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Cover Picture

Skylab View of Arbuckle Mountains

The cover photograph shows the major structures of the Arbuckle Mountains, and part of the Ardmore basin to the south, in south-central Oklahoma. The white line that runs to the left of center from north (top) to south is Interstate Highway 35, which cuts across the Arbuckle anticline (providing an outstanding panorama of geologic features along the road cuts). Just above the center of the photograph, the folds of the Dougherty anticline can be seen. To the right of center the irregular outline of the Tishomingo anticline can be discerned; this anticline is cut by the Reagan fault on the north flank and is crossed by the Washita Valley fault zone along the south flank.

The photograph was taken by the Skylab-4 crew on January 30, 1974, at 10:53 a.m., CST, as part of the Earth Resources Experiment Package (EREP). The nominal altitude of the spacecraft was 435 kilometers. The camera system employed a multispectral photographic camera consisting of six high-precision cameras with matched optical systems, mounted and boresighted together. Each had an *f*/2.8 lens with a focal length of 152 millimeters. Various combinations of film types and filters were used. The cover photograph was taken by camera five, using Panatomic-X black and white film with a filter that let only red light through (wavelength region of 0.6 to 0.7 micrometer). This film and filter combination provided the best ground resolution (approximately 30 meters) of the six combinations used on this mission.

The photograph can be ordered from the EROS (Earth Resources Observation Systems) Data Center, Sioux Falls, South Dakota, using the mission identification number (SL4), roll (A5), and frame (195). The price per photograph depends on the size and form.

—*P. Jan Cannon*

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Short articles on aspects of Oklahoma geology are welcome from contributors. A set of guidelines will be forwarded on request.

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Geologic Interpretation of Viersen and Cochran's 25-1 Weyerhaeuser Well, McCurtain County, Oklahoma

August Goldstein, Jr.[1]

Abstract—Viersen and Cochran's 25-1 Weyerhaeuser well was drilled in the core area of the Ouachita Mountains in McCurtain County, Oklahoma, in the Broken Bow-Benton uplift. The well penetrated a sequence of 10,019 feet of low-grade metasedimentary rocks belonging to the greenschist facies. These rocks were originally carbonaceous shale, quartzose sandstone, and impure limestone. They appear to have been dynamically metamorphosed under considerable shearing stress at relatively low temperatures. The carbonaceous shales were metamorphosed into graphitic clay-slate, slate, phyllite, and schist. The sandstones were metamorphosed into metasandstones and metaquartzites. The limestones were metamorphosed into graphitic calcite marble and dolomite marble, locally quartzose. All of the rocks contain abundant veinlets and more massive intrusions of quartz and calcite.

Age determinations on micas from the 25-1 Weyerhaeuser well and from nearby outcrops of Ordovician age give ages ranging from Devonian to Early Permian, strongly suggesting that the geologic clock has been reset since the strata were deposited. Presumably the ages obtained represent the time of metamorphism of these samples.

All of the lithologies found in the well are similar to those found in the Collier and Crystal Mountain formations as recognized by Honess and Pitt in the Broken Bow-Benton uplift, and it is possible that there are both steep dips and repetition of beds in this well. However, it seems probable that at least some of the metasedimentary rocks penetrated are older than the oldest rocks cropping out in this area, but they resemble closely the Collier and Crystal Mountain formations exposed at the surface.

Although the 25-1 Weyerhaeuser well did produce some gas, production is from a fracture and is not commercial. The rocks penetrated in this well are more or less completely recrystallized, and there is very little interstitial porosity. There seems to be little reason to expect to find commercial accumulations of oil or gas in the core area of the Ouachita Mountains in McCurtain County, Oklahoma, or anywhere in thelower Paleozoic strata of the entire Broken Bow-Benton uplift.

INTRODUCTION

Viersen and Cochran's 25-1 Weyerhaeuser well, 720 feet east and 266 feet south of the center of the northwest quarter of sec. 25, T. 5 S., R. 23 E., McCurtain County, Oklahoma, is one of the most interesting and geologically significant wells ever drilled in southeastern Oklahoma. The well is located in the so-called core area of the Ouachita Mountains, described by Pitt (1955). According to the mapping of Honess (1923, pl. 1), the well was spudded in the Blakely Sandstone of Ordovician age. Pitt (1955, p. 23-24) discusses the outcrop in which the well was spudded and concludes that the

[1]General manager, Lubell Oil Company, Tulsa, Oklahoma.

sandstone is "Lukfata"[2] and certainly not correlative with the "type Blakely" in Arkansas. Figure 1 shows the well superimposed on the mapping of Honess and Pitt. Table 1 gives the stratigraphic sequence of the core area, as recognized by Honess and Pitt.

Sediments exposed below the Blakely in the core area of the Ouachita Mountains range in thickness from a maximum of about 1,700 feet (Honess) to about 1,030 feet (Pitt). The 25-1 Weyerhaeuser well was drilled to a total depth of 10,019 feet, so that by far the greater part of its drilling was in rocks that presumably are older than any outcropping in the Ouachita Mountains.

The well spudded on June 6, 1970, reached total depth on July 26, 1970, and was completed as a shut-in gas well on September 8, 1970. According to Petroleum Information's scout ticket, the well is capable of producing gas from a fracture of 6,990-91 feet. The gauge (open flow) of the well was not determined. The maximum shut-in pressure recorded was 62 pounds. The heating value of the gas is low; it ranges from 412 to 616 Btu per cubic foot in analyses by Oilab, Inc., and from 570 to 574 Btu per cubic foot in determinations by the U.S. Bureau of Mines. The gas is about 53.4 percent methane, about 40 percent nitrogen, and about 3.5 percent carbon dioxide. During drilling, a flow of fresh water at a rate of approximately 200 barrels per hour was encountered at a depth of about 1,220 feet.

The Oklahoma Geological Survey loaned me the thin sections for this study. I am grateful to them for this opportunity. Dr. R. E. Denison suggested that the writer study this well and generously made available to him all of his petrographic work and an advance copy of an unpublished manuscript discussing this well. He also took all of the photomicrographs of thin sections. Dr. T. L. Rowland[3] studied thin sections of cuttings and cores from this well for the Oklahoma Geological Survey, and he generously furnished copies of all his petrographic descriptions. It is doubtful that this project would have been finished without the assistance and encouragement of Dr. Denison and Dr. Rowland. Dr. Denison criticized the manuscript and made numerous valuable suggestions.

The writer wishes to thank Sam K. Viersen, Jr., and Doyle Burke for furnishing information on the well and for allowing me to publish the results of these studies. Before the well was even spudded, Mr. Viersen looked upon it as a basis for geological knowledge and as his contribution to drilling history. Viewed in that light, it is a tremendous success, as generations of geologists working in the Ouachita Mountains will study and restudy this well.

[2]Pitt's "Lukfata sandstone," below the Collier Shale, may or may not be a valid formation. Some of the outcrops mapped as Lukfata appear to be overturned Crystal Mountain Sandstone (written communication to R. E. Denison, consulting geologist, Dallas, Texas, from C. G. Stone, Arkansas Geological Commission, Little Rock, Arkansas). Other mapped "Lukfata sandstone" appears to be older than Collier.

[3]Present affiliation: Michigan Wisconsin Pipe Line Company, Oklahoma City, Oklahoma.

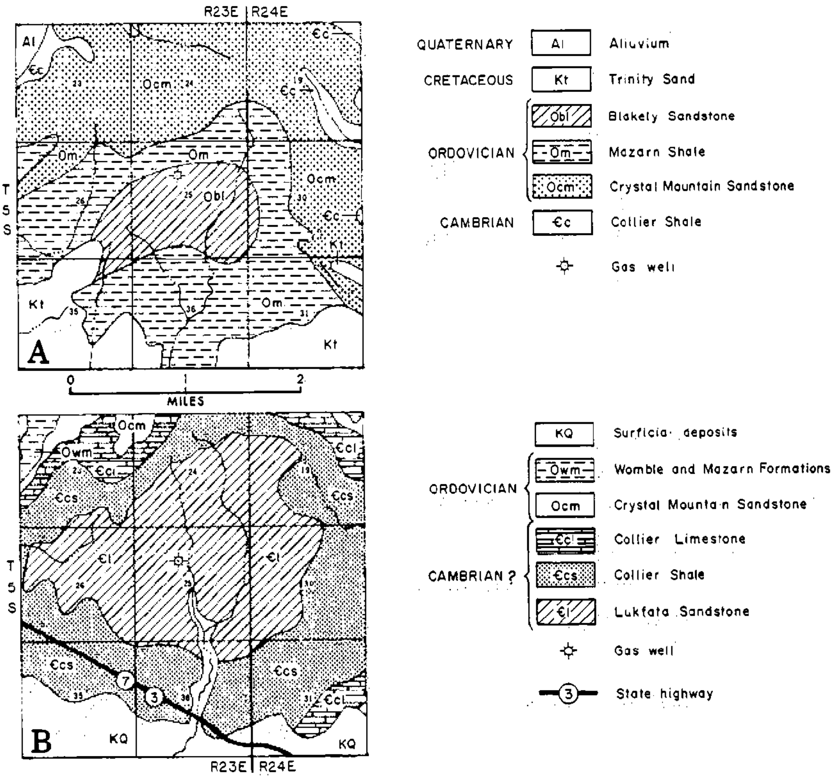

Figure 1. Location of Viersen and Cochran 25-1 Weyerhaeuser (shut-in gas well) in McCurtain County, Oklahoma, superimposed on areal geologic mapping: *A*, after Honess (1923, pl. 1); *B*, after Pitt (1955, pl. 1).

SAMPLE STUDY

The single most important factor in binocular-microscopic examination of well cuttings is determining which cuttings are in place and which are caving from above. This difficulty is compounded in a rank wildcat well and is triply compounded where the rocks being penetrated do not crop out anywhere. Nevertheless, with sufficient background derived from study of wells of the Ouachita facies, it is possible to construct a sample log of considerable usefulness, if not exactness.

Denison and others (in preparation) studied the Weyerhaeuser well and discussed its lithology and petrography. Denison divided the rocks into four groupings on the basis of bulk composition:

Unit A	0-1,800 feet	Graphitic marbles with sandy and slaty-phyllitic intervals.

Unit B	1,800-6,900 feet	Mostly calcareous slate-phyllite and calcareous quartz-albite-mica schists.
Unit C	6,900-8,800 feet	Mostly rutiliferous, graphitic phyllites and fine schists.
Unit D	8,800-10,019 feet	Mostly quartzo-feldspathic schists with graphitic phyllite intervals.

Denison and others discuss the possibility that the well was drilled on a large recumbent fold and penetrated a reversed stratigraphic sequence. He concludes that this is not likely and that the rocks are older with increasing depth. The increased feldspar content of his Unit D suggests that it was derived from a nearby granitic source, possibly as a basal transgressive sandstone.

If Honess (1923) were correct in his mapping and the well was spudded in Blakely Sandstone, one would expect to encounter below the surface pipe from 600 to 1,000 feet of Mazarn Shale, followed by a possible maximum of 500 feet of Crystal Mountain Sandstone, and then 200 to 300 feet of Collier shale and limestone. The samples do not support this. Pitt (1955) mapped this outcrop as Lukfata Sandstone; his mapping appears to be more nearly correct, although some of the rocks he mapped as Lukfata may be overturned Crystal Mountain Sandstone (Denison and others, in preparation).

The first sample examined is at 40 feet; it is in rocks described megascopically as metashale, metaquartzite, and phyllite. The rocks contain abundant quartz veinlets. Locally, there are calcite veinlets and massive calcite in the matrix of the metasediments. From 40 feet to 720 feet the cuttings contain as much metaquartzite as metashale. This is not at all typical of the Mazarn formation exposed at the surface in the core area, as it consists of dark fissile "shale" with local laminae of sandstone and limestone (Pitt, 1955, p. 23). Tentatively, these samples from 40 to 720 feet are referred to the Crystal Mountain Sandstone.

From 720 feet to about 1,000 feet the predominant lithology is dark-gray to black metashale and clay-slate, quite fissile, locally with microphyllitic bedding. There is some interbedded metaquartzite, and some of the metashale and clay-slate is calcareous. Quartz and calcite veinlets, and more massive inclusions of quartz and calcite, are ubiquitous.

From 1,000 feet to about 2,500 feet the predominant lithologies are dark-gray to black, highly impure, graphitic calcite marble and black metashale and clay-slate. There are some beds of dolomite marble, and there is a zone from 1,320 feet to about 1,500 feet which contains considerable quartz. Brown micaceous minerals can be noted along partings, and brown mica is locally abundant. There are numerous veins and veinlets of white calcite. The scout ticket of Petroleum Information calls the rocks from 1,200 to 3,370 feet the Viersen dolomite, but there is far more calcite marble than dolomite marble, and metashale and clay-slate are as abundant as marble.

From 2,500 feet to about 3,150 feet the rocks are largely metashale, clay-slate, and metaquartzite. There is very little calcareous material in this zone. A wavy, corrugated texture similar to phyllite, but less coarse, is locally conspicuous in the metamorphosed argillaceous rocks. Quartz veinlets and massive white "bull" quartz are common; there is a little white vein calcite, pyrite, and chalcopyrite(?).

From 3,150 to 3,360 feet there are some interbedded calcite marbles, although the principal lithology continues to be black metashale and clay-slate.

At about 3,360 feet there is a conspicuous break that was recognized by the Viersen and Cochran staff and named the Robinson black shale. It is relatively pure, black, glossy, fissile metashale and clay-slate containing quartz and calcite-vein material but very little marble or metaquartzite. The rock was probably a relatively clean carbonaceous clay shale before metamorphism. In samples, the base of the clean metashale and clay-slate is at about 4,020 feet, where there are some thin marbles, and there is metaquartzite at about 4,120 feet.

From 4,120 feet to 7,000 feet the rocks are mostly black metashale and clay-slate with interbedded metaquartzite. Most of the metaquartzite beds appear to be thin, but there are some massive beds. Loose quartz- and calcite-vein material is abundant. Copper mineralization occurs in a few places. Green chlorite(?) occurs locally in vein quartz, and there is some unidentified talcose material. At a few places (as, for example 6,500-6,610 feet), the samples are ground too fine for binocular-microscopic study.

At about 7,000 feet the degree of recrystallization of the rocks increases. This was noted first in samples, but the induction log of this well also supports it. The reconstituted micaceous minerals are coarser, and some of the rock fragments were identified megascopically as quartz-chlorite phyllite and schist. Feldspar and magnetite are more abundant. From 7,000 feet to about 8,250 feet metamorphosed argillaceous sediments predominate. From 8,250 feet to 10,019 feet chlorite metaquartzite, locally feldspathic, is most abundant, although there are zones of slate and phyllite (as from 8,610 to 8,810 feet and from 9,210 to 9,410 feet). Green biotite, white muscovite, and brown biotite can be seen in the metaquartzite occasionally.

The well produces its gas from 6,990 to 6,991 feet, and metamorphism increases noticeably at about 7,000 feet. This can hardly be a coincidence. It is hypothesized that the well cut a major thrust fault at 6,990 feet, along which the gas is trapped. The metasediments from 40 to 6,990 feet are low-grade metamorphics with a high shearing component. The metasediments from 6,990 to 10,019 feet are still low-grade metamorphics with a high shearing component but are more completely reconstituted and recrystallized and somewhat coarser grained. Denison (personal communication) suggests that these beds were more competent and more resistant to deformation than the more pelitic rocks in the upper part of the well, thus accounting for the more complete reconstitution and recrystallization.

In summary, one would hypothesize that there were three major rock types that were metamorphosed to form the metasediments penetrated by this well: (1) black carbonaceous shale, locally calcareous; (2) impure car-

TABLE 1.—ORDOVICIAN STRATA OF CORE AREA OF OUACHITA MOUNTAINS

AGE	FORMATION	DESCRIPTION AND THICKNESS (HONESS, 1923)
Late Ordovician	Polk Creek Shale	Coal-black graphitic, firmly indurated but soft slate and shale. Thickness estimated at 100 to 200 feet.
Middle Ordovician	Bigfork Chert	Hard black chert, coal-black shale, and black cherty limestone. Thickness estimated at 500-800 feet.
	Womble Shale	Green (weathering red) schistose, micaceous, fine-grained sandstones and grits. Local lentils of black cherty limestone. Thickness about 1,000 feet.
Early Ordovician	Blakely Sandstone	Sandstone and quartzite cut by thin veins of smoky and milky quartz Locally fine-grained, thin-bedded, compact ripple-marked sandstone. Thickness ranges from 0 to 15 feet.
	Mazarn Shale	Dark-colored, carbonaceous, hard clay shale and slate cut by veins of quartz and kaolinite. Thickness estimated at 1,000 feet.
	Crystal Mountain Sandstone	Uniform, medium-grained, massive gray sandstone, locally quartzitic, locally calcareous. A basal conglomerate contains chert and limestone inclusions. Abundant quartz-orthoclase veins and pegmatites. Thickness estimated at 500 feet.
	Collier Shale	Graphitic, unctuous shale carrying boulder beds in upper part and capped by 30 feet of thin-bedded replacement limestone. Large quartz-orthoclase pegmatites occur. Thickness estimated at 200 feet.
	Lukfata Sandstone (may not be valid formation)	Not recognized by Honess.

bonaceous limestone; (3) a relatively clean quartzose sandstone, locally calcareous and feldspathic. The first two may be called the Collier type and the third may be called the Crystal Mountain type.

On highly insufficient evidence, based on binocular-microscope study, it is postulated that Crystal Mountain-type rocks were penetrated from 40 to 720 feet, Collier-type rocks from 720 feet to 6,990 feet, a major thrust fault at 6,990 feet, Collier-type rocks from 7,000 feet to about 8,250 feet, and Crystal Mountain-type rocks to the total depth of 10,019 feet. It may well be that the rocks from 7,000 to 8,250 feet are metamorphosed Mazarn-type rocks, but we have no evidence for or against this supposition. It also may be correct, as Denison and others suggest, that the sandstones from 8,250 to 10,019 feet are a completely new formation derived from a nearby granitic source. They are more feldspathic and richer in iron than typical Crystal Mountain rocks, but this may be a local variation of limited significance.

PETROGRAPHY AND METAMORPHISM

Turner (1948, p. 93) defines the greenschist facies to "include all rocks formed at grades of metamorphism below that at which almandine appears

After Honess (1923) and Pitt (1955)

DESCRIPTION AND THICKNESS (PITT, 1955)	FOSSIL CONTROL
Not described.	Late Ordovician graptolite fauna.
Not described.	Middle Ordovician megafossils and graptolites.
Laminated siltstone and fissile shale with abundant limestone near base. No estimate of overall thickness.	Middle Ordovician graptolites in several zones, and Early Ordovician graptolites near base of formation in Arkansas.
Not described except by reference to Honess' descriptions.	Graptolites in middle of formation in Arkansas are of late Canadian (Early Ordovician) age.
Dark fissile shale with local laminae of sandstone and limestone. Thickness estimated at 600 feet.	Graptolites in lower part of formation are of middle Canadian (Early Ordovician) age.
Basal conglomerate is a calcareous sandstone with fragments of limestone, chert, and micaceous minerals. Massive sandstone is fine grained, locally medium grained, and is cemented by silica or calcite. Thickness ranges from 5 to 100 feet.	Essentially unfossiliferous.
Lower shale member is variegated, normally brown, fissile shale with numerous laminations of siltstone, sandstone, and silty limestone. Upper limestone member is dark-bluish gray, finely crystalline limestone and interbedded fissile shale. Thickness overall estimated at 230-330 feet.	Essentially unfossiliferous.
Lower member is interlaminated, thin-bedded limestone and shale. Middle member is interbedded platy sandstone and shale. Upper member is more massively bedded sandstone with some laminae of shale. Thickness estimated to be at least 145 feet.	Essentially unfossiliferous.

in pelitic rocks. . . ." He divides the greenschist facies into two subfacies which he calls the muscovite-chlorite subfacies (lower grade of metamorphism) and the biotite-chlorite subfacies (higher grade of metamorphism). Turner (1948, p. 93) states that "Rocks of the greenschist facies are formed by low-grade regional metamorphism."

All of the thin sections made from cuttings and cores from Viersen and Cochran's 25-1 Weyerhaeuser well are of low-grade metamorphic rocks that have been subjected to considerable dynamic stress (figs. 2-5). All of these rocks are restricted to the greenschist facies, or the chlorite and biotite zones of some English petrographers.

The mineral assemblage, structure, and texture of a newly formed metamorphic rock result primarily from four variables: (1) composition of the original rock before metamorphism; (2) temperatures to which the rock has been subjected; (3) pressure to which the rock has been subjected; and (4) metamorphism, whether the rock has been metamorphosed under unidirectional pressure due to load or under conditions of applied stress, and the depth of burial at the time of metamorphism.

Insofar as the composition of the original rocks before metamorphism is concerned, one can say confidently that all were sedimentary rocks of three major lithologies: (1) carbonaceous shale; (2) quartzose sandstone, locally calcareous; (3) impure limestone, usually either shaly or sandy.

The temperatures to which these rocks were subjected were relatively low; no garnet was found in any of the slides studied, and all of the newly formed minerals are compatible with low-temperature metamorphism.

These rocks were subjected to considerable shearing stress and were formed under dynamic metamorphism. Flaser and augen structures occur locally, as do strain shadows, irregular twinning, and bent and broken crystals. In addition, schistose and slaty cleavages and phyllitic structure are well developed in some specimens, indicating that metamorphism took place at least at moderate depths.

Flawn's classification for metamorphosed argillaceous and arenaceous rocks (Flawn and others, 1961, table 1) was used in this study. This classification is based on the degree of reconstitution of the matrix and the presence or absence of preferred mineral orientation or slaty cleavage. The degree of reconstitution of the matrix ranges from about 25 percent in some

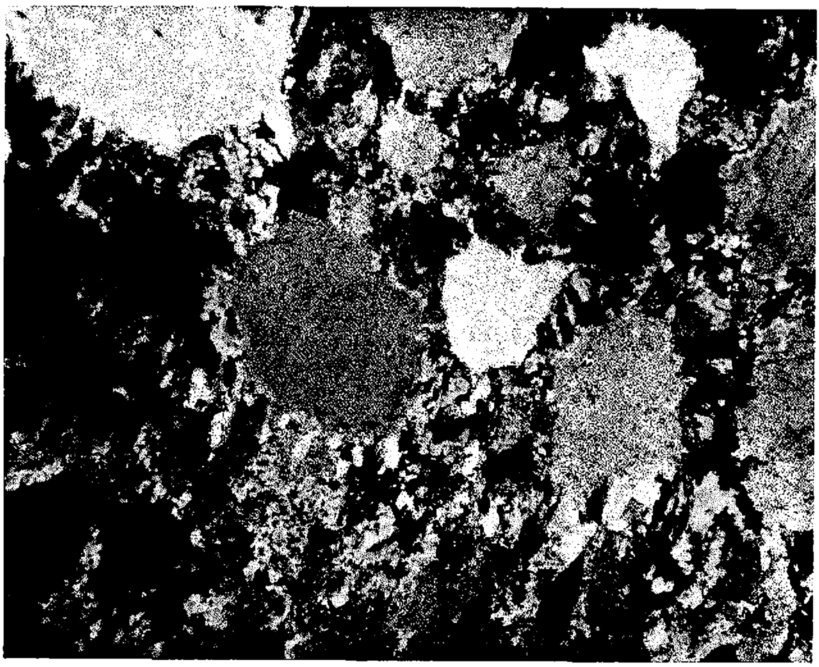

Figure 2. Photomicrograph of thin section; depth, 160-165 feet. Calcareous metaquartzite. Quartz grains are poorly sorted, mostly of medium- to coarse-sand size. Tiny dust particles marking original grain boundaries may be seen at places, but present boundaries are complexly sutured. "Matrix" of quartzite is mostly subhedral to anhedral calcite and silt-size quartz. Original interstitial clay has been reconstituted into sericite and chlorite. Greenschist facies, sericite-chlorite subfacies, Crystal Mountain lithology. Crossed nicols, ×52.

of the clay-slates originally containing large amounts of organic matter to complete reconstitution in some of the cleaner metaquartzites. Abundant organic matter lowers the degree of reconstitution under metamorphism and reduces the size of the reconstituted micaceous minerals.

Almost all of the rocks show preferred mineral orientation or slaty cleavage, and none were identified as argillite or hornfels. The argillaceous rocks range from clay-slate through slate to phyllite and schist. The arenaceous rocks are metasandstone and metaquartzite. The calcareous rocks are dolomite marble and calcite marble.

Most of the thin sections of rocks from this well show that the rocks are in the muscovite-chlorite subfacies. The three critical mineral assemblages of this subfacies are (1) muscovite and chlorite, (2) chlorite and calcite and quartz, (3) dolomite and quartz. All of these critical mineral assemblages are found in rocks from this well, as well as the quartz-biotite-chlorite assemblage typical of the biotite-chlorite subfacies.

The argillaceous rocks are difficult to work with, because the original

Figure 3. Photomicrograph of thin section; depth, 9,197-9,200 feet. Metaquartzite layer in quartz-calcite-sericite slate. Extremely poorly sorted quartz and calcite grains of sand size are intermixed with recrystallized quartz of sand size. Note how smaller quartz and calcite grains bend around large metamorphic quartz grain in center of photomicrograph in crude "augen" structure. Greenschist facies, sericite-chlorite subfacies. Crossed nicols, ×52.

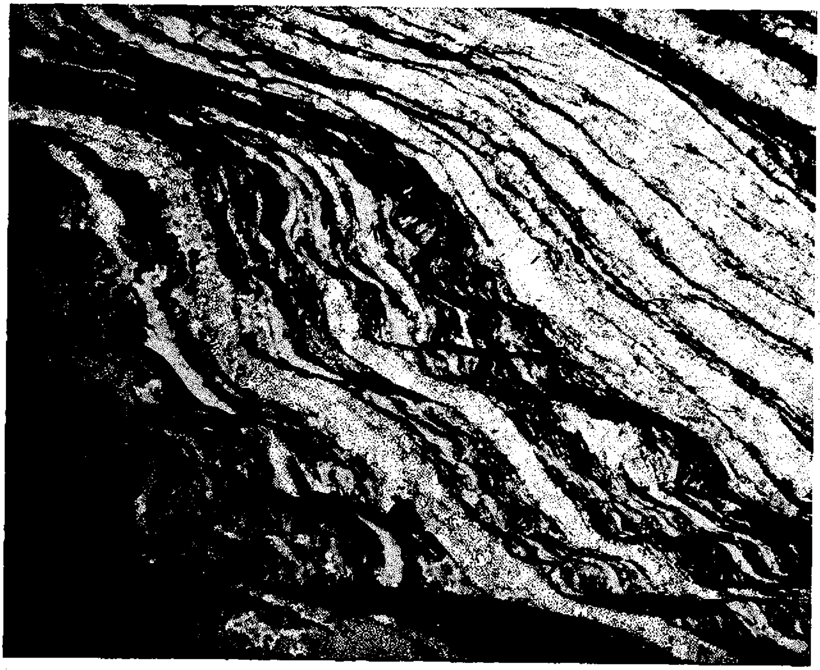

Figure 4. Photomicrograph of thin section; depth, 6,818 feet. Quartz-graphite-sericite microphyllite. Dark layers contain abundant finely divided graphite, and clays and detrital micas are incompletely reconstituted. Light-colored layers are mostly sericite and quartz and have been completely reconstituted. Note wavy bedding typical of phyllites, but on much finer scale. Greenschist facies, sericite-chlorite subfacies. Plane-polarized light, ×20.

sediment was high in organic matter, and this has been metamorphosed into graphite; much of the graphite is opaque in normal thin-section thickness (0.03 mm). However, these rocks are graphitic clay-slate, slate, phyllite, and schist cut by veinlets and massive inclusions of calcite and recrystallized quartz, usually containing some chlorite. Many of the specimens are thin-bedded, with layers of silt-size metaquartzite alternating with clay-slate. The metaquartzite is completely recrystallized in most slides, with abundant newly formed muscovite, chlorite, and a pale-brown mica that is either phlogopite or iron-poor biotite. The clay-slate layers interbedded with the metaquartzite are less recrystallized, owing to the high content of organic matter; the original clay minerals have not been reconstituted completely, and the average size of the newly formed micaceous minerals is smaller than in the adjacent metaquartzite layers. Some of the graphitic clay-slates show a microphyllitic structure with a wavy foliation surface (bedding?). All sections cut perpendicular to the slaty cleavage show a definite preferred orientation of the long axes of the micaceous minerals. Pyrite is abundantly distributed throughout the clay-slate and slate; rutile is less common.

The arenaceous rocks are easier to work with, because they are completely transparent to transmitted light. They are metasandstones and metaquartzites, locally calcitic and dolomitic, and usually contain small amounts of sodic plagioclase feldspar, potash feldspar, perthite, chlorite, and muscovite-sericite. Iron-poor biotite or phlogopite is found at a few places from the surface to 6,990 feet, and dark-brown iron-rich biotite in the somewhat more completely recrystallized rocks below 6,990 feet to total depth. The typical mineral assemblage is quartz-carbonate-chlorite-muscovite, with quartz-carbonate-chlorite-biotite-muscovite less common. The calcite and quartz are intercrystallized with complexly sutured boundaries. The original sandstone was poorly sorted to fairly well sorted, and some of the rocks show large relict grains or, possibly, porphyroblasts of quartz and scattered feldspar. At places the relict grains or porphyroblasts are also poikilitoblastic with mica and quartz. In some specimens the original sand-grain boundaries can still be seen, although they are frayed, corroded, "moth-eaten." Elsewhere, the metaquartzite has been recrystallized completely.

The original clays and detrital micas in these metamorphosed sandstones have been completely reconstituted into new micas and chlorite. Minor accessory minerals in the metasandstones and metaquartzites are rutile, sphene, zircon, tourmaline, leucoxene, magnetite, epidote, pyrite, and chalcopyrite(?).

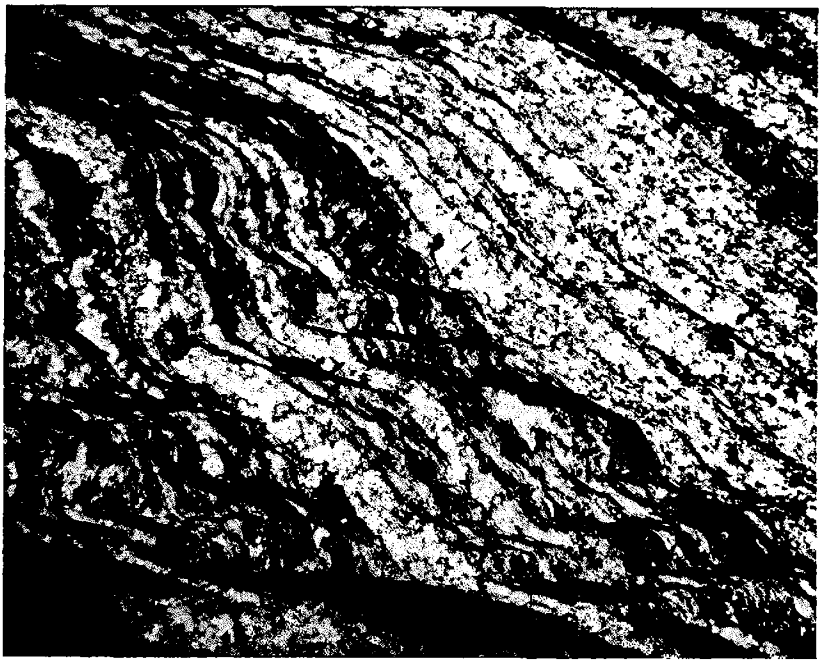

Figure 5. Same section as figure 4, crossed nicols.

Almost all of these metamorphosed sandstones are cut by veinlets and more massive intrusions of quartz and calcite. Specimens cut perpendicular to the schistosity show that the quartz grains have been broken, stretched out, and rotated so as to offer minimum resistance to stress. Augen structure occurs locally, and bent and broken grains, strain shadows in quartz, and wavy extinction indicate a high shearing component in the metamorphism.

When a relatively clean, pure limestone or dolomite is subjected to low-grade regional metamorphism, it recrystallizes into a dolomite or calcite marble, usually with some stress effects such as bent crystals and deformed twinning lamellae. Where clay minerals and detrital micas are present, they are reconstituted into new micaceous minerals.

Most of the carbonate rocks found in thin sections from this well were impure limestones containing abundant organic matter and some clay and silt. They have been metamorphosed into graphitic calcite marble and dolomite marble, locally quartzose. In most cases the quartz sand grains have reacted with the carbonate during metamorphism, and the borders of the quartz grains are corroded and irregular. Some of the rocks were peletoid limestones before metamorphism, and the dark patches are still preserved at places. There are very few megafossils; Rowland found a pelmatozoan plate at 1,240-1,245 feet. The marbles are cut by veinlets of calcite and quartz. In one specimen, there are three types of quartz: as relict sand grains, in cross-cutting veinlets, and as void-space fillings. Both calcite and dolomite may occur in the same rock, but all of the carbonate veins appear to be calcite. The reconstituted micaceous minerals are chlorite, sericite, and muscovite.

Deformed twinning lamellae are very common, and some of the marbles have been sheared as well as recrystallized. Interbeds of graphitic micaceous clay-slate and slate are fairly abundant.

AGE DETERMINATIONS

Mobil Research and Development Corporation's Field Research Laboratory at Dallas, Texas, made isotopic age determinations on micas from Viersen and Cochran's 25-1 Weyerhaeuser and also some age determinations on control samples outcropping near the well. The samples from the well range in age from 307±6 to 265±5 million years. The oldest sample was on mica from the base of Denison's Unit B (1,800-6,900 feet), and the other three ages were on mica from Denison's Unit D (8,800-10,019 feet). These ages would be Pennsylvanian and Early Permian.

Age determinations made by Denison and co-workers from the Collier slate outcropping near the well location gave ages of 301 and 318 million years. Age determination from the Mazarn slates gave ages ranging from 313 to 378 million years. All determinations were made on micaceous concentrates. These ages range from Devonian to Early Pennsylvanian.

Inasmuch as the Mazarn slate contains an Early Ordovician graptolite fauna and overlies the Crystal Mountain and Collier formations, one can only conclude that the geologic clock has been reset in this area and that the age determinations made on the 25-1 Weyerhaeuser well and on the outcrop samples do not represent the age at time of deposition but represent some later event. Denison and others (in preparation) concluded that the ages were genuine and reflected the time of metamorphism of these samples. One is tempted to conclude that at least the younger ages represent the time of deformation of the Ouachita geosyncline and the formation of the Ouachita Mountains, which is usually considered to have begun in the Pennsylvanian and ended in the Early Permian.

ELECTRIC-LOG INTERPRETATION

Viersen and Cochran ran a magnificent suite of electric and radioactive logs on the 25-1 Weyerhaeuser well: (1) Dual Induction-Laterolog 8, (2) Compensated Formation Density with Gamma Ray, (3) Sidewall Neutron Porosity, (4) Thermal-Data (temperature log for gas detection).

Run no. 1 of the dual induction laterolog was from 30 to 658 feet. Self-potential was run on 20 millivolt units, and there are off-scale deflections in both directions. From the minimum to the maximum reading there is a separation of 330 millivolts. The rocks are generally thin-bedded. The deep induction curve ranges from a resistivity of just over 1 ohm to almost 200 ohms. The formation density log through this interval shows bulk densities of about 2.75 grams per cubic centimeter. Sharp deviations to the left (apparent porosity) are uniformly due to washouts. The sidewall neutron tool is calibrated to read porosity directly if lithology is known, but it has not been calibrated for metamorphic rocks. If the rocks were sandstone, the porosity would be about 3-8 percent.

At 710 feet the character of the self-potential curve on the electric log changes, becoming much more uniform. This character extends to about 1,600 feet, where the formations become thin and broken again. This thin-bedded, broken zone extends to about 3,250 feet. From 710 to 1,600 feet the maximum excursions of the SP curve are about 255 millivolts, but most of it is in a sharp excursion to the right at about 1,200 feet. Deep resistivity curves read from about 1.5 ohms to greater than 100 ohms. The formation density log in this interval shows bulk densities from 2.62 to 2.82 grams per cubic centimeter (cc), neglecting washouts. The lowest density readings are in apparent "shales." Plots of sidewall neutron porosity versus density porosity through this interval show no gas effect.

From 1,600 feet to 3,250 feet, the self-potential curve indicates relatively thin beds of varying lithology. The resistivity curves show a tremendous range, from about 1 ohm to about 400 ohms; from 2,845 to 2,955 feet the laterolog-8 curve is saturated and greater than 2,000 ohms. The maximum SP deflection is about 275 millivolts. Most of the density-log readings in this interval are between 2.65 and 2.75 grams per cc, averaging about 2.70 for bulk density. A few sharp variations from this norm result from washouts. The sidewall-neutron-porosity readings are generally low, with the highest apparent porosities in "shales." At a few places there are abrupt washouts where the pad did not make good contact.

From 3,250 to about 6,990 feet, the self-potential curve on the dual induction log is quieter than it was up the hole. Most of the time the SP curve is on scale and the maximum range of deflection is only 230 millivolts. The resistivity curves range from a maximum of almost 2,000 ohms on the deep-investigation curve to less than 0.2 ohms, but most of the resistivities are generally low, with only a few highly resistive beds. Bulk densities average about 2.72 grams per cc over this interval, and there is little apparent porosity not due to washouts. The density readings are remarkably consistent. This uniformity of lithology is supported by the sidewall neutron log. Density-neutron plots of porosity show gas effect at 6,496-6,538 feet and at 6,788-6,799 feet, but the porosity is very low.

At 6,990 feet the character of the dual induction log changes abruptly. The SP log makes an abrupt shift to the right at 6,990 feet but stays on scale thereafter, and the total range of deflection is only 175 millivolts. Resistivity of the rocks penetrated increases greatly, and the laterolog-8 curve is completely saturated at 2,000 ohms much of the time. The resistivity curves move back and forth abruptly, suggesting a thin-bedded nature for the rocks. Bulk density of the rocks averages 2.75 grams per cc, with some density readings as high as 2.78. The gamma-ray curve of the density log indicates that the rocks are much more broken and thin-bedded than the SP curve would suggest. The side wall neutron porosity tool confirms the thin-bedded nature of the rocks. The highest porosity readings are in "shales."

SIGNIFICANCE OF 25-1 WEYERHAEUSER WELL IN INTERPRETING HISTORY OF OUACHITA MOUNTAINS

Prior to the drilling of this well, the geologic interpretation of the Broken Bow-Benton anticlinorium of the Ouachita Mountains was based almost entirely on study of the surface outcrops. The oldest units cropping out in the Ouachita Mountains are the Collier Shale and the Lukfata Sandstone (if valid) of probable Late Cambrian or Early Ordovician age. Ham (1959, p. 82-83), by extrapolating the top of the Precambrian from the Arbuckle province into the Ouachita province, concluded that the depth to the Precambrian beneath the Lukfata in McCurtain County is about 500 feet in normal stratigraphic sequence. Drilling of this well seems to have disproved this hypothesis. The rocks encountered in the 25-1 Weyerhaeuser are comparable in lithology and metamorphic grade to rocks found in deep wells of the Luling field, Caldwell County, Texas, but in the 25-1 Weyerhaeuser these rocks were penetrated to 10,019 feet, giving a third dimension to supplement the surface studies.

From surface to total depth, the rocks penetrated are low-grade metasedimentary rocks of the greenschist facies characteristic of the interior foldbelt of the Ouachita system. All the lithologies found may be referred to the Collier and Crystal Mountain formations, although some of the rocks are more completely recrystallized than can be found in surface outcrops. Although the rocks below the fault at 6,990 feet are generally more completely recrystallized than those above the fault, they still appear to be of Collier and Crystal Mountain lithologies.

No dipmeter was run in the well, so there is no knowledge of how steeply the beds are dipping. Furthermore, there may be some repetition of beds. However, based on this well, one may conclude either (a) that the Collier and Crystal Mountain formations are either repeated several times or are considerably thicker than surface measurements indicate, or, more probably, (b) there is a considerable thickness of metasedimentary rocks below the Collier Shale, which are of undetermined age but which resemble closely the Collier and Crystal Mountain formations exposed at the surface.

OIL AND GAS POSSIBILITIES OF CORE AREA

The core area of the Ouachita Mountains in McCurtain County, Oklahoma, is not a good place to look for commercial amounts of oil and gas. Although the 25-1 Weyerhaeuser well did produce some gas, the production is from a fracture, probably along a fault zone. The prime reason for pessimism is that the rocks encountered in this well have been more or less completely recrystallized, and original void space has been almost completely destroyed. It is unlikely that there is any complex fracture system in the core area with enough reservoir capacity to hold commercial accumulations of gas.

Consequently, there is no reason to expect to find commercial amounts of oil and gas in the core area of McCurtain County, Oklahoma, nor would one expect any in the lower Paleozoic beds of the entire Broken Bow-Benton anticlinorium.

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Kenneth V. Luza

William Earl Harrison

OGS Adds Two Staff Geologists

Dr. Charles J. Mankin, director of the Oklahoma Geological Survey (and of the School of Geology and Geophysics of The University of Oklahoma), has announced the appointment of two geologists, Kenneth V. Luza and William Earl Harrison, to the OGS professional staff.

Ken Luza will occupy the newly created position of engineering and environmental geologist. The immediate scope of Ken's investigations will encompass studies of waste disposal and pollution, potential geologic hazards, and foundation conditions, and he plans to do a resource study of sand and gravel deposits of the state. He will also work with Kenneth S. Johnson, Survey geologist, and Arthur J. Myers, professor for the OU School of Geology and Geophysics, on a 3-year inventory of Oklahoma's surface-mined lands. The project, begun by Johnson, has received a $75,000 boost from the U.S. Geological Survey, and the 3-member research team plans to examine past and present mining activity in each of Oklahoma's 77 counties (excluding coal fields, which are under separate investigation by the Survey staff).

Dr. Luza came to the Oklahoma Geological Survey from the Nevada Bureau of Mines and Geology at Reno, where he was engaged in similar studies. A native of Wisconsin and a former resident of Illinois, he received his B.S. degree in geological engineering from the University of Arizona, later completing work toward M.S. and Ph.D. degrees from the South

Dakota Schol of Mines and Technology, where he served as a teaching assistant. He was employed as a geologist (WAE) for the U.S. Bureau of Mines, studying bog-iron deposits in the Black Hills, and was a member of the University of Nevada graduate faculty, teaching engineering geology and directing master's theses.

A member of The Geological Society of America, the Society of the Sigma Xi, and the American Institute of Mining, Metallurgical, and Petroleum Engineers, Ken is also a reserve officer in the U.S. Army Corps of Engineers. He is married and has one child, a son, David, 2 years old.

William Earl Harrison, who received his master's degree in geology from The University of Oklahoma in 1968, has returned to Norman as petroleum geologist for the Oklahoma Geological Survey. He received his B.S. degree in geology from Lamar State College of Technology at Beaumont, Texas, and is a 1975 Ph.D. candidate at Louisiana State University with a major in geochemistry and a minor in marine science. He served as an instructor at Lamar and at LSU.

Bill's chief interest has been in the field of biogeochemistry, especially in reference to hydrocarbons. He has also conducted studies in the petrography of heavy minerals and in palynology, the study of fossil pollens and spores. He was with Shell Oil Company from 1968 to 1971, working on petroleum-source-rock analyses, mapping surface carbonate sediments, and logging abandoned petroleum wells and shallow water wells for subsurface control. Prior to that he did geophysical work for Mobil Oil Corporation. His master's thesis was the result of a heavy-mineral research project of the Sun Oil Company Research Laboratory. At LSU he initiated and completed geochemical laboratory experiments on the microbial generation of methane from ancient and modern sediments and on the degradation of pine pollen by microbes. His Ph.D. dissertation is on "Laboratory Generation of Hydrocarbons from Ancient and Modern Organic-Rich Sediments."

Bill plans to institute a study of Oklahoma's reservoirs for the Survey, with the purpose of providing information that will serve as a basis for future projects of enhanced recovery of petroleum and natural gas from wells in the State. Future investigations are also proposed to deal with recovery of "heavy" oil from Oklahoma's tar sands.

Bill is a member of The American Association of Petroleum Geologists and the Organic Geochemical Branch of the Geochemical Society. He is married and has two children.

New Thesis Added to OU Geology Library

The following M.S. thesis has been added to The University of Oklahoma Geology and Geophysics Library:

Lithostratigraphy and Subsurface Study of the Chaetetes-*Bearing Lower Strawn Formation (Pennsylvanian), Gaines County, Texas,* by Ellis Randolph.

OGS Director Attends White House Conference

Charles J. Mankin, director of the Oklahoma Geological Survey and of the School of Geology and Geophysics of The University of Oklahoma, attended a conference held July 21 in the East Wing of the White House for the purpose of bringing together over 70 top scientists representing the 36,000 geologists and geophysicists making up the 18 member societies of the American Geological Institute (AGI). The White House Conference was called by Fred S. Honkala, executive director of AGI, and Dr. Mankin attended in his capacity as president of the Association of American State Geologists.

Thirteen speakers from energy and mining industries, governmental agencies, and academic institutions offered their views before an attentive audience that included officials of the Department of the Interior, the Federal Energy Administration, the Energy Research and Development Administration, and the National Science Foundation.

Major concern at the conference was expressed over energy resources. The American Association of Petroleum Geologists' president, John E. Kilkenny, stressed the importance of accelerated domestic production of oil and gas, stating that there is "no alternative, other than drastic energy conservation." It is his belief that resources are still more than adequate to keep the country going while alternative sources are being developed, but without increased production dwindling reserves in this country plus high prices and embargoes on foreign supplies will result in severe shortages.

AGI president Frank B. Conselman stated that unless they can be profitably created and marketed, alternative sources such as geothermal or solar energy must be considered only supplemental. He offered his opinion that "oil, gas, coal, and breeder reactors will remain the basic sources for American energy because they are our only proven and dependable sources." Several petroleum geologists urged review of state and federal environmental regulations, as petroleum minerals can be recovered from both on- and off-shore deposits with minimal effect on the environment.

Geological-mining experts James Boyd and Ernest L. Ohle warned that although we are not in immediate danger of running out of strategic minerals, shortages of minerals other than hydrocarbons may soon cause "even greater crises for American technology." They emphasized the necessity of accelerated domestic exploration for these resources and also the development of methods for conserving and recycling vital minerals.

Dr. Mankin believes that it is too early to determine the full impact of this conference. Its primary contribution was to grant scientists an opportunity to engage in direct communication with the executive branch of government. Opinions were voiced on a broad range of topics of concern to the geological sciences—natural resources, environmental concerns, and earth-science education in addition to energy problems. Plans are being developed to continue the White House Conferences on an annual basis, and as long as there is a free flow of ideas between scientists and the administration, the people of this nation are bound to profit.

Petroleum Data File Available Through ORA

Although most of the U.S. Department of the Interior energy-related data files are built and maintained in-house, others are operated on a contract basis. Such is the case with the U.S. Geological Survey's Petroleum Data System (PDS), which is in the process of being made available to the public. The University of Oklahoma Office of Research Administration recently completed the sixth year of a contract with the USGS that called for construction of a searchable computerized data base, utilizing the General Information Processing System (GIPSY) developed at OU, that would contain information on oil and gas fields in the United States; PDS is the result.

The Petroleum Data System contains approximately 68,000 oil- and gas-pool records, and it will continue to expand. Information in the file includes the official name of the field or pool and its location by county; size; cumulative and annual production of oil and gas; geologic occurrence with respect to discovery well, type of entrapment, and age of reservoir; engineering data on reservoir temperature, pressure, and petrophysics; and analyses of crude oil, brine, and natural gas. Information is included on all fields and pools for which data are available from nonproprietary sources.

The basic data sources are the reports of the several state regulatory agencies and geological surveys of the oil- and gas-producing states. Data from within the federal government are derived principally from the U.S. Bureau of Mines, the U.S. Geological Survey, and the Federal Power Commission. Significant amounts of information in the file are prepared on a continuing basis by the International Oil Scouts Association and released to the USGS through a cooperative agreement. All geologic basins carry the same name and code as The American Association of Petroleum Geologists (AAPG) Committee on the Statistics of Drilling. Each reservoir includes the USGS formation name and era-system-series designation. Each field is assigned a Federal Power Commission field code, and each state and county has the Federal Information Processing Standards (FIPS) code.

Additional data in the United States and Canada have been and are continuing to be added to the file through a grant awarded to AAPG by the USGS. A large number of AAPG volunteer workers throughout the United States are checking and updating the field data already in the PDS file and adding additional geologic data where available. This information will continue to be added and updated throughout the remainder of 1975.

The PDS file is made available to the public under the Freedom of Information Act. Access to the file may be made through time-sharing at The University of Oklahoma. Effective August 1, 1975, the PDS file was put on-line from 0800 CST through 2400 CST. In addition, special studies may be made on request or arrangements can be made for purchase of the tapes by directing inquiries to Mrs. Jerlene Bright, the Office of Information Systems Programs, known informally as the Oil Information Center, 1808 Newton Drive, Room 116, Norman, Oklahoma 73069; phone (405) 325-7251.

Alternate Energy Projects Undertaken by Federal Agencies

Geothermal Energy

Assessment of Geothermal Resources of the United States—1975, edited by D. F. White and D. L. Williams, has been published by the U.S. Geological Survey as Circular 726. The report shows that although great amounts of geothermal heat are present in rocks underlying all 50 states, only a small percentage can be utilized under present economic and technologic conditions.

Estimates compiled by the USGS with support of the Energy Research and Development Administration (ERDA) are separated into two major categories: the "geothermal resource base," which is the total heat in the ground to a depth of 10 kilometers (about 6 miles), and "geothermal resources," the portion of the resource base that is recoverable with current and near-current technology at present prices or higher. "Geothermal resources" are further subdivided depending on the cost of their recoverability, but most such resources are located in localized hot spots near the surface, such as young volcanic systems in 11 western states, hydrothermal convection systems containing steam or hot water, and "geopressured" areas along the Texas and Louisiana Gulf Coast.

Results of the assessment, according to V. E. McKelvey, USGS director, indicate that while geothermal energy cannot be considered a panacea, it has sufficient potential to "justify both exploration and technological research and development."

Copies of Circular 726 are available free on request from the U.S. Geological Survey, Branch of Distribution, 1200 South Eads Street, Arlington, Virginia 22202.

Solar Energy

The Federal Energy Administration has released a report on the activities of 14 federal agencies in the area of the development of solar heat as a source of energy. These agencies sponsored 171 solar projects over the 19-month period for July 1973 through January 1975, about half of which were demonstrations for the heating and cooling of buildings. Funding was over $25 million.

The report shows that the National Science Foundation was responsible for 80 percent of the projects and 77 percent of the cost, and this agency plans a budget of $50 million for this purpose in 1975.

Solar Energy Projects of the Federal Government (publication number, PB 241 620), which includes a summary of each of the 171 projects, can be obtained for $6.25 from the National Technical Information Service, Sales Department, 5825 Port Royal Road, Springfield, Virginia 22151.

Possible Man-Made Sinkholes at Southard, West-Central Oklahoma: A Case Study in Landscape Modification

William Carl Jameson[1] and Joseph B. Schiel, Jr.[2]

A study of a series of collapse-sink dolines near the town of Southard in Blaine County, west-central Oklahoma, indicates these karst-type structures to be the inadvertent result of gypsum mining in the area. There are many natural sinkholes in the Blaine County area (Gould, 1905), but in an area about half a mile square in Southard there are about 50 of these depressions, ranging up to 60 feet in depth and 50 feet in diameter, that correspond closely to underground-mining operations (fig. 1). They appear to be an excellent example of man's sometimes unanticipated ability to modify the landscape.

Blaine County, in west-central Oklahoma, is the center for gypsum mining in the State, having extensive commercial deposits of high-quality gypsum which have been mined and processed in Southard since 1894. The United States Gypsum Company acquired the Southard plant in 1916 and is currently processing about half a million tons a year to provide gypsum products that are shipped throughout the country. The chief use of this material is in wallboard for building construction, but the gypsum also yields calcium and sulfur for a yeast food for livestock; in addition, it is utilized as a conditioning agent for water in the brewing of beer (burtonizing), a retainer in cement, and a soil conditioner (Sheahan, 1971).

The gypsum deposits mined are in the Blaine Formation of Permian age, which is 75-100 feet thick in this area and which contains 4 gypsum members, the Shimer, Nescatunga, Kingfisher Creek, and Medicine Lodge. Each of these members is separated by sequences of reddish-brown gypsiferous silty clay shales, and the Shimer, Nescatunga, and Medicine Lodge are underlain by dolomite beds as well (fig. 2).

The Shimer gypsum is from 8 to 15 feet thick in the Southard area (Fay and others, 1962, p. 10), and underground mining of this bed began in 1923 and continued until 1948, when it was abandoned for more economical surface mining. A double-entry room-and-pillar method was used in the underground mining, with rooms 22 feet wide and 7 feet high separated by 10-foot-square pillars that were robbed 2 feet on a side upon abandonment of the underground workings (Fay and others, 1962).

Officials of the United States Gypsum Company at Southard have suggested that as they abandoned the underground workings, the retreating miners blasted through the top of the Shimer gypsum. It is also thought

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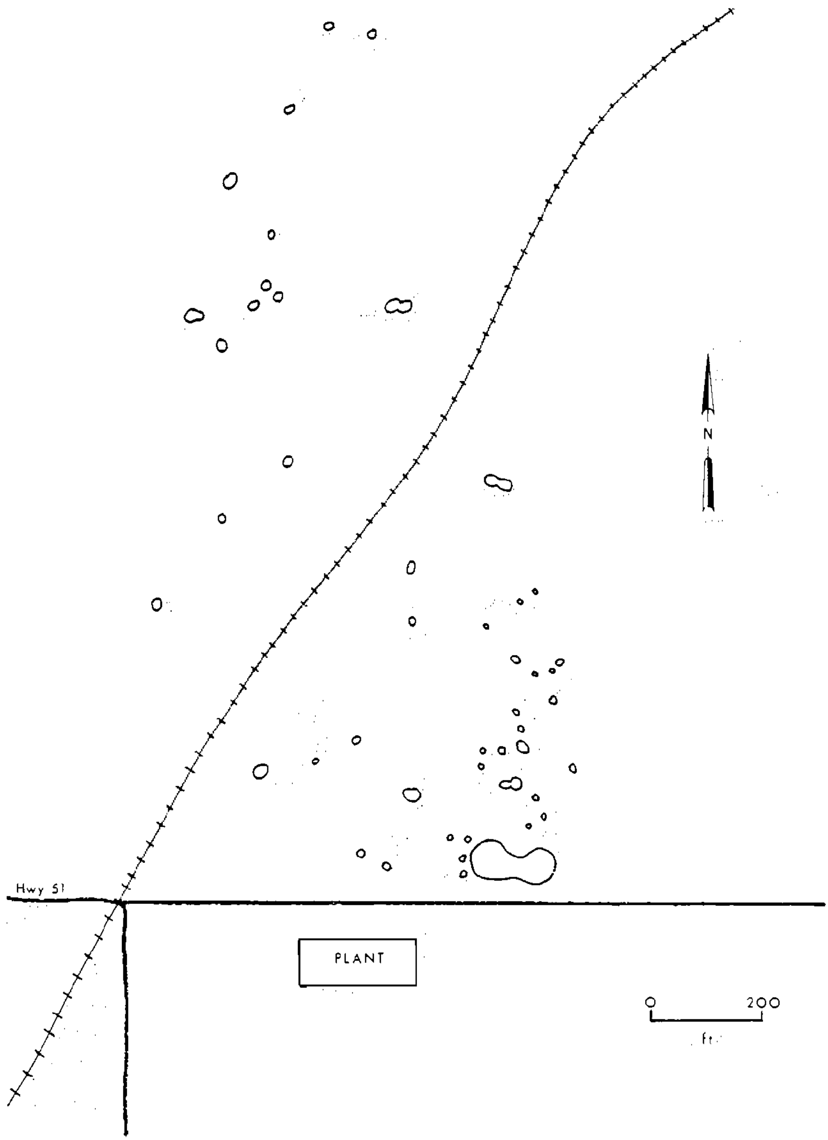

Figure 1. Distribution of sinkholes at Southard in relation to gypsum-processing plant of United States Gypsum Company.

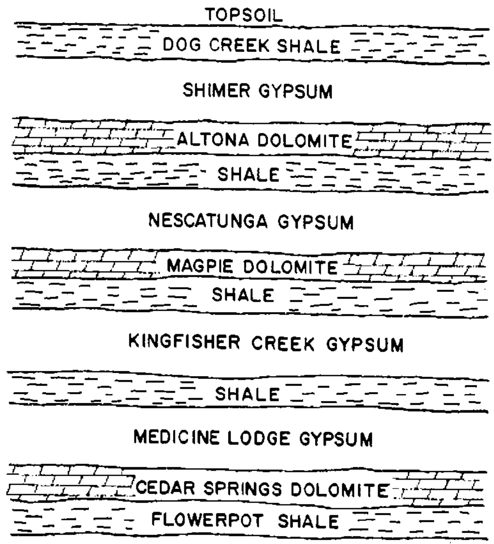

Figure 2. Layering of gypsum, dolomite, and shale members of Blaine Formation (Permian).

that in the course of normal mining operations tunneling occurred very close to the top of this gypsum layer. Thin, layered gypsum is not a very strong supportive material, and several breaks may have occurred, resulting in slow movement of the thinly consolidated material above the Shimer member through the openings formed, with percolation of rain water through the soil augmenting the process. The initial result was shallow surface collapse of 2- to 5-foot depths over the breaks in the abandoned tunnels, and the areas of such collapse eventually became well-developed sinkholes. Several examples of shallow collapses that may be the beginning of newly developing sinkholes can be seen today in the Southard region. Several well-developed sinkholes can be seen on the 1964 Blaine County soil-conservation aerial photographs.

The most notable karst areas in the world are in regions where limestone underlies the surface, although in some localities the rocks may be gypsum, dolomite, or dolomitic limestone. Thornbury (1969) mentions that solution features may develop on other soluble rocks like gypsum but that these are of minor importance because of their limited areal extent, except in places like Oklahoma (Myers and others, 1969).

Thornbury (1969) lists four conditions that contribute to the maximum development of karst topography, of which sinkholes are but one manifestation. First, he says, there must be present at or near the surface a soluble rock, preferably limestone. At Southard, a soluble rock is present, but in this case it is, of course, gypsum. Second, the soluble rock should be dense, highly jointed, and preferably thinly bedded. Gypsum does have these characteristics; in fact, it is due mainly to these particular characteristics that the magnificent gypsum caverns of northwestern Oklahoma were formed. Third, the existence of entrenched valleys below uplands underlain by soluble and well-jointed rocks is required. This condition favors the downward movement of ground water through the rock. This condition occurs at Southard in the Salt Creek Canyon area near the gypsum escarpment. Last, the region must be one of at least moderate rainfall. Thornbury goes on to state that, in general, arid and semiarid regions do not exhibit marked development of karst. Blaine County has an average yearly precipitation of about 28 inches and has been classified as having a dry, subhumid climate (Fisher, 1968, p. 55). Much water percolates downward from Pleistocene terrace material, however, and comes out at the base of the Blaine escarpment as gypsum and salt springs.

In short, the locality under consideration displays all the requisites for the development of karst structures, and it is certain that sinkholes could occur in Southard and other areas in western Oklahoma. In fact, Fay (1958) discusses the existence of a natural sinkhole in Blaine County that probably resulted from collapse of the Shimer layer.

The older sinkholes at Southard appear to be growing in diameter but not in depth. The authors witnessed the enlargement of several sinkholes by approximately 2-4 feet in diameter within a period of about 60 days. The enlargement followed a period of heavy rainfall, and it is suspected that the rainwater washed the loosely consolidated soil material from the sides downward into the sinkholes.

In order to assess the lateral growth of the sinkholes over a period of years, an attempt was made to measure the enlargement of three selected sinkholes between the years 1964-71. The analysis was done with the aid of aerial photographs. One aerial photograph of the region, taken in 1964, was obtained from the U.S. Geological Survey and was one of a series taken for the U.S. Soil Conservation Service. The 1971 aerial photograph was taken from a light aircraft flying at low altitude by members of the Department of Geography of The University of Oklahoma (fig. 3).

The scale of the 1964 photograph was obtained by measuring some section lines and averaging these figures, as a section is of known size and photo distance versus ground distance can be readily calculated.

Determining the scale of the 1971 photograph, which was a low-angle oblique photo, was a bit more complicated. Owing to the continuous change of scale across the photograph, it was necessary to find a known distance which was close to the sinkholes and which also appears on the 1964 photograph. Such a line was designated between two reference points. Using the scale and distance from the 1964 photograph, the length of this line was calculated, enabling calculation of the scale of the 1971 photograph.

Having the scale of both photographs now made measurement of the selected sinkholes quite easy. Measurement was made using a comparator and a plotter's scale, with the measurements converted to ground distance for the respective photographs.

The results of this analysis indicate an enlargement of two of the sinkholes under investigation (table 1). Sinkholes A and C increased in size by 6.6 feet and 3.9 feet respectively, whereas sinkhole B did not exhibit any enlargement during this time period. Perhaps the size of the original underground opening has something to do with the largest diameter the sinkhole can achieve. At some places, two or more enlarging sinkholes have

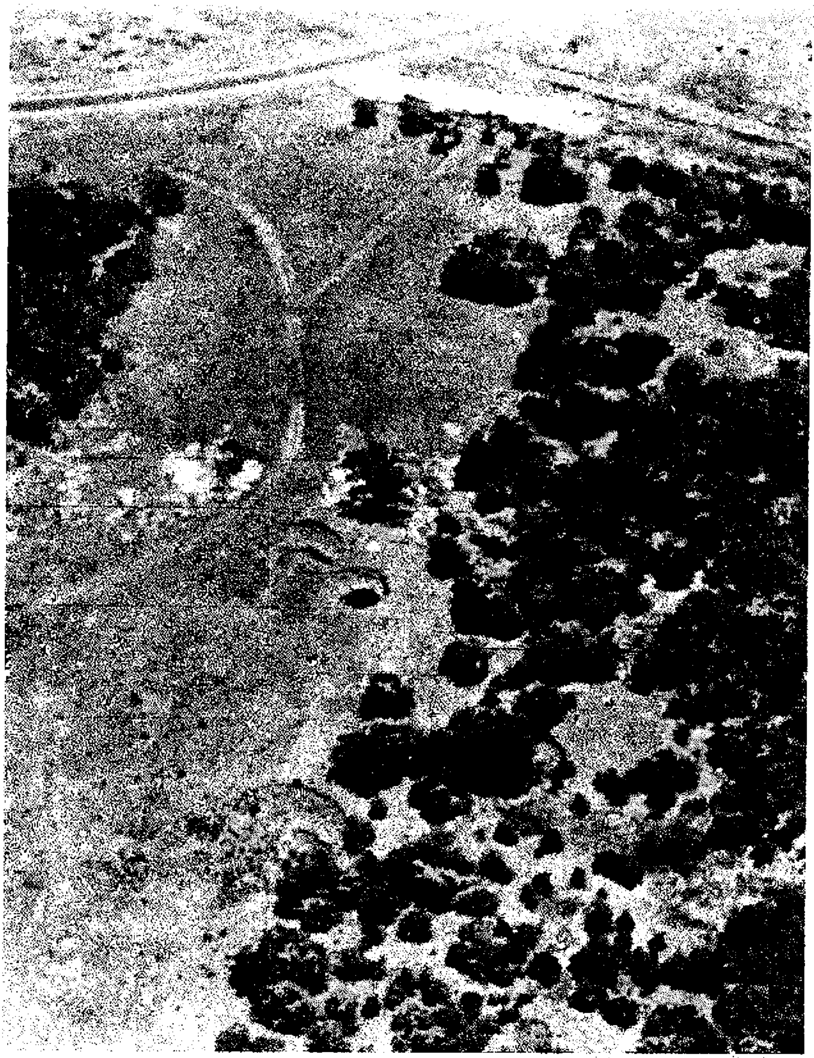

Figure 3. Aerial view of three possible man-made sinkholes at Southard.

TABLE 1.—RESULTS OF GROWTH ANALYSIS OF THREE SELECTED SINKHOLES DURING 1964-71

	A	B	C
1964 (diameter)	40.3 ft	32.2 ft	48.3 ft
1971 (diameter)	46.9 ft	32.1 ft	52.2 ft
Growth	6.6 ft	*−.1 ft	3.9 ft

*Slight error possibly occurred as a result of scale change from 1964 photograph to 1971 photograph.

coalesced to form an even larger hole. In any event, based on this analysis and other empirical observations, it can be concluded that many of the sinkholes of this region are undergoing an enlargement process and will probably continue to do so for some time to come.

Most of the sinkholes are found on property owned by the United States Gypsum Company and have little effect on the health and economy of the surrounding area. These sinkholes, however, can and do pose some interesting problems.

One of the obvious problems is that they act as traps for unsuspecting animals, both domestic and wild. Owing to their depth and relatively steep sides, animals that survive the fall into the sinkholes sometimes cannot find their way out and so may perish from starvation. The most common victims of these sinkholes appear to be rattlesnakes. It has been reported to the authors that livestock have occasionally fallen in the holes, although not in recent years.

Where the sinkholes have occurred in agricultural fields that have been planted in wheat, a certain amount of acreage is lost to production; thus not only is the collapsed area out of production, but a considerable area surrounding the sinkholes must be avoided for safety reasons.

Furthermore, in relation to farming, the sinkholes and the associated underground tunnels drain away surface and subsurface water more rapidly than under normal conditions, thus placing a greater water stress on plants.

It has been suggested that as long as the sinkholes exist, they should be put to some kind of use, such as making them receptacles for solid waste, the concept being that this would eliminate the ugly open dumps that are commonly associated with the small towns in this region. There has, in fact, been some dumping, apparently by the gypsum company, of discarded gypsum products into at least one of the holes. However, leachates from such dumps go directly into the catchment water that stands in the tunnels, and although the region is sparsely settled and there is little chance for human or livestock consumption the water could nevertheless become polluted if the holes were to be used as garbage depositories.

Another environmental and health problem that would result from the use of the sinkholes as dumps is that the dumps and catchment water would serve as breeding places for mosquitoes, flies, rodents, and other vermin.

Luckily, Southard is far removed from any large settlement, and the impact of the sinkholes on local health and economy is minimal. The situation might be completely different if such a condition existed near a large metropolitan area.

Man's activities in obtaining needed resources from the earth sometimes have had unforeseen results. Such efforts have been responsible for creating subsidence elsewhere in the United States, e.g., Galveston, Texas, Long Beach, California, and Las Vegas, Nevada. Other examples outside this country include Mexico City, Tokyo, London, and localities in Venezuela (Marsden and Davis, 1967; Flawn, 1970). But man has more rarely been associated with the creation of sinkholes, such as those described in the vicinity of Southard, Oklahoma.

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Mineral Resources Discussed in USGS Report

The energy situation has been and is being intensively and extensively explored; *Mineral Resource Perspectives 1975*, U.S. Geological Survey Professional Paper 940, focuses attention on the equal dependence of the nation's economy upon its minerals.

The 24-page report is a summary of the status of mineral resources, mineral reserves, mineral-resources research, and mineral exploration in the United States in 1974. It defines the problem as being "simply that the United States does not have an adequate known domestic supply of all the minerals needed to maintain our society for the foreseeable future." Although the country's minerals needs have continued to grow, we have never had all we needed and have always imported. Now, with nationalization, cartels, and new competitors for materials, obtaining minerals from overseas is becoming increasingly costly and increasingly uncertain.

The possible solutions considered are similar to those put forth for solving energy scarcities: reduced demand, substitution, conservation, recycling, and increasing domestic supply. These are all essential, and, as is the case with energy fuels, higher prices and advanced technology will lead to new reserves; but as the report states, geologic availability is the prime consideration, and whereas low-grade ores can be mined, the price in energy required may be too high.

The report emphasizes the primary necessity of evaluation, realistic appraisals, technical and scientific exploration, so that we can know what we have and how long it will last. Also essential is standardization of terminology, classification.

USGS Professional Paper 940 can be obtained for 95 cents (prepaid) from the U.S. Geological Survey, Branch of Distribution, 1200 Eads Street, Arlington, Virginia 22202.

New Publications from AAPG

The following publications have been announced by The American Association of Petroleum Geologists and can be obtained from the association at this address: P.O. Box 979, Tulsa, Oklahoma 74101. All orders totaling less than $50.00 must be accompanied by payment.

Geological Highway Map 9

The ninth of The American Association of Petroleum Geologists' proposed series of 11 geological highway maps has now been published. Encompassing 5 states of the southeastern region of the United States—Louisiana, Mississippi, Alabama, Georgia, and Florida—Geological Highway Map 9 includes, in addition to the surface geology of the region: columnar sections; cross sections; a tectonic map; a satellite photographic image; and information on fossil and gemstone localities, parks, museums, points of geological interest, and Everglades National Park.

The map was prepared with the cooperation of the U.S. Geological Survey and state agencies and was compiled under the supervision of Allan P. Bennison, a consultant in Tulsa. The 28- × 36-inch map is in color, and mapping is at a scale of 1 inch = 30 miles.

The cost is $3.00, plus 50 cents handling charge.

Comprehensive Index for AAPG Publications

Comprehensive Index of Publications of The American Association of Petroleum Geologists, 1966-1970, a 616-page volume prepared by June McFarland and Peggy Rice, was released recently by AAPG. The clothbound index includes listings from AAPG bulletins and special publications, and indexing is computerized, with entries under titles, authors, and key words.

The price is $14.00 to members of AAPG and SEPM, $17.00 to others.

Studies in Geology Series

With publication of *Methods of Estimating the Volume of Undiscovered Oil and Gas Resources,* edited by John D. Haun of the Colorado School of

Mines, AAPG has initiated a new series designated as "Studies in Geology." This timely volume contains a collection of papers presented at the AAPG research conference on this subject held at Stanford University in August 1974. Authors included are experts with such varied affiliations as federal agencies of this country, Canada, and France; state agencies; academic institutions; and petroleum companies; as well as independent and consulting geologists. The publication is unusual, because it offers a printed record of ideas presented at the type of session where a no-publication rule is often enforced, under the belief that ideas will be exchanged more freely.

Studies in Geology No. 1 is available, paperbound, for $8.00 to members of AAPG and SEPM, $10.00 to nonmembers.

The second volume in this new series, Studies in Geology No. 2, contains 8 papers on Belize (formerly British Honduras) and one paper on the Yucatan Peninsula. *Belize (British Honduras) Shelf—Carbonate Sediments, Clastic Sediments, and Ecology,* edited by Kenneth F. Wantland and Walter C. Pusey III, is priced at $15.00 for members of AAPG and SEPM and $19.00 for nonmembers. It is available in paperback form.

Circular 27 Reprinted by OGS

Cellular Products from Oklahoma Volcanic Ash, by A. L. Burwell, with a section on "Geology and Petrology" by William E. Ham, first published by the Oklahoma Geological Survey in 1949 as Circular 27, has been out of print for several years but has now been reprinted in response to a steady demand.

In the 89-page, well-illustrated circular, Burwell, former chemist with the Survey, now deceased, gives the results of chemical analyses of samples of volcanic ash from 10 Oklahoma counties and presents detailed descriptions of laboratory experiments performed on the raw materials to yield cellular lightweight products suitable for use in construction and in sound, temperature, and electrical insulation. Ham, former OGS geologist, also deceased, discusses the origin, deposition, and geological occurrences of volcanic materials in Oklahoma and gives petrologic data on the samples of volcanic ash and petrographic data on the particles contained. Glass shards found in the samples give clear indication of volcanic origin, and the history of the nearest volcanic activity indicates the origin to have been from New Mexico volcanoes. Evidence indicates that the windblown dust was deposited in quiet lakes, such as now exist on the plains.

Volcanic ash, the finest matter to be ejected from a volcano, is known from 25 counties in Oklahoma, occurring as widely scattered deposits in western, central, and east-central parts of the State. Most of the beds are shallow, less than 20 feet thick, but one bed quarried in Beaver County, in the Panhandle, attains a thickness of 70 feet.

Circular 27 can be obtained from the Oklahoma Geological Survey, 830 Van Vleet Oval, Norman, Oklahoma 73069. The price is $2.00.

Charles Gould Honored At OU

On hand September 12 for the dedication of a granite marker honoring the founding in 1900 by Charles N. Gould of the world's first school of petroleum geology at The University of Oklahoma were, left to right: Jack Wettengel, director of the Oklahoma Historical Society; Sloan K. Childers, Phillips Petroleum Company, president of the Oklahoma Petroleum Council; Hugh M. Thralls, chairman of the Alumni Advisory Council of the OU School of Geology and Geophysics; Charles J. Mankin, director of the Oklahoma Geological Survey and the OU School of Geology and Geophysics; and John E. Kilkenny, Union Oil Company of California, president of The American Association of Petroleum Geologists. The marker has been erected at the west side of Gould Hall on the OU campus, facing Van Vleet Oval. The project is the eleventh in a series sponsored jointly by the Oklahoma Petroleum Council and the Oklahoma Historical Society.

CROWNS OF *Parapisocrinus* FROM OKLAHOMA AND TENNESSEE

HARRELL L. STRIMPLE[1]

Members of the crinoid family Pisocrinidae are cosmopolitan, particularly in Silurian time. It would appear that they could be utilized to good advantage in biostratigraphic studies; however, there has been little effort made in that direction. Springer (1926) summarized information concerning species from the Silurian of North America and included new material from his large collections. Unfortunately, no close stratigraphic control can explain the large number of congeneric species from one formation, i.e., the Beech River Formation (of the Brownsport Group) in western and central Tennessee.

The most extensive study of the family made to date is by Bouška (1956), wherein a division was made between *Pisocrinus,* in which the basals are visible in side view of the cup, and those in which the basals are confined to the basal concavity and are not visible in lateral view of the cup. For the latter group he proposed the name *Ollulocrinus* Bouška. Unfortunately, in a study by Mu (1954) the same division was made with a proposed subgenus, *Parapisocrinus* Mu, for reception of species of *Pisocrinus* that have the basals entirely confined to the basal concavity. The results of Bouška's study were presented on February 4, 1954, so he could not have been aware of the study by Mu. As a matter of fact, this writer was not aware of it until recently.

Webster (1973, p. 184, 208) accepted both subgenera and listed *Ollulocrinus* as an objective junior synonym of *Parapisocrinus*. Moore, Lane, and Strimple (Moore and Strimple, 1973, p. 16) list both *Parapisocrinus* Mu and *Pisocrinus* de Koninck as genera of the family Pisocrinidae but make no mention of *Ollulocrinus* or of the elevation of *Parapisocrinus* to generic status. It is nevertheless clear that the subgeneric concept was rejected, and *Pisocrinus ollula* Angelin is the type species of *Parapisocrinus.*

Crowns (cup with arms attached) of crinoids are rare in both the Henryhouse Formation of Oklahoma and in the Brownsport Group of Tennessee. The writer has in hand a small crown of *Parapisocrinus quinquelobus* (Bather, 1893) collected by Richard Alexander many years ago while he was a student at The University of Oklahoma. Acceptable photographs could not be made until the specimen was colored with Alizarin Red-S and then coated with sublimate of ammonium chloride. The resulting photographs are shown here (fig. 1b, c). Cups of *P. quinquelobus* are prolific in the upper portion of the Henryhouse Formation, in most of the exposures in NW¼SW¼ and SE¼SW¼ sec. 4, T. 2 N., R. 6 E., and in road outcrops 900

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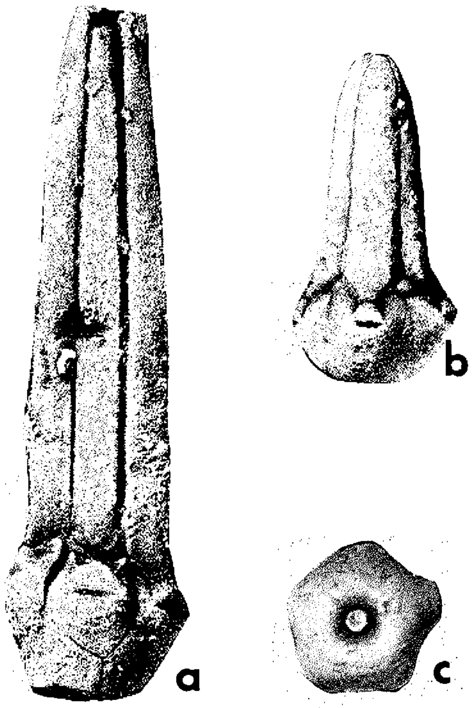

Figure 1. *Parapisocrinus tennesseensis* (Roemer, 1860) and *P. quinquelobus* (Bather, 1893) from Tennessee and Oklahoma, respectively: *a*—hypotype crown (SUI 38692) of *Parapisocrinus tennesseensis* viewed from *B* ray, ×4; b, c—hypotype crown (SUI 38691) of *Parapisocrinus quinquelobus* viewed from *D* ray and base, with *A* ray at top, ×4.

feet south of NW cor. sec. 33, T. 3 N., R. 6 E., Pontotoc County, Oklahoma. The specimen discussed herein came from the NW¼SW¼ sec. 4. Overall length of the crown is 10.9 mm; cup height to articular facet, 2.2 mm; width, 5.1 mm; ratio of arm length to cup height, 3.5.

Parapisocrinus tennesseensis (Roemer, 1860) is extant with *P. quinquelobus* in both the Henryhouse Formation and the Brownsport Group. In the spring of 1972, on a cold rainy day in Tennessee, I found a magnificent crown in a glade about 3 miles west of Perryville in Decatur County. Rain enhances collecting opportunities in the Brownsport, because when it is wet the matrix becomes darker, with a soft green coloration, and the crinoids become lighter or at least appear to be. The specimen (fig. 1a) discloses very long primibrachs *2*, apparently with primibrachs *3* restricted to the distal ends of the arms. In Springer's (1926) monograph on American Silurian crinoids, no crowns of *P. tennesseensis* are illustrated, so this may be the first specimen with arms to be reported. The arms are relatively large with flattened exteriors and are thus more closely akin to those of *Pisocrinus* *campana* Miller than to *Parapisocrinus quinquelobus,* which has short, well-segmented arms with well-rounded exteriors. In *P. quinquelobus,* the distal portion of primibrach *2* narrows more drastically than in *P. tennesseensis* or in *Pisocrinus campana.* The crown of the hypotype of *Parapisocrinus tennesseensis* is 23 mm long; cup height to articular facet is 3.4 mm; width, 6.2 mm; ratio of arm length to cup height, 5.7.

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"Las Cruces Country"

A lot of walking and some climbing will be the order of the day on each of the three days of the 26th annual field conference of the New Mexico Geological Society, November 12-15. Registration and housing will be in Las Cruces, with field excursions leaving each morning from the headquarters at the Rodeway Inn.

The first day's trip will offer a complete Paleozoic section, plus some Cretaceous and Tertiary exposures in the southern San Andres Mountains. The second day will cover middle Tertiary volcanics of the Sierra de las Uvas area and Quaternary basalts of the Aden-Afton fields, with a stop at Aden crater and a discussion of geomorphic evolution of the southern Mesilla Valley. The third day will offer an opportunity to investigate the structure and stratigraphy in the Rio Grande uplift and Quaternary evolution of the region between Las Cruces and Hatch.

For registration information, contact Lester Tofte, New Mexico State University, P.O. Box 3AB, Las Cruces, New Mexico 88003.

Copies of the field-trip guidebook, *Las Cruces Country,* edited by W. R. Seager, R. E. Clemons, and J. F. Callender, can be obtained from the same address for a pre-publication price of $17.75. The guidebooks of the New Mexico Geological Society are always outstanding publications, and this book contains about 35 articles on various aspects of geology and on the energy resources, mineral deposits, ground water, vegetation, and history of the region. Comprehensive road logs are included.

Choctaw County Report Issued by OGS

Geology and Mineral Resources of Choctaw County, Oklahoma, incorporating the results of investigations by George G. Huffman, Pedro P. Alfonsi, Richard C. Dalton, Andres Duarte-Vivas, and Edwin L. Jeffries, has just been released by the Oklahoma Geological Survey as Bulletin 120. The 39-page, illustrated volume contains information on the geography, stratigraphy, structural geology, geologic history, and economic geology of the county, with an introductory section on the history of previous investigations in the area dating back to 1799 and an appendix of measured stratigraphic sections. A new geologic map of Choctaw County (at a scale of 1 inch to the mile) included with the bulletin represents a significant contribution to the knowledge of the geology of the State.

This report represents another step toward the Survey's goal of providing updated information on the basic geology and mineral and energy resources of each county in Oklahoma. Programs of detailed geologic mapping covering Custer, Noble, Payne, Muskogee, and Bryan Counties are now in various stages of completion.

Bulletin 120 can be obtained from the Oklahoma Geological Survey for $8.00 hardbound and $6.00 paperbound.

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