GEOLOGY OF DAVIS-BRONSON POOL, ALLEN AND BOURBON COUNTIES, KANSAS

by

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INTRODUCTION

The lenticular and linear bodies of sandstone of the Cherokee Group, Desmoines Series, in southeastern Kansas and northeastern Oklahoma are known as the "shoestring sands." Because their occurrence is erratic and highly unpredictable the sand bodies may be missed entirely by offsetting a well location a few hundred feet perpendicular to the trend. The reservoir rock of the Davis-Bronson pool is a "shoestring sand."

LOCATION

The Davis-Bronson pool is in the northeastern part of Allen County and the northwestern part of Bourbon County, Kansas (Fig. 1). It is in parts of sections 34 and 35, of T. 23 S., R. 21 E., and sections 2, 3, 10, 11, 14, 15, of T. 24 S., R. 21 E. Some of the fields in the area are Bronson-Xenia, Kincaid, Moran.

Southeastern Kansas is on the Bourbon Arch; a mild, east-west trending upwarp which separates the Forest City Basin, to the north, from the Cherokee Basin, to the south. The dominant tectonically positive elements in the region during the time of sand deposition were the Nemaha Ridge west of the area and the Ozark Uplift to the southeast (Fig. 1).

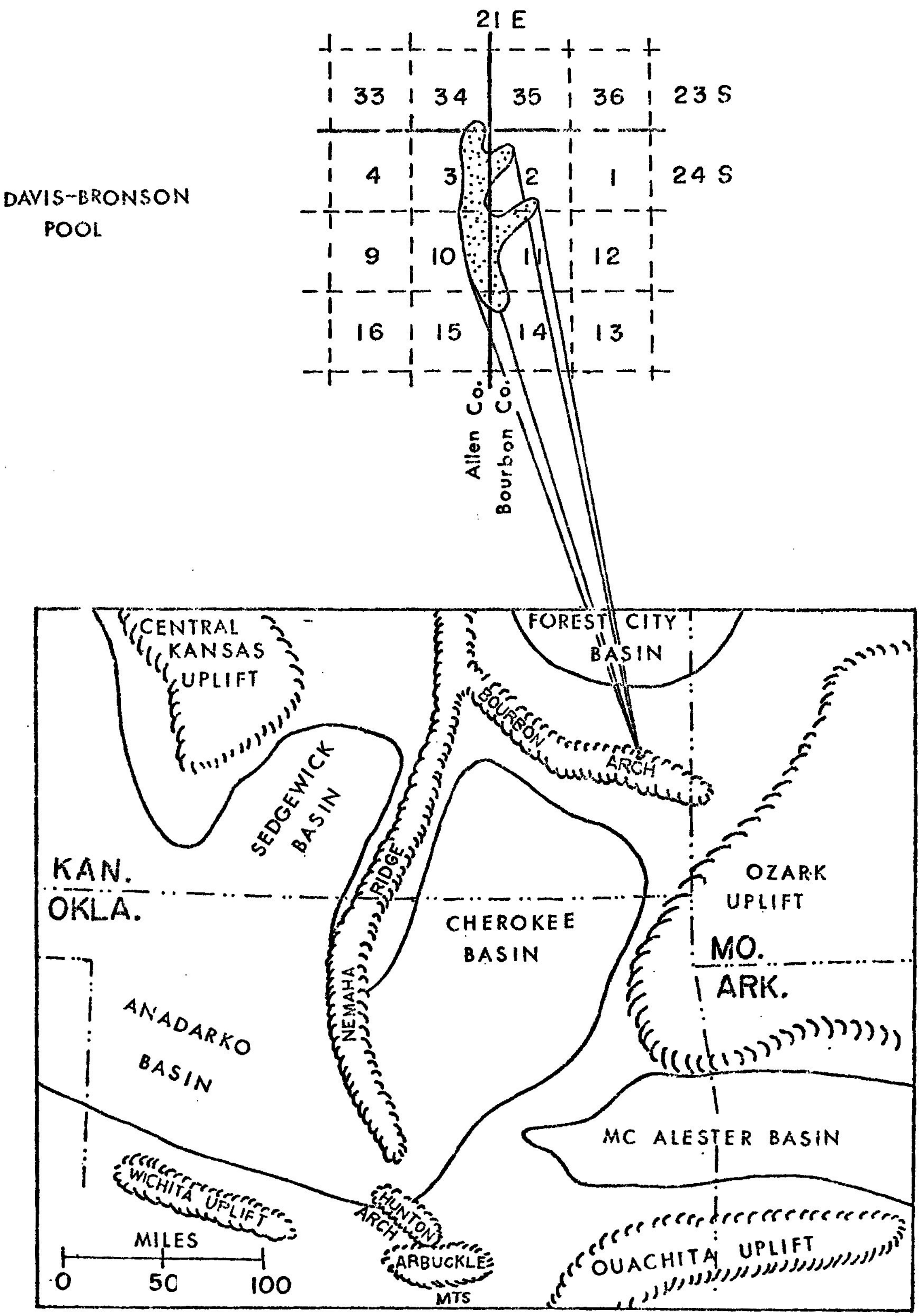


Figure 1. Tectonic features of the Midcontinent region during the Pennsylvanian Period.

PROBLEM AND PROCEDURE

This detailed subsurface study of the reservoir rock in the Davis-Bronson pool was undertaken to determine the character of the sandstone body, and its relation to the stratigraphic sequence, which is important in exploration or exploitation of petroleum traps of this type. The main objectives of this study were the determination of: (1) the environment of deposition of the "shoestring sand," (2) the geologic history of the area at the time of sand deposition, (3) the present attitude of the sandstone body, (4) the relation of sandstone geology to petroleum accumulation. This information is also expected to contribute to the understanding of the depositional history of the area.

A combination of field and laboratory techniques was used to determine the geology of the stratigraphic interval. Structural and stratigraphic cross sections, isopachous maps, and structure maps were used to show the geometry and stratigraphic position of the sandstone body. A petrographic analysis was used to determine the mineralogy of the sandstone and hcw authigenis might have affected the reservoir rock. Grain size analyses were used to determine the character of the sand at the time of deposition.

HISTORY OF OIL PRODUCTION

In 1860 the first oil in Kansas was discovered near Paola in Miami County (Haworth, 1908). In 1873 a gas well was drilled at Iola in Allen County. Several gas wells were drilled in eastern Kansas following the Civil War; however, little oil was produced until about the turn of the century. During the time from 1900 until the late 1920's, the eastern Kansas oil and gas industry was booming. Since the mid 1930's water flooding has been widely practiced in eastern Kansas.

Oil was discovered in the Davis-Bronson pool over fifty years ago. Since 1937 the pool has been water flooded by independent oil producers in the area.

PREVIOUS INVESTIGATIONS

Since their discovery, the origin of the "shoestring sands" has been a controversial subject among geologists. Some of the earliest publications about "shoestring sands" were by J.L. Rich (1923, 1926, 1938). Bass (1936) made one of the first studies concerning the origin of the "shoestring sands." Charles (1927) published a comprehensive report on the Bush City Field, Anderson County, Kansas.

Some preliminary geologic investigation of the Davis-Bronson pool was done by J.L. Rich (as a consultant geologist) for an independent oil producer, during the early 1950's. However, a complete geologic study of the Davis-Bronson pool has not been compiled, although it has produced oil and gas for about a half century.

S T R A T I G R A P H Y

NOMENCLATURE AND CLASSIFICATION

The Cherokee Group, as defined by the Kansas Geological Survey, is the lowest division of the Desmoines Series, Middle Pennsylvanian System. It includes the rocks described by Haworth and Kirk (1894, p. 105-106) in Cherokee County, Kansas, and extends upwards from the unconformable Mississippian Limestone surface to the base of the Fort Scott Limestone, basal formation of the Marmaton Group. In 1953, Krebs and Cabaniss Groups were adopted to replace the term "Cherokee" Group. At a meeting in Lawrence, 1955, the Cherokee Group was readopted because of its convenience and wide-spread usage (Howe, 1956, p. 20-21).

The brief lithologic descriptions of the Marmaton and Cherokee formations, and subsurface markers used in this thesis are presented here. The author did not investigate the petrology of the formations included, except the sandstone investigated; they were taken in part from Leatherock (1937), Moore, et. al., (1951), Howe (1956), Baker (1962), Jordan (1957), and the files of M.C. Colt Inc., Iola, Kansas.

DESCRIPTION OF LITHOLOGIC UNITS--PENNSYLVANIAN SYSTEM

Desmoines Series

Marmaton Group

Fort Scott Limestone--The Fort Scott Limestone is the basal formation of the Marmaton Group, described by Haworth and Kirk near Oswego, Kansas in 1894, and is equivalent to the Oswego lime of the subsurface in Oklahoma. It is approximately 30 feet thick and is uniformly distributed throughout the area of study. In descending order, it is composed (Moore, 1951, p.99) of a light gray thin-bedded to massive limestone top member, about twenty feet thick (Higginsville Limestone); a black platy shale containing phosphatic concretions and coal, approximately 5 feet thick (Little Osage Shale); and a lower 5 foot limestone member (Blackjack Creek Limestone).

The Blackjack Creek Limestone is underlain by beds of black platy shale containing phosphatic concretions and coal (Mulky coal) which are in the top of the Cherokee Group. The black phosphatic shales above and below the Blackjack Creek Limestone give an easily recognizable, characteristic, "hot kick" on a gamma ray curve. Because it is so easily recognized, the base of the Fort Scott Limestone is widely used as a subsurface marker by geologists in Kansas and Oklahoma. The base of the Fort Scott Limestone coincides with the top of the Cherokee Group and is used as a datum in this thesis.

Cherokee Group

The Cherokee Group is composed primarily of shale with minor amounts of sandstone, coal, and limestone arranged in cyclic succession. The succession represents both marine and non-marine facies that may undergo extreme lithologic changes within relatively small vertical or lateral distances. The area was on a relatively unstable platform and/or mild upwarp throughout Cherokee time with the sea invading from the south. The cyclic sequence is a reflection of the transgressions and regressions of the Cherokee sea upon the Mississippian unconformity.

Figure 2 is a type log stratigraphic section showing the divisions of the subsurface Cherokee Group and some of the significant marker beds used in this thesis. It shows typical gamma ray curves and stratigraphic columns of the area investigated. The stratigraphic columns were compiled from core and drill sample descriptions. The Cherokee divisions and subsurface terminology were adapted in part from the nomenclature used by an independent oil producer in Iola, Kansas.

Breezy Hill Limestone--The Breezy Hill Limestone was first described by Pierce and Courtier (1937, p.33) at Breezy Hill in Crawford County, Kansas. It is an irregularly bedded to conglomeratic, dark gray, sandy limestone usually about 4 feet thick (Howe, 1956, p. 80-81)--in the Davis-Bronson Pool it is approximately 2 feet thick. Sometimes it is not recorded on a drillers log, but it is likely to be within the area of study.

TYPE LOG STRATIGRAPHIC SECTION

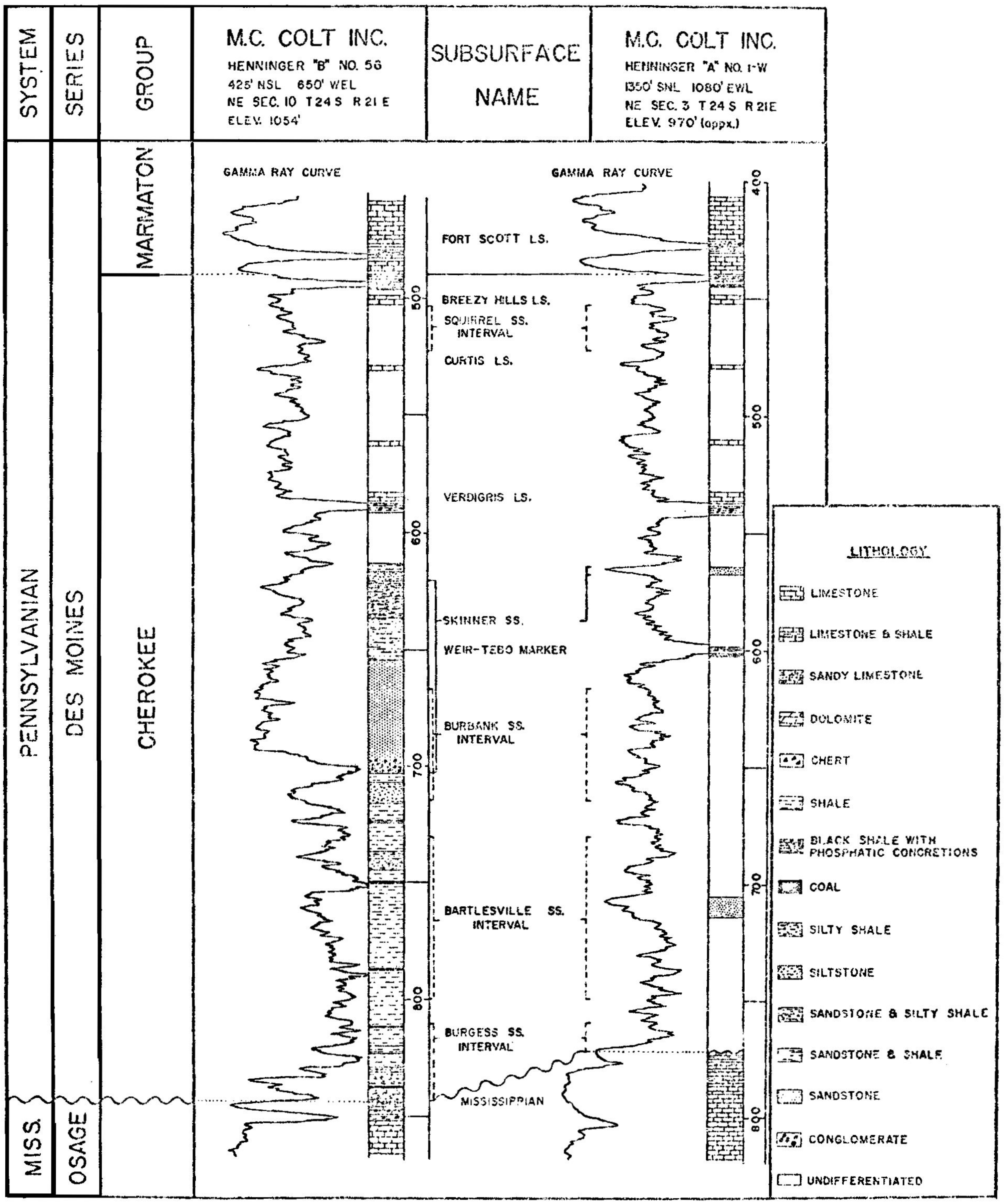


Figure 2. Generalized type log stratigraphic section of the Cherokee Group.

Squirrel sandstone--The Squirrel sandstone is the uppermost major sandstone in the Cherokee Group. It is part of the Lagonda Formation in outcrop, first described by Gordon (1893, p. 13, 19-20). The Squirrel, described by Shanon and Trout in 1915 from its occurrence in the Bartlesville field of Washington County, Oklahoma, is the equivalent of the Prue sandstone of Oklahoma (Jordan, 1957, p. 184). It is gray to buff, fine grained, angular, micaceous, thinly cross-bedded sandstone which may contain fossil plant fragments. The thickness varies from 0 to 35 feet and it may occur at various levels in a 50 foot thick interval below the base of the Fort Scott Limestone. The Squirrel is not developed in the area of study.

Curtis limestone--The "Curtis limestone" is 2 to 4 feet thick and occurs approximately 35 feet below the base of the Fort Scott Limestone. It is not a formal stratigraphic unit recognized by the Geological Survey of Kansas. The "Curtis limestone" is strictly a local term introduced by D. A. Busch in stratigraphic studies done for an independent oil producer in Iola, Kansas. It is identifiable on gamma ray logs of wells on the Curtis lease in the S 1/2 - SE 1/4 of Sec. 29, T. 23 S., R. 18 E. Although the "Curtis limestone" is not used as a marker in this thesis, it appears to be persistent enough to be recognized in the area of study and could be used as a marker in future investigations.

An unnamed limestone occurs approximately 75 feet below the base of the Fort Scott Limestone; between the "Curtis limestone" and the Verdigris Limestone. It is 2 to 4 feet thick and is one of the many thin limestone beds in the lower part of the Lagonda Formation in outcrop, reported by Howe (1956, p. 80-81).

Verdigris Limestone--The Verdigris Limestone (Smith, in Woodruff and Cooper, 1928) was named from its outcrop along the Verdigris River in Rogers County, Oklahoma. The Verdigris occurs approximately 100 feet below the base of the Fort Scott Limestone and is continuous throughout the area of study. The Verdigris consists of three thin dark gray limestone beds and intervening shale units which total about 3 feet in thickness at its outcrop in southeast Kansas (Howe, 1956, p. 74-78). Drillers logs and gamma ray logs in the area of study, record a limestone 2 feet thick as the Verdigris. Its stratigraphic position is determined by underlying beds of black platy shale containing phosphatic concretions which give a "hot kick" on gamma ray logs.

According to Howe (1956, p. 26, 74), the Verdigris Limestone and underlying black shale sequence is very similar to that of the lower part of the Fort Scott formation. The black shale underlying the Verdigris is also recognized in Oklahoma, Missouri and Iowa. Because of its widespread occurrence and its association with the Verdigris Limestone, therefore, the black shale is a subsurface marker bed frequently used by geologists in in eastern Kansas.

Skinner sandstone--The Skinner sandstone of the subsurface of Oklahoma is equivalent to the surface Chelsea sandstone of

Oklahoma and Kansas. It was first described by Wood in 1913 from its occurrence under the Skinner lease in the Lauderdale pool in Pawnee County, Oklahoma. There have been no reports of the Skinner sandstone in the subsurface of Kansas. The Skinner may occur in a zone about 35 to 120 feet below the Verdigris Limestone. The sandstone investigated is correlative to the Skinner. Its stratigraphic position and lithology will be described in detail later under the heading "Geology of Sandstone Body."

Weir-Tebo marker--Another gamma ray marker, similar to the Verdigris Limestone marker, occurs approximately 165 feet below the base of the Fort Scott Limestone. Howe (1956, p. 54) reports a black shale containing phosphatic concretions overlying the Tebo coal. This explains the "hot kick" on the gamma ray log in that position--if the phosphatic shale beds, like those below the Verdigris Limestone and in the lower part of the Fort Scott formation, are the source of the high radiation shown on the gamma ray log. In some localities (Howe, 1956, p. 47) the Tebo coal and stratigraphically lower Weir coal are in contact. Gamma ray logs do not clearly show the position of coals, and coals are usually not recorded on drillers logs, so it is not known for certain how the Weir and Tebo coals are related. Regardless of how the two coals are related, the associated gamma ray marker is persistent throughout the area and is widely used as a subsurface marker. In this study it will be referred to as the Weir-Tebo marker. The Weir-Tebo marker is present in the area of study except where the sandstone investigated occupies its stratigraphic position.

Burbank sandstone--The Burbank sandstone (Sands, 1929; Bass, 1942; and Hunter, 1956) is equivalent to the subsurface Red Fork sandstone and the surface Taft sandstone in Oklahoma. It is a gray, very fine to fine gained, subangular, massive and cross bedded, loosely cemented sandstone. The Burbank can occur, in about a 50 foot interval, below the Weir-Tebo marker and above the Bartlesville sandstone. It is present about 1/2 mile southwest of the Davis-Bronson pool and in the Bronson-Xenia field about 3 miles south of the area of study. It is also present in a few wells west of the main trend of the Davis Bronson pool in the extreme SE 1/4 of Sec. 34, T. 23 S., R. 21 E. and the extreme NE 1/4 of Sec. 3, T. 24 S., R. 21 E. Much of the oil and gas produced in southeastern Kansas is from sandstones that occupy the position of the Burbank sandstone.

Bartlesville sandstone--The Bartlesville was first described by Hutchinson in 1911 (Jordan, 1957, p. 14) from its occurrence in the Bartlesville pool of Washington County, Oklahoma. It is equivalent to the Bluejacket sandstone, originally described in outcrop in Kansas and Oklahoma by Ohern (1914, p. 28-29. It is light gray, very fine to fine grained, angular to subangular, massive or cross-bedded sandstone that may contain fragments of shale or chert. It ranges in thickness from 0 to 100 feet. Where it is fully developed the Bartlesville may be divided into an upper and lower zone. The Bartlesville occurs below the Burbank sandstone interval and above the Burgess sandstone interval; sometimes it is developed upon or just above the underlying unconformable "Mississippi lime." Sandstone occupying the Bartlesville position is recorded in the logs of a few wells in the NW 1/4 of Sec. 14, T. 24 S., R. 21 E., immediately south of the defined Davis-Bronson pool shown in Fig. 1. Also, Bartlesville sandstone is recorded in the logs of a well west of the main sandstone trend in the NE 1/4 of Sec. 3, T. 24 S., R. 21 E. which is shown in Fig. 2. The extent of its distribution in and around the Davis-Bronson pool is unknown because only a few wells were drilled through the Bartlesville sandstone horizon.

Burgess sandstone--The Burgess sandstone, first described by Ohern and Garret in 1912 (Jordan, 1957, p. 31), is equivalent to the Warner or Little Cabin sandstone (Wilson, 1935, p. 508; Wilson and Newell, 1937, p. 37-39) of the surface in Kansas and Oklahoma, and the subsurface Booch sandstone in Oklahoma (Howe, 1956, p. 33). It occurs in about a 20 foot interval above the unconformable "Mississippi lime" surface. The Burgess is often confused with the "Mississippi chat," which sometimes occurs on the eroded Mississippian surface. The chat is a conglomerate composed of chert fragments eroded from the underlying "Mississippi lime." The Burgess sandstone occurs at the top of the chat and is a true sandstone, containing fragments of chert. Burgess sandstone is recorded in the logs of a few wells in the NW 1/4 of Sec. 14, T. 24 S., R. 21 E., immediately south of the Davis-Bronson pool. It is also recorded in the log of a well in the NE 1/4 of Sec. 3, T. 24 S., R. 21 E., west of the main sandstone trend. It is difficult to determine its true areal extent because very few wells were drilled to the Burgess sandstone horizon.

Shales--The Cherokee shales consist of four main groups described by Baker (1962). They are as follows: (1) Greenish gray shales composed chiefly of quartz, chlorite, sericite and minor amounts of siderite. They are silty, with poor fissility and essentially unfossiliferous. (2) Gray, pyritic shale composed of quartz, chlorite, and sericite. The shales are organic and contain plant and marine fossils. (3) Black, organic, pyritic shale containing quartz, illite, and chlorite. (4) Underclay, olive-gray, composed of quartz and various clay minerals. They contain limestone nodules, pyrite, ankerite veins and carbonized plant remains.

DESCRIPTION OF LITHOLOGIC UNITS--MISSISSIPPIAN SYSTEM

Osage Series

The Cherokee rocks in southeastern Kansas and northeastern Oklahoma rest upon the eroded surface of the "Mississippi lime." Mississippian limestones of Osagian age are present in the area of study and crop out in extreme southeastern Kansas (Merriam, 1963, p. 135-144). The thickness of Mississippian limestone in the area of study is about 300 feet. It is a hard, sandy, cherty limestone, the upper surface of which was eroded during the post Mississippian, pre-Desmoines time.

GEOLOGY OF SANDSTONE BODY

STRATIGRAPHIC POSITION

The sandstone body which is the reservoir rock is approximately 130 to 220 feet below the base of the Fort Scott Limestone and occurs in the interval below the Verdigris Limestone down to almost the base of the Burbank sandstone interval (Fig. 2). The top of the sandstone is usually encountered about 35 feet below the Verdigris with the base extending down through and below the Weir-Tebo marker for 30 to 40 feet. The upper part of the sandstone is silty, interlaminated and interbedded with silty shale, and is generally not as well sorted or as pure as the lower part. It ranges in thickness from a feather edge to almost 100 feet and averages about 40 feet. The thickest part of the sandstone is in the central part of the trend. It is correlative with the Chelsea sandstone that crops out in Kansas and Oklahoma, the subsurface Skinner sand of Oklahoma, and the subsurface "900 foot" sandstone or Colony sandstone of southeastern Kansas.

GEOMETRY

Areal Distribution

The sandstone body, which trends roughly north-south, is linear, and is about 2 1/2 miles long, and 1000 feet wide. Two minor trends, northeast-southwest, occur on the east side of the main trend (Fig. 1). The main trend is slightly arcuate, and the southern end is slightly east of south.

The sandstone body is well defined along the eastern and western margins by dry holes; however, the northern and southern margins are not defined by dry holes and the sandstone body appears to extend farther north and south. The reason why more wells have not been drilled at the north and south ends will be discussed under "Petroleum Geology."

Because a well is shown on a map as a dry hole does not necessarily indicate that there was no sandstone encountered. In some wells, located along and away from the margins of the thick sandstone body, a few feet of sandstone or siltstone was recorded on the drillers log or shown on the gamma log such as for well No. Henninger "A" 1-W in Fig. 2.

Cross Sections

Approximately 250 drillers logs, supplemented by 35 gamma ray logs, supplied the subsurface information used in compiling cross sections and maps of the sandstone body.

The base of the Fort Scott Limestone was used as the time marker or "key" bed in constructing stratigraphic cross sections and an isopachous map. The basic assumption is that the base of the Fort Scott Limestone does not transgress time, i.e., it represents the sea floor at an instant in geologic time. The base of the Fort Scott was the nearest reliable datum.

Although some of the drillers logs had the Verdigris Limestone recorded, there were not enough of them to warrant its use as a datum. If all the wells had gamma ray logs, picking a close reliable datum would be no problem. Although drillers logs have a few defects, they reveal a wealth of information if used with their shortcomings in mind, in studies involving old records such as this.

Stratigraphic Cross Sections

According to Busch (1959, p. 2829-2843) the cross sectional shape of a sand body is an indicator of its depositional environment. Bar type sand deposits have a generally flat base and a convex upper surface. Conversely, the upper surface of a channel type sand is flat or irregular; the lower surface is convex down and thickens downward by cutting through older units.

Stratigraphic cross sections were constructed at right angles to the length of the sandstone body in an attempt to show its cross sectional shape which in turn would aid in the interpretation of the depositional environment.

The interval used in the stratigraphic cross sections is from the base of the Fort Scott Limestone to the base of the sandstone. Only wells that went through the sandstone and into the underlying shales were used in making the cross sections. By using a marker bed above the sandstone body as a horizontal datum, the attitude of the sandstone body would be shown at the time the marker bed was deposited. In this study the base of the Fort Scott Limestone was used as the horizontal datum, and the attitude of the sandstone body is shown at the time of Fort Scott deposition. Assuming there were no adverse structural movements or extensive interruptions in the sedimentation sequence from the time of sand deposition until the Fort Scott was deposited, the attitude of the sand body at the time of its deposition is shown in the cross sections. This is a seemingly valid assumption because the strata above the sandstone body appears to be a continuous marine sequence with maybe only a few minor diastems. The small areal extent of this study keeps distortion of the true cross sectional shape of the sand body, caused by any unconformities in the stratigraphic cross section interval, to a minimum.

Transverse stratigraphic cross sections of the main sandstone body (Fig. 3) show a lower surface that is convex down. A cross section of the Burbank sandstone, in four wells in the SE 1/4 of Sec. 34, T. 23 S., R. 21 E., on the west side of the main trend, indicates its lower surface is horizontal. The cross sections also show that the two northeast-southwest trends and the main north-south trend occupy the same stratigraphic position.

Structural Cross Sections

Structural cross sections, using sea level as a datum, were drawn at right angles to the trend of the sandstone body. The interval between the base of the Fort Scott Limestone and the base of the sandstone was also used in the structural cross sections. The structural cross sections were drawn to show the present attitude of the sandstone body and to show any changes that might have taken place after the deposition of the sand.

The structural cross sections are similar to the stratigraphic cross sections. The general shape of the sandstone body is the same; the main difference is that the sandstone body is flatter and does not show the convex lower surface to the degree it is shown in the stratigraphic cross sections. Structural cross sections also show that the sandstone body is tilted slightly to the west and that the Fort Scott Limestone is folded slightly over the sandstone body. The Verdigris Limestone is recorded on a few drillers logs, and it too shows a slight warping over the sandstone body that is essentially parallel to the base of the Fort Scott Limestone.

Maps

Isopachous Map

An isopachous map of the interval from the base of the Fort Scott Limestone to the base of the sandstone was constructed to show, with a contour interval of ten feet, the attitude of the sand body at the time of its deposition (Fig. 4). The same assumptions used in constructing the stratigraphic cross sections were also applied in making the isopachous map.

The isopachous map shows a decrease in the isopach interval away from the center of the sandstone body toward the east and west margins. An exception to this is in the SE 1/4 of Sec. 34, T. 23 S., R. 21 E., where the Burbank sandstone apparently has a flat base; the contour lines do not include these oil well control points because the Burbank sandstone is probably part of another older sandstone body. Because of the lack of control, the north and south ends of the map do not show an increase in isopachous interval. It shows that the two northeast-southwest trends on the east side of the main trend, are in the same stratigraphic position and are part of the main north-south trend. The contour lines of the northeast-southwest trend in the NW 1/4 of Sec. 11 are dashed because some of the wells did not penetrate the sandstone base.

Base of Channel Fill Structure Map

A structural contour map, with a sea level datum, of the base of the sandstone body was constructed to show its present attitude (Fig. 5). The structure map shows the same general shape of the sandstone body as the isopachous map. The structural contours are consistently of greater value on the east and west margins of the base of the sandstone body are structurally higher than the central part. Also, they show an increase in value of about 20 feet toward the north end and about 80 feet toward the south end. The structurally high ends of the trend, with respect to the lower central part, illustrate a canoe-like shape to the sandstone body.

This is true except for the Burbank sandstone in the SE 1/4 of Section 34, T. 23 S., R. 21 E. The base of the sandstone is essentially horizontal--there are not enough control points to show the attitude, or extent, of the Burbank in that area.

Base of Fort Scott Limestone Structure Map

A structural contour map, with a sea level datum, of the base of the Fort Scott Limestone (Fig. 6) was constructed to show its draping effect over the sandstone body that was noted in the structural cross sections. The structure of the Fort Scott Limestone coincides with the structure of the base of the sandstone body. The map shows a slight bulging of the limestone over the sandstone trend and a structural low in the central part of the map, both the north and south ends being higher than the central part.

Interpretation of Cross Sections and Maps

Stratigraphic Cross Sections

The transverse stratigraphic cross sections (Fig. 3) of the sandstone body indicate a channel type sand; i.e., the sand thickens downward at the expense of the underlying shales. The central part of the sandstone body is the thickest, with a thinning or pinching out toward the outer margins as shown in cross sections C - C' and D - D' of Fig. 3. The top of the cross sections may be rather flat and irregular (C - C' and D - D') or concave like the one shown in A - A' of Fig. 3. Cross section E - E' shows the thickest part of the sandstone at the left side of the now-defined trend. This can be accounted for by the supposition that the western limit of the sandstone body, in that immediate area, is not fully defined at the present time. Some cross sections, not shown here, show the thickest part of the sandstone developed toward one margin or the other and not in the central part of the trend. A meandering stream would cut channels and deposit thick sand not only in the central part of the valley but along the edges, thus explaining this phenomenon.

The Burbank sandstone recorded in four wells, west of the main trend, in the SE 1/4 of Sec. 34, T. 23 S., R. 21 E., has a

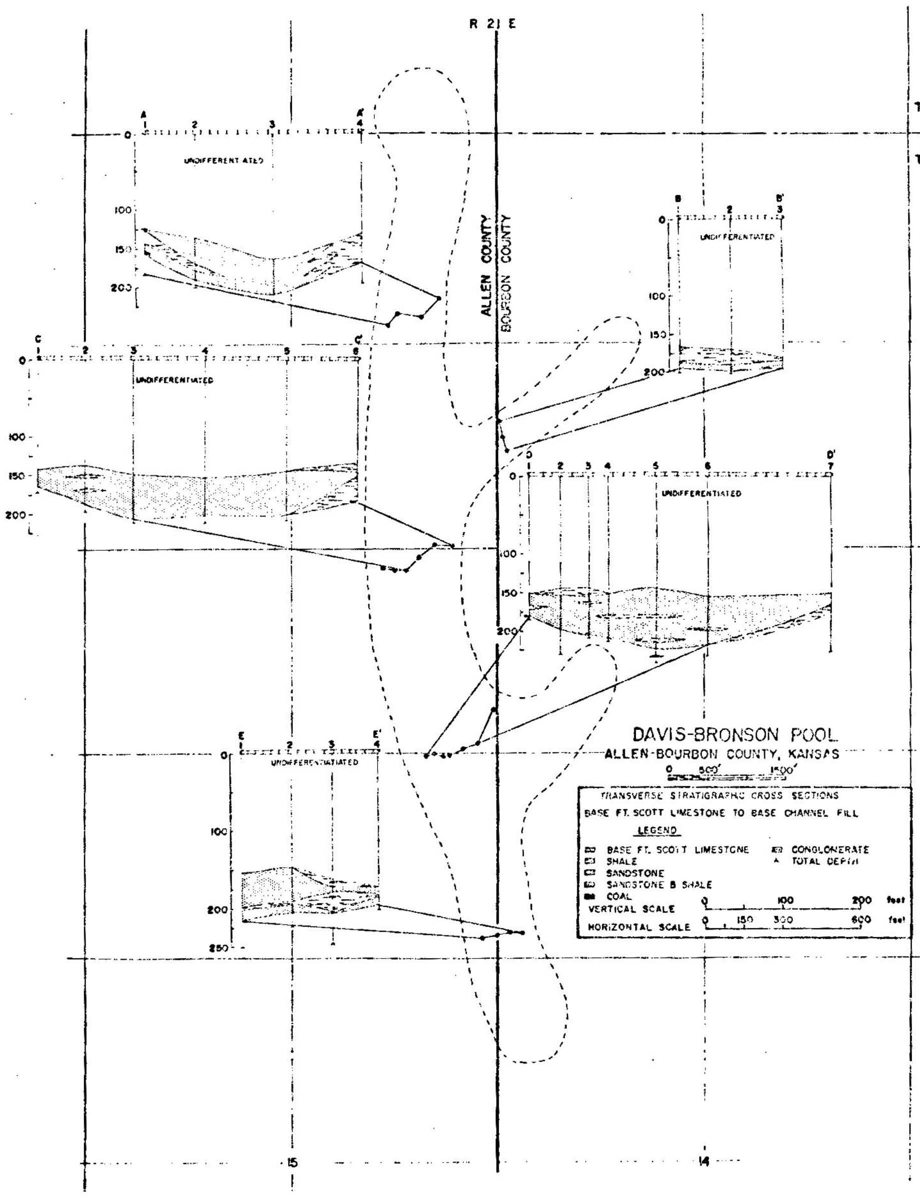


Figure 3. Transverse stratigraphic cross sections of the Davis-Bronson Pool, of the interval from the base of the Fort Scott Limestone to the base of the channel fill.

horizontal base. This suggests it is a bar type deposit; however, there are not enough control points to definitely define its cross sectional shape or areal extent.

Some wells outward and away from the trend or along the margins of the sandstone trend have only a few feet of poorly developed sandstone or siltstone. An example of this is shown in the gamma log of well No. Henninger "A" 1-W in Fig. 2. The gamma log shows 4 or 5 feet of sandstone in the upper part of the sandstone horizon, but does not show sandstone in the position of the Weir-Tebo marker as does the gamma log of well No. Henninger "B" 56. This indicates that the sandstone deposited at the location of well No. Henninger "A" 1-W was not a part of the main channel to the east. It might represent a thin sheet phase of sand deposition that took place after the stream channel was filled with sediments. The stream then spread laterally, depositing this thin sand sequence in immediately adjacent areas. These areas are represented by well logs that do not show downcutting through marker beds in the channel sandstone interval such as is shown in the gamma log of well No. Henninger "B" 56.

Silty and shaly lenses in the better developed sand are shown in the cross sections. They could be interpreted as remnants of buried meanders of a stream as the channel cut from side to side during aggradation of the valley. The poorly sorted or shaly lenses represent the slip off slope on the inside of a stream meander where the transporting power of the stream diminishes and loads of silt and mud were deposited. Zones of better sorted sand and conglomerate can also be explained in this manner.

They represent the ancient stream channel where transporting power was at its greatest and was therefore able to carry loads of larger pebbles and cause better sorted sand. There is also generally poorer sorting of the sand and increase of silty or shaly sand in the upper part of the sandstone body. This can be explained as a loss in transporting power of the stream as aggradation continued.

Cross Section D - D' of Fig. 3 shows downcutting through a coal bed, another indication of a channel type sand. The cross sections of the northeast-southwest trends show the same characteristics as those of the north-south trend. This indicates that they are related and could possibly be tributaries to the main north-south channel.

Structural Cross Sections

The structural cross sections of the sandstone body have the same general shape as the stratigraphic cross sections; the main difference being, that the sandstone body is somewhat flatter and is tilted slightly to the west. The tilting of the sandstone body to the west is in accordance with the regional dip of the area, so that is not difficult to explain. The flatness of the sandstone body can be attributed to differential compaction of the sandstone and enveloping shales. The surrounding shales were more compactable than the sand body. As the shales compacted, the thinner margins of the sand body would be lowered with respect to the thick part--thus giving rise to its flattened cross sectional shape.

A slight folding of the Fort Scott Limestone over the sandstone body was also noted in the cross sections. This too can be explained by differential compaction of the sandstone body and surrounding shales.

Isopachous Map

The isopachous map (Fig. 4) of the interval from the base of the Fort Scott Limestone to the base of the sandstone shows the attitude of the sandstone body at the time of deposition. This generalization is somewhat misleading.

First of all, because no major unconformities occur in the stratigraphic interval, the isopachous map shows the attitude of the sandstone body at the time of deposition of the Fort Scott Limestone. Therefore, the map should be a fair representation of the attitude of the sandstone body at the time it was deposited. Secondly, if the sand body is part of an ancient stream channel, as indicated by the cross sections, the base of the sandstone marks the base of the channel fill. Consequently, cross sections or maps of the sandstone base should be called "base of the channel fill."

The contour lines of the isopachous map are sinuous and quite irregular, as would be expected in a channel type deposit. Close spacing of the contour lines indicates an area of downcutting and maximum sand development, whereas a wider spacing of the contour lines represents a slip off slope on the inside of a meander bend with poorer sand development. A good example

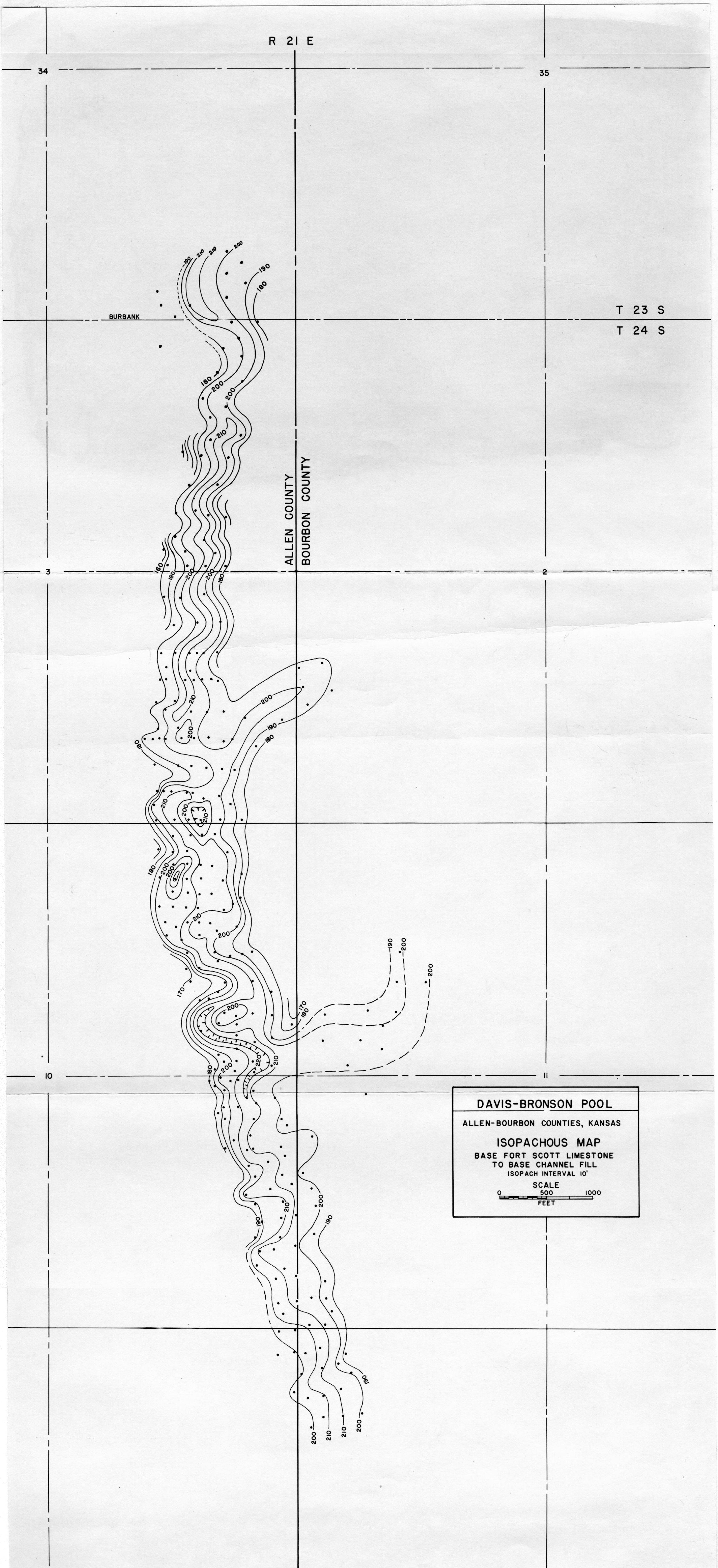


Figure 4. Isopachous map of the interval from the base of the Fort Scott Limestone to the base of the channel fill.

of this is shown in the extreme southern part of the NE 1/4 of Sec. 10, T. 24 S., R. 21 E.

The closed contours on the west side of the trend, about 500 feet south of the boundary between Sec. 10 and 3, indicate an island area. This can represent a splitting of the stream channel or the trace of its earlier course. The closed depression in the SE 1/4 of Sec. 3 and NE 1/4 of Sec. 10 could represent an area of downcutting, and later filling after the stream had taken a different course.

The isopachous interval increases noticeably from north to south and is interpreted as the gradient of a south flowing stream or river.

The greatest isopachous interval in the wells north of the line between T. 23 S. and T. 24 S., that are not part of the Burbank sandstone, is about 210 feet. Several wells in the SE 1/4 of Sec. 10, have an isopachous interval of 217 feet. There is an increase of approximately 7 feet in the isopachous interval from the north to the south ends of the map; which can be interpreted as a gradient, of about 3 to 3 1/2 feet per mile, of a south flowing stream at the time of maximum downcutting. It seems that the true gradient of the hypothetical stream would not be as great as 3 to 3 1/2 feet per mile, as indicated by the map, if it is aggrading and depositing its sediment load. This can be explained in that an encroaching sea could cause the stream to reach base level and aggrade while it was still in a rather young stage of history, and the longitudinal profile of the stream valley was relatively steep. This might also explain why the sandstone body is rather straight and does not have the meandering character of an old age aggrading stream or river.

The relatively great difference in isopachous interval (hypothetical stream gradient) might also be due to lack of control. Oil well control points may not be located at the points of greatest isopachous interval (deepest part of hypothetical stream channel).

Several wells within the closed contour in the NE 1/4 of Sec. 10, have an isopachous interval of over 220 feet. These wells might not be representative of the true gradient of the proposed stream; nonetheless, they do show a marked increase of interval or of stream gradient southward. There are other irregular increases and decreases of isopachous interval, or stream gradient, throughout the length of the map. These irregularities can be explained as alternating deeps and shoals (bars), formed by variable current velocities (Twenhofel, 1950, p. 218-221) as the river channel meandered from side to side of the valley and/or lack of control at the points of maximum downcutting. Determination of the true gradient of the hypothetical stream is difficult because of the small areal extent of the defined channel fill.

The map also indicates that the northeast-southwest trends are in the same stratigraphic position and were deposited in conjunction with the main north-south trend. The two minor trends could possibly be tributaries to the main stream channel because they intersect the main trend at an acute angle as would tributaries of a south flowing stream or river.

The contours of the northeast-southwest trend in the NW 1/4 of Sec. 11, are dashed because some of the wells were not drilled through the sandstone. The contour on the west side of the trend in the SW 1/4 of Sec. 10, is dashed because of the lack of control points. There is a possibility there is more sandstone in that area of the trend, to the west. The contours on the north and sound are stopped abruptly in apparently thick sandstone; the reason why more wells were not drilled farther north and south will be discussed later.

All the features of the isopachous map just discussed can be found in modern streams; it would then not be too unreasonable to think that the isopachous map represents the base of an ancient stream valley channel fill.

Base of Channel Fill Structure Map

A structural contour map of the base of the channel fill (Fig. 5) shows that the present attitude of the sandstone body is different from the attitude at the time of deposition. It has the same general characteristics of the isopachous map; however, the northern and southern ends of the main sandstone trend are structurally higher than the central part. This structural shape of the length of the sandstone body is that of a canoe. The map also indicates, by the closeness of the contour lines on the western margin, that the sandstone body has been tilted

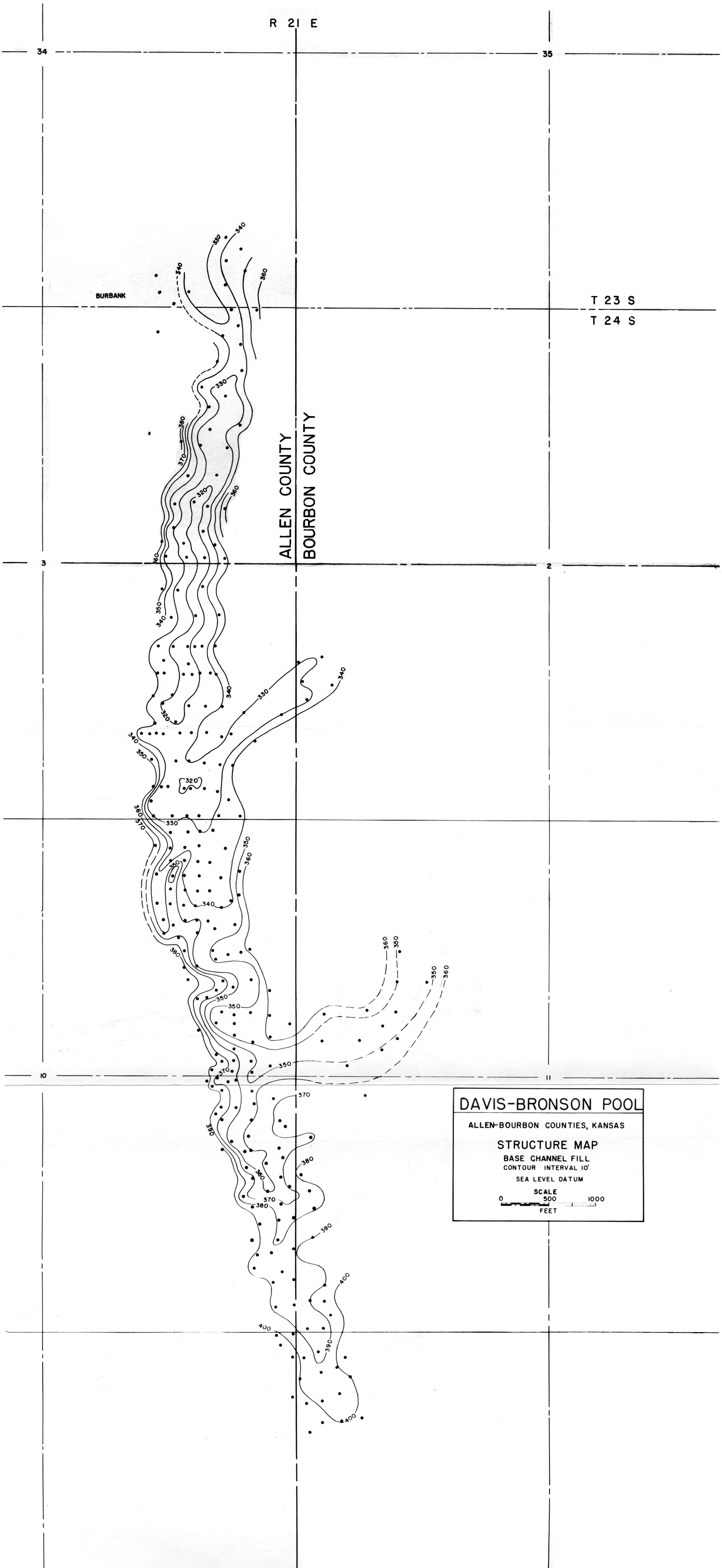


Figure 5. Structure map of the base of the channel fill.

to the west which is in accordance with the regional dip of the area.

The structurally higher ends of the trend could have been caused by structural movement or differential compaction of the Cherokee shales over irregularities on the eroded "Mississippi lime" surface. Structure similar to this in other "shoestring" oil and gas pools of the area is not uncommon according to Rich (1923) and Charles (1927).

Differential compaction of the Cherokee shales over irregularities on the Mississippian limestone surface could have caused the structural attitude of the sandstone body. A slight thinning of the lower part of the Cherokee section is noted in a well log in the northern part of the trend as compared to a well log in the south central part (see Fig. 2). Well logs in the NW 1/4 of Sec. 14, immediately south of the limits of the Davis-Bronson pool shown in Fig. 1, also show thinning of the lower part of the Cherokee section, similar to that shown in the well log from the northern part of the trend, in Fig. 2. This thinning indicates high areas on the "Mississippi lime" surface at the time of Cherokee deposition. Draping of the sandstone body over the "highs" on the unconformable Mississippian surface could cause, upon burial and compaction, the structurally high areas in the northern and southern parts of the trend. It hardly seems likely that differential compaction could have caused the elevation difference of 80 feet between the central part of the trend and the southern end of the sandstone body. According to McCoy (1934), differential compaction is less important in initiating structures than in accentuating those developed by other means. Differential compaction and/or post Fort Scott structural movement is probably the best explanation for the structural attitude of the sandstone body.

Base of Fort Scott Limestone Structure Map

A structure map of the base of the Fort Scott Limestone, approximately 200 feet above the sandstone body, has characteristics similar to the base of the channel fill structure map. The limestone is warped upward over the sandstone trend and a structural depression is in the central part of the map, with the north and south ends higher.

The bulging of the limestone over the sandstone body can be attributed to differential compaction of the sandstone and enveloping shales. Rich (1938) has shown that folding, due to differential compaction, over buried sandstone bodies may be of sufficient magnitude to affect even surface rocks. This study did not include the attitude of the surface rocks over the sandstone body; however, folding of the Fort Scott Limestone due to differential compaction is clearly shown in the map, Fig. 6.

Folding was also noted over the two northeast-southwest trends to the degree that it might be useful in following them farther northeast. There is a reversal of dip on the western margin of the map about 750 feet south of the northern boundary

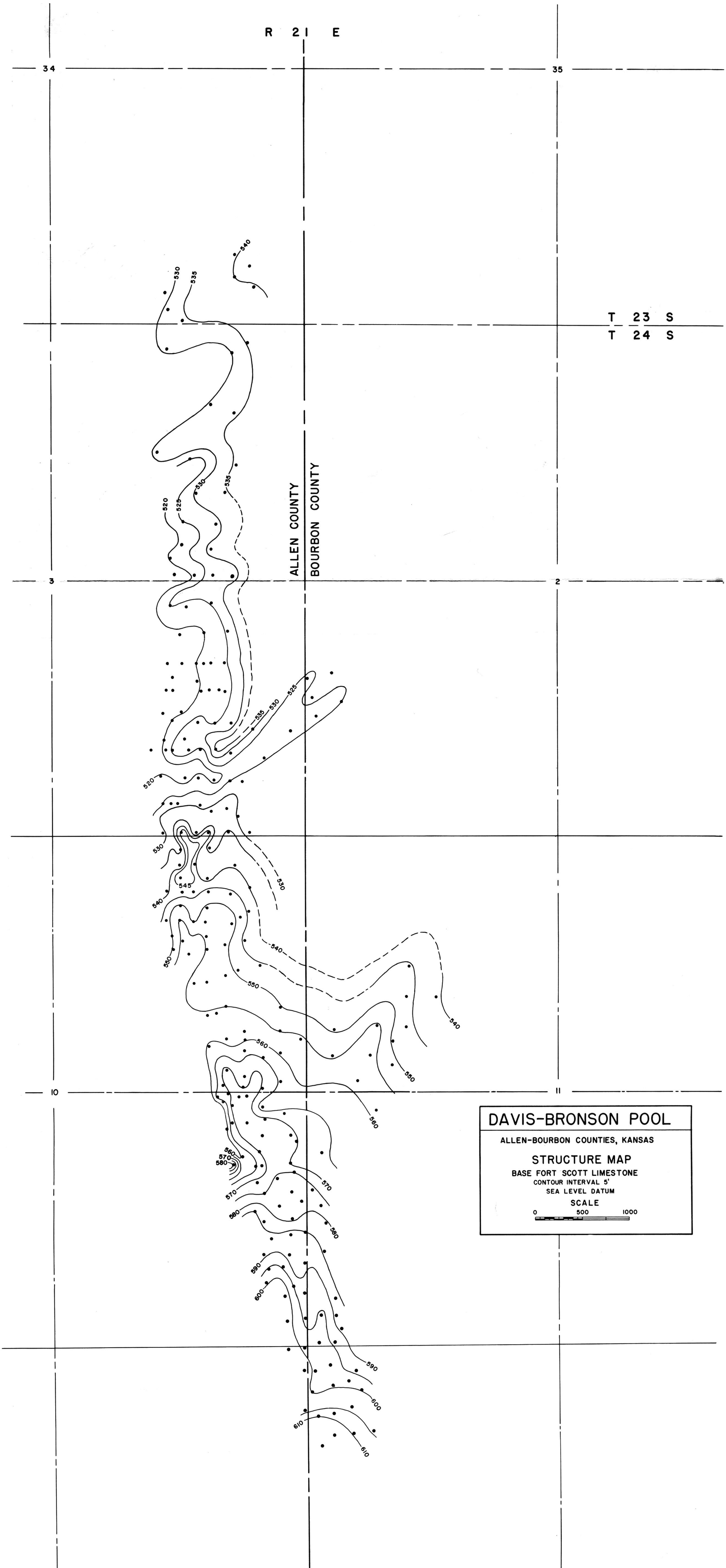


Figure 6. Structure map of the base of the Fort Scott Limestone.

of the SW 1/4 of Sec. ten. This indicates the possibility of a westward extension of the sandstone body in that area that caused a reversal of dip similar to that shown over the trends on the east side of the main trend.

The north and south ends of the map show structurally high areas coincident to the channel fill structure map. The same causes of the structural attitude of the sandstone body apply to the structure of the base of the Fort Scott Limestone.

SANDSTONE ANALYSIS

Oil well core samples were used in the sandstone analysis; sample locations are shown in Table 1. The analysis consisted of a mineralogical investigation and grain size-roundness studies, both done in thin section. Also, X-ray diffraction was used to substantiate petrographic mineral identification and to identify clay minerals.

Sampling Procedure

Random samples were taken at widely separated locations throughout the length of the sandstone body so that it would be well represented. They were chosen at zones of the best sand development in the available cores; no attempt was made to analyze samples in the shaly or silty portions of the sandstone.

Table 1.

Locations of Sandstone Samples

Sample number	Depth	Feet above base of sandstone	Location
1	680'	17	Gillaspie No. 2-A 125' WEL 560' SNL NE/¼ Sec. 10, T. 24 S., R. 21 E. Allen County, Kansas
2	678'	11	Purdon No. 16 460' SNL 460' WEL NW/¼ Sec. 14, T. 24 S., R. 21 E. Bourbon County, Kansas
3	616'	14	Henninger "C" No. 1-A 475' NSL 540' WEL NE/¼ Sec. 3, T. 24 S., R. 21 E. Allen County, Kansas
4	620'	27	Henninger "A" No. 29-E 410' SNL 580' WEL NE/¼ Sec. 3, T. 24 S., R. 21 E. Allen County, Kansas
5	655'	5	Henninger "B" No. D-55-A 540 NSL 60' WEL NE/¼ Sec. 10, T. 24 S., R. 21 E. Allen County, Kansas

Laboratory Procedure

Thin Sections

Disaggregation was attempted by vigorous pounding with a metal mortar and pestle; but because the sandstone contains quartz cement, examination with a binoucular microscope revealed quartz aggregates and euhedral grains with quartz overgrowths, a fine fraction of ground up metamorphic rock fragments, and clay matrix. It was concluded that a sieve analysis of the samples would reveal a meaningless measure of quartz overgrowths and fines not representative grain size of the original sediment. Therefore, thin sections were used instead of sieve analysis for the determination of grain size parameters. The disaggregated samples were labeled and later used in X-ray analyses.

Thin sections of samples 1, 2, and 5 were cut perpendicular to the bedding planes of the sandstone in order to show the angular laminations and to give a representative sample of particular minerals or mineral grains what might be concentrated at the lamination interface. The sandstone in samples 3 and 4 appeared to better sorted than the other three; thin section slabs were cut parallel to the inferred plane of bedding since it was not clearly evident. Thin sections of samples 1 and 4 were cut through shale pebbles with respect to bedding planes and to examine the pebble's mineral constituents. All the thin sections were mounted and ground to the desired thickness by a commercial operator, but the sample slabs were cut by the writer.

X-ray Samples

Untreated U.S. Standard Sieve Mesh number 230 and finer fractions (pan fractions) of the previously disaggregated sandstone samples, were used in the preparation of random powder samples. It was assumed that the 230 and finer fractions would be representative of all the minerals in the sandstone samples. The powder was mounted in aluminum frames to be used in X-ray analyses. The pan fractions of the 5 disaggregated samples were put into 600 ml. beakers, partially filled with distilled water, dispersant added, agitated, and allowed to settle 5 minutes. Part of the fine fraction in suspension, after 5 minutes settling, was removed with a pipette and placed on a glass microscope slide and allowed to dry, producing an oriented sample.

Fresh chips of dolomite (?) and clay ironstone pebbles were crushed with a mortar and pestle, mounted in aluminum frames, and used as randomly oriented samples for X-ray analyses.

X-ray Analysis

Oriented and random powder samples were analyzed with Ni-filtered Cu K-alpha radiation from a constant potential Norelco Wide Range Diffractometer with the following setting: 38 kilovolts and 18 milliamperes, scaning speed 1° (two theta) per minute, chart speed 1/2 inch per minute, and a time constant of 2 seconds. The slit system consisted of a divergent and antiscatter slit of 1°, and receiving slit of 0.006 inch. The pulse height analyzer (PHA) was set at a level of 16 volts with a window of 11 volts; the detector range was 1.7 kilivolts. A scale factor of 200 or 500, depending on intensities of peaks, was used.

All random powder samples were first run from 0 to 90 degrees (two theta), to identify the mineral content. The oriented slides of the clay fraction were run from 0 to 60 degrees (two theta) to identify the clay minerals. The heated oriented slides of the clay fraction were then run to detect changes, if any, in the clay mineral structures, which would clarify or invalidate previous identification. A random powder sample of dolomite (?) pebbles was run to clarify previous identification of the handspecimen.

Heat Treatment

Heating clay minerals is another method used to pinpoint clay mineral identification. The kaolinite crystal structure collapses after heating above 550° C, which will result in the loss of the kaolinite peak at 7.15 A.U. Chlorite and illite are not affected by temperatures below 700° C. All oriented slides were heated in a muffle furnace at 700° C for 30 minutes, followed by X-ray analysis. The two theta values of the spacings were converted to Angstrom Units (A.U.) using the "Table for Conversion of X-ray Diffraction Angles to Interplanar Spacing," published by the U.S. Dept. of Commerce, National Bureau of

Standards, Applied Mathematics Series 10 (1950).

Petrographic Modal Analysis

The mineralogy of five samples was obtained with a petrographic microscope by the point count method (Chayes, 1954) using 1400 points per slide. A three fourths inch by one inch area was marked on the slide, and a series of traverses, of predetermined spacing was made across the marked area, during which the mineralogy at each stop was recorded on a multiple lab counter. For a more thorough discussion of the area point count method the reader is referred to Chayes, (1954).

Figure 7 shows the average composition of the sandstone body; Table 2 gives the mineral constituents and their percentages in each of the sandstone samples investigated.

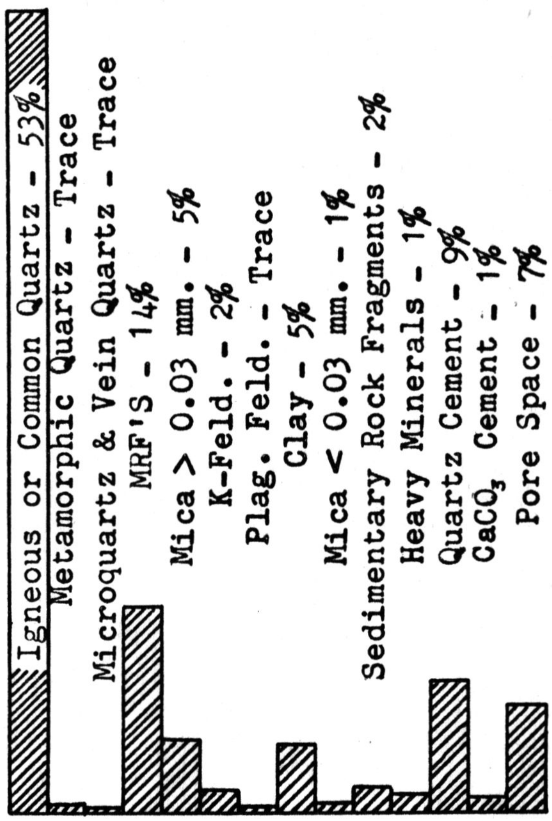


Fig. 7 Histogram showing average mineral composition of the sandstone thin sections.

Table 2

MODAL ANALYSIS (PERCENT) FOR THIN

SECTIONS OF SANDSTONE INVESTIGATED

Sample number:	1	2	3	4	5
Q constituents					
Igneous quartz	50	51	54	57	55
Schistose metaquartz	0	t	t	1	1
Recrystallized metaquartz	t	t	t	0	t
Vein quartz	t	0	t	0	0
Microquartz	t	t	t	t	t
M constituents					
Stretched metaquartz	t	t	0	0	0
Metamorphic rock fragments (MRF's)	18	18	12	9	13
Biotite > .03 mm.	6	5	4	1	5
Muscovite>.03 mm.	1	1	t	t	2
F constituents					
Microcline	t	0	0	0	0
K-feldspar	1	1	1	t	t
Oligoclase (An)	1	t	1	t	t
Apatite	0	0	t	0	t
Zircon	t	t	t	t	0
Tourmaline	t	t	t	t	0
Ores (undifferentiated)					
detrital	1	1	1	t	1
authigenic	0	0	1	t	t
Clay minerals (undifferentiated)	5	4	6	4	3
Mica "hash" < .03mm.	1	1	t	1	1
Chlorite < .03 mm.	0	t	0	0	0
Limestone rock fragments	0	t	0	0	0
Quartz overgrowths or cement	9	8	8	8	11
Calcite cement	1	1	2	1	1
Pore space	4	9	8	10	5
Pebbles	2	0	0	6	0

t = trace (less than 1 percent)

Mineralogical Description

Quartz

Quartz is the dominant mineral in the sandstone investigated; it amounts to about 73 percent of the detrital fraction. Several types of quartz were observed in the thin sections of the sandstone samples. The different quartz types observed were: (1) Igneous or common quartz, (2) Schistose metaquartz, (3) Stretched metaquartz, (4) Recrystalized metaquartz, (5) Vein quartz, (6) Microquartz. The amount of each quartz type found in the thin sections is shown in Table 2.

Igneous or Common Quartz--According to Folk (1961, p. 68-72), igneous or common quartz is derived from granite batholiths or granite gneisses and may be further divided into several subtypes: (1) Single grains, straight extinction; (2) Single grains slightly undulose extinction; (3) Single, equant grains with strongly undulose extinction; (4) Straight extinguishing elongate fragments, size somewhat less than the rest of the common quartz, probably chips from the splitting of larger grains. All the listed sub-types may contain mineral inclusions, few or abundant vacuoles, and rutile needles.

All the quartz sub-types described are found in the sandstone samples. Igneous or common quartz averaged 53 percent of each sample examined. Most of these grains have undulose extinction. A few grains are composite with strongly undulose extinction. Inclusions are common; microlites of mica are the

EXPLANATION OF PLATE I

Fig. 1. Photomicrograph of a quartz grain with vacuole trails (a) and a slight overgrowth (b).

Fig. 2. Photomicrograph of a quartz grain with an overgrowth (a) and authigenic kaolinite adjacent (b).

PLATE I

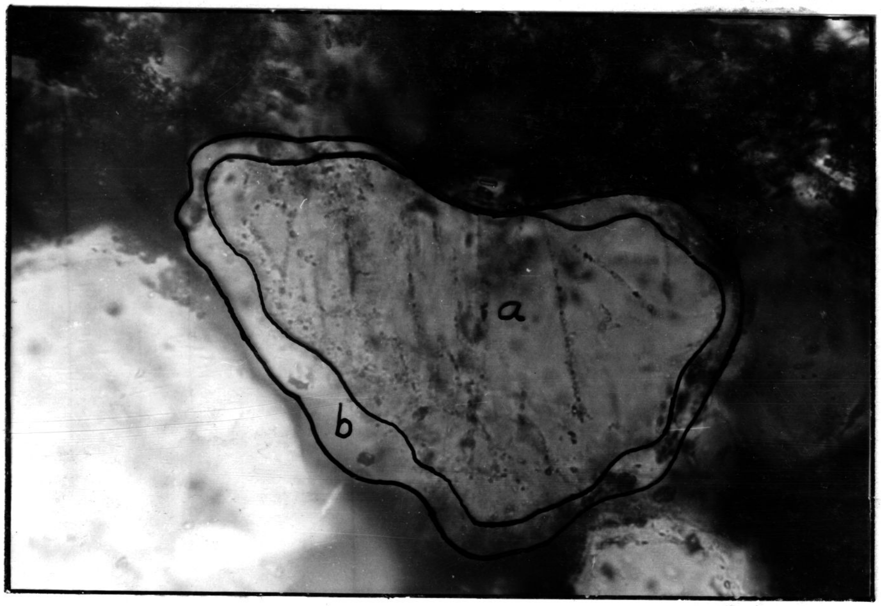


Fig. 1. X nicols

Scale:
Each division = 0.01 mm.

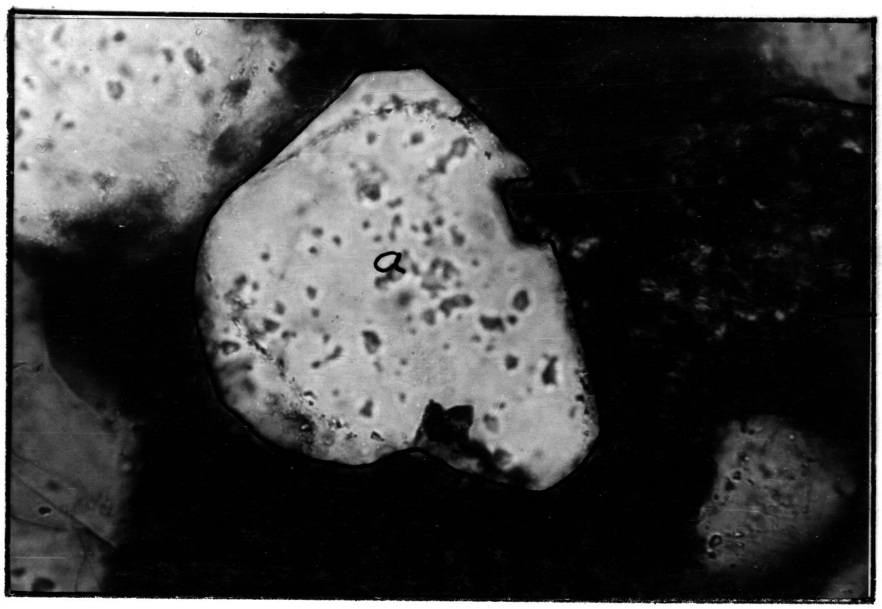


Fig. 2. X nicols

Scale:
Each division = 0.01 mm.

EXPLANATION OF PLATE II

Fig. 1. Photomicrograph of a schistose metaquartz grain.

Fig. 2. Photomicrograph of a schistose metaquartz grain (a) and calcite cement (b).

PLATE II

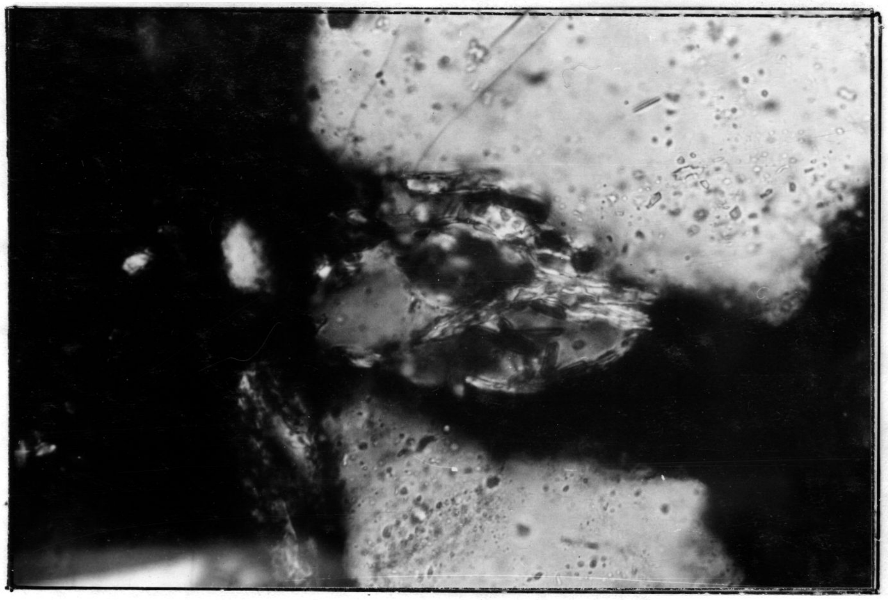


Fig. 1. X nicols

Scale:
Each division = 0.01 mm.

Fig. 2. X nicols

Scale:
Each division = 0.01 mm.

EXPLANATION OF PLATE III

Fig. 1. Photomicrograph of stretched metaquartz.

Fig. 2. Photomicrograph of microquartz.

PLATE III

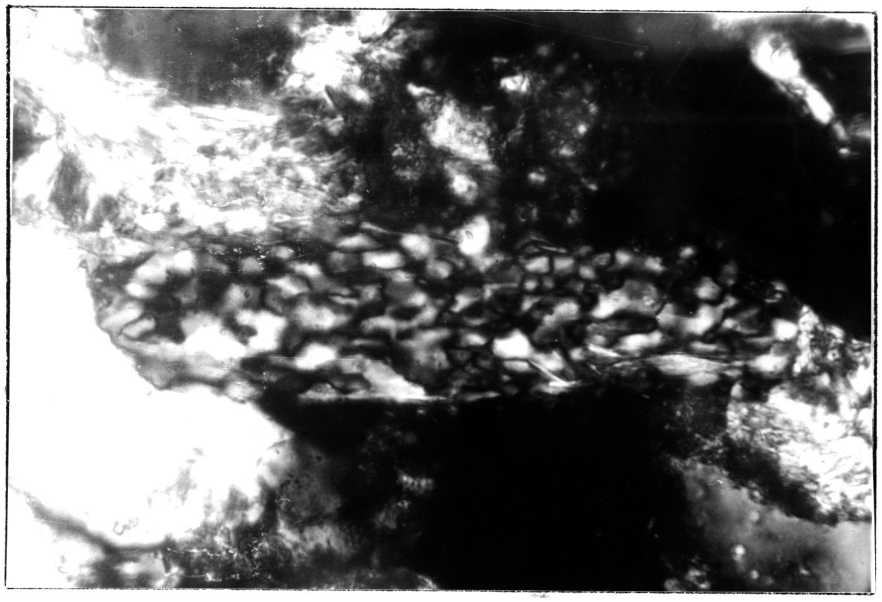


Fig. 1. X nicols

Scale:
Each division = 0.01 mm.

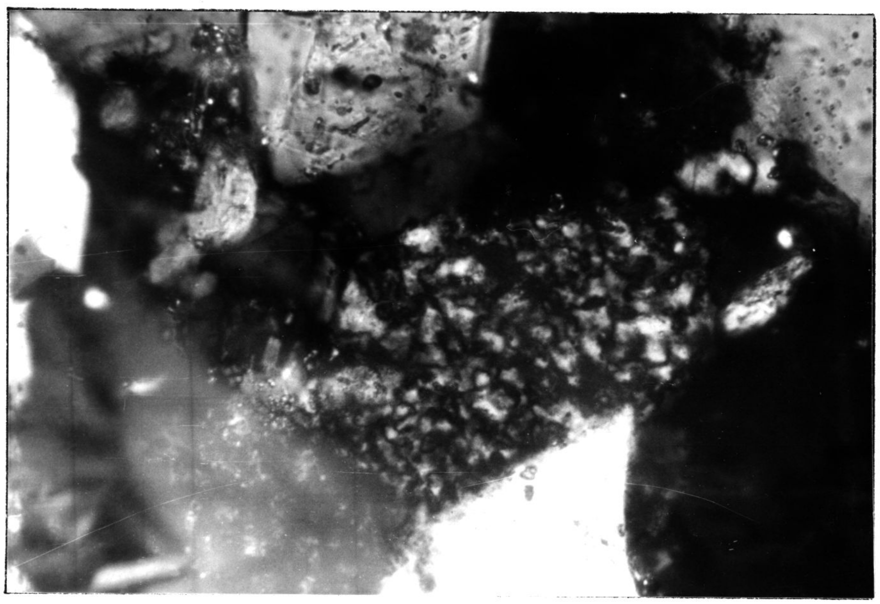


Fig. 2. X nicols

Scale:
Each division = 0.01 mm.

Recrystallized Metaquartz--Recrystallized metaquartz is another type of metamorphic quartz formed under intense stress _with_ recrystallization (Folk, 1961, p. 70). It makes up approximately one fourth of the metamorphic types observed in the thin sections. The polycrystalline grains form a mosaic of anhedral crystals of quartz with straight boundaries. They are easily confused with fragments of quartzose cemented sandstone, but a diagnostic feature is the widely different optical orientation of the individual crystals of quartz.

Vein Quartz--Some vein quartz grains, derived from pegmatites or hydrothermal veins, were observed in the sandstone. Some grains are single anhedral crystals with undulose extinction and others are polycrystalline with "cock's comb" extinction. Vacuoles are common in both types and give the grains a milky appearance in reflected light.

Microquartz--Microquartz (Fig. 2 of Plate III) comprises only about two percent of the total grains. The microcrystalline quartz identified in the thin sections is probably chert. The grains are made up of equidimensional anhedral crystals ranging from 5 to 10 microns in diameter. Also, the chert grains appear to be more rounded than the associated grains of metaquartz. Chert is derived from carbonate rocks and chert beds, which is indicative of an older sedimentary source (Folk, 1961, p. 78).

Metamorphic Rock Fragments (MRF's)

Metamorphic rock fragments, schist and phyllite, make up an average of 10 to 15 percent of the total detrital fraction in the sandstone samples analyzed. Plate IV shows some typical metamorphic rock fragments. The grains show excellent parallel optical orientation of mica and finely recrystallized quartz. The grains are mostly angular to subangular, but a few rounded grains occur. About 70 percent of the grains are fresh or only slightly weathered; the remainder are moderate to extensively weathered. A multicycle history is suggested by the fresh angular MRF's and rounded weathered grains.

Mica

Mica greater than 0.03 mm. in diameter makes up about five percent of the total detrital fraction (Fig. 7). Biotite totals four percent, whereas muscovite makes up about one percent. Some mica flakes occur randomly throughout the samples, but most are concentrated at laminations of the sandstone (Plate X, Fig. 1). About two-thirds of the mica is fresh. Biotite exhibits a greater degree of weathering than muscovite, accounting for most of the weathered mica. The highly weathered biotite appears to be almost altered to clay. The weathered grains have a dull brown color and the grain boundaries appear ragged and irregular. Plate V, Fig. 1, is a photomicrograph of a typical grain of muscovite. Note the angularity and freshness; the

EXPLANATION OF PLATE IV

Fig. 1. Photomicrograph of an angular metamorphic rock fragment (MRF).

Fig. 2. Photomicrograph of a rounded metamorphic rock fragment (MRF).

PLATE IV

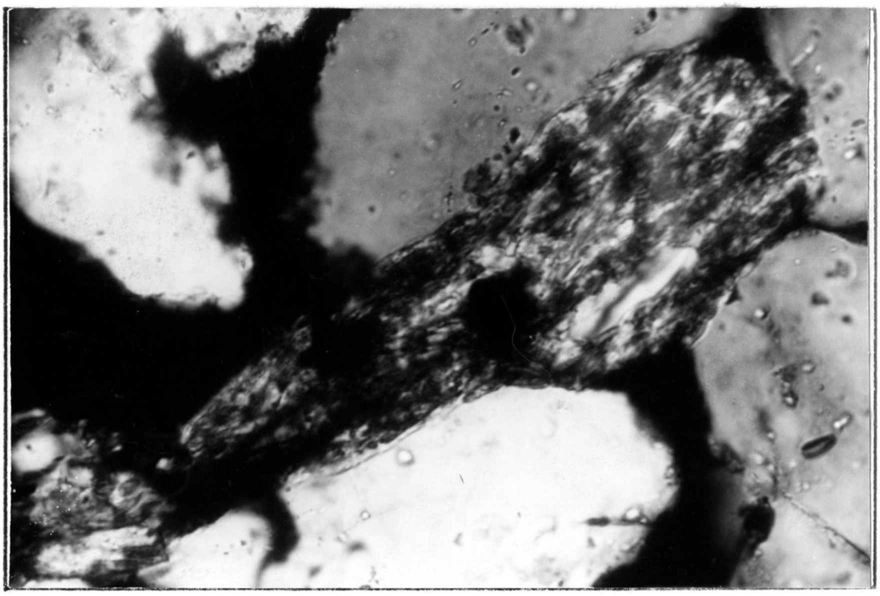


Fig. 1. X nicols

Scale:
Each division = 0.01 mm.

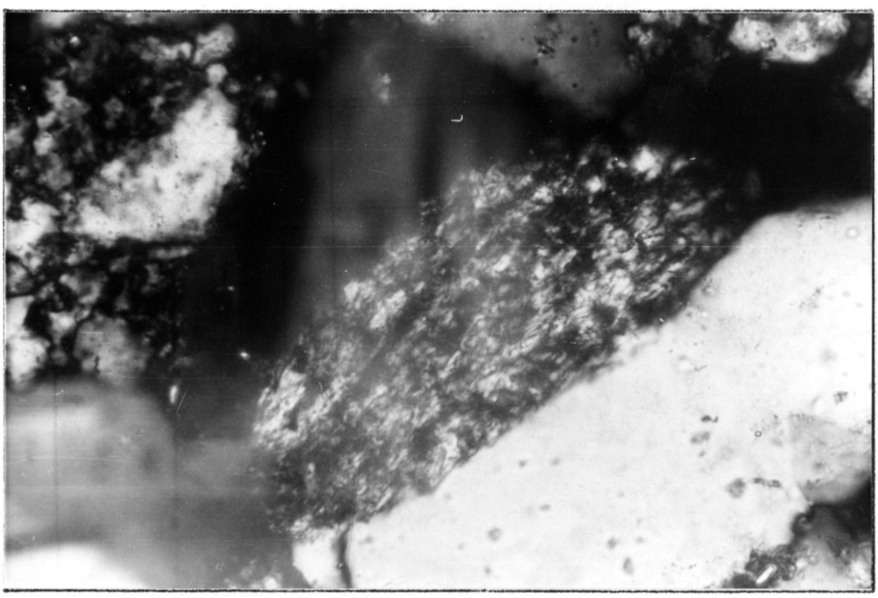


Fig. 2. X nicols

Scale:
Each division = 0.01 mm.

PLATE V

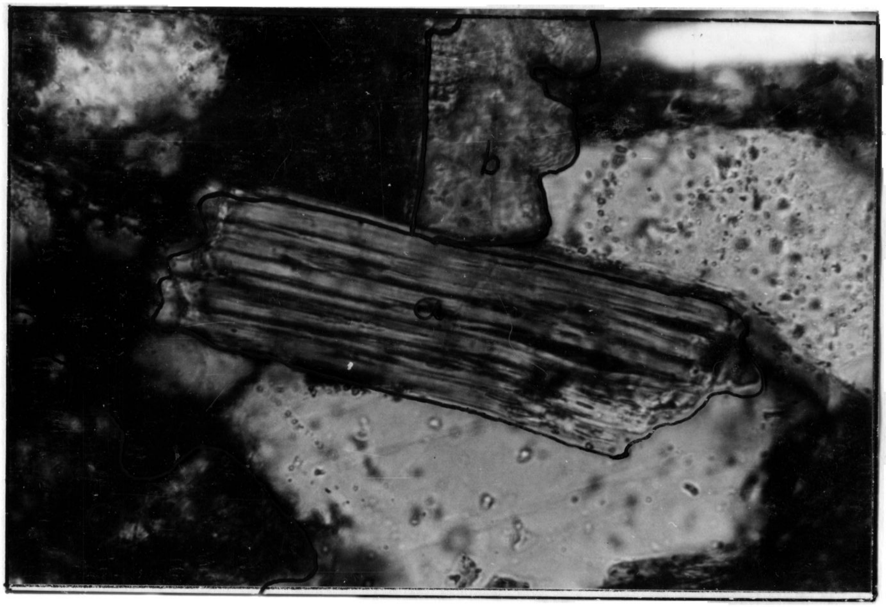


Fig. 1. X nicols

Scale:
Each division = 0.01 mm.

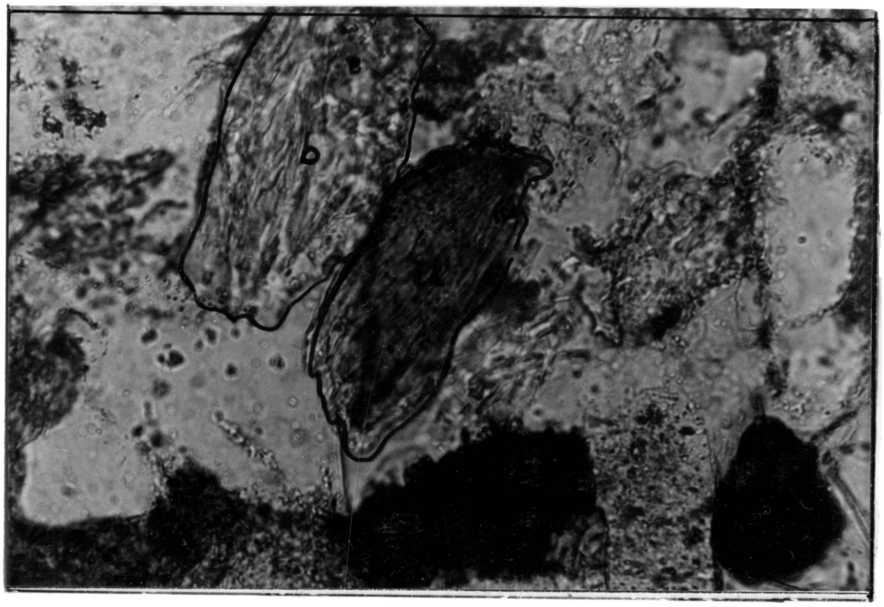


Fig. 2.

Scale:
Each division = 0.01 mm.

high length-width ratio is because the crystallographic C-axis is parallel to the plane of the microscope stage. Typical biotite is shown in Plate V, Fig. 2. It shows some weathering and a more equidimensional character of the flake. Biotite is chemically more unstable than muscovite. An erosion rate that exceeds the rate of weathering in the source area is indicated when biotite is more abundant than muscovite (Folk, 1961, p. 84). The abundance of biotite could also be due to a source area which had abundant biotite and little muscovite.

Mica "hash"

Mica hash consists of flakes of biotite, muscovite, or chlorite less than 0.03 mm. in diameter. Table 2 shows the percentage of mica hash in the thin sections of the sandstone. It occurs as a matrix and shows various degrees of weathering. The flakes may be fairly fresh, highly altered, or in any stage of weathering between the extremes. Mica hash was derived from larger mica flakes and/or metamorphic rock fragments that were broken down during transport to the depositional site of the sandstone.

Feldspar

Feldspar averages about two percent of the samples. Table 2 shows the percentages of the various types of feldspar. Plate VI is a photomicrograph of typical feldspar grains observed in the slides. The median size of the feldspars is somewhat greater

EXPLANATION OF PLATE VI

Fig. 1. Photomicrograph of an orthoclase grain with overgrowth.

Fig. 2. Photomicrograph of an oligoclase (An) grain with polysynthetic twinning and overgrowth.

PLATE VI

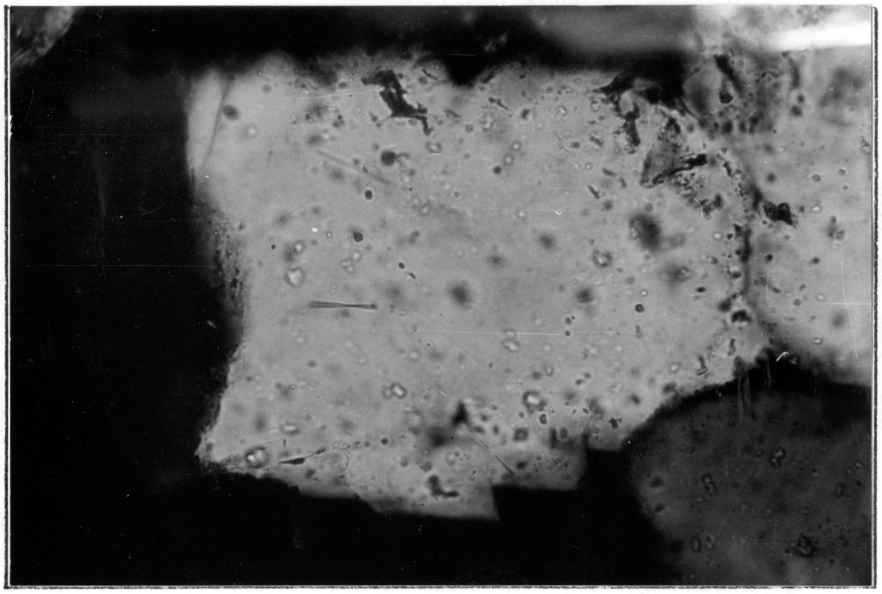


Fig. 1. X nicols

Scale:
Each division = 0.01 mm.

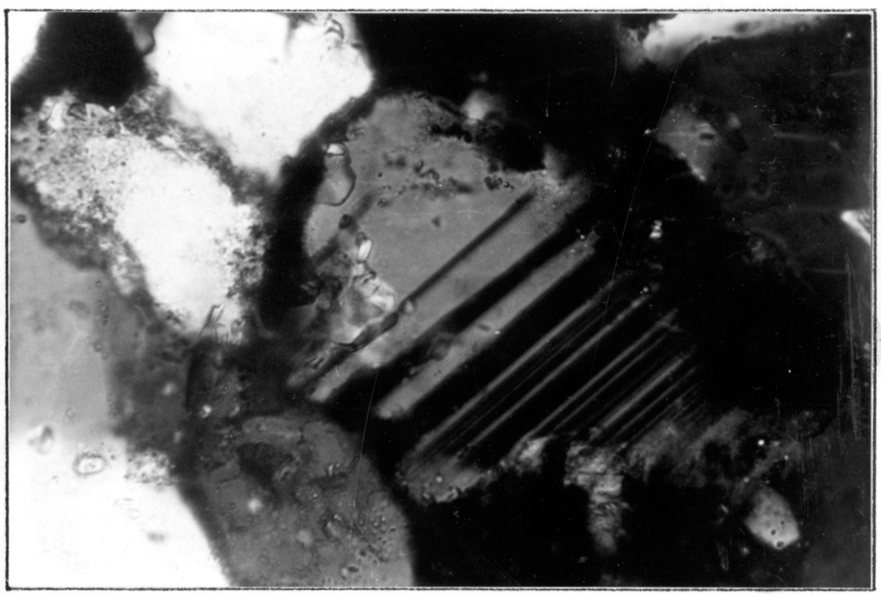


Fig. 2. X nicols

Scale:
Each division = 0.01 mm.

(approximately 0.25 mm.) than the median size of the quartz grains. Orothoclase is the most abundant feldspar, making up almost 80 percent of the total feldspar grains in each sample.

More than 75 percent of the orthoclase grains exhibit a high degree of kaolinization; these grains show more rounding than the remainder of the feldspar, which are subangular and fairly fresh. A few grains of fresh, angular orthoclase were observed; on the other hand, a few grains are fairly well rounded and highly kaolinized.

About 20 percent of the total feldspar in each sample is plagioclase. Using the Michel-Levy extinction method, the plagioclase was identified as Oligoclase (An_{14}). Fig. 2 of Plate VI shows a typical plagioclase grain in the thin sections. All the plagioclase grains observed are fresh and subangular; they are more angular than associated quartz grains. A grain of microcline was observed during the point count of one slide (see table 2); however, it was not part of the count and was recorded as only a trace. The content of microcline in the samples is probably very minor. Like the plagioclase grains, the microcline is fresh and fairly angular. Overgrowths are fairly common on both plagioclase and orthoclase grains and average from five to fifteen microns in width (Plate VI). Inclusions of mica fragments and clay are in the overgrowths, indicating that the overgrowths developed after the sand was deposited. Weathering of the feldspar probably took place before sand deposition, because neighboring grains show a wide variation in the degree of weathering. The orthoclase indicates a granitic or gneissic source area.

Heavy Minerals

Heavy minerals, opaques and non-opaques, constitute about one percent of the total minerals in the thin sections. Tourmaline and zircon occur in about equal amounts, whereas apatite was found in only two thin sections (see Table 2).

The apatite was in the form of subhedral six-sided prismatic crystals. Usually, the basal section of the crystals showed only a small amount of abrasion. Tourmaline (Plate VII, Fig. 1) occurs as partially rounded, prismatic, brown grains, or (Plate VII, Fig. 2) euhedral, brown prismatic grains.

The euhedral tourmaline grain (Plate VII, Fig. 2) probably represents a first cycle deposit; the rounded grains indicate that the grains were reworked from an older sedimentary source. Little can be said about the primary source of the tourmaline grains, other than it was igneous or metamorphic, as they may be derived from either.

The zircon grains in the thin sections are colorless to pale yellow, with the short prismatic crystals showing some rounding, which would indicate more than one erosional cycle; therefore, the grains were probably derived from an older sedimentary source. The primary source, like tourmaline, may be either igneous or metamorphic rocks.

Table 2 shows the percentages of detrital and authigenic opaques in the thin sections. Magnetite or ilmenite was identified as the detrital fraction of the heavy minerals. Pyrite,

EXPLANATION OF PLATE VII

Fig. 1. Photomicrograph of a partially rounded tourmaline grain.

Fig. 2. Photomicrograph of a mosaic of interlocking quartz overgrowths and a euhedral tourmaline grain.

PLATE VII

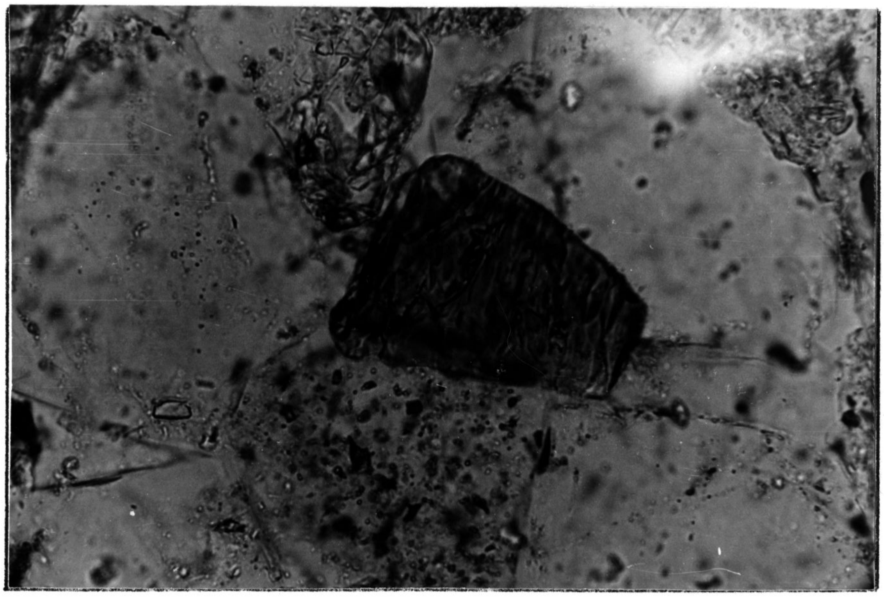


Fig. 1.

Scale:
Each division = 0.01 mm.

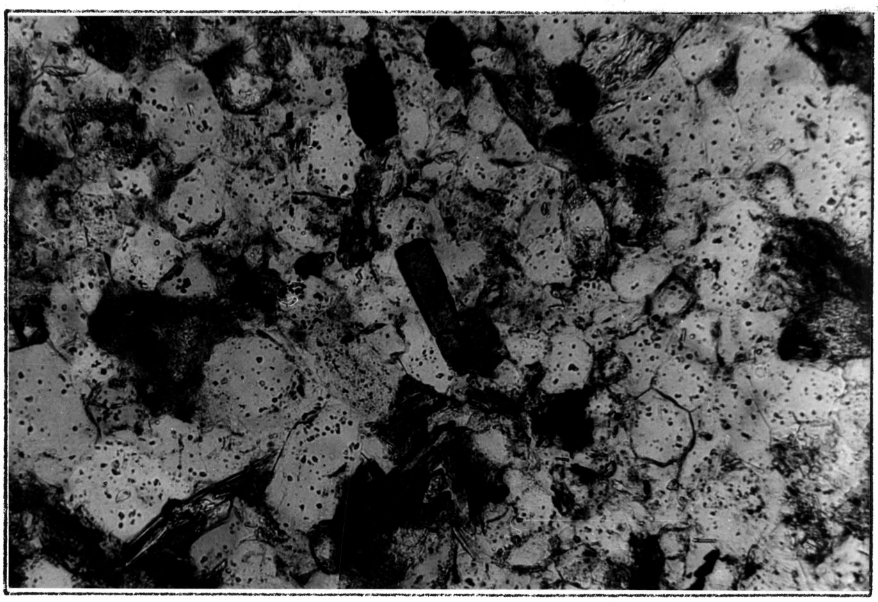


Fig. 2.

Scale:
Each division = 0.01 mm.

occuring as anhedral pore filling or euhedral crystals in fractures or large pores in the sandstone, comprised the authigenic oqaques. Undoubtedly, pyrite also occurs in the detrital fraction, due to its relative abundance in the older underlying shales. Magnetite is a common constituent of recent and ancient sediments. No significance can be placed on its origin, because it is common in igneous and metamorphic source rocks. Pyrite is very common in the samples and can be observed with the microscope as well as in handspecimen. It can commonly be found as a secondary growth in the sandstones or enveloping shales throughout the stratigraphic interval.

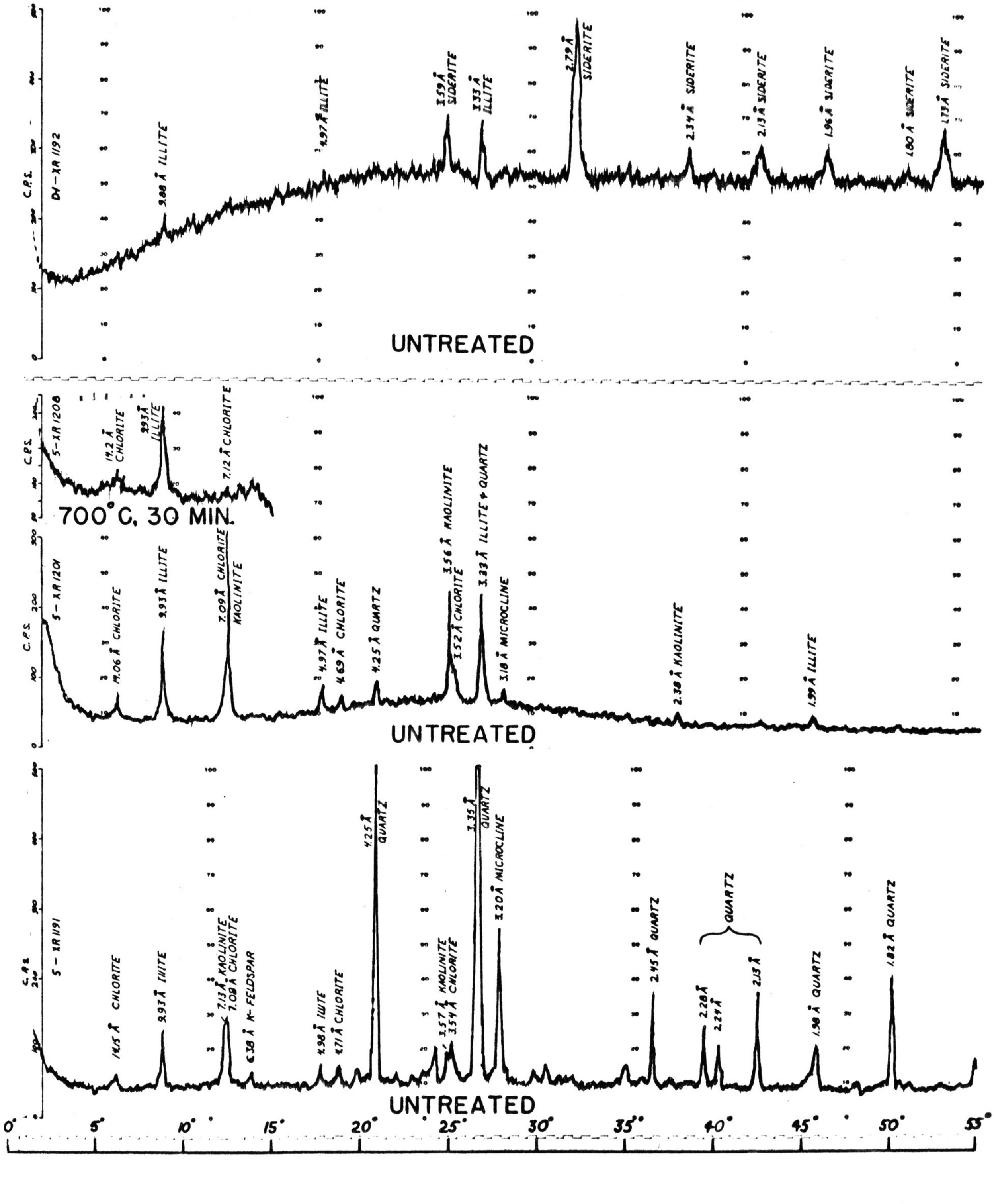
Clay Minerals

Each sample contained an average of five percent clay minerals, as determined by point count. Detrital and authigenic clays were identified in the thin sections. X-ray diffraction patterns of the samples were used in conjunction with the petrographic microscope to identify the clays and establish their genetic relationships. Plate VIII shows typical x-ray diffraction patterns of the samples analyzed.

Identification of the clay minerals was based primarily on x-ray techniques, the genetic relationship of the clays was determined with the petrographic microscope. The clay minerals identified are: kaolinite, illite, and chlorite.

EXPLANATION OF PLATE VIII

Typical x-ray diffraction patterns of the sandstone samples analyzed.


C.P.S.
DI-XR 1192
9.88 Å ILLITE
4.97 Å ILLITE
3.59 Å SIDERITE
3.33 Å ILLITE
2.79 Å SIDERITE
2.34 Å SIDERITE
2.13 Å SIDERITE
1.96 Å SIDERITE
1.80 Å SIDERITE
1.73 Å SIDERITE
UNTREATED
5-XR 1208
14.2 Å CHLORITE
9.93 Å ILLITE
7.12 Å CHLORITE
700° C, 30 MIN.
5-XR 1201
14.06 Å CHLORITE
9.93 Å ILLITE
7.09 Å CHLORITE KAOLINITE
4.97 Å ILLITE
4.69 Å CHLORITE
4.25 Å QUARTZ
3.56 Å KAOLINITE
3.52 Å CHLORITE
3.33 Å ILLITE + QUARTZ
3.18 Å MICROCLINE
2.38 Å KAOLINITE
1.99 Å ILLITE
UNTREATED
5-XR 1191
14.15 Å CHLORITE
9.93 Å ILLITE
7.13 Å KAOLINITE
7.08 Å CHLORITE
6.38 Å K-FELDSPAR
4.98 Å ILLITE
4.71 Å CHLORITE
4.25 Å QUARTZ
3.57 Å KAOLINITE
3.54 Å CHLORITE
3.35 Å QUARTZ
3.20 Å MICROCLINE
2.45 Å QUARTZ
QUARTZ
2.28 Å
2.24 Å
2.13 Å
1.98 Å QUARTZ
1.82 Å QUARTZ
UNTREATED
0° 5° 10° 15° 20° 25° 30° 35° 40° 45° 50° 55°

Kaolinite--Kaolinite (Plate IV, Fig. 2) in thin section appears to be predominantly authigenic. The kaolinite "books" observed in the thin sections do not show any indication of transport, suggesting they grew in place after the sand was deposited. Detrital grains of kaolinite are probably in the samples, and were the starting point for growth of the secondary kaolinite "books"; however, the amount of detrital kaolinite, if any, could not be readily determined from the thin sections. Kaolinite appears to be the most abundant clay mineral, as shown by the x-ray diffractograms (Plate VIII). The peak intensity in x-ray diffractograms is an indication of the relative abundance. Illite and chlorite are also present in lesser amounts, illite being more abundant than chlorite.

Several workers believe that kaolinite is detrital and that it may indicate a source area in which aluminum silicate parent material has been altered by extensive leaching conditions (Keller, 1964, p. 17). All kaolinite observed in the thin sections appears to be authigenic, with the possibility of some detrital grains. Kaolinite is present in the Cherokee shales (Baker, 1962) around the sandstone body. In view of the different sources possible for kaolinite and its apparent authigenic occurrence, the writer feels it would be difficult to draw any specific conclusions about its use as an indicator of source. About all that can be surmised about the kaolinite is that it is authigenic and was probably derived from the shales enveloping the sandstone body.

Illite--Illite, the next most abundant of the clay minerals of the sandstone, is shown in the x-ray diffractogram (Plate VIII). The illite in the samples is probably detrital. According to Folk (1961, p. 89), weathering of phyllites yields illite, and MRF's are abundant in the samples. Also, illite may be derived from shales. The illite in the samples may have been derived from the same metamorphic source area as the MRF's and/or the Cherokee shales. However, it is ubiquitous and therefore does not indicate any specific source.

Chlorite--Chlorite is the least abundant clay mineral in the samples and, like illite, is probably detrital. Chlorite may be derived from metamorphic rocks or shales. Weathering of the abundant biotite in the sandstone may also yield chlorite. Any one, or a combination, of the aforementioned sources could contribute the chlorite to the sediment.

Limestone Rock Fragments

A trace of limestone fragments was observed in the thin section of sample No. 2 (see Table 2). The limestone fragments are subangular to subround and have a mean size about the same as the associated quartz grains, which is 3.8 ϕ. These fragments may have been derived either from thin limestone beds that occur throughout the Cherokee section of from reworked grains from the underlying limestones of Mississippian Age.

Quartz Overgrowths and Cement

Almost all the quartz grains observed in thin sections have at least some overgrowths; they range in thickness from a trace to 20 microns. Plate I shows typical quartz grains with overgrowths. Most of the grains have extensive or thick (about 15 microns) overgrowths and they may merge to form an interlocking mosaic, Plate VII, Fig. 2.

Quartz contributes almost 90 percent of the cementing agent of the sandstone, and calcite makes up the remaining 10 percent (see Fig. 7). It is difficult to place a boundary as to where the overgrowths stop and quartz cement begins. Plate VII, Fig. 2, shows how the overgrowths merge to form a mosaic; however, many quartz grains have authigenic overgrowths developed in a clay matrix (Plate I, Fig. 2), so putting an arbitrary boundary between the two seems warranted. In this study overgrowths that form a mosaic and quartz cement in pore spaces, not part of a quartz overgrowth, are collectively defined as quartz cement. Several theories have been proposed on the origin of silica cement. Travis (1963) presented a review of the different theories on the origin of silica; parts of the following discussion are taken from his review.

The theory that diagenetic changes in shale provide a source for silica has been proposed by Siever (1962). He showed that the transformation of montmorillonite to kaolinite, and illite, yields excess SiO_2:

Montmorillonite

$$1.2NaO_{66}\ Al_{3.34}MgO_{.66}\ Si_8O_{20}\ (OH)_4 \bullet nH_2O \quad 6.4H^+ \longrightarrow 2Al_2Si_2O_5(OH)_4$$

Kaolinite

$$+\ 5.6\ SiO_2 + 0.79Na^+ + 0.79Mg^{++} + (1.2n + 3.6)H_2O$$

Montmorillonite

$$1.78NaO_{66}\ Al_{3.34}MgO_{.66}\ Si_8O_{20}\ (OH)_4 \bullet nH_2O + 3.7H^+ + 1.33K^+ + 4.82Mg^{++} \longrightarrow$$

Illite

$$K_{1.3}\ Al_{5.33}Mg_6\ Si_{6.77}O_{20}(OH)_4 + 7.63SiO_2 + 1.18Na^+ + (1.78n + 3.4)H_2O$$

The free silica may be transported by connate water and precipitated as a cementing agent.

The argument for his theory is that montmorillonite is relatively rare in sediments which are older than Mesozoic and the frequently occurring clay minerals of pre-Mesozoic age are illite and chlorite. If the source area is the controlling factor of clay mineral distribution, as proposed by Weaver (1958), the theory of diagenetic changes of clay minerals as a source of silica is difficult to explain. The abundance of secondary kaolinite and absence of identified montmorillonite, in the samples investigated, suggests that this theory might account for the quartz cement.

Walker (1957), suggested that carbonate replacement of quartz may be a source for silica. Because no chemical explanation has been proposed to account for this type of replacement, his theory has not been widely accepted. However, the apparent replacement of several quartz grains by calcite was observed in the thin sections (Plate IX); carbonate replacement may be a possible source of the silica cement.

A theory proposed by Waldschmidt (1941) suggested that the quartz cement is formed by the process of continuous solution of silica from quartz grains at points of contact. This idea was based on the following observations: (1) Mosaics of interlocking quartz grains that contain appreciable amounts of recrystallized quartz; (2) faceted quartz crystals that occur around sand grains; (3) euhedral and subhedral crystals that are oriented independent of sand grains; and (4) the uniform distribution of recrystallized quartz throughout a sandstone. Any or all of the requirements of Waldschmidt's theory can be observed in the thin sections of the sandstone; this could possibly be another source of the quartz cement.

A few of the theories on origin of quartz cement have been presented here, with their arguments for and against them, as a possible explanation for the quartz cement of the sandstone samples. In view of the fact that any one of the theories might explain the origin of quartz cement in the sandstone, the writer feels that not just one, but a combination of the outlined theories was the source for the quartz cement.

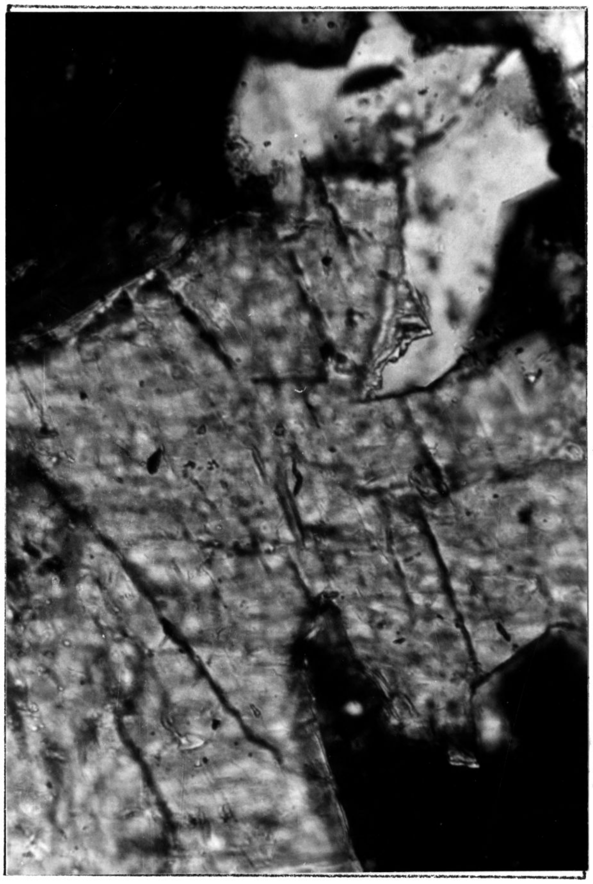
Calcite Cement

Calcite accounts for approximately 10 percent of the cementing agent in the sandstone samples (see Table 2). Calcite cement is shown in Plate IX. Its occurrence is scattered and patchy in the thin sections examined; in places, it appears to

EXPLANATION OF PLATE IX

Photomicrograph of calcite cement partially replacing a detrital grain of quartz.

PLATE IX



X nicols

Scale:

Each division = 0.01 mm.

be replacing quartz grains. The calcite cement partially or wholly surrounds quartz grains and parts of the quartz grain seem to be missing or replaced by calcite.

Pore Space

The average porosity of the sandstone samples investigated is approximately 7 percent (Table 2). By subtracting the percentages of authigenic minerals the porosity, of the sandstone before diagenesis, was approximately 17 percent. It is clearly evident that authigenic minerals have greatly reduced the sandstone porosity.

Pebbles

Conglomerate zones of pebbles occur throughout the sandstone body. They may be found at various levels and are almost always present at the base of the sandstone. The "pebbles" range from about 1.5 to 50 millimeters in diameter, and are subrounded. They are usually elongate, but may also have a compact or equidimensional shape. Most of the "pebbles" observed in the sandstone samples are composed of shale, a typical shale "pebble" is shown in Plate X, Fig. 2. The shale "pebbles" in thin sections 1 and 4 (see Table 2) are composed of quartz fragments 8 to 20 microns in diameter, some altered biotite and muscovite, and undifferentiated clay minerals. The shale pebbles are brown, elongate, and subparallel to the plane of bedding. Some of the shale pebbles are gray to green, with varying amounts

EXPLANATION OF PLATE X

Fig. 1. Photomicrograph of micaceous, laminated sandstone, showing parallel arrangement of mica and oil saturation along the laminae plane.

Fig. 2. Photomicrograph of a shale pebble.

PLATE X

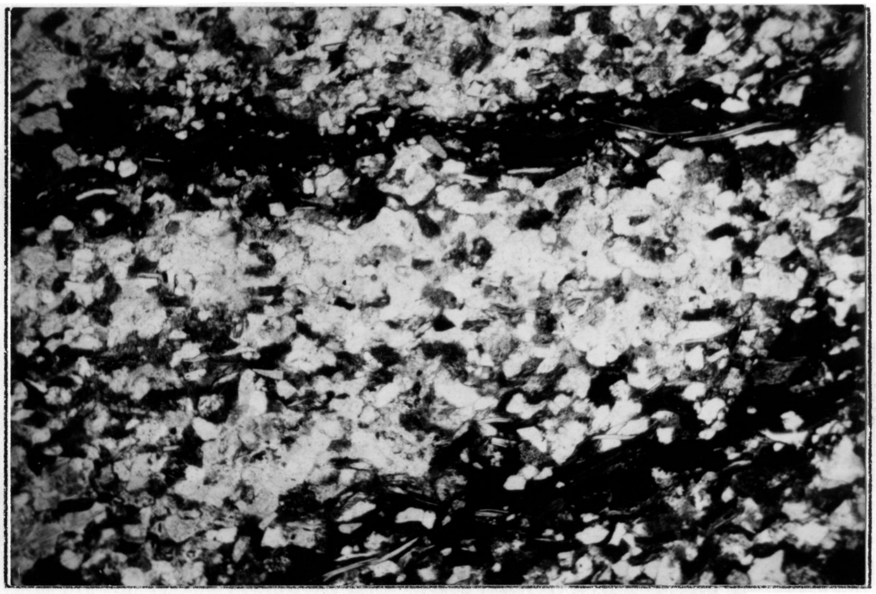


Fig. 1.

Scale: Each division = 0.01 mm.

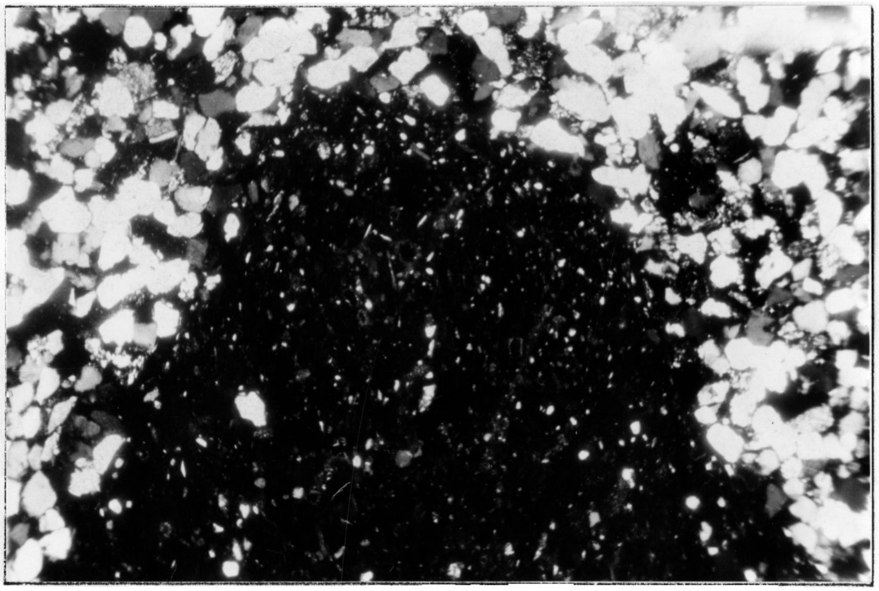


Fig. 2. X nicols

Scale: Each division = 0.01 mm.

of mica.

A light brown pebble of dolomite (?) was analyzed by the x-ray diffractometer to substantiate identification in hand-specimen. The results were very surprising. The previously identified dolomite pebble was actually clay ironstone. The x-ray diffractogram (Plate VIII, Sample D-1 - XR 1192) showed the composition to be siderite with some illite. A sample of bedded clay ironstone was x-ray analyzed and the diffractogram was almost identical to that of the dolomite (?) pebble. Thin clay ironstone beds, occurring with Burbank sandstone bodies, were observed by the writer in oil well cores during the summer and fall of 1965, while employed by an independent oil producer in Iola, Kansas. Thinly bedded clay ironstone occurs throughout the Cherokee section and could be the source of the clay ironstone pebbles. The shale pebbles were probably derived from the underlying shales.

Textural Analysis

Grain size determinations were made from the thin sections with the aid of a micrometer ocular of a petrographic microscope using one hundred points per slide. A grid system was used to determine points of each of the 100 points counted. Five parallel traverses twenty mm. long, spaced one mm. apart, were made across each of the thin sections; the recording points on the grid were located at the successive one mm. interval stops with the aid of "click wheels" on a mechanical stage. The uniform spacing of points by the use of "click wheels" insures a consistent, unbiased, selection of the grains measured. The one mm. spacing between each recording point was chosen so that a different grain would be measured and recorded. A preliminary check on the mean size of the grains in the thin sections revealed the average grain size to be about 0.1 mm. or less. Therefore, the one mm. spacing between recording points was sufficient to insure that a different grain was measured at each stop.

According to Chayes (1954, p. 96-101) measurements made in thin section are valid estimates of the true grain size of the rock sample examined. So long as some scheme for random location of recording points is used, the measurements of a section is an unbiased estimate of volume, regardless of grain sizes, shapes, or orientations, because area is related to volume (Chayes, 1954, p. 96). The results are independent of the grain shape or grain orientation to the plane of the section. The somewhat rigorous mathematical proof used to prove the relation of area to volume is not presented here; the reader is referred to Chayes' article for the complete discussion.

The phi scale devised by Krumbein, was used in preference to a scale expressed in millimeters and is used almost entirely in recent work. Data are presented more conveniently and statistical parameters can be read directly from grain size curves plotted with a phi scale. The size scale used in this investigation is from Folk (1961, p. 24) as modified by Twiss (1965, personal communication) and is in Table 3.

Table 3

GRAIN SIZE SCALE

U.S. Standard Sieve Mesh #	Millimeters	Microns	Phi	Wentworth Size Class
25	0.71		0.5	Coarse Sand
30	0.59		0.75	
35	0.50	500	1.0	
40	0.42	420	1.25	
45	0.350	350	1.5	Medium Sand
50	0.30	300	1.75	
60	0.25	250	2.0	
70	0.210	210	2.25	
80	0.177	177	2.50	Fine Sand
100	0.149	149	2.75	
120	0.125	125	3.0	
140	0.105	105	3.25	
170	0.088	88	3.5	Very Fine Sand
200	0.074	74	3.75	
230	0.0625	62.5	4.0	
270	0.053	53	4.25	
325	0.044	44	4.5	Very Coarse Silt
	0.037	37	4.75	
	0.031	31	5.0	
	0.0156	15.6	6.0	Coarse Silt
	0.0078	7.8	7.0	Medium Silt
	0.0039	3.9	8.0	Fine Silt
	0.0020	2.0	9.0	Very Fine Silt
	0.00098	0.98	10.0	
	0.00049	0.49	11.0	
	0.00024	0.24	12.0	Clay
	0.00012	0.12	13.0	
	0.00006	000.06	14.0	

Procedure

Grain Size--At each point encountered in the traverse the grain under the cross hairs was measured with a micrometer ocular. The size of the grain was not recorded, but placed into a predetermined size class interval. Placing the grain into a size class interval was determined by using the smallest projecting diameter that would stop a grain from passing through a sieve opening, and recording it within the limits of the appropriate 0.25 phi interval. For example: A grain with a least projecting diameter of 0.13 mm. is measured; this grain would pass through the opening of a U.S. Standard # 100 mesh sieve, but would not pass through, and be caught by a # 120 sieve. The grain would then be placed in the 3.0ϕ class interval because it would pass through a 2.75ϕ opening and could not pass through a 3.0ϕ opening.

A 0.25 phi interval was chosen because of the small differences in grain size of the samples. A difference in grain size would be masked if a larger, say 0.5 or 1.0 phi, class interval were used when plotting curves. This method of placing the measured grain directly into a size class interval rather than recording the size and placing it into a class interval later, greatly facilitated and speeded the plotting of curves.

This procedure of recording grain size in the point count is analogous to weighing and recording size fractions in a sieve analysis. The basic assumptions are that the smallest projecting grain diameter governs the sieve on which it is accumulated and each sieve is the class interval.

Roundness--Along with grain size measurements, the roundness of grains over 0.03 mm. was compared to a Powers (1953) roundness chart and recorded. Each major division of the Powers scale of roundness was further subdivided into fourths. Each grain encountered in the point count was assigned a roundness (ρ) value, based on comparison to the chart. Rho (ρ) is the logarithmic expression of the scale on the Powers roundness chart. The limits of the scale classes are: 0.0 - 1.0 very angular, 1.0 - 2.0 angular, 2.0 - 3.0 subangular, 3.0 - 4.0 subround, 4.0 - 5.0 round, 5.0 - 6.0 very round (Folk, 1961, p. 10).

Other properties--In addition to size and roundness, the presence and extent of overgrowths, types of mineral inclusions, presence and abundance of vacuoles, and degree of weathering were noted.

Analysis of Grain Size

The data obtained from the grain size analysis were plotted on cumulative curves with arithmetic ordinates and probability ordinates. The arithmetic ordinate is the most commonly used, and it is shown in Fig. 8. Cumulative curves, (see Appendix) with a probability ordinate, are less pictoral but are more accurate for determining statistical parameters; all statistical parameters were calculated from probability cumulative curves.

The following statistical parameters were used to quantitatively describe certain features of the curves: median,

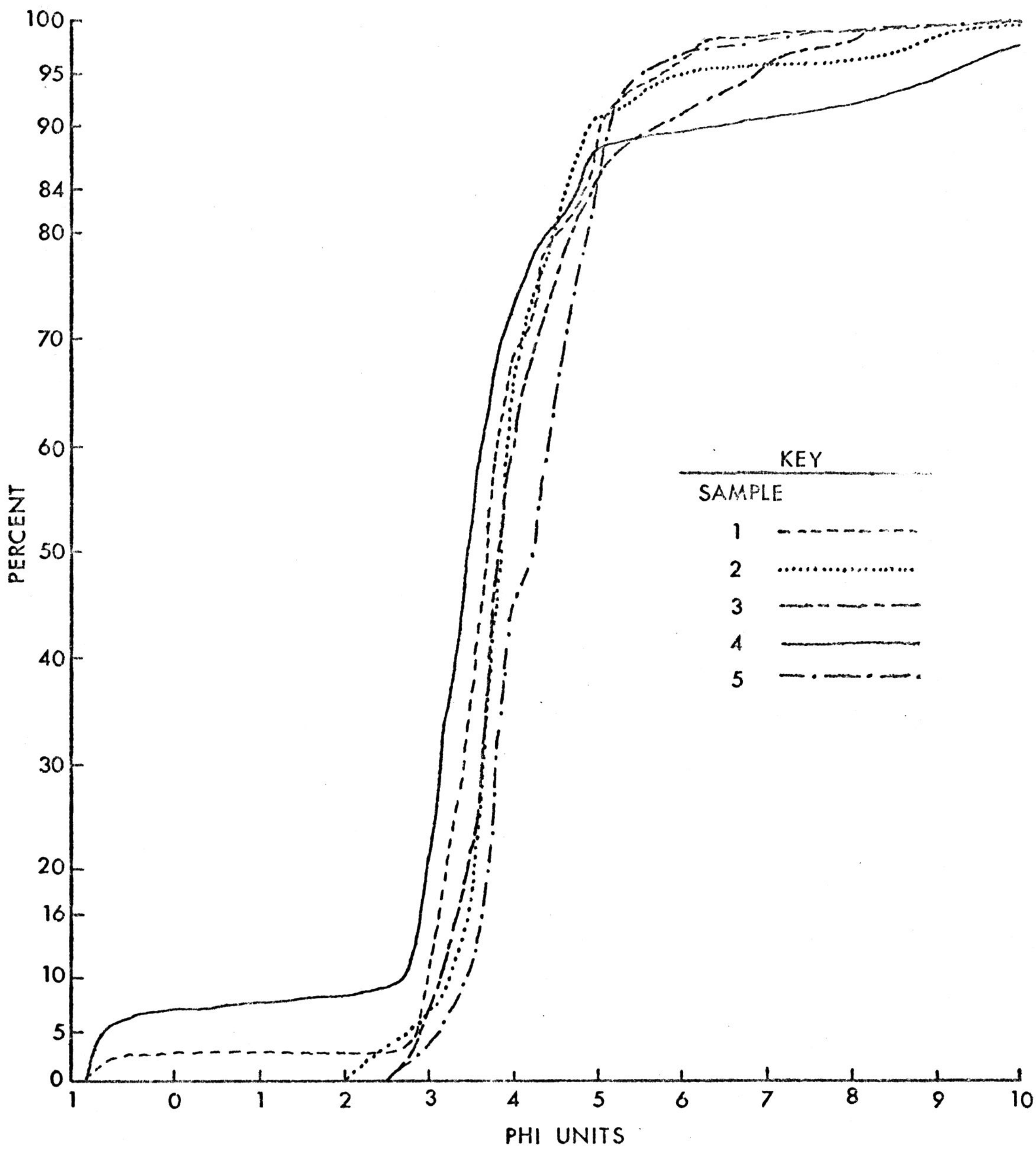


Figure 8. Cumulative grain size distribution curves of sandstone samples.

mode, mean, inclusive graphic standard deviation, inclusive graphic skewness, and kurtosis. A brief definition and description of each, as taken from Folk (1961, p. 43-48), is presented in order to familiarize the reader with the various parameters used.

Median--The median is the grain size that corresponds to the 50 percentile mark on the cumulative curve. Half of the particles are coarser than the median, and half are finer. It is the most commonly used measure and the easiest to determine; however, it is not affected by the extremes of the curve and does not reflect the overall size of the sediment.

Mode--The mode is the most frequently occurring particle diameter and corresponds to the point of inflection (steepest point) on the cumulative curve. The disadvantages are that it is difficult to determine and it is not a good measure of overall average size.

Graphic Mean--The graphic mean or mean average, as it's sometimes called, is the best measure for determining overall size and is given by the formula $M\ (\phi16 + \phi50 + \phi84)\ /\ 3$. It is superior to the median because it is based on three points and gives a better overall picture.

Inclusive Graphic Standard Deviation--The inclusive graphic standard devistion, (σ), is given by the formula: $(\phi84 - \phi16)/\ 4 + (\phi95 - \phi5)/\ 6.6$. This formula includes 90 percent of the grain size distribution and is the best overall measure of sorting. The verbal classification scale for the sorting, as suggested by Folk (1961, p. 45), is as follows:

under 0.35ϕ, very well sorted
0.35ϕ - 0.50ϕ, well sorted
0.50ϕ - 0.71ϕ, moderately well sorted
0.71ϕ - 1.00ϕ, moderately sorted
1.00ϕ - 2.00ϕ, poorly sorted
2.00ϕ - 4.00ϕ, very poorly sorted
over 4.00ϕ, extremely poorly sorted

Inclusive Graphic Skewness--Inclusive graphic skewness is a measure of the degree of asymmetry of the grain size distribution curve and is given by the formula (Folk, 1961, p. 46) $Sk_I = (\phi16 + \phi84 - 2\phi50) / 2(\phi84 - \phi16) + (\phi5 + \phi95 - 2\phi50) / 2(\phi95 - \phi5)$. In this study Folk's inclusive graphic skewness is used because it measures 90 percent of the curve. Most skewness occurs in the "tails" of the curve and a measure that doesn't include 90 percent of the grain size distribution curve is not sensitive enough to show differences in the "tails."

Symmetrical curves have $Sk_I = 0.00$; those with an excess of fine material have a tail to the right (positively skewed). Those curves with an excess of coarse material have a tail to the left (negatively skewed). The following are the verbal limits of skewness suggested by Folk (1961, p. 46).

+1.00 to +0.30, strongly fine-skewed
+0.30 to +0.10, fine skewed
+0.10 to -0.10, near-symmetrical
-0.10 to -0.30, coarse-skewed
-0.30 to -1.00, strongly coarse-skewed

Kurtosis--Kurtosis is the measure used to describe the departure from normality of a grain size distribution curve and it is expressed by the formula (Folk, 1961, p. 47) $K_G = (\phi95 - \phi5) / 2.44(\phi75 - \phi25)$. Again this measure includes 90 percent of the size distribution curve and is sensitive enough to show the sorting in the "tails" and the sorting in the central part. If the central portion of the curve is better sorted than the tails the curve is leptokurtic; if the tails are better sorted than the central portion, the curve is playtkurtic or flat peaked. Folk (1961, p. 47) suggested the following verbal limits for Kurtosis:

Under 0.67, very platykurtic
0.67 to 0.90, platykurtic
0.90 to 1.11, mesokurtic
1.11 to 1.50, leptokurtic
1.50 to 3.00, very leptokurtic
Over 3.00, extremely leptokurtic.

The data calculated from the probability cumulative curves (see Appendix) of the sandstone samples are shown in Table 4. The mean size of the sandstone ranges from 3.73ϕ(0.078 mm.) to 4.32ϕ(0.050mm.), with an average of 4.005ϕ(0.063mm.). The average modal diameter is 3.69 ϕ(0.072 mm.) with a range from 3.8ϕ (0.07 mm.) to 3.85ϕ(0.01 mm.). The median diameter ranges from 4.25ϕ(0.053 mm.) to 3.5ϕ(0.088 mm.) and averages 3.8ϕ(0.071 mm.). The inclusive standard deviation (σ) ranges from 0.648 to 1.2230 and an average of 0.880. The inclusive graphic skewness ranges from 0.302 to 0.637 with an average of 0.484. Kurtosis ranges from 1.024 to 4.084 with an average of 2.125.

These data indicate that the sandstone samples range from a very fine sand to a very coarse silt-sized sandstone that is moderately sorted, strongly fine skewed, very leptokurtic. Texas river sediments so far measured have a (σ) between 0.400 to 2.50(Folk, 1961, p. 45). The sorting values of the sandstone investigated fall within these limits, indicating it was deposited in a fluvial environment.

A comparison of some statistical measures of the sandstone samples and measures by Friedman (1961), show a very close relationship to recent river sand samples and the sandstone of the Davis-Bronson pool. Friedman (1961, p. 519-522), plotted different parameters from beach, river and dune sands, using mean, standard deviation (sorting), skewness, and kurtosis.

Friedman used parameters computed by the method of moments; the parameters computed for the sandstone samples from the Davis-Bronson pool were arrived at by probability curves or the graphical method. In this case the graphical method may not be as accurate and lacks the true sensitivity of the method of moments, but the graphical method is a very close approximation of the method of moments.

Friedman (1961, p. 519) plotted skewness against kurtosis for beach and river sands using the phi scale. River sands are generally positively skewed, as are dune sands, whereas beach sands are not. The points can be separated into two distinct fields, one of beach sands, and the other of river and dune sands. A plot of skewness versus kurtosis was made of the sandstone samples and were compared to Friedman's plot to the same parameters. The points of the sandstone samples analyzed fell within the field of river sands on Friedman's plot.

Although kurtosis is not environment sensitive, skewness reflects the depositional environment of a sediment. River sands and dune sands are both finely skewed, whereas beach sands are negatively (coarsely) skewed (Friedman, 1961, p. 520-521). The

Table 4

GRAIN SIZE ANALYSIS PARAMETERS

Sample #	Median	Mean	Mode	(σ_1)	Skewness	Kurtosis
1	3.75	3.93	3.75	0.785	0.302	1.024
2	3.80	3.98	3.80	0.648	0.382	1.500
3	3.82	4.065	3.75	1.068	0.658	1.640
4	3.50	3.730	3.35	1.223	0.4395	4.084
5	4.25	4.320	3.80	0.716	0.637	2.376
Average:	3.824	4.005	3.69	0.88	0.484	2.125

difference between dune and river sands, both positively skewed, might be shown by the degree of sorting. River sands are usually more poorly sorted than dune sands. To develop a method to clearly distinguish between river and dune sands, it is necessary to select other properties which reflect different physical characteristics of the transporting media, such as frosting of grains, or a heavy mineral analysis.

Andressen (1961) has shown, in his work on Illinois fluvial sediments, that the sorting becomes poorer upwards from the base of the sandstone. Comparison of Table 1 and Table 4 shows that generally poorer sorting values occur above the base of the sandstone. This is an indication of aggradation, i.e., the competence of the depositing medium was decreasing as sandstone deposition continued.

The samples analyzed have similar sorting, skewness, and kurtosis values as the samples analyzed by Friedman. The plotted points of the samples analyzed fell within the field of river sands on the plots by Friedman. The poor sorting and fine skewness of the samples, similar to those analyzed by Friedman, strongly indicates a fluvial environment of deposition.

Roundness Analysis of Grains Larger Than 0.03 mm.

The roundness values of grains larger than 0.03, based on comparison with the Powers (1953), roundness chart, taken during the grain size point count were plotted as arithmetic cumulative curves (Fig. 9). All statistical parameters on roundness were calculated from probability cumulative curves. Roundness

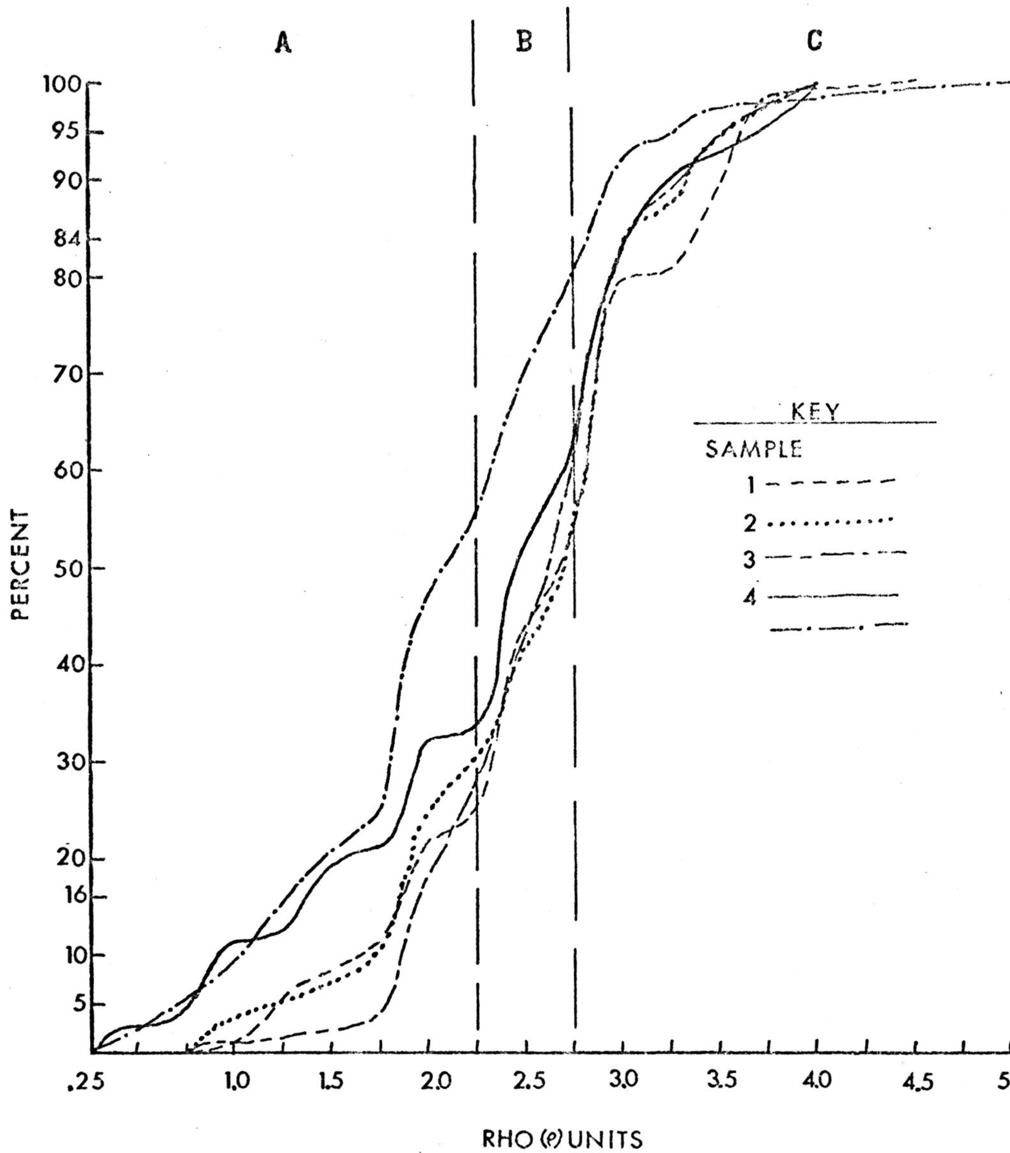


Figure 9. Cumulative distribution grain roundness curves of sandstone samples.

parameters and the mineralogical composition of the roundness modes are shown in Table 5.

The average mean roundness of the sandstone samples investigated is 2.4ϕ, which places them into the subangular class. The roundness sorting (σ_ρ) of the samples is 0.736 (good roundness sorting, Folk, 1961, p. 10), which means there is only a minor variation of the roundness values. All roundness values are significant at the 0.04 level, which means that 4 sandstone samples out of 100 will have roundness values different from those of the sandstone samples investigated. Approximately seventy percent of the grains range from 1.25ρ - 3.0ρ on the roundness surve (Fig. 5), which shows they are angular to subangular.

The roundness curves shown in Figure 9 can be split roughly into three dominant modes, or groups of modes, A,B, and C. Table 5 shows the modal mineralogical composition and mineralogy versus roundness modal variation. The dominant modes containing the greater percentage of grains are roughly centered over 2.0ρ, 2.5ρ, and three (3.0)ρ. Quartz is the dominant mineral in each mode, but modes A and C have a wide variation in the percentage of the other minerals present. Mode A is composed of quartz with lesser percentage of MRF's, mica, feldspar and metaquartz grains. The size of the quartz grains is about 3.25ϕ to 3.65ϕ (very fine sand). There is a high percentage of MRF's in this mode, most of them being fresh or only slightly weathered. The mica is almost all very fresh and quite angular. The mica in this mode is mainly muscovite with some fresh biotite; very little muscovite is in the other modes. The feldspar is fresh and about the same size or a little finer than the quartz grains. The metaquartz percentages are fairly constant in all modes.

Mode B is made up of 80 percent quartz and about equal amounts of the other mineral grains except mica, which is only 2 percent of the constituents. Also, 41 percent of the quartz in the samples is in this mode.

Quartz is the dominant mineral in mode C with a great increase of feldspar and a sharp decrease of MRF's, as compared to mode A. The feldspars are almost all weathered by kaolinization in this mode, also the MRF's show a fairly high degree of weathering. The mica is almost all biotite that is highly weathered but some weathered muscovite occurs.

Silt sized quartz slivers, small flakes of fresh mica, and a small percentage of fresh MRF's make up most of the sediment fraction of roundness values less than about 1.5ρ. On the other hand, the minerals with the highest roundness values (over 3.5ρ), subround and rounded, are highly weathered feldspar and MRF's. Some highly weathered biotite shows a fairly high degree of rounding. A few grains of well-rounded quartz are in the samples.

According to Folk (1961, p. 13), the number of angular grains is an indication of how much rounding is taking place in the last site of deposition. The sandstone samples show very little rounding; most grains are angular to subangular. The abundance of angular to subangular grains indicates a low energy environment of deposition such as near shore or fluvial.

Table 5

ROUNDNESS ANALYSIS DATA

A 45 %	B 12 %	C 43 %
2.25 (Ang.)	2.25-2.75 (Subang.)	2.75 (Subrnd-rnd.)

ROUNDNESS MODE COMPOSITION

Quartz	43%	Quartz	80%	Quartz	72%
MRF's	33%	MRF's	8%	Feldspar	9%
Mica	13%	Metaquartz	6%	Metaquartz	7%
Feldspar	4%	Mica	2%	MRF's	7%
Metaquartz	7%	Feldspar	4%	Mica	5%
Total	100%	Total	100%	Total	100%

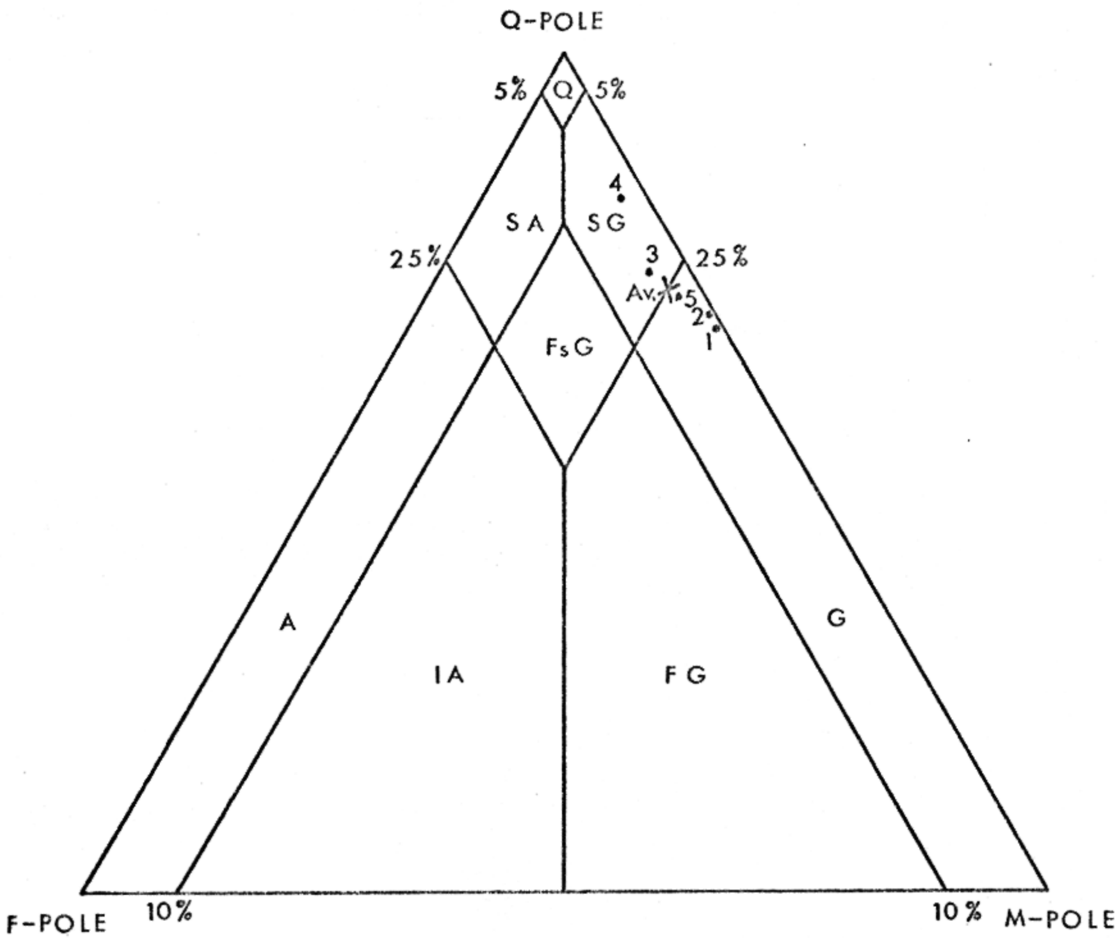
MINERALOGICAL VARIATION IN ROUNDNESS MODES

						Total
Quartz	23%	Quartz	41%	Quartz	36%	100 %
MRF's	70%	MRF's	16%	MRF's	14%	100 %
Mica	66%	Mica	10%	Mica	24%	100 %
Feldspar	22%	Feldspar	27%	Feldspar	51%	100 %
Metaquartz	37%	Metaquartz	27%	Metaquartz	36%	100 %

A multiple source area is indicated by an abnormal relation between roundness and mineral hardness and by angular and rounded grains in the same grade size (Folk, 1961, p. 13). The rounded, weathered MRF's--along with fresh, angular MRF's of the same grade size in the samples investigated--indicate a multicycle sediment or multiple source area, as does the presence of both weathered, rounded feldspar and fresh angular feldspar. Also, well-rounded quartz grains and angular quartz grains are still another indication of a multiple source area. Angular and rounded tourmaline (compare Fig. 1 and Fig. 2 of Plate VII) is an indicator of a multicycle sedimentation history (Folk, 1961). The roundness curves (Fig. 9) and mineralogy versus roundness variation (Table 5) clearly indicate the sandstone investigated has a multicycle history, and probably a multiple source area.

Classification of Sandstone

Most present day classifications of sandstones are based on mineralogy and texture. According to Folk (1961, p. 11), the mineralogy of sandstone is determined by the composition of the source area, and the texture is a reflection of the environment in which it was deposited. Textural maturity is a key to the nature of the environment of deposition and consists of four stages: immature, submature, mature, and supermature (Folk, 1951, 1956). A sediment is in the immature stage if it contains more than five percent terrigenous clay matrix and the sand grains are poorly sorted and angular. The sediment passes



Q ORTHOQUARTZITE

SG SUBGRAYWACKE

G GRAYWACKE

SA SUBARKOSE

A ARKOSE

FsG FELDSPATHIC SUBGRAYWACKE

FG FELDSPATHIC GRAYWACKE

IA IMPURE ARKOSE

Figure 10. Sandstone classification ternary diagram (after Folk, 1961).

into the submature stage when it contains less than five percent clay, but sand grains are still poorly sorted (σ over 0.50) and not well rounded ($\rho = 3$). The sediment reaches the mature stage when it contains little or no clay and the grains are well sorted and well rounded (ρ over 3.0).

The mineralogical classification used in this study, taken from Folk, (1961) is shown in Fig. 10. In order to determine the constituents for each pole; the clay matrix and the cement are ignored and the percentages of detrital minerals are recalculated to 100 percent. The Q constituents contain all types of quartz except stretched metaquartzite and chert; the F constituents include single grains of all types of feldspar and igneous rock fragments; and the M constituents consist of metamorphic rock fragments, including stretched metaquartzite and micas coarser than 0.03 mm. The clay matrix includes clay, micaceous hash finer than 0.03 mm., accessory minerals, and heavy minerals. The calculated Q, M, and F constituents for the five sandstone samples investigated are shown in Table 6. The authigenic minerals are disregarded as they are not a part of the original sediment and are not indicators of the source area.

The sandstone samples are graywackes and subgraywackes (Fig. 10). The average composition of the five samples falls into the graywacke class; four of the samples lie in the graywacke field and the other one is a subgraywacke. There is very little difference in the amount of F constituents of the samples; the largest variation is in the Q and M constituents. The relatively small dispersion shown in the sample plots indicates

Table 6

PETROGRAPHIC MODAL ANALYSIS DATA

Section #	Q Constituents	M Constituents	F Constituents
1	67 %	32 %	1 %
2	68 %	31 %	1 %
3	74 %	21 %	5 %
4	83 %	14 %	3 %
5	71 %	26 %	3 %
Average	72 %	25 %	3 %

that the composition of the sandstone is nearly homogenous--assuming of course that the five samples analyzed are a true representation of the sandstone body. The confidence level of the various means in the mineralogical analyses (quartz, MRF's, mica, feldspar, etc.) calculated by the "t" test is 0.04. This means one can be 96 percent sure the true formation is represented by the five samples. In other words, there are only 4 chances out of 100 a sample of the true formation will have a different composition than the ones analyzed. The measures of grain size and roundness used in this study also have a 0.04 confidence level. The analyses of grain size and roundness indicate the sandstone investigated is in the immature stage. Using Folk's classification the sandstone can be called a silty very fine sandstone; siliceous, immature, micaceous, graywacke. This name is descriptive and also cumbersome. Immature graywacke or simply graywacke is probably a more appropriate name.

Sedimentary Structures and Fabric

Sedimentary fabric represents the orientation of the aggregate of particles in a deposit. Larger features of the deposit, as bedding, ripple mark and concretions are sedimentary structures (Krumbein and Sloss, 1958, p. 95). The sandstone contains several features which can be defined as sedimentary fabric or structure. The sedimentary fabric and structure of the sandstone can be best surmised in oil well core descriptions.

The following core description was made by J.L. Rich (a consultant geologist) for an independent oil producer in the area. This is the core from which the sample used in making thin sections was taken from a depth of 680 feet (Table 1).

Core Sample Examination

Gillaspie No. 2-A Elev. 1038

NE/4 Sec. 10, T. 24 S., R. 21 E.

Samples taken each foot

625	Coal
626-628	Dark gray clay shale, contorted and slickensided.
629	Gray shale, slightly contorted.
630-634	Gray shale, even.
635	Dark shale with layer of plant fragments on one side.
636	Shale, gray, with a few plant fragments.
637	Smooth gray shale.
638	Light gray shale, contorted, with plant fragments, slightly silty.
639	Dark gray shale with fine silt and mica.
640	Sand, muddy, light brown, with thin shale partings at about 1/3 inch intervals. Light smoke and smell.
641-643	Smooth gray shale.
644	Sand, brown, "wavy" on account of very thin shale partings. Fair saturation.
645	Gray sandy shale with laminae of light brown sand.
646	Gray shale, slightly contorted.
647	Shaly sand with plant fragments. Smoke and smell of oil.
648-652	Sand. dark brown, medium grain, clean, highly saturated. Oil shows on bag, coalified wood fragments at 650.
653,654	Sand with thin laminae of coaly fragments. Good saturation. Evidently a soft coal was eroded and its fragments were incorporated in the sand.
655,656	Gray Shale.
657	Gray shale, a little more silty and micaceous.
658	Gray shale, smooth.
659	Crumpled gray shale and fine light gray sand and silt, laminated.
660,661	Gray silty shale.
662	Smooth gray shale.
663	Slightly crumpled laminated gray shale and fine light siltstone.

664-666	Smooth dark gray shale.
667	Crumpled gray shale and fine white and light brown silt and sand.
668,669	Gray siltstone.
670	Crumpled gray silty shale and light gray siltstone.
671	Oil sand, fine, light brown, fairly good saturation.
672	Oil sand, brown, medium fine, with thin coaly streaks. Good saturation.
673	Sand, fine, white, with white clay cement or pore filling. Spotted with light brown siderite (?).
674	White siltstone, laminar.
675	Sand, medium fine, brown, cross-bedded and laminated with white muddy sand. About 1/6th sand, saturation fairly good.
676	Same as 675, but oil partly dead.
677-681	Light gray laminated siltstone.
682,683	Siltstone, cross-bedded with some laminae of oil-stained fine sand. Live oil.
684	Light brown massive fine sand, fair saturation.
685,686	Same as 682
687	Oil sand, fine, fairly dark brown, containing many pebbles of light greenish gray shale. Partly dead oil, may be mostly dead, but I think not.
668-690	Like 682 except a little more shaly at 689
691	No sample.
692,693	Oil sand, fine, dark brown, with thin shale partings. Dead oil
694,695	Laminated brown fine oil sand and gray-green siltstone. Oil live. Saturation fair to poor. Sand is very fine.
696	Oil sand, fine, massive, dark brown, hard, saturation fair. Oil may be partly dead.
697	Greenish white fine sand, calcareous.
698-700	Dark gray slickensided clay shale.
701	Gray clay shale.
702,703	Dark gray clay shale.
704	Contorted gray shale.

....

From the core description it is evident that we are not dealing with a vertically homogeneous sandstone body. Shale, siltstone, and silty sandstone laminations and beds occur throughout. Even the best-developed sandstone zones are very fine sand to coarse silt sized-particles. Cross-bedding and silty laminations are present throughout the sandstone. Silty sandstone and silty shale zones are more prevalent above the base of the sandstone, indicating that a loss in energy of the transporting medium occurred as the sand was deposited. Locally derived shale pebbles and coal fragments indicate a fluvial environment. The thin coaly streaks are further indication of a fluvial environment and associated land areas. Almost all the sedimentary structures of the sandstone body are found in present day fluvial environments. Thin films of silts and muds occur on well developed sand bars in modern rivers and these could be analogous to the silty laminations of the sandstone body. The "slip-off slope" on the inside of meanders where a decrease of transporting power drops leads of silts and mud are in modern rivers. After burial and compaction they would form silty lenses upon and with fairly well sorted sand. Modern rivers also have gravel bars, developed in high water and high energy conditions, that are analogous to conglomerate zones in ancient sandstone bodies. In view of these facts, it hardly seems feasible for a sandstone body of this nature to be formed in anything but a low-energy fluvial environment.

Source of Sediment

The source of the sediments of the sandstone bodies in the Cherokee Group has long been a puzzle to geologists. Pinpointing the source area of a sediment involves a regional study that would show any variations in the occurrence of the sediment, or variations in the type of sediment, which would indicate it was derived from a particular area. Also, this would involve a petrographic study of the possible source areas that could supply sediment to the area investigated. On the other hand, detailed studies are needed to describe the characteristics of the sediment and define the extent of its occurrence. In an investigation of small areal extent, such as this one, it is virtually impossible to pinpoint the particular area from which the sediment was derived; therefore, only possible sources, based on the data available, will be discussed. The results of detailed investigations of this type can be combined in a regional study to define the sediment source area of the sandstone bodies in the Cherokee Group of southeastern Kansas and northeastern Oklahoma.

Mineralogical evidence indicates that the following three types of rock were sources of the sandstone investigated: (1) Igneous plutonic (granites or geneisses), (2) moderately regionally metamorphosed rocks, (3) and older sedimentary rocks. Possible source areas will be discussed in the order of apparent importance.

A granitic source area is indicated by the abundance of plutonic or "common" quartz. The Canadian Shield area, to the north, is a possible source area of the "common" quartz.

The Nemaha Granite Ridge, west of the area (see Fig. 1), was uplifted and exposed during Desmoinesian time; it is another possible source of the plutonic or "common" quartz. Studies by Maderak (1960) and McElroy (1961) suggest that the Nemaha Ridge did not contribute appreciable amounts of sediment to the Forest City or Cherokee Basins. The Ozark Uplift, to the southeast, was a positive element during Early and Middle Pennsylvanian. However, it is thought that due to its low relief and clean carbonate cover it did not contribute much sediment to the basinal areas to the west (Merriam, 1963, p. 144). The active positive areas in southern Oklahoma (see Fig. 1) are other possible sediment source areas, but the sediments would have to be transported across the Cherokee Basin to the present depositional site. This could possibly be accomplished by long shore currents, but again it would involve a more regional study to resolve this problem.

The abundance of MRF's and several types of metamorphic quartz in the sandstone indicate a metamorphic source. The fragments of schist and phyllite in the thin sections indicate a source area of rather intense folding. The only area of intense folding during Desmoinesian time was the southern Oklahoma active belt. The Nemaha Ridge may have had some associated metamorphic rocks, but it probably contributed only a minor amount, if any, to the sandstone.

Older sedimentary rocks contributed significant amounts of detritus to the sandstone investigated. Rounded and angular quartz of the same grade size indicate a multicycle history, i.e., the rounded quartz grains may have been derived from older sandstones and the subangular quartz grains derived from primary sources. Tourmaline grains that are euhedral, and some that are partly rounded, indicate a multicycle history. Rounded and angular MRF's are another indication of multicycle sedimentation. Grains of chert and fragments of limestone also indicate an older sedimentary source. The chert bearing Mississippian limestones underlying the Cherokee Group are possible sources of the chert and limestone fragments in the sandstone samples. Thin limestone beds that occur throughout the underlying Cherokee shales could also be the source of the limestone fragments. Shale pebbles, clay ironstone pebbles, and coaly fragments are all locally derived from older sedimentary rocks.

From the previous discussion it is clearly evident that the sandstone had a multiple source and that some of the detrital fraction had a multicycle sedimentation history. As mentioned earlier, pinpointing the specific sediment source areas would involve a study beyond the scope of this investigation.

P E T R O L E U M G E O L O G Y

NATURE OF OIL ACCUMULATION

According to Russell (1960, p. 166), the conditions essential for the occurrence of petroleum in commercial quantities are: (1) source rocks, (2) reservoir rock, (3) a suitable trap. Each of these conditions played a role in the accumulation of oil and gas in the Davis-Bronson pool.

Source Rock

The source of petroleum has been the subject of research since the evolution of the petroleum industry during the last half century. It is generally thought that the source rocks of petroleum are of marine origin (Russell, 1960, p. 182). Studies by Baker (1962) indicate that the nonreservoir facies of the rocks in the Cherokee Group were the source of the petroleum which has accumulated in the Cherokee petroleum province of southeastern Kansas and northeastern Oklahoma. Other characteristics of source rocks are: they are probably fine grained and rather deficient in oxygen; rocks with a high organic content are likely to be good source rocks of oil (Russell, 1960, p. 171-174).

The thick sequences of shale associated with the sandstone body in the area are probably of marine origin and contain various amounts of organic material. Thin limestone beds, which contain marine fossils, in the shales surrounding the sandstone body indicate they are of marine origin. The occurrence of dark gray and black shales indicate they were deposited in poorly oxygenated or reducing conditions. The fact that the sediments surrounding the sandstone body are shales, mean they are fine grained. Thus, the Cherokee shales adjacent to the reservoir rock in the Davis-Bronson pool exhibit the characteristics of petroleum source rocks.

Migration and Accumulation

Rich (1934) proposed that oil originated in the deeper basins in Oklahoma and migrated northward onto the platform or shelf areas where it accumulated in the "shoestring sands" or other reservoir rocks in the region. Later, Wierich (1953) suggested that oil originated and accumulated on the shelf or platform and did not migrate from the deep basin. Baker (1962) in his study of the Cherokee petroleum province, indicated that the non-reservoir rocks of the Cherokee Group were the source of petroleum in the "shoestring sands." The writer believes that the source rocks are in the immediate area and the petroleum would not have to migrate long distances before it accumulated in the "shoestring sand" reservoirs. Oil and gas originating in the surrounding non-reservoir rocks (Cherokee shales) could have migrated into the sandstone body of the Davis-Bronson pool.

Because of the lack of permeability, shales enveloping the Davis-Bronson sandstone reservoir also serve as a trap rock. Now all three of the conditions necessary for petroleum accumulation (source, reservoir, trap) are fulfilled. The shales surrounding the sandstone body are possible source rocks and serve as the trap rock; whereas the sandstone body is the reservoir rock.

The structure of the sandstone body is a controlling factor in the accumulation of petroleum in the Davis-Bronson pool. The area of greatest accumulation of petroleum is in the central, structurally low, part of the reservoir. An increase of gas and decrease of oil is encountered in the structurally high south end of the sandstone trend. Very little or no gas is mentioned in the comments on drillers logs of wells in the structurally low central part of the trend; some drillers logs of wells in the structurally high south end of the pool record gas and little or no oil.

Because there is an increase of gas and decrease of oil at the south end of the pool, no more wells have been drilled farther south. During the development of the Davis-Bronson pool, oil has been worth more than gas; the high gas to oil production ratio in the south end of the pool has placed an economic limit to its further expansion to the south.

The north end of the pool is 10 to 20 feet structurally higher than the central part. Drillers logs of the area record good oil saturation with a trace of gas. Further expansion northward was probably limited due to poor development of the sandstone reservoir rather than to an increase in structural elevation, with increased gas production, as is the case in the southern end of the pool.

The gravity of the oil is about 28 API and is usually capped by low pressure gas, especially in the southern end of the pool. In the lower part of the sandstone reservoir, the oil is asphaltic or of extremely low gravity (API). Asphaltic or "dead" (immobile) oil is mentioned several times at depths from 676 to 696 feet in the core description (p. 99), which was taken from a well in the NE 1/4 of Sec. 10. In some wells the lower part of the oil-saturated sandstone is entirely asphaltic or immobile. Light oil usually overlies the lower zone of "dead" oil, but sometimes it occurs with the "dead" oil in the lower part of the sandstone reservoir. It is thought that the "dead" oil was caused by oxidation of sulfates in waters associated with the oil. Also, the structural attitude of the sandstone body seems to have no control in the occurrence of "dead" oil; it seems to occur in all parts of the reservoir.

Reservoir Rock Physical Properties

The reservoir rock of the Davis-Bronson pool is a very fine-grained sandstone, as shown in Table 4. The pore space of the samples ranges from 4 to 10 percent and averages about 7 percent. Furthermore, the original porosity of the sediment before cementation was approximately 17 percent. Porosity values of the sandstone have been lowered considerably by the cementing agents of the sandstone, namely quartz.

The abundance of clastic fines (<0.03 mm.) and authigenic kaolinite also has lowered the porosity of the reservoir rock. It is evident then, that diagenetic changes have altered the reservoir rock considerably. These changes, caused by authigenic quartz and kaolinite, can and do cause oil production problems.

SECONDARY RECOVERY OPERATIONS

Oil moves through the pores of the reservoir rock to the bore hole because of the pressure of dissolved gases in the oil and/or because of the pressure from a gas cap. Another type of reservoir depletion mechanism is water influx into the reservoir as oil is produced, e.g., water drive. Still another type of reservoir depletion is gravity drainage. The depletion mechanism for the Davis-Bronson pool was a combination solution gas, gas cap, and gravity drainage. There aren't any water levels or water influx into the reservoir of the pool.

After a reservoir is produced for a while the gas pressure drive is greatly reduced or lost entirely--especially if the untapped reservoir had an original low gas cap pressure. In the low pressure reservoirs of southeastern Kansas, such as the Davis-Bronson pool, other means must be used to drive the oil from the reservoir to the bore hole after the reservoir pressures have been lowered so that primary oil production is very low or not economically feasible.

Repressuring of oil-bearing rocks by the injection of water, air, or gas has become the principal method of oil production stimulation in Kansas since the passage of a law governing secondary recovery practices in 1935 (Hilpman, et. al., 1964, p. 24). During the last few years other methods such as fire flood (insitu combustion), and steam injection, have been introduced so as to produce the low gravity (API) or asphaltic oil from the "shoestring sand" reservoirs in the area. Since 1937 the Davis-Bronson pool has been under water flood by independent oil producers in the area; no other secondary methods have been used to stimulate oil production.

When the injection of water began in 1937, the input wells were drilled in a rectangular pattern with distances of 600 feet on a north and south line and 300 feet on an east and west line. Oil wells were spaced about 300 feet apart. Since then the pattern has been modified; now the input wells and producing wells are arranged in alternating rows perpindicular to the trend of the sandstone body. The input wells are spaced about 200 feet apart; producing wells are also spaced about 200 feet apart. The distances between alternating rows of input wells and producing wells is about 300 feet. The alternating rows of input and producing wells are arranged perpendicular to the trend of the sandstone body for maximum efficiency of the water sweep in the reservoir.

The water used for flooding was fresh water from a nearby stream, conditioned by filtration and chemical treatment before injection. In the last few years treated water from the Mississippian limestones and older rocks has been used for flooding. The water is injected into the reservoir at a pressure of about 500 pounds per square inch.

FURTHER EXPLOITATION

Several parts of the Davis-Bronson pool might be further exploited by using the isopachous map in conjunction with the Fort Scott Limestone structure map as guides to future drill sites.

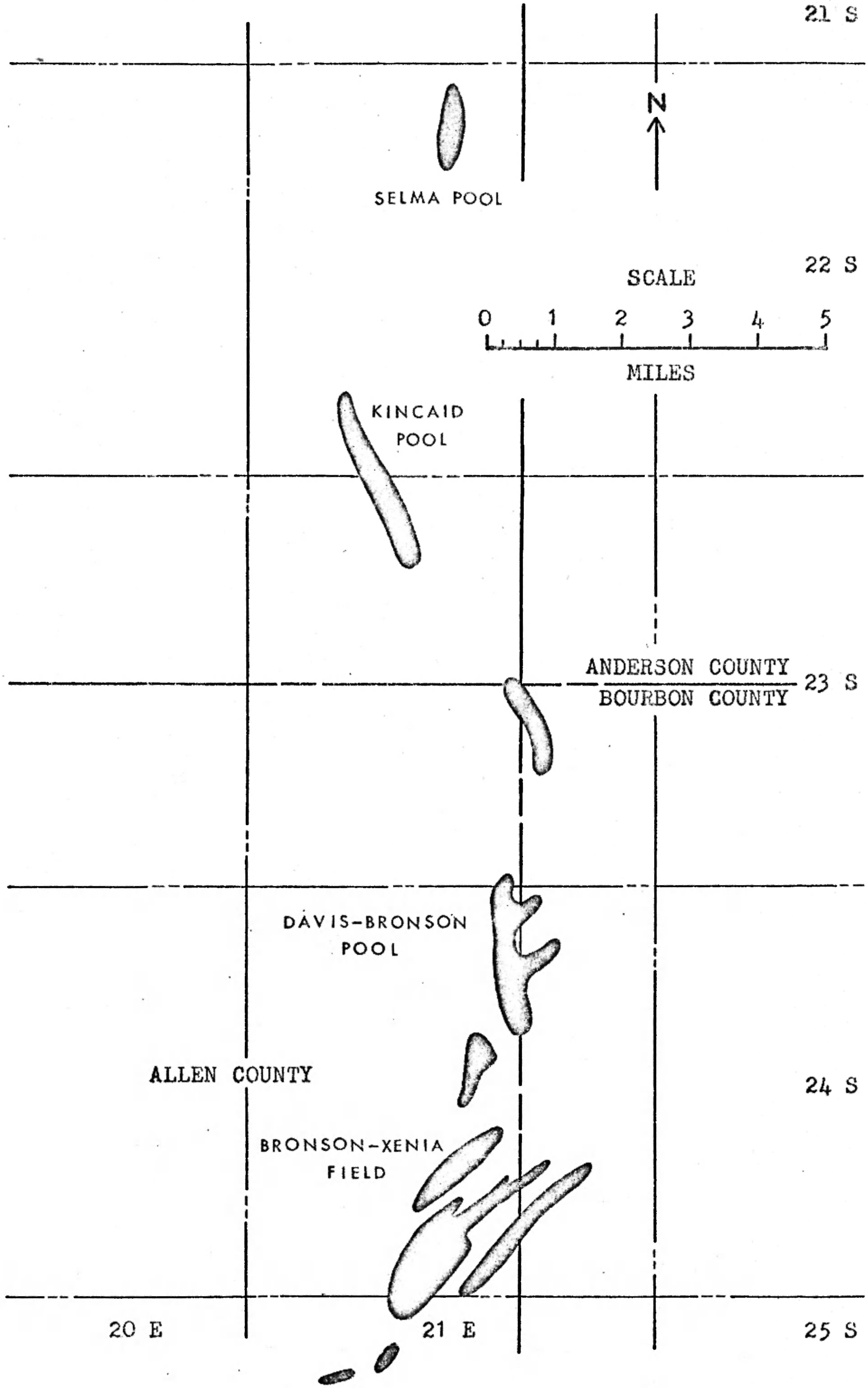
The Burbank sandstone recorded in four wells west of the main trend in the SE 1/4 of Sec. 34, T. 23 S., R. 21 E., probably extends farther west and/or north. Westward extension of the Burbank is also suggested by the bulging of the Fort Scott Limestone Structure map (Fig. 6).

The Burbank sandstone might also be east of the main channel trend. Because of lack of control, nothing specific can be said about exploitation of the Burbank sandstone in that area.

The closely spaced dashed contours of the isopachous map

EXPLANATION OF PLATE XI

Sketch map of the Davis-Bronson Pool and some of the pools in the area. (Taken from a map by D.A. Busch, for M.C. Colt Inc.-Iola, Kansas).



21 S
N
SELMA POOL
22 S
SCALE
0 1 2 3 4 5
MILES
KINCAID
POOL
ANDERSON COUNTY
BOURBON COUNTY
23 S
DAVIS-BRONSON
POOL
ALLEN COUNTY
24 S
BRONSON-XENIA
FIELD
20 E
21 E
25 S

on the west side of the trend in the SE 1/4 of Sec. 10 (Fig. 4) indicate the sandstone body might extend further west. Westward extension of the sandstone body is also suggested by a thick sandstone buildup on the west side of the cross-section E-E', Fig. 3. The closely spaced contours might reflect thicker sand development, on the outside of a meander bend, as a result of more downcutting by the stream. Westward extension of the sandstone body is also suggested by the east-west trending contours and by the reversal of dip in the Fort Scott Limestone in the SE 1/4 of Sec. 10 as shown by the base of the Fort Scott Limestone structure map; this is in the same area of westward extension suggested by the isopachous map.

A southeasterly trending tributary to the main channel, similar to the tributaries in the SW 1/4 of Sec. 11 and SW 1/4 of Sec. 2, might be present west or northwest of the main trend in the SE 1/4 of Sec. 10, as suggested by the closely spaced contours on the isopachous map. The reversal of dip of the Fort Scott Limestone on the west side of the main trend in the SE 1/4 of Sec. 10, as a result of differential compaction of the overlying sediments over a sandstone buildup, might reflect a southeasterly trending tributary in that area.

An undiscovered sandstone body to the west of the main trend could cause a reversal of dip in the overlying Fort Scott Limestone shown in Fig. 6. A northward extension of the sandstone body to the southwest of the Davis-Bronson pool (PLATE XI) might also cause the reversal of dip, and open contours to the west, shown on the Base of the Fort Scott Limestone structure map, in the SE 1/4 of Sec. 10, T. 24 S., R. 21 E.

The two northeast-southwest trends on the east side of the main trend might extend farther northeast. This is suggested by the open isopachous contours in the isopachous map and the bulging of the Fort Scott Limestone over the trends shown by the base of the Fort Scott Limestone structure map.

The open contours of both the structure map of the base of the Fort Scott Limestone and the isopachous map at the north and south ends of the pool indicate that the sandstone reservoir extneds farther north and south. Plate XI is a sketch map of some of the oil and gas pools in the immediate area. The Bronson-Xenia field to the south is probably not related to the Davis-Bronson pool because the reservoir rock in the Bronson-Xenia field is the Burbank sandstone, thought to be older and of marine origin.

The sandstone body probably extends farther south. However, southward exploitation of the Davis-Bronson pool might not be warranted due to its structurally high position, which results in mostly gas and very little oil in the reservoir.

The structural attitude of the northern end of the Davis-Bronson pool is more favorable to further exploitation than the southern end. The Selma pool, Kincaid pool, and a small pool to the immediate north might be correlative to the Davis-Bronson pool. The sandstone reservoir rock of the Davis-Bronson pool might extend northward and be the same as the reservoir rock in the pools to the north shown on the map (PLATE XI). Further study would show if the Davis-Bronson pool and the pools to the north are part of the same sandstone body. The channel sand reservoir rock may be present in the areas between the Davis-Bronson and the pools to the north, but additional drilling would be needed to determine this.

Economics plays an important role in the further exploitation of the Davis-Bronson pool and related areas. If the reservoir rock extends northward it might be on a structural "high" which would result in the accumulation of gas and probably little oil. The return from the investment in drilling, in order to determine if it is related to the areas to the north, might not permit further exploitation of the Davis-Bronson pool northward.

GEOLOGIC HISTORY

During the interval between the deposition of the Weir Coal and the Verdigris Limestone, the Cherokee sea retreated and the area was subjected to erosion. A south flowing drainage system developed on the exposed surface, downcutting through about 90 feet of the soft underlying sediments. The main north-south trend of the sand body in the Davis-Bronson pool was part of this south flowing drainage system. The two northeast-southwest trends were smaller tributaries to the main north-south channel.

Submergence of the exposed land area by the Cherokee sea that encroached from the south, caused the base level of the south flowing stream to be reached. Upon reaching base level, degradation gave way to aggradation as the dominant process in the stream valley. The stream valley gradually filled with sediment as the stream base level was raised because of the encroaching sea. After the stream valley was filled with sediments, the stream spread material laterally, and the thin phase of the sandstone was deposited. The encroaching sea once again covered the area and the sediments overlying the sandstone body were deposited.

As the thick sequence of sediments overlying the sandstone body accumulated, differential compaction of the sand body and enveloping shales caused draping of the Fort Scott Limestone over the locus of maximum sand deposition. Post Fort Scott structural movement and/or differential compaction gave rise to the "canoe" effect of the sandstone body and the north-south reversal of dip in the overlying Fort Scott Limestone.

C O N C L U S I O N S

The conclusions that can be drawn from this investigation are as follows:

(1) The sandstone body occupies the stratigraphic position 130 to 220 feet below the base of the Fort Scott Limestone. It is correlative to the Chelsea sandstone of the surface in Kansas and Oklahoma, and the subsurface Skinner sand of Oklahoma.

(2) The sandstone body is part of an ancient river channel. The two northeast-southwest trends are in the same stratigraphic position and were deposited in conjunction with the main north-south trend. They are tributaries to the ancient south flowing river.

(3) The present attitude of the sandstone body is different from the attitude when it was deposited. The change in the attitude of the sandstone body was caused by post Fort Scott Limestone structural movement and/or differential compaction.

(4) The base of the Fort Scott Limestone is draped over the axis of the sandstone body, due to differential compaction. The same processes which caused the "canoe" effect in the sandstone body are responsible for the structural attitude of the base of the Fort Scott Limestone.

(5) The reservoir rock of the Davis-Bronson pool is a silty, very fine sandstone: siliceous, immature, micaceous graywacke; or simply graywacke. The characteristics of the sandstone are also a strong indication that it was deposited in a fluvial

environment.

(6) The sediment of the reservoir rock had a mixed source area.

(7) Authigenic minerals have greatly altered the reservoir rock of the Davis-Bronson pool since its deposition.

(8) The oil and gas accumulated in the Davis-Bronson pool could have been derived from the surrounding Cherokee shales.

(9) The structural attitude of the sandstone body affects the accumulation of oil and gas in the Davis-Bronson pool.

(10) The sandstone body reservoir probably extends farther north and south beyond the present limits of the Davis-Bronson pool.

(11) More work needs to be done on the nomenclature and classification of the subsurface Cherokee Group in southeastern Kansas.

(12) The geologic principles and methods used in this investigation can be applied in exploiting or exploring for stratigraphic traps of this type in other areas.

(13) Other implications of this study are:

a. The phosphatic shale beds approximately 100 feet below the base of the Fort Scott Limestone and immediately below the Verdigris Limestone cause an easily identified "hot kick" on gamma ray logs in the area.

b. The phosphatic shale beds approximately 175 feet below the base of the Fort Scott Limestone and above the Burbank Sandstone interval, associated with the Weir-Pittsburg coal, cause a "hot kick" on gamma ray logs in the area.

A C K N O W L E D G E M N T S

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A P P E N D I X E S

APPENDIX A

Petrographic modal analysis point count data.

Table 7. Number of points counted for each constituent in area point count of petrographic modal analysis.

Sample number:	1	2	3	4	5
Igneous or common quartz	675	748	765	841	825
Schistose metaquartz	0	4	5	11	8
Recrystallized metaquartz	5	2	3	0	1
Stretched metaquartz	4	6	0	0	0
Vein quartz	1	0	2	0	0
Microquartz	5	6	5	1	1
Metamorphic rock fragments (MRF'S)	238	259	165	129	192
Biotite > 0.03 mm.	80	66	55	10	76
Muscovite > 0.03 mm.	12	9	2	5	32
Microcline	1	0	0	0	0
K-Feldspar	7	9	40	31	29
Oligoclase (An)	6	6	15	1	3
Apatite	0	0	7	0	2
Zircon	2	4	2	2	0
Tourmaline	1	3	1	1	3
Ore minerals (detrital)	15	13	8	3	10
Ore minerals (authigenic)	3	0	7	3	7
Clay minerals (undifferentiated)	63	59	90	59	52
Mica hash < 0.03 mm.	15	14	12	5	10
Chlorite < 0.03 mm.	0	3	0	0	0
Limestone rock fragments	0	3	0	0	0
Quartz overgrowths or cement	122	112	118	116	169
Calcite Cement	10	8	25	15	17
Pore space	49	131	115	151	71
Pebbles	27	0	0	62	0
Total	1340	1465	1442	1471	1508

The shale pebble in thin sections 1 and 4 is brown, elliptical shaped, and is composed of quartz fragments 8.0 to 20.0 microns in diameter, mica hash, and clay minerals. The shale pebble in slide 1 is 1.84 mm. X 4.95 mm., and in slide 4 is 3.4 mm. X 4.9 mm.

APPENDIX B

Textural modal analysis point count data.

PHI (φ) UNITS

SAMPLE #1

ROUNDNESS (ρ) VALUES

-0.75	2.25	2.75	3.00	3.25	3.50	3.75	4.00	4.25	4.50	4.75	5.00	5.25	5.50	5.75	6.00	6.25	6.50	6.75	7.00	7.25	8.00	8.25	9.00	9.25	10.00	11.00	12.00	13.00	ρ
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																													4.75
					F																								4.50
																													4.25
PP						/	//																						4.00
			/				oo		/																				3.75
					o /		//		/	/	/																		3.50
						/																							3.25
		o	F	oo ///		oo ///	///	//	//		/				/	/													3.00
			/	/	o /	X		/	/		/	/																	2.75
					F /	////	////	/	X	o	B	//	/																2.50
			/	//																									2.25
			X	o X	X	//	/				X	/	/																2.00
					X	B							B																1.75
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																													1.25
						X							B																1.00
																													0.75
																													0.50

Table 8. Textural analysis data from 100 point count.

Table 8 (cont.)

PHI (ϕ) UNITS

OTHER PROPERTIES		-0.75	2.25	2.75	3.00	3.25	3.50	3.75	4.00	4.25	4.50	4.75	5.00	5.25	5.50	5.75	6.00	6.25	6.50	6.75	7.00	7.25	8.00	8.25	9.00	9.25	10.00	11.00	12.00	13.00
INCLUSIONS	Mica				/	//	/	////	//		/																			
	Other																													
OVERGROWTHS	Slight							/																						
	Exten.				/	///	//	o 𝍸 ///	𝍸 𝍸	///	///	o //	/	///	/															
WEATHERING	Fresh				XX		XX	XX B	X				X B		BB															
	Mod.				F	X	X				XX																			
	Exten.						FF				X																			
VACUOLES	Few						//	/	/	/	/																			
	Abdt.				/			/	//																					

Detrital grains	92
Pore space	3
Quartz cement	4
Authigenic clay	1
Total	100

<u>Key</u>

- P Pebble
- / Quartz
- X Metamorphic rock fragment
- o Metaquartz
- B Biotite
- F Feldspar
- C Detrital clay

PHI (ϕ) UNITS

-0.75	2.25	2.75	3.00	3.25	3.50	3.75	4.00	4.25	4.50	4.75	5.00	5.25	5.50	5.75	6.00	6.25	6.50	6.75	7.00	7.25	8.00	8.25	9.00	9.25	10.00	11.00	12.00	13.00	ROUNDNESS (ρ) VALUES
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																													4.50
																													4.25
			F				I																						4.00
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				I	III	I	F																						3.50
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			I	I	I X O	卌 F	卌 I OO	B I		F	B																		3.00
						I	III O	I	I	II	I				I														2.75
						X	III	II	III						I														2.50
	II					X		I	I						I														2.25
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						I B																							1.75
						XX																							1.50
								X																					1.25
					B	X				0																			1.00
																													0.75
												B																	0.50

SAMPLE #2

Table 9. Textural analysis data from 100 point count.

Table 9 (cont.)

PHI (ϕ) UNITS

OTHER PROPERTIES		-0.75	2.25	2.75	3.00	3.25	3.50	3.75	4.00	4.25	4.50	4.75	5.00	5.25	5.50	5.75	6.00	6.25	6.50	6.75	7.00	7.25	8.00	8.25	9.00	9.25	10.00	11.00	12.00	13.00
INCLUSIONS	Mica					/			//																					
	Other						/	//	/////			/																		
OVERGROWTHS	Slight		/				//	/		/	/		/																	
	Exten.					/	/	///	///// ////	////	///	/					/													
WEATHERING	Fresh						B	XX				Ɪ F		B																
	Mod.							XXX B	XX F	X B			B																	
	Exten.				F	XX	X	F	X B	F			B																	
VACUOLES	Few							//	/																					
	Abdt.																													

Detrital grains	88
Pore space	6
Quartz cement	5
Calcite cement	1
Total	100

<u>Key</u>

- / Quartz
- X Metamorphic rock fragment
- o Metaquartz
- B Biotite
- F Feldspar
- Ɪ Muscovite
- H Mica hash

PHI (ϕ) UNITS

SAMPLE #3

ROUNDNESS (ρ) VALUES

ROUNDNESS (ρ) VALUES	-0.75	2.25	2.75	3.00	3.25	3.50	3.75	4.00	4.25	4.50	4.75	5.00	5.25	5.50	5.75	6.00	6.25	6.50	6.75	7.00	7.25	8.00	8.25	9.00	9.25	10.00	11.00	12.00	13.00
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3.00				/	// x F	FF	x //	// xx	//		/		/																
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1.25																													
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0.50																													

Table 10. Textural analysis data from 100 point count.

Table 10 (cont.)

PHI (ϕ) UNITS

OTHER PROPERTIES		-0.75	2.25	2.75	3.00	3.25	3.50	3.75	4.00	4.25	4.50	4.75	5.00	5.25	5.50	5.75	6.00	6.25	6.50	6.75	7.00	7.25	8.00	8.25	9.00	9.25	10.00	11.00	12.00	13.00
INCLUSIONS	Mica							/	//	/																				
	Other			/					/																					
OVERGROWTHS	Slight					//		/	//	/	/	//		/																
	Exten.						/	~~////~~ /	~~////~~ /	////	//	//	///		/															
WEATHERING	Fresh				X				XX		X					B			▯											
	Mod.				B		X	XXX XXX	XX																					
	Exten.					X	FFF X			F	F	B		X																
VACUOLES	Few			/						/																				
	Abdt.				/			///																						

Detrital grains	89
Pore space	5
Quartz cement	5
Calcite cement	1
Total	100

Key

- / Quartz
- X Metamorphic rock fragment
- o Metaquartz
- B Biotite
- ▯ Muscovite
- F Feldspar
- C Detrital clay
- H Mica hash

PHI (φ) UNITS

SAMPLE #4

ROUNDNESS (ρ) VALUES

	-0.75	2.25	2.75	3.00	3.25	3.50	3.75	4.00	4.25	4.50	4.75	5.00	5.25	5.50	5.75	6.00	6.25	6.50	6.75	7.00	7.25	8.00	8.25	9.00	9.25	10.00	11.00	12.00	13.00
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Table 11. Textural analysis data from 100 point count.

Table 11 (cont.)

PHI (ϕ) UNITS

OTHER PROPERTIES		-0.75	2.25	2.75	3.00	3.25	3.50	3.75	4.00	4.25	4.50	4.75	5.00	5.25	5.50	5.75	6.00	6.25	6.50	6.75	7.00	7.25	8.00	8.25	9.00	9.25	10.00	11.00	12.00	13.00
INCLUSIONS	Mica			/	/	//		////	//	//	///																			
	Other		/		//	/	////	/	/																					
OVERGROWTHS	Slight		/		/	////	𝍸	///	/																					
	Exten.			/	/	/	/	///	𝍸	/	/	//																		
WEATHERING	Fresh				F	F		X X F	X	X		X	0																	
	Mod.		B		X	B X F		F					0																	
	Exten.						X F																							
VACUOLES	Few						/	/																						
	Abdt.				/	//	/	/	/																					

Detrital grains	91
Pore space	4
Quartz cement	4
Calcite cement	1
Total	100

Key

- P Pebble
- / Quartz
- X Metamorphic rock fragment
- O Metaquartz
- B Biotite
- 0 Muscovite
- F Feldspar
- C Detrital clay

SAMPLE #5

PHI (ϕ) UNITS

ROUNDNESS (ρ) VALUES	-0.75	2.25	2.75	3.00	3.25	3.50	3.75	4.00	4.25	4.50	4.75	5.00	5.25	5.50	5.75	6.00	6.25	6.50	6.75	7.00	7.25	8.00	8.25	9.00	9.25	10.00	11.00	12.00	13.00
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Table 12. Textural analysis data from 100 point count.

Table 12 (cont.)

PHI (ϕ) UNITS

OTHER PROPERTIES

		-0.75	2.25	2.75	3.00	3.25	3.50	3.75	4.00	4.25	4.50	4.75	5.00	5.25	5.50	5.75	6.00	6.25	6.50	6.75	7.00	7.25	8.00	8.25	9.00	9.25	10.00	11.00	12.00	13.00
INCLUSIONS	Mica						//	/	///		///	////	//	///																
	Other						/	//	///	//	/	/	/	/																
OVERGROWTHS	Slight					/		/		/																				
	Exten.					//	///	//// o	𝍸		𝍸	///	////	////																
WEATHERING	Fresh			F	X			X		X	X				BB															
	Mod.							X	XXX BB		X BB	XXX	B				X						X							
	Exten.				B		B	FF B	XX	X	B		B																	
VACUOLES	Few								/					//																
	Abdt.								/																					

Detrital grains	92
Quartz cement	6
Pore space	2
Total	100

Key

- / Quartz
- X Metamorphic rock fragment
- O Metaquartz
- B Biotite
- F Feldspar
- C Detrital clay
- H Mica hash

APPENDIX C

Cumulative grain size frequency curves plotted on probability paper.

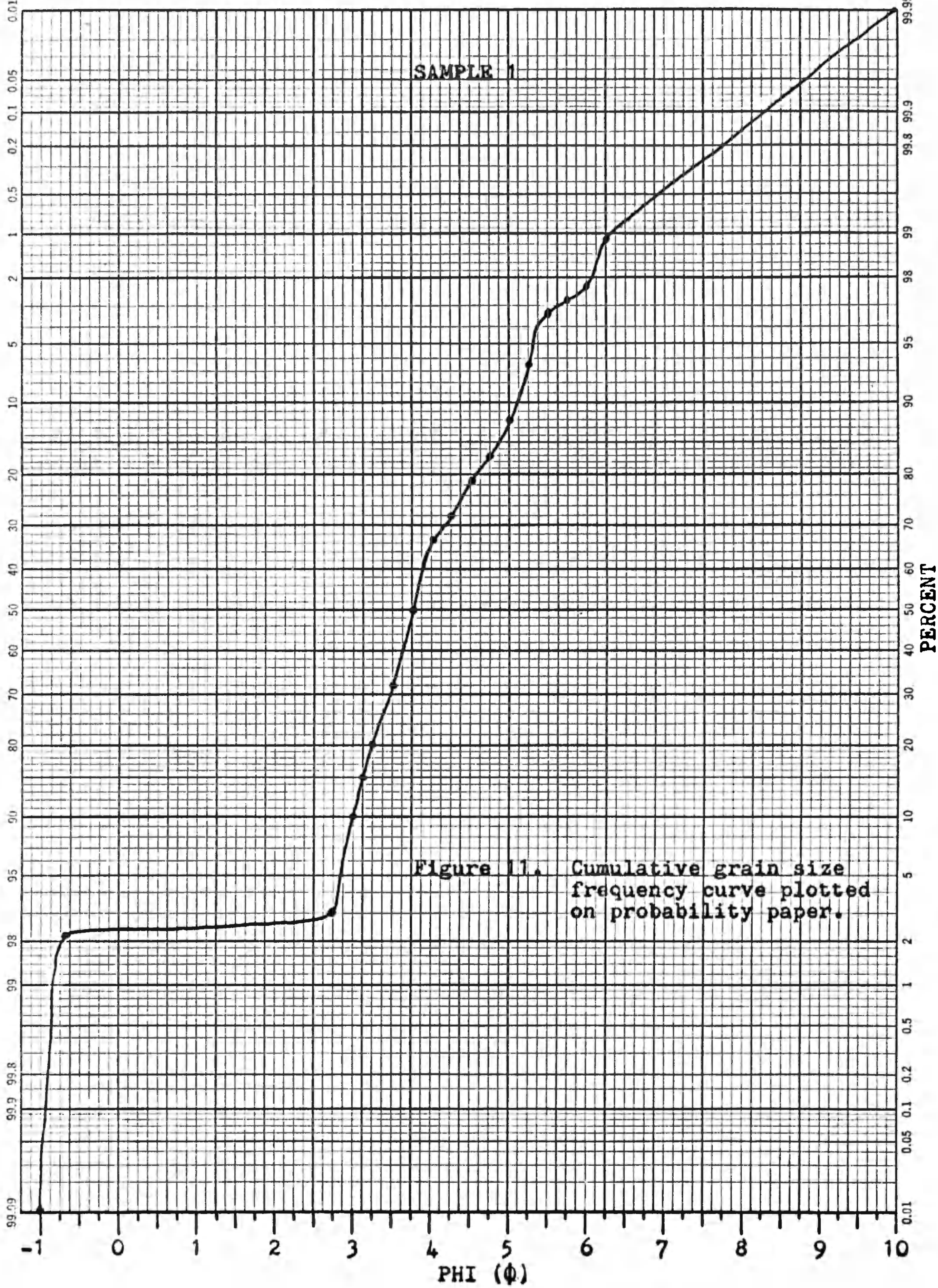

Figure 11. Cumulative grain size frequency curve plotted on probability paper.

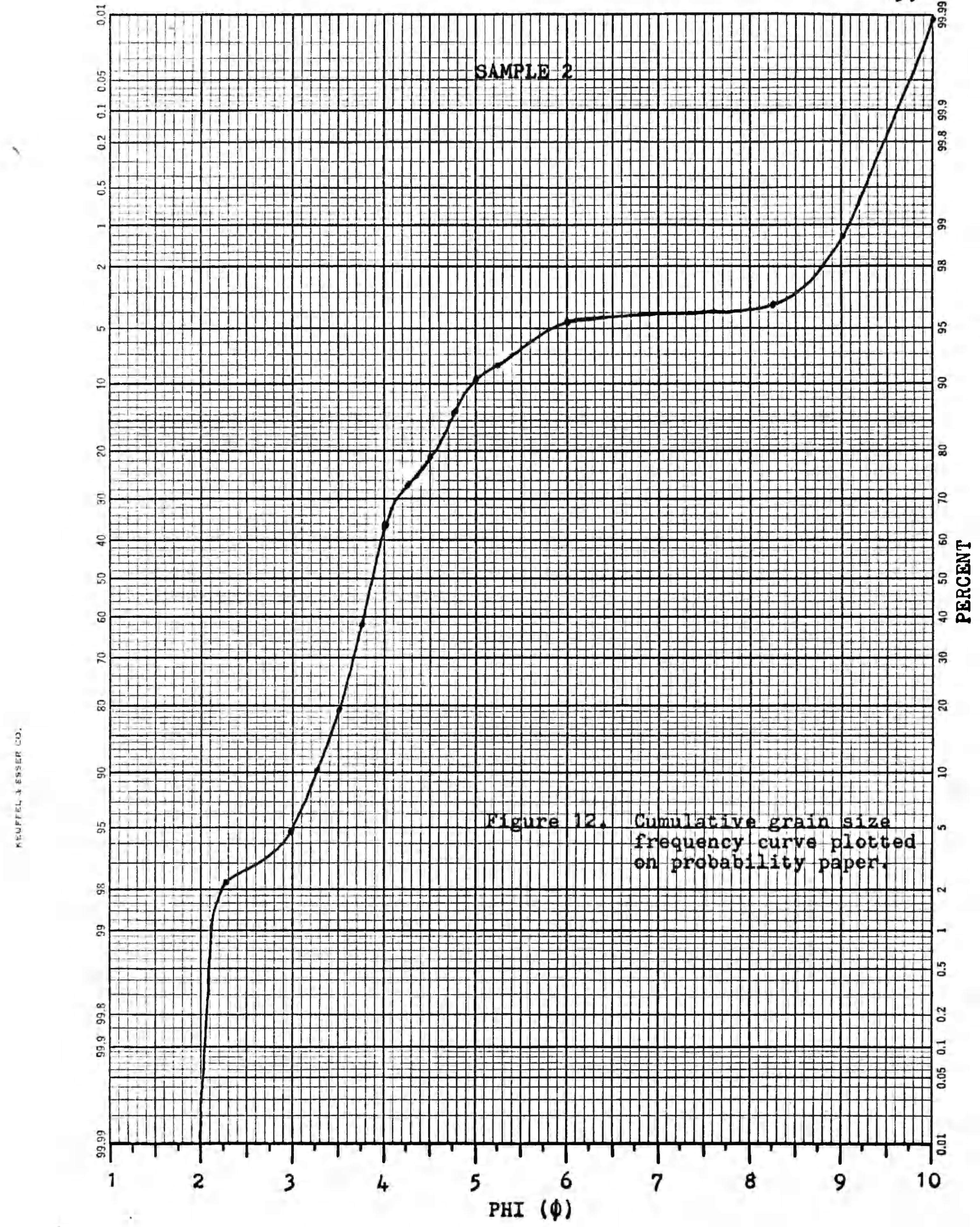

Figure 12. Cumulative grain size frequency curve plotted on probability paper.

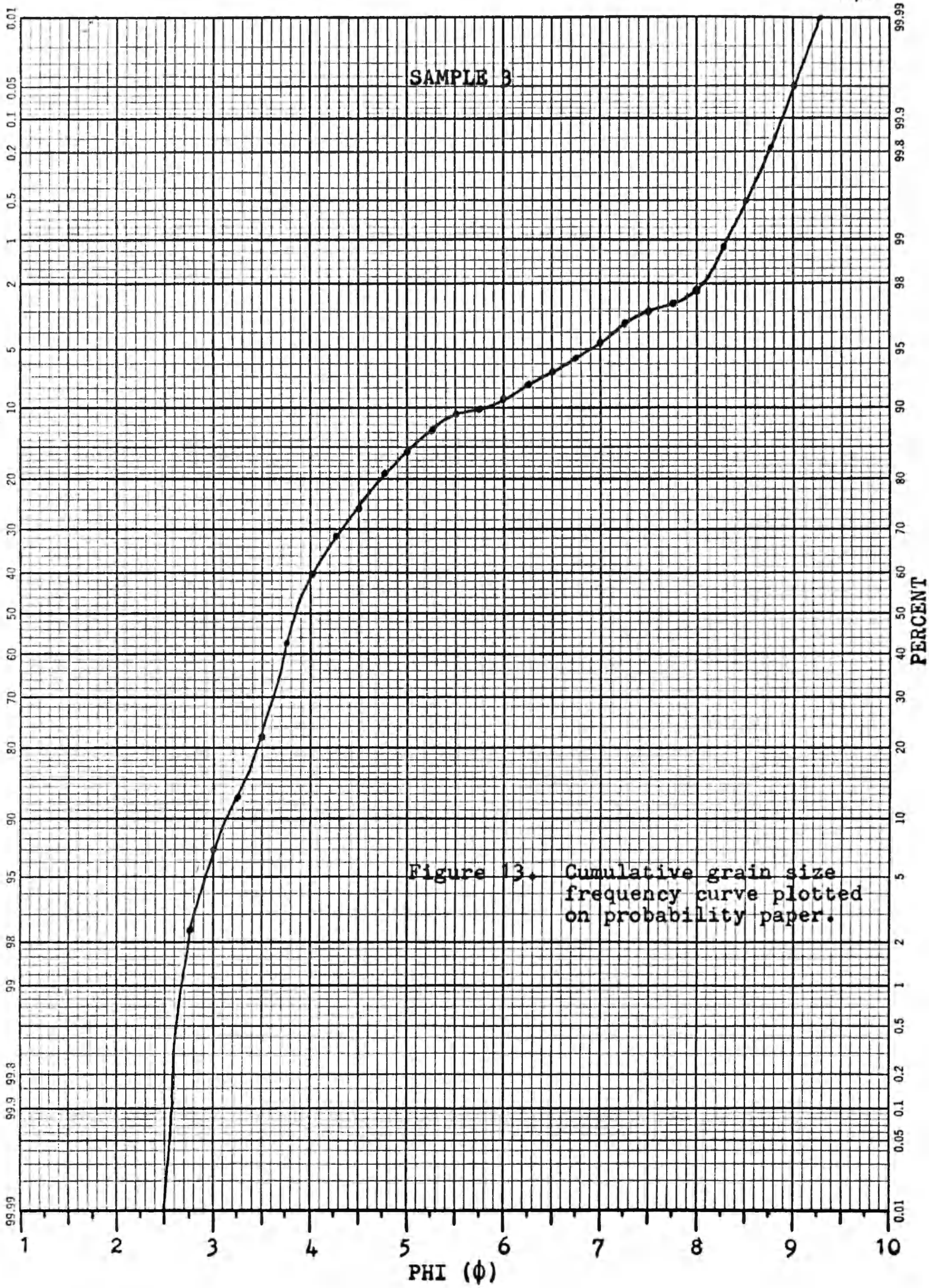

Figure 13. Cumulative grain size frequency curve plotted on probability paper.

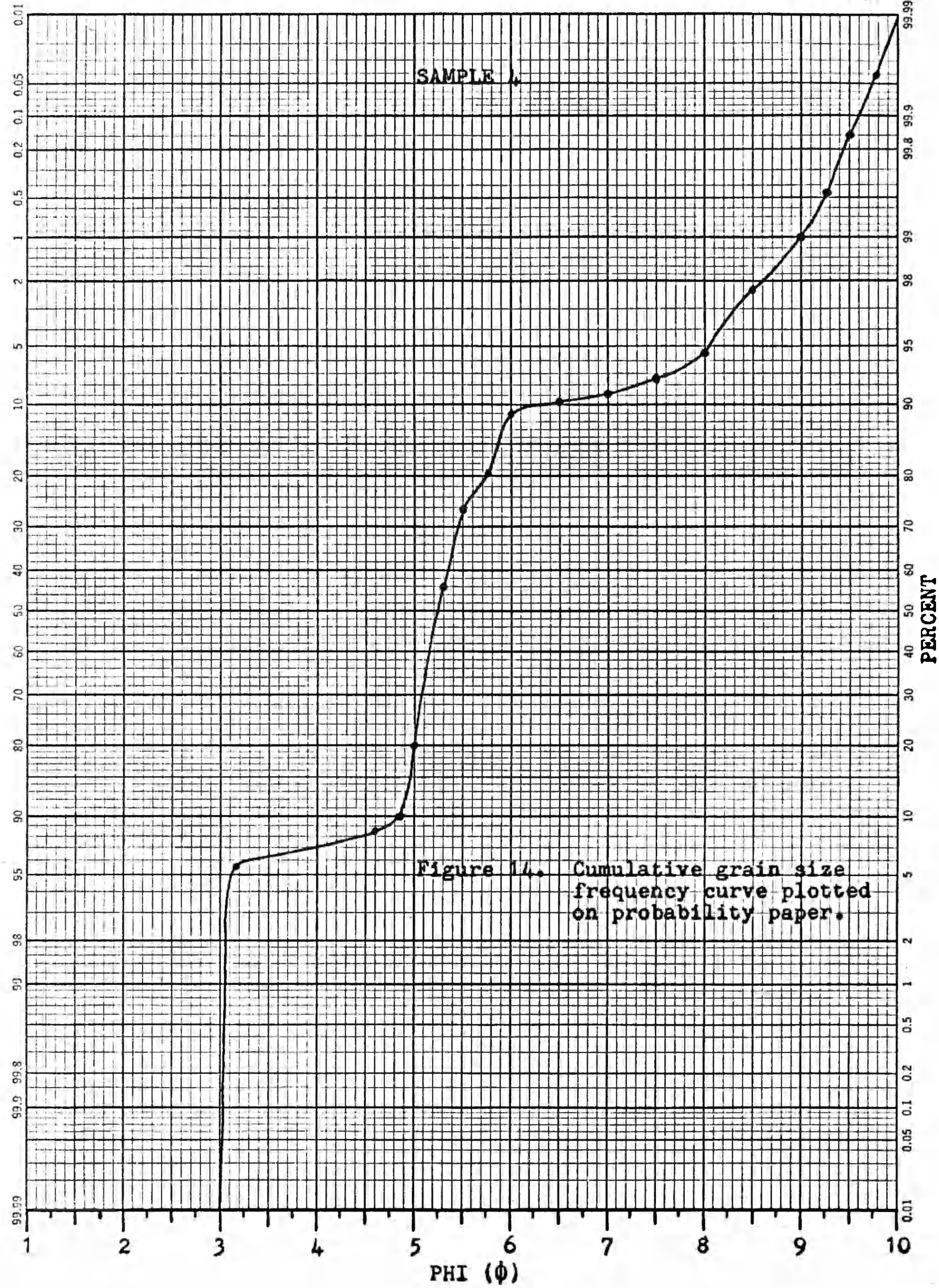

Figure 14. Cumulative grain size frequency curve plotted on probability paper.

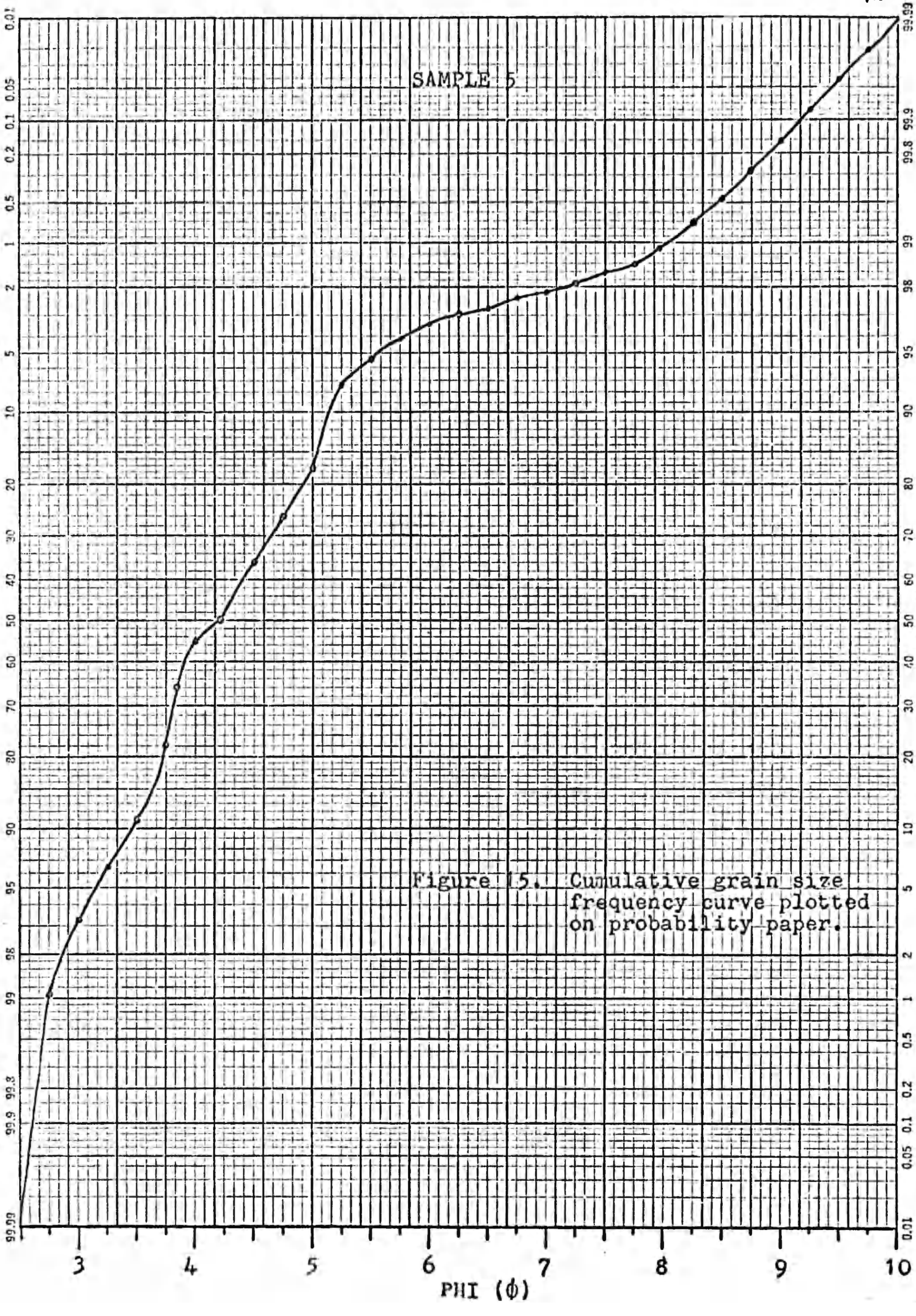

Figure 15. Cumulative grain size frequency curve plotted on probability paper.

GEOLOGY OF THE DAVIS-BRONSON POOL, ALLEN AND BOURBON COUNTIES, KANSAS

by

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B. S., Kansas State University, 1962

AN ABSTRACT OF A THESIS

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The reservoir rock of the Davis-Bronson Pool in Allen and Bourbon Counties, Kansas is a shoestring sand that trends northward. The pool is on the Bourbon Arch, and the tectonically positive elements in the immediate region, during the time of sand deposition, were the Nemaha Ridge to the west and the Ozark Uplift to the southeast.

The sandstone body is in the Cherokee Group, Desmoines Series, Middle Pennsylvanian System. It is correlative with the subsurface Skinner sand of Oklahoma, the surface Chelsea sandstone of Kansas and Oklahoma, and subsurface "900 foot" sand or Colony sand in southeastern Kansas.

Transverse stratigraphic cross sections of the sandstone body, with the base of the Fort Scott Limestone as a horizontal datum, and an isopachous map, of the interval from the base of the Fort Scott Limestone to the base of the channel fill, were used to show the attitude of the sand body at the time of deposition. They indicate that the reservoir rock in the Davis-Bronson Pool is part of an ancient south flowing stream channel with at least two southwest trending tributaries.

Mineralogical and grain size-roundness analyses of thin sections of the sandstone show that the reservoir rock is a silty, very fine sandstone: siliceous, immature, micaceous graywacke. The sandstone contains rounded and angular grains of plutonic quartz, metamorphic quartz, MRF'S, micas and small quantities of orthoclase and plagioclase. This diverse suite of minerals and the abnormal relationship between roundness and mineral hardness indicates a mixed source area.

The sandstone is cross-bedded and contains an abundance of locally derived shale pebbles, clay ironstone pebbles, and fragments of coal; these also indicate that the sandstone was formed in a fluvial environment. Authigenic quartz overgrowths have reduced the porosity and permeability of the sandstone reservoir rock.

A structure map of the base of the channel fill shows that the northern and southern ends of the sandstone reservoir are structurally higher than the central part. A structure map of the base of the Fort Scott Limestone shows that it is arched over the sandstone trend and that the central part of the map is structurally lower than the north and south boundaries. The structural attitude of the Fort Scott Limestone coincides with the structure of the sandstone body. The folding of the Fort Scott Limestone over the locus of maximum sand deposition was caused by differential compaction of the sandstone body and surrounding shales. Structural movement after deposition of the Fort Scott Limestone and/or differential compaction over irregularities on the surface of the "Mississippi lime" caused the structure of the sandstone body and the north-south reversal of dip in the overlying Fort Scott Limestone.

The structure of the sandstone body is a controlling factor in the accumulation of petroleum. The area of greatest oil accumulation is in the central, structurally low, part of the shoestring reservoir. An increase of gas, and decrease of oil accumulation, is encountered in the structurally high south end of the sandstone trend.

The sandstone reservoir probably extends farther north and south, but the high ratio of gas to oil at the south end of the pool has placed an economic limit on further exploitation southward. Poor sandstone development has limited exploitation of the reservoir northward. If the sandstone body extends northward, it might correlate with the reservoir rock in the Selma, Kincaid, or Centerville pools--but further investigation would be necessary to determine this.