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GEOLOGY AND GLASS SAND RESOURCES, CENTRAL ARBUCKLE MOUNTAINS, OKLAHOMA

by

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GEOLOGY AND GLASS SAND RESOURCES, CENTRAL ARBUCKLE MOUNTAINS, OKLAHOMA

by

WILLIAM E. HAM

ABSTRACT

Deposits of high grade glass sand in the central part of the Arbuckle Mountain region of south-central Oklahoma have been worked since 1913 and have accounted for virtually all high silica sand produced in the State. At present there are 3 plants, one each near Sulphur, Roff, and Mill Creek, and a fourth is under construction at Hickory. The district in 1944 produced an estimated 130,000 tons of sand with a value of about $235,000, nearly all of which was shipped to glass plants in Oklahoma and Texas.

The worked deposits are in the sandstone members of the McLish and Oil Creek formations of the Simpson group (Ordovician), which are lithologically similar to and approximately the same age as the St. Peter sandstone of the upper Mississippi Valley.

Detailed mapping with aid of aerial photographs shows that the glass sand beds occur in structurally complex synclines and on the margins of large anticlines, in association with younger sedimentary formations that range in age from upper Ordovician (Trenton) to late-middle Pennsylvanian (pre-Virgil). These strata lie on the very thick Arbuckle dolomite of Cambro-Ordovician age and are covered on the northwest margin of the district by the overlapping Pontotoc conglomerate of late Pennsylvanian age. The synclinal and anticlinal structures were developed in early Pennsylvanian (pre-McAlester) time and modified by faulting, more complex folding, and some overthrusting in late Pennsylvanian (post-Hoxbar: pre-Pontotoc) time. Erosion has dissected one prominent overthrust sheet in the Sulphur area, forming 14 outliers or klippen and uncovering a wide outcrop of high grade glass sand. The downfolding and grabenlike faulting, however, are largely responsible for preserving the glass sand beds from complete removal by post-Pennsylvanian erosion. Workable deposits accessible to railroad transportation occur in the Mill Creek syncline, Sulphur syncline, Hickory syncline, on the south and west flanks of the Belton anticline, and on the northwest flank of the Hunton anticline. Outcrops of Simpson and younger strata covering about 50 square miles are shown on detailed geologic maps of these areas. The reserves of glass sand in the district are enormous.

The glass sands are massive or poorly stratified sedimentary beds 150 to 400 feet thick associated with a thicker sequence of limestone and shale strata. They crop out generally in curving

bands, 500 feet to 1.5 miles wide, that are related to structural trends. The deposits are worked where the dips are low to moderate and the sand is exposed over a wide area. The sands are loosely consolidated and weather to gently rolling, forested plains on which actual exposures of the sand body are uncommon, so that prospecting must be done by geological mapping together with exploratory pits or drill holes. The overburden ranges in thickness from 3 to 20 feet, averaging 5 to 10 feet, and consists of loose iron-stained sandy soil or alluvial clay. The practice in the Oklahoma district is to remove the overburden and quarry the sand by hydraulicking from an open pit 30 to 70 feet deep. The sand is beneficiated chiefly by washing, although one company uses tabling and flotation to remove pyrite. Processed sand is marketed as "moist" or dry, depending on specifications of the consumer.

The sands are white to pale buff or greenish and are composed chiefly of rounded, frosted, and pitted grains of quartz. They contain 0.04 to 0.71 percent detrital feldspar (orthoclase, microcline, and albite) and an inconstant but small amount of the clay mineral illite. The heavy minerals of authigenic origin, pyrite and its alteration product limonite, are the chief sources of iron. Most of the iron is present as a thin coating of limonite on the sand grains. Detrital heavy minerals are schorlite tourmaline (dominant), zircon (common), and garnet, rutile, ilmenite, ceylonite, and epidote (rare); they contribute practically no iron to the sands. The crude sands contain 99.57 to 97.82 percent SiO_2, 0.09 to 0.40 percent Fe_2O_3, 0.04 to 1.16 percent Al_2O_3, and very small quantities of CaO and MgO. The clay and most of the iron minerals are removed by beneficiation, so that the processed sands contain about 99.85 percent SiO_2, 0.03 to 0.044 percent Fe_2O_3, and 0.04 to 0.09 percent Al_2O_3. Such sand is suitable for all but optical grades of glass.

Sieve analyses show that the texture of the sands is fine-grained, 83 to 90 percent being in the fine and very fine sand grades of the Wentworth scale. The average median diameter of the sands is 0.142 mm and the average sorting coefficient is 1.20. Although considerably finer than the St. Peter sand of Illinois, Missouri, and Arkansas, the fine-sized Simpson sands have been used successfully for 32 years in Oklahoma glass plants, producing excellent quality containers, table glassware, and plate glass.

INTRODUCTION

Purpose of Report. Published information on the geology of glass sand deposits in the Arbuckle Mountains is contained chiefly in Buttram's report of 1913.[1] This report is now out of print and therefore not generally available to the public. Although serving a valuable purpose in helping to start the glass sand industry in the Arbuckle Mountains, it was written before production actually began and contains no detailed information on the operating plants and no comprehensive map of the glass sand district. The Geological Survey has thus had insufficient data to answer the many requests concerning glass sands that recently have come to its attention, and the present investigation was undertaken to fill this need. By mapping the glass sand beds in the producing district, in the central part of the Arbuckle Mountains, and through detailed sampling and analysis, the investigation has resulted in establishing the high quality of the sands and indicating large reserves at the existing plants and in undeveloped localities.

Location of Area. The producing glass sand district of Oklahoma is in the central part of the Arbuckle Mountain region, which in turn is in the south-central part of the State (fig. 1). The district has a crude triangular outline with the towns of Roff, Mill Creek, and Sulphur approximately at the apexes of the triangle, and covers slightly more than 400 square miles in parts of Johnston, Murray, and Pontotoc counties. Outcrops of the glass sand formations, however, are restricted to about one-eighth of this area.

A main line of the Frisco Railroad (St. Louis—San Francisco Railway) crosses the east side of the area through Roff, Hickory, Scullin, and Mill Creek, and Sulphur (population about 5,000) is connected with the main line by a spur from Scullin. This railroad serves all the glass sand producers of the district.

Previous investigations. Our previous knowledge of Oklahoma glass sands and their properties is owed chiefly to the work of Buttram, whose report "The Glass Sands of Oklahoma" was published in 1913.[2]

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[1] Buttram, Frank, "The Glass Sands of Oklahoma": *Okla. Geol. Survey Bull.* 10, 91 pp., 1913.

[2] Buttram, Frank, *op. cit.*

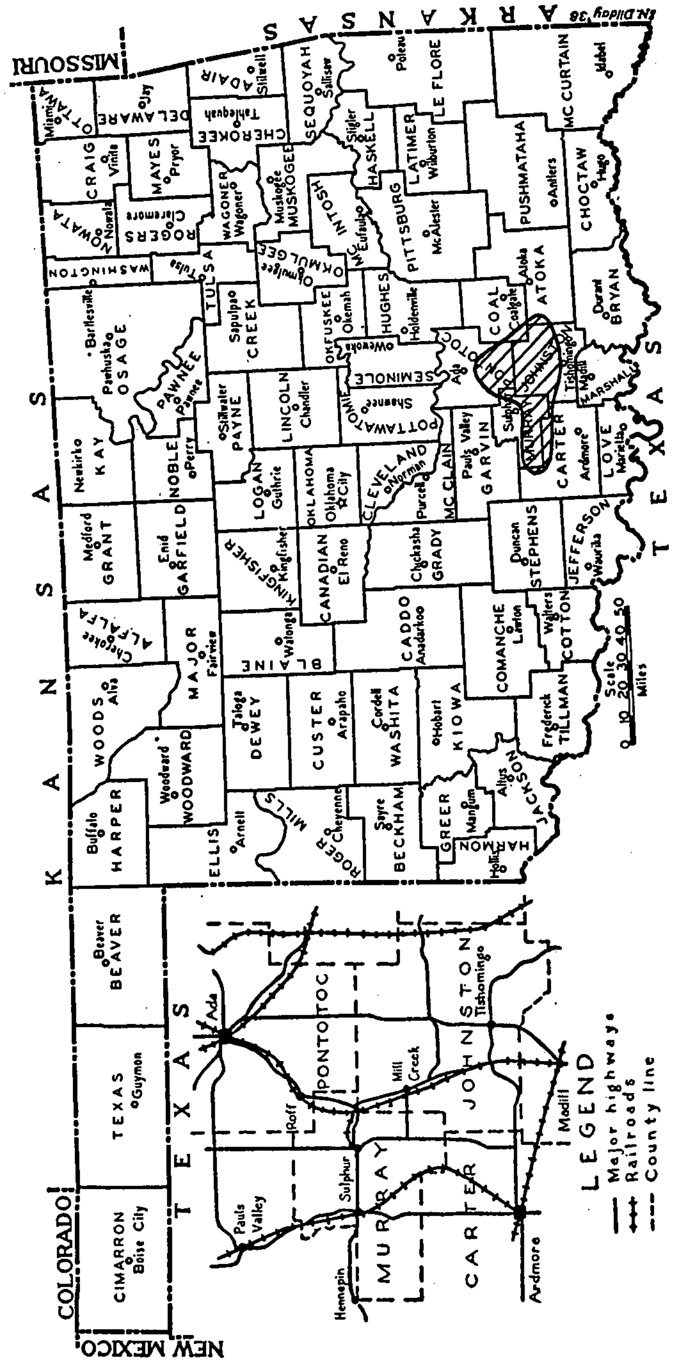

Fig. 1. Index map of Oklahoma showing location of Arbuckle Mountains

A brief report on "Oklahoma Glass Sands" was prepared in 1930 by C. N. Gould and J. O. Beach of the Oklahoma Geological Survey, and published by the Oklahoma Corporation Commission. It was a compilation of information contained in certain reports and in the files of the Geological Survey. Later this report was incorporated in a Mineral Report of the Geological Survey.[3] Both of these publications and the one by Buttram are now out of print.

The quarrying and beneficiation practices at one plant in the Arbuckle Mountains, the Mid-Continent Glass Sand Company, are described in detail in a recent trade journal article.[4]

A few publications on the Simpson group are worthy of citation here because it contains the workable glass sand beds in the Arbuckle Mountains. Taff is the nomenclator, having first used the term Simpson formation in 1902.[5] In a later report[6] he submitted the first map of the Simpson formation in the Arbuckle Mountains and mentions in it "beds of pure sand" and "white sandstone".

Decker, in 1931, raised the Simpson formation to the rank of group and divided it into five formations.[7] The formations were mapped separately and each of the upper four contains a basal sandstone member. Because of the relation to the glass sand beds, this stratigraphic classification serves a valuable purpose for the present report and is used substantially as given by Decker. Ulrich offered a somewhat different classification of the Simpson but his formations were not mapped and some of them are poorly defined.[8]

Two recent publications concerning the glass sand district of the Arbuckle Mountains are of interest. One publication[9] shows

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[3] Beach, J. O., "Glass Sands": *Okla. Geol. Survey Min. Rept.* 3, 1939.

[4] Swanson, H. E., "Beneficiating Glass Sand": *Rock Products*, Vol. 48, No. 3, pp. 58-61, 84, March, 1945.

[5] Taff, J. A., *U. S. Geol. Survey Geol. Atlas, Atoka Folio* (No. 79), 1902.

[6] Taff, J. A., "Geology of the Arbuckle and Wichita Mountains in Indian Territory and Oklahoma": *U. S. Geol. Survey Prof. Paper* 31, 97 pp., 1904; reprinted as *Okla. Geol. Survey Bull.* 12, 1928.

[7] Decker, C. E., and Merritt, C. A., "Stratigraphy and Physical Characteristics of the Simpson Group": *Okla. Geol. Survey Bull.* 55, 112 pp., 1931.

[8] Ulrich, E. O., "Simpson Group of Oklahoma" (abstract): *Bull. Geol. Soc. Am.*, Vol. 44, pp. 105-106, 1933.

[9] Gorman, J. M., Flint, G. M., Jr., Decker, C. E., and Ham, W. E., "Geologic Map of the Sulphur Asphalt Area, Murray County, Oklahoma": *U. S. Geol. Survey Oil and Gas Investigations, Preliminary Map* 22, 1944.

detailed structure in the vicinity of the asphalt pits, chiefly in sec. 22, T. 1 S., R. 3 E., and the other[10] discusses structure and stratigraphy in the complex area south of Sulphur.

A comprehensive bibliography on the geology of the Arbuckle Mountains would contain too many entries to be of value here. A voluminous literature is in existence, however, because of the excellent outcrops, abundance of fossils, diversity of geologic features, and the fact that petroleum geologists may study, here at the surface, formations that are encountered in the oil fields of the northern Mid-Continent region. These formations include prolific oil sands and limestones.

Present work. Most of the field work for this report was devoted to detailed mapping of the glass sand beds and associated strata in four separate areas of the central Arbuckle Mountains. Although the entire glass sand district has an area of about 400 square miles, about 350 square miles of this is outcrop of Arbuckle dolomite. The accompanying maps (Plates I, II, III, and IV) cover only the 50 square miles related to glass sands.

The field work was done in the summer and fall of 1944. The help of Dr. Charles E. Decker for about 6 weeks was invaluable, for without his knowledge of the lithology and fossils of the different rock units it would have been extremely difficult if not impossible to establish some of the complex field relations, especially in the early part of the work. Experience gained with Dr. Decker enabled the writer to become familiar with the strata so that the completion of the mapping was a relatively simple matter. A debt of gratitude to Dr. Decker is hereby acknowledged.

The base for the maps was provided by aerial photographs. The scale of 1:20,000 or about 3.2 inches to the mile was satisfactory for all areas mapped except a few localities of very complex structure. The field maps were made on transparent cellulose acetate overlay sheets at the same scale as the photographs, thus enabling excellent horizontal control. Stereoscopic study of the photographs aided materially in geologic interpretation and mapping.

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[10] Lehman, R. P., "Thrust Faulting in Arbuckle Mountains, Oklahoma": *Bull. Am. Assoc. Petrol. Geol.*, Vol. 29, pp. 187-209, 1945.

The formations were recognized by lithology, fossils, and field relations. Practically, the mapping of the glass sand beds was a problem of recognizing the boundaries of the limestone units overlying and underlying them, as the sand beds themselves are mostly covered with loose sand or soil.

The chemical analyses were made in the laboratory of the Oklahoma Geological Survey by Dr. A. C. Shead.[11]

The cordial cooperation of the glass sand producers in the Arbuckle Mountains was of great value in the preparation of this report, and the support of Mr. K. P. Larsh of the Mid-Continent Glass Sand Co., Mr. John Hurst of the Sulphur Silica Co., and Mr. Paul Straughan of the Mill Creek Sand Co. is gratefully acknowledged. To Mr. Robert H. Dott, director of the Survey, thanks are due for spending several days in the field checking the map, offering many helpful suggestions on structural interpretation, and making a critical review of the manuscript. Mr. J. O. Beach, secretary-editor of the Survey, has rendered valuable assistance in editing the report and giving constructive criticisms.

NATURE OF GLASS SAND

"Glass sand" is sand used in the manufacture of glass. It is composed of nearly pure silica and is called "melting sand", "glass sand", "silica sand", or "high silica sand" to distinguish it from the more impure varieties used for construction, molding, sand blasting, and abrasives. It is obtained from deposits of crude sand or sandstone. The distinction between sand and sandstone is based on degree of cementation, the term "sand" referring to loose or slightly cemented grains and the term "sandstone" referring to a consolidated rock. Commercially, however, crude sandstone in the quarry and processed sand alike are referred to as "sand".

Sand is used in glass making as a source of silica. The chief specification therefore is a very high content of silica; also the iron oxide content must be very low because this impurity gives objectionable colors to the glass. The exact specifications for high grade glass are so strict that even the best grades of crude sand must

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[11] Associate professor of analytical chemistry in the University of Oklahoma, on leave as chemist of the Oklahoma Geological Survey, 1944-45.

be beneficiated, chiefly by washing, so that all but slight amounts of iron and other impurities are removed. As it is not economically feasible to attempt beneficiation of most low silica sands, glass sand producers seek those deposits which contain in the crude state a silica content of at least 98 percent and prefer those containing 99 percent or more. Deposits of this type constitute the bulk of our present supply of sand for the glass trade, but compared to normal sandstones they are extremely uncommon. A composite analysis of 253 sandstones[12] shows only 78.66 percent silica, the other constituents being principally alumina, iron oxide, lime, magnesia, carbon dioxide, and potash.

Commercial deposits of glass sand may be divided into two groups, consolidated and unconsolidated. The consolidated deposits, chiefly of Paleozoic age, furnish most of the sand used in the United States. In general, the sand in such deposits is rather loosely bound together, so that the rock may be easily disaggregated. A few deposits, like the St. Peter (Ordovician) in the Ottawa district, Illinois, and the McLish and Oil Creek (Ordovician) in Oklahoma, are very loosely consolidated and are quarried simply by hydraulicking, whereas the sand in most other deposits has to be crushed. Examples of the latter type include the Oriskany (Devonian) sandstone in Pennsylvania and West Virginia, certain sandstones of Pennsylvanian age in Ohio, and the St. Peter in Missouri and Arkansas.

Deposits of unconsolidated sands are of comparatively young geologic age. Probably the best known deposits of this type are the Miocene sands of New Jersey, from which sand is pumped by dredges. Beach deposits (sand dunes) in California have likewise been worked for glass sand in recent years.

There are a few places where economic factors are favorable for glass manufacture, yet are not close to deposits of high grade sand. In these places it is feasible to beneficiate local sands of inferior grade by acid leaching. It is clear, however, that deposits which must be leached can compete with high grade crude sand only under exceptional circumstances.

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[12] Clarke, F. W., "The Data of Geochemistry" (5th edition): *U. S. Geol. Survey Bull.* 770, p. 547, 1924.

Historical Summary of Glass Sand Production in Oklahoma

The history of glass in Oklahoma is closely linked with a sequence of vicissitudes affecting certain glass plants in the United States during the early part of the present century. With a decline of natural gas production in Indiana, many glass plants being served by the Indiana pools moved westward to the newly-discovered gas fields of southeastern Kansas. During the period 1902-05, twenty plants were established in Kansas and one at Bartlesville across the line in Indian Territory (now Oklahoma).[13] These plants were supplied with glass sand from the St. Peter sandstone in eastern Missouri (Crystal City district), the freight charges bringing the total cost of the sand to about 4 times its price at the quarry. "Besides the disadvantage of the high cost of sand", according to Burchard, "these plants are at times subjected to a sand famine, due to the inability of remote producers to fill their orders promptly and to the inabililty of railroads to move the material when it is needed". "Probably nowhere in the United States is there at present a greater need for a local supply of glass sand than in southeastern Kansas".[14] This unfavorable condition, plus the partial exhaustion of some gas pools, eventually led to the decline of glass manufacturing in Kansas. Whereas there were 20 plants in 1905, there were only 5 plants in 1919, 2 in 1927, 1 in 1929, and in 1939 no plants were listed.[15]

A similar condition might have affected the infant glass industry in Oklahoma had it not been for the high grade glass sand deposits in this State. After the discovery of natural gas in northeastern Oklahoma beginning about 1904, there was some migration of the Kansas plants into Oklahoma. The change probably was caused in part by a desire to escape keen competition in Kansas and at the same time a new market was being created by the demands of a new and rapidly growing state.[16] By 1913 there were 6 plants in Oklahoma, two each at Tulsa and Okmulgee and one

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[13] Burchard, E. F., "Glass Sand of the Middle Mississippi Basin": *U. S. Geol. Survey Bull.* 285, p. 460, 1906.

[14] Burchard, E. F., "Notes on Various Glass Sands, Mainly Undeveloped": *U. S. Geol. Survey Bull.* 315, p. 379, 1907.

[15] 15th and 16th Census of the United States: *Bureau of the Census*, 1930 and 1940.

[16] The population of Oklahoma increased from about 800,000 in 1900 to 1,400,000 in 1907 (Statehood), 1,600,000 in 1910, and 2,000,000 in 1920.

each at Bartlesville and Avant, and all of them were obtaining glass sand from eastern Missouri.[17] Before this time it had become apparent that an investigation was needed of the glass sand possibilities of the State and on Jan. 1, 1913, Buttram's report on "The Glass Sands of Oklahoma" was published by the Oklahoma Geological Survey. Buttram examined and established the general high quality and suitability for glass making of sand deposits in three areas: Burgen Sandstone of Ordovician age in northeastern Oklahoma, near Tahlequah; several different sand beds in the Simpson formation (Ordovician) in the Arbuckle Mountains in south-central Oklahoma; and the Trinity sandstone of Cretaceous age, which crops out in a broad band between the Arbuckle Mountains and Red River to the south, extending from a point near Ardmore eastward to the Oklahoma-Arkansas line.

As near as can be determined, glass sand was first produced in Oklahoma from deposits in the Arbuckle Mountains, the first car being shipped from Roff in August, 1913, by the Mid-Continent Glass Sand Company. The sand from this deposit proved to be satisfactory and about 1918 two additional pits were opened in the Arbuckle Mountains, one near Hickory and another near Mill Creek. There also had been a steady increase in the number of glass plants, so that in 1919 there were in Oklahoma 16 establishments employing 1,692 wage earners and making glass products valued at $4,750,844.[18] Afterward there was a decline in the number of establishments to 10 in 1929, 9 in 1937, and 10 in 1945, although the value of the products increased to $6,200,136 in 1937, this year being the last for which statistics are available.[19] Many plants have specialized in pressed ware, fruit jars, and jelly glasses, and in 1939 Oklahoma with 5 plants led all states in the number of establishments manufacturing these products.

Production of glass sand has been attempted unsuccessfully from the Trinity formation in the belt south of the Arbuckle Mountains and some attention has been given to possibilities of the deposits near Tahlequah, but the Arbuckle Mountain deposits appear to have the most favorable economic features and all production is at present obtained from this district. Three plants are currently in operation and a fourth is now being constructed. It is estimated that the district produced in 1944 approximately 130,000 tons of glass sand with a probable value of about $235,000.

GEOLOGY

The glass sand beds of the Arbuckle Mountains are sedimentary deposits laid down in an Ordovician sea, probably at or very near the shore line. They are included within a sequence of marine shales and limestones known as the Simpson group, which is about 2,000 feet thick and contains five formations. Sand beds occur in the upper four formations but production of glass sand to the present time has been obtained from only two, the Oil Creek and McLish.

The Simpson beds are part of a much thicker section of marine sedimentary rocks consisting of limestones, dolomites, shales, cherts, and sandstones that crop out in the Arbuckle Mountains (Table I). These range in age from Upper Cambrian to lower Pennsylvanian and aggregate about 10,000 feet in thickness. In early Pennsylvanian time the sedimentary strata were folded and elevated to mountainous height, and late in the Pennsylvanian period they were subjected to intense compressive forces. The later deformation produced numerous faults, many of which are of great magnitude and some of which are overthrusts. Thus the present structural pattern of the region was developed.

Subsequent erosion reduced the original mountainous region to its present rather gently undulating topography. At places of maximum erosion in the structurally high or anticlinal areas the younger sedimentary formations have been stripped off, exposing locally the older, pre-Cambrian granite floor and, throughout a large area in the Arbuckle Mountain region, the Arbuckle limestones and dolomites. The Simpson and younger formations have been preserved on the margins of the anticlines and in structurally

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[17] Buttram, Frank, "The Glass Sands of Oklahoma": *Okla. Geol. Survey Bull.* 10, p. 90, 1913.

[18] "15th Census of the United States, Manufactures, 1929": *Bureau of the Census*, Vol. II, p. 869, 1930.

[19] "Census of Manufactures, 1937; Oklahoma Summary": *Bureau of the Census*, March 30, 1939.

TABLE I
GENERALIZED CHART OF FORMATIONS IN ARBUCKLE MOUNTAINS

GEOLOGIC PERIOD	FORMATION OR GROUP NAME	LITHOLOGY	THICKNESS (Feet)
Pennsylvanian	Pontotoc (Vanoss) conglomerate	Coarse, gray limestone conglomerate with thin lenses of buff sandstone and red shale.	0-100+
	Ada formation	Shale, coarse sandstone, and limestone conglomerate.	100±
	Springer, Dornick Hills, Deese and Hoxbar (?) (in Mill Creek syncline)	Limestone conglomerate; gray, red, and green shale; massive gray limestone (Wapanucka?); buff sandstone; and thin-bedded chert.	Thick
Mississippian	Caney shale	Blue-black, fissile, clay shale.	1600±
	Sycamore limestone	Massive, blue-gray, sandy limestone, weathers buff to yellowish.	0-200
	Woodford chert	Siliceous shale and chert, mostly thin-bedded; black, gray, or tan color.	100-650
Devonian Silurian	Hunton group	Massive gray limestone, oolitic at base and cherty in upper part, with marl and shale in middle.	0-300
Ordovician	Sylvan shale	Thin-bedded, gray to greenish clay shale, locally calcareous.	60-300
	Fernvale limestone	Massive, coarse-crystalline, gray limestone.	0-80
	Viola (Trenton) limestone	Massive gray limestone, cherty, chiefly fine grained.	500±
	Simpson group: Bromide fm. Tulip Creek fm. McLish fm. Oil Creek fm. Joins fm.	Alternating limestone, shale, and sandstone in thick and thin beds. Contains the workable glass sand beds in the Arbuckle Mountains.	600-2300
	Arbuckle group	Fine-grained gray limestone, massive to thin-bedded, chiefly in Ordovician; gray dolomite, coarse-crystalline, massive, chiefly in Cambrian.	5800-6700
Cambrian	Honey Creek limestone	Limestone or dolomite, coarse-crystalline, sandy and glauconitic.	60-235
	Reagan sandstone	Coarse-grained arkosic sandstone and conglomerate, glauconitic.	0-475
Pre-Cambrian	Tishomingo granite	Pink granite, mostly coarse-grained, with dikes of porphyry, diabase, and pegmatite.	

low or synclinal areas. Such areas are therefore favorable to glass sand production.

The areas of glass sand preservation, produced by a combination of structural deformation and erosion, are in some places of very small extent. For example, of a total of about 400 square miles in the glass sand district, the Simpson and younger formations have been preserved in only 50 square miles, or 12 percent, and have been completely eroded from the remaining area.

Altitudes in the glass sand district range from about 950 feet near Mill Creek, in the southern part, to slightly more than 1,300 feet at Roff, in the northern part. Whereas the maximum relief for the district is about 350 feet, in a given square mile it is commonly less than 75 feet. Topographic maps of the Stonewall and Tishomingo quadrangles cover the area under discussion. These were published in 1901 by the U. S. Geological Survey on a scale of 1:125,000 and a contour interval of 50 feet.

The topography and vegetation reflect the kind of outcropping rock. Gently rolling prairies that support excellent grass for pasture are found chiefly on the outcrop of Arbuckle dolomite. The younger formations are mostly limestone, sandstone, and shale. The limestones crop out in ridges of barren rock, whereas the sandstones and shales crop out in low-lying plains or valleys with flat to gently undulating topography. A forest of oak and hickory generally grows on the sandstones and grass on the shales. In many places such lands are now in cultivation.

STRATIGRAPHY OF THE GLASS SAND FORMATIONS IN THE SIMPSON GROUP

The Simpson formation was first described by Taff and was named by him from the former village of Simpson, located in sec. 12, T. 1 S., R. 6 E., Johnston County, near the present town of Pontotoc.[20] He called attention to an upper and lower division, separated by a persistent sandstone bed, but made no attempt to

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[20] Taff, J. A., "Geology of the Arbuckle and Wichita Mountains in Indian Territory and Oklahoma": *U. S. Geol. Survey Prof. Paper* 31, 97 pp., 1904; reprinted as *Okla. Geol. Survey Bull.* 12, 1928.

TABLE II

THICKNESS IN FEET OF SANDSTONE AND LIMESTONE MEMBERS OF McLISH AND OIL CREEK FORMATIONS IN GLASS SAND DISTRICT

		SULPHUR AREA			MILL CREEK AREA	HICKORY AREA			ROFF AREA		
		Sec. 13, R. 3 E., T. 1 S.	Secs. 11 and 14, T. 1 S., R. 3 E.	Sec. 19, T. 1 S., R. 5 E.	Sec. 8, T. 2 S., R. 5 E.	Sec. 14, T. 1 N., R. 4 E.	Sec. 13, T. 1 N., R. 4 E.	Sec. 16, T. 1 N., R. 5 E.	Sec. 18, T. 2 N., R. 5 E.	Secs. 13 and 23, T. 2 N., R. 5 E.	Sec. 17, T. 2 N., R. 5 E.
McLish Formation	Limestone Member		340							290	
	Sandstone Member		165						180+	125+	
Oil Creek Formation	Limestone Member	350		190	200+	155					110
	Sandstone Member	400		400+	360		230	160+			130+

subdivide the strata into smaller units. Decker,[21] in a detailed report, divided the Simpson into five formations and raised the rock sequence to the rank of a group, for which the name Simpson was retained. The formations are, from oldest to youngest: Joins, Oil Creek, McLish, Tulip Creek, and Bromide. The formations represent ". . . five more or less complete sedimentary cycles with a basal sand at the bottom of each of the four upper ones and a conglomerate at the base of the lowest one."[22] The strata are of Ordovician age and are correlated by Decker with the Chazy and Black River formations of the eastern United States.

Three of the formations—Oil Creek, McLish, and Bromide—are presistent in areal distribution throughout the Arbuckle Mountains, although the thickness of each unit is different from place to place. The Tulip Creek and Joins, however, are best developed in the western and southern parts of the region (Arbuckle anticline) and are either very thin or lacking in the area mapped for this report. Accordingly, the Joins, if present at all, is mapped with the Arbuckle limestone, which it closely resembles, and the Tulip Creek is mapped with the basal beds of the Bromide formation. An exception is made in sec. 21, T. 1 S., R. 3 E., where Decker definitely identified the Joins by graptolites contained in green shale.

The thickness of the Simpson group in the area south of Sulphur is about 1,650 feet. The thickness of the formations and members important to glass sand production are shown in Table II.

OIL CREEK FORMATION

The Oil Creek formation was named by Decker from exposures on Oil Creek in the eastern part of T. 2 S., R. 3 E., Murray County, about 10 miles south of Sulphur. It is overlain by the McLish formation, and underlain in the western part of the Arbuckle Mountains by the Joins formation and in the eastern part by the Arbuckle limestone. An unconformity separates the Oil Creek from the Arbuckle where the Joins is absent. Decker correlates the formation with the lower Chazy.

The Oil Creek formation is composed of two members, a basal sandstone and an upper member of interbedded limestones and

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[21] Decker, C. E., and Merritt, C. A., "Stratigraphy and Physical Characteristics of the Simpson Group": *Okla. Geol. Survey Bull.* 55, 1931.

[22] *Idem.*, pp. 11-12.

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		SULPHUR AREA			MILL CREEK AREA	HICKORY AREA			ROFF AREA		
		Sec. 13, R. 3 E., T. 1 S.	Secs. 11 and 14, T. 1 S., R. 3 E.	Sec. 19, T. 1 S., R. 5 E.	Sec. 8, T. 2 S., R. 5 E.	Sec. 14, T. 1 N., R. 4 E.	Sec. 13, T. 1 N., R. 4 E.	Sec. 16, T. 1 N., R. 5 E.	Sec. 18, T. 2 N., R. 5 E.	Secs. 13 and 23, T. 2 N., R. 5 E.	Sec. 17, T. 2 N., R. 5 E.
McLish Formation	Limestone Member		340							290	
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	Sandstone Member	400		400+	360		230	160+			130+

subdivide the strata into smaller units. Decker,[21] in a detailed report, divided the Simpson into five formations and raised the rock sequence to the rank of a group, for which the name Simpson was retained. The formations are, from oldest to youngest: Joins, Oil Creek, McLish, Tulip Creek, and Bromide. The formations represent ". . . five more or less complete sedimentary cycles with a basal sand at the bottom of each of the four upper ones and a conglomerate at the base of the lowest one."[22] The strata are of Ordovician age and are correlated by Decker with the Chazy and Black River formations of the eastern United States.

Three of the formations—Oil Creek, McLish, and Bromide—are presistent in areal distribution throughout the Arbuckle Mountains, although the thickness of each unit is different from place to place. The Tulip Creek and Joins, however, are best developed in the western and southern parts of the region (Arbuckle anticline) and are either very thin or lacking in the area mapped for this report. Accordingly, the Joins, if present at all, is mapped with the Arbuckle limestone, which it closely resembles, and the Tulip Creek is mapped with the basal beds of the Bromide formation. An exception is made in sec. 21, T. 1 S., R. 3 E., where Decker definitely identified the Joins by graptolites contained in green shale.

The thickness of the Simpson group in the area south of Sulphur is about 1,650 feet. The thickness of the formations and members important to glass sand production are shown in Table II.

Oil Creek Formation

The Oil Creek formation was named by Decker from exposures on Oil Creek in the eastern part of T. 2 S., R. 3 E., Murray County, about 10 miles south of Sulphur. It is overlain by the McLish formation, and underlain in the western part of the Arbuckle Mountains by the Joins formation and in the eastern part by the Arbuckle limestone. An unconformity separates the Oil Creek from the Arbuckle where the Joins is absent. Decker correlates the formation with the lower Chazy.

The Oil Creek formation is composed of two members, a basal sandstone and an upper member of interbedded limestones and

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[21] Decker, C. E., and Merritt, C. A., "Stratigraphy and Physical Characteristics of the Simpson Group": *Okla. Geol. Survey Bull.* 55, 1931.

[22] *Idem.*, pp. 11-12.

shales. The thickness of the formation ranges from 240 feet in the vicinity of Roff to 750 feet in sec. 13, T. 1 S., R. 3 E., 3 miles south of Sulphur. The sandstone member ranges in thickness from 130 feet to 400 feet, and the limestone member from 110 to 350 feet. Because of its thickness and high quality, this sandstone is the most important glass sand bed in the district.

SANDSTONE MEMBER OF THE OIL CREEK FORMATION

The lower member of the Oil Creek formation is massive-bedded, fine-grained, white sandstone composed almost entirely of quartz (silica) sand. In many places it is very loosely consolidated so that the individual grains may be disaggregated easily by crushing between the fingers. In quarries, such as the one at Mill Creek, the sandstone appears massive and nearly structureless, although faint bedding planes appear on weathered surfaces. A fresh quarry face of the sand has a dazzling white color. Locally, as in secs. 15 and 22, T. 1 S., R. 3 E., the sandstone is impregnated with asphalt and is quarried for road material.

The sandstone member is thickest in the southern part of the district and thins to the north and east. It is 400 feet thick in sec. 13, T. 1 S., R. 3 E., 3 miles south of Sulphur, and about the same thickness in sec. 19, T. 1 S., R. 5 E., 3.5 miles north of Mill Creek. The sandstone is 360 feet thick 1.5 miles east of Mill Creek, in sec. 8, T. 2 S., R. 5 E. A thickness of 230 feet was calculated in sec. 11, T. 1 N., R. 4 E., 1 mile north of Hickory, and in sec. 16, T. 1 N., R. 5 E., 4 miles east of Hickory, it is 160 feet thick. The Oil Creek sandstone is thinnest in the vicinity of Roff, where measurements based on rather incomplete field data gave 130 feet.

The sand is well sorted and dominantly fine-grained, sieve analyses revealing that 60 to 67 percent is of the fine sand grade (0.246-0.124 mm diameter) and about 23 percent is of the very fine sand grade (0.124-0.061 mm diameter). There is a small percentage of medium-sized sand and silt, and no grains of coarse sand size (larger than 0.5 mm diameter). (See Table XI).

The shape of the grains is decidedly rounded to sub-rounded in all but the finest sizes, in which they tend to be sub-angular and

angular. A few are ovoid or sub-rectangular in general outline. A most conspicuous feature, easily observed under the microscope, is the frosting, or etching, and pitting on practically all grains. There is a wide range in the degree of frosting, the coarsest grains being deeply pitted and frosted whereas the smaller ones are only faintly etched. A broken grain readily shows the transparent, fresh interior and its contact with the frosted surface. A very few secondary enlargements, or crystal overgrowths, were noted, and the crystal faces on them have been etched like the other grains.

Although remarkably pure in comparison to common sandstones, the sandstone member of the Oil Creek does contain a small percentage of constituents other than quartz sand grains. A little clay is distributed rather uniformly throughout the sand body and small concretionary masses of limonite are found sparingly in the quarries and in some outcrops. The grains are held together by the clay or by thin films of silica cement, but the bond is not strong and the sand is disaggregated commercially by hydraulic jets at a comparatively low cost.

The sandstone member of the Oil Creek is not entirely free from carbonate cement and lenses of carbonate rock. Layers of cream-colored, laminated, fine-grained dolomite and sandy dolomite have been observed in several places, chiefly in the upper half of the member. A ledge of this rock about 6 feet thick occurs in an abandoned quarry at Hickory; thinner beds crop out in sec. 13, T. 1 S., R. 3 E., Murray County, and in a road cut 200 feet east of the SW cor. sec. 17, T. 1 S., R. 5 E., Johnston County. A bed of sandy dolomite about 1 foot thick occurs near the base of the quarry at Mill Creek, and a hard, calcareous bed of similar thickness was encountered in the quarry of the Sulphur Silica Co. The carbonate beds are lenticular and may occur in any part of the sandstone, but as a rule they are not sufficiently abundant or thick to aid in mapping or to cause concern to the sand producers. They are a detriment to a glass sand deposit because the rock is so hard that it interferes with quarrying operations, it will not break down under water pressure, and it is not acceptable to the glass industry. Fortunately, most deposits are virtually homogeneous sand bodies and any original calcareous cement the sand may have had has been leached away.

Locally the sandstone has been hardened along thin seams or veins by the precipitation of silica around the sand grains. Sandstone cemented by numerous veins of silica is known to the quarrymen as "fishbone" and is ordinarily avoided, if at all possible, because it will not disaggregate readily. As a general rule the veined rocks are not abundant enough to cause trouble in the quarries.

Field recognition and outcrop. Actual outcrops of the sandstone member of the Oil Creek formation may be found in a few places but generally there is no direct evidence of the sand body, for the sandstone itself is covered by an overburden of residual sandy soil or alluvium (Pl. V, A). Consequently reliance must be put on such indirect evidence as character of soil, vegetative cover, and contacts with underlying and overlying rocks. These are sufficiently definite for reasonably accurate mapping. There are a few places, as along Pennington and Mill Creeks, where the outcrop is deeply covered by alluvium and here the presence of sandstone must be determined solely on geological observations or test drilling.

At some places the sandstone is hardened virtually to quartzite and crops out as loose, intricately veined boulders or irregular pedestal rocks 10 feet or less in height. The hardening is accomplished chiefly by the deposition between sand grains of a siliceous cement that probably was leached from the sandstone itself by ground waters. Most outcrops of quartzitic sandstone are aligned in a narrow band along faults, where ground waters flowing through the sand body commonly are restricted against impervious limestone or dolomite on the opposite side of the fault. A few indurated boulders not on recognizable faults probably were cemented through restricted flow of water along normal sandstone-limestone contacts in small synclines or other structural features.

An isolated sandstone outcrop ordinarily can not be identified as the Oil Creek member by its lithology alone. The white, fine-grained sandstone is very similar in appearance to sandstones in other Simpson formations and even resembles some thin sandstone beds in the upper part of the Arbuckle dolomite. The greater thickness of the sandstone member of the Oil Creek formation and its wider outcrop is one feature helpful in distinguishing this unit from the sandstone members of the McLish and Bromide formations. Thin, cream-colored dolomite beds characteristic of the sandstone of the Oil Creek are not found in the McLish or Bromide but there are similar beds in the Arbuckle formation for which they might be mistaken. Because of this sameness of lithology the sandstone of the Oil Creek was identified by other inherent features, chiefly by its stratigraphic position in relation to other rock units.

The sandstone unit of the Oil Creek formation lies on the Joins formation in the southern and western parts of the Arbuckle Mountain region, but in much of the glass sand district the Joins is absent and the Oil Creek rests on Arbuckle dolomite. It is overlain by the limestone member of the Oil Creek formation. Thus the sandstone can be mapped as Oil Creek if the underlying and overlying strata can be identified, and in most places both are easily recognized by distinctive lithology.

In the glass sand district the Arbuckle is composed almost exclusively of dolomite. The uppermost strata are thin-bedded, compact, finely crystalline, slightly cherty, argillaceous, laminated, and greenish to yellowish gray on a fresh surface. The beds weather cream to light gray in color. Interstratified with the dolomite are many layers of buff or white sandstone that range in thickness from less than 1 foot to several tens of feet. Because the thicker sandstone beds in the upper part of the Arbuckle can not be readily distinguished from the overlying sandstone of the Oil Creek formation, the Oil Creek-Arbuckle contact is generally placed at the highest dolomite bed. Normally the loosely cemented sandstone in the basal part of the Oil Creek formation is so scattered by wind erosion and slope wash that the exact contact with the Arbuckle is obscured, although in most places a close approximation is possible.

LIMESTONE MEMBER OF THE OIL CREEK FORMATION

The upper member of the Oil Creek formation consists of interstratified beds of limestone and shale. The typical limestones are very coarsely crystalline, slightly argillaceous, highly fossiliferous, gray blue on fresh surface and a characteristic yellow on weathered outcrop. Small chert pebbles and flakes of glauconite occur sporadically in the lower beds. Individual beds are about 2 to 4 inches thick although locally there are massive beds up to 4 feet thick.

Fossils of many different kinds are abundant in the limestone and evidently are responsible for its coarse-crystalline texture. Gastropods, bryozoa, and stems and plates of cystids are perhaps most common, but there are many brachiopods, pelecypods, cephalopods, trilobites, and ostracodes.

Interbedded with the limestone are olive-green to gray clay shales. These shales are exposed in a very few places, being covered in most places with prairie soil. The proportions of shale and limestone apparently differ from place to place in the glass sand district, although generally the lower beds are dominantly limestone and form an escarpment in which outcropping beds may be seen plainly. The limestones in the upper part are less prominent, thinner, and relatively unfossiliferous; many are sandy and cross-bedded on a small scale.

The limestone member of the Oil Creek has its maximum thickness of 350 feet in sec. 13, T. 1 S., R. 3 E., 3 miles southeast of Sulphur. It thins eastward and northward, being 190 feet thick at the NE cor. sec. 19, T. 1 S., R. 5 E., 4 miles east of Mill Creek. At Hickory, in sec. 14, T. 1 N., R. 4 E., the limestone member is 155 feet thick and in the vicinity of Roff it is 110 feet.

Field recognition and outcrop. The physical features of the limestone—coarse-crystalline texture, yellow color on weathered surfaces, and highly fossiliferous character—probably are most useful for general field identification. Certain fossils also are of considerable help, notably the trilobite *Pliomerops;* an abundance of characteristic gastropods, as yet unidentified; a characteristic cystid plate that has 5, 6, or 7 ridges radiating from a central point; and the pelecypods which occur in a bed near the base. The fossils and lithology together are so distinctive that this limestone unit is one of the most easily recognized in the Simpson group.

The topographic expression of the limestone locally aids in its recognition. Where the strata have rather low dip the lowermost beds, being composed dominantly of limestone, form a scarp that rises above the less resistant, underlying sandstone member. The base of the scarp marks the approximate position of the sandstone-limestone contact. In the upper part of the member shales are more abundant and the outcrop is a gently rolling grass-covered prairie which is much used for pasture. Where the dip of the beds is steep the outcrop of the limestone is narrow and the scarp may be poorly developed.

The numerous layers of shale interbedded with the limestones caused the formation to react incompetently in response to structural deformation, and, as the rocks have been folded and faulted nearly everywhere in the district, the shale beds have been squeezed and the limestone beds as a general rule show erratic dips. On exposure, moreover, the shale is worn away rapidly, causing the hard limestone beds to slump, become detached, and eventually weather to loose slabs of rock. Owing to these erratic dips the thicknesses calculated for the Oil Creek limestone are not as reliable as could be desired.

McLish Formation

The McLish formation was named by Decker for the McLish ranch, the old headquarters of which "is about 4 miles northwest of Bromide".[23] It consists of a basal sandstone member and an overlying limestone and shale member. In the glass sand district the thickness of the McLish formation ranges from 415 feet in secs. 14 and 23, T. 2 N., R. 5 E., 2 miles southeast of Fitzhugh, to 505 feet in secs. 11 and 14, T. 1 S., R. 3 E., 2 miles south of Sulphur. The limestone member ranges in thickness from 290 feet to 340 feet, and the sandstone is between 125 and 180 feet thick.

The formation is underlain by the limestone member of the Oil Creek formation and is overlain, in the southern and western part of the Arbuckle Mountains, by the basal sandstone of the Tulip Creek formation. In the district covered by this report, however, the Tulip Creek is either very thin or absent and is dif-

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[23] Decker, C. E., and Merritt, C. A., "Stratigraphy and Physical Characteristics of the Simpson Group": *Okla. Geol. Survey Bull.* 55, p. 26, 1931.

ficult to recognize, so that the strata overlying the McLish are mapped as Bromide.

Based on the presence of certain fossils, notably *Maclurites magna,* the McLish is correlated by Decker with the middle Chazy formations of the eastern United States.[24]

SANDSTONE MEMBER OF THE MCLISH FORMATION

The sandstone member of the McLish formation is a loosely consolidated, fine-grained, white sand body composed dominantly of rounded and frosted quartz grains. Sieve analyses show about 6 percent medium sand, 63 percent fine sand, 27 percent very fine sand, and 4 percent silt and clay (Table XI). In many places there are thin beds and lenses of calcareous sandstone which are irregular both in horizontal extent and vertical distribution.

In some outcrops, particularly in the vicinity of Roff, the green clay mineral illite is so abundant as to give the entire outcrop a green or blue green color. The clay is distributed uniformly through the sand and is not concentrated in layers or shale beds. It occurs as discrete particles in the interstices between sand grains. There is no effective bond between the clay particles and sand grains, and simple washing will remove the clay, leaving a sparkling white sand.

Pyrite is present in the sandstone in some places, occurring as tiny crystals of cubic and octahedral habit, locally clustered together in aggregates, and seemingly of nearly uniform distribution. None was found in veins or fissures and the occurrence is such that the origin is clearly syngenetic, that is, the pyrite was precipitated from sea water during the deposition of the sand. Pyrite and its alteration product, limonite, are serious detriments to glass sand deposits because both have a high iron content.

Except at Roff, where the McLish is being quarried for glass sand adjacent to the railroad, there are few places in the mapped district where this sandstone is likely to be exploited commercially. Mostly the outcrops are narrow and located some distance from railroads.

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[24] Decker, C. E., and Merritt, C. A., *op. cit.*, p. 36.

The best exposures for measurement of thickness are about 2 miles southeast of Sulphur, where the sandstone has a nearly constant thickness of 165 feet through secs. 12, 13, and 14, T. 1 S., R. 3 E. Somewhat inconclusive field data give thicknesses of 125 feet in sec. 23, T. 2 N., R. 5 E., and 180 feet in sec. 18, T. 2 N., R. 5 E.

Field recognition and outcrop. The sandstone of the McLish, having nearly homogeneous composition and being practically unfossiliferous, is recognized in the field chiefly by its stratigraphic position between the underlying limestone member of the Oil Creek and overlying limestone member of the McLish, both of which can be identified by characteristic fossils and lithology. The sandstone crops out between the limestone ridges as a sandy plain, completely forested originally but cleared and cultivated in many places. Where the dip of the rocks is steep the outcrop is a narrow valley.

The greenish color of the sandstone, caused by disseminated green clay (illite), may be used to establish a tentative identification of the sandstone of the McLish and to distinguish it from that in the Oil Creek formation, which is not greenish. This criterion must be used with care, however, because the green color is not universally present in the McLish and also it occurs in certain beds of the Bromide formation.

Many of the calcareous beds in the sandstone member of the McLish have a faint greenish cast and this can be used as suggestive evidence, but more reliable is the occurrence of small plates of the cystid *Paleocystites tenuiradiatus,*[25] a fossil that has been widely used as a marker for the McLish in the Arbuckle Mountains.

Of some help to the field geologist also is the fact that the sandstone member of the McLish is considerably thinner than the sandstone of the Oil Creek, except in the vicinity of Roff, and field evidence suggesting a relatively thick sand body would be taken to indicate the Oil Creek member instead of McLish.

LIMESTONE MEMBER OF THE MCLISH FORMATION

The upper member of the McLish formation is a gray to

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[25] Decker, C. E., and Merritt, C. A., *op. cit.*, Pl. VIII, p. 31.

greenish-gray limestone, some beds of which are abundantly fossiliferous and coarsely crystalline and others of which are very fine-grained and "dense". Probably the most distinctive lithologic type is the "birdseye" limestone in the upper part of the member. It is composed of a uniformly fine-grained, nearly lithographic groundmass of limestone with numerous small crystalline aggregates of clear, transparent calcite. The beds are more or less sandy in places and there are a few thin layers of shale. The green color of some of the beds is caused by disseminated particles of the green clay mineral illite.

The limestone has a thickness of 340 feet in secs. 11 and 14, T. 1 S., R. 3 E., 2 miles south of Sulphur, and 290 feet in secs. 14 and 23, T. 2 N., R. 5 E., 2 miles southeast of Fitzhugh. Throughout the district the limestone crops out in a low, barren ridge above the plain of the underlying sandstone member.

In addition to the "birdseye" lithology there are certain fossils, notably the large gastropod *Maclurites magna* and the spherical alga *Girvanella ocellata,*[26] that are useful for field identification. Furthermore, the sandy limestone beds near the base of the limestone member commonly contain many plates of *Paleocystites tenuiradiatus,* and these extend upward in the formation.

BROMIDE FORMATION

The Bromide formation was named by Decker for exposures near Bromide village in sec. 32, T. 1 S., R. 8 E., Coal County, at the eastern edge of the Arbuckle Mountains.[27] It has wide distribution and consists of a lower member of sandstone, shale, and thin sandy limestone, and an upper member of massive gray limestone. The sandstone beds in the lower member generally are thin and somewhat erratic. The thickness of the formation is approximately 400 feet in sec. 21, T. 1 S., R. 3 E., 3.5 miles southwest of Sulphur.

All strata lying immediately above the McLish limestone which might correspond to the Tulip Creek formation in other parts of the Arbuckle Mountains are in this report included in the basal part of the Bromide formation.

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[26] Decker, C. E., and Merritt, C. A., *op. cit.*, pp. 30-36 and Pl. VIII.

[27] Decker, C. E., and Merritt, C. A., *op. cit.*, p. 40.

Normally the lower shale and sandstone beds are poorly exposed in the district and crop out as a plain or in the scarp face underneath the upper massive limestones. As it is very difficult to determine in the field whether the lower beds are sandstone or shale, or sandstone, shale, and limestone beds interstratified, subdivision of the Bromide could not be made satisfactorily, except in the Roff area, and the formation was mapped as a single unit. From general considerations also it is apparent that the sandstone beds have a comparatively small areal outcrop and they do not appear to offer promise of being developed for glass sand in this district.

The formation is recognized by the lithology and fossils of the upper, massive limestones and by its stratigraphic position between the underlying McLish formation and overlying Viola limestone. The upper limestones of the Bromide are non cherty, gray to bluish gray, and very fine grained (dense) to rather coarsely crystalline and abundantly fossiliferous. Lithologically they are very similar to some beds in the McLish. The lithology of the Viola limestone, however, is distinctive and can be identified by beds in the lower part which are laminated and contain many nodules and thin bands of light buff chert. The Viola limestone contains also an abundance of characteristic graptolites and the trilobite *Cryptolithus tesselatus.*

The most useful fossils for rapid field identification of the Bromide formation are brachiopods, principally *Rafinesquina minnesotensis* which occurs in the upper few feet of the limestone member. *Orthis tricenaria* and *Dinorthis subquadrata* also are useful markers.[28] Locally these fossils are silicified.

STRUCTURAL GEOLOGY

The dominant structural units of the Arbuckle Mountains were recognized and named by Taff.[29] The structure has been discussed

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[28] Decker, C. E., and Merritt, C. A., *op. cit.*, Pl. XIII and pp. 44-47.

[29] Taff, J. A., "Geology of the Arbuckle and Wichita Mountains in Indian Territory and Oklahoma": *U. S. Geol. Survey Prof. Paper* 31, 1904; reprinted as *Okla. Geol. Survey Bull.* 12, 1928.

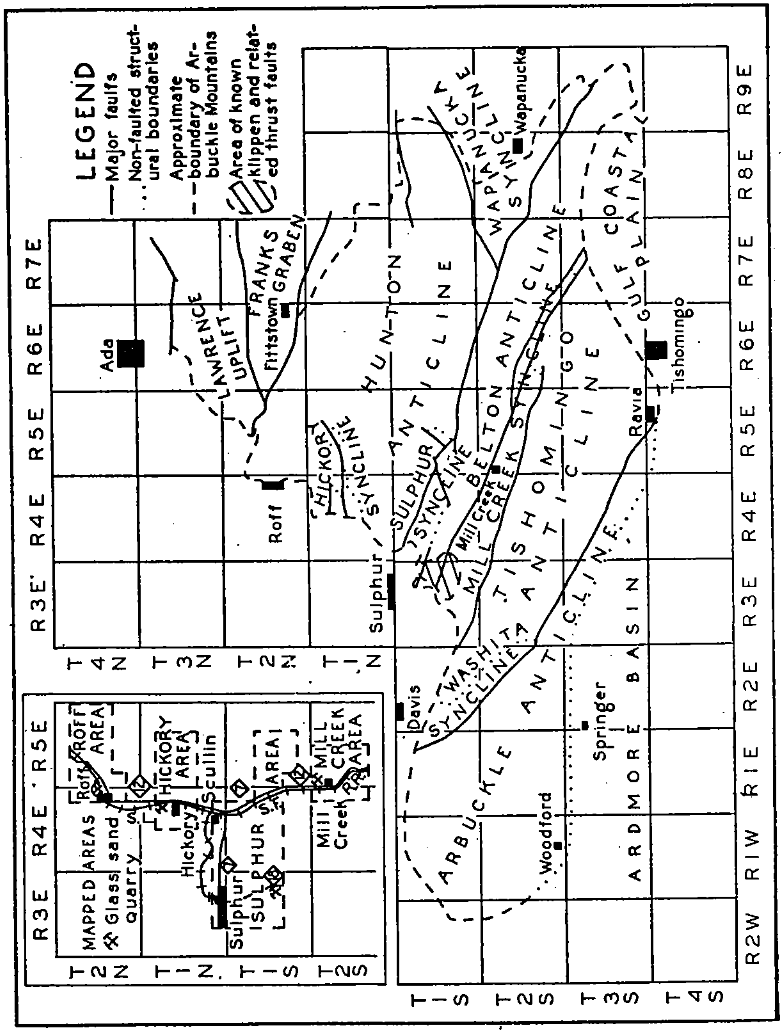

Fig. 2. Outline structural map of the Arbuckle Mountains showing location of the producing glass sand district

by Reeds,[30] Morgan,[31] and others, and a comprehensive analysis is given by Dott.[32] The major structural units include, from southwest to northeast, the Arbuckle anticline, Washita syncline, Tishomingo anticline, Mill Creek syncline, Belton anticline, Wapanucka syncline, Hunton anticline, Franks graben, and Lawrence uplift (fig. 2). All are northwest-trending structural features that are separated in most places by major faults.

These faults strike N. 60°—70° W. and many of them can be traced for miles along a rather straight line, indicating a high angle of dip but yielding no indisputable evidence as to whether they are of the normal or reverse type. A few of the smaller faults show marked curvature and probably are low-angle overthrusts.

The central part of the Arbuckle Mountains covered by this report embraces parts of the Mill Creek syncline, Belton anticline, and Hunton anticline, as well as two smaller structural units—the Sulphur syncline and Hickory syncline. The synclinal areas are important in a consideration of glass sand because in them the glass sand beds are found.

In most places the dip is moderate, ranging from 5° to 30°, although locally it is much steeper and in a few places the beds are vertical to overturned.

The folding in the glass sand district is believed by Dott to have taken place during the early Pennsylvanian (pre-McAlester: lower Des Moinesian) and to have been modified by thrust faulting in the late Pennsylvanian (post-Hoxbar: upper Missourian).

MILL CREEK AREA

The Mill Creek area as mapped for this report includes chiefly the outcrop of Simpson strata in the general vicinity of Mill Creek village, in the northwestern part of T. 2 S., R. 5 E. and adjoining sections in T. 2 S., R. 4 E., Johnston County. The mapped area

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[30] Reeds, C. A., "A Report on the Geological and Mineral Resources of the Arbuckle Mountains, Oklahoma": *Okla. Geol. Survey Bull.* 3, pp. 43-53, 1910.

[31] Morgan, G. D., "Geology of the Stonewall Quadrangle, Oklahoma": *Bur. Geol. Bull.* 2, 248 pp., Norman, 1924.

[32] Dott, R. H., "Overthrusting in Arbuckle Mountains, Oklahoma": *Bull. Am. Assoc. Petrol. Geol.*, Vol. 18, pp. 567-602, 1934.

covers about 6 square miles of outcrop on both sides of the Frisco Railroad (fig 2).

Parts of two major structural features in the eastern Arbuckle Mountains, the Mill Creek syncline and the Belton anticline, are shown on the map (Pl. I).

The Mill Creek syncline is a narrow, northwestward-trending graben of complex structure that in the Mill Creek area contains strata ranging in age from upper Ordovician to middle Pennsylvanian. The south fault of the syncline strikes N. 70° W. and has its greatest stratigraphic displacement, at least 8,000 feet, in the NE¼ sec. 20, T. 2 S., R. 5 E., where upper Bromide limestone is in contact with pre-Cambrian granite of the Tishomingo anticline. The north fault strikes N. 60° W. and brings beds of Pennsylvanian age in contact with Arbuckle and younger strata of the Belton anticline. The thickness of Pennsylvanian strata missing through faulting is unknown, but the stratigraphic displacement probably is of the order of 5,000 feet at the contact of Arbuckle dolomite and Pennsylvanian conglomerate, 1,300 feet south of the NW cor. sec. 1, T. 2 S., R. 4 E. Formations of the Simpson group crop out in the southern third of the syncline.

The prevailing strike is WNW and the dip is northeastward at angles generally steeper than 30° and locally reaching 90°, but there are many local differences in both dip and strike owing to faults and small folds. One prominent fault trends N. 80° E. through sec. 13, T. 2 S., R. 4 E., diagonally offsetting the beds about 2,000 feet. Another fault has such a curving trace that a low-angle overthrust is suggested. It strikes N. 70° E. through the central part of sec. 18, T. 2 S., R. 5 E. and curves southeastward through the southern part of sec. 17 along a line trending N. 65° W. In sec. 18 the fault is marked by the contact of Arbuckle limestone with vertical beds ranging from Simpson through Hunton. The outcrop of the Woodford formation is not appreciably changed and it continues southeastward just north of the fault. Between this fault and the Tishomingo anticline there are outcrops of Viola limestone and formations of the Simpson group.

In the northern part of the Mill Creek syncline are outcrops of Pennsylvanian rocks whose correlations with other areas have not been fully established. The oldest beds cropping out above the Caney shale are medium crystalline, fossiliferous, oolitic limestones, which correspond in stratigraphic position to the Wapanucka limestone of the eastern Arbuckle Mountains and to the lower Dornick Hills of the Ardmore basin. Lying above the limestones are beds of sandstone (Atoka?), chert conglomerate, reddish shale, cherty limestone, and limestone conglomerate, all of which probably correspond to the upper Dornick Hills, Deese, and Hoxbar formations of the Ardmore basin, of Des Moines and Missouri age. No mapping of the Pennsylvanian beds was attempted in this investigation.

Bordering the Mill Creek syncline on the north is the broad, northwest-trending Belton anticline. The southern margin of the anticline is modified in the Mill Creek area by a local syncline that contains a complete section of Simpson beds. The syncline covers about 2.5 square miles. Dips are 10° to 16° on the Arbuckle and increase to 40° on the Bromide limestone in the central part of the syncline. A small fault at the northern boundary of the syncline strikes N. 60° W. and displaces the Oil Creek sandstone-Arbuckle contact, the uppermost thin-bedded, laminated, argillaceous dolomite of the Arbuckle having been upthrown and eroded away.

SULPHUR AREA

The Sulphur area as used in this report embraces a strip of land about 4 miles wide that lies 1 to 4 miles south of Sulphur and extends eastward for 12 miles (Pl. II). It is contained in the east-central part of T. 1 S., R. 3 E., the central part of T. 1 S., R. 4 E., and the west-central part of T. 1 S., R. 5 E. The Murray-Johnston county line bisects the area into about equal eastern and western parts. The map covers all or a substantial part of 30 land sections.

The Frisco Railroad crosses the strip about one-third the distance from its eastern edge, in secs. 13 and 24, T. 1 S., R. 4 E., along a line between the towns of Scullin and Mill Creek. A spur of this railroad extends from Scullin to Sulphur a few miles north of the glass sand area.

Two major highways and many improved section-line roa also serve the district. An asphalt-surfaced road, Oklahoma Hig way 18, passes northward through the western part of the area Sulphur and beyond. It is used by the Sulphur Silica Co. to tru sand from their deposit to the drying plant in Sulphur. Oklahoı Highway 7 is a gravelled road that crosses the eastern part of t area parallel to the railroad.

The Sulphur area contains three major northwest-trendi structural features, the Sulphur syncline on the north, Belton aı cline in the middle, and the Mill Creek syncline on the soı (fig. 2). Faults of considerable displacement separate these un smaller faults occur within them, and one prominent thrust fa with related klippen, is known in the area. The outcropping b are chiefly Arbuckle (Ordovician) through Woodford (Mis sippian), and these are covered on the west by the Pontotoc (up Pennsylvanian) conglomerate.

SULPHUR SYNCLINE

The Sulphur syncline, named for the city of Sulphur, is elongate triangular-shaped area covering about 11 square mile the surface and extending from a point about 1.5 miles soutl the city southeastward for 11 miles. Sulphur itself is on outc of the Pontotoc conglomerate but the syncline extends beneat in subsurface.

The syncline is downwarped, and in most places faulted, tween the Hunton anticline on the north and Belton anticlin the south. The synclinal trend and the strike of the boun faults are about N. 70° W., being nearly parallel to the other n structural features of the central Arbuckle Mountains. Strat the Simpson group and of the Viola limestone within the syn are folded into smaller structural units of diverse orientation in some places are broken by faults.

The greatest width of the Sulphur syncline is about 2 ı through secs. 5, 8, and 18, T. 1 S., R. 4 E., and it narrows to a 0.5 mile in sec. 19, T. 1 S., R. 5 E. Eastward, in secs. 20 an T. 1 S., R. 5 E., the structural trend changes, the dips are l

and the Simpson beds have wider outcrop. Farther eastward, the syncline gives way to a fault cutting Arbuckle dolomite between the Hunton and Belton anticlines.

Strictly synclinal conditions prevail in the western part of the area. Outcrops of upper Simpson formations, and locally those of the Viola limestone, can be traced southwestward from sec. 5, T. 1 S., R. 4 E., to the axial part of the syncline in sec. 18, of the same township, and northwestward from here in a narrow band immediately north of the south-bounding fault to the NW¼ sec. 11, T. 1 S., R. 3 E. On the irregular northeast limb the dips are about 20° westward and on the southwest limb they range between 30° and 60° northeastward. The Ordovician beds are covered northwestward by an irregular outcrop of Pontotoc conglomerate.

In the central part of the Sulphur syncline the sandstone member of the Oil Creek formation crops out with low to moderate dip over a wide area and forms a broad, northward-plunging anticlinal nose. Against the south fault of the Hunton anticline the northward dip is locally and sharply reversed and a chain of small anticlines and synclines is developed along the fault.

The eastern third of the Sulphur syncline has rather complex structure and contains three separate structural units of different orientation. One is an eastward-trending syncline in the Oil Creek and McLish formations. It is about 0.5 mile wide through the northern parts of secs. 23 and 24, T. 1 S., R. 4 E., and narrower at its fault contact with Arbuckle dolomite near the N¼ cor. sec. 19, T. 1 S., R. 5 E. The north and south boundaries of the syncline are defined by faults, the north one of which may extend westward and connect with the major fault in sec. 18, T. 1 S., R. 4 E. The south fault strikes N. 75° E. and has its greatest stratigraphic displacement of at least 800 feet near the W¼ cor. sec. 24, T. 1 S., R. 4 E. where McLish limestones are faulted against Arbuckle.

Another structural unit with somewhat different trend is found in secs. 19, 20, and 29, T. 1 S., R. 5 E. The Arbuckle dolomite crops out in the southern part of the unit and dips north to northeast under the sandstone member of the Oil Creek at an average of 40°. The limestone member of the Oil Creek has substantially the same direction and magnitude of dip through the central part of sec. 19. Near the E¼ cor. sec. 19 the Oil Creek limestone curves northward along the section line to outline a northwest-plunging syncline, within which are outcrops of McLish sandstone and two small patches of McLish limestone. At the SW cor. sec. 17, T. 1 S., R. 5 E. the Oil Creek limestone curves southeastward around a sharp anticlinal nose, and is faulted on the north and east against upper Arbuckle dolomite. The wide outcrop of the sandstone member of the Oil Creek in secs. 20, 28, and 29, T. 1 S., R. 5 E. also is terminated by faults, one striking east and the other N. 40° W.

The third structural unit in the eastern part of the Sulphur syncline is a small syncline developed in the Oil Creek formation. On the northwest side the beds are broken by a fault that strikes N. 35° E. through secs. 16 and 21, T. 1 S., R. 5 E. and brings the upper part of the Oil Creek limestone in the axial part of the syncline into contact with Arbuckle dolomite. The strike of this fault is noteworthy because it is quite different from that of other major faults in the central part of the Arbuckle Mountains.

A deposit of barite and brown iron ore occurs along this fault 1,700 feet south of the NE cor. sec. 16. Another deposit, 1,500 feet east and 600 feet north of the SW cor. sec. 15, lies on upper Arbuckle dolomite and contains nodular limonite and ocher. There is no evidence of faulting at this deposit.

The fault that strikes east through secs. 27, 28, and 29, T. 1 S., R. 5 E. probably corresponds to the one mapped by Taff as the north fault of the Belton anticline. It is identified in the field chiefly by the contact of typical laminated, finely crystalline, and cream-colored dolomite at the top of the Arbuckle with very cherty and medium crystalline dolomite belonging an unknown distance below the top.

The present mapping of the Sulphur syncline differs in many respects from older maps. The first published map of the area[33] showed a persistent fault between the Simpson and Arbuckle formations along the south side of the syncline, but no fault on the north. There is now positive evidence that a fault of considerable magnitude is present along the north flank. At several places along this fault the limestone member of the Oil Creek formation is in contact with Arbuckle dolomite, the full 400 feet of Oil Creek sand having been downfaulted below the surface. Moreover, in sec. 5, T. 1 S., R. 4 E., the Arbuckle is in contact with still younger beds—the McLish and Bromide formations. The stratigraphic displacement at the Bromide-Arbuckle contact is at least 1,250 feet and evidently increases toward the northwest where the fault is covered by the Pontotoc conglomerate.

There is, furthermore, no fully reliable field evidence to indicate a continuous fault along the south flank of the Sulphur syncline, although several sub-parallel faults are present. No faulting is indicated in the S½ sec. 19, T. 1 S., R. 5 E., where both the upper Arbuckle dolomite and the limestone member of the Oil Creek have virtually the same strike and dip and the calculated thickness of the sandstone member of the Oil Creek between them checks with measurements in sec. 13, T. 1 S., R. 3 E. The contact appears normal and if there is a major fault corresponding to the one shown on older maps, it must lie farther south, entirely within the Arbuckle dolomite. By the same reasoning, there probably is no fault between the Oil Creek sand and Arbuckle dolomite at the curve in their contact in the western part of sec. 23, T. 1 S., R. 4 E.

The major fault identified by Taff as the north boundary of the Belton anticline probably extends as he mapped it from the eastern part of the Arbuckle Mountains to the eastern part of the Sulphur syncline. Although Taff mapped this fault northwestward along the south margin of the Sulphur syncline, it is apparent from the present mapping that the predominant fault lies along the *north* margin of the Sulphur syncline. This fault should logically be associated with Taff's fault in the eastern part of the Arbuckle Mountains to give a master fault line whose strike is N. 70° W., entirely in accordance with the other major structural trends. The stresses that produced this master fault apparently were resolved into several components in the eastern third of the Sulphur syncline,

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[33] Taff, J.A., *op. cit.*, (*Prof. Paper* 31), Pl. I.

forming small synclinal and anticlinal structures and fault blocks of different orientations.

The map accompanying Bulletin 55 of the Oklahoma Geological Survey shows the Sulphur syncline to have simple synclinal structure with thin bands of the Oil Creek formation bordering a large central area of the McLish formation. It is now recognized that the Oil Creek has much the more extensive outcrop and that the McLish is absent in the middle division of the syncline.

BELTON ANTICLINE

Only the northwestern part of the Belton anticline concerns the Sulphur area. This is a strip slightly more than 1 mile wide that trends northwestward about 4 miles from sec. 20, T. 1 S., R. 4 E. In this strip the anticline plunges northwestward, exposing the uppermost beds of Arbuckle dolomite and successively younger strata of the Simpson group. These beds are concealed on the west by the Pontotoc conglomerate. The prevailing dip is 8° NW on the Simpson beds and about 15° NW on the Arbuckle. Faults that strike N. 70° W. separate the anticline from the Sulphur syncline on the north and from the Mill Creek syncline on the south.

MILL CREEK SYNCLINE

The southernmost structural unit in the Sulphur area is the Mill Creek syncline, undoubtedly the most complex structural feature in the central part of the Arbuckle Mountains. Only the northwestern part of the syncline is shown on the accompanying map (Pl. II).

Rocks identified with the Mill Creek syncline lie south of the Belton anticline and include the pre-Pontotoc outcrops in secs. 21, 22, all except the NE¼ NE¼ sec. 23, and the south half of 24, all in T. 1 S., R. 3 E., and the southern part of sec. 19, T. 1 S., R. 4 E. The Mill Creek syncline and the Belton anticline are separated by a northwest-trending fault which, in sec. 19, lies between Arbuckle dolomite and the limestone member of the Oil Creek formation. The rocks dip steeply southward, forming the north limb of the Mill Creek syncline, and are broken by many strike faults.

OVERTHRUSTING IN THE SULPHUR AREA

Field studies in the Sulphur area indicate that a sheet of Paleozoic sedimentary rocks ranging in age from Ordovician to Pennsylvanian was thrust northward in late Pennsylvanian time from the Mill Creek syncline, or conceivably from the Tishomingo anticline, in accordance with the dominant structural movements of the Arbuckle Mountains. It moved as a low angle overthrust over the eroded surface of the Mill Creek syncline and extended onto the Belton anticline and Sulphur syncline, where it is now represented by 14 known klippen. The present northern boundary of the main overthrust sheet is marked by the trace of the curving Prindle Creek fault. The measurable horizontal displacement is at least 8,000 feet but the total displacement is unknown.

These concepts are advanced in a recent article by Lehman,[34] which describes the field occurrences and discusses the genetic possibilities in some detail, based on field work done in 1934-1935 for Phillips Petroleum Company. In mapping the area in 1944, the present writer and Dr. Decker were totally unaware of Lehman's earlier discoveries. Later the two maps were compared and found to be in close agreement. It was gratifying, moreover, that the idea of overthrusting had been conceived quite independently by the different field parties. Dott[35] had previously suggested overthrusting in the Arbuckle Mountains largely on theoretical grounds and his conclusions now seem justified in the light of specific evidence in the Sulphur area.

Curvature of the Prindle Creek fault. The fault that marks the present northern extent of the thrust sheet has been named the Prindle Creek fault,[36] from a small tributary of Buckhorn Creek that flows southward from the asphalt area in sec. 22, T. 1 S., R. 3 E. The pronounced curvature of the trace of this fault is suggestive of a low-angle overthrust. The fault has been mapped for 4.5 miles,

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[34] Lehman, R. P., "Thrust Faulting in Arbuckle Mountains, Oklahoma": *Bull. Am. Assoc. Petrol. Geol.*, Vol. 29, pp. 187-209, 1945.

[35] Dott, R. H., "Overthrusting in Arbuckle Mountains, Oklahoma"; *Bull. Am. Assoc. Petrol. Geol.*, Vol. 18, pp. 567-602, 1934.

[36] Gorman, J. M., Flint, G. M., Jr., Decker, C. E., and Ham, W. E., "Geologic Map of the Sulphur Asphalt Area, Murray County, Oklahoma": *U. S. Geol. Survey Oil and Gas Investigations, Preliminary Map* 22, 1944.

extending northeastward from the west central part of sec. 22, T. 1 S., R. 3 E. to the south central part of sec. 14, whence it curves southeastward for 2 miles to a point 800 feet south of the NW cor. sec. 30, T. 1 S., R. 4 E. From here it curves northeastward to the south central part of sec. 19, T. 1 S., R. 4 E, and then southeastward to the SW¼ sec. 20 of the same township. The fault extends beyond the area mapped for this report. Within the overthrust sheet, which includes the outcrops south of the Prindle Creek fault, the structure is generally synclinal, with McLish and younger beds dipping steeply southeastward in the western part of the sheet (secs. 22 and 23, T. 1 S., R. 3 E.) and westward in the eastern part (secs. 19 and 30, T. 1 S., R. 4 E.). The central part of the syncline contains outcrops of the Woodford formation, Caney shale, and a succession of lower to middle Pennsylvanian limestone, shale, and conglomerate.

The apparent displacement and offset are widely different at different places along the fault, a condition that suggests non-uniform movement of the thrust sheet. Tremendous stratigraphic displacement is shown by the contact of Pennsylvanian (Deese-Hoxbar?) conglomerate, dipping 75° NE, with Ordovician (McLish) limestone, dipping gently westward, at a point 500 feet north and 2,300 feet east of the SW cor. sec. 14, T. 1 S., R. 3 E.; and also by the contact of Pennsylvanian (Wapanucka?) limestone and Ordovician (Viola) limestone near the S¼ cor. sec. 24, T. 1 S., R. 3 E. In contrast, the apparent offset of the base of the Viola limestone is only 1,200 feet along the fault on Prindle Creek, in the center of the W½ sec. 22 of the same township. Lehman discusses the rotational movement of the fault in some detail.[37]

The steeply dipping Pennsylvanian conglomerate in the south-central part of sec. 14, T. 1 S., R. 3 E. is considerably older than the Pontotoc conglomerate and differs from it in being composed largely of Simpson, Hunton, and Woodford fragments, whereas the Pontotoc is composed dominantly of pebbles and cobbles of Arbuckle limestone. The conglomerate in the overthrust sheet rests on rocks in the Belton anticline and the south-bounding fault of the Belton anticline passes beneath it.

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[37] Lehman, R. P., *op. cit.*, pp. 203-206.

Structural correlation of rocks lying beneath overthrust sheet in Mill Creek syncline. South of the Belton anticline, on the map of the Sulphur area (Pl. II), only two exposures of about 1 square mile each are interpreted as representing the Mill Creek syncline proper, and the remaining 2.5 square miles that lies south of the Prindle Creek fault is identified with the overthrust sheet. The sheet is believed to have covered at one time all the Mill Creek syncline in this locality, the two present exposures of the syncline having been uncovered by erosion of the overthrust sheet. One of these exposures lies north of the Prindle Creek fault, chiefly in SE¼ sec. 24, T. 1 S., R. 3 E. and in the southern part of sec. 19, T. 1 S., R. 4 E., and contains outcrops of the Simpson formations and Viola limestone. The strata dip generally southward, away from the Arbuckle dolomite in the Belton anticline, to form the north limb of the Mill Creek syncline. Most of the dips are steep, ranging from 20° to vertical, and there are several strike faults of comparatively small displacement. The other exposure representing the Mill Creek syncline is a local faulted anticline that lies north and west of the Prindle Creek fault, chiefly in sec. 21 and the northern and western part of sec. 22, T. 1 S., R. 3 E. In the northern part of this exposure are outcrops of the Oil Creek formation dipping 6° NW. In the southern part are outcrops of the Simpson and Viola formations which dip steeply southward as in the other exposure of the Mill Creek syncline discussed above, and apparently the two exposures can be correlated by projecting their structural trends underneath the overthrust sheet.

ERRATIC MASSES (KLIPPEN) ON THE BELTON ANTICLINE AND SULPHUR SYNCLINE

The isolated, erratic masses of Simpson and Viola limestones on rocks of different age in the Sulphur area provoked considerable thought early in the field investigations, although the first mass found was such an anomaly that overthrusting was suspected at once. The hypothesis of overthrusting was strengthened as additional masses were discovered; and when it was learned, somewhat later, that Lehman had found these masses and independently had reached the conclusion that they are klippen, the phenomenon of overthrusting was established beyond reasonable doubt. At the present time 14 erratic masses are known, 10 on the Belton anticline and 4 on the Sulphur syncline. Field investigators who have seen them are agreed that they are erosional remnants or outliers of an overthrust sheet and that the parent sheet lies in the Mill Creek syncline to the south, where its northern boundary is marked by the trace of the curving Prindle Creek fault.

Most of the klippen are small, circular to elliptical hills that range in height from about 15 to 35 feet and in diameter from 200 to 600 feet. Probably the most conspicuous klippe is located 1,400 feet west and 1,700 feet south of the NE cor. sec. 14, T. 1 S., R. 3 E., or 200 feet west of State Highway 18 at a point 2.5 miles south of Sulphur (Pl. V, B). It rises about 35 feet above the comparatively level plain of the McLish sand. Another klippe, 2,100 feet west and 2,400 feet north of SE. cor. sec. 13, is perfectly conical and rises about 15 feet above the surrounding surface. In contrast, the small klippe 2,000 feet south and 500 feet east of the NW cor. sec. 13 has no distinctive topographic expression and is easily overlooked in the field. All 14 of the klippen are described in detail by Lehman.[38]

The klippen are composed of massive limestone. Ten are dominantly limestone of the Bromide formation, with lesser amounts of Viola limestone, generally near the crest of the hill; one is composed entirely of Viola limestone; two entirely of limestone of the McLish formation, as near as can be determined; and one of limestones of the McLish and Bromide formations. From evidence furnished by graptolites it is known that only the basal few feet of the Viola limestone are present, and the Bromide is represented by fine-grained limestone typical of the upper part of the formation, containing in many places the characteristic *Rafinesquina minnesotensis*. As the klippen are erosional remnants, it is obvious that only resistant rock like massive limestone could be preserved.

The rocks in the klippen are broken into many blocks that are oriented in every conceivable attitude and direction, but in which the original bedding surfaces are preserved. Most of the blocks

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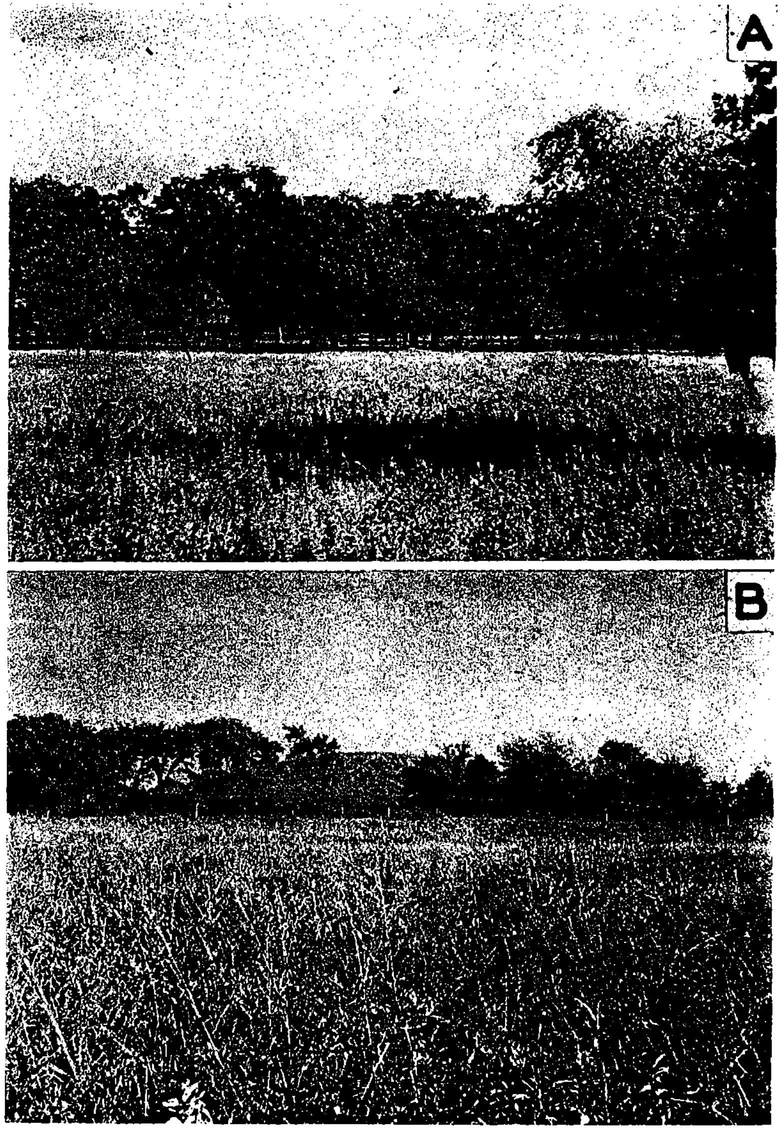
[38] Lehman, R. P., *op. cit.*, pp. 195-200.

PLATE V



A. Surface expression of sandstone member of Oil Creek formation. Flat topography, characterized by growth of oak trees. NW¼ sec. 24, T. 1 S., R. 3 E.

B. Klippe. Conical hill about 35 feet high composed of lower Viola and upper Bromide limestones, resting on flat surface of sandstone member of the McLish formation (in foreground). At least 700 feet of strata are missing between the klippe and underlying bedrock. NE¼ SW¼ NE¼ sec. 14, T. 1 S., R. 3 E., 2.5 miles south of Sulphur on State Highway 18.

have a volume of a few cubic feet or cubic yards. The lowest beds in some of the klippen are not broken to this extent and show synclinal or basin-like dip.

Stratigraphic relations. Probably the most cogent field evidence establishing the nature of the klippen is the absence of sedimentary beds normally lying between them and the underlying bedrock. This relation is best shown by the six klippen of Viola and Bromide limestones that rest on the limestone and sandstone members of the Oil Creek formation, at which the thickness of missing rocks is greatest. These klippen are located in the central part of sec. 13, the NW¼ sec. 24, and the SE¼ SE¼ sec. 12, T. 1 S., R. 3 E.

The rocks in these klippen represent the basal few feet of the Viola limestone and not more than the upper 50 feet of the Bromide formation. Hence at those erratic masses which rest on Oil Creek limestones the lower 350 feet of the Bromide and the full 500 feet of the McLish formation, a total of 850 feet, is the minimum thickness of missing strata. The additional 350 feet of the limestone member of the Oil Creek must be added to the 850 feet of McLish and Bromide, to give a total of 1,200 feet, at the klippe 1,350 feet east of the NW cor. sec. 24, where a mass of Viola and Bromide limestones rests on the sandstone member of the Oil Creek. In the two klippen of Viola and Bromide in the NE¼ sec. 14, T. 1 S., R. 3 E. that rest on McLish sand, 750 feet of section is missing, and the klippe near the center of the N½ sec. 14, which rests on the lower part of the limestone member of the McLish, has about 650 feet missing.

The only reasonable alternative to overthrusting and erosion as an explanation of these erratic masses is gravity slumping from a former escarpment capped by the Viola limestone and limestone of the Bromide formation. A very strong if not insurmountable objection to this alternative is that those masses of Viola and Bromide limestones which rest on the sandstone member of the Oil Creek formation must have slumped through about 1,200 feet of sedimentary rocks, including 350 feet of massive limestones of the McLish formation and 400 feet of limestone in the upper member of the Oil Creek formation. Even for those masses which rest on the sandstone of the McLish or on the limestone of the Oil Creek, it is necessary to assume slumping through the resistant limestones of the McLish, which seems a remote possibility.

In addition to the nine erratic masses described above, there are five other masses in the Sulphur area. The geologic relations at the five masses are such that each could be explained by gravity slumping, provided these relations were considered individually and not in association with other evidence to suggest overthrusting. For example, the erratic mass 2,400 feet west and 1,900 feet north of the SE cor. sec. 12, T. 1 S., R. 3 E., is composed of Viola and Bromide limestones, and rests on sandstone in the lower part of the Bromide formation. The present outcrop of the Viola limestone itself is only 500 feet north, and, as it dips northward, this bed formerly extended southward at a higher elevation. It is not inconceivable that an outlier capped by Viola and Bromide limestones might have slumped downward, through the soft rocks in the middle and lower part of the Bromide formation, and come to rest on rocks near the base of the Bromide. The validity of the slumping hypothesis is mitigated, however, when it is considered that the five erratic masses with this kind of stratigraphic, topographic, and structural relations are closely associated with undoubted klippen. The fourteen erratic masses are so similar that all probably owe their development to a common cause, namely overthrusting.

Significance of complex structure in the klippen. The significance of the broken character of the rocks and the synclinal dip in the klippen is not fully understood, although it is known that both features may be developed by normal slumping. For example, the small outlier of Oil Creek limestones resting on Oil Creek sands in the NW¼ sec. 15, T. 1 S., R. 4 E., has well-formed synclinal structure that developed by slumping from a higher elevation through the underlying loosely consolidated sands. In the NW¼ sec. 14, T. 1 S., R. 4 E. are two complexly broken masses of "birdseye" (McLish) limestone that lie partly on limestone of the Oil Creek formation and partly on loose sand of the McLish formation. The rocks are broken into blocks exactly like those in the true klippen. Another mass of the "birdseye" limestone with similar structure, but in its expected stratigraphic position, is found at the east edge of Roff, 500 feet southeast of the center of sec. 24, T. 2 N., R. 4 E. A third example is a complexly broken outlier of massive limestone from the upper part of the Bromide formation that rests on soft sands in the lower part of the same formation. It is 2,000 feet east of the SW cor. sec. 15, T. 2 N., R. 5 E. None of these outliers is related to any known overthrust fault and the stratigraphic and field evidence indicate clearly that they owe their complex structure to gravity slumping through loose sands or shales. From these observations it may be concluded that complex dips in themselves do not give unequivocal proof of faulting or thrusting and may not, in fact, be suggestive of it. As the nature of the true klippen is established chiefly on stratigraphic and other evidence, and not on complex dips, it may well be that the internal structure of the klippen is not related to overthrusting, and that the klippen developed their complex and synclinal dips by slumping in comparatively recent time, since their original emplacement as a part of the overthrust sheet. The magnitude of this slumping is believed to be small.

Age of the Thrusting

The youngest beds involved in the thrusting are strata of Pennsylvanian age—limestone conglomerate and red shale—which crop out in the north central part of sec. 23, T. 1 S., R. 3 E. and adjoining part of sec. 14. Their exact age is unknown but they probably correspond to some part of the Deese-Hoxbar (pre-Virgil) section in the Ardmore basin, as suggested by Lehman.[39] The thrusting evidently occurred after the deposition of these steeply dipping beds, and before the deposition of the gently folded Pontotoc conglomerate in late Virgil time. The Pontotoc conglomerate also is known to overlap the older beds. The age of the thrusting thus can be assigned to late Pennsylvanian time.

From evidence presented by Dott,[40] it is known that two major periods of structural deformation have affected the rocks in the Arbuckle Mountains, the first being a gentle arching of the Hunton,

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[39] Lehman, R. P., *op. cit.*, p. 195.

[40] Dott, R. H., "Overthrusting in Arbuckle Mountains, Oklahoma": *Bull. Am. Assoc. Petrol. Geol.*, Vol. 18, pp. 582-588, 1934.

Belton, and Tishomingo anticlines in early Pennsylvanian (pre-McAlester) time that uplifted and subjected these structural units to erosion. The second period was marked by more powerful stresses, culminating in late-middle Pennsylvanian (late Hoxbar) time, that produced intense deformation. These stresses formed the closely folded and overturned Arbuckle anticline, and thrust it northward, and subjected the Tishomingo anticline, Mill Creek syncline, and Hunton anticline to additional faulting, more complex folding, and some overthrusting.

Presumably, then, it was the erosional surface developed in mid-Pennsylvanian time over which the sheet in the Sulphur area was thrust in late Pennsylvanian time, this thrusting corresponding in age to the folding and thrusting of the Arbuckle anticline.

Hickory Area

The Hickory area embraces a strip of land 3 miles wide and 7 miles long in the central parts of T. 1 N., Rs. 4 and 5 E., Murray and Pontotoc Counties, extending through the town of Hickory to the vicinity of the Horseshoe ranch headquarters (Pl. III). The Frisco Railroad and State Highway 12 cross the area along the east edge of Hickory. The outcropping formations are upper Arbuckle dolomite and the lower beds of the Simpson group. Significantly, in this area as in other parts of the glass sand district, the Simpson beds have been preserved from erosion by local downfolding and faulting.

The Hickory area lies at the western edge of the Hunton anticline, as defined by Taff. (See fig. 2). Its general synclinal structure, however, is so distinct from the Hunton anticline that an individual name is warranted, and the name Hickory syncline is here proposed. The Hickory syncline is thus a localized structural unit within and subsidiary to the Hunton anticline.

Actually, there are three separate synclinal structures in the Simpson beds of the Hickory area, one south of the town, one north of it, and one about 4 miles eastward on the Horseshoe ranch. All the synclines are broken on the north by east-trending faults of moderate displacement. Beds in the south Hickory and north Hickory synclines have prevailing north dips at angles ranging between 8° and 25° and these are locally reversed due to drag against their respective faults. A major fault separates these units through the central parts of secs. 13, 14, and 15, T. 1 N., R. 4 E. The fault continues eastward to sec. 17, T. 1 N., R. 5 E. where it curves northward to a strike of N. 60° E. through secs. 9, 10, and 16 of the same township, north of the Horseshoe ranch headquarters. Here, southeast of the fault, is the third synclinal unit. The fault cannot readily be traced northeastward beyond sec. 10, as Arbuckle dolomite of similar lithology is on both sides of its trace. Its westward extension is covered by Pontotoc conglomerate in the SW¼ sec. 15, T. 1 N., R. 4 E. The maximum stratigraphic displacement is about 400 feet.

The Oil Creek formation cropping out in the north Hickory syncline is terminated on the north against Arbuckle dolomite by a fault that trends eastward through the central parts of secs. 10, 11, and 12, T. 1 N., R. 4 E. This fault has a maximum stratigraphic displacement of about 250 feet.

The best available measurements near Hickory indicate a thickness of 230 feet for the sandstone member of the Oil Creek and 155 feet for the limestone member.

Roff Area

The Roff area of this report embraces primarily the outcrop of strata in the Simpson group near Roff and Fitzhugh and covers parts of 14 sections in T. 2 N., R. 4 E., and T. 2 N., R. 5 E., southern Pontotoc County (Pl. IV). The area is well served by transportation lines, including the Frisco Railroad, State Highways 12 and 61, and many good section line roads.

The area lies at the northwest edge of the Hunton anticline, as defined by Taff, which includes the broad outcrop of upper Arbuckle dolomite lying between the Sulphur and Wapanucka synclines, on the south, and the Lawrence uplift and Franks graben, on the north (fig. 2). The dominant local structural feature in the Roff area is a broad anticlinal nose that plunges north-northwest off the Hunton anticline (Pl. IV). It is overlapped on the north and west by the Ada formation, which in this area contains limestone conglomerate, considerable shale, and some sandstone. The Arbuckle dolomite forms the central part of this nose and dips northeastward and northwestward at angles ranging between 5° and 20°; there are no dips to the southeast that indicate a major, closed structure. On either side of the axis the Simpson beds dip away into smaller folds that are separated from the Hunton anticline, at least partly, by faults. On the northeast flank is a somewhat asymmetrical syncline in Simpson and Viola strata, the northwest limb dipping 35°–50° NE and the southeast limb dipping northward 15°–20°. The Simpson beds in this syncline are separated from the Arbuckle by a fault that strikes N. 60° W. and has its greatest displacement of about 650 feet at a point 600 feet south of the NW cor. sec. 22, T. 2 N., R. 5 E. Here, in the axial part of the syncline, limestone in the upper part of the McLish formation is in fault contact with Arbuckle. The displacement is less in both directions from this point and the fault itself dies out in the north central part of sec. 17, T. 2 N., R. 5 E.

The limestone member of the Oil Creek formation can be traced, without displacement, northwestward from sec. 16, around the anticlinal nose in sec. 17, and thence southwestward to the vicinity of Roff. The outcrops in the western part of the area are of the Oil Creek and McLish formations, which have moderate dips ranging from 22° to horizontal. There are several small structural features in the western part of the area, one being a shallow syncline in sec. 18, T. 2 N., R. 5 E. and another being an anticlinal fold covering about 1 square mile in secs. 18 and 19, T. 2 N., R. 5 E. and secs. 13 and 24, T. 2 N., R. 4 E. The small anticline has low dips and has exposed a large area of McLish sand in its eroded crest; it is here that glass sand is being produced by the Mid-Continent Glass Sand Co.

The fault on the northwestern flank of the main anticlinal nose strikes N. 30° E. and has its greatest displacement, about 400 feet, in the NE¼ sec. 25, T. 2 N., R. 4 E, where beds in the lower part of the McLish limestones are in contact with upper Arbuckle dolomite. The fault disappears beneath conglomerates of the Ada formation in the NE¼ sec. 25, although it doubtless continues southwestward. The fault can be traced northeastward, with diminishing throw, until it dies out in the south-central part of sec. 18, T. 2 N., R. 5 E.

ECONOMIC GEOLOGY OF THE GLASS SANDS

Determination of plant site. The glass sand deposits in the central part of the Arbuckle Mountains have very poor surface exposures and consequently are best found by a combination of geology and engineering exploration. Where the geology indicates a potential glass sand deposit, test pits should be dug or drill holes made to obtain subsurface samples. Plant sites are then determined by the following economic considerations.

A sand body of sufficiently high quality, thickness, and areal extent must be proved. The crude sand should contain at least 98 percent silica and preferably less than 0.20 percent iron oxide. If the iron oxide is higher, it must be determined whether cheap beneficiation can reduce this compound to the allowable limit for finished sand. A sand of white color generally indicates a low content of iron oxide. The sand should be rather loosely consolidated, as an abundance of siliceous or calcareous cement may prevent disaggregation by simple hydraulicking. The sand should be at least 40 feet thick and cover enough acreage, probably 20 acres or more, to insure an adequate supply of sand for continuous production.

The deposit should be reasonably close to transportation lines, preferably a railroad. A good deposit of sand, however, might warrant the construction of a railroad spur of 1 mile or even longer.

The overburden must not be excessively thick. In the Oklahoma glass sand district overburden as thick as 20 feet has been removed, but this probably is the upper limit and overburden less than 10 feet thick is desirable.

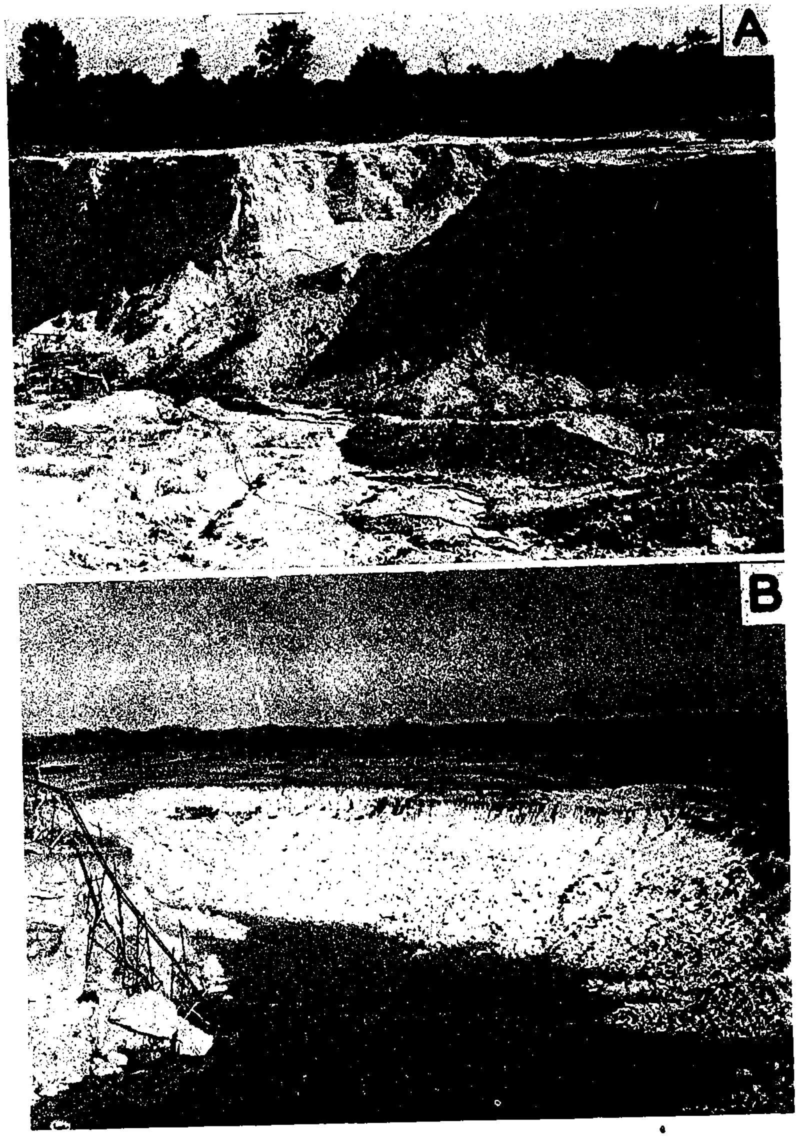
There must be a plentiful supply of water for mining and washing the sand. This is the least difficult of all factors to meet because if a surface supply is not readily available, water can be obtained from wells in the glass sand bed itself, which is a good aquifer. The Mill Creek Sand Co. obtains water from springs in an abandoned part of their pit; the Mid-Continent Glass Sand Co. depends on reclaimed water held in an abandoned pit; and the Sulphur Silica Co. uses water from a surface spring.

Quarrying. All quarries in the Oklahoma district are pits sunk in comparatively level ground (Pl. VI). The overburden consists of iron-stained, sandy soil and clay and ranges in thickness from 3 to 20 feet. It is removed by tractor-drawn scrapers and discarded on useless ground or in worked-out pits. Overburden should be removed from several acres in advance of the working face so that the ferruginous material in it will not be washed into the pit by rain.

Once the fresh sand is exposed, a pit is dug and deepened as rapidly as possible in order to provide a working face. The chief advantages of a deep pit are (1) a large face is available for production, (2) the cost of removing overburden has already been met, and (3) in general, there is less probability of surface iron-staining at lower depths and the sand will be of better quality. These advantages must be adjusted to the increased cost of pumping from greater depths and the operator himself must decide whether it is more economical to remove more overburden and start a new face or pay more for pumping. Forty or fifty feet of sand certainly can be worked profitably and one plant in the Arbuckle Mountains, the Mill Creek Sand Co., operates a face 67 feet high and pumps the sand 85 feet vertically from sump to wash house.

The sand is washed from the quarry face by hydraulic monitors under about 100 pounds pressure (Pl. VII). Most of the sand is loosely consolidated and is easily broken down by hydraulicking, although all operators loosen the face with light charges of dynamite. Most shot holes are drilled by hand augur. Some parts of the quarry at Mill Creek are too hard for hand auguring and the company has resorted to power drilling. Large sections of the face are shot to allow mass disaggregation under exposure to weathering, chiefly freezing and thawing. The loose sand washed from the face goes to a sump, from which it is pumped to the plant by steam pulsometer.

PLATE VI



A. Glass sand quarry of Mill Creek Sand Co. Massive sandstone of the Oil Creek formation in face 62 feet high. Pulsometer in left foreground.

B. Glass sand quarry of Mid-Continent Glass Sand Co., Roff. Pit no. 2 (abandoned) in green sands and calcareous sandstone beds of the McLish formation. Flat alluvial plain in background.

Beneficiation. Crude sand is not acceptable to glass manufacturers as a general rule, principally because it contains too much iron and other impurities. It is possible to reduce the impurities sufficiently by rather simple washing and this is the chief beneficiation given the Oklahoma sands. The washing process removes practically all the clay and provides also an abrasive action whereby small particles of limonite attached to the surface of sand grains are scoured off and go to waste as fines. The commercial washed sands contain 99.8 percent silica and 0.03 to 0.04 percent iron oxide (Table III).

The discharge of crude sand from the pulsometer at the plant passes a 26-mesh vibrating stainless steel screen on which rock fragments and aggregates of pyrite and limonite are rejected. Screening is an important adjunct to washing, for some of the iron in the crude sands has the form of limonite aggregates 0.5 to 1 inch in diameter. A composite sample of these aggregates from crude Oil Creek sand at Mill Creek contained 28.96 percent Fe_2O_3.

After screening, the sand goes to concrete wash boxes or cylindrical metal tanks that commonly are arranged in pairs so that the discharge from one goes to the other. An attempt is made to keep the sand agitated by vertically-directed water currents from jets in the bottom of the box, or by other means, because the greater the agitation the greater the loss of impurities. The sand from the wash boxes is dewatered, taken to wet storage, and drained for 36 hours or more on a bed of coarse cinders.

All the Oklahoma plants use the above process, but the Mid-Continent Glass Sand Co. uses in addition a combination of tabling and flotation, these practices being instituted when pyrite was encountered in the crude sand. The company has 12 Buchart tables adjusted to reject minerals of specific gravity greater than 3.0, and an eight-cell flotation unit designed to float and reject sulfides (pyrite).[41] The table heavy rejects contain considerable quartz and zircon, and rather small quantities of tourmaline, pyrite, and

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[41] Swanson, H. E., "Beneficiating Glass Sand": *Rock Products,* Vol. 48, No. 3, pp. 58-61, 84, March, 1945.

limonite. A count of the heavy minerals from the table rejects showed 82.7 percent zircon and only 1.4 percent pyrite. It may be mentioned, although quite apart from a consideration of glass sands, that these rejects may have some value as a source of zircon, as zircon concentrates containing 55 percent zirconia (ZrO_2) have a value of about $60.00 per ton f. o. b. Altantic seaboard.[42]

Whether the drained sand is sold as such, or is dried, depends upon the specifications of the glass manufacturer. A few prefer moist sand because it is claimed there is a reduced loss of fines in the furnace, whereas others insist on dry sand. The sand is dried at the plants in direct-fired, rotary kilns, using fuel oil or natural gas. The sand is shipped in paper-lined box cars, tarpaulin-covered coal cars, or gondolas, all of 50 tons capacity.

Uses and Markets. Virtually the entire production of sand from the plants in the Arbuckle Mountains district is used for manufacture of glass. A few cars have been shipped for foundry sand and miscellaneous uses but the tonnage is negligible compared to that consumed by the glass industry.

The principal existing markets for the sand are the glass plants in Oklahoma and north Texas. These include the Hazel-Atlas plants at Ada and Blackwell, both of which are supplied by the Mill Creek Sand Co.; Pittsburgh Plate Glass Co. at Henryetta; Ball Brothers plants at Okmulgee and Wichita Falls, Texas; Southwestern Sheet Glass Co., Okmulgee; Liberty Glass Co., George F. Collins Co., and Bartlett-Collins Co. at Sapulpa; Kerr Glass Co. and Kerr-Hubbard-Kelly Inc. at Sand Springs; and Hyatt Glass Co. at Poteau.

The longer freight haul nearly prohibits the Arbuckle Mountains producers from competing successfully in the area eastward and northward from Oklahoma, as the demand in that territory is met by sand producers in north central Arkansas (Guion and Everton), east central Missouri (Crystal City district), and north central Illinois (Ottawa district). Southward from Oklahoma, in Texas and possibly in Louisiana, are glass sand markets that are not being supplied with Oklahoma sand but which are closer geo-

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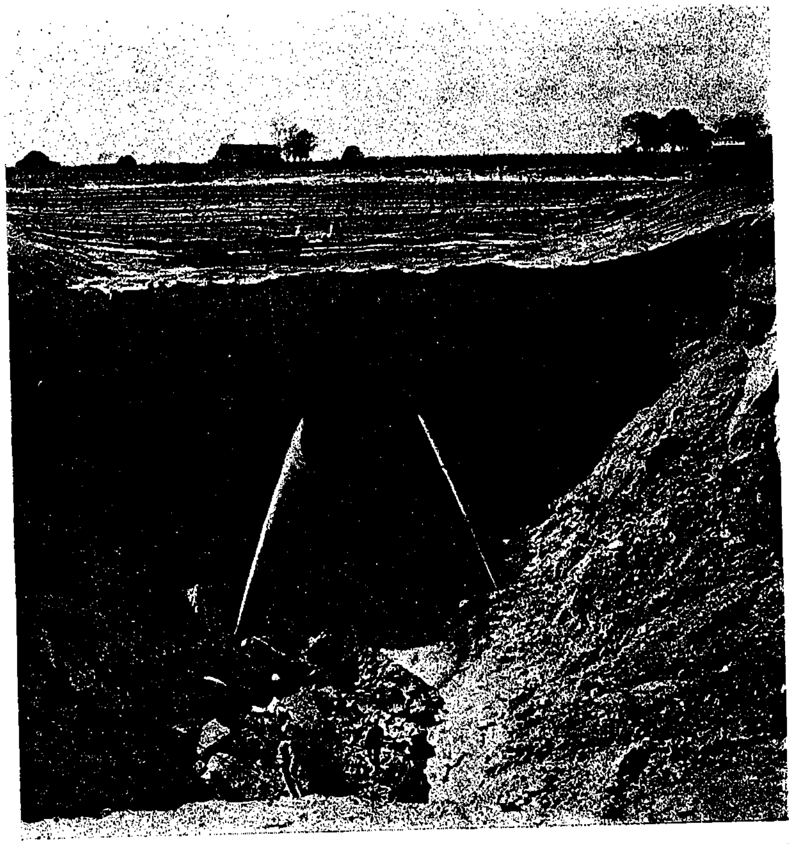
[42] *U. S. Bur. Mines Minerals Yearbook* for 1941, p. 810, 1943.

PLATE VII



Hydraulic mining of glass sand. Pit no. 3, Mid-Continent Glass Sand Co., Roff, in the sandstone member of the McLish formation. Sand in the quarry face is disaggregated by the two hydraulic monitors.

graphically to the Oklahoma deposits than to any other source. For example, the airline distance from Waco, Texas, to Sulphur, in the Arbuckle Mountains, is about 200 miles, whereas the distance from Waco to Guion, Arkansas, the nearest competitor, is approximately 400 miles. The saving in freight considerably enhances the possibility of Oklahoma producers to supply the Texas markets with high quality glass sand.

Production statistics and prices. Production of Oklahoma sands for manufacture of glass dates back at least to 1913, when Mid-Continent Glass Sand Co. shipped their first car from Roff, and about 1918 the deposit at Mill Creek was opened. These deposits have been worked continuously and have accounted for practically all the glass sand produced from Oklahoma. Between 1920 and 1930 the annual production averaged 24,569 tons with a value of $45,541.[43] In 1941, shortly after the Sulphur Silica Co. opened their pit, production increased to 80,437 tons valued at $128,699[44] and the writer estimates from data furnished by operators that approximately 130,000 tons with a probable value of about $235,000 was produced in 1944. The current price of processed sand per ton, f. o. b. plant, is $1.95 dry and $1.65 moist.

The Oklahoma Silica-Sand Co., Inc. in the spring of 1945 had nearly finished the construction of their plant at Hickory, thus making a total of 4 plants and indicating a healthy growth of the glass sand industry in Oklahoma. With increased use of sand for making glass and glass products in existing markets, with the possibility of extending the glass sand market into central Texas, and with the probability of finding new markets such as in ground silica, industrial sands, silica-lime brick, and manufacture of chemicals (sodium silicate, silicone, etc.), there is good reason to believe that the production may increase in the post-war period. If the demand is increased materially, it can be met by expansion of existing plants or erection of new ones. There are hundreds of acres of sand in the district that are undeveloped and could supply an amount many times the present production.

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[43] Beach, J. O., "Mineral Production of Oklahoma, 1885-1940": *Okla. Geol. Survey Min. Report* 13, p. 12, 1942.

[44] *U. S. Bur. Mines Minerals Yearbook* for 1941, p. 1274, 1943.

AREAS OF PRODUCTION

Mill Creek Area

Production of glass sand from the Oil Creek formation in the Mill Creek area was started about 1918. The original pit, still in operation, is in the SE¼ NW¼ sec. 6, T. 2 S., R. 5 E., 0.7 mile north of Mill Creek. The property was acquired about 1923 and has been continuously worked by the Mill Creek Sand Co., a subsidiary of Hazel-Atlas Glass Company. Mr. Paul Straughan is superintendent of the plant.

The quarry is an elliptical pit about 800 feet long east-west, 300 feet wide, and 67 feet deep. The overburden consists of yellowish to reddish sandy soil that has been derived from the sandstone by weathering. It ranges in thickness from 20 feet on the worked-out north face to 3 feet at the present workings in the center of the south face. About 1 acre of overburden is removed in advance of quarrying.

A measurement of the Oil Creek sandstone 1 mile southeast of the pit indicates a thickness of 360 feet, and a test hole drilled to a depth of 240 feet immediately south of the pit penetrated white sand without reaching the bottom of the Oil Creek formation. The beds in the pit represent the middle part of the sandstone member of the Oil Creek formation; they dip 15° SSE in the west wall of the quarry.

The sand in the pit is white, fine-grained, and massive (Pl. VI, A). It is rather friable and breaks down easily by hydraulicking, although light shots of dynamite are used occasionally to loosen the face. The sand in the center of the south face is lightly cemented by fine-grained silica and is too hard for hand auguring, so that recently the company has resorted to power drilling. A few small masses of strongly cemented sandstone, veined with siliceous stringers, occur here and there. In the bottom of the pit are two lenses of sandy dolomite, each about 1 foot thick, which either are left unmolested or are blasted out and abandoned in the pit. The only other visible impurities are small aggregates of limonite pseudomorphous after pyrite that are distributed along thin beds and joint surfaces.

A sample representing 62 feet of crude sandstone from the south face contained 99.57 percent SiO_2, 0.25 percent Al_2O_3, and 0.09 percent Fe_2O_3 (Table III).

The sand is washed from the quarry faces by hydraulic jets to a sump, from which it is taken by pulsometer to the wash house 85 feet above. The washed sand is taken to wet storage bins and allowed to drain 48 hours or more; only moist sand is shipped. All production goes to the Hazel-Atlas glass plants in Ada and Blackwell, Oklahoma. The washed sand is of high quality and contains 99.87 percent SiO_2, 0.04 percent Al_2O_3, and 0.03 percent Fe_2O_3 (Table III).

Favorable localities. The Oil Creek sand seems to offer the only favorable localities for new glass sand production in the Mill Creek area. It is thick, of high quality, and crops out near the railroad. Probably the best localities are in the area north and east of Mill Creek, along the curving outcrop of Oil Creek sand 1,400 feet to 2,500 feet wide in secs. 5, 6, and 8, T. 2 S., R. 5 E., and sec. 1. T. 2 S., R. 4 E. (Pl. I) The character of the sand and thickness of overburden should be similar to the exposures in the quarry of the Mill Creek Sand Co. The sand may be hardened by cementation, however, near the fault in sec. 1, T. 2 S., R. 4 E.

Two exposures of Oil Creek sand south of Mill Creek may have some possibilities, although both have been disturbed by major faulting and the sandstone may be too hard for simple hydraulicking. One exposure covers about 30 acres in the SW¼ sec. 17 and the NE¼ SE¼ sec. 18, T. 2 S., R. 5 E. The Frisco Railroad crosses the eastern part of the outcrop. The surface is covered with a heavy growth of oak trees and many boulders of very hard sandstone are strewn over the surface. The second exposure in the west central part of sec. 18, T. 2 S., R. 5 E. and adjoining section on the west covers about 70 acres. The surface soil is loose sand. A few exposures of the sand in the road cuts along the west line of sec. 18 show moderately soft, lightly-stained sand, apparently of good quality. This locality is 2,500 feet, air-line, from the railroad.

SULPHUR AREA

Glass sand has been produced from the Oil Creek formation in one locality in the Sulphur area since about 1939. A few cars were shipped at intervals but consistent production was not begun until April, 1944. In October the plant had an estimated capacity of 4 cars (200 tons) of dry sand per 12-hour day.

The original pit was opened on the property of the Sulphur Silica Co. in the NW¼ NE¼ NE¼ sec. 23, T. 1 S., R. 3 E. and sand from it was trucked to Sulphur for shipment by rail. The pit in operation during the summer and fall of 1944 is in the SE¼ NE¼ NE¼ sec. 23, T. 1 S., R. 3 E. and produces from the upper part of the sandstone member of the Oil Creek formation. The top of the sandstone is marked by the base of the limestone member of the Oil Creek about 200 feet west of the pit. The rocks dip southwestward at angles ranging between 17° and 23°.

The quarry is a circular pit 22 feet deep and 100 feet in diameter; the overburden is 3 to 5 feet thick and consists of dark-colored clay and loam. About 35 stratigraphic feet of sand is exposed. The lower 15 feet is fine-grained, friable, and white in color, whereas the upper 20 feet is cream to pale buff and contains some clay and streaks of bitumen, together with a few small nodules of limonite pseudomorphous after pyrite. A composite sample of crude sand from the upper and lower beds showed on analysis 99.44 percent SiO_2, 0.30 percent Al_2O_3, and 0.115 percent Fe_2O_3. The white sand in the lower 15 feet of the pit evidently is a very good grade of glass sand and if sand of this quality is present in stratigraphically lower beds of the Oil Creek formation to the east and north, in secs. 24 and 13, there is a large area and volume available for production.

The sand is hydraulicked from the pit and pumped by pulsometer to a wash box, from which it is taken by clam-shell crane to open piles for wet storage. The moist sand is hauled by truck to the drying plant in Sulphur, a distance of 3.5 miles. Practically all the company's sales have been dry sand for glass manufacture. A sample of the washed and dried plant run sand taken October 18, 1944, contained 99.83 percent SiO_2, 0.09 percent, Al_2O_3, and 0.04 percent Fe_2O_3 (Table III).

Favorable localities. The Oil Creek sand is thicker and has wider distribution than any other sand body in the Sulphur area, and deserves first consideration as a potential source of glass sand. Measurements made at several places indicate the sand is about 400 feet thick. From chemical analysis the sand is known to be of high quality and the major factors to determine new plant locations are distance to railroad transportation, thickness of overburden, induration of the sand, and availability of a plentiful water supply. The sandstones of the McLish and Bromide formations are thinner and are favorably exposed in very few localities.

The outcrops may be divided into 3 generalized areas: eastern, central, and western (Pl. II). The Oil Creek sand in the eastern area lies east of the Frisco Railroad, beginning in a narrow band 500 feet wide in the central part of sec. 24, T. 1 S., R. 4 E. and trending eastward through the central part of sec. 19, T. 1 S., R. 5 E., where the width of outcrop is increased to 1,000 feet. The outcrop is widened considerably by a fold in sec. 20, T. 1 S., R. 5 E., and about one-half of the section is underlain by the Oil Creek sand. As Pennington Creek flows along the outcrop, the overburden of alluvium probably is thick. Another outcrop 1,500 to 2,500 feet wide is exposed in a northeastward-trending belt through secs. 16, 21, and 28, T. 1 S., R. 5 E. On outcrops this sand seems to be of good quality and the only apparent disadvantage is its distance from the railroad.

Several lens-like outcrops of Oil Creek sand are exposed along the fault in secs. 13 and 14, T. 1 S., R. 4 E. but the areal extent of these is definitely small and the sandstone probably is hardened by silica cement.

The McLish sand in the syncline in the northern part of sec. 19, T. 1 S., R. 5 E. is poorly exposed and little is known of its character.

The most favorable locality in the eastern part of the Sulphur syncline appears to be the outcrop of the sandstone member of the

Oil Creek extending through the central parts of sec. 24, T. 1 S., R. 4 E. and sec. 19, T. 1 S., R. 5 E. There are very few hard blocks lying on the surface to indicate advanced induration of the sandstone, the overburden does not appear to be thick, and it is near railroad transportation.

The broad anticlinal area in the central part of the Sulphur syncline exposes an outcrop of the sandstone member of the Oil Creek formation about 1 mile wide and 3 miles long, covering most of secs. 14, 15, and 16, T. 1 S., R. 4 E. The rocks have low to moderate northward dip and the surface is mostly flat and cultivated. The eastern edge of the outcrop is less than 0.5 mile from the railroad, so that a spur could be extended, without excessive cost, to serve many plant locations. The area is worthy of consideration by any party interested in producing glass sand in the Arbuckle Mountains, and drill holes or test pits should be put down to determine the thickness of the overburden and to obtain samples for chemical analysis.

Outcrops of Oil Creek sand in the western part of the Sulphur area are at a disadvantage because of the distance to a railroad, the nearest being at Sulphur, about 3 miles north. The sand, however, is of high quality and has been produced from one locality since 1939. The principal outcrop is a band 2,000 to 3,500 feet wide that trends northeastward through secs. 13, 23, and 24, T. 1 S., R. 3 E. The surface is rather flat, it is cultivated in most places, and the overburden does not appear to be excessively thick. A few exposures in the belt and at the sand pit in NE¼ NE¼ sec. 23 show that the sand is white and friable.

Northwestward, chiefly in sec. 14, T. 1 S., R. 3 E., a belt of McLish sand 1,000 to 1,500 feet wide trends northeastward parallel to the outcrop of Oil Creek sand. The strata dip 8° NW. The best exposure of the sand is in an abandoned pit 1,200 feet west and 700 feet south of the NE cor. sec. 14, in which the sand is impregnated with asphalt.

A wide outcrop of Oil Creek sand is exposed in the vicinity of the pits of the Southern Rock Asphalt Co. in secs. 15, 21, and 22, T. 1 S., R. 3 E. The sand contains 7 to 8 percent bitumen and

has been extensively quarried for road material.[45] The northeast-trending band of Oil Creek sand in the eastern part of sec. 21, however, is only slightly stained with asphalt and appears to be a good quality glass sand, low in iron oxide impurities.

HICKORY AREA

Sand from a pit 1,500 feet north and 200 feet west of the SE cor. sec. 11, T. 1 N., R. 4 E., 0.5 mile north of Hickory, was used for glass manufacture during a period from about 1918 to about 1923. The pit, now abandoned, is about 200 feet in diameter and 40 feet deep and lies between the railroad and State Highway 12. The exposed rocks are in the middle part of the sandstone member of the Oil Creek formation, dipping 12° NW. The sand is rather well stratified, fine-grained, moderately soft, and white to pink in color. At the top of the north face of the pit is a 6-foot bed of cream-colored, fine-grained dolomite and northward beyond it are many surface blocks of quartzitic sandstone.

Interest was revived in the glass sand possibilities of the Hickory area when, early in 1944, the Oklahoma Silica-Sand Co., Inc. began erecting a plant on the west side of the railroad opposite the abandoned pit. Completion of the plant has been delayed, however, owing to the difficulty in obtaining machinery under war-time restrictions. Mr. C. W. Gould, Ada, Oklahoma, is secretary of the company. The plant has equipment for washing and drying the sand and a siding about 1,700 feet long has been constructed on the west side of the railroad. About 10 feet of sandy soil overburden has been stripped from the quarry site adjoining the plant on the west, exposing a few feet of the Oil Creek sand which apparently is of good quality.

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§The Oklahoma Silica-Sand Co. started commercial production in October, 1945, after the manuscript for this bulletin was submitted for publication. A sample of plant run sand taken October 22, 1945, was analyzed in the laboratory of the Oklahoma Geological Survey

Chemical Analysis*

Fe_2O_3	0.029
Al_2O_3	0.104
CaO	0.000
MgO	0.006
L. O. I.	0.074
SiO_2 (by difference)	99.787

*A. L. Burwell, analyst.

Sieve Analysis

Screen (mesh)	percent retained
60	1.3
80	15.0
115	50.5
170	28.7
250	3.5
Pan	0.9

[45] Gorman, J. M., et al, "Geologic Map of the Sulphur Asphalt Area, Murray County, Oklahoma": *U. S. Geol. Survey Oil and Gas Investigations, Preliminary Map* 22, 1944.

Favorable localities. A plentiful supply of sand is available near the site of the Oklahoma Silica-Sand Co., as the outcrop is 1,300 to 2,000 feet wide in a strip extending southwest of the plant in secs. 11 and 14, T. 1 N., R. 4 E., and covers more than 200 acres near the railroad (Pl. III). The sandstone dips northwest about 11° and is 230 feet thick in this locality. The Oil Creek sand crops out in an additional 200 acres in the NW¼ sec. 15 and the SE¼ sec. 10, T. 1 N., R. 4 E.

The second area of potential glass sand is the outcrop of Oil Creek sand that covers more than 900 acres and extends as an east-trending belt south and east of Hickory, through parts of secs. 13, 14, 22, and 23, T. 1 N., R. 4 E., and sec. 18, T. 1 N., R. 5 E. The railroad crosses the central part of this outcrop. There are few exposures of sand within the belt but it is so extensive and so close to the railroad that a program of exploration by test pits or drill holes, to determine the feasibility of a plant location, would be justified.

The outcrop of Oil Creek sand near the Horseshoe ranch headquarters is similar to those near Hickory but has the disadvantage of being 3.5 miles from railroad transportation.

ROFF AREA

The Mid-Continent Glass Sand Co. operates its quarries and beneficiation plant at the northeast edge of Roff. The company is the original producer of glass sand in Oklahoma and has been in continuous operation since August, 1913. The plant has a rail siding from the main line of the Frisco Railroad, and all quarries are within 900 feet of the plant. Mr. Kenneth P. Larsh is managing partner of the Company. Mid-Continent has extensive holdings of glass sand properties in the area.

Briefly, the production methods include hydraulicking crude sand from the pit to a sump and pumping by steam pulsometer to the plant, where it is washed, tabled, and subjected to flotation to remove pyrite. These practices are described in detail by Swanson.[46] The processed sand contains 99.83 percent SiO_2, 0.044 per-

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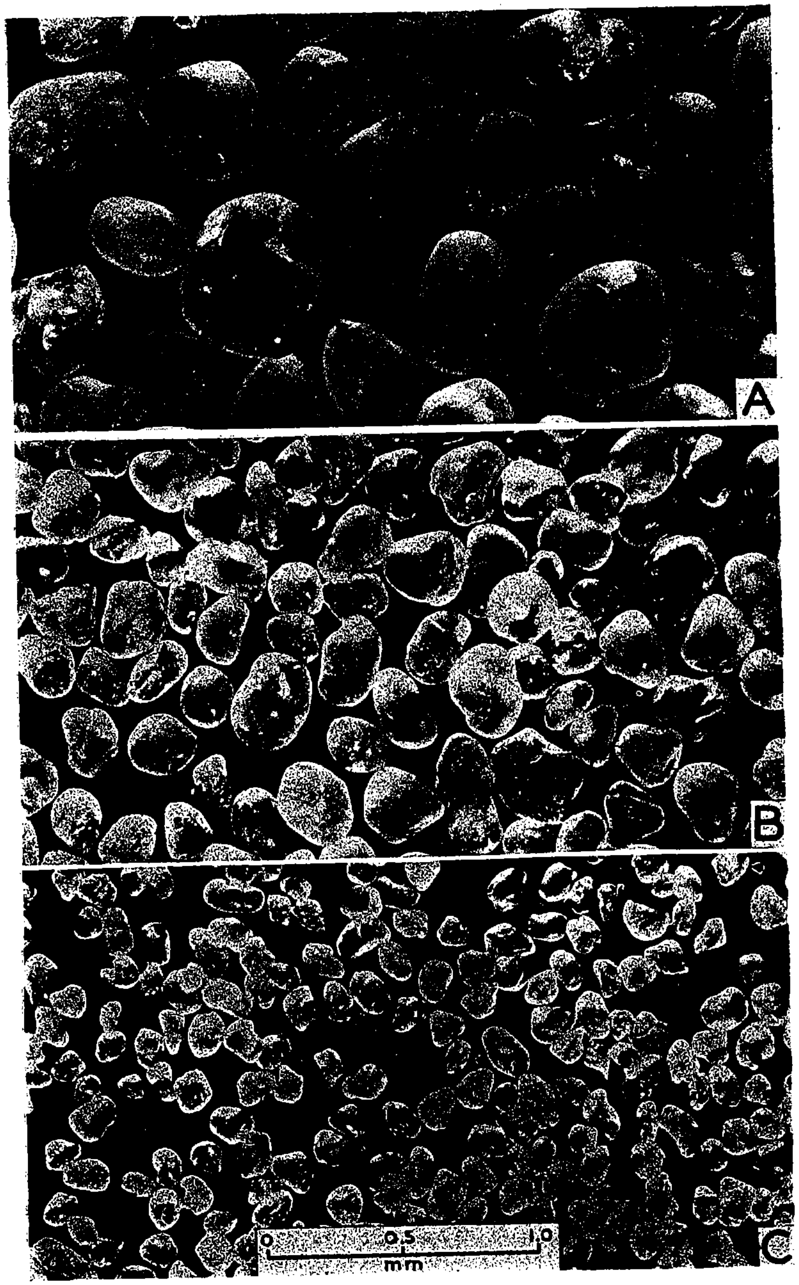
[46] Swanson, H. E., "Beneficiating Glass Sand": *Rock Products*, Vol. 48, No. 3, pp. 58-61, 84, March, 1945.



Photomicrographs illustrating shape and surface features of Simpson sands. Plant run sand from the McLish formation, Mid-Continent Glass Sand Co. X35.

A. Medium sand, 0.5—0.25 mm diameter.

B. Fine sand, 0.25—0.12 mm diameter.

C. Very fine sand, 0.12—0.06 mm diameter.

cent Fe_2O_3, and 0.054 percent Al_2O_3 (Table III). The company's production of about 300 tons per day goes mostly to Oklahoma glass plants; a small amount is shipped to foundries for molding sand.

In this locality the surface is a practically flat, cultivated, alluvial plain of black clay and silt, with local lenses of well-rounded stream pebbles (Pl. VI, B). The alluvium has been derived from Blue Creek, which flows eastward in a sinuous course south of the sand plant. There are no sandstone outcrops on the plain and but a few in the valley of Blue Creek. To the northeast, in the SW¼ sec. 18, T. 2 N., R. 5 E., is a low scarp of McLish limestones, dipping 8° NE, and to the north and west is a somewhat higher scarp formed by conglomerate, shale, and sandstone of the Ada formation. These scarps, together with the course of Blue Creek, mark the approximate boundaries of the largest outcrop of McLish sand in the Roff area (Plate IV). The glass sand quarries are near the center of this outcrop.

The structure is predominantly anticlinal and is centered around the common corner of secs. 18 and 19, T. 2 N., R. 5 E., and secs. 13 and 24, T. 2 N., R. 4 E. Dips of low magnitude prevail and generally range between 4° and 8°. Modifying the axial part of the anticline in the SE¼ sec. 13 is a local syncline, in which a small outlier of McLish limestone has been preserved from erosion.

The three pit quarries of the Mid-Continent Glass Sand Co. are located around the edges of the limestone outlier, which is regarded by the operators as a "cap rock". The original and largest pit (pit no. 1) skirts the southern boundary of this "cap rock" in a semi-circular pattern. This pit is 1,500 feet long, 250 feet wide, and 50 feet deep. It exposed the uppermost 40 feet of buff to white sandstone and, below it, a few feet of green-colored sand, all in the sandstone member of the McLish formation. When the pit had been worked out, a new one (pit no. 2) was begun about 300 feet south. It encountered only the lower "green" sand, the upper white sand not being present owing to the north dip of the strata. Numerous beds and boulders of calcareous sandstone eventually forced its abandonment after working out 3.5 acres of sand to an average depth of 30 feet. A third pit (pit no. 3) was then excavated north of the original one, on the north side of the limestone outlier. It encountered 38 feet of the upper sandstone and exposed 12 feet of the "green" sand in the bottom of the pit. During the fall of 1944 most of the sand, about 80 percent, was produced from the upper buff-colored beds in a pit 200 feet wide and 300 feet long. The overburden in the vicinity of the plant consists of black to brownish soil, clay, and gravel, and ranges in thickness from 9 to 11 feet.

The prevailing color of the upper sandstone beds is white, but owing to differences in iron oxide content it is cream, buff, or yellowish-brown locally. In quarry faces the sand appears massive yet shows faint bedding planes that divide the formation into beds 0.5 to 2 feet thick. The chief impurity is iron oxide, which occurs in the form of small aggregates of limonite and as coatings on the surface of the sand grains. It is clear that the limonite originated from the weathering of pyrite, and some, perhaps most, of the iron oxide resulting from this weathering has been transported in solution by ground water to be deposited later as the surface films on the individual grains. The sand grains are dominantly of fine size and consist of loosely consolidated, rounded and frosted quartz.

The lower green-colored sandstone, of which about 50 feet is exposed in the pits, is characterized by an abundance of the green clay mineral illite, a common constituent in sedimentary rocks. The sand grains themselves are typical white, fine grained, and frosted Simpson sands, but the clay is so uniformly distributed that it gives an outcrop a distinctive aquamarine color. Most of this sand is friable and the clay is easily washed off. There also is a small amount of fresh pyrite in small cubic crystals and crystal aggregates. The most serious detriment to sand producers, however, is the occurrence of beds and discontinuous lenses of calcareous sandstone about 25 feet below the top of the green sand unit. Several of these beds, 12 to 18 inches thick, are present in pit no. 2, interstratified with layers of sand. The calcareous sandstones prevent economical quarry operations because they must go to waste, yet have to be quarried in order to reach the intervening sand beds. Pit no. 2 was abandoned because these hard beds were so abundant. Detailed sieve tests, chemical analyses, and mineralogical investigations of these sands are considered in the chapter on composition of the sands.

Favorable localities. Sandstone beds of three formations, the Oil Creek, McLish, and Bromide, have possible value as glass sand in the Roff area. The sandstone of the Bromide formation is the least attractive of the three because it does not crop out along the railroad, the nearest outcrop being about 0.5 mile distant, in sec. 16, T. 2 N., R. 5 E. Here the dip is so steep that only a narrow band of sandstone is exposed. The best exposure of Bromide sandstone extends south 400 feet from the NW cor. sec. 22, T. 2 N., R. 5 E., along the east cut of the road. The sand is friable, fine-grained, moderately iron-stained, and has only a few feet of overburden. This locality is about 9,000 feet, airline, from the railroad.

The McLish sand has its widest outcrop near the pits of the Mid-Continent Glass Sand Co., and considerable sand is still available in this vicinity. The most promising undeveloped area appears to be a tract covering about 50 acres north of the railroad in the SW¼ sec. 18, T. 2 N., R. 5 E., between the pits and the basal beds of the McLish limestones to the northeast. The overburden is of about the same order of thickness as at the present pits, but the purity of the sand is unknown and will have to be determined by drilling. Southward and eastward from the plant the overburden seems to increase in thickness toward Blue Creek and the sand itself probably contains beds of calcareous sandstone.

A narrow strip of McLish sand about 700 feet wide trends northeastward for about 1 mile through secs. 17 and 18, T. 2 N., R. 5 E., nearly parallel to and 500-700 feet north of the railroad. About 80 acres of sand crop out in this belt.

The other areas of McLish sand in the Roff area are not likely to be exploited because of their small outcrop and long distance from the railroad.

The Oil Creek formation, which produces high quality glass sand in the southern part of the glass sand district, is much thinner and its outcrop is less extensive in the Roff area. No exceptionally good locations are available here, the best apparently being the outcrop along which the railroad passes through secs. 17 and 18,

T. 2 N., R. 5 E. The sand is exposed for a short distance along a tributary to Blue Creek, about 50 feet downstream from the railroad trestle 1,300 feet north and 1,100 feet west of the SE cor. sec. 18. It is fine grained, cream-colored by surface iron oxide, and has a few siliceous veins. The overburden is about 8 feet thick. Southwestward in sec. 19 there is a considerable thickness of wind-blown sand that may form an excessive overburden. The overburden in the western part of sec. 16, T. 2 N., R. 5 E., and in the northeastern part of sec. 17 also appears to be great. The quality of the Oil Creek sandstone in the Roff area will have to be determined by detailed sampling, although by analogy with the deposits at Mill Creek and Sulphur it probably is of high quality.

GLASS SANDS IN OTHER PARTS OF THE ARBUCKLE MOUNTAINS

Although not investigated for this report, sandstones of the Simpson group crop out in the western, southern, and eastern parts of the Arbuckle Mountains. The sands in these outcrops probably have about the same chemical, mineralogical, and physical properties as those in the producing district. As most of these outcrops are several miles from a railroad, they can not, under present economic conditions, be considered commercial deposits. Buttram studied many of these localities and from his report[47] is taken the following information on deposits reasonably close to existing railroads.

The Simpson formation is exposed along the Gulf, Colorado, and Santa Fe Railway on the east bank of Washita River, 0.5 mile south of Crusher, in NW¼ sec. 31, T. 2 S., R. 3 E., Murray County. The beds dip 75° southwest and consist of interbedded layers of sandstone, shale, and limestone. Buttram makes a three-fold division of the strata, the lowest division of which contains an 86-foot bed of sand. It is the thickest sand bed exposed and probably corresponds to the lower member of the Oil Creek formation of present usage. The average of three samples of crude sand from the top, middle, and bottom of the ledge shows 99.209 percent SiO_2, 0.106 percent Al_2O_3, 0.075 percent Fe_2O_3, 1.419 percent CaO, and 0.067 percent MgO. The lower and middle samples consist dominantly of medium and fine sand, whereas the upper sample consists of fine and very fine sand.[48]

The sand crops out along the railroad in a solid bluff about 100 feet high. The chief disadvantage of the locality is that the outcrop of the sand body is only about 100 feet wide, owing to the steep dip of the beds. Furthermore, there is little space at the foot of the bluff available for the erection of a washing plant.

Buttram discusses in some detail a wide outcrop of sandstone beds of the Simpson, chiefly the sandstone member of the McLish formation as mapped by Decker, in the southeast part of T. 1 S., R. 7 E., Johnston County, about 3 miles west of Bromide. One exposure in this area is a bluff along Delaware Creek in sec. 35, which indicates sand beds at least 21 feet thick. Their chemical composition is similar to the one cited from near Crusher, and the grain size is substantially the same, most samples containing about 15 percent medium sand, about 60 percent fine sand, and 25 percent very fine sand.[49]

The beds are nearly horizontal and some outcrops are near Delaware Creek, which could provide a source of water for washing the sand. One serious objection to this locality, however, is that it is about 2 miles from the railroad at Bromide.

Another outcrop of sand in the vicinity of Bromide was investigated briefly by the Survey in 1943 because of its relatively coarse grain size. The sandstone bed is about 10 to 20 feet thick and crops out locally in the central part of sec. 36, T. 1 S., R. 7 E., about 1 mile west of the Dolese Bros. limestone quarry. The outcrops show definitely that the sand would have to be mined underground, although fortunately there is a massive limestone overlying the sand that would make a satisfactory roof.

The samples of loose sand available at the outcrop are so obviously stained with surface concentrations of iron oxide that a

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[47] Buttram, Frank, "The Glass Sands of Oklahoma": *Okla. Geol. Survey Bull.* 10, 1913.

[48] Buttram, Frank, *op. cit.*, p. 52.

[49] Buttram, Frank, *op. cit.*, p. 63.

chemical analysis would be valueless, but it may be presumed by analogy with other deposits in the region that fresh samples will be of good quality, provided that carbonate cement is lacking.

The sand is exceptionally coarse, two samples showing 25.0 to 5.6 percent coarse sand (larger than 32 mesh), 71.0 to 90.7 percent medium sand, and 3.5 to 2.9 percent fine sand. The grains are rounded, pitted, and frosted, and most of them are free from secondary enlargements.

COMPOSITION OF THE SANDS

Field Sampling. All field samples were taken by the writer in such a way as to yield the nearest approximation to representative material. Outcrops of the sandstones were sampled by the channel method. A channel 1 to 3 inches wide and about 1 inch deep was cut vertically in the quarry face with a sharp-pointed hammer, the sand from the channel being put on an oilcloth about 4 feet square and the hard pieces broken to a diameter of about ¼ inch. The sand was then mixed and quartered to about 50 pounds and this constituted the laboratory sample.

The plant-run samples were obtained (1) by cutting a channel from the surface and along the length of a loaded 50 ton car, ready for shipment; or (2) by taking a cut from the car-loader with a hollow metal pipe, sampling continuously for 45 minutes; or (3) by inserting a hollow pipe 4½ feet long and 1 inch in diameter at many places in a stock pile. For all methods, large cuts weighing 150 to 200 pounds were taken and quartered to about 50 pounds.

Laboratory preparation. In the laboratory the crude sands were disaggregated by gentle rubbing with a porcelain mortar and pestle, porcelain being used to prevent iron contamination. The bulk of each sample was comparatively soft and responded easily to the rubbing. The plant run sands were already disaggregated and needed no further treatment. The samples, after drying on a hot plate, were split on a standard Jones splitter to yield one fraction for chemical analysis, one for mineralogical examination, and one for sieve analysis. The remainder is stored in the files of the Geological Survey.

CHEMICAL ANALYSES

Chemical analyses of the crude and plant run sands quarried in the central Arbuckle Mountains are shown in Table III. The analyses were made in the laboratory of the Oklahoma Geological Survey by Dr. A. C. Shead. Standard procedure recommended by the Committee on Standards of the Journal of the American Ceramic Society[50] were used, with the exception that for the determination of silica, ammonium fluorides were substituted for hydrofluoric acid. Shead has explained the use and accuracy of this method in an earlier article.[51]

The analyses cited in Table III show the chemical composition of the glass sands being produced in the Arbuckle Mountains. More samples should be analyzed before general conclusions can be drawn, but outcropping beds are uncommon in the district covered by this report and the few outcrops available are mostly hard blocks, indurated with siliceous cement and stained by surface concentrations of iron oxide. Such samples would not be representative and accordingly no collections were made. On the other hand, the quarry samples represent considerable thicknesses of strata and are free from impurities of surface weathering. They are considered a reliable indication of the general quality of the sand. Local differences undoubtedly exist, so that it would be necessary to obtain subsurface samples at any contemplated quarry site.

The Oil Creek sand is being worked for glass sand at Mill Creek and Sulphur. The table shows a close similarity in chemical composition for the crude sands, the SiO_2 averaging 99.51 percent; Fe_2O_3, 0.10 percent; and Al_2O_3, 0.28 percent. The combined CaO and MgO average 0.04 percent. Most of the iron is present as a coating on the sand grains and in small aggregates of limonite, whereas the alumina occurs chiefly in the clay minerals. In the washed sands the SiO_2 is increased to an average of 99.85 percent; the Fe_2O_3 is decreased about 65 percent to 0.035 percent; Al_2O_3 is decreased about 75 percent to 0.065 percent, and CaO plus MgO

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[50] *Jour. Am. Ceram. Soc.*, Vol. 11, No. 6, pp. 368-371, June, 1928.

[51] Shead, A. C., and Smith, G. Frederick, "The Decomposition of Refractory Silicates by Fused Ammonium Fluoride and its Application to the Determination of Silica in Glass Sands": *Jour. Am. Chem. Soc.*, Vol. 53, pp. 483-486, 1931.

TABLE III

CHEMICAL ANALYSES OF OKLAHOMA CRUDE AND PLANT RUN GLASS SANDS

Operator	Location	Geologic Formation	Date Sampled	Nature of Sample	SiO_2 (Silica)	Al_2O_3 (Alumina)	Fe_2O_3 (Iron Oxide)	CaO (Lime)	MgO (Magnesia)	H_2O (−105°C)	Loss on Ignition (+105°C)	Total
Mill Creek Sand Co.	Sec. 6, T. 2 S., R. 5 E., Johnston Co.	Oil Creek	Oct. 17, 1944	Crude Sand 62 Feet	99.57	0.25	0.09	0.021	0.058	0.06	0.17	100.22
				Plant Run (washed)	99.87	0.04	0.03	0.01	0.01	0.01	0.076	100.05
Sulphur Silica Co.	Sec. 23, T. 1 S., R. 3 E., Murray Co.	Oil Creek	Oct. 18, 1944	Crude Sand 35 Feet	99.44	0.30	0.115	0.027	0.055	0.063	0.127	100.127
				Plant Run (washed)	99.83	0.09	0.04	0.007	0.001	0.017	0.049	100.034
Mid-Continent Glass Sand Co., Roff	Sec. 13, T. 2 N., R. 4 E., Pontotoc Co.	McLish	Oct. 19, 1944	Crude Sand Upper 38 Feet	98.39	0.75	0.26	0.06	0.007	0.14	0.32	99.927
				Crude Sand Lower 12 Feet	97.82	1.16	0.40	0.16	0.003	0.22	0.49	100.25
				Plant Run (washed, tabled, and floated)	99.83	0.054	0.044	0.02	0.004		0.09	100.042

is reduced to an average of 0.006 percent. The chemical composition of the processed sands is very satisfactory for glass manufacture.

The crude McLish sand which is being produced currently at Roff contains considerably more alumina and iron oxide than the crude Oil Creek sandstone samples. The upper bed is 38 feet thick and contributes at least 80 percent of the sand processed at the plant. Crude sand from this bed has 98.39 percent SiO_2, 0.26 percent Fe_2O_3, and 0.75 percent Al_2O_3, with a low content of CaO and MgO. The iron and alumina are present as a coating of ferruginous clay and particles of limonite on the sand grains, and to a lesser extent as small aggregates of limonite. A small percentage of alumina is in feldspar. (See Table VI). The lower bed is exposed in the lower 12 feet of the quarry and contributes less than 20 percent of the processed sand. Two mineralogic features characterize this lower sand bed: (1) a relatively high content of green clay (illite) and (2) an abundance of small pyrite crystals, such as was observed at no other place in the district. The iron content of 0.40 percent is much higher than would be acceptable in a normal crude glass sand. The alumina is likewise high (1.16 percent) and CaO is higher than is desired. The sand grains themselves, however, are perfectly white and unstained by iron oxide or clay. Practically all the iron is in the pyrite; and all the alumina and calcium, together with a small amount of iron, are in the green clay. Both pyrite and clay are removed by washing, tabling, and sulfide flotation at the plant and the processed McLish sand then contains 99.83 percent SiO_2, 0.044 percent Fe_2O_3, 0.054 percent Al_2O_3, 0.02 percent CaO, and 0.004 MgO. This analysis compares favorably with processed Oil Creek sand and also with leading glass sands in other parts of the United States.

Detailed comparisons of the chemical composition of glass sands from different parts of the United States are, in general, difficult to make owing to the different methods of analysis used and to the incompleteness of data regarding source of the sample. Many published analyses do not specify whether the sand is crude or washed, or whether the sample is a selected hand specimen or represents a complete quarry face. In view of these uncertainties it is impossible to make comparisons that are fair to all producers or to all districts.

Recommended chemical specifications. The specifications laid down by glass producers, however, indicate a general composition to which competitive sands must conform, and it is safe to say that all sands produced for glass in Oklahoma and the Illinois-Missouri-Arkansas district undoubtedly meet these specifications. Although no definite standards have been adopted, a list of specifications has been given by the American Ceramic Society and the United States Bureau of Standards. The recommended percentage compositions, based on ignited samples, of sands for the better grades of glass are given in Table IV.

TABLE IV

Chemical Specifications of Glass Sands for Certain Grades of Glass[52]

	SiO_2 minimum	Al_2O_3 maximum	Fe_2O_3 maximum	CaO+MgO maximum
First quality optical glass	99.8 ±0.1	0.1 ±0.05	0.02 ±0.005	0.1 ±0.05
Second quality glass containers, tableware	98.5 ±0.5	0.5 ±0.1	0.035 ±0.005	0.2 ±0.05
Third quality flint glass	95.0 ±1.0	4.0 ±0.5	0.035 ±0.005	0.5 ±0.1
Fourth quality sheet glass rolled and polished plate	98.5 ±0.5	0.5 ±0.1	0.06 ±0.005	0.5 ±0.1
Fifth quality sheet glass, rolled and polished plate	95.0 ±1.0	4.0 ±0.5	0.06 ±0.005	0.5 ±0.1
Sixth quality green glass containers and window glass	98.0 ±1.0	0.5 ±0.5	0.3 ±0.05	0.5 ±0.1

It is to be noted that the Oklahoma sands meet the specifications for flint glass, glass containers, tableware, sheet glass, and rolled and polished plate glass. Moreover, the writer believes that with special care and beneficiation it would be possible to produce sand for optical glass from certain deposits in the Arbuckle Mountains.

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[52] Weigel, W. M., "Technology and Uses of Silica and Sand": *U. S. Bur. Mines Bull.* 266, p. 132, 1927.

PLATE IX

A. Photomicrograph of plant run sand from Oil Creek formation, Mill Creek Sand Co., X35.

B. Photomicrograph of plant run sand from Oil Creek formation, Sulphur Silica Co. X35.

MINERAL COMPOSITION

Procedure. The minerals in the sandstones were disaggregated and the loose grains studied with a petrographic microscope. The investigations were facilitated by use of the "heavy mineral" method.

The "heavy minerals" in a clastic rock such as a sandstone are those with a specific gravity greater than quartz (2.65). They commonly constitute a fraction of 1 percent of the sample. By convention, a liquid of specific gravity greater than that of quartz is used, the quartz and other light minerals being retained by floating or in suspension whereas the heavy minerals sink and the two fractions are thus separated.

Widely used as a means of investigating the provenance, or source area, of clastic rocks and of establishing criteria valuable for correlation, the heavy mineral method also has a useful application in the study of glass sands. Besides yielding information regarding provenance and correlation, it provides detailed knowledge of the minerals that contain iron and thus suggests the best means of eliminating those objectionable compounds.

The heavy mineral method is now so well known that it has been more or less standardized. Substantially the standard method has been used in this report. Bromoform with specific gravity of 2.853 was employed for all separations. Five to ten grams of sand, weighed to 4 decimals on an analytical balance, were placed in bromoform in a separatory funnel and allowed to remain 3 to 5 hours, with occasional gentle stirring and tapping. The heavy minerals were then drawn off at the base by releasing a clamp on a short section of rubber tubing, and retained on filter paper. The light minerals were drawn off later in the same manner. After washing with alcohol and drying, the heavy minerals were weighed to 4 decimals and their percentage calculated. The "heavies" were mounted in piperine ($n=1.68$) and the "lights" were filed in glass vials for other studies. The mineral grains were studied and counted with a petrographic microscope, using medium power magnification.

LIGHT MINERALS

Quartz is the most abundant light mineral in the Oil Creek and McLish sands in the central Arbuckle Mountains. Several feldspars, including orthoclase, microcline, and albite, are present in small quantities and the clay mineral illite was identified in the lower green-colored strata from the pits in the McLish sand at Roff.

Quartz. The quartz grains in the Oil Creek and McLish sands range in size from medium sand to silt, the majority of grains being in the fine and very fine sand grade. The grains are rounded to sub-rounded in the coarser sizes and become progressively more angular with decreasing grain size. Coarse grains are well frosted and pitted and the fine grains are lightly etched. Secondary enlargements are practically unknown in the Simpson glass sands from the quarries in the central Arbuckle Mountains and in this respect they differ from the St. Peter sand in Arkansas, which shows all degrees of enlargement.[53]

Many inclusions are contained within individual quartz grains of the Simpson sands. Following the procedure of Mackie[54] and Tyler,[55] the inclusions were classed as acicular (thin needles), crystal (regular), fluid (irregular), and negative (inclusions absent). Mackie determined on Scottish rocks that acicular and fluid inclusions were characteristic in the quartz of granite and that crystal inclusions predominate in the quartz from schist and gneiss. Tyler checked these conclusions on 7 American rocks and found fluid inclusions clearly predominating in granite and gneiss, with crystal inclusions constituting 92 to 100 percent in schist.[56] In applying the general inclusion law to the St. Peter sandstone in Wisconsin, Tyler found that practically every quartz grain contained some type of inclusion, and he gives the following proportions:[57] fluid inclusions, 77 percent; acicular, 15 percent; and crystal inclusions, 8 percent.

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[53] Giles, Albert W., "Textural Features of the Ordovician Sandstones of Arkansas": *Jour. Geol.*, Vol. XL, pp. 104-109, 1932.
[54] Mackie, William, "The Sands and Sandstone of Eastern Moray": *Trans. Edinburgh Geol. Soc.*, Vol. 7, pp. 148-172, 1896.
[55] Tyler, Stanley A., "Heavy Minerals of the St. Peter Sandstone in Wisconsin": *Jour. Sed. Petrology*, Vol. 6, pp. 55-84, 1936.
[56] *Idem.*, p. 73.
[57] *Idem.*, p. 74.

TABLE V

Percentage of Inclusions, by Types, in Quartz from McLish and Oil Creek Sands

	Fine Sand Grade (60-115 mesh)					Very Fine Sand Grade (115-250 mesh)				
	Fluid	Negative	Acicular	Crystal	Number grains counted	Fluid	Negative	Acicular	Crystal	Number grains counted
McLish sand, upper 38 feet, Mid-Continent Glass Sand Co., Roff	85	9	4	2	851	81	15	1	3	783
Oil Creek sand, 62 feet, Mill Creek Sand Co.	88	7	3	2	799	85	12	1	2	1006

He concluded that the St. Peter sandstone had been derived largely from a granitic terrane.

A determination of inclusions in the quartz of the McLish and Oil Creek sandstones reveals that fluid inclusions are most abundant, negative inclusions rather common, and acicular and crystal inclusions rare. The minerals identified as crystal inclusions include chiefly tourmaline, apatite, zircon, and opaque minerals, possibly magnetite. The acicular inclusions are too small to identify but may be rutile. The relative amount of each type of inclusion is shown in Table V.

Inspection of the table shows an average inclusion content of 85 percent fluid, 11 percent negative, 2 percent acicular, and 2 percent crystal. There are more negative inclusions in the very fine sand grade, a distribution undoubtedly caused by breakage of large grains during transportation into smaller particles, many of which represent inclusion-free parts of larger grains. The low content of crystal inclusions, particularly those high in iron, is an advantage to the glass sand producer because such inclusions would increase the iron content and they could not be removed economically.

The study of inclusions in the quartz of the Simpson sands indicates clearly an ultimate derivation from granitic igneous rocks and agrees rather well with the results obtained by Tyler for the St. Peter sand in Wisconsin. The St. Peter sand seems to be quite different in Arkansas where, according to Giles,[58] "most of the grains are free from mineral and other inclusions".

Feldspars. The feldspars occur as sub-rounded to subrectangular, detrital grains in the finer grade sizes of the Simpson sands. Many grains appear unaltered and rather fresh, whereas a few are clouded with numerous minute dark-colored specks, probably kaolinite. The secondary crystal faces that indicate authigenic growth, and which are common in many sedimentary rocks,[59] including the St. Peter sandstone,[60] are completely lacking in the samples of Simpson sands studied for this report.

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[58] Giles, Albert W., "Textural Features of the Ordovician Sandstones of Arkansas": *Jour. Geol.* Vol. XL, p. 109, 1932.

[59] Tester, Allen C., and Atwater, Gordon I., "The Occurrence of Authigenic Feldspars in Sediments": *Jour. Sed. Petrology,* Vol. 4, pp. 23-31, 1934.

Microcline and orthoclase are present in about equal amounts. Microcline was recognized by its diagnostic grilled twinning pattern under crossed nicols and orthoclase by the absence of twinning. Albite is much less abundant and is distinguished by the typical plagioclase twinning. The maximum index of refraction of each feldspar, determined in immersion oils, is less than 1.54.

To determine the relative proportions of the different feldspars and their ratio to quartz in the light fractions of the sands, the grains were mounted in an oil of 1.54 index of refraction. In this medium quartz has low relief but still a higher index, and the feldspars have moderately high relief and lower index. The application of this method was considered satisfactory after preliminary examination showed no intermediate plagioclase with maximum index higher than quartz. The results of the grain counts are given in Table VI.

Inspection of the table reveals that feldspar is present in the finest grade sizes of the sands. In the McLish sand from Roff there is no feldspar in the fine sand grade, 1.3 percent in the very fine sand grade, and 8.2 percent in the silt grade. As the silt fraction constitutes 4.0 percent of the total sample, and the very fine sand, 29.0 percent, it follows that the sample as a whole contains 0.71 percent feldspar, of which 0.38 percent is in very fine sand and 0.33 percent in silt. Orthoclase and microcline occur in about equal amounts, with albite constituting hardly more than a trace.

The sample of Oil Creek sand contains 0.3 percent feldspar in the silt grade but none in the fine sand or very fine sand grades. Orthoclase and microcline are present in nearly equal amounts, and albite is absent. The silt grade in this sample is 13.1 percent and thus the total feldspar in the Oil Creek sand as a whole is 0.04 percent.

Several conclusions may be drawn from Table VI. First, the extremely high percentage of quartz makes the sand bodies vir-

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[60] Thiel, George A., "Sedimentary and Petrographic Analysis of the St. Peter Sandstone": *Bull. Geol. Soc. Am.,* Vol. 46, pp. 559-614, 1935.

TABLE VI

Quartz-Feldspar Volume Perentage in Dominant Size Grades of McLish and Oil Creek Sands

	McLish sand upper 38 feet (crude) Mid-Continent Glass Sand Co., Roff			Oil Creek sand 62 feet (crude) Mill Creek Sand Co., Mill Creek		
	Fine sand 60-115 mesh	Very fine sand 115-250 mesh	Silt <250 mesh	Fine sand 60-115 mesh	Very fine sand 115-250 mesh	Silt <250 mesh
number grains counted	854	1759	1052	1088	1883	3064
Quartz	100	98.7	91.8	100	100	99.7
Total Felspar	—	1.3	8.2	—	—	0.3
Orthoclase	—	0.6	3.8	—	—	0.14
Microcline	—	0.5	4.1	—	—	0.16
Albite	—	0.2	0.3	—	—	—

tually homogeneous silica deposits and hence satisfactory sources of high silica sand. It is interesting to note, by way of comparison, that the sand being transported by the Mississippi River between Cairo, Illinois, and the Gulf of Mexico contains about 65 percent quartz and about 22 percent feldspar.[61]

Second, the small amount of feldspar is insufficient to account for the alumina shown by chemical analysis. Most of the alumina is contained in clay minerals, which are easily removed from the sands by washing. Beneficiation to remove alumina would not be so simple if it were contained chiefly in feldspars.

A third conclusion concerns the origin of the sand body itself. It is known from an examination of the inclusions in the quartz grains that the Simpson sands were derived ultimately from granitic rocks, high in feldspar. That these sands now contain practically no feldspar is good indication of prolonged decomposition, during which the feldspar was destroyed while the relative insoluble quartz remained slightly affected. It is clear from the concentration of the feldspar in the fine sizes that decomposition took place before and not after deposition of the Simpson sands, as decomposition in place certainly would remove the fine sizes of feldspar first or at least remove proportionate amounts of it from the fine, medium, and coarse sizes.

To trace the geologic history of the sands from an obscure beginning in granitic igneous rocks to their present deposit of nearly pure quartz probably involves (1) long transportation, through several cycles of erosion and deposition, during which the feldspar grains were reduced in size by mechanical splitting along their excellent cleavage planes, and (2) intense decomposition, while the sediments were exposed in the emergent phase of each sedimentary cycle and also during periods of transportation and deposition. It is nearly impossible to say which of these environments produced the most decomposition and greatest loss of feldspar, but their combined effects have been sufficient to reduce the feldspar from an original content of about 60 percent, the same as in most granites,

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[61] Russell, R. Dana, "Mineral Composition of Mississippi River Sands": *Bull. Geol. Soc. Am.*, Vol. 48, pp. 1307-1348, 1937.

to their present small content of less than 1 percent in the Simpson sands.

Illite. The clay mineral illite[62] is abundant in the lower part of the McLish sand in the vicinity of Roff, where it is associated with pyrite. The clay-sand mixture is easily separated by shaking in water, allowing the sand to settle, and decanting the clay suspension. Some of the clay is of colloidal size and is readily flocculated by lowering the pH slightly below 7. Petrographic examination of clay purified by simple decantation showed homogeneous illite without a trace of quartz. A sample of purified illite analyzed by A. C. Shead contained 6.90 percent Fe_2O_3.

The clay as it occurs in a moist condition is decidedly aquamarine green; purified, concentrated, and dried it is pale apple-green.

Under the petrographic microscope the mineral is seen to consist of pale green aggregates and micaceous slivers. Extinction is sensibly parallel to the perfect clevage in one direction. Birefringence is moderate and the interference colors are mottled—mica-like—at extinction positions. The slivers have positive elongation. In immersion oils the index γ' is $1.597 \pm .003$ and α' is $1.567 \pm .003$; $\gamma' - \alpha' = 0.030$. These data clearly indicate illite.[63]

HEAVY MINERALS

The minerals separated from the glass sands by the bromoform method have a specific gravity greater than 2.853 and include tourmaline, zircon, pyrite, limonite, garnet, leucoxene, ilmenite, ceylonite, rutile, epidote, and wurtzite. These minerals may be divided into 2 groups: (1) *detrital,* or those transported along with the quartz grains as broken particles and deposited from suspension, and (2) *authigenic,* or those which are chemical precipitates and which were deposited from solution during or after deposition of the sandstone. The authigenic minerals are pyrite and limonite, both of which are sources of iron and are the chief objectionable

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[62] Grim, R. E., Bray, R. H., and Bradley, W. F., "The Mica in Argillaceous Sediments": *Am. Mineralogist,* Vol. 22, pp. 813-829, 1937.

[63] Grim, Ralph E., "Properties of Clay": *Recent Marine Sediments* (special publication) Am. Assoc. Petrol. Geol., p. 470, 1939; reprinted as *Ill. Geol. Survey Circ.* 45, 1939.

minerals in the glass sand deposits. Wurtzite also is believed to be authigenic. The other minerals are detrital in origin and are comprised dominantly of tourmaline and zircon.

The heavy minerals constitute 0.006 to 0.307 percent by weight of the crude sands, being greater in samples with abundant pyrite and limonite. The detrital minerals occur chiefly in the very fine sand and silt grades (<115 mesh).

Tourmaline. (Sodium, iron, boron-aluminum silicate) Tourmaline, most abundant of the detrital minerals, occurs in the three finest grade sizes of the sand and is typically spherical to egg-shaped, with high degree of rounding. In reflected light the grains appear black and many are finely etched on the surface. Most of the tourmaline contains no inclusions but a few are characterized by numerous fluid inclusions and some have black mineral inclusions. Under the petrographic microscope tourmaline is recognized by its strong pleochroism absorption ($\omega > \epsilon$) and rather high birefringence. As many grains tend to lie nearly parallel to the basal pinacoid, which incidentally suggests breakage along a basal parting, excellent uniaxial interference figures are readily obtained.

The most common type has O=dark olive green or dark golden brown and E=pale yellowish green or light brown. Abundant also are types with O=black and E=light shades of brown and green or smoky gray. A few grains pleochroic in shades of blue are present. The indices of refraction given in the following table indicate that all the tourmaline probably is the schorlite variety, comparatively high in iron.[64]

The indices were determined in immersion oils on single grains, using the method described by Lindberg[65].

Zircon. ($ZrSiO_4$) Zircon is most abundant in the very fine sand and silt grades, although a few well-rounded grains occur in the

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[64] Winchell, A. N., *Elements of Optical Mineralogy, Part II,* John Wiley and Sons, pp. 301-304, 1933.

[65] Lindberg, Marie L., "A Method for Isolating Grains Mounted in Index Oils": *Am. Mineralogist,* Vol. 29, pp. 323-324, 1944.

TABLE VII

Optical Constants of Tourmaline in McLish and Oil Creek Sands

Ray	Color (in grains 0.09 to 0.06 mm. diameter)	Index of refraction (±0.003)	Birefringence
O	dark olive green	1.661	0.033
E	pale greenish yellow	1.628	
O	black	1.667	0.035
E	light golden brown	1.632	
O	dark blue	1.665	0.032
E	light gray-violet	1.633	

fine sand size. Most zircon grains show some part of the original prismatic and pyramidal crystal faces, abraded at edges and corners to sub-rounded grains, and some, especially in the finest sizes, are perfectly euhedral. Zoning, inclusions, and surface etching are rather common. Clear and colorless grains are predominant but clear grains with pink to lilac color (hyacinth variety) are common, and types that are distinctly clouded and altered are rare. The altered zircon is the malacon variety that shows low birefringence. Gradation from typical, unaltered zircon to malacon was noted in single grains, although such grains are very rare.

Garnet. (Calcium, magnesium, iron aluminum silicate) Garnet is a rare constituent in the heavy mineral suites. The grains are clear, colorless to pale pink, and are sub-rounded to sub-angular, with deeply pitted surfaces. They are recognized by the high refractive index, high relief, and isotropic character.

Ilmenite and leucoxene. Ilmenite, $FeTiO_3$, occurs as spherical to sub-rounded opaque grains that are steel-gray to reddish in reflected light; many are partly or completely altered to leucoxene. Both minerals are so rare that no attempt was made to distinguish between them.

Rutile. (TiO_2) Practically all of the rutile is contained in the silt grade. The grains range in shape from euhedral-prismatic to stubby and sub-rounded. They have deep reddish-brown color, high birefringence, and high relief.

Ceylonite. ($Mg, FeAl_2O_4$) Ceylonite is the green, iron-bearing variety of spinel. Under the microscope the ceylonite grains are deep green to blue-green, rounded and spherical, and with etched surfaces. They are distinguished by the green color, isotropic character, high refractive index, and high relief.

Epidote. (CaFeAl silicate) Epidote occurs in rounded grains of yellowish-green color, with slight pleochroism and high birefringence.

Rutile, ceylonite, and epidote are rare accessories and constitute less than 0.5 percent of the heavy minerals in all samples.

Pyrite. (FeS_2:iron, 46.6 percent) Pyrite occurs most abundantly in the lower part of the McLish sand at Roff, where it has the form of minute cubic crystals, some of which show octahedral faces. Pyrite here composes 50 to 65 percent of the total heavy minerals and 0.06 percent of the total sandstone. The grains are opaque and typically brass-yellow in reflected light. In the other samples pyrite is present as small granular aggregates that are partly or completely altered to limonite, so that a single grain may contain both minerals.

Limonite. ($Fe_2O_3.nH_2O$: iron, about 55 percent) Irregular aggregates of limonite are common in nearly all heavy mineral separates. They are opaque and appear reddish-brown in reflected light.

Wurtzite. (ZnS). Wurtzite occurs in crystals about 0.05 mm in diameter and comprises 7 percent of the heavy mineral fraction in the silt grade of the lower part of the McLish sand at Roff. The crystals have 8 perfectly developed faces and show no sign of attrition, although a few grains broken possibly in preparing the sample show conchoidal fracture. The color is pale purplish-brown to dark brown. Examined carefully under high magnification, the grains are seen to have a pair of dominant, six-sided crystal faces (basal pinacoid) modified by six smaller rhombohedron faces. The basal pinacoid commonly shows a division into six segments. (See Pl. X, A).

The mineral was identified as wurtzite by R. C. Emmons, of the University of Wisconsin, who determined the following properties:[66]

Refractive index	2.43
Birefringence	Low
Crystallization	Rhombohedral (base and rhombohedron present)
Cleavage	Prismatic
Hardness	3

This identification is confirmed by the fact that the mineral is soluble in HCl, the solution yielding a positive microchemical reaction for zinc.

The sandstone in which the wurtzite occurs is unconsolidated and lacking in any suggestion of recrystallization or other evidence of metamorphism or high temperature. In view of the euhedral form of the crystals and the probability that zinc sulfide would not survive transportation in the form of detrital grains, because it is too soluble, it seems that the wurtzite here was precipitated syngenetically from the sea water in Ordovician time. Accordingly the temperature of deposition probably was well below 100°C., an abnormal environment in comparison to the generally recognized occurrence of wurtzite in ore deposits.

Table VIII shows the heavy mineral composition, by size grades, of the glass sands in the central part of the Arbuckle Mountains.

Summary of heavy minerals. Detrital minerals common to both the Oil Creek and McLish sands are tourmaline, zircon, and garnet, whereas ilmenite-leucoxene, ceylonite, rutile, epidote, and wurtzite were found only in the McLish. They occur chiefly in the very fine sand and silt grades. The table clearly shows the dominance of tourmaline and zircon, about 98 percent or more of the detrital suite being composed of these two minerals. Tourmaline is more abundant than zircon, comprising 83-100 percent in the fine sand grade, 86-92 percent (average 88 percent) in the very fine sand, and 19-66 percent (average 46 percent) in the silt. Zircon is

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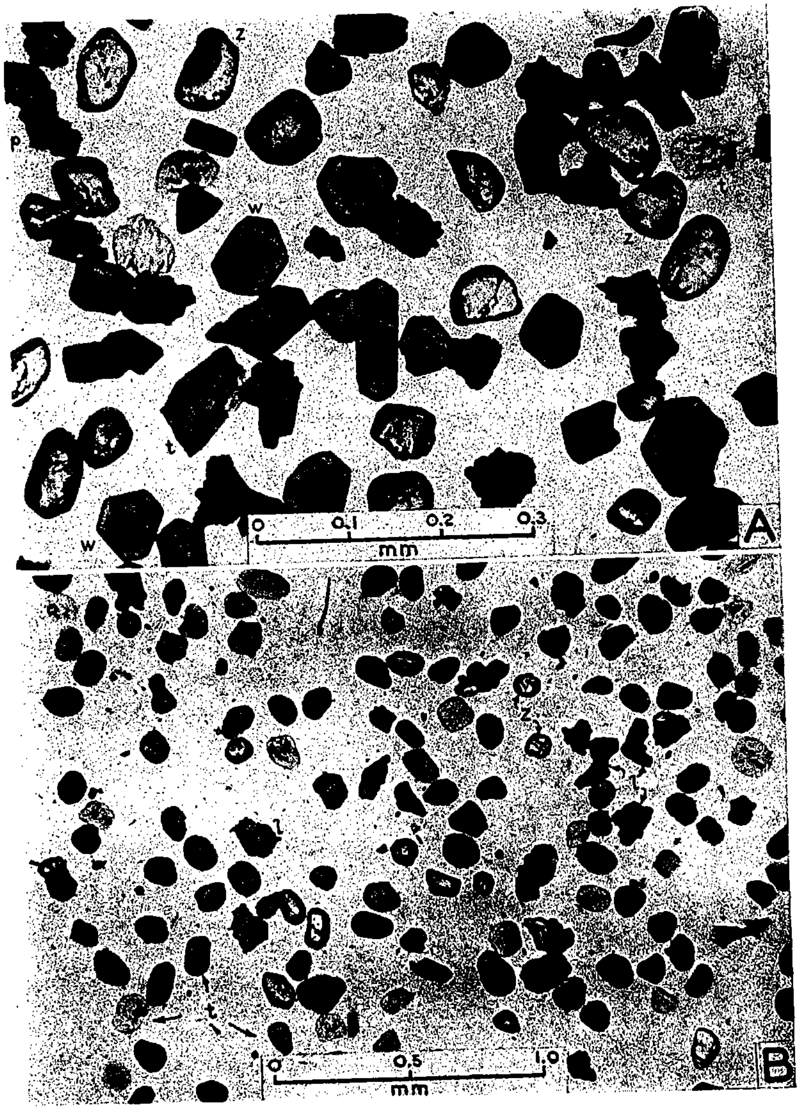
[66] Letter to the writer dated Jan. 29, 1945.



Photomicrographs of heavy minerals from sandstone member of McLish formation, Roff.

A. Wurtzite (w), zircon (z), pyrite (p), and tourmaline (t) from silt fraction (—250 mesh) in lower green colored sand. Plane polarized light. X120.

B. Typical assemblage from very fine sand grade (115-250 mesh) in upper part of the sandstone member, showing abundance of spherical and oval tourmaline (t) with lesser amounts of zircon (z) and limonite (l). Plane polarized light . X35.

TABLE VIII
HEAVY MINERALS IN McLISH AND OIL CREEK SANDS

Geologic Formation	Location and Producer	Kind of Sample	Size Grade (mesh)	Percent Heavy Minerals (by wt.)	Number of Grains Counted	PERCENT DETRITAL MINERALS†							PERCENT AUTHIGENIC MINERALS†			QUARTZ† (Attached to Pyrite or Limonite)	Calculated Percent Fe_2O_3 Contributed to Total Sampl by Limonite and Pyrite
						Tourmaline	Zircon	Garnet	Ilmenite-Leucoxene	Ceylonite	Rutile	Epidote	Pyrite	Limonite	Wurtzite		
Oil Creek	Sec. 6, T 2 S., R. 5 E., Johnston County Mill Creek Sand Co.	Crude Sand 62 feet	60-115	0.010	79	33 [93]	3 [7]						38			26	0.003
			115-250	0.053	817	64 [85]	11 [15]	VR [VR]					21			3	0.011
			<250	0.016	526	21 [66]	11 [34]	VR [R]					67			1	0.008
		Plant Run	Entire Smpl.	0.006	234	65	14						18			3	0.001
Oil Creek	Sec. 23, T. 1 S., R 3 E., Murray County Sulphur Silica Co.	Crude Sand 35 Feet	60-115	0.008	158	20 [100]								50		30	0.004
			115-250	0.015	273	70 [92]	5 [7]	R [1]					R	21		3	0.003
			<250	0.006	197	10 [47]	11 [49]	1 [4]						55		23	0.003
		Plant Run	Entire Smpl.	0.007	107	58	3	VR						36		4	0.003
McLish	Sec. 13, T. 2 N., R. 4 E., Pontotoc County Mid-Continent Glass Sand Co.	Crude Sand Upper 38 Feet	60-115	0.031	232	9 [83]	1 [13]	VR [4]						47		42	0.011
			115-250	0.046	474	67 [86]	10 [13]	VR [VR]	R [1]			VR [VR]		21		2	0.006
			<250	0.288	1183	39 [53]	33 [45]	1 [2]	R [VR]	VR [VR]	VR [VR]			27			0.005
		Crude Sand Lower 12 Feet	60-115	0.110	190								50			50	0.035
			115-250	0.105	1082	37 [90]	4 [10]	VR [VR]	VR [VR]			VR [VR]	50		1	8	0.035
			<250	0.307	1334	5 [19]	21 [79]	VR [2]	VR [VR]	VR [VR]		VR [VR]	65		7	1	0.14
		Plant Run	Entire Smpl.	0.025	636	46	12	R	2					34		6	0.006
		Heavy Rejects from Tables	Entire Smpl.	Not Determined	1864	12	83	2	1	VR	VR	VR	1	VR			

†Percent of heavy mineral suite, calculated to nearest whole number. Minerals comprising less than 1% are classed as rare (R) if 0.5 1.0%, and very rare (VR) if less than 0.5%. Unbracketed figures show percentage on basis of total heavy minerals, including pyrite limonite. Bracketed figures show percentage on basis of detrital minerals alone, calculated from original grain count.

absent in the fine sand of two samples and in the other two it ranges between 7 and 13 percent; it comprises 7-15 percent (average 11 percent) in the very fine sand and 34-79 percent (average 52 percent) in the silt grade. The tourmaline-zircon ratios in the different grade sizes probably are directly related to the relative abundance and difference in grain size of these minerals in the original granitic rock from which the sandstone was derived.

SOURCES OF IRON IN THE SANDS

The sources of iron in the Simpson sands of the Arbuckle Mountains are the iron-containing minerals limonite, pyrite, illite, and tourmaline. By mineralogical examination it is possible to determine which of these minerals are most deleterious to the sands and thereby to suggest the best beneficiation procedure to remove them.

The clay mineral illite, containing 6.90 percent Fe_2O_3, is of very fine size and is almost entirely removed by washing, so that practically no iron is contributed to the processed sand by this mineral. Pyrite, FeS_2, containing the equivalent of 65.8 percent Fe_2O_3, and limonite-quartz admixtures, containing 28.96 percent Fe_2O_3, more or less, occur in particles of microscopic size to aggregates 1 inch in diameter. Aggregates of these minerals larger than 26 mesh (openings 0.0245 inch or 0.61 mm) are rejected on the scalper screen; finer particles pass the screen and enter the wash tanks with the sand. Tourmaline also passes the scalper screen. Pyrite, limonite, and tourmaline are so heavy that they are not eliminated by washing and, unless removed by tabling or flotation, remain with the sand during the entire beneficiating process. At first thought it would seem that the small particles of these minerals account for the iron in the finished sand, and the following calculations were made to determine whether this is true.

The tourmaline is the schorlite variety and probably contains about 12 percent FeO.[67] By calculating the weighted average of the tourmaline in the crude samples from Table VIII and converting the iron from this mineral to iron oxide in the total sample, it is found that the Oil Creek sand at Mill Creek has 0.001 percent; the Oil Creek sand at Sulphur, less than 0.001 percent; the upper part of the McLish sand at Roff, 0.002 percent, and the lower part of the McLish sand at Roff, 0.001 percent (Table IX).

As the only significant figure has a value of 2 or less in the third decimal place and because this is outside the limits of accuracy of ordinary analytical procedure, it is readily seen that iron from tourmaline is too small to affect the purity of the glass sands.

Similar calculations of the iron oxide contributed by limonite and pyrite in the heavy mineral fraction of the crude sands show 0.005 percent in the Oil Creek sand at Mill Creek; 0.004 percent in the Oil Creek sand at Sulphur; 0.010 in the upper part of the McLish sand at Roff; and 0.039 percent in the lower part of the McLish sand at Roff.

Using the same basis as above for calculating the iron content in the heavy minerals of the plant run sands, it is found that tourmaline contributes a negligible amount, and that pyrite and limonite contribute 0.001 percent at Mill Creek, 0.003 percent at Sulphur, and 0.006 percent at Roff. Comparison of these values with the chemical analysis of the total sand sample is shown in Table IX.

It is evident from Table IX that the iron contained in the heavy minerals of the crude sands is chiefly in pyrite and limonite; but it is equally evident that most of the iron is unaccounted for by the heavy minerals alone and must therefore be associated with the light minerals. Examination of the light minerals shows minute particles and thin films of limonite on the surface and in the tiny pits of many sand grains. The limonite was deposited from solutions that obtained iron from the decomposition of pyrite in the zone of weathering. As the quartz grains themselves contain practically no inclusions of iron-bearing minerals, this surficial coating of limonite must account for the bulk of the iron oxide in the glass sand deposits. A very small amount is contained in the clay mineral illite.

There is a similar distribution of the iron oxide in the processed sands, although in them the large aggregates of limonite and pyrite,

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[67] Dana, J. D., *System of Mineralogy*, 6th Edition: John Wiley and Sons, p. 554, 1914.

TABLE IX

COMPARISON OF TOTAL IRON OXIDE WITH IRON OXIDE CONTRIBUTED FROM HEAVY MINERALS IN OKLAHOMA GLASS SANDS

PRODUCER AND GEOLOGIC FORMATION	CRUDE			PLANT-RUN		
	Iron Oxide Shown by Chemical Analysis	Calculated Percent of Iron Oxide Contained in Heavy Mineral Grains		Iron Oxide Shown by Chemical Analysis	Calculated Percent of Iron Oxide Contained in Heavy Mineral Grains	
		Tourmaline	Pyrite + Limonite		Tourmaline	Pyrite + Limonite
Mill Creek Sand Co. Oil Creek sand	0.09	0.001	0.005	0.03	0.0005	0.001
Sulphur Silica Co. Oil Creek sand	0.115	<0.001	0.004	0.04	0.0005	0.003
Mid-Continent Glass Sand Co., Roff McLish sand upper 38 ft.	0.26	0.002	0.010	0.044	0.002	0.006
McLish sand lower 12 ft.	0.40	0.001	0.039			

some of the smaller particles and films of iron oxide, and nearly all the clay are removed by beneficiation. Calculations from the table show that in the plant run sands the heavy mineral grains of limonite and pyrite contribute 5 to 18 percent of the total iron oxide and that the remaining 82 to 95 percent must be contributed by the unremoved iron oxide films on the sand grains. These calculations are corroborated by chemical analyses of a sample of plant run sand from Roff, one before, and the other after extraction of the heavy minerals. These analyses showed no appreciable difference in iron oxide content.

The above investigation indicates without any doubt that the principal concern of the glass sand operators in the Arbuckle Mountains is to wash and scrub the sand grains in order to remove the limonite coating, and, given crude sand of the same quality, the more thorough the washing and scrubbing process, the less iron will be contained in the finished sand. Exception is made to sand such as that in the lower part of the McLish sand at Roff, in which pyrite clearly is the chief source of iron.

Contrary to popular belief, the large and small grains are coated alike and there does not seem to be more iron in the finer grade sizes of the sand.

The frosted and pitted surfaces of the larger grains provide numerous recesses for the lodgment of iron oxide and makes difficult its removal by washing. Fortunately, most of the grains are uncoated and the iron content of the crude sands is not excessively high. The beneficiation practices used at the sand plants produce high quality glass sand at a reasonable cost.

SIEVE ANALYSES

The number and kind of sieves used by different investigators, particularly in older reports, has shown such a lack of uniformity that the results obtained are difficult to compare. There is at present a strong tendency among sedimentary petrologists to use as a standard the Wentworth scale of grade sizes and the sieves for this scale were used for the present investigation. It was found, however, that the Simpson sands were so fine-sized that the standard scale did not have enough divisions to reveal more than general textural features, and it was necessary to use additional screens of intermediate size. The sieves used in this report, together with the standard grade size classification, are given in Table X.

TABLE X

Mesh and openings of Tyler sieves used for size analysis

Tyler sieve (mesh)	Openings millimeters	Openings inches	Grade size
16	0.991 (1)	0.039	very coarse sand
32	0.495 (½)	0.0195	coarse sand
42	0.351 (1/3)	0.0138	medium sand
60	0.246 (1/4)	0.0097	
80	0.177 (1/6)	0.0069	fine sand
115	0.124 (1/8)	0.0049	
170	0.088 (1/12)	0.0035	very fine sand
250	0.061 (1/16)	0.0024	
325	0.043 (1/23)	0.0017	coarse silt
	—	—	<325: chiefly silt

Procedure. A fraction weighing several kilograms was split from the original sample and subjected to further rubbing with a porcelain mortar and pestle until the disaggregation was essentially complete. This sample was then split to about 100 grams, weighed to one decimal, and sieved for 15 minutes on a Ro-Tap mechanical shaker. The sand fractions on the different screens were weighed and the weight percentage calculated. Table XI shows the results of the sieve analyses.

It is apparent from Table XI that the crude McLish and Oil Creek sand in the central Arbuckle Mountains are very similar texturally, and that the dominant grade size is fine sand, with very fine sand comprising a substantial amount, and medium sand and silt together comprising the small remaining part. The analyses further reveal a high degree of sorting, 84 to 91 percent of the sand being classed as fine sand and very fine sand combined. The grade size distribution is virtually unchanged by washing the sands for

TABLE XI

SIEVE ANALYSES OF CRUDE AND PLANT RUN OKLAHOMA GLASS SANDS

Geologic Formation	Operator	Location	Nature of Sample	Weight Sieved (Grams)	Tyler Sieve No.	32	42	60	80	115	170	250	325	—325		
					Size of Openings mm	0.495	0.351	0.246	0.177	0.124	0.088	0.061	0.043	—		
					Size of Openings In-ches	0.0195	0.0138	0.0097	0.0069	0.0049	0.0035	0.0024	0.0017	—		
					Grade Size	Coarse Sand	Medium Sand		Fine Sand		Very Fine Sand		Coarse Silt	Chiefly Silt	Sieve Loss	Total
					PERCENT BY WEIGHT R-retained—C-cumulative											
Oil Creek	Mill Creek Sand Co.	Sec. 6, T. 2 S., R. 5 E., Johnston Co.	Crude Sand 62 Feet	81.1	R	Trace	0.1	3.1	15.5	43.8	16.2	7.8	6.3	6.8	0.5	100.1
					C		0.1	3.2	18.7	62.5	78.7	86.5	92.8	99.6		
			Plant Run (washed)	86.8	R	Trace	0.2	2.9	16.5	52.2	17.7	8.5	1.8	Trace	0.1	99.9
					C		0.2	3.1	19.6	71.8	89.5	98.0	99.8			
Oil Creek	Sulphur Silica Co.	Sec. 23, T. 1 S., R. 3 E., Murray Co.	Crude Sand 35 Feet	85.9	R	Trace	0.1	1.9	14.3	53.1	16.5	5.5	5.2	3.3	0.1	100.0
					C		0.1	2.0	16.3	69.4	85.9	91.4	96.6	99.9		
			Plant Run (washed)	96.4	R	Trace	0.1	1.2	12.3	57.7	17.8	6.4	4.4	Trace	0.0	99.9
					C		0.1	1.3	13.6	71.3	89.1	95.5	99.9			
McLish	Mid-Continent Glass Sand Co., Roff	Sec. 13, T. 2 N., R. 4 E., Pontotoc Co.	Crude Sand Upper 38 Feet	86.0	R	0.2	1.2	5.6	12.9	47.0	19.2	9.8	3.7	0.3	0.2	100.1
					C	0.2	1.4	7.0	19.9	66.9	86.1	95.9	99.6	99.9		
			Crude Sand Lower 12 Feet	94.9	R	Trace	0.4	3.9	13.2	52.5	19.3	5.8	3.9	0.9	0.1	100.0
					C		0.4	4.3	17.5	70.0	89.3	95.1	99.0	99.9		
			Plant Run (Washed, tabled, and floated)	99.5	R	Trace	1.0	4.6	10.4	48.2	20.1	11.2	4.3	Trace	0.2	100.0
					C		1.0	5.6	16.0	64.2	84.3	95.5	99.8			

commercial use, except for a slight reduction in percentage of silt size and slight increase in that of the coarser sizes.

TEXTURAL COMPARISON OF SIMPSON AND ST. PETER SANDS

From the work of Thiel,[68] Giles,[69] Lamar,[70] Dake,[71] and Tyler[72] it is evident that the St. Peter sandstone in Illinois, Minnesota, Wisconsin, Missouri, and Arkansas is uniformly composed of high silica sand with local lenses of carbonate cement and that its heavy minerals are dominantly tourmaline, zircon, and garnet. The grains are well sorted, rounded to sub-rounded, frosted, and pitted. Locally, as in the Arkansas and Missouri deposits, there are pronounced secondary enlargements. Except for this feature, the characters of the Simpson and St. Peter sands are so similar that it would be difficult if not impossible to distinguish between them. The most notable difference is the finer grain size in the Simpson sands of Oklahoma.

The cumulative frequency curves[73] plotted on semilogarithmic paper in figs. 3 and 4 show this comparison. The crude St. Peter sand from Illinois has the coarsest texture and consists chiefly of coarse and medium sand. In Arkansas and Missouri the St. Peter is dominantly medium and fine sand, whereas the Simpson sands in Oklahoma are classed in the fine and very fine sand grades. The median diameter, obtained by finding the grain diameter at which the cumulative curve crosses the 50-percent line, for the two St. Peter sands in Illinois are 0.45 mm and 0.34 mm; for the Missouri sand it is 0.27 mm; and for the Arkansas samples it is 0.235 mm. The median diameters of the McLish and Oil Creek sands in Oklahoma show close correspondence at a value of 0.14 mm.

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[68] Thiel, George, A., "Sedimentary and Petrographic Analysis of the St. Peter Sandstone": *Bull. Geol. Soc. Am.*, Vol. 46, pp. 559-614, 1935.

[69] Giles, Albert W., "St. Peter and Older Ordovician Sandstones of Northtrn Arkansas": *Ark. Geol. Survey Bull.* 4, 1930.

[70] Lamar, J. E., "Geology and Economic Resources of the St. Peter Sandstone of Illinois": *Ill. Geol. Survey Bull.* 53, 1928.

[71] Dake, C. L., "The Sand and Gravel Resources of Missouri": *Mo. Bur. Geol. and Mines*, Vol. 15, 2nd Ser., 1918.

[72] Tyler, Stanley A., "Heavy Minerals of the St. Peter Sandstone in Wisconsin": *Jour. Sed. Petrology*, Vol. 6, pp. 55-84, 1936.

[73] The use and desirability of cumulative curves for comparing textures is described by Krumbein, W. C., and Pettijohn, F. J., *Manual of Sedimentary Petrography*, Chapters 7 and 8, Appleton Century, 1938.

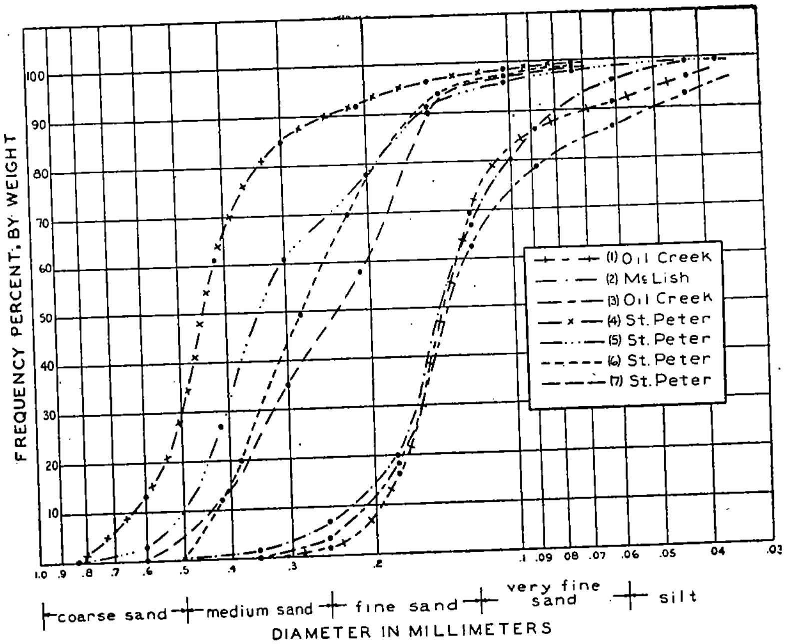

Fig. 3. Cumulative frequency curves showing textural comparison between Simpson and St. Peter sandstones. Crude samples

(1) Oil Creek. Sulphur Silica Co., Sulphur, Oklahoma
(2) McLish (upper 38 feet). Mid-Continent Glass Sand Co., Roff, Oklahoma
(3) Oil Creek. Mill Creek Sand Co., Mill Creek, Oklahoma
(4) St. Peter. Ottawa Silica Co., Ottawa, Illinois. (average of 6 samples, no. 1-5)*
(5) St. Peter. Higby-Reynolds Silica Co., Utica, Illinois. (sample no. 36)*
(6) St. Peter. Pittsburgh Plate Glass Co., Crystal City, Missouri. (average of 3 samples)†
(7) St. Peter. Average of 18 samples near Guion, Arkansas.§

*Lamar, J. E., "Geology and Economic Resources of the St. Peter Sandstone of Illinois": ILL. GEOL. SURVEY BULL. 53, Table 10, facing p. 148, 1928.

†Dake, C. L., "The Sand and Gravel Resources of Missouri": MO. BUR. OF GEOL. AND MINES, Vol. XV, 2nd Ser., chart facing p. 126, samples 32, 33 and 34, 1918.

§Giles, A. W., "St. Peter and Older Ordovician Sandstones of Northern Arkansas": ARK. GEOL. SURVEY BULL. 4, Table 5, facing p. 28, sample series 6, 7, 8, 9, and 11, 1930.

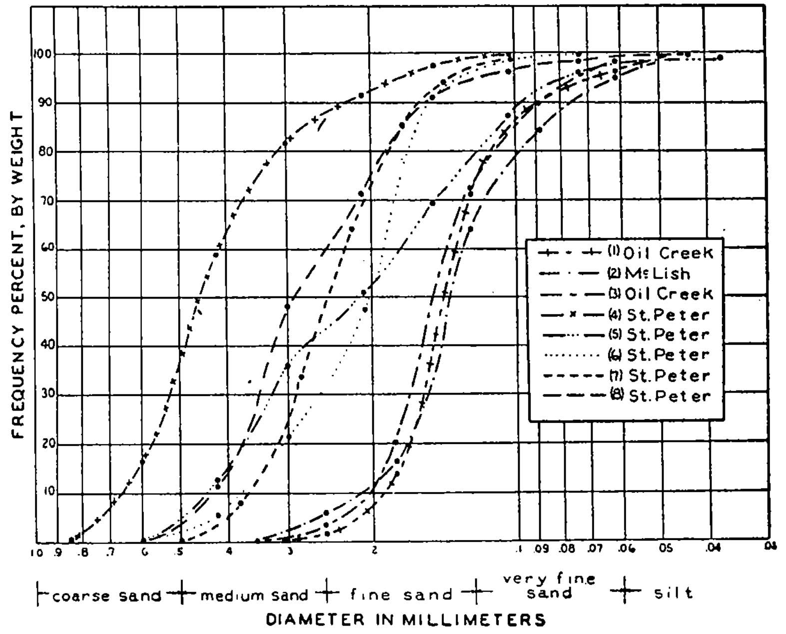

Fig. 4. Cumulative frequency curves showing textural comparison between Simpson and St. Peter sandstones. Plant run samples.

(1) Oil Creek. Sulphur Silica Co., Sulphur, Oklahoma
(2) McLish. Mid-Continent Glass Sand Co., Roff, Oklahoma
(3) Oil Creek. Mill Creek Sand Co., Mill Creek, Oklahoma
(4) St. Peter. Ottawa Silica Co., Ottawa, Illinois. (sample no. 6)*
(5) St. Peter. Higby-Reynolds Silica Co., Utica, Illinois. (sample no. 37)*
(6) St. Peter. National Silica Co., Oregon, Illinois. (sample no. 53)*
(7) St. Peter. Pittsburgh Plate Glass Co., Crystal City, Missouri.†
(8) St. Peter. Silica Products Co., Guion, Arkansas.§

***Lamar, J. E., "Geology and Economic Resources of the St. Peter Sandstone of Illinois": ILL. GEOL. SURVEY BULL. 53, Table 10, facing p. 148, 1928.**

†Dake, C. L., "The Sand and Gravel Resources of Missouri": MO. BUR. OF GEOL. AND MINES, Vol. XV, 2nd. Ser., chart facing p. 126, sample no. 111A, 1918.

§Giles, A. W., "St. Peter and Older Ordovician Sandstones of Northern Arkansas": ARK. GEOL. SURVEY BULL. 4, Table 5, facing p. 28, sample no. 29, 1930.

The curves of washed sands, which are used chiefly for the manufacture of glass, show a similar comparison. The three samples from Illinois have median diameters of 0.45 mm, 0.21 mm, and 0.20 mm; the one from Missouri has 0.245 mm; and the one from Arkansas has 0.28 mm. In Oklahoma, the plant run Oil Creek sands have median diameters of 0.14 mm at Sulphur and 0.15 mm at Mill Creek, and the McLish sand from Roff has 0.135 mm. These figures are compared in Table XII.

TABLE XII

Comparison of Median Diameters of St. Peter and Simpson Sands

	ST. PETER			SIMPSON
	Illinois	Missouri	Arkansas	Oklahoma
CRUDE	0.45—0.34mm	0.27 mm	0.235mm	0.14mm
PLANT RUN	0.45—0.20mm	0.245mm	0.28 mm	0.15—0.135mm

Another method of comparing the sands is by their degree of sorting or uniformity of size. This feature is of much interest to glass manufacturers because uniformly sized sands give an even melt without excessive foaming or the formation of scum, cords, stones, and seeds in the glass batch.[74] For purposes of comparison, the sorting coefficient of Trask[75] is well suited and can be determined from cumulative curves. The coefficient of sorting is defined as $So=\sqrt{\frac{Q_1}{Q_3}}$, in which Q_1 is the first quartile, or that grain diameter in millimeters on the curve which intersects the 25-percent line, and Q_3 is the third quartile, or the diameter at the 75-percent line. The coefficient is thus a ratio between the first and third quartiles, the interval between these quartiles representing 50 percent of the sand in the most important part of the size distribution. Hence if $Q_1=0.4$ mm and $Q_3=0.1$ mm, then

$$So=\sqrt{\frac{0.4}{0.1}}=\sqrt{4}=2$$

It is readily seen that as Q_1 and Q_3 approach equality, So approaches unity, or a value of 1; and, the smaller the value of So,

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[74] Fettke, C. R., "American Glass Sands, Their Properties and Preparation": *Trans. Am. Inst. Min. Met. Eng.*, Vol. LXXIII, pp. 406-409, 1926.

[75] Trask, P. D., *Origin and Environment of Source Sediments of Petroleum*, American Petroleum Institute (printed by the Gulf Publishing Co., Houston) pp. 70-72, 1932.

the greater the sorting of the sediment. Trask concluded from an examination of 170 sediments, chiefly from modern seas, that "if So is less than 2.5 the sample is well-sorted; that if it is greater than 4.5, the sediment is poorly sorted; and that if it is about 3.0, the deposit is normally sorted".[76]

The sorting coefficient of selected plant run sands from the St. Peter in the central United States and from the Simpson in Oklahoma, calculated from fig. 4, are shown in Table XIII. All the coefficients are lower than 1.64, which indicates a uniformly high degree of sorting. The Oklahoma sands, however, in general have slightly lower coefficients and therefore a higher degree of sorting than the St. Peter sands. In this respect the Simpson sands from Oklahoma have a small textural advantage for glass manufacture.

TABLE XIII

Sorting coefficient (So) of plant run St. Peter and Simpson sands

Formation	Producer	Sorting Coefficient (So)
Simpson	Sulphur Silica Co. Sulphur, Okla.	1.16
	Mid-Continent Glass Sand Co. Roff, Okla.	1.22
	Mill Creek Sand Co. Mill Creek, Okla.	1.21
St. Peter	Ottawa Silica Co. Ottawa, Ill.	1.27
	Higby-Reynolds Silica Co. Utica, Ill.	1.64
	National Silica Co. Oregon, Ill.	1.20
	Pittsburgh Plate Glass Co. Crystal City, Mo.	1.22
	Silica Products Co. Guion, Ark.	1.34

Coarse-textured sands like those in Illinois seem to have a slight advantage over the other high-silica sand deposits in the central United States because they can be used for a wider variety of industrial purposes. The coarse grades, for example, are preferred for sand blasting and for certain grades of filter sand.

In glass manufacture the sand used must not be "too coarse" or "too fine", but the exact size limits are indefinite, for what is "too fine" for one plant may be "satisfactory" for another. Much of the opinion concerning most desirable grain size is based on the experience of the manufacturer. If he has been using sand with median diameter of 0.25 mm, then he may believe that sand of 0.15 mm median diameter is too fine. The answer to the question "Is 0.15 mm sand too fine?" is found in the fact that the Simpson sands of Oklahoma, which are of this size, have been used for about 30 years in the Oklahoma glass plants, and these plants have consistently produced high quality glassware in competition with other plants using medium sand.

The statement has been made that more impurities, chiefly heavy minerals, are in the fine sizes and that there should be a maximum permissible limit on fines. As a broad generalization this statement may be true, but the writer has shown on preceding pages that for the Oklahoma sands the heavy minerals are not sufficiently abundant to influence materially the iron content, and that the chief source of iron oxide is the thin coating on the surface of individual sand grains. The coating is mostly removed by normal plant processing and the finished product compares favorably with widely recognized sands in other states.

Nor does the fine grain size of the Simpson sands prevent their use for molding and casting. Foundrymen who have used these sands state that excellent results are obtained when the proper admixture of sand and binder is determined by experience.

A natural fine-sized sand has advantages over coarse sands for some uses. For filler and abrasive purposes, a fine sand may be usable as such and the necessity of screening is thus eliminated; and for the production of ground silica, in which the cost of grinding is the principal factor governing selling price, a fine sand is

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[76] Trask, P. D., *op. cit.*, p. 72.

superior because it requires less grinding than a coarse one. Ground silica is specified for glass fibers, silicone, and other products. Also, in the manufacture of sodium silicate (water glass) fine sand is said to be preferable, apparently because of its faster reaction with the other raw materials.

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