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GEOLOGY OF THE CAVANAL SYNCLINE
LE FLORE COUNTY, OKLAHOMA

BY

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ABSTRACT

The Cavanal syncline is expressed at the surface by Cavanal Mountain and the Potato Mountains. Exposed rocks are of the Savanna and Boggy formations, Krebs group, Des Moines series. The syncline is a broad downwarp cut by north-south faults.

INTRODUCTION

Physical and Cultural Features of Area

The area under consideration is in east-central Oklahoma from three to four miles west and northwest of Poteau, the county seat of Le Flore County, and extending southwest to section 27, T. 6 N., R. 22 E., about 5 miles northwest of Fanshawe in Latimer County. Approximately 100 square miles were mapped, including parts of T. 6 N., Rs. 22 E., 23 E., 24 E., and T. 7 N., Rs. 23 E., 24 E., 25 E. The exact shape and location of the area are shown on the index map (Figure 1).

With the exception of a few cattle ponds, feeding sheds, and the buildings on Dr. Lowery's ranch (sec. 2, T. 6 N., R. 23 E.), the axial portion of the syncline is almost entirely lacking in evidence of the presence or influence of man. There is only one road passable by automobile which traverses the area in a north-south direction, and it passes by Lowery's ranch in Wildhorse Hollow. In the less rugged fringe area of the syncline there are a few gravel roads which run east-west. By turning west at Shady Point off U. S.

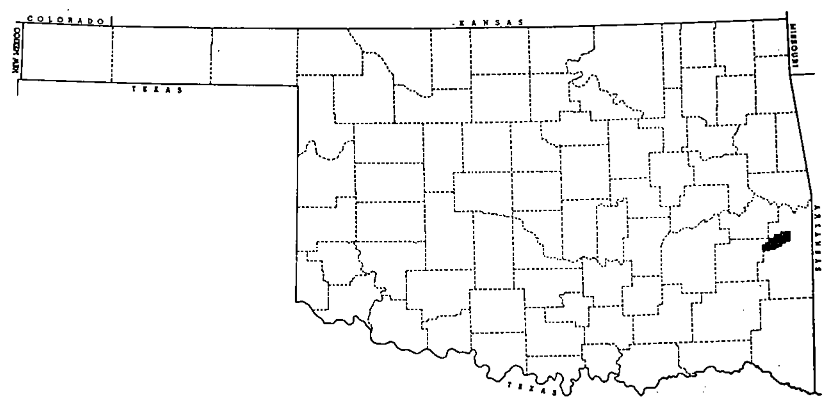

Figure 1. Index map showing location of Cavanal syncline area.

Highway 59, 271, six miles north of Poteau, one can make a complete trip around the area passing through Calhoun (sec. 2, T. 7 N., R. 24 E.), Walls (sec. 20, T. 7 N., R. 23 E.), and Red Oak (sec. 3, T. 5 N., R. 21 E.) from which the return to Poteau is made by driving east on U. S. Highway 270 through Wister. In addition to these roads there are improved dirt roads leading to most ranches. Although the roads reach these isolated ranches, telephone and electric power lines generally do not. By way of exception Mr. Sam Sorrels' house on top of Cavanal Mountain is served both by a road and by a power line. Originally an old Indian or deer trail, this road performs a double service—access to the area and exposure of almost all the rocks in the Boggy formation present in the syncline. A State Police radio relay station, two ponds, two wells, and an abandoned orchard are on the mountain top.

Many wagon trails, overrun by brush or rutted by streams, zigzag across the rugged central portion of the syncline including an old road leading south from Calhoun (formerly named Sutter) to Wister. Most of the coal mines, of which there were scores, are in the belt between the described route that circumscribes the area and the deepest penetration of the improved roads into the central part of the syncline.

A few logging skids and cattle trails provide means of relatively easy passage through the hills for a person on foot or horseback. These can in most cases be located by a careful study of the aerial photographs.

Method of Investigation

With the exception of about two square miles at the extreme southwestern tip of the area, aerial photographs (scale 1:20,000) supplied by the Oklahoma Geological Survey were used in mapping the report area. The geological features were traced directly on the aerial photographs with a grease pencil and the section lines with very soft lead. Transparent overlays were then made covering the entire area and the geology traced, making a map which is the same scale as the photographs. The dip readings, which had been made in the field, and the culture were then traced.

Sections were measured in five places where the rocks are well enough exposed to warrant it. In all five localities a Brunton compass was set at the true dip where the traverse was made perpendicular to the strike.

Purpose of Investigation

This investigation was made to study the character and distribution of rocks cropping out in the central and eastern parts of the Cavanal syncline and to study the relations these rocks exhibit with reference to the regional geologic picture. This report covers an area which has not been mapped in detail before, and thus it fills in one of the few gaps in such mapping on the geological map of Oklahoma.

Previous Investigations

The subject of previous investigations divides itself, for purposes of this report, both chronologically and geographically. The heart of the area was itself covered on foot, on horseback, or by wagon by the authors of several reports dating from 1821 to 1914. This first group of papers did not include detailed map work in the area proper, although some measured sections have been recorded.

The second group of papers, dating from 1926 to 1949, includes detailed maps of areas on all sides of the area but nothing of this nature in the area itself. There were many wagon roads in the area (see U. S. Geological Survey topographic maps) at the time of the older studies and transportation in and about the syncline was better, by the standards of that time, than it is now, since automobiles must be left at the fringe of the area and horses would be fairly hard to obtain for use in an investigation of this type. This is probably one of the reasons for better coverage of the area in earlier days.

Of the first group of reports, the earliest was the result of several trips across the region between Sugarloaf and Cavanal Mountains by Thomas Nuttall (1821) in 1819 for the purpose of studying the botany and geology of the area.

In 1853, Jules Marcou (1853), working for a railroad company, traversed the area immediately south of the Arkansas and Canadian Rivers and made some geologic observations. It is likely that Marcou passed over or very near the region under consideration in this report.

H. M. Chance (1890) was the first to attempt correlations, based on geologic data, of the coal beds in the region. He erroneously correlated the Secor coal with the Mayberry coal, which is higher in the section (Branson, April, 1954). The latter is reported by Chance to be 1,200 feet below the summit of "Kavanaugh Mountain." Chance also noticed a general trend in the synclines (S70°-80°W) and anticlines (S40°W) of the region.

J. J. Stevenson (1895) studied the coals and attempted to correlate the sections made by Chance with a section (unpublished) compiled by Arthur Winslow in Arkansas.

In 1897 a report by N. F. Drake (1897) was published by the American Philosophical Society. Drake (a) noted two trends of folds in the region, (b) noted the regional dip of the beds, (c) used "Cavaniol" and Poteau group designations (in Upper Coal Measures), and (d) noticed the decrease in the number and thickness of sandstones in the interval between the McAlester and Mayberry coals in a northwesterly direction between Cavanal Mountain and Brooken.

Taff and Adams (1900) covered the area for the U. S. Geological Survey and published the results in the 21st Annual Report of that agency. Taff (1899) had named the formations present in the area from other parts of Oklahoma. One of the few changes in formational boundaries in the area of this report since the general mapping by Taff and Adams has been the moving of the base of the Boggy formation to the base of the Bluejacket sandstone member (Branson, Jan., 1954). In the 22d Annual Report of the U. S. Geological Survey Taff placed the base of the Boggy formation between the Lower and Upper Witteville coals and correlated the Upper Witteville coal with the Mayberry coal of Drake. Taff also discussed the structure of the coal field in this paper.

In 1910 a book entitled *Coal Land in Oklahoma* was distributed as Senate Document No. 390, which was a compilation of information regarding the attitude, thickness, and quality of coals with division into numbered tracts. This information from U. S. Department of the Interior Circulars 1-5 (1904-1906) included a report on the Howe-Poteau District (Circular No. 3).

In 1914 the U. S. Geological Survey and the Oklahoma Geological Survey published papers covering the area proper (Smith, 1914 and Snider, 1914). Both describe the attitude, thickness, and structural relations of the rocks in the Cavanal syncline. Again, the mapping is not detailed in the syncline proper.

Twelve years then went by before any new geologic work was done. The period between 1926 and 1949 saw first the publication by the Oklahoma Geological Survey of two papers—one dealing with coal in Oklahoma (Shannon and others, 1926) and the other with oil and gas (Stone and Cooper, 1929). The first described all the workable coals from the Lower Hartshorne to the Upper Witteville (Secor) in the Howe-Poteau District (for purposes of this paper), and the second described the structure and producing horizons in gas sands in the vicinity of Cavanal Mountain. In this paper the author also commented on the carbon ratio theory.

Finally, the more important papers are those which show on maps the rocks cropping out immediately adjacent to and completely surrounding the area. These include Hendricks' work (1939) on the south and southwest, the report by Oakes and Knechtel (1948) on the west in Haskell County, and mapping done by Knechtel in northern Le Flore County (1949) covering the north and east sides of the syncline.

Acknowledgments

The people who have homes in the area all gave time and effort to showing outcrops which could otherwise have gone unnoticed. Special thanks are due Dr. Lowery, who gave the writer a place to stay at his country home and the use of a good horse for working the adjacent hills.

The Oklahoma Geological Survey aided in field expenses and provided aerial photographs. Dr. Carl C. Branson directed this work and made suggestions and corrections, as did Dr. C. A. Merritt and Dr. H. E. Hunter. The report was submitted as a thesis for the Master of Science degree at the University of Oklahoma.

GEOMORPHOLOGY

Regional

The Cavanal syncline is one of the more prominent structures chiefly in rocks of early and middle Pennsylvanian strata in the structural trough known as the McAlester basin. The region is one characterized by gently to moderately dipping strata forming anticlines and synclines which are marked, in the case of the former, by cuestas and by hogbacks away from the axial portions of the folds. In the case of the synclines, cuestas are replaced by hogbacks away from the axis. These ridges are dependent upon the relatively well-indurated sandstone layers for their support whereas the valleys between follow the outcrops of the less erosion-resistant shales. Near the central portions of many of the synclines, where the dips are relatively low, the ridges give way to steep slopes leading up to a flat-topped summit or conical hill. Where these folds plunge, the ridges trace an arcuate pattern across the countryside. In the synclines sandstone beds become more noticeable on the geologic map due to their extension down the dip slopes. This is especially so in areas where the strata have a relatively low dip. These dips are the reason for the presence of synclinal mountains and anticlinal valleys which are so characteristic of the region. Throughout the McAlester basin, and especially near the Arkansas-Oklahoma border, the strata on anticlines dip more steeply than those in the synclines.

Taff (1899) reported the existence of a peneplain and of a marine erosion plain—the latter of Cretaceous age and the former of post-Cretaceous, probably "Tertiary" age. Concerning the Cretaceous leveling, Taff noticed the concordant summit levels of the higher hills and uniform altitudes of the crests of the lower ridges from Atoka west across the south end of the coal field. He states that farther north in the vicinity of Lehigh the ridges grow higher and the valleys lower in elevation. The crests of these ridges, he reports, lie almost within the original Cretaceous base-level. Farther north a plain at 900 feet is in evidence.

Near the northern border of the Atoka quadrangle the two levels converge at a height of 850 feet owing to the fact that the slope of the Cretaceous base level was less than that of the "Tertiary" peneplain. South of this point the "Tertiary" base leveling has destroyed evidence of the marine erosion plain, limiting it to a belt 10 to 30 miles wide. Both plains bevel all types of rock alike.

Concerning the post-Cretaceous denudation, Taff (1902) drew most of his conclusions from the gravel and sand terrace deposits found in eastern Oklahoma. This plain, he stated, stands now at a level of 700 to 800 feet. All the terrace gravels found lie about 50 to 100 feet above the present level of the streams. Knechtel (1949, p. 33), Oakes and Knechtel (1948, p. 63), and Hendricks (1937, p. 275) all mention these gravels, as does Morgan (1924), who states that they are probably of Pleistocene age. The discovery of a mammoth tusk in a terrace deposit near Steedman, Oklahoma, supports this theory. Taff's "Tertiary" age (about Eocene to Miocene) had been based on the position of the gravels over lower "Tertiary" strata and the occurrence of the gravels in northeastern Texas, southeastern Oklahoma, and southwestern Arkansas. In Texas the terraces lie about 700 feet above sea level also. The broad distribution of the surficial deposits in wide and elevated river channels, their relation to Tertiary deposits, and the equal beveling of shale and sandstone (a characteristic feature of a peneplain) suggested strongly to Taff (1902) that that surface stood near sea level when it reached this near "endrumpf" stage (Penck, 1924). It has since been uplifted, tilted, and partly dissected.

Local

The place of Cavanal Mountain with relation to the regional geomorphology is that of a monadnock-like prominence rising 1,600 feet above Taff's "Tertiary" peneplain, which is assumed to be at a level of between 700 and 800 feet in this area. In the general vicinity there are three similar features—Sans Bois Mountain to the west and Sugarloaf Mountain and Poteau Mountain to the east. The highest part of Cavanal Mountain lies in the northeastern part of section 20, T. 7 N., R. 25 E. where the summit (2,369 feet) is supported by a bed of gently dipping sandstone of the Boggy formation. The strata surrounding the mountain, which range down to the alternating sandstones and shales of the Savanna formation, make parallel ridges which outline the syncline and curve

across its axis exposing progressively older beds to the west. The relief of the top of the ridges over the depth of the valleys between is a function of the thickness of the sandstone bed capping the ridge, but more important, the thickness of the shale underlying the ridge—the thicker the shale, the deeper the valley. From east to west, the hilltops become progressively lower, ranging from 2,369 feet in the east to 1,450 feet in the Potato Peaks area, to 1,250 feet east of Pigeon Mountain in section 10, T. 6 N., R. 23 E., and to 1,450 feet east-northeast of Red Oak.

Cavanal Mountain is an outlier of the Boggy formation. The origin of and the prominence of the mountain can be ascribed to several causes. In the first place, the axis of the syncline plunges toward the area beneath the highest peak from both sides. Therefore, at one time the profile which the syncline presented to the processes of erosion must have been higher in the west, allowing it to be eroded faster by more powerful streams. Next, the high altitude of the peak itself may be owing to the fact that the section in the eastern part appears to be sandier and slightly thicker than that in the west. Only the first three beds above the Bluejacket sandstone member could be measured for purposes of comparison; however, the sand to shale ratio, by thickness of beds, is about 1:7 in the west whereas it is only 1:5 in the east. Since the upper beds of the formation are absent in the west, it has been assumed that the relationship between these ratios has remained the same because it does so upward in the section in the east. Finally, degradation of the rocks in the Cavanal syncline took longer than in neighboring areas because the section is thicker there than elsewhere.

Retreat of Slopes

The retreat of the concave slopes of the mountain will apparently produce, eventually, a sharply pointed monadnock-like hill of the type Penck (1924) describes. The concavity of the slopes will be maintained by the undercutting of the topmost sandstone by steep-gradient streams. Penck is an advocate of the concept of parallel retreat of slopes from an original V-shaped valley. Bryan (quoted in Cotton, 1948, p. 233) stated, on the parallel retreat of slopes:

> In the area between two parallel streams (the local base-level) the steep slopes from either side retreat until the original highland is consumed, and thereafter the divide is lowered and the relief of the area reduced. . . . Penck holds that steep slopes retreat without loss in their inclination and that steepness disappears only because the land above the grade of the Haldenhange has been consumed. Gentle slopes replace steep slopes at the time when the Haldenhange meet on the divides.

From the relationship between Cavanal Mountain and the floodplain of the Poteau River, these processes seem to be taking place in the area, although Penck was describing the degradation of an homogeneous mass. The wide floodplain of the Poteau River to the east and south of Cavanal Mountain suggests the beginning of the peneplanation brought about by corrasion. The surface of the plain truncates sandstone and shale beds alike.

River Terraces

In the area there are river terraces composed of sand and gravel which lie about 50 feet above the streams now degrading them. These are assumed to be of the same age and origin as the terraces reported by Taff in support of a postulated peneplain 700 to 800 feet above sea level. Here, too, the terraces on the south side of Cavanal Mountain lie at an altitude of between 700 and 800 feet. Other evidence for peneplanation is the fact that many of the summits of the smaller hills and ridges from the south side of Cavanal Mountain in T. 6 N., Rs. 24 E. and 25 E. to the peaks of Wildhorse and Badger Mountains in T. 11 N., R. 24 E. and T. 12 N., R. 23 E., respectively, lie at a general level of 750 to 800 feet. Evidence of this surface is not present immediately adjacent to the Arkansas River, which now constitutes the regional base level, at an elevation of about 425 feet north of the area.

The abandonment by streams of the level of the terraces may be due to one of two causes—surges in the rate of erosion due to intermittent uplift or climatic fluctuations in an uninterrupted cycle of denudation. Cotton (1948, p. 205) stated that a theory of terracing based on intermittent erosion during continuous upheavel is open to the same objections as Penck's expanding dome theory of piedmont benchlands, which has been discredited in this country. The accepted theory is one paralleling that of W. M. Davis (1932) based on accelerated upheaval.

The area is too limited to show evidence in support of a post-Pleistocene upwarp other than the abandonment of the terraces

themselves. However, there is one fact which at least points to the origin of the terraces—the coincidence, in time, of the melting of many thousands of cubic miles of ice and the degradation of these Pleistocene deposits. Another indication of change in climate, though of a recent nature and perhaps insignificant, is the growth of trees and brush on Sans Bois Mountain, west of Cavanal. Blake (1856), a member of the Whipple Expedition of 1853 (Oakes and Knechtel, 1948, p. 11), stated: "The Sans Bois mountains rise to a height of about 2,000 feet, above a heavily timbered plain; and, as their name indicates, are nearly or quite without trees." What effect, if any, this indication of change in climate might have on the down-cutting of terraces is not known. It seems possible that, at least locally, moderate increases in the amount of rainfall (although it is not known how great these may have been) over a period of one hundred years would be sufficient to cause the trenching of surficial deposits to a depth of 50 feet. The actual change in climate probably began much earlier since the advance of the foliage up a mountain as small as Sans Bois would seem to be merely the last evidence of climate variance.

It seems more probable that melting glaciers in the Rocky Mountain region caused a rejuvenation of the Arkansas and Canadian Rivers, thus causing a drop in local base level. The sublimation and evaporation of ice and meltwater also had an effect on rainfall over large areas.

Drainage

Almost all the erosion of rocks of the area is done by water. The resequent and insequent streams transport their local load down to the larger subsequent streams, running in shale beds between the parallel ridges of resistant strata. Wildhorse, Opossum, and Nigger Creeks on the north, and Mountain Creek and an unnamed creek on the south of Cavanal Mountain are the more important. These streams, with their tributaries, form a trellised drainage pattern. In the south part of the area, consequent streams, which bridge resistant strata through the process of joining of former insequent and resequent streams, form water gaps and flow nearly parallel to one another. These streams are thought by the writer to have been initiated in and to owe their present course to weak zones along the strike of north-south faults.

In other parts of the area, where hills exist, the local drainage pattern is radial. However, the waters of all these streams, after passing into the trellised pattern downstream, eventually find their way into Fourche Maline Creek on the south or into Brazil Creek on the north. Both of these major creeks are, in turn, tributaries of Poteau River, which flows into the Arkansas about 25 miles to the northeast of Cavanal Mountain.

Minor Weathering Features

"Pimple" mounds are found in the vicinity of the area. These small circular hummocks range in size from 2 to 5 feet in height and 50 to 100 feet in diameter. A discussion of the origin of these features is in Oklahoma Geological Survey, Bulletin 68 (Knechtel, 1949, p. 10-11). From the observations that the writer has made, it would seem that Knechtel is correct in attributing the origin of the mounds to "a network of small streams and rivulets upon a thin but widespread layer of soft surficial material." All erosion of material on slopes, no matter how gentle, must begin somewhere. The "somewhere" is usually attributed to original small irregularities on the surface. Sheetwash on a plain of surficial debris will give way, due to these original irregularities, to rillwash. The rills then coalesce to become small streams and rivulets which carry the material farther away from the more positive areas, in this case the "pimple" mounds. The vegetation and gentle slope of the surfaces prevent gullying.

The sandstone beds weather into regular, rectangular blocks. The breaking off of the blocks is caused by erosion of underlying, less water-resistant units with accompanying landslides. Root action and, to a small extent, frost action must also play a part in this quarrying. The boundaries of breakage of the blocks are provided by two joint sets, which are approximately at right angles to one another, and bedding planes.

In some places the joints have provided a means for the passage of iron-rich ground water. Where the iron has been deposited in the pores of the sandstone, the effect has been similar to the case-hardening of steel. The joints in many places are raised in relief above the surface of the rock, separated by square hollows about 1 to 2 inches wide where the sandstone which was not "case-hardened" has been removed.

SEDIMENTARY PETROGRAPHY

Studies were made to gather evidence to ascertain the source of the mineral grains which make up the strata of the area. Thin sections were cut from random samples of the sandstone beds and examined under a petrographic microscope. Shale samples were washed and examined by means of a binocular microscope. In the following pages information which sheds light on the depositional environment of the mineral grains is discussed, whereas in the work described only the source area of the sediments is sought.

It has been fairly well established that the source of the sediments in the McAlester basin was a landmass of some type to the south and southeast. Hendricks, Knechtel, and Bridge (1937), for example, mention, as evidence in support of this conclusion: (1) pebbles in the Atoka, McAlester, and Savanna formations near Atoka, Oklahoma, which came from the southeast within the area now occupied by the Ouachita Mountains; (2) northward felling of *Cordaites* trunks near Heavener, indicating northward flowing streams; (3) the absence of channeling in the Morrow formation on the flanks of the Ozark uplift, which indicates low relief and the absence of large streams flowing to the south and west at that time; (4) channel deposits in the Hartshorne formation showing a northward trend; and (5) small pebbles which came from the east occurring in the lower part of the Atoka of the Boston Mountains. Because the Boggy and Savanna formations in the area are similar in lithology to the other rocks in the basin of deposition, it is assumed that the original source of the sediments for these deposits was to the south and southeast also. There is some indication that a minor amount of the sediment in the basin was derived locally, however. Hendricks (1937) reports some thinning of sediments over anticlines and also reports the presence of shale plates lying at an angle to the bedding planes in the sandstone strata. These observations indicate crustal movement during deposition of the sediments and also point to a local source, consisting of previously deposited material. The only other possible source area for the McAlester basin rocks and, in particular, those of the area is the Ozark region to the northeast. All the evidence supports the idea of a southeastern source.

The thin sections disclosed that the rocks in the area are composed mostly of quartz (80 to 90 percent). The mineral grains range from angular to subrounded in shape and contain inclusions of what appears to be iron tourmaline and rutile. These inclusions are so small, however, that only the identification of the tourmaline is valid. Dust particles also appear to be present within the quartz. The inclusions are not pronouncedly acicular as would be the case with quartz particles derived from a metamorphic source (Krynine, 1940); nor are the inclusions lined up. Authigenic silica occurs and appears to be the major cementing material. The authigenic silica has been distinguished on the borders of the grains by the line between quartz that contains inclusions and that which does not. Also, crenulated borders, characteristic of metamorphic quartz (Krynine, 1940) are absent.

Other minerals which occur in small amounts include crenulated muscovite and brown biotite, sphene, chlorite and sericite, limonite, one piece of plagioclase almost completely altered to clay minerals, zircon, ilmenite and magnetite altered to leucoxene, and two green minerals. These last minerals (only one grain of each was found) and tentatively identified as hornblende and augite (which may be altered to tremolite-actinolite). Crenulation of the muscovite and biotite is probably post-depositional and is due to compaction and authigenesis. Ankerite has been reported from these strata (Branson, personal communication, 1958), but none could be identified in the thin sections. Also, in an analytical statement prepared from a water sample collected from a stream on Cavanal Mountain, the presence of calcium, magnesium, sodium, bicarbonate, and chlorine are reported. It is not known what part of these substances is due to recent organic reactions between the water and the plant remains in the soil. However, the ankerite was suggested as a possible source of the magnesium.

From the nature of the inclusions and the absence of crenulated borders on the quartz crystals, it has been concluded that the original source of the quartz is igneous. The presence of iron tourmaline as inclusions in the quartz suggests an original siliceous igneous rock. Rutile also occurs in rocks such as granite and diorite. Diorite is mentioned because a body of this rock is reported by Miser (1943) in McCurtain County to the south. The diorite is considered to be Ordovician or later in age. A diorite source would also explain the presence of the hornblende and biotite, which are the principal mafic minerals of a diorite. It is possible that this diorite could have formed by a stringer from a more acidic igneous body making contact with more basic or, more probably, calcareous rocks. Van der Gracht (1931) thinks that Arbuckle facies rocks lie under strata of the Ouachita facies. In a gas well drilled in northern Le Flore County (Red Bank Oil Company's Fee No. 1 in SW¼ NW¼ section 23, T. 9 N., R. 24 E.), strata including much limestone and rocks largely equivalent to those in the Arbuckle Mountains were penetrated below the Atoka formation (Knechtel, 1949, p. 34).

Magnetite (altered to limonite), ilmenite (altered to leucoxene), and muscovite are constituents of acid igneous rocks such as granite. Sphene and zircon are common accessories of such rocks. Finally, dickite has been reported from the rocks of northern Le Flore County (Knechtel, 1949, p. 60-61). This clay mineral is commonly of hydrothermal origin, it is stated, and solutions from deep-seated magmas may have entered the Pennsylvanian strata of Le Flore County during or following the deformation of the area. The iron oxides, which stain the rocks of the area and which are commonly found along joint planes and zones of smaller grain size in the sandstones, may owe their distribution to these solutions, probably diluted with meteoric waters.

For evidence supporting the conclusion that the source of the sediments in the area was to the south and southeast, a comparison of the mineral suite was made with those reported both north and south of the area. Use of heavy mineral analyses to determine the source and correlation of strata of the McAlester basin sediments has been largely unsuccessful in the past. Pitt (1955) mentions the presence of a suite of minerals from pre-Mississippian rocks of the core area of the Ouachita anticlinorium including pyrite, iron oxides, zircon, garnet, rutile, apatite, ilmenite, graphite, hematite, kaolin, and goethite.

Goldstein and Reno (1952), in their study of the petrology and metamorphism of the rocks in the Ouachita Mountains, show three stages of metamorphism of argillaceous sediments in order of increasing intensity—the zone of clastic micas, the zone of chlorite, and finally the zone of biotite. They also report low-temperature ore minerals—cinnabar, stibnite, and manganese oxides. The argillaceous sediments contain finely divided interstitial clay and micas which alter to sericite and chlorite. The hydrated iron oxides alter to magnetite and hematite.

Scruton (1950) studied the minerals of the strata from the Atoka formation to the Bluejacket sandstone member of the Boggy formation in northeastern Oklahoma. Special emphasis was placed on the Warner-Pryor area where he showed evidence for the presence of a delta built out from the Ozark area, which was a low positive area at that time. The heavy minerals Scruton found include leucoxene, zircon, tourmaline, muscovite, rutile, staurolite, and chlorite, all derived from the Ozark dome. There is no significant change in the mineral suite upward in the section that would indicate a change in source area. Scruton advocates a northern source because of the increased sand:shale ratio in that direction and the lack of garnet in his samples. Garnet is characteristic of Silurian and later rocks to the south, he stated. Of the minerals common to the area and to the Warner-Pryor district he stated: (1) that the authigenic quartz is best developed south of the Arkansas River (as would be expected in the deepest part of the basin); (2) that the feldspar is angular and unaltered; (3) that the leucoxene percentage is 40 percent greater north of the Arkansas River; (4) that muscovite is ubiquitous but was only deposited where the competency of the depositional medium was very low, as would be expected from a consideration of the shape and specific gravity of this mineral; (5) that pink zircon is found in the north in variable amounts up the section of rocks but that its presence is dependent also on the transporting agent and not on a shift in source area; and (6) that tourmaline (purple) is common in the Little Cabin sandstone member, less so in the Warner sandstone member, and absent in the Hartshorne sandstone. It is also found in the lower part of the formation where its reappearance indicates a return to the site of deposition of a more competent transporting agent. The grains are well rounded.

Using these mineral occurrences for a background, a comparison was made with the minerals found in the area. Of the sixteen minerals and interstitial materials found in the thin sections from the Cavanal syncline, 13 were reported in the north and 11 from the south. However, two minerals reported in the north, spinel and staurolite, are indicative of a metamorphic source. Spinel characteristically crystallizes from a magma very low in silica when it is of igneous origin. These minerals, then, do not fit in with the evidence pointing to a siliceous igneous rock as the source rock of the sandstones in the Cavanal syncline and would be expected to be missing. It is probable that the rocks which Scruton studied had a mixed source or perhaps a source completely different from the rocks in the Cavanal area, as he believes.

Of the minerals found to the south, but not in the Cavanal area, the missing goethite is most easily explained. It could have been altered to form a part of the iron oxide which is abundant in the sandstone beds. The absence of garnet and apatite cannot be explained satisfactorily, but both of these minerals are at least associated with the type of rock postulated as occurring in the source area of the quartz in the Cavanal area. These minerals may have been overlooked or may merely not be present in the 0.75 mm of rock studied in the 25 thin sections. In addition, the source of the rutile seems to have been to the south since it increases in quantity south of the Arkansas River according to Scruton. Tourmaline in the north is well rounded, indicating a considerable distance of travel from the source. Leucoxene is white and rusty and 40 percent more abundant north of the Arkansas River, and this fact may be due to increased alternation of ilmenite and magnetite during travel away from the source. It is not known if the amount of ilmenite and magnetite decreases correspondingly north of the Arkansas River. Another fact pointing to a southern source is the absence of biotite to the north whereas it occurs in the rocks of the Cavanal area and to the south as well. Feldspar is unaltered as Scruton reports, but also some is highly decomposed (Wilson, 1935) in the Bluejacket sandstone member of the Boggy formation in the Muskogee-Porum district, just as it is in the Cavanal area. This may be an indication of a mixed source for the sediments of the Muskogee area.

Finally, from the binocular examination of the washed shale samples from the area, one more fact was uncovered which is suggestive rather than conclusive evidence of the source of the sediments. In all the shale samples studied, the writer noticed aggregates of fine-grained snow-white quartz crystals. The only report of a pure white sandstone which the writer noted was in a description of the lithology and petrology of the Stanley and Jackfork formations by Bokman (1953). Bokman states that some of the sandstones of the Jackfork formation of the Ouachita Mountains have the appearance of quartzites bound together by silica cement—the sandstones are reported by him to be white through gray and blue, dense, and homogeneous. Bokman (1952, p. 22) considers the quartz of the Jackfork sandstones as having been derived from a metamorphic source; however, he considers the quartz of the underlying Stanley sandstones to have been derived from a granite.

STRATIGRAPHY

General

The indurated rocks belong to the Savanna and Boggy formations of the Krebs group. These two formations are a part of the rocks laid down in the McAlester basin, a structural trough which occupies a part of a large geosyncline. The area itself lies in what was the deepest part of the basin as evidenced by the relatively great thicknesses of rock sections. The strata of both formations in the Cavanal syncline aggregate about 5,350 feet. The upper part of the Boggy formation has been eroded so that the higher beds of the formation are absent.

Both formations consist of alternating beds of fine- to medium-grained sandstone and silty shale with coal beds and ironstone layers occurring in the shales. No limestone was found although thin impure limestones have been reported in Haskell County (Oakes and Knechtel, 1948). In addition to those rocks laid down in the Pennsylvanian period there are deposits of locally derived gravel and sand in terraces fifty feet above the level of the streams in the area.

There are few good exposures of sandstone in the Cavanal syncline and even fewer exposures of shale. The shale, which makes

up more than one half of the geologic column, is almost everywhere covered with residual soil, vegetation, and talus from above. It normally occurs in the steep valley sides which are supported by the overlying sandstones. It is for this reason that there are places on the map where two sandstones are shown to coalesce. At these localities the shale, it should be remembered, may thin or remain the same thickness but in either case it cannot be mapped as a separate unit. An example of this type of mapping is at the southwest corner of section 7, T. 7 N., R. 25 E. Shale exposures have been found in that unit to the west but they are so few that they were impossible to map where no break in slope occurred. However, in the southwest part of section 18, T. 7 N., R. 24 E. Knechtel (1949) maps a sandstone crossing the fork of Opossum Creek as continuous with the upper unit of the Bluejacket sandstone member. This interpretation is believed to be in error and the sandstone occurring at that fork appears to be a slumped portion of a higher bed, now separated from the main body by a stream.

History of Usage

The boundaries of the Savanna formation are not everywhere easy to locate. Wilson (1935) included part of the McAlester and Boggy formations in his mapping of the Savanna. At present the lower boundary of the Savanna is placed below the Spaniard limestone member where that member is present. In general, until 1954 the boundaries remain much as they had been described by Taff (1899). Taff (1902) changed the upper boundary of the Savanna formation by placing it between the Secor and Lower Witteville coals. This usage has been largely overlooked or ignored as has the concept of "Savanna sandstone" of Collier (1907) in Arkansas. Oakes and Knechtel (1948) show that the uppermost persistent sandstone unit of the Savanna formation, the "Spiro," is not identified in the general region of which the present area is a part since the "Spiro" constitutes only a part of the uppermost beds of the formation in Haskell County.

The boundary between the Savanna and Boggy formations has been changed again more recently. The lower boundary of the Boggy formation is now placed at the base of the Bluejacket sandstone member (Branson, Jan. 1954).

Savanna Formation

First reference: Taff, J. A., 1899

Nomenclator: Taff, J. A., 1899

Type locality: Taff does not specify where the type locality is, but it is presumably near the town of Savanna, Pittsburg County, Oklahoma.

Original description: Taff and Adams (1900) wrote concerning the Savanna formation from Hartshorne east to the Oklahoma-Arkansas line:

> The Savanna formation contains three prominent divisions or collections of sandstone beds, having thicknesses of from 100 to 200 feet each and separated by sequences of shale and thin sandstone, with two known workable coal beds. The upper division of this series of sandstones is the thickest, being nearly 200 feet thick; its upper strata are locally massvie. . . . . The medial bed is the next in importance and thickness and is also a prominent ridge maker. . . . . The lowest sandstone, while neither so thick in section nor so prominent as a ridge-forming rock is not less important, from the fact that it is associated with a prominent coal bed.

The only known workable coal bed in the area occurs closer to the medial sandstone than to the lowest one. It is the Cavanal coal. Another variation from the original description is the fact that a fourth sandstone appears just east of the area. It was mapped by Hendricks (1939) on the southeast flank of Cavanal Mountain, whereas in the Sans Bois syncline in southeast Haskell County, the Savanna formation as mapped consists of any two sandstone units.

Distribution and Thickness

The Savanna formation is present along the southern and western limbs of the Cavanal syncline. The sandstones form the low ridges surrounding Cavanal Mountain. The Savanna formation is present in all parts of the McAlester basin, to the north to Kansas, and to the west into central Oklahoma where it becomes conglomeratic. Knechtel (1949) reports that it is 140 to 960 feet thick in northern LeFlore County, increasing in thickness to the southeast. Oakes and Knechtel (1948) report that in Haskell County the Savanna is 450 to 1,400 feet thick in the south and 100 to 200 feet thick in the north. Hendricks (1937) gives a thickness of 1,120 to 1,325 feet in

the McAlester district and 1,140 to 1,610 feet in the Fort Smith district (Hendricks and Parks, 1950). In T. 6 N., R. 25 E., Hendricks (1939, p. 272) reports a thickness of 1,750 feet. All of these figures do not include the upper shale member recently transferred to the Savanna formation. On the northeast side of Cavanal Mountain the uppermost shale member is thought to be 800 feet thick. The writer obtained a thickness of 2,377 feet west of the place where Hendricks measured his section.

Character and Stratigraphic Relations

The Savanna formation consists of alternating sandstones (2) and shales (3) with one minable coal. Thicknesses of individual members of the formation can vary greatly over short distances. The sandstones are generally buff or gray-green, fine-grained, ripple-marked at contacts with superjacent shale, cross-bedded, and relatively free of argillaceous material. The shales are gray-green (locally dark gray), silty or sandy, and at places are compressed in concretionary concentric-breaking masses which seem to be the result of sliding before lithification on a slope covered with semi-indurated silt.

In T. 6 N., R. 24 E., the contact between the lowest sandstone and shale is indistinguishable, but the sandstone may have reached a thickness of about 300 feet estimated on the basis of topographic expression. The medial and uppermost sandstones are 125 to 175 feet thick respectively. The Cavanal coal lies in the lowest shale in the formation about 800 feet above the base of the formation. Near McAlester, the Cavanal coal lies 550 feet above the base of the formation. It is also found on Sugarloaf Mountain to the east and on the Hartford anticline. In the area the coal is about 2 feet 6 inches to 3 feet thick. It is not thought that either the Charleston or Paris coals of Arkansas is the equivalent of the Cavanal coal although a thin coal one-fourth mile east of the northwest corner of section 17, T. 7 N., R. 21 E., is at about the same stratigraphic position as the Paris coal. No other coal seam was observed in the Savanna formation of the area.

The variation in thickness of the members of the Savanna can be appreciated when one notices (see measured sections 2 and 5) that the uppermost sandstone increases in thickness from west to east from 53 feet to 173 feet in a map distance of only four miles.

In the same distance the uppermost shale of the Savanna also thins fifty feet in the same direction whereas the shale below the top sandstone thins from about 443 feet to 110 feet.

In general, the formation thins in all directions from the Cavanal syncline so that the area must be at a position where the McAlester basin is deepest. The most marked thinning is to the north. It appears that much of the thinning is due to the loss of sandstone beds either by convergence or gradation to shale with thinning of individual units. Wilson (1935) reports that the "Spiro" sandstone is the uppermost sandstone in the Muskogee district and that the Cavanal coal occurs in the shale above it—40 to 50 feet below the base of the Bluejacket. As has been seen in the area, there are at least two major sandstone zones above the Cavanal coal. Hendricks (1939) maps a third sandstone unit above the Cavanal coal, but this is absent in the area. Wilson and Newell (1937, p. 45) give evidence for overlap between the Spiro sandstone and the Bluejacket sandstone members. One hundred and sixty feet of the "lower Boggy" (now upper Savanna) is absent in T. 12 N., and is present in T. 10 N. Wilson and Newell think that the loss of beds is due to overlap caused by overfilling of the basin of deposition.

Regionally the Savanna rests with slight erosional unconformity on the McAlester formation. Hendricks and Parks (1950) report that the Savanna formation cuts down across the McAlester shale at an angle of one to two degrees. This contact is not exposed in the area. The upper boundary of the Savanna sandstone is exposed there and it is definitely gradational. Sandstones cannot be correlated due to pinch-outs and changes in map units. Correlations are not closely related to time in the McAlester basin as a rule. It is thought that the formational contacts cross time lines at low angles, a result of slowly transgressive marine conditions. Since the transgrassion occurred in a northwesterly direction, the more accurate time correlations will be made from comparisons of sections along a northeast-southwest line (or ENE-WSW line).

Boggy Formation

First reference: Taff, J. A., 1899

Nomenclator: Taff, J. A., 1899

Type locality: The type locality is thought to be outcrops in the valleys of Clear and Muddy Boggy Creeks in Pontotoc, Coal, and Pittsburg Counties.

Original description: Hendricks (1939) in his report on the Howe-Poteau district describes the Boggy formation as follows:

> Only the lower 1,200 feet of the Boggy shale is present in this district, although 4,000 feet of beds in the Boggy shale occur on Cavanal Mountain, just north of the district, in T. 7 N., R. 24 E., where the top of the formation is not present. .... The part of the formation present consists of dark shale in which are several sandstone beds and two beds of coal. ....

Distribution and Thickness

The Boggy formation is widespread but can not be continuously traced over much of eastern Oklahoma. The occurrences of the formation are limited to the capping of synclinal mountains as outliers of the more continuously traced units to the west. To the east, less than 100 feet of Boggy beds cap Poteau Mountain, 500 feet occur south of Charleston, Arkansas, and 900 feet have been found on Short and Horseshoe Mountains (Hendricks and Parks, 1937). To the north, the Boggy formation is about 300 feet thick (Wilson and Newell, 1937) and can be traced into Kansas. To the west, the Boggy beds extend to the Arbuckle Mountains and have been reported to be 1,700-1,900 feet thick in T. 6 N., Rs. 15 and 16 E., in the Quinton-Scipio district (Dane, Rothrock, and Williams, 1938), 2,000 feet thick in the Sans Bois syncline and 1,100 feet thick in T. 7 N., R. 19 E. (Oakes and Knechtel, 1948, p. 56), 1,250 to 1,500 feet thick in the northern part of T. 3 N., R. 11 E. (Knechtel, 1937, p. 107), and 2,850 feet thick in the McAlester district in southeastern T. 4 N., R. 13 E. (Hendricks, 1937, p. 24). Russell (1958) reports a thickness of 2,140 feet in the Sans Bois syncline in T. 7 N., Rs. 20 and 21 E.

In contrast with these observed thicknesses, 2,977 feet of the Boggy formation is measured and described in Cavanal Mountain, and this figure does not include the lowermost shale unit which has been included in the thickness figures quoted above (except Russell); nor does this figure represent the total thickness of the Boggy formation deposited originally in the syncline. It appears that the greatest sinking of the McAlester basin in Boggy time must have occurred along a line extending west or southwest from Cavanal Mountain through the Sans Bois syncline through T. 6 N., Rs. 15 and 16 E., to the thick section in southeastern T. 4 N., R. 13 E.

Character and Stratigraphic Relations

The Boggy formation consists of alternating units of fine- to medium-grained sandstone, siltstone, and silty shale with three coal beds and some ironstone layers in the shale. The sandstone is generally buff to gray-green. Some of the sandstone of the Bluejacket sandstone member is dark green. The sandstones are ripple-marked in places and cross-bedding and minor channeling have been observed in the Bluejacket in the western part of the area in a gorge near Pigeon Mountain. In the Potato Peaks area there are eight sandstone and seven shale units. Plant fragments are found as float and sand casts of *Calamites* and *Stigmaria* have been identified.

The formation rests conformably upon the Savanna formation in all places in the area. The contact is well exposed in section 19, T. 6 N., R. 24 E., section 23, T. 7 N., R. 23 E., and section 20, T. 6 N., R. 23 E. It has been reported that the Thurman formation rests conformably upon the Boggy formation in the McAlester district (Hendricks, 1937). In Stonewall Quadrangle to the west, Morgan (1924) reports an unconformity at the base of the Boggy formation as it was previously defined. This unconformity, however, is local and due to the uplift of the Arbuckle Mountains. To the north, Wilson and Newell (1937) report that 160 feet of the upper shale member of the Savanna formation is absent due to overlap between T. 10 N. and T. 12 N.

For purposes of more detailed discussion, the Boggy formation has been divided here into parts—the Bluejacket sandstone member, the strata above the Bluejacket, and the coals of the Boggy formation. The following discussion will deal primarily with the nature of these divisions in the area and a comparison of the measured sections with those of other areas so as to arrive at some tentative correlations of lithologic units. As has been stated above, the units of the Boggy cannot be traced directly out of the area. The variability in thickness and character of units over short map distances was demonstrated in the discussion on the Savanna formation. The same variability holds true for the Boggy formation so that the correlations can in no sense be interpreted as exact with respect to time of deposition of the whole unit. The writer found casts of ostracods in all the shale units on Cavanal Mountain and, although a study of these was impossible to include in this paper, it is felt that these microfossils will be the answer

for time correlation in the McAlester basin. The fact that these fossils are present in the area, the site of the most rapid deposition in the McAlester basin in Savanna and Boggy times, should indicate that they are present elsewhere where the deposition has been relatively slower (in fact the shales are relatively uniform in thickness, character and persistence over the basin as a whole). Other microfossils have been studied in the McAlester basin and may also be widespread (Galloway and Ryniker, 1930, and Alexander, 1954).

The Bluejacket Sandstone Member

The Bluejacket was named in an unpublished manuscript by D. W. Ohern from the hills west of the town of Bluejacket, Craig County, Oklahoma (cited by Gould, 1925, p. 64).

In the Cavanal area this unit consists of sandstone, shale, shaly sandstone, and sandy shale. In the east the sandstones are dark green, fine- to medium-grained and weather brown. In the west they are buff to gray-green. Owing to the variance in lithology and to poor exposure in the area the member was not mapped as two sandstone units with an intervening shale unit as has been done just north of the area by Knechtel (1949). It is felt that over most of the area the amount of shaly sandstone between the upper and lower sandstone units of Knechtel does not warrant separation into three units. Also, according to Oakes and Knechtel (1948, p. 60), only the uppermost massive sandstone unit is present north of about T. 8 N. in Haskell County and this change may be reflected in the area.

Near the Kansas-Oklahoma state line, the unit is 50 to 60 feet thick; however, the Bluejacket thickens to the south and has been mapped into central Oklahoma (in the subsurface). From the south side of Haskell County to T. 8 N. the Bluejacket is 100 to 150 feet thick and consists of two sandstone units and a shale unit. In the northeast part of the Cavanal area the Bluejacket consists of but one sandstone unit and is about 317 feet thick. In the southwestern part of the area the total Bluejacket section amounts to about 687 feet and probably consists of two sandstone units and an intervening shale; however, the exposures are so poor that the gradational sequence of sandstone, shaly sandstone, sandy shale, and shale could not be mapped as such. In contrast, from a measured section in the McAlester district (Hendricks, 1937, p. 25), it appears that only 12 feet of Bluejacket is present there.

The Bluejacket sandstone member of the surface has been correlated with the following subsurface units by Wilson (1935): the Bartlesville, Salt, and Glenn sands.

Strata Above the Bluejacket

The nature of the strata above the Bluejacket sandstone member has been discussed generally above. The more detailed features of these beds include a horizon of ironstones associated with brachiopod impressions and internal molds in a dark gray shale about 1,954 feet above the base of the formation in measured section number 1. Also the top sandstone unit contains joint fractures along which iron oxide is deposited heavily. Layers showing evidence of prelithification sliding of shale occur near the horizon of the dark gray shale mentioned above.

On Cavanal Mountain six sandstone units, one of which is lenticular, lie above the Bluejacket. Taff and Adams (1900) report a "noteworthy" sandstone about 400 feet below the western summit. They say it is 100 feet thick, is white and pink, and "resembles pure sandstone." It is reported that 400 feet of blue clay shale underlies this sandstone. It is not known exactly which sandstone bed they referred to, but by comparison with the measured section (number 1) it appears that the sandstone which lies 378 feet below the top of the section (bed number 12) fits the description except for the 400 feet of blue clay shale below it. That sandstone is different from all the others in the section in that it is light gray with no green in it at all. Taff and Adams consider it to be "definitely" marine.

By a comparison of measured sections with Hendricks' section in southeastern T. 4 N., R. 13 E., it can be seen that many beds of shale directly above the Bluejacket and below the Secor coal in the area are absent in the McAlester district. Also, between Hendricks unit number 24, which he describes as 95 feet thick, and as "shale, bluish green, non-fissile; breaks concentrically and contains many clay-ironstone concretions" and his unit number 7—"sandstone, massive and banded with limonite parallel to joints"—there occurs 750 feet of strata. There occur, in the Cavanal area, two such zones a comparable distance apart. The bottom zone includes the

top of bed number 21 (in measured section number 1), all of bed number 22, and the lower portion of bed number 23. The zone is about 70 to 100 feet thick and is composed of bluish black to green shale which is broken concentrically and has many clay-ironstone layers in it (this group of features is considered to represent an environment of deposition which may have been widespread enough to have persisted over the distance between the two sections). The concentric breakage in the two areas may be contemporaneous due to a slight increase in rate of subsidence. Another 900 to 950 feet above this zone there is a massive sandstone which has limonite deposited along the joints in much greater quantity than elsewhere in the section. It is the top bed on Cavanal Mountain. A correlation of two units such as these, the writer realizes, is extremely tenuous, but since the ironstone layer described is present all over the area (not just a local occurrence) at the same horizon and since the limonite is deposited so abundantly in the top bed of Cavanal Mountain (deposition here may be from a source of abundant iron which occurs nowhere below that bed), the correlation is made for lack of better evidence. The source needed to produce the amount of iron oxide present probably was above the bed and was made up of an oxidized layer of shale or sandstone such as the one reported by Hendricks in his unit number 4. It is also possible that the source of the iron oxide was present in neither area but that it contributed to the deposition in both areas simultaneously. The idea that the source of iron oxide was present above the rocks now left at Cavanal Mountain is strengthened by the fact that the amount of iron oxide increases upwards in the section. Such an oxidized layer may well have been widespread as oxidizing conditions do not normally coexist with reducing conditions in the same environment (the rest of the section is indicative of reducing conditions). If the iron is authigenic, derived from plant material deposited in the sandstone bed in question, the conditions which would produce and preserve the plant remains in a sandstone would also be widespread. Because this deposition of abundant iron oxide is confined to this particular bed in both areas and for the reasons stated above, it will be assumed here that the two beds are nearly equal in time of origin. This hypothesis will be used as the basis for estimation of the thickness of the strata which have been removed from Cavanal Mountain.

By comparing the ratio of thickness of beds above the Bluejacket in both areas and by applying this ratio to the absent beds of the formation, an approximation of the amount of strata which has been stripped off Cavanal Mountain can be made. A comparison of the two sections shows great similarity in thickness of shales and position of sandstones above the Bluejacket horizon; therefore it is assumed that the conditions in both areas were much alike with respect to relative rates of deposition. The two localities are also on the east-northeast-west-southwest line which marked the deepest part of the McAlester basin. In addition, it has been mentioned that because the advance of the sea was in this general direction and because the fold axes, which must have been developing during deposition, also lie in this direction, like strata at localities along a line in this direction would be most likely to be contemporaneous.

In the interval between the top of the Bluejacket and the limonite-banded sandstone in the McAlester district there lies 1,868 feet of strata. In the Cavanal area 2,663 feet of strata occupy that interval, with most of the thickening due to an increase in thickness of the sand units to the east. Six hundred and forty feet of strata lie above the limonitic sandstone in the McAlester district. Therefore it is estimated that the original thickness of absent Boggy strata on Cavanal Mountain must have been on the order of 900 feet, giving a total thickness of about 3,900 feet originally present and perhaps more where the Bluejacket is 400 feet thicker in the south part of the area. This estimate is also based somewhat on the position of the Secor coal in the first shale above the Bluejacket in both areas.

In projecting the units above the Bluejacket sandstone northward it appears that, on the basis of stratigraphic position and the assertion by Oakes and Knechtel (1949) that the upper part of the Bluejacket continues northward beyond T. 8 N. whereas the bottom does not, the Crekola sandstone member of Wilson (1935) and Wilson and Newell (1937) is equivalent to the first sandstone above the Secor coal. Both sandstones and shales thin to the north, as can easily be seen by comparison of thicknesses of the Bluejacket in both areas (317 to 50 feet in T. 15 N.)—the overlying shale thins from 293 to 24 feet in T. 15 N. The shale interval below the Secor

coal thins from 133 feet in T. 7 N. to zero feet north of T. 15 N. where the Secor coal lies directly upon the Bluejacket sandstone.

It has been emphasized before that correlations such as "the sandstone above the Bluejacket with the Crekola sandstone" are almost without basis in time. Since there is some sandstone reported in Wilson and Newell's unit B9, a shale underlying the Crekola may easily be the northward extension of IPb-1. The sandstone in B9 may be only a local sandstone bed. Such a problem would arise were the writer to try to correlate the Taft sandstone member (or Lower Red Fork of the subsurface) with a unit in the Cavanal sequence. However, for lack of better evidence, this is exactly what must be done. The Taft sandstone is probably equivalent to some phase of IPb-2b, the third sandstone unit above the Bluejacket, whereas the sandstone B9, separated by 125 feet of shale from the Crekola sandstone in T. 15 N., R. 17 E., is probably best correlated with some phase of IPb-2a. One fact in favor of these correlations is the thick development of sandstones IPb-1, IPb-2a, and IPb-2b in the Cavanal syncline area. These are the thickest and best developed sandstone units above the Bluejacket in the area and may have persisted widely. More about this correlation will be said later.

The Coals of the Boggy Formation

There are three coals in the Boggy formation in the Canaval area—the Lower Witteville, the Secor (Upper Witteville), and the Mayberry coals.

The Lower Witteville coal is about 4.8 feet thick and the outcrop of that coal is just below a thick massive sandstone unit in the uppermost part of the Bluejacket sandstone. The coal is separated by a variable number of shale partings. It is absent near Calhoun and at Short Mountain possibly because of an unconformity at that horizon (Knechtel, 1949, p. 50-51). A coal which occurs in sections 1 and 2, T. 6 N., R. 16 E., and section 27, T. 8 N., R. 17 E. (Dane, Rothrock, and Williams, 1938) may be the equivalent of the Lower Witteville coal in view of the fact that it occurs at about the right position below the Secor.

The Secor coal occurs 170 to 210 feet above the Lower Witteville and about 135 feet above the Bluejacket sandstone on the north and east sides of Cavanal Mountain. On the south side of the mountain the Secor is 370 feet above the Bluejacket. It is about 3 feet thick on the north and a little thicker (3.1 feet thick) in southern exposures. The coal was not seen in outcrops near Dr. Lowrey's ranch in section 2, T. 6 N., R. 23 E., but in coring done at the ranch in September, 1952, coal was noted about 20 feet below the surface in front of the ranch house. In one hole, the coal aggregated 4.5 feet and was divided into three benches by two "slate" partings of 1.3 feet and 0.75 feet in thickness. This coal is probably the Secor as it occurs in the shale above the Bluejacket sandstone. Sixty-five sections were cored in the vicinity and almost all showed coal.

The Secor coal has been found extensively in eastern and northeastern Oklahoma. Shannon and others (1926) have correlated the Secor coal with the Blocker, the Massey, and the Jones Creek coal of the McCurtain-Massey district. Shannon also notes the position of a coal (the Bluejacket coal) as just above the Bluejacket sandstone in Craig and Mayes Counties. The writer could find no mention of this coal unless Wilson and Newell (1937) refer to the same coal when they note a coal just above the Bluejacket in the Muskogee area. The writer assumes that the "Bluejacket" coal is the equivalent of the Secor.

The Mayberry coal received notice only in the very early articles written about the coal field. Chance (1890) is the first to locate the Mayberry coal clearly. Chance states that the Mayberry coal is 1,200 feet vertically below the summit of "Kavanaugh Mountain." Drake (1897) reports a coal 140 feet below the Mayberry coal. If this distance is taken vertically, then this description may fit the horizon of the Secor coal. Drake also reports a coal horizon just above the fourth thick sand of Cavanal Mountain. At this horizon (above IPb-2b) the writer found only dark gray shale and ironstone concretions. Taff and Adams (1900, p. 301) state that "The Upper Witteville is the coal which was called the Mayberry coal where it was formerly mined, north of Cavanal Mountain." However, Taff and Adams were in error in this correlation. The writer found the Mayberry coal 739 feet above the top of the Bluejacket or 1,048 feet above the base of the Boggy formation (about 1,200 feet vertically from the summit of the mountain) in section 10, T. 7 N., R. 25 E. It consists of two benches of coal; the lower 18 to 20 inches thick and the upper more than 30 inches thick, separated by about 6 feet of shale which has a light gray, perhaps slightly limy, layer near the top (but not at the top). When Taff and Adams (1900) described the Mayberry coal as located in section 11, T. 7 N., R. 24 E., and consisting of "lower bench, 22 inches; shale 1 to 2 inches, coal 12 to 14 inches, coal 16 inches" they were undoubtedly describing the Secor coal as it occurs near Calhoun.

In the area the Mayberry coal horizon occurs from about 600 feet above the Secor in the east and north to about 362 feet above the Secor in the southwest part of the area. It is possible that the coals described by Dane, Rothrock and Williams (1938) as 240 or 265 feet above the Secor coal in T. 7 N., R. 15 E., are correlatives of this coal. In that case their unit number 2 probably is equivalent to IPb-1 of the Cavanal syncline. This great lateral extension of the unit would support the correlation with the Crekola sandstone to the north. Because of the relative uniformity of the units the Taft sandstone would then be the equivalent of unit 4 of the Quinton-Scipio district and number IP-2b of the mapped area. The stratigraphic position of all three units is about the same.

In the north, in T. 15 N., R. 17 E., a coal is reported 7 feet above the Crekola sandstone. If the correlation of the first sandstone above the Bluejacket in the area with the Crekola sandstone is correct, the coal is probably the correlative of the Mayberry. The fact that the coal is present that far north may be used, in reverse, to support the correlation. The horizon of the Inola limestone would then be just above the Mayberry coal. In the Cavanal area a three- to four-inch layer of light, calcareous-appearing material was reported (measured section number 1) in the interval between the two coal beds of the Mayberry (for measured sections used for comparison see Wilson and Newell, 1937, p. 181-182). The light layer is not thought to be underclay.

Quaternary System

Gerty Sand (Pleistocene)

First reference: Taff, J. A., 1899

Nomenclator: Taff, J. A., 1899

Type locality: Town of Gerty in southern Hughes County, Oklahoma.

Original description: Taff's original description reads in part as follows:

> . . . an extensive deposit of gravel, sand and silt . . . These gravels and sands are not cemented into hard rocks; instead, they are incoherent deposits, and resemble recent river or lake sand plains . . .
>
> The material of the gravel is all foreign to this region. It is composed of brown quartzitic sand, conglomerate, and various shades of red, white, and black quartz, jasper, and chert. The gravel occurs at the base of the deposit, but is not everywhere present there.

In the Cavanal area the terrace gravels which lie approximately 50 feet above the present levels of the streams are tentatively correlated with the Gerty sand. The materials in the sands in the area seem to have been derived from rock exposed in the Cavanal syncline whereas those deposits farther west are made up of exotic materials.

The Pleistocene date was set primarily on evidence unearthed near Steedman, Oklahoma (Morgan, 1924)—the tusk of a mammoth.

Recent Alluvium

The beds of all the streams in the area are bottomed by alluvium. In the mountains this debris consists of gravel and boulders whereas at the sites where the streams emerge from the hills the streams deposit sand and silt. Many of the outcrops are covered by these deposits yet they serve to indicate the previous course of the larger rivers of the region.

STRUCTURE

General

The area includes only part of one syncline, but this feature is unique in at least two ways—in that the amount of sediment deposited in it is greater than that in any other portion of the Arkoma coal basin and in that it is cut by north-south faults. There is one large north-south fault in the east end of the Backbone anticline a few miles east of the Oklahoma-Arkansas state line which nearly parallels the faults in the area. It trends slightly west of north. The Cavanal syncline on the whole strikes east-northeast as do most of the other folds in that part of the basin; however, the strike roughly parallels the border of the Ouachita Mountain fold belt. Chance (1890, p. 660) noted that in most of the region near the area the anticlines strike about S 40° W whereas the synclines trend S 70-80° W. Since the anticlines are generally better developed than the synclines, a line perpendicular to their strike is probably near the direction the deforming forces took. Melton (1929) mentions a direction of N 40° W on the basis of the position of the joint systems of the Ouachitas.

Apart from the strike of their axes, other differences between anticlines and synclines have been noted. For example, the anticlines are described by Taff (1902) as steeper than the synclines. The fact that they are narrow and deep must have contributed toward their tendency to overturn to the north. This steepness of anticlines is probably due to the process in which the axes of the anticlines and synclines became delineated during early deposition of the coal basin sediments, which were, even in the beginning, slightly thicker in the troughs as a result of contemporaneous deposition and folding. The weight of the sediments in the trough would discourage the release of pressure by the initiation of new upfolds within the troughs; therefore, structural compensation would continue along most of the original fold axes. In addition to the evidence for contemporaneous deposition and deformation cited earlier concerning neighboring regions, two facts support the idea in the area—first, more sandstone is deposited in the Cavanal syncline at the two extremities of Cavanal Mountain than in the middle. This indicates that the present plunge of the axis of the syncline was developed by late Boggy time and formed a basin then (the plunge is toward the center of the mountain from the east and west ends). The second fact which supports this hypothesis is the progressive northward migration of the synclinal axis up the section.

Hendricks and Parks (1950) divide the structural features of the McAlester basin into two patterns. North of the Backbone anticline and fault the gentle folds are broken by many high-angle normal faults with the downthrown sides to the south as in the Boston Mountains. South of the Backbone anticline and fault, long, narrow, steep-sided anticlines are separated by broader synclines. These features are broken at a few places by reverse faults related to the Ouachita type deformation. The reason for the abrupt change in type of structure lies in either or both of two reasons—the greatest change in thickness of coal basin strata lies along that line as a result of the fact that the north margin of the basin lay near the position of the Backbone anticline during most of early Atoka time, and/or the large displacement of the Backbone fault served to relieve the pressures applied to the strata in the coal basin thereby reducing the forces which were transmitted northward.

The folds from south to north grade from asymmetrical anticlines and synclines with the north limb of the anticline steeper, to symmetrical anticlines and synclines, to anticlines which have the south limb steeper. It is believed that the compressive forces which deformed the coal basin rocks came from the south. The reason for the fact that the northern anticlines are steeper on the south side probably has to do with Newton's third law of mechanics—every action produces an equal but opposite (in direction) reaction. When the compressvie forces were exerted on the strata of the coal basin, they pushed those rocks northward against the Ozark area, which stood as a buttress and pushed back, so to speak, producing forces exerted southward.

The faulting of the Ozark region is in general genetically related to the uplift of that domal feature—the faults radiate from the center of the uplift. Farther away from the Ozark dome, however, certain general trends of structural features have been noticed and related to the structures on the flanks of or

close to the uplifted area. Arbenz (1955) divides Oklahoma structural features into three categories based on compass direction. Two of these apply here. His Ozark trend, which is defined for features which strike on points of the compass from east-northeast to north-south includes in part, (a) tension faulting of the Ozark region, (b) alignment of en echelon fault belts of the Central Oklahoma Platform, (c) the transverse disturbances in the fold patterns of the Ouachita Mountains and McAlester region, and (d) the northeast striking fault pattern of the Arbuckle-Criner Hills-Wichita system of orogenic disturbance. What Arbenz calls "Arbuckle strike" (west-northwest to east-west) includes the major faults and folds of the Arbuckle-Criner-Wichita system outlining the horst and graben block pattern of this tectonic unit and the subsurface faults of the Central Oklahoma Platform.

The writer marked the direction of plunge of the anticlines and synclines on the structure maps of Hendricks and Parks (1950), Knechtel (1949), and Oakes and Knechtel (1948). It was found that the sites where the direction of plunge of the anticlines and synclines changes to the opposite direction line up well. The lines marking these changes in direction of plunge bear roughly northwest to north-northwest and are from 2 to 10 miles apart. In general the distance between these lines increases to the northeast. For example, one of the longest lines runs from just west of the town of McCurtain in Haskell County (section 21, T. 8 N., R. 22 E.) across part of the Shropshire Valley anticline in section 25, T. 9 N., R. 21 E., across the Comco syncline in section 14, T. 9 N., R. 21 E., across the Garland fault about a mile west of the town of Garland, Haskell County, across the Stigler syncline at the northwest corner of section 15, T. 10 N., R. 21 E., and finally across the Mudlark fault and the Lone Star anticline.

The trend of these linear features relates them genetically to the major folds of the Arbuckle-Criner-Wichita system. It has been mentioned that Arbuckle rocks have been found below the strata of the coal basin (e.g., Simpson group, Middle Ordovician, at a depth of 6,119 feet) (Knechtel, 1949, p. 34). The fact that the lines increase in distance apart farther to the northeast may be taken as evidence of the direction from which the forces that formed the irregularities came. Also, if one were to take a sheet of rubber and push into it with his hand, the rubber would bend more at the point of contact than farther away. Therefore, the fact that the distance between any two lines normally increases to the northwest is also offered to support the writer's hypothesis—namely, that these lines are related in some way to the trends of the fold axes in the substratum and that these folds were formed at some time before the deposition of Atokan rocks, probably in the Main Wichita orogeny of Van der Gracht (1931) at the end of Morrowan time.

There seems to be no way of determining, at the surface, whether the substratal folds are upfolds or downfolds since the lines of change of plunge cross surface or near-surface anticlines and synclines alike, and at the points of crossing the strata plunge both toward and away from the sites where the axes of folds and lines of change in plunge direction cross. The writer arrived at these conclusions independently and later found a map (Taff and Adams, 1900, Plate XXXVI) where the same type of thing was done. Taff and Adams, however, mapped the intensity of the folds and did not note the fact that the places where the intensities were greatest line up. The writer believes that in this case the axes of anticlinal folds are related to the lines of greatest intensity since these are the places where the drag of the substratum on the McAlester basin beds, then being folded to the northwest and north, would be greatest.

Arbenz (1955) has stated that he believes that the Ouachita folding represents a typical compressive orogen with thick geosynclinal sediments that tend to eliminate or obscure any basement influence by disharmonic folding or decollement. The writer believes that once initiated, the upfolds and downfolds in the overlying coal basin rocks probably continued along the original axes due to some degree of competence of the rocks in the upfolds. If decollement of the basement rocks occurred later, the original folds would continue along the same axes due to the weight and competence of the sediments already deposited in the synclines and the Roman arch "keystone" effect of the semi-competent strata. Faulting and tension jointing might be expected at the position of the "keystone." It is true that the thick sediments would obscure the

position of the basement fold axes, however. For example, it was mentioned that as deposition proceeded in the mapped area the fold axis migrated northward. It follows, then, that the part of the line of change in direction of plunge which runs through the Cavanal syncline would probably be farthest from the axis of the original initiating fold of the basement. In the Cavanal area the deepest part of the syncline of Boggy time was probably manifested by the great amount of faulting in T. 7 N., R. 24 E. At any rate it shows the area of greatest intensity of deformation. If the lines of change in plunge were drawn on a structural map of the Boggy formation, one line would theoretically pass through the center of T. 7 N., R. 24 E. On the structure map on the Upper Hartshorne coal, however, the line should probably be drawn east of there. In areas where the Atoka formation is at the surface such lines drawn on a structure map of the Atoka will probably be close to the position of the substratal axes due to the fact that the drag caused by the substratum would be more effective because it is closer in time and space. The economic implications of these observations will be discussed under that topic.

Relationship Between Faults and Folds

The faults of the area, most of them trending slightly west of north, are not related to the effects of the basement directly but may have some indirect relationship to the Ozark trend. The faults and folds of the Cavanal area were probably formed at about the same time. There is no direct evidence for this in the area. In the north part of the Fort Smith district there is some evidence that the faults and folds formed within a single stage of deformation. Hendricks and Parks (1950, p. 87) report that the Game Hill anticline is terminated against a fault at its east end. The Massard Prairie anticline of that district is both interrupted in the center and terminated at its east end by faults. This would indicate that the faults formed before or during folding. Both anticlines lie on the upthrown sides of the faults; therefore, the vertical component of movement was in the same direction both on the anticline and on the fault which terminates it. This relationship indicates that at the junction of the anticline and fault the vertical component of movement produced by folding was transformed to vertical movement of the fault. Therefore, both features were formed in response to the same forces from the south and are probably contemporaneous in origin. Some other anticlines and faults have the same relationship.

There is indirect evidence in the Cavanal area concerning the fold-fault relationship in time of formation. The north-south fault which trends through sections 23, 14, and 11, T. 7 N., R. 24 E., shows evidence that the west side is upthrown in section 14. In section 11 the upthrown side is on the east. This may be an indication that faulting is contemporaneous with deposition. Evidence has been presented earlier that deposition was contemporaneous with folding. Miser (1943) presents evidence that the initiation of faulting may have occurred slightly earlier than the initiation of folding in the Caddo Gap area of Arkansas. The evidence cited from the area may be interpreted differently, however.

It is thought that most of the north-south faults in the southern part of the area are of rotational origin on the basis of the small amount of lateral displacement of rock units across the faults. Dips are markedly different on opposite sides of the faults. In the case of the large fault mentioned above, the change in upthrown and downthrown sides on the same side of the fault may indicate the rotational nature of the north-south faulting in the mapped area. The same relationship appears to manifest itself in the fault in sections 25 and 36, T. 7 N., R. 24 E. The faults to the west of it throw the blocks into what once were small horsts and garbens, at least on their south ends.

The overall picture of the forces acting on these strata includes a force from the south with drag acting in the opposite direction below. The reason for the rotation of the north-south fault blocks is due to this force acting after rupture along planes parallel to the direction of horizontal compression. The longitudinal or east-west faults in the area are probably the result of the effects of fracturing in the strata near the axis of the syncline in response to compression and may be related to the "keystone effect" in anticlines. The east-west fault in sections 28 and 29, T. 7 N., R. 24 E., is later than the north-south fault that truncates it on the west. The fault which runs through sections 30 and 32, T. 7 N., R. 24 E., coupled with the north-south fault east of it, from the boundaries of the upthrown

block between them. Shear stresses were brought to bear here. All of the faults in the area are likely to have high angle fault planes—the first fault mentioned above in this paragraph is probably a reverse fault whereas the two which bound the upthrown block are normal. No evidence can be presented to substantiate these statements, which are based on the overall structural picture.

Relationship of Joints to Folds and Faults

Two sets of joints, nearly perpendicular to each other, are present in the Cavanal syncline area. This fact alone has made some writers in the past believe that the cause of the jointing was torsional forces. As shown by Nevin (1953, p. 151) only one set of joints should form under such circumstances. The two joint sets present trend about N 13° W and N 85° E. The first set has by far the greatest number of representatives. Melton (1929) found the same to be true and showed that the joints radiate from the Ouachita Mountain fold belt trending almost due north at the Oklahoma-Arkansas state line while the average value is about N 37° W. The joints are nearly vertical with respect to the bedding planes.

The set which trends N 13° W is considered to be made up of compression or transverse joints formed perhaps because lateral movement was easier than shearing movement due to compression (horizontal). These joints are almost invariably closed except where iron oxide has been deposited and even there they are very tight. Transverse joints associated with compressive stresses are best developed if the confining pressures are not large enough to force the rock to fault along shear planes. This fact indicates that there must have been little overburden in the area at the time of jointing.

The joint set which trends N 85° E is most commonly open and is thought to be the result of tension acting in the same direction as compression. This set is mineralized in the Caddo Gap-De Queen area of Arkansas due to the fact that they were kept open by tension. The mode of formation of these longitudinal or tension joints was demonstrated in an experiment by Griggs (1936).

Griggs worked with limestone samples which were subjected to both confining and compressive pressure (vertical and horizontal). He found that if the experiments were halted by release of the compressive load, and then release of vertical pressure before compressional rupture, but after some solid flow had taken place, the specimen ruptured along planes perpendicular to the direction of the original compressive force. The analogy between the experiments and the forces acting in the Cavanal area is admittedly not perfect. The greatest divergence seems to be in the fact that if faulting, folding, and deposition (these joints may be a little older than some faulting as will be discussed later) went on more or less at the same time, no confining or vertical pressure can be postulated since not much sediment had been deposited by the time of faulting, folding or jointing. However, from the attitude of the north ends of the fault blocks of the north-south faults on the south side of the syncline and from what has been said of the "keystone" effect (that anticlines would continue to grow along the same axes and that synclines would continue to be depressed with further compression), there probably was a downward component of force acting on the strata, affecting the rocks in much the same way as would a downward force due to overburden. These longitudinal fractures, then, are caused by tension due to compression acting on the structure. The joints running east and west on the folds will be referred to as longitudinal or tensional. Those running in a general north-south direction will be referred to as transverse or compressional. Movement along these was at right angles to the strike of the fold axes.

In the map area it appears that the tension joints formed after the compressional ones. This statement is based on the assumption that the tension joints are related to the east-west faults in some way. The east-west faults formed after the north-south ones. The fact that such faulting has occurred in the area may give, at least locally, some explanation why the tension joint set is so poorly developed. This reasoning seems to be in error because Miser (1943) reports his belief that the tension joints formed first in the Caddo Gap area. The relationship of the joints to the faults and folds seems to be plain in that area since the mineralized tension joints are crushed and faulted but not folded. Engel (1952) also thinks the tension joints are the older of the two sets. He says that the transverse fractures were generally not mineralized because they

stayed tightly closed until the period of mineralization was almost over. Engel adds, however, that the faulted veins are not folded because of their orientation parallel to the direction of movement during folding (the writer assumes from these papers that all the sections studied are perpendicular to the line of strike of the fold axes). Apparently the only thing which can be stated with certainty is that some of the faults are younger than some of the mineralized veins in the Caddo Gap area.

Melton (1929) dated most of the jointing in the coal field as prior to most of the folding whereas he recognized the fact that the joints in the Ouachita area are later than the initial folding. Melton also stated that radiating joints cut strata as high as Mid-Permian age in the Central Plains. This leads to some statements on the dating of the Ouachita orogeny and the deformation of the area.

Time of Deformation

Knechtel (1949), in writing on northern LeFlore County, believed, from evidence present, that the Ouachita orogeny took place in late or post-Boggy time. Cheney and others (1945) gave evidence for placing the Pottsville-Allegheny boundary (which may be an indicator of major orogeny) at many different places in the section based on indicative features. For example, (1) beds from Hartshorne to early Boggy (now late Savanna) age overlap the Atoka, and (2) beds from Atoka through Senora age overlap the Morrow rocks. Evidence of breaks are both faunal and based on unconformity. Locally and even regionally there are many good breaks. For instance, were the writer to try to date the major pulsation of the Ouachita orogeny two factors point strongly to the conclusion that it occurred some time between Thurman and Senora time. The highest beds in the McAlester basin which were affected by the Ouachita-type folding are the Thurman and possibly part of the Stuart formations. Huffman (1958) reports that on the flanks of the Ozark uplift the oldest beds not affected by the Ouachita-type folding are in the basal Senora formation (Tiawah limestone). Farther west and south Senora beds are affected by the folding, however. Therefore the evidences of folding are not only related to the distance from the source of the compressive forces but also to the probability that all the folding was not done at one time.

The age of the joints varies from south to north, apparently, finally appearing in rocks as young as the Mid-Permian Garber sandstone (Melton, 1929). Probably the folds, which were dependent on the same forces, also vary in age from place to place. Taking into account the numerous local and regional breaks in the section between Atokan and Mid-Permian time (and, if the evidence of Cline [1956] and Cline and Moretti [1956] is considered, the range of orogeny may be further extended), it appears to the writer that the theory which fits the facts best, is the concept that encompasses the idea of a long extended period of epeirogeny with relatively minor pulsations occurring periodically (but not regularly). This may be the chief cause for the confusion concerning the dating of the Ouachita orogeny.

GEOLOGIC HISTORY

According to Wellman (1951), the inception of the McAlester basin came at the end of Devonian time; however, it was much later that appreciable amounts of sediment were deposited there. True geosynclinal sedimentation in the basin did not begin until the Atokan epoch. South of the McAlester basin the thick geosynclinal deposits of the Stanley-Jackfork-Johns Valley sequence were laid down in the Ouachita geosyncline during Late Mississippian time. The source area was to the south in a landmass or island arc stretching from Louisiana into Texas. Van der Gracht (1931) is of the opinion that the Ouachita flysch section includes all rocks from the base of the Stanley formation to the top of the Johns Valley formation, which is now considered to be Upper Mississippian. The molasse was considered by him to be the Stapp conglomerate and the later rocks up into the Permian period. In reference to the Ouachita Mountain and McAlester basin rocks, the term orogeny is probably meaningless except when referring to the major pulsation, as the writer has tried to demonstrate above. However, the terms "flysch" and "molasse" are useful as indices of the direction which the intensity and/or periodicity of pulsation

are taking. Just before the deposition of the Atoka series the writer believes that all the rocks underlying the coal basin were folded by forces acting from the southwest. Thrusting of the Ouachita facies rocks took place sometime after the deposition of Atoka rocks had begun. Rocks as young as the Garber sandstone of Mid-Permian age are affected in some way (jointing) by the results of the compressive forces caused by the thrusting.

Beginning in Atoka time and continuing through the Desmoinesian epoch the McAlester basin was geosynclinal. The hinge line between the basin proper and the shelf area to the north migrated northwest across the basin (Weirich, 1953). The axis of the geosyncline extended across central LeFlore County and through the present position of the Backbone anticline and stayed there during most of early Atokan time. At that time the shelf area was narrow and unstable, but in later Demoinesian time the shelf became broad and stable (Branson, 1955). From Atoka to Savanna time the Hunton arch acted to prevent the hinge line from crossing it. However, during the deposition of the rocks in the Cavanal area, the hinge line advanced to the crest of the arch owing to its quiescence and the advance of seas from the south and southeast. A minor overlap was noted by Wilson and Newell (1937) in the uppermost shale member of the Savanna formation on the Lawrence uplift.

During Hartshorne, McAlester, Savanna, and Boggy time the shelf area received deposits of sandstone made up of subangular quartz and angular feldspar. The presence of the feldspar and its grain shape indicate a nearby source—either the Ozark area, the craton to the northwest, or both. Since muscovite is also present in all the sediments of the basin and shelf alike, it is probable that the transporting power of the streams was low with few areas of high relief. Muscovite will rarely be deposited by streams with high transporting power owing to its shape and specific gravity. The fact that locally there was some relief is suggested by the channeling observed in the Bluejacket sandstone member in the map area.

It appears that the sandstones, at least from the evidence found in the area, were deposited under fluviatile conditions. Channeling, cross-bedding, and ripple-marking show that they were not deposited far from sea level when they were submerged. In the area proper the sandstones are free of argillaceous material. It seems strange that in an area where deposition must have been relatively rapid (compared to other parts of the basin where thinner sediments were deposited) the sandstones should be so "clean," whereas only a few miles to the west Russell (1958) reports that the sandstones are generally poorly sorted and argillaceous. At any rate, in the area the sandstones, originally deposited as graywackes and sub-graywackes according to Pettijohn (1957, p. 300), show good sorting as a result of the effects of winnowing and washing. They resemble orthoquartzites in their sorting; however, they are unlike the orthoquartzites in that the grains are not well rounded. This fact seems to point to the conclusion that they are close to their original source in terms of space and geomorphic cycles. If the grains came from a land area lying south of the present position of the Ouachita Mountains, the grains should be angular as most of them are. The few sub-rounded grains may show that part of the sand was derived from pre-existing strata such as those of the Jackfork and Stanley formations. Transportation from such a nearby source should not alter the shape of quartz grains much even though they become classified as second-cycle grains. Pettijohn states that such sandstones, called protoquartzites by Krynine (1941), are generally local, but gives the Hartshorne sandstone as an example. Casts of brackish-water plants have been found in the sandstones. Carbonized plant remains were found in some sandstones but mainly in associated iron oxide bands or layers. This may be a cause and effect relationship. Finally, the sandstones thin to the west and north showing a southeasterly source.

The shales in the area are silty, showing that they were not deposited far from land. The siltstones show bottom-markings which were made by storm instigated density currents. Such currents may be responsible for the amount of silt present in normal shales. The bottom of the sea was locally steep, perhaps as a result of local, recurrent folding, and this may have produced sliding evidenced by the concentric-breaking shale bodies found above and below a dark gray shale horizon. This sequence indicates a local sinking of the basin. Also, the shales are all marine in the area since ostracod casts have been found quite commonly in each. However, the appearance of coal horizons shows that marshy conditions were recurrent. Coals indicate conditions of poor or sluggish drainage just as does the presence of the muscovite in the sandstones. Finally, the shales thin to the north but not greatly to the west, showing the fan-like advance of the sea to the north.

The Cavanal area and most of the McAlester basin in Krebs time would have presented a general picture as follows: gentle to moderate folds separated local basins of deposition where, at times, the synclinal basins were partially or wholly under water with shale being deposited near the axes. Scouring rushes and other plants grew in abundance slightly above the water level while the crests of the anticlines which stood slightly above the water level also supported a profuse flora. Sluggish streams carried debris into the marshes and deeper water. However, all the water was shallow in an absolute sense, and the action of waves and currents carried silty and argillaceous material farther from the anticlines which may have appeared as islands at times. The climate must have been generally warm and humid, but the relief was so low that sheetwash and slow moving streams did a rather inefficient job of carrying the debris far from its source. Locally faulting and folding would produce minor relief, and channeling occurred. If the water level rose (with respect to the land) occasionally owing to a regional or local sinking of the basin, dark muds formed and sliding of semi-indurated material preceded and post-dated such a condition because of steeper slopes. Folding must have continued long after deposition of the Boggy formation had been accomplished. The amount of authigenic silica and well-developed strain shadows of the quartz crystals may be indicative of this fact. If the folding continued at least into Senora time and the joints and faults related to the epeirogeny or orogeny continued to form until a much later date, it would appear that the similarity to the Appalachian events is heightened.

Finally, as more areas became more positive (e.g., Ozark area), deltas were forming where the streams ran into the sea. Busch (1954) states that the Booch sand of the McAlester formation is deltaic to the north of the area. Because the Savanna and Boggy formations overlap the McAlester formation, the area must not have been marginal and the Boggy should not be deltaic. This should apply to any area on a line east-northeast or west-southwest of the area.

Finally, all the beds in the McAlester basin were uplifted relative to sea level and eroded twice—once in Cretaceous time and once in the Tertiary. The area has been tilted to the southeast most recently and the streams are cutting into the shales more vigorously (Taff, 1899).

ECONOMIC CONSIDERATIONS

Coal

There are four good coal beds in the area—the Cavanal, the Lower Witteville, the Secor, and the Mayberry. The only operation now being conducted in the area is the removal of coal from the Secor bed for minor domestic use. After the war with the switch to diesel locomotives and the removal of tracks leading to some of the mines on the north face of Cavanal Mountain, most of the operators had to close down. Truck haulage of the coal was not found to be economically feasible. Good summaries of the occurrances of the Secor, Cavanal, and Lower Witteville coal in neighboring areas are included in the reports of Knechtel (1949), Oakes and Knechtel (1948), and Hendricks (1939). The Mayberry coal of the area occurs too high up the mountain to be of any use under the present conditions.

Traces of gallium have been reported in some coals to the north, and it would seem that testing for this element might be worthwhile. The element is coming into widespread use in electronic equipment.

Natural Gas

Most of the gas wells are shut down in the Red Oak field and the gas field on the Brazil anticline. A few wells are still producing in the Poteau-Gilmore field west of Poteau. The field is owned and operated by the LeFlore County Gas and Electric Company and has produced over 35 billion cubic feet of gas, almost all of

which has come from the Hartshorne formation at depths of 1,300 to 1,800 feet. For a time some gas was produced from the Atoka formation. A few farms in the region are heated by gas from noncommercial wells.

Water

In the area there are many springs which issue forth where the contacts between overlying permeable and underlying impermeable strata have been exposed by erosion. Large municipal and industrial supplies, if needed in this area, can be found more readily available from surface streams. The water in the springs and streams generally contains only a small amount of dissolved solids.

Petroleum

The fact that no commercial reservoirs of oil have been found in the region probably is more closely connected with the absence of source beds of liquid hydrocarbons than to the degree of metamorphism of the sediments as indicated by fixed carbon ratios. Oil originated on the shelf to the northwest during the same time that the sorting or washing of the sands in the southern part of the McAlester basin resulted in the loss of any liquid hydrocarbons which might have been forming. The sandstones of the basin generally have poor permeability, but even if they were ideal for the accumulation and production of oil, no wide connecting avenues for the oil to follow from the shelf into the basin exist (Weirich, 1953, p. 2031). With respect to the carbon ratio theory, it seems reasonable that the depth of burial of the coals should have some effect on the amount of fixed carbon, especially since folding continued even after deposition of the highest coals, as in the Cavanal area. Yet the amount of fixed carbon in the coals decreases to the west where the older coals are present and where dynamic forces may have been more intense or have acted longer. McCoy (1921) stated that the loss of the lighter hydrocarbons may be the result of original sedimentation or of a process of drying and solidification before the sediments were deeply buried. The case for dynamic metamorphism as the cause of higher fixed carbon content in the coals is further weakened by the occurrence of heavy oil near the foot of the Arbuckle Mountains, a region which has been highly folded. Finally, it appears that the McAlester basin is one of the few places in the world where the carbon ratio theory appears to fit the facts.

The best locations for drilling for oil, in the writer's opinion, should be near or on the lines of change of direction of plunge of anticlines and synclines. Source and reservoir rocks are present below the McAlester basin facies, as demonstrated by the gas well in section 23, T. 9 N., R. 24 E. That well may have been drilled off-structure with respect to the substrata as it lies almost exactly in the middle between two lines of change of direction of plunge. The top of pre-Atoka rocks is probably more than 13,000 feet below the base of Cavanal Mountain. It should be remembered, however, that oil has not been found in rocks where its presence was indicated by much stronger evidence than that which presents itself in this case.

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APPENDIX

MEASURED STRATIGRAPHIC SECTIONS IN THE CAVANAL SYNCLINE

I. Secs. 4, 9, 14, 15, 16, 20, and 21, T. 7 N., R. 25 E. Measured on road from position 50 yards west of stream in SW¼ Sec. 14, T. 7 N., R. 25 E. to top of Cavanal Mountain in NE¼ Sec. 20, T. 7 N., R. 25 E. Computed and compiled from elevations determined by barometer, dips measured by Brunton, hand level data, and horizontal angles and distances measured on aerial photographs.

Boggy formation	**Feet**
Unnamed sandstone member (IPb-5)	
1. Sandstone: light-gray, fine- to medium-grained; light-orange to red iron oxide streaks on fracture surfaces	25.8
2. Covered: probably shale	17.1
3. Covered: probably sandstone	26.0
4. Sandstone: green, fine-grained, fine- to medium-bedded; joint surfaces rusty	25.7
5. Covered: probably sandstone on basis of topography and weathered material	17.1
Unnamed shale member	
6. Covered: probably silty shale	43.0
Unnamed sandstone member (IPb-4)	
7. Covered	38.7
8. Sandstone: green-gray, medium-bedded	4.3
9. Covered	17.2
10. Covered: probably sandstone	17.1
11. Sandstone: gray, rusty, fine- to medium-grained, thick-bedded; weathers red; iron oxide in joints	85.9
12. Sandstone: gray, fine- to medium-grained; weathers light-gray to off-white; laminated with oxidation streaks; contains disseminated carbonaceous material	25.8
13. Covered: probably sandstone	34.4
14. Sandstone: gray, fine- to medium-grained; weathers light-gray to off-white; laminated with oxidation streaks; contains disseminated carbonaceous material	8.6
Unnamed shale member	
15. Shale: green, silty; weathers rusty to gray	33.0
16. Sandstone: green, silty, fine-grained, thin-bedded; weathers rusty; contains carbonaceous material	34.4
17. Shale: green, silty; weathers rusty to gray	77.3
18. Sandstone: green; weathers bluish to rusty	6.4
19. Shale: green, silty; weathers red to reddish brown	28.0
Unnamed sandstone member (IPb-3b)	
20. Sandstone: light gray-green, fine- to medium-grained; weathers gray and rusty-brown; contains **Stigmaria**	17.5
Unnamed shale member	
21. Shale: green; breaks in concentric masses; carbonaceous material along planes of breakage; zone of ironstone concretions 3.4 feet thick 267 feet above base of unit	361.2
22. Shale: dark-green to bluish-black, non-fissile; ironstone layers with brachiopod impressions	19.2
23. Shale: green; breaks into concentric masses; carbonaceous material along planes of breakage	17.5
Unnamed sandstone unit (IPb-3a)	
24. Sandstone: green-gray, fine grained, silty; breaks into concentric masses	37.9

25. Shale: light green; weathers green, gray, and red; heavily fractured and folded	52.8
26. Sandstone: green, thin-bedded; stained with rust and carbonaceous material along bedding planes	8.9
Unnamed shale member	
27. Shale: light green; weathers red and light gray-green	174.6
28. Covered: probably shale	13.9
Unnamed sandstone unit (IP-2b)	
29. Siltstone: green; weathers buff	13.7
30. Siltstone: green; weathers light gray-green and pink	32.5
31. Shale: green, silty; friable; weathers ash gray, pale green, and rusty	44.5
32. Siltstone: green, well-indurated, jointed	3.8
33. Shale: silty; friable; weathers ash gray, pale green to rusty	26.7
34. Siltstone: green; well-indurated; jointed	12.2
35. Shale: silty; friable; weathers ash gray and pale green	22.9
36. Sandstone: green-gray, fine-grained, silty	13.0
37. Shale:	16.8
38. Sandstone: green-gray, fine-grained, silty; weathers rusty to light brown	13.7
39. Shale: green, silty; weathers rusty	27.2
40. Shale: green; weathers rusty and pale gray; becomes silty and sandy in top 2 to 3 feet	34.0
41. Sandstone: green-gray, fine- to medium-grained, thin- to medium-bedded; jointed markedly	21.3
Unnamed shale member	
42. Shale: similar to that below; does not weather into extremely red soil; friable; upper 26 feet dark gray	190.2
Unnamed sandstone member (IPb-2a)	
43. Sandstone: light-gray, fine- to medium-grained; weathers gray and rusty; iron oxide cement along bedding planes and joints; upper 5 feet is green	52.0
44. Sandstone. sandy shale, shaly sandstone, and shale; transition zone; same description as above and below	39.0
Unnamed shale member	
45. Shale: light gray-green; friable; weathers to very pale grayish green and to red	32.5
46. Coal: Mayberry	2.5
47. Shale: contains light gray calcareous (?) layer 3 to 4 inches thick near tip	6.2
48. Coal: Mayberry	1.5
49. Shale:	29.3
50. Shale: light gray-green, silty; friable; weathers pale gray-green and red	9.8
51. Covered: probably shale	9.8
52. Shale: light gray-green	182.0
53. Covered: probably shale	39.0
54. Shale: dark gray-green; friable; weathers red to ash gray	26.0
Unnamed sandstone member (IPb-1)	
55. Covered: sandstone	12.8
56. Covered: shale	13.1
57. Covered: sandstone	33.0
58. Covered: shale	13.2
59. Covered: sandstone	12.5
60. Covered: shale	26.0
61. Covered: sandstone	32.5
Unnamed shale member	
62. Shale: green, silty; friable; weathers rusty	182.2
63. Sandstone: gray-green, medium-grained; weathers rusty; where leached it is streaked with bands of oxidized material	27.4

64. Shale: green, silty; weathers rusty ... 26.4
65. Sandstone: green, fine- to medium-grained; contains some clayey material ... 7.0
66. Shale: light gray, silty; fissile; banded with limonite streaks ... 49.1

Bluejacket sandstone member (IPbb)

67. Sandstone: green, fine-grained; weathers orange; contains carbonaceous material ... 125.8
68. Shale: green, clayey with silty layers; contains carbonaceous material along bedding planes ... 67.1
69. Sandstone: dark-green, fine-grained, thick and thin bedding; well-indurated; weathers brown and gray ... 73.1
70. Shale: green, silty; gradational contacts above and below ... 16.7
71. Sandstone: dark-green, fine- to medium-grained; well-indurated; weathers dark brown to black ... 33.6

Savanna formation

Unnamed shale member

72. Shale: dark gray, silty and sandy; well-indurated; weathers dark brown ... 8.4
    (This shale member extends well below the base of this measured section)

Total section measured ... 2,985.3

II. Secs. 16, 21, 28, T. 6 N., R. 23 E. Base of Section in SW corner Sec. 28, T. 6 N., R. 23 E. At base of first sandstone member north of Oklahoma State Highway 270, at fork in road. Top of section in NW¼ SW¼ section 16, T. 6 N., R. 23 E. computed and compiled from elevations determined by barometer, dips measured by Brunton, hand level data, and horizontal angles and distances measured on aerial photographs.

Boggy formation — **Feet**

Bluejacket sandstone member (IPbb)

1. Sandstone: green-gray, medium-grained; weathers brown ... 69.3
2. Covered: probably sandstone and shaly sandstone ... 256.2
3. Sandstone: green, fine-grained; carbonaceous ... 100.8
4. Covered ... 22.7
5. Sandstone and sandy shale: green, some sandstone is medium-grained ... 22.7
6. Covered: probably shaly sandstone and sandy shale ... 21.6
7. Shaly sandstone ... 86.4
8. Sandy shale ... 17.3
9. Sandstone: pale green, fine- to medium-grained, thin-bedded to massive; weathers brown, black, and gray ... 15.7
10. Sandstone: same as above and below; shaly ... 95.0
11. Sandstone: pale green, fine- to medium-grained, thin-bedded to massive; weathers brown, gray, and black ... 43.2
12. Sandstone: brownish green, silty and shaly ... 45.0

Savanna formation

Unnamed shale member

13. Shale and sandy shale ... 110.5
14. Shale: green; locally crushed; carbonaceous; contains few sandstone or siltstone layers 2 to 3 inches thick ... 112.2
15. Shale: green; carbonaceous; locally crushed ... 54.6
16. Shale: green, silty; weathers ash gray and pale green ... 55.1
17. Shale: green, silty; with thin-bedded siltstone ... 165.2
18. Shale: green; weathered ... 112.3

Unnamed sandstone member

19. Sandstone: green-gray, fine-grained; jointed markedly; weathers rusty brown ... 52.4

Unnamed shale member

20. Covered ... 63.6
21. Shale: greenish brown, silty to sandy ... 115.6
22. Shale: dark-gray to bluish black; contains ironstone layers ... 144.5
23. Shale: green, carbonaceous; silty at top ... 57.8
24. Covered ... 57.8

Unnamed sandstone member

25. Sandstone: green, fine-grained; well-indurated; carbonaceous; interbedded with green sandy shale and shaly sandstone ... 379.6
26. Shale: green, sandy; weathers red ... 159.8
27. Sandstone: green-gray, fine- to medium-grained, medium-bedded; weathers tan to rusty brown ... 72.5

Unnamed shale member

28. Covered; probably shale ... 398.5

Unnamed sandstone member

29. Sandstone: green-gray-buff, fine- to medium-grained, medium-bedded; weathers tan to rusty brown; some sandy shale and shaly sandstone ... 305.0

Total section measured ... 3,212.9

III. Secs. 4 and 9, T. 6 N., R. 23 E. Base of section on stream near upper contact of dark shale with basal Bluejacket sandstone member in NC Sec. 4, T. 6 N., R. 23 E. Top of measured section in NE Sec. 9, T. 6 N., R. 23 E. Computed and compiled from Brunton traverse up stream gorge. Top of section is not top of Bluejacket sandstone member as mapped.

Boggy formation — **Feet**

Bluejacket sandstone member (IPbb)

1. Sandstone: weathers gray, red, rusty, and tan; carbonaceous ... 10.6
2. Covered ... 15.9
3. Sandstone: weathers gray, red, rusty brown and tan; carbonaceous ... 5.3
4. Sandstone: green, fine-grained; weathers gray and brown; contains bands of blue-black and green silty shale 1 inch to 3 feet thick ... 100.6
5. Shaly sandstone: green ... 3.0
6. Covered: probably sandstone ... 2.7
7. Sandstone: green; weathers blue-gray and rusty brown; thin-bedded to massive ... 57.3
8. Covered ... 37.3
9. Sandstone: green-gray, medium-grained, medium-bedded; weathers light gray to brown ... 5.3

Savanna formation

Unnamed shale member

10. Shale: green-gray, partially black and carbonaceous; crushed locally; silty ... 14.5

Total section measured ... 252.5

IV. Secs. 23, 26, and 35, T. 7 N., R. 23 E. Base of measured section on road in center Sec. 23, T. 7 N., R. 23 E. east of pond. Top of section at top of Bluejacket sandstone member as mapped in center Sec. 35, T. 7 N., R. 23 E. Compiled and computed by Brunton traverse.

Boggy formation	**Feet**
Bluejacket sandstone member	
1. Sandstone: green, fine-grained, thin- to medium-bedded; weathers rusty, maroon, buff; carbonaceous; bottom-markings; some shaly sandstone	16.2
2. Sandstone and shale: sandstone is green-gray and shale is blue-gray and sandy, unit weathers tan, rusty and maroon	59.4
3. Sandstone: green, fine-grained, thin- to medium-bedded; weathers rusty, maroon, buff; carbonaceous; bottom-markings; inter-bedded with shaly sandstone and sandy shale	50.4
4. Shale: silty; weathers gray to off-white	10.0
5. Sandstone: same as above	106.5
Savanna formation	
Unnamed shale member	
6. Shale: green and dark gray, sandy and silty especially near top; interbedded with medium-grained, carbonaceous, ferruginous sandstone which weathers red and light gray	194.0
Total section measured	436.5

V. Secs. 19 and 30, T. 6 N., R. 24 E. and Secs. 1, 12, 13, T. 6 N., R. 23 E. Base of measured section at curve in road in WC Sec. 30, T. 6 N., R. 24 E. Top of measured section on road in SC Sec. 1, T. 6 N., R. 23 E. Compiled and computed by Brunton traverse.

Boggy formation	**Feet**
Unnamed shale member	
1. Covered	5.3
2. Shale: green, sandy	65.6
3. Shale: green, gray, black; carbonaceous; contains some ironstones	5.3
4. Shale: green, sandy; weathers gray	26.5
Unnamed sandstone member (IPb--)	
5. Sandstone: green-gray, medium-grained	10.7
6. Shale: dark-gray; contains ironstone concretions	8.9
7. Covered	12.6
8. Shaly sandstone and sandstone: carbonaceous	19.5
Unnamed shale member	
9. Covered: probably gray-green shale and sandstone	99.2
10. Shale: green, silty	7.5
11. Coal: Secor	3.1
12. Shale: gray-green, silty; carbonaceous	49.5
13. Sandstone: green-gray, fine- to medium-grained; weathers maroon	20.9
14. Covered: probably green shale	297.5

	Feet
Bluejacket sandstone member (IPbb)	
15. Shaly sandstone: green-gray; weathers rusty	74.4
16. Covered	49.0
17. Shaly sandstone: green-gray	47.0
18. Covered: probably shaly sandstone	122.4
19. Sandstone and shaly sandstone: gray-green; weathers rusty	297.9
20. Shale, sandy shale, shaly sandstone, and sandstone: shows minor flowage and failure features	95.8
Savanna formation	
Unnamed shale member	
21. Shale: gray-green, silty; possibly a sandstone lentil about 10 feet thick 406 feet above the base of the member	648.5
Unnamed sandstone member	
22. Sandstone: brown to buff, fine- to medium-grained	172.6
Unnamed shale member	
23. Covered: probably green shale	109.8
Unnamed sandstone member	
24. Sandstone: brown to buff, fine- to medium-grained	125.5
Unnamed shale member	
25. Covered: shale	156.9
Total section measured	2,531.9

INDEX

(Main references are in boldface)

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