limestone, dolomite, and sandy layers of the upper Everton. While fossils are exceedingly rare in the sandstone, it is interpreted as marine in origin, resulting from deposition in a shallow transgressing sea.

Structural features.—The Kings River sandstone generally occurs in a single massive layer of finely and evenly laminated sandstone. The laminations parallel the bedding, and cross-bedding, typically fine, is developed in many places between the laminations. Both lamination and cross-bedding are conspicuous on surfaces fluted by weathering. Like the St. Peter, the Kings River sandstone has developed conical columns converging downward and resulting from the formation of solution cavities in the underlying limestone into which the sand settled before it had become indurated. These are best seen on steep valley sides, where erosion has exposed the columns.[11] Folding is absent and dips are gentle, one to three degrees, toward the south and south-southeast away from the center of the Ozark dome.

PHYSICAL AND CHEMICAL FEATURES

The Kings River sandstone is described by Purdue and Miser as a white, friable sandstone composed of "clear, well-rounded quartz grains of medium size and with smooth surfaces."[12] The sandstone is composed of nearly pure quartz sand, which in hand specimens is indistinguishable from specimens of the St. Peter and Calico Rock sands. Like these sandstones, the Kings River is very uniform from top to base, although in places at its base the sandstone may contain pebbles of chert, quartzite, and limestone derived from the underlying rocks. Exposures of the sandstone so closely resemble the St. Peter that it is impossible to distinguish the two sandstones by their physical features alone.

In Table 52 the results of representative mechanical analyses of samples selected as typical of the Kings River sandstone are given.

The averages of the mechanical analyses, when compared with the averages of analyses of samples of the St. Peter and Calico Rock sandstones (Tables 5 and 35), very clearly indicate the marked physical similarity of the three sand-

[10] Eureka Springs-Harrison Folio, pp. 6 and 18.
[11] Eureka Springs-Harrison Folio, p. 6.
[12] Eureka Springs-Harrison Folio, p. 6.

Table 52.—Results of Screen Tests of Kings River Sand

Sample No.	Locality	Horizon in Formation	Size of Sample (grams)	PER CENT BY WEIGHT								Fineness Modulus	Effective Size	Uniform. Coef.
				On 28	On 35	On 48	On 65	On 100	On 150	On 200	Total			
25-A	Little Clifty Creek East Benton County	Near top	50	....	9.00	26.60	30.80	29.40	3.24	0.60	99.64	2.31	0.156	1.79
25-B	Little Clifty Creek East Benton County	Near top	50	....	11.50	27.44	28.20	25.20	5.14	0.84	98.32	2.29	0.153	1.93
2	Average		....	....	10.25	27.02	29.50	27.30	4.19	0.72	98.98	2.30	0.155	1.86

stones. A large proportion of the Kings River sand is retained on the 100 mesh. The average fineness modulus of the Kings River sand is identical with that of the Calico Rock sand (2.30) but is somewhat higher than the modulus of the St. Peter which was found to be 2.17. The average effective size is 0.155 as compared with 0.146 for the St. Peter sand and 0.153 for the Calico Rock sand. The average uniformity coefficient of the Kings River sand was determined to be 1.86 as compared with 1.83 for the St. Peter and 1.91 for the Calico Rock sand. Although the averages as computed for the Kings River are based on but two samples, yet they demonstrate when considered with other features already described close similarity of the Kings River sand to the St. Peter and Calico Rock sands.

Chemically the Kings River sand is a quartz sand averaging as high in silica as the St. Peter sand. Analyses of the Kings River sand are given in Table 50, samples 25-A-B. The analysis ran over 99 per cent silica and showed a remarkably low content of iron and alumina and an absence of both lime and magnesia. The analysis compares closely in all respects with the averages obtained in the analyses of St. Peter and Calico Rock sands. It is apparent that chemically the Kings River sand is as free from impurities, as low in lime, alumina, and iron, and as high in silica as either the St. Peter or the Calico Rock sand.

An analysis of the heavy minerals in one sample of Kings River sand was made by Dr. Littlefield, and the sand was found to contain zircon and tourmaline. The results are given in Table 28.

USES OF THE SAND

It is apparent from the preceding discussion that the Kings River sand is remarkably similar in its physical character and chemical composition to the St. Peter and Calico Rock sands. This similarity makes the Kings River sand available for the same uses as those of the St. Peter sand and the Calico Rock sand. It should find successful application for all purposes where a clean, pure, high-silica sand is demanded.

COMMERCIAL POSSIBILITIES OF THE SANDSTONE

The Kings River sandstone has commercial possibilities in the area south, southeast, and southwest of Eureka Springs, in southeastern Benton, northern Madison, and southwestern Carroll counties. In this area its thickness averages 25 feet and reaches a maximum of 40 feet. There are, however, no transportation facilities available in this region. On Osage Creek, in southern Carroll County, and near Compton, in northern Newton County, the sandstone is 10 to 12 feet thick, but railroad transportation is lacking, the distance to the nearest railroad, the Missouri and North Arkansas, being 10 miles or more. In this area, as in that exploited farther west, the St. Peter sandstone is also thick enough to be commercially attractive, so that both sandstones could be developed if transportation facilities were available.

POSSIBLE ECONOMIC VALUE OF THE ST. PETER AND OLDER ORDOVICIAN SANDSTONES IN NORTHERN ARKANSAS

By E. E. Bonewits

ABSTRACT

Detailed knowledge of the distribution, thickness and character of the St. Peter and other high silica sondstones of northern Arkansas permits an estimation of their availability for various commercial purposes. At the present time the principal use to which these sandstones can be put is for the manufacture of glass products. A consideration of the relation between the processes involved in the manufacture of the principal types of commercial glass, the freight rates on raw materials and finished products, and the estimated trade territory available leads to the conclusion that a glass plant in northern Arkansas operated by automatic machine method could profitably make and sell window glass (sheet method) and various types of bottles, jars and jugs.

The St. Peter sandstone of northern Arkansas in addition to being utilized in glass manufacture is also being used for molding, brass, core and steel sand. The present production is ample to supply the market for these sands.

There is no present market for chemical sand in the trade territory served by the northern Arkansas deposits. A future market may create a demand.

SCOPE OF THE REPORT

Information concerning the St. Peter and older sandstones of northern Arkansas has heretofore been meagre, has related only to their availability as a source of silica sand applicable to certain uses and has been restricted to the sandstones in small, scattered areas. The general availability of these sandstones for utilization in preparing materials for various uses could not be determined until a general survey of the whole of these deposits in the State of Arkansas had been made and a detailed report on them had been prepared. This report, which is here presented, has just been completed by Dr. Albert W. Giles. It covers all areas of the St. Peter, Calico Rock, and Kings River sandstones and contains tables showing their features. The sands they yield are compared with those produced from the same formations in Illinois, Missouri, and Oklahoma. The thickness and areal extent of the deposits are shown, as well as their physical features and chemical composition as determined by tests of samples taken at many places. The report shows the cleanness of the sand produced from these sandstones, the size of the sand grains as determined by screen tests and measurements, the soundness and the shapes of the grains, the weight of a given volume of the grains and the number of grains in a given volume, the refractoriness of the grains and their frosting, pitting, and color, as well as the principal uses of the sand.

The report considers the adaptation of these sands to the manufacture of certain products, the plants for which, being located within the State of Arkansas, would have advantages due to their nearness to the raw materials, to the difference in freight rates, nearness to available manufacturing requisites, population and trade served, power and fuel, all of which would give the plants a certain strategy of location.

None of the sandstones described by Dr. Giles has been used commercially except the St. Peter sandstone, which is utilized at Guion, Izard County, by the Silica Products Company, at a plant that has been in operation for several years. Here glass sand, core sand, and molding sand are produced, but by far the larger part of the output is glass sand, most of which is sent to glass plants at Shreveport, La.

GLASS SAND

The economic value of the sandstone deposits of northern Arkansas lies in the fact that they are the source of good glass sand. When the present markets for silica sand available for many uses are considered, it becomes apparent that the deposits may not be utilized for some time, but when the possibility of creating new markets is considered it will be seen that their location gives them a more favorable prospect. The most feasible project for their utilization involves the location of glass plants near the deposits.

The chemical analysis and the size and shape of the grains, when compared with those of glass sand produced in other parts of the United States, show that the sand produced from the St. Peter, Calico Rock, and Kings River sandstones is well suited for use in the manufacture of glass. At some places these sandstones are too hard for economical preparation for this use, but at others they can be easily disintegrated by passing them through rolls.

KINDS OF GLASS MADE

Glasses have been classified according to process of manufacture, commercial use, and chemical composition. The following classification, prepared by Robert Linton[2], shows the kinds of glass now made.

COMMERCIAL CLASSIFICATION OF GLASSES

1. Polished plate. Embraces all glass cast upon a smooth table, rolled to the required thickness with a roller, annealed, and then ground and polished.
2. Rough plate. Embraces all glass cast as above, but not ground and polished. The principal varieties are ribbed plate, colored cathedral, rough plate, wire glass, and heavy rough plate for skylights.
3. Window glass. Embraces glass blown in cylinders and afterward cut, flattened out, and polished while hot. Used chiefly for glazing, pictures, mirrors, etc.
4. Crown glass. Embraces glass blown in spherical form and flattened to disk shape by centrifugal motion of the blow pipe. A little is made for decorative purposes.
5. Green glass. Embraces all the common kinds of glass and is not necessarily green in color. It is used in the manufacture of bottles, carboys, fruit jars, etc.
6. Lime flint. Embraces the finer grades of bottles used for the prescription trade, tumblers, certain lines of pressed table ware, and many novelties.
7. Lead flint. Embraces all the finest products of glass making, such as fine cut glass, table ware, optical glass, artificial gems, etc.

WINDOW GLASS

Cylinder method.—Only a few plants in the United States make window glass by the old hand-blowing method. Most manufacturers now make window glass by machinery. Molten glass is ladled from the rounded nose of a tank furnace into clay pots. Two such pots rest on a reversible mechanism, so that while glass is being drawn from the upper pot the lower one is in a draining position. The normal diameter of the cylinders drawn in this manner is 24 inches.

In drawing glass, a double metal disk having a hole in the center, attached to a hoist, is lowered into the glass in

[2]Linton, Robert, Glass: The Mineral Industry for 1899, vol. 8, New York, 1900.

the pot. The drawing mechanism is then started. The disk is slowly raised, the cylinder of glass following. During the process of drawing, air is blown into the cylinder. All adjustments as to speed of drawing, temperature of glass, pressure of blown air, and atmospheric pressure must be made perfect to insure glass of even thickness.

The usual length of the drawn cylinder is 48 feet. When the cylinder reaches this length its bottom is cut off at the pot by a piece of cold steel. The lower end of the cylinder is then protected by a hoop, and it is then slowly lowered into a wooden cradle.

While it is in the cradle, the glass is cut into desired lengths by the use of an electrically heated wire. After it is cut into lengths, sawdust is distributed on the inside of the cylinder and a heated piece of steel is used to fracture the glass for the entire length of the piece. Next a diamond is used to cut the glass for about one inch in length on the side opposite the fracture. By gently bending the glass downward it is divided into two semicircular sheets.

These half cylinders are then removed to flattening ovens, which have tops of large flat blocks of fire clay, upon which the glass is placed, with the concave side up. The temperature of the oven causes the glass to flatten into a sheet. In order to remove the irregularities of the surface, a wooden block attached to a handle is rubbed over the glass.

After this flattening the top of the oven turns slowly and the glass is removed to the rods of the anealing oven, where it is allowed to cool slowly. After it is annealed it is dipped into a solution of dilute hydrochloric acid. From the acid bath it goes to the cutters, who cut the glass to the desired dimensions and box it for shipment.

Sheet method.—The sheet method of drawing is coming into extensive use in the United States. This method has been used for several years by the Libby Owens Glass Company in their plant at Shreveport, La. The Harding Glass Company of Fort Smith, Ark., installed a similar method in its plant at Fort Smith in 1928.

By this method the glass is drawn from the pots by a series of rollers. Glass slowly comes out of the rolls on to tables, where it is cut into the desired lengths and passed to the annealing ovens, in which it is slowly cooled. By this method much of the work of the cylinder method is dispensed with. Flattening is the most expensive operation in making window glass by the cylinder method, for it is during this operation that most of the breakage occurs. The expense of maintaining flattening ovens and of fuel and additional handling is also saved.

PLATE GLASS

Plate glass is manufactured by two different methods, which produce glass of two different types.

Rolled plate glass.—Rolled plate glass is made by rolling the glass into a sheet on a metal plate with heavy iron rollers. The molten glass is taken from the furnace with an iron ladle and placed on a metal plate. A power-driven heavy iron roller is then passed over the molten glass until it is of the desired thickness. After the glass has cooled sufficiently it is drawn from the iron table to a stone table and is later transferred to the annealing lehr for annealing. After it is annealed it goes to the cutting room, where it is trimmed, sorted, and packed for shipment. Rolled glass is used largely for skylights. The batch for rolled plate glass is fused in a continuous tank furnace.

Polished plate glass.—The batch for polished plate glass is fused in a large open glass pot in a furnace. Extreme care is taken to have the batch perfectly melted and fused. When the molten glass has reached the required fining, the pot is lifted from the furnace and the glass gall is skimmed from the pot. The glass is then poured from the pot on to the casting table and the pot is immediately returned to the furnace to prevent further cooling. A power-driven roller next passes over the glass and presses it to the required thickness, and it is then quickly passed to the annealing lehr which, for making plate glass, is of the continuous type.

After it is annealed the glass is carried to the cutting room and the cullet is trimmed off. From the cutting room the plate is sent to the polishing room, where it is set in plaster of paris. It is then ground, first with coarse sand, then with fine sand, and then with fine emery. After both sides of the plate have been ground it is then removed to the buffing tables, where it is buffed with felt buffers, which, by the use of rouge, give it the final finish. The plate then goes to the cutting room, where it is cut, sorted, and boxed for shipment.

GREEN OR BOTTLE GLASS

Green glass is used for making bottles, carboys, fruit jars, etc. Continuous tank furnaces, because of the economy of their manipulation, are used for fusing bottle glass. Bottles are still both hand blown and machine made. For the hand process a hollow iron rod is used to gather the glass. It is then placed in a mold corresponding to the shape of the bottle and blown until it fills the mold. It is then taken from the mold, broken from the rod, reheated in a small furnace, and its neck fashioned. The bottle then goes to the annealing oven, where it is annealed, and then to the packing room for sorting and packing.

By the machine process the molten glass is drawn into a preliminary form that contains the proper quantity of glass to make a bottle and is then placed in a mold, where the neck of the bottle is shaped. It then goes to a mold in which the body of the bottle is blown by compressed air. The bottles are then annealed, sorted, and packed. In a few plants some of these operations are performed manually.

With the latest type of machines, which are used at many of the plants of the Owens Bottle Company, the material is not touched by man from the time the batch is placed in the furnace until the bottles reach the cold end of the annealing lehr. Some of the larger Owens machines turn out 120 bottles a minute. (Pl. XII, A.)

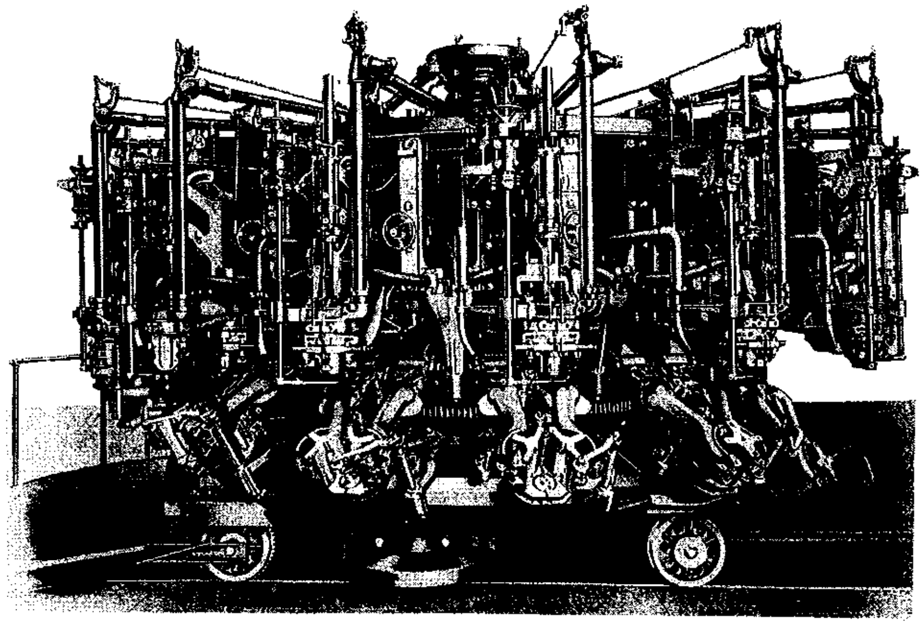
The factors considered in the location of the Owens glass plants are (1) a large supply of good glass sand, (2) a large and ready market for the finished product, (3) a supply of natural gas, (4) a supply of coal from which producer gas may be manufactured, (5) a large supply of petroleum that may be used as fuel.

PROCESSES EMPLOYED IN MAKING GLASS

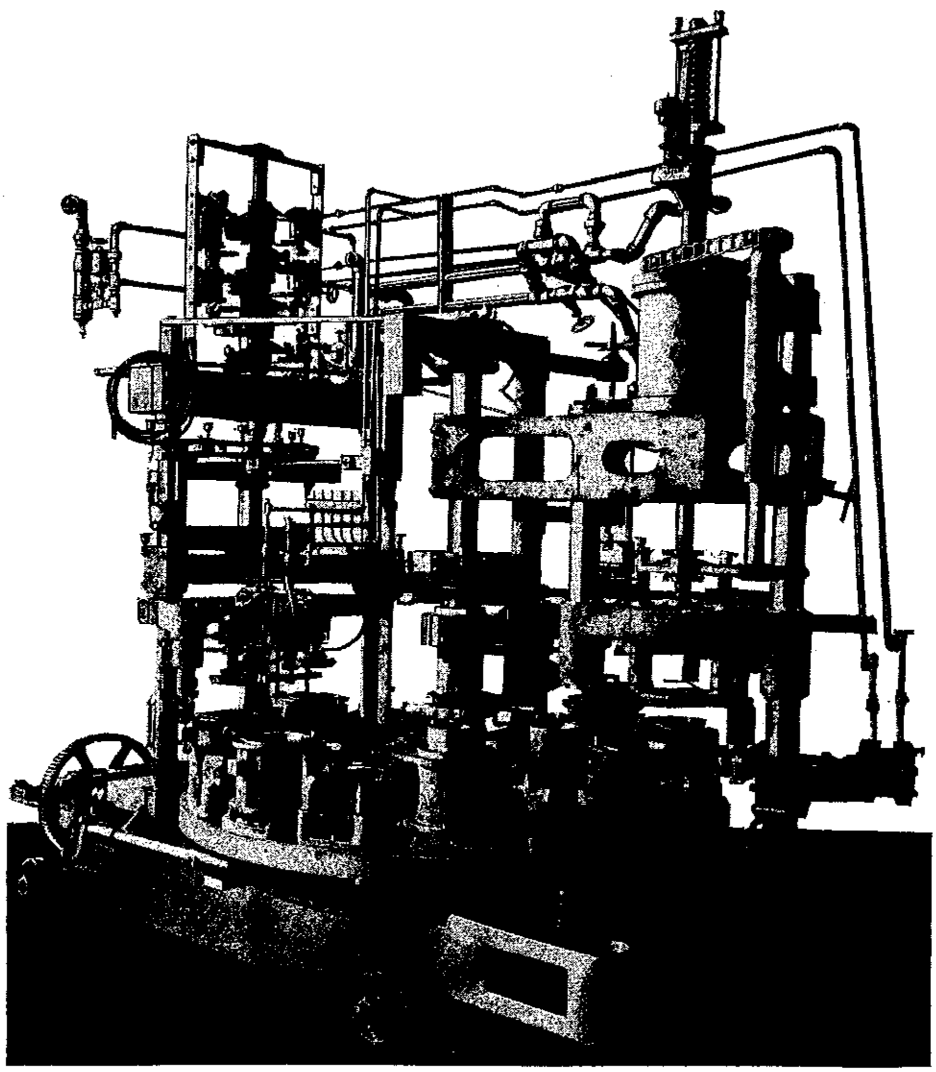
General requirements.—Some of the glasses listed above cannot be economically distributed from Arkansas on account of the distance of the markets, and for this reason the only processes here considered are those used to make glass products that can compete in the present markets.

The raw materials from which glass is made are carefully proportioned by weight, and to them a certain amount of cullet or scrap glass is added. These materials are then thoroughly mixed to form what is called a "batch" before they are placed in the furnace. After the batch is melted in the furnace it may be shaped into any form desired by blowing, by pressing, and by casting.

Some types of glass can be made only in certain types of furnaces, and the kind of glass desired therefore determines



A.—BOTTLE MACHINE USED BY THE OWENS-ILLINOIS GLASS COMPANY, TOLEDO, OHIO



B.—BOTTLE MACHINE MANUFACTURED BY WILLIAM J. MILLER, INC, SWISSVALE, PA.

VIEWS OF TWO TYPES OF BOTTLE-MAKING MACHINES the type of furnace to be used. The two general types of furnaces used are the pot furnace and the tank furnace. Pot furnaces are of two types, open and covered. Tank furnaces are also of two types, continuous tank furnace and intermittent tank furnace.

Continuous tank furnace.—A continuous tank furnace consists of three sections or chambers, the charging chamber, the refining chamber, and the working chamber. The width of an ordinary furnace is five times its depth and the length is three times the width. The floors and the walls of the tank are covered with refractory clay blocks, and the roof consists of an arch of silica brick capable of withstanding a high temperature.

Intermittent tank furnace.—The intermittent tank furnace is constructed much in the same way as the continuous tank furnace. The batch is fed into the charging chamber, which is then closed. After the glass is thoroughly fused and is free from gas bubbles the temperature is allowed to fall until the glass reaches the proper viscosity. The work hole in the nose is then opened and the glass is manufactured. A tank of this type is often called a "day tank," for it is usually charged in the afternoon and the glass is worked on the following day. It is very wasteful of heat and expensive to maintain, because of the daily expansion and contraction.

Open-pot furnace.—The open-pot furnace is rectangular in shape and is used for making plate glass. It is usually built to contain from ten to twenty pots, which are arranged in two rows. Each pot weighs from one to two tons.

Covered-pot furnace.—The covered-pot furnace is similar in shape to the open-pot furnace and is used for making lead glass. The material used in the construction of pot furnaces must be capable of withstanding a temperature of 2,800° F., for temperatures of 2,650° to 2,800° are required for the complete fusion of the batch. The pots for furnaces must be made from clay having a fusion point higher than 3,075° in order to withstand the great heat of the furnace.

FUEL USED IN MAKING GLASS

Natural gas is considered the ideal fuel for the manufacture of glass, and most glass plants are now built near gas fields, particularly the plants in Arkansas, Oklahoma, and Louisiana. The availability of natural gas at a low price evidently determined the location of these plants, the raw materials having been of secondary importance.

The fuel for many glass plants in the United States is producer gas made from soft coal. Some of the plants near gas fields whose supply is waning maintain gas producers to supplement the natural gas.

In locating a glass plant the availability of a supply of natural gas at a reasonable price should be considered first and the availability of soft coal for making producer gas should be considered next.

NATURAL GAS

Pipe lines.—Plate XIII shows the gas-pipe lines in the State of Arkansas. The 22-inch pipe line of the Mississippi River Fuel Corporation from the Monroe field to St. Louis, Mo., now under construction, is also shown. The St. Louis line passes within a short distance of the sandstone areas of northern Arkansas.

The Arkansas Natural Gas Company gathers its supply from the fields in northwestern Louisiana known as the Shreveport area. The supply from this source is supplemented by a line, 96 miles long, constructed from the Clarksville, Ark., field and connecting with the Louisiana line at Little Rock. The two Camden lines take their supply from the Monroe gas field. The St. Louis line will take its supply from the Monroe gas field and will be interconnected with the Richland field southeast of Monroe, La. The Fort Smith area is supplied by a pipe-line system extending into the five producing fields of the area.

Shreveport area.—The Shreveport area obtains its supply of natural gas from several gas fields. Some of the deeper gas-producing sands that have lately been developed in this area add materially to the recoverable reserves and give further assurance of continuity of production. This area has for years served central and southwestern Arkansas, Beaumont (in Texas), and the Shreveport area with natural gas.

Monroe area.—The Monroe gas field, which lies north of Monroe, La., has a proven area of about 400 square miles. It is one of the largest gas fields yet developed. The gas is found in a limestone having a porosity averaging 20 per cent and a thickness of 10 to 100 feet. The rock pressure varies from 1,000 pounds in over half the field to about 300 pounds in a 25-mile area where the withdrawal has been heavy on account of the high gasoline content of the gas.

The present output of the Monroe field comes from the "top sand," which contain a reserve of 2,500,000,000,000 cubic feet of recoverable gas. A second sand lies from 300 to 400 feet below the top sand. A few wells have been drilled into the second sand, and most of them were large producers, one having an open flow of 30,000,000 cubic feet a day.

The Richland field of the Monroe area is only three years old. It contains many producing wells, but its area and its recoverable reserve have not yet been determined. The present development, however, indicates a productivity equal to about half that of the Monroe field.

An analysis of the gas from the Monroe field gave the following results:

	Per Cent
Carbon dioxide	0.3
Oxygen	0.4
Methane	93.4
Ethane	1.0
Hydrogen	4.9
B. T. U. content, per cubic foot.....About	1,000

Smackover area.—The Smackover oil fields lie north of El Dorado. They have yielded gas, which was piped to Camden and El Dorado for domestic and industrial uses. The supply has materially diminished, and the Arkansas Natural Gas Company therefore constructed a line into the Monroe field to augment it. A second line serves El Dorado and Camden with industrial gas from the Monroe field, which is owned by the Industrial Gas Company of Monroe, La.

Fort Smith area.—Five natural gas fields supply the Fort Smith area through the gathering system of the Twin City Pipe Line Company of Fort Smith. Four of these fields are now practically exhausted, but the remaining one is adequate to supply the present domestic and industrial demands for many years. A glass plant at Fort Smith owns a sixth gas field, which lies north of Fort Smith and supplies gas for the plant.

Clarksville area.—The Clarksville field is two years old, and its output is owned by the Arkansas Natural Gas Company, which has constructed an 8-inch line to Little Rock to augment the supply from Louisiana. The initial rock pressure in this field is normal, but that of the fields in the Fort Smith area is subnormal. The promise of the field was sufficient to justify the building of the Little Rock line.

Arkansas Valley area.—The prospect of obtaining gas in the Arkansas River Valley east of the Clarksville area is encouraging. A recent report on that area published by

George C. Branner, State Geologist, has given impetus to prospecting there, and a number of wells are now being drilled. Mr. Branner says: "Geologists have agreed for many years on the gas possibilities of the region." Dr. John C. Branner, State Geologist of Arkansas from 1887 to 1892, stated that "there is no reason for assuming that commercial gas-producing horizons do not extend to the eastern portion of the Arkansas River Valley of Arkansas."

Dr. N. F. Drake, State Geologist of Arkansas from 1912 to 1920, writes: "It is likely that the producing areas may be extended farther eastward, along the northern part of the field, even to the extreme east border of this area." The area referred to is the Arkansas River Valley, which is of interest owing to its short distance from the sandstone deposits of northern Arkansas.

Prices of gas.—The gas companies consider the load and the demand in making a rate for gas for industrial uses. The Arkansas Natural Gas Company makes industrial rates on a sliding scale of 16 to 25 cents per 1,000 cubic feet. It is understood that the Arkansas Power and Light Company will handle the distribution and sale of gas in Arkansas from the line of the Mississippi River Fuel Corporation. A glass plant sufficiently large to justify the construction of a branch pipe line could expect a rate somewhat lower than the industrial rates of the Arkansas Natural Gas Company. The rates to the glass plants at Fort Smith range from 11 to 15 cents and are determined by the demand and the quantity consumed. The average is 12.3 cents per 1,000 cubic feet. The rate at the Shreveport glass plants is about three-fourths that at the Fort Smith plants. Probably a rate can be given for a glass plant taking its supply from the St. Louis line that will be at least equal to the rate in effect at the Fort Smith plants.

COAL

Character of the coal.—The coal area of Arkansas extends from Russellville to Fort Smith, in the western part of the State. The coal increases in hardness from the west line of Arkansas eastward. The coal in the western part of the State is bituminous but it grades into semi-bituminous to semi-anthracite in the eastern part.

A satisfactory producer-gas coal should contain but little sulphur. Of the coals listed above the Denning, Jenny Lind, Bonanza, Huntington, and Hartford are suitable for the manufacture of producers gas. These are soft coals having a ratio of fixed carbon to volatile combustible matter of less than five.

Representative Analyses of Arkansas Coals

[U. S. Geological Survey]

	Russellville	Paris	Hartford	Jenny Lind
Moisture	2.07	2.41	2.89	1.60
Volatile matter	9.81	17.23	19.29	17.40
Fixed carbon	78.82	70.35	67.34	73.09
Ash	9.30	10.01	10.48	7.91
Sulphur	1.74	3.21	1.10	1.42
B. T. U.	13,702	13,523	13,271	14,162
	Huntington	Bonanza	Spadra	Denning
Moisture	3.53	1.99	3.12	3.64
Volatile matter	16.66	15.90	11.39	15.32
Fixed carbon	72.04	75.05	77.03	73.88
Ash	7.77	7.06	8.46	7.16
Sulphur	1.29	1.05	1.86	2.43
B. T. U.	14,017	14,087	13,793	13,743

Prices of coal.—Bituminous coal can be purchased at the mines at an average price of $4.50 per ton. This is the price of chestnut coal (5/8 to 1 1/8 inch), a size suitable for use in gas producers. The freight rates range from $1.58 to $2.52 per ton to rail points in and near the sandstone area, making the cost of the coal from $6.08 to $7.02. Mine-run coal is a dollar a ton cheaper.

OIL

A few glass plants in the United States use fuel oil, which has been used in Pennsylvania with reasonably good results.

There are eight producing oil fields in southern Arkansas. The first oil well was brought in in 1921. The annual production since then has been as folows:

	Barrels
1921	10,473,000
1922	12,712,000
1923	36,610,000
1924	46,028,000
1925	77,398,000
1926	59,229,000
1927	40,005,000
1928	32,295,000

Fuel oil of 18 to 22 gravity can be purchased in the sandstone area at from $1.20 to $1.30 a barrel.

RAW MATERIALS USED IN MAKING GLASS

Glass sand.—Quartz sand is the most essential constituent of glass. All glasses contain silica, which can be replaced by other acid oxides, such as are used in optical glass, only in small percentages.

Dr. Giles gives a number of analyses of glass sand in his report on the sandstone deposits of northern Arkansas, which, as he shows, yield good glass sand. The St. Peter sandstone is utilized at Guion, where the glass sand it yields has been used for several years in glass plants at Shreveport, La., and other places.

An ideal glass sand should consist of subangular to angular grains of pure white quartz of the same size (medium or fine), consisting of 100 per cent of silica. Dr. Giles shows by photomicrographs that the sand grains are of various shapes and are only partly rounded.

From 60 to 75 per cent of the materials that make up a batch prepared for fusing consists of glass sand. It therefore follows that, after assurance of a supply of natural gas at reasonable prices and of ready access to available markets, a glass plant should be placed as near as possible to a supply of glass sand.

Soda.—The second item of importance in weight, and the costliest among the materials that make up the glass batch, is a heavy chemical—soda. In the manufacturing processes described, soda is added to the batch of glass in the form of salt cake (sodium sulphate) or soda ash (sodium carbonate). From 15 to 23 per cent of the batch consists of one or both of these materials. In locating a glass plant the supply of these materials should be considered next to that of glass sand.

The source of supply of salt cake that lies nearest to the glass sand area in Arkansas is North Little Rock. Salt cake is produced also at East St. Louis, Ill. The nearest source of soda ash is Detroit, Mich.

Lime.—Next to sand and soda, lime is the largest constituent of glass. Lime is added to the batch either as crushed limestone, quicklime, or slacked lime. Crushed limestone is most commonly used. Limestone suitable for this purpose may be had at many places in the glass-sand area. A high calcium lime and limestone can be obtained near Batesville. From 10 to 15 per cent of the batch consists of limestone.

If the process used requires a magnesian lime or limestone a suitable supply can probably be found in the dolomite and magnesian limestone deposits of northern Arkansas. Analyses show that samples taken from these deposits contain much iron, but the analyses made cover only a small part of the deposits. The magnesian limestones along the St. Louis and San Francisco railroad between Black Rock and Mammoth Spring seem to be the best available. They contain silica in small quantities, but as it is distributed through the stone as sand it is not an objectionable impurity.

Lead.—Litharge, or red lead, which is used in making lead-flint glass, can be obtained in the Joplin, Mo., lead and zinc district and at East St. Louis, Ill.

ADVANTAGES IN ARKANSAS IN RAW MATERIALS AND FUEL

A window-glass factory located at a point in northern Arkansas sufficiently close to its supply of glass sand to insure a freight rate of not more than 50 cents a ton, assuming that the glass batch would be the same as that used in the plant at Shreveport, La., would have an advantage of about 45 cents per ton of glass in the cost of glass sand, salt cake, and limestone.

The glass plant at Shreveport can obtain imported salt cake, delivered at the plant, for about $16.60 per ton, which is cheap in view of the fact that domestic salt cake in northern Arkansas costs from $20.00 to $20.50 per ton at the plant. If the cullet, or scrap glass, is regarded as part of the batch, salt cake will form about 20 per cent of the weight of the batch. The Shreveport plant therefore has an advantage of from 78 to 88 cents per ton of glass. A plant in northern Arkansas would have to offset this advantage by differences in the cost of glass sand and limestone. A plant in northern Arkansas will have an advantage in the cost of these two materials of $1.23 to $1.33 per ton of manufactured glass, leaving a net advantage in the cost of the three principal materials of 45 cents.

As the price of the gas supplied to the Shreveport plant is only about three-fourths the price that may be obtained by a plant in northern Arkansas, the plant at Shreveport has an advantage in the cost of fuel. A difference of 1 cent per thousand cubic feet would make a difference of about 25 cents per ton of glass produced. Assuming that the difference in rate would be 4 cents per thousand feet the Shreveport plant has an advantage in cost of fuel amounting to $1.00 per ton of glass. The deduction from this sum of the advantage of 45 cents gained by the north Arkansas plant in materials leaves an advantage of 55 cents per ton of manufactured glass in favor of the Shreveport plant.

It has already been stated that some of the deeper producing gas sands that have recently been developed have added materially to the recoverable reserves of the Shreveport area, yet the Henry L. Doherty interests, which own the Arkansas Natural Gas Company, have just announced the construction of a 100-mile 20-inch gas pipe line from the Monroe field to Shreveport. The industrial rates in the Shreveport area will therefore probably be increased about 2 cents per thousand cubic feet at the expiration of the present contracts. This increase in the cost of gas at the Shreveport plant will wipe out all but 5 cents of its advantage in the cost of fuel.

TABLE 54.—*Window-glass Factories in Arkansas, Indiana, Kansas, Louisiana, Oklahoma, and Texas*

State and Company	Location	Facilities
ARKANSAS		
Harding Glass Co.	Fort Smith	6 Fourcault machines. 4 Harding machines.
INDIANA		
Blackford Window Glass Co.	Vincennes	8 Fourcault machines.
KANSAS		
Loriaux Glass Co.	Fredonia	4 machines.
National Sash & Door Co.	Independence	4 sheet machines.
LOUISIANA		
Libbey-Owens Sheet Glass Co.	Shreveport	7 Libbey-Owens machines.
OKLAHOMA		
Baker Bros. Glass Co.	Sapulpa	30 pots.
Victory Window Glass Co.	Sapulpa No. 1	4 machines.
Victory Window Glass Co.	Sapulpa No. 2	Baker Bros. flat glass.
Pittsburg Plate Glass Co.	Henryetta	Under construction, 4 machines.
TEXAS		
Wichita Falls Window Glass Co.	Wichita Falls	6 machines.

The higher the silica content of the glass the more fuel is required to fuse the batch. A glass plant in a locality where gas is cheap and at a considerable distance from its supply of raw materials may choose a glass batch mixture involving the use, within certain limits, of larger quantities of cheap material and smaller quantities of costly material. Such manipulation of the mixture always involves a variation in the kind of glass produced and a greater expense for fuel. As the fuel is proportionately cheaper than the materials forming the batch, the cost of the glass may be thus reduced, but the glass must be kept within the limits of the trade tolerance for the particular kind of glass manufactured.

By judiciously proportioning the glass batch material a glass plant in northern Arkansas may save 10 cents per ton on glass. This saving will consist largely of reductions in the cost of the coal used for the decomposition of the sulphates in the batch and in the cost of other material used, such as manganese and white arsenic, but the greater part of it will be made by the use of more of the cheaper materials and less of the costlier materials that form the batch.

This saving of 10 cents will absorb the 5 cent advantage of the Shreveport plant in the cost of fuel and will leave a net advantage of 5 cents in favor of the Arkansas plant.

A study of the cost of materials used in glass plants in Oklahoma shows that a plant in Arkansas will have a minimum advantage over these plants of $1.10 per ton of glass and a maximum advantage of $1.80. Some of the plants in Oklahoma, however, have an average advantage of 2 cents per thousand cubic feet in the cost of gas, which cuts the advantage of an Arkansas plant in cost of materials and fuel to 60 cents per ton of glass. This advantage offsets the difference in the freight on shipments of glass westward from Arkansas to a line drawn through Sapulpa, Okla., and Kansas City, Mo. The plants at Wichita Falls, Texas, compete with those in Oklahoma.

TRADE TERRITORY

Figure 20, a map of the central United States, shows the location of glass factories in seventeen States and the kinds of glass made.

Table 53 shows the bottle and hollow-ware factories in nine of the seventeen States. The other eight States have no such factories.

Table 54 shows the window-glass factories in six of the seventeen States. The remaining eleven States have no window-glass factories.

Table 55 shows the polished plate-glass factories, which are confined to three of the seventeen States.

Table 56 shows the fire, ribbed, figured, opalescent, rough and polished glass factories, which are confined to five States.

Table 57 shows the pressed and blown ware factories, which are confined to five states. The manufacture of this ware would not be profitable in Arkansas. Two of the plants at Fort Smith, Ark., manufacture these products.

The advantages and disadvantages that a glass plant in northern Arkansas will have in the cost of raw materials and fuel have been shown. As power respresents only 1 per cent or less of the cost of glass, no comparison of the cost of power has been made. Electric power is available from the transmission lines of the Arkansas Power and Light Company.

Figure 21 shows the location of all the window-glass plants in the seventeen States that occupy the central part of the United States. This map shows the trade territory to be divided between the plants in northern Arkansas and the existing plants. The territory in which the Arkansas plants will have a distinct advantage is limited on the north and east by the window-glass plant in southern Indiana. In the cost of material and fuel there is enough difference in favor of the Arkansas plant to enable it to absorb five-sevenths of the freight to Vincennes, which moves the limits of the territory in which the Arkansas plant has an exclusive advantage to within two-sevenths of the distance to Vincennes.

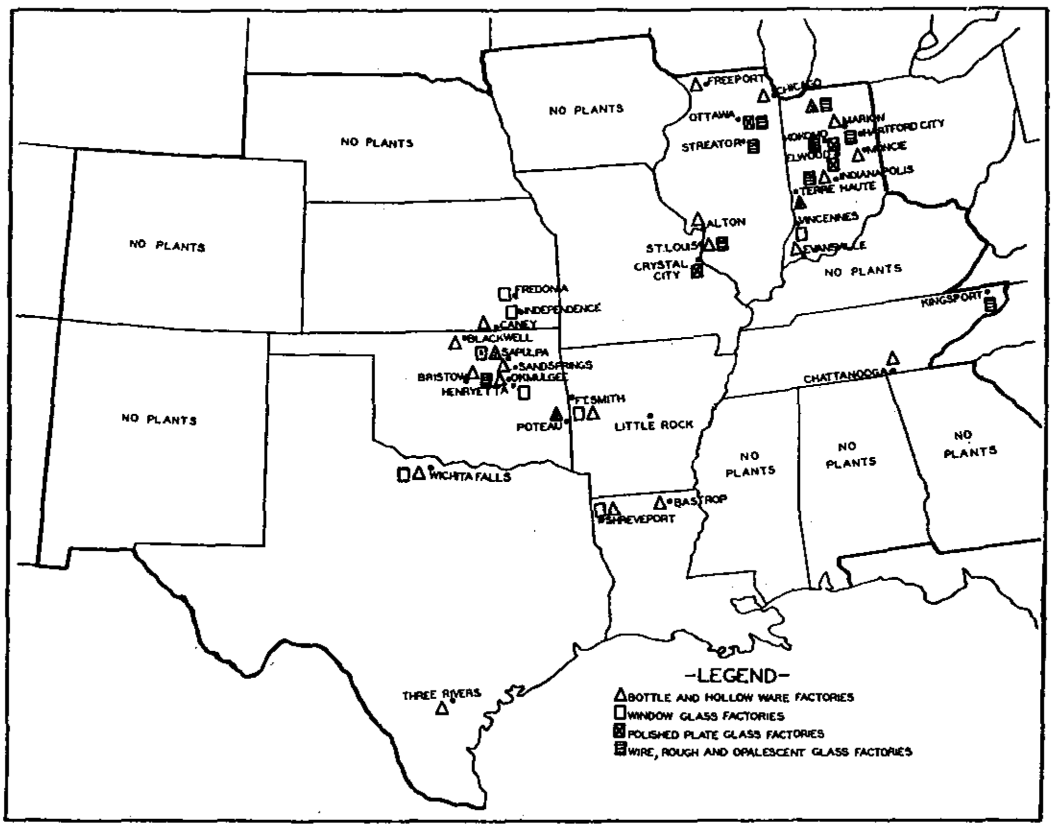


FIGURE 20.—Map showing location of glass factories in central United States in 1929.

The eastern limits of the territory are influenced by the plants in Ohio and West Virginia. The line marking this limit passes through Chattanooga and runs just east of the Alabama-Georgia State line. The western boundary of the territory is fixed by the plants in Kansas and Oklahoma. The southern boundary is fixed by the plants in Shreveport, La., and the area that can be reached by imported glass.

The advantages that a plant in northern Arkansas will have in raw material and fuel is sufficient to offset the difference in freight on western shipments from the plant to a line passing through Sapulpa and Kansas City and to give the plant in Arkansas an even chance with the plants in Oklahoma and Kansas. The freight for a long haul on glass mov-

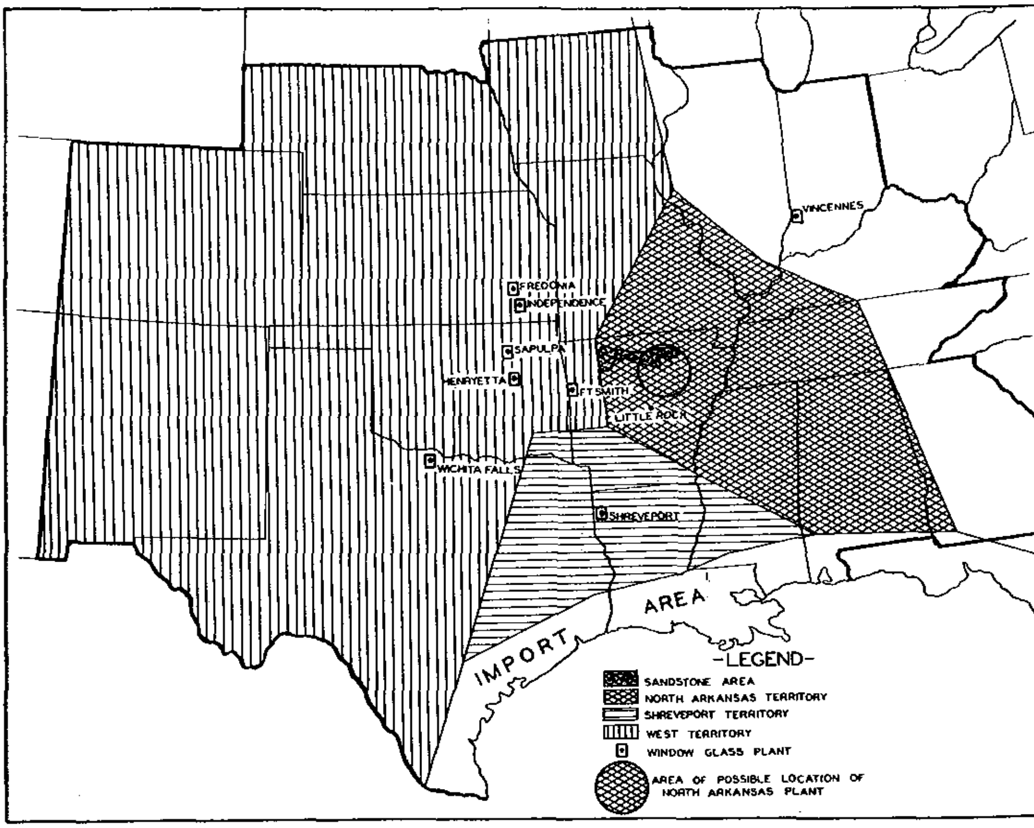


FIGURE 21.—Map of the Central States showing division of trade territory between the present window glass plants and one in northern Arkansas.

ing westward is less per ton-mile than the freight for a short haul, and the western limit of advantage on shipments from northern Arkansas to points in western Arkansas may be drawn at a line 25 miles east of the plant at Fort Smith.

TABLE 55.—*Polished Plate Glass Factories in Illinois, Indiana, and Missouri*

National Plate Glass Co.	Ottawa, Illinois
Pittsburg Plate Glass Co.	Kokomo, Indiana
Pittsburg Plate Glass Co.	Ellwood, Indiana
Pittsburg Plate Glass Co.	Crystal City, Missouri

The plants in the area around Shreveport, La., have a distinct advantage. A plant in northern Arkansas, by using rail-barge transportation and moving the finished product to the Mississippi River through the Helena or Memphis gateway and then to Baton Rouge for distribution, may be able to compete in the Shreveport territory because of the saving

TABLE 56.—*Factories in Indiana, Illinois, Missouri, Oklahoma, and Tennessee making Wire, Opalescent, Figured, Rough, and Ribbed Glass*

State and Company	Location	Product
INDIANA		
Highland-Western Glass Co.	Shirley	Rough, ribbed, figured, wire prism, polished wire and cathedral glass.
Johnson Glass Co.	Hartford City	Ground, chipped and etched glass; bent, ovals, circle and beveled glass, and non-scattering auto glass.
Kokomo Opalescent Glass Co.	Kokomo	Opalescent, cathedral and sign glass.
Wells Glass Co.	Kokomo	Opalescent, cathedral and figured glass.
Marietta Mfg. Co.	Indianapolis	Onyx table and counter tops, scale plates, bathroom shelves, wainscoting, floors and ceilings.
ILLINOIS		
Highland-Western Glass Co.	Streator	Rough, ribbed, figured, wire and cathedral glass.
Peltier Glass Co.	Ottawa	Opalescent glass.
MISSOURI		
Mississippi Glass Co.	St. Louis	Rough, ribbed and figured wire glass and polished wire glass.
OKLAHOMA		
Southwestern Sheet Glass Co.	Okmulgee	Rolled, ribbed, figured and wire glass, rough and polished.
TENNESSEE		
Blue Ridge Glass Co.	Kingsport	Rough, ribbed and figured wire glass and polished wire glass.

in freight made by the use of the Mississippi barge line. It may be able to compete in the Shreveport territory in eastern Texas, but a large share of the freight will have to be absorbed in this competition.

Comparisons of the cost of materials for making window glass have already been presented, and similar comparisons of the cost of making bottle and hollow ware from soda-lime glass may be made. Figure 22 shows the trade territory that may be divided between the existing bottle and hollow-ware plants and one established in northern Arkansas. The area of distinct advantage to such a plant in Arkansas is somewhat less than that for a window glass plant, on account of competition by plants in Illinois, Tennessee, and southern Texas. The plants of northern Illinois remove from competition the plants in Iowa and the Three River plant in Texas, and they remove southern Texas from competition in the western territory, in which the Arkansas plant will have an equal opportunity with the plants in Kansas and Oklahoma.

Jobbers and purchasers of bottle and hollow ware in Arkansas report that practically all the plants shown on Figure 22 except the Three River plant, in Texas, sell their product within the State.

Many kinds of ware are made at bottle and hollow ware plants, but those that seem to have the best opportunity for competitive distribution are soda-water bottles, fruit jars, and condiment containers. The people of the South consume large quantities of bottled soft drinks, and there appears to be pportunity for a plant making soda-water bottles.

The demand throughout the United States for beer bottles has increased greatly during the last few years.

The South has recently made great strides in orcharding and vineyarding, and several plants have been established for packing fruits, preserves, and juices. The ware made for this purpose is not re-used by the packers, as are the bottles made for soft drinks, and the annual demand for this ware increases with the increase in consumption.

There are several vinegar plants in the territory to be served, as well as canneries that make catsup. The manufacture of bottles for this trade should be profitable.

The division of trade territory for wire, opalescent, cathedral, rough and polished, ribbed and figured glass, and glass tile plants is practically the same as that for window glass. A plant that manufactures most of these kinds of glass is in operation in St. Louis, but the cost of manufacture in Arkansas would be so much less that a plant in Arkansas could

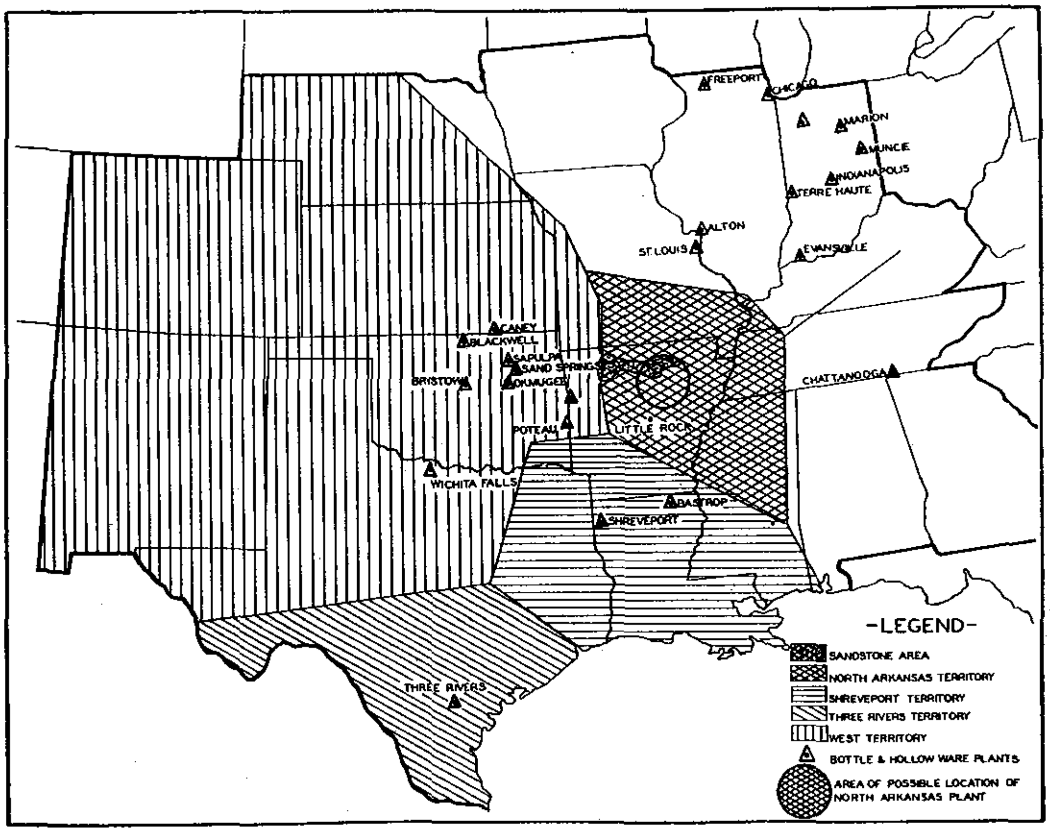


FIGURE 22.—Map of the Central States showing division of trade territory between present bottle and hollow-ware plants and one in northern Arkansas.

sell in St. Louis as cheaply as the plant in St. Louis. These products can also be made as cheaply in Arkansas as in Okmulgee, Okla., and a plant in Arkansas would therefore have an equal opportunity with the plant in Oklahoma. The market could be extended southward to include the Shreveport area. The disadvantage of a plant making these products is that the consumption in the territory to be served is small compared with that in Illinois, Indiana, and Ohio.

The plate-glass industry is controlled by a few manufacturers, who also control the distribution of the product. For this reason it is not believed a factory making polished plate glass would be successful in Arkansas.

Manufacturers of mirrors use large quantities of single, double, and triple thick window glass and polished plate glass. The factories making mirrors in the seventeen States considered are shown in the table below.

Manufacturers of Mirrors in Arkansas, Missouri, Illinois, Tennessee, Louisiana, Kansas, Oklahoma, and Texas

Anderson & Co., Geo. H.	Chicago, Illinois
Binswanger & Co	Memphis, Tennessee
Binswanger & Co	Houston, Texas
Burroughs Glass Co	St. Louis, Missouri
Chicago Mirror & Art Glass Co	Chicago, Illinois
Crystal Mirror & Glass Co	St. Louis, Missouri
Federal Glass & Paint Co	Dallas, Texas
Karl Hansen Co	New Orleans, Louisiana
Hubbuch Glass Co	Chattanooga, Tennessee
Indianapolis Glass Co	Indianapolis, Indiana
Johnson Glass Co	Hartford City, Indiana
Kahn Mirror Plate Co	St. Louis, Missouri
Kellman Glass & Mirror Co	Chicago, Illinois
Kokomo Automotive Manufacturing Co	Kokomo, Indiana
National Mirror Works	Rockford, Illinois
Nurre Companies, The	Bloomington, Indiana
Nurre Companies, The	St. Louis, Missouri
Nurre Companies, The	Kansas City, Missouri
Nurre Companies, The	Memphis, Tennessee
Porter Mirror & Glass Co	Fort Smith, Arkansas
Porter Mirror & Glass Co	Shelbyville, Indiana
Simonel Mirror Plate Co	Evansville, Indiana
Southwestern Glass & Paint Co	Abilene, Texas
Southwestern Glass & Paint Co	Wichita Falls, Texas
United Plates & Window Glass Co	Oklahoma City, Oklahoma
Walsh-Coffey Mirror Co	St. Louis, Missouri

CONCLUSIONS

The results of the study made indicate that a glass plant in northern Arkansas operated by automatic machine methods could successfully make and sell window glass (sheet method) and bottles for soda water, beer, prescriptions, condiments, and preserves, as well as fruit jars, glass jugs and jars.

MOLDING AND SIMILAR SAND

CHARACTER AND PRODUCTION

Molding sand is of several kinds, the kind used depending upon the size and the shape of the casting, the smoothness desired, and the temperature of the molten metal.

The term "molding sand" is generally applied to sand and bonding material used to form a mold for gray iron casting. Molding sand for casting brass, bronze, and aluminum is generally termed "brass sand."

Specifications for molding sand may be obtained from the American Foundry Association, 222 Adams Street, Chicago, Ill., which has adopted tentative standards.

Molding sand has been produced at Guion, Ark., for several years and has been used with good results by foundries in Arkansas and adjacent States. Its permeability is slightly less than that of standard Albany (N. Y.) sand. The grade produced at Guion can be varied between number 3 and number 4, A. F. A. standards, and has a clay content of 15 to 25 per cent. One foundry that uses large quantities of Guion sand obtains some molding sand from Columbus, Ohio, for facing. The operators report that the Guion sand is not so "open" as the Columbus sand and that for large castings the molds are vented, but that they obtain very satisfactory results.

Dr. Giles's report indicates that molding sand of all classes may be produced from the St. Peter and Ordovician sandstones of northern Arkansas.

The sand plant at Guion also produces core sand, which has been successfully used by foundries. One foundry superintendent, who has had large experience in different parts of the United States, reports that it is as good as any core sand he ever used. Artificial binder is employed.

The sand from the St. Peter sandstone consists of almost pure silica. It is extremely refractory and is therefore well adapted for casting steel. It contains very little iron, calcium, and magnesia. The plant at Guion supplies the steel-casting foundries of the adjacent region with sand. Sand produced from the St. Peter sandstone in the vicinity of St. Louis, Mo., and Ottawa, Ill., are extensively used for casting steel.

MARKETS

The plant of the Silica Products Company at Guion, Ark., has ample capacity to supply molding, brass, core, and steel sand to the foundries that constitute its present market, and therefore there are no present inducements for the further utilization of the St. Peter and Ordovician sandstones of northern Arkansas for these products.

The iron deposits of northeastern Texas will probably be utilized in a few years. Recent experiments in making sponge-iron by the use of Arkansas semi-anthracite coal as a reducing agent have been successful. Two large power plants that use powdered lignite for fuel, recently built in the lignite area of east-central Texas, point the way to the production of cheap electric power in the iron ore area. Large deposits of lignite are available for this purpose within the iron-ore area in Cass, Marion, Morris, and Upshur counties. Recent tests have also shown that the lignite is suitable for use as fuel in the new regenerative sponge-iron furnace.

The development of the sponge-iron industry in northeastern Texas will be followed by the development of an iron and steel manufacturing industry, which will be a large user of gray iron and steel casting sands. The sandstone deposit in central-south Oklahoma is nearer the northeast Texas iron ore area than the sandstone deposits of northern Arkansas. The nearest source of sand to the iron ore area is at Roff, Oklahoma.

Shipments of sand to iron or steel foundries in northeastern Texas would involve interstate movements. Shipments of Oklahoma sand would move over railroads competing with railroads hauling Arkansas sand. A rate based on mileage would obviously discriminate against the Arkansas sand, and it therefore might be expected that the Interstate Commerce Commission would provide a rate from Arkansas that would enable competition with Oklahoma.

CHEMICAL SAND

With the possible future development of a paper box industry in connection with a paper mill making pasteboard and strawboard from rice straw, there will probably be built in the South a plant for the production of sodium silicate.

Sodium silicate has many uses but is employed principally as a constituent of soap and as an adhesive and sizing in paper and straw board made for containers. About 85 per cent of the output in the United States is used for these purposes. An available supply of salt cake and soda ash must be considered in determining the location of a plant for the production of sodium silicate in addition to the location of relatively pure silica sand deposits such as are abundant in northern Arkansas.

Sodium silicate is made in several grades. The constituents of a batch for four grades to be made in reverberatory furnaces are indicated below. The figures given represent parts.

	1	2	3	4
Silica	150	100	100	100
Salt cake	80	68	60	50
Soda ash	20	32	30	16
Coke	3	3	3	3

Sand of sufficient purity for this purpose can be produced from the St. Peter and Ordovician sandstones of northern Arkansas, and sodium silicate produced in Arkansas or Louisiana will increase the market for the sand.

SAND FOR OTHER USES

Silica sand is employed for more than two hundred purposes. For many of these purposes the common sand of stream beds, bars, and banks can be used, and with such sand the silica sand prepared from sandstone deposits cannot compete. Silica sand is used in many factories, most of which are north of Arkansas and east of the Mississippi River, far from the sandstone deposits of Arkansas.

The sandstone deposits of Arkansas can be used at present only for producing glass sand and sand for use in foundries, and no attempt to exploit them for other uses would be justified until industries that employ sand for those uses are established within distances of the Arkansas deposits that will permit the sand to compete with that obtained in other regions.

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