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On The Cover —

Gertrude Selma Sober, "Queen of the Arbuckles" (1869–1949)

Gertrude Selma Sober discovered the Southwest Davis Zinc Field in 1909—a significant find because the zinc occurs in Arbuckle carbonates, a host rock for major lead-zinc deposits in the Midcontinent. Future work could lead to a major discovery.

Gertrude was born near Farragut, Iowa, on December 26, 1869. In 1889, her family moved to the Oklahoma City area, where Gertrude clerked in stores, taught school, and worked as a secretary. Between 1895 and 1899, the Sober family lived on a small farm near McCloud. In 1899, a homestead claim was filed for Gertrude on 160 acres near Sweetwater (Roger Mills County). She lived in a dug-out on the homestead until 1901, when she returned to the Oklahoma City area.

At that time, Gertrude (who had shown an interest in geology from an early age [Fay, 1981]) heard stories about the Arbuckles from people who had been on Charles N. Gould's field trips to Turner Falls and Price's Falls, and her interest in the region was piqued further by an itinerant peddler's description of fabulous riches in the mountains. With her hammer on her saddle horn, she made horseback vacation trips through the Arbuckles. In 1907, she began prospecting for minerals with R. C. Hope, a medical doctor in Davis.

In August 1909, Gertrude found a major zinc deposit in the western Arbuckle Mountains, Murray County (NE¼NE¼ NE¼NW¼ sec. 28, T. 1 S., R. 1 E.), on what is now the Butterly Ranch. She had discovered the Southwest Davis Zinc Field. (The host rock is the Butterly Dolomite [Lower Ordovician] of the Arbuckle Group.) Hope and Sober announced the

(continued on p. 146)

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OKLAHOMA GEOLOGY Notes

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History and Mapping of the Paden Copper Prospect, Okfuskee County, Oklahoma

Robert O. Fay[1]

Abstract

The oldest red-bed copper deposit in the Midcontinent is the Paden Copper Prospect, located southwest of Paden, in southwestern Okfuskee County, in central Oklahoma. The ore is mainly malachite, altered from chalcocite, in a red-brown sandstone of the Ada Group (Pennsylvanian, Virgilian). Mining began about 1925. The ore was shipped from Paden to El Paso, Texas. Some gold and silver were noted. Interest in the area continued until 1965.

Introduction

The purpose of this article is to document the history and mapping of the oldest known red-bed copper deposit in the Midcontinent. Sedimentary copper deposits in red beds were noted in Oklahoma by Capt. Randolph B. Marcy in 1849–1852 while he was exploring southwestern Oklahoma (Marcy and McClellan, 1854, p. 150–185; Marcy, 1856, p. 8; 1866, p. 120–123, 188). Early studies were made by Haworth and Bennett (1901), Tarr (1910), Fath (1915), Reiter (1920), and Merritt (1940). Approximately 35 red-bed copper deposits were noted in Oklahoma by Fay (1975, p. 153).

The common copper mineral that formed in the red beds was chalcocite, which was later altered to malachite (green) and azurite (blue). Gold, silver, and uranium have been found associated with some of the deposits. Native copper also has been found (Shockey and others, 1974; Hale, 1981; Totten and Fay, 1982).

A common theory for the origin of these deposits is that the metallic ions were carried in solution under oxidizing conditions from surrounding uplands and deposited in a basin under reducing conditions; evaporation was also a factor after deposition. Smith (1976) and Renfro (1974) discuss the sabkha process. Later, ground water moved through the rocks near the surface, probably concentrating the copper in the more permeable siltstones and sandstones, especially along fault zones.

Location

The Paden Prospect is located in southwestern Okfuskee County, Oklahoma, ~4 mi southwest of Paden, and 5 mi east-southeast of Prague, which is in Lincoln County (Fig. 1). The mined area can be reached by going 4 mi east of Prague on U.S. Highway 62 to a curve that intersects a section-line road, then turning south 1.5 mi to the end of the road (Fig. 2). Follow the old road south-southeast for about one-eighth mile, then turn eastward for about three-eighths mile, then south for about one-eighth mile. The mined area is about one-eighth mile west and slightly southwest, mainly in the NE¼NW¼SE¼SW¼ sec. 31, T. 12 N., R. 7 E. (Fig. 3). The Prague NE Sheet (scale 1:24,000) is a modern topographic map of the area (USGS, 1967).

[1]Oklahoma Geological Survey.

Stratigraphy

The copper minerals occur in greenish-gray sandstone pods and veins, within a 35-ft bed of reddish-brown fine-grained sandstone; the pods are in the upper part and the veins in the lower part of the sandstone (Fig. 4). The Copper sandstone occurs in the lower part of the Ada Group (Pennsylvanian, Virgilian). The Ada Group, which occurs in north-central Oklahoma (Fig. 1), is mainly red-brown shale and fine-grained sandstone, ~150 ft thick, that dips about one-half degree or more westward. Just above the Ada is the Vanoss Group, with a thin limy greenish-gray siltstone at the base, correlated as the Reading Limestone or Bed. The Reading does not occur in Okfuskee County. Below the Ada is the Vamoosa Group of fine-grained sandstones and red-brown shales, with some chert conglomerates, ~675 ft thick. The Lecompton Limestone (<10 ft thick) occurs at the base of the Ada and is composed of several thin dolomitic limestones, each <1 ft thick, separated by greenish-gray shales. The basal Lecompton is composed of two beds, each ~8 in. thick, or more; the upper bed is reddish-brown, resembling bricks, and the lower bed is yellowish-brown. These two units are correlated as the Beil Limestone (Fig. 2). A greenish-gray shale, about 3–5 ft thick, occurs above the Beil. The upper Lecompton is a thin tan dolomitic limestone ~1 ft thick. Ries (1954) mapped the area, but did not attempt to subdivide the Ada Group. The Wakarusa Bed of limy siltstone and sandstone is ~20 ft above the top of the Copper sandstone in the Ada Group, and this is shown on the geologic map of the area (Fig. 2). The Wakarusa and Lecompton beds are the only named units of the Ada Group in this region.

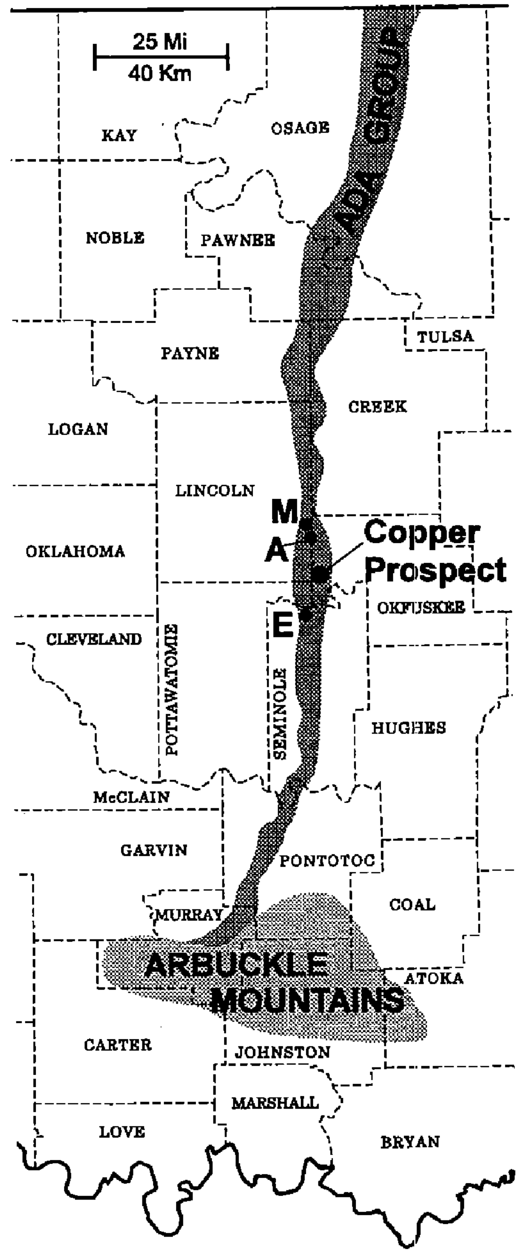
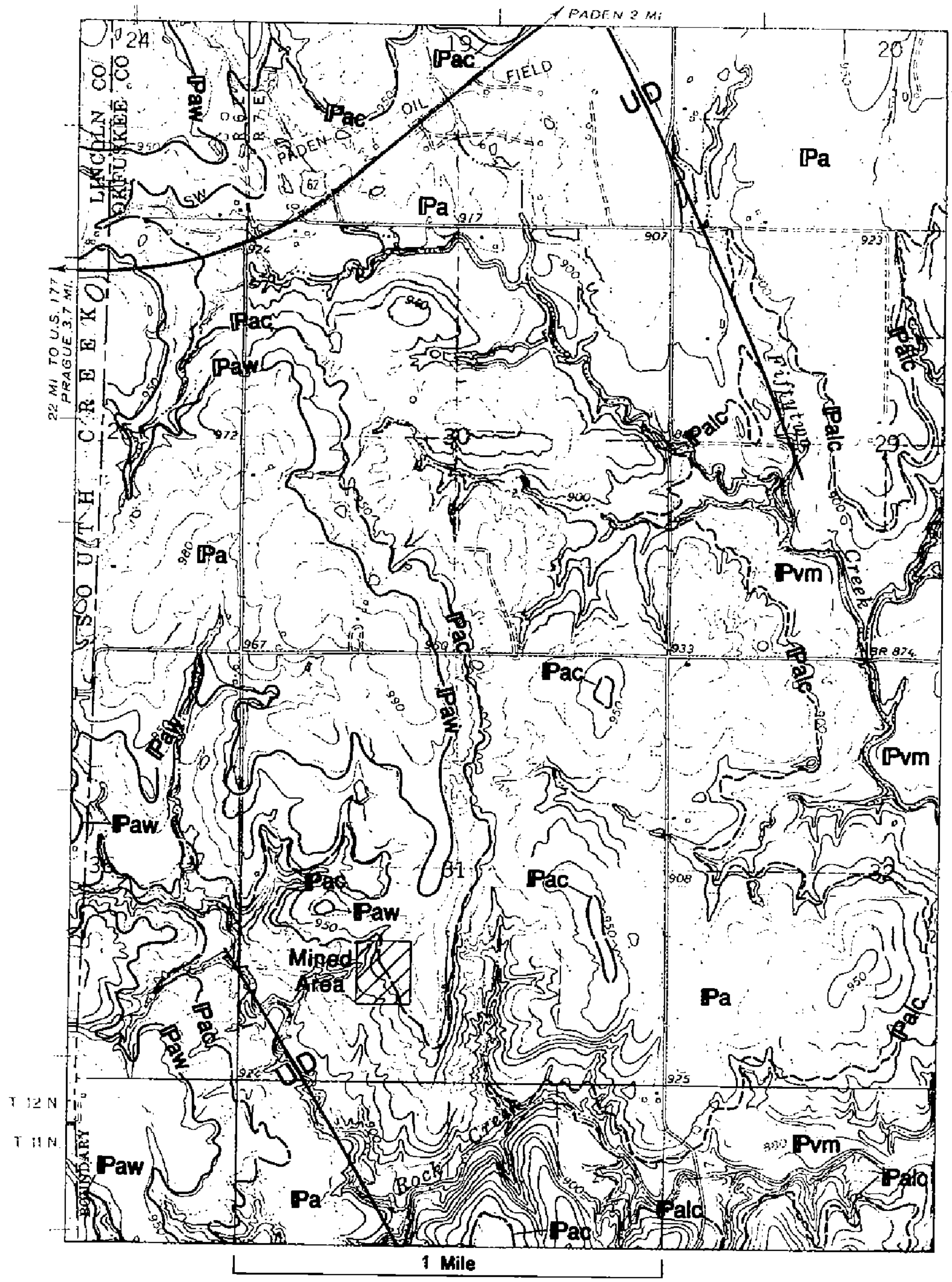


Figure 1. Index map of the Paden Copper Prospect in the Ada Group (Pennsylvanian, Virgilian), Okfuskee County, Oklahoma. Other prospects are the Jack Ellis (E) in Seminole County and the Max Martin (M) and the East Arlington (A) in Lincoln County.

Mineralogy

The main ore mineral is malachite ($Cu_2CO_3(OH)_2$), which is bluish-green in color; it is probably altered from chalcocite (Cu_2S). LaHarpe, an early French explorer who traded with Indians in 1719 near the present-day town of Leonard south of Tulsa, mentions in his journal of that year that the Indians had verdigris or green copper rock for trade. This is probably the earliest mention of malachite in Oklahoma.



Pa —— Paw —— —— Pac —— ---- Palc ----	ADA GROUP (Pa). Red-brown sh. and fine-grained ss.; 150+ ft thick; top not exposed. **Wakarusa Bed** (Paw) limy siltstone and ss. about 50 ft below top. **Copper sandstone bed** (Pac at top) is ~35 ft thick; top ~20 ft below *Wakarusa Bed*. **Lecompton Ls.** (Palc) is 5–10 ft thick; at base; consisting of two dolomitic ls. beds 8–22 in. thick, separated by greenish-gray sh.; the basal ls. is correlated as the *Beil Ls.* ~30 ft below base of Copper sandstone.
Pvm	VAMOOSA GROUP (Pvm). Red-brown sh. and ss. ~675 ft thick; with some chert conglomerates.

Figure 2. Geologic map of the Paden prospect area. Base is the U.S. Geological Survey Prague NE quadrangle (1967), scale 1:24,000. The mined area (lined rectangle) is in the SW1/4 sec. 31, T. 12 N., R. 7 E., in southwestern Okfuskee County, Oklahoma.

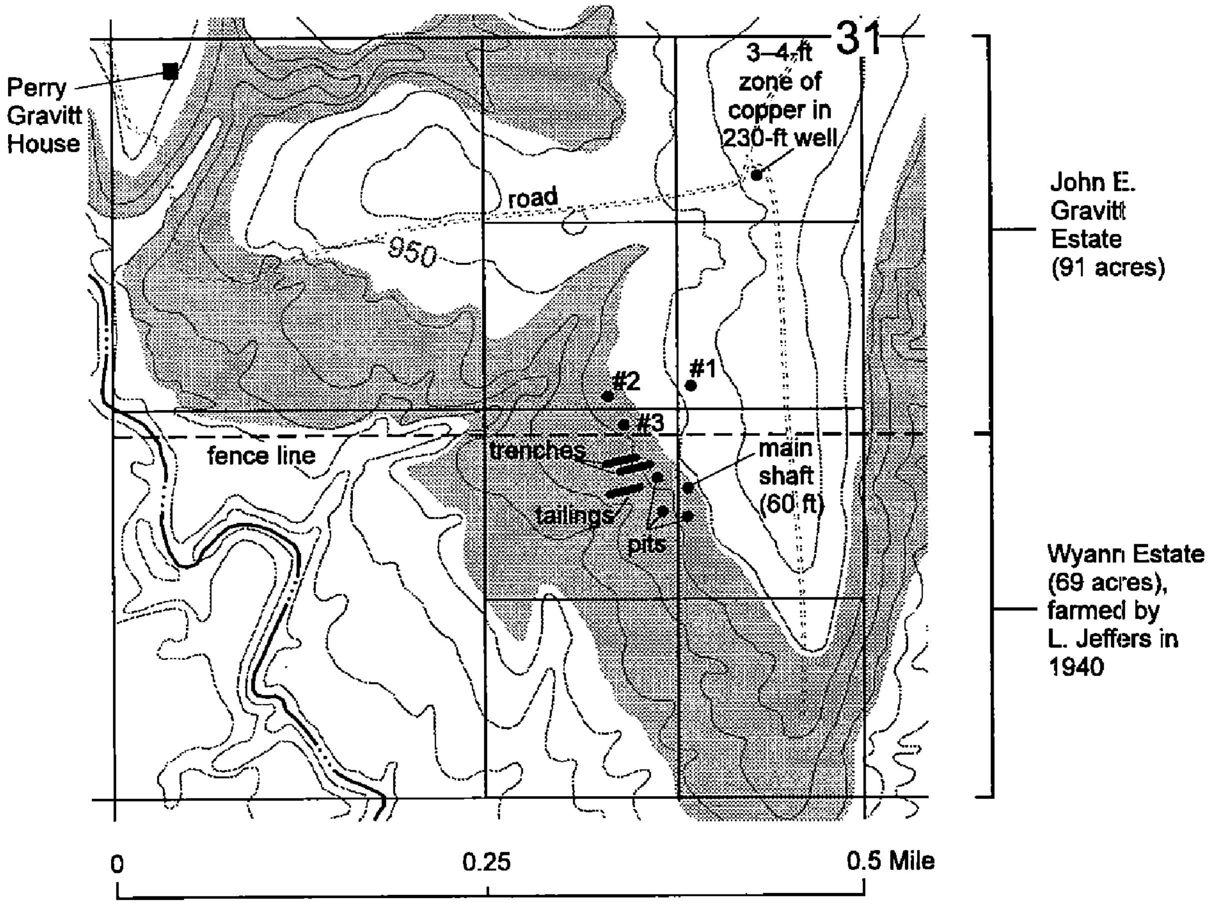


Figure 3. Detailed geologic map of mined area in the SW¼ sec. 31, T. 12 N., R. 7 E., showing Copper sandstone (shaded area), and main shaft, pits, tailings, trenches, and a well.

Merritt (1940) was the first mineralogist to visit the Paden prospect. He noted other minerals, such as azurite ($Cu_3(CO_3)_2(OH)_2$), calcite ($CaCO_3$), chrysocolla ($Cu_2H_2(Si_2O_5)(OH)_4$), dolomite ($CaMg(CO_3)_2$), hematite (Fe_2O_3), limonite ($Fe_2O_3 \cdot H_2O$), melanterite ($FeSO_4 \cdot 7H_2O$), native copper (Cu), pyrite (FeS_2), and tenorite (CuO), in the main Copper sandstone. He also noted other minerals from a core taken from a limestone or dolomite bed (probably the Lecompton Limestone), ~50 ft below the Copper sandstone pods. The minerals were galena (PbS), pyrite (FeS_2), and sphalerite (ZnS). Merritt thought that local faults helped to localize the copper deposits. In 1925, some gold and silver had been recovered from the ore at El Paso, Texas, where it had been shipped for smelting.

Mining History

Soon after World War I, about 1919–1920, Mr. John E. Gravitt purchased 91 acres of land, mostly in the N½SW¼ sec. 31, T. 12 N., R. 7 E., and a small strip of 11 acres in the northern part of the S½SW¼ sec. 31 (Fig. 3). His son, Perry Gravitt, built a house ~300 ft from the northwest corner of the property. In 1925, John Gravitt scraped up several wagon loads of ore from the surface in the upper part of the Copper sandstone and took the ore to Paden, for shipment to El Paso, Texas. Some

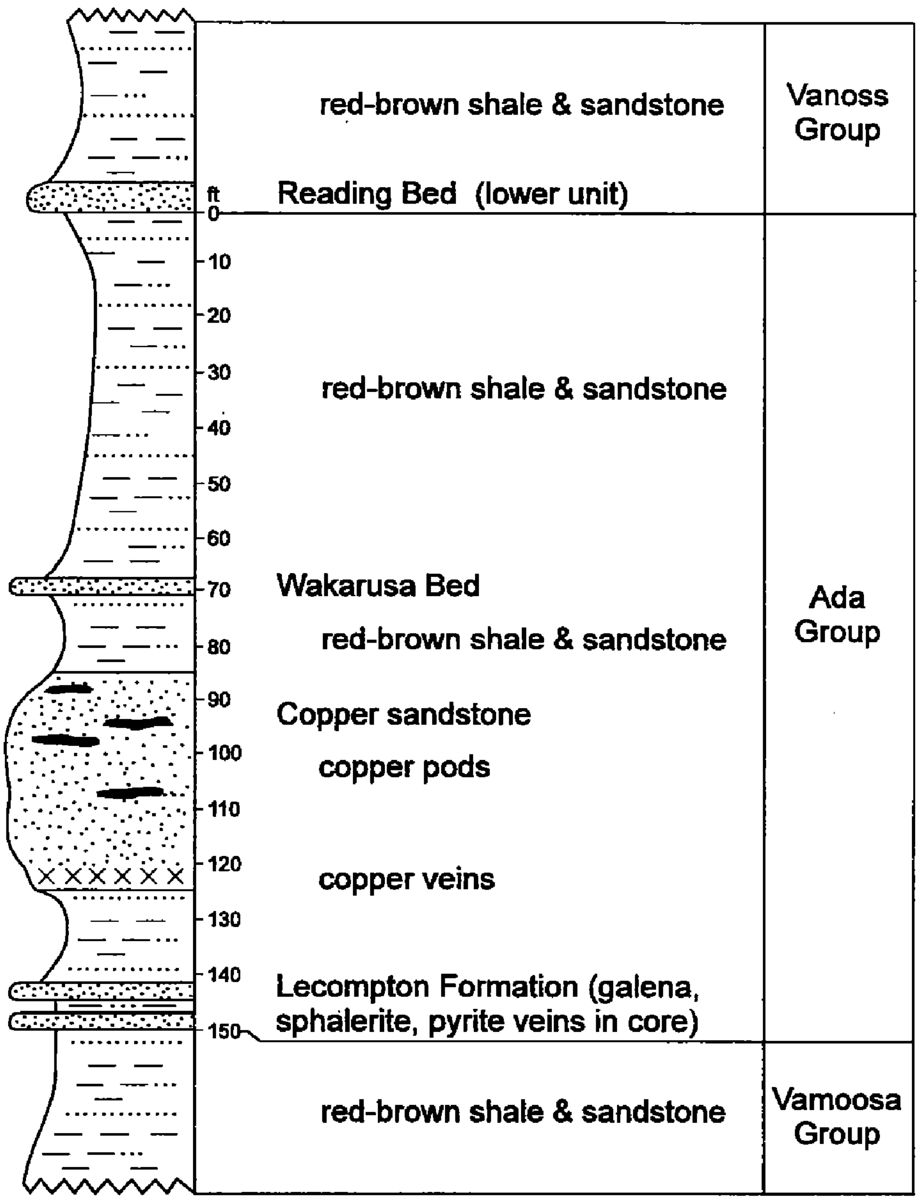


Figure 4. Stratigraphic column of Ada Group in Okfuskee-Lincoln Counties area, showing position of the Copper sandstone. The Reading Bed is not present in Okfuskee County.

gold and silver was noted in the assays. About 25 tons was mined, and John Gravitt cleared about $200 after expenses.

In 1931, two oil men from Oklahoma City, Mr. Charles F. Urschel and Mr. Walter Jerrett, leased the Gravitt farm and the 69-acre Wyann Estate to the south, farmed by Mr. L. Jeffers. Mr. Urschel later became famous after being kidnapped by George R. Kelly Barnes (alias "Machine Gun Kelly") on July 22, 1933, from his home at 327 N.W. 18th St. in Oklahoma City (Kirkpatrick, 1934, p. 135). Urschel and Jerrett hired two middle-aged miners from the Joplin-Miami District to mine the copper ore and paid them 30¢ an hour. They sank one deep shaft, ~60 ft deep, in the SW¼ NW¼NW¼SE¼SW¼ sec. 31, T. 12 N., R. 7 E. The 30-ft level was mined laterally, following a 2-ft vein along cross-faults. A pump was used to keep out the ground water, and the miners dug in a constant rain of mist. According to Merritt (1940), several other shafts, 26–30 ft deep, were dug. About 30 tons of ore was mined and shipped to El Paso, Texas. When I visited the area in 1970, I found the main shaft and six smaller pits or shafts, two east-west trenches, and some tailings from the main shaft, all shown in Figure 3. I collected some of the ore minerals from pit no. 3 (Figs. 5, 6).

After John Gravitt passed away, his son maintained interest. Mr. Perry Gravitt located four other copper prospects in northern Seminole County and southeastern Lincoln County, one in the Reading Limestone, one in the Wakarusa Bed, and two below the Wakarusa Bed.

Since the early 1950s, Mr. Roy Ellis, a grandson of John Gravitt, has taken care of the leases. He is the son of one of John Gravitt's daughters, and lives in Prague, Oklahoma, at the Ellis Courts (Box 815). In 1970, the only living heirs were Mr. Ellis' mother and her sister. Mr. Ellis, who worked in the mines while he was in high school, related much information about the mines, and I was able to update the mine's history from the original papers, in his possession. About eight leases were made from 1950 to 1965, as follows:

1. A Mr. Henson of Estes Park, Colorado, looked at the area in the early 1950s.
2. Osage Petroleum Corporation of Bartlesville, Oklahoma, leased the area in the 1950s.
3. Cedar Creek Coal Company, Box A, Shady Point, Le Flore County, Oklahoma. Mr. John Mixon leased the area and did some drilling, and has assays from Denver, Colorado.
4. L. D. Matson of Fort Worth, Texas, cored the area in 1955.
5. Rogers County Coal Company leased the area in 1956.
6. Eagle-Picher Company of Miami, Oklahoma, had an interest but did not lease.
7. Harold Morgan, attorney and State senator, and H. R. Kimberling of Vinita, Oklahoma, cored the area.
8. In 1965, Mr. Gene Taylor of the Ben Hur Mining Company, Box 807, 121 N. 4th St., Henryetta, Oklahoma, cored the area. One core was 400 ft deep. The cores were donated to the Oklahoma Geological Survey.

I was not able to locate the core holes or where the above-mentioned holes were drilled. A well was drilled in the NE¼NE¼SW¼ sec. 31, T.12 N., R. 7 E., to 230 ft, and a 3- to 4-ft zone of copper minerals was found. The Ben Hur Company cored in the NE¼, SE¼, and SW¼ of sec. 31, T. 12 N., R. 7 E. Apparently no one mined the area after 1931.

Other Prospect Areas

As previously mentioned, Mr. Perry Gravitt found four other areas of copper prospects. Two areas are in Seminole County ~4 mi south-southwest of the Paden Prospect, in the N½ sec. 35, T. 11 N., R. 6 E. They are in the Ada Group, in sandstones below the Wakarusa Bed, ~1 mi south of the North Canadian River. In one area (NE¼NE¼ sec. 35), old pits that were dug in a bluff in 1933 are now covered by alluvium. The copper horizon was just below the Wakarusa Bed. The other location is low in Turkey Creek (NE¼NE¼ sec. 35), ~40 ft below the Wakarusa Bed. It is also covered now by alluvium. Mr. Jack Ellis of Centerview, 3 mi north of the river on State Highway 99, who lived in the section 35 area in the 1930s, gave me this information. Mrs. Bart Aldrige of Wewoka owned the property in 1970. I have named these two areas the Jack Ellis Prospects (Fig. 1).

Figure 5. Gravitt Mine area (March 29, 1973), pit no. 3, looking east at upper part of the Copper sandstone in the NW¼NE¼NW¼SE¼SW¼ sec. 31, T. 12 N., R. 7 E., Okfuskee County, Oklahoma.

Figure 6. Close-up view of pit no. 3, Gravitt Mine area (March 29, 1973), looking east at a malachite-limonite streak (marked by geology hammer, 12 in. long) in the upper part of the Copper sandstone.

The third area of copper prospect found by Mr. Perry Gravitt, which I have named the East Arlington Prospect (Figs. 1, 7), is in Lincoln County, 6 mi north and 1.5 mi east of Prague, near an old spring. In a 15-ft bank, now caved in, some copper mineral shows were reported in a sandstone that correlates with the Wakarusa Bed in the Ada Group. The bank is ~300 yds west and 100 ft south of the north quarter corner sec. 27, T. 13 N., R. 6 E.

In Lincoln County, on the Max B. Martin place, 7 mi north and 1 mi west of Prague, in the SW¼SW¼ sec. 16, T. 13 N., R. 6 E., malachite occurs in the lower part of the Reading Limestone. I have named this area the Max B. Martin Prospect (Figs. 7–9). The lower Reading forms a mappable escarpment in the area, and the bed is exposed on the east side of a small creek that runs north-northeastward into Deer Creek, ~400 ft east and 225 ft north of the southwest corner of sec. 16. The bed is ~1 ft thick there, and is a greenish-gray and reddish-brown silty limestone, with fossils in places. The beds above and below are reddish-brown shales and sandstones, and the Reading is at the base of the Vanoss Group, above the Ada Group. The geology is shown on Figure 7. The beds dip about one-half degree westward. The area was mapped by Masters (1955); he traced the Reading southward to ~3 mi east of Prague, in sec. 23, T. 12 N., R. 6 E., where the bed is a greenish-gray and reddish-brown sandstone, which makes it difficult to distinguish from others like it.

The Reading is ~80 ft above the Wakarusa Bed. The Wakarusa is ~2 ft thick and is a reddish-brown limestone, gradational into sandstone in places. Apparently, it is not found as a limestone south of sec. 28, T. 13 N., R. 6 E. (just southeast of Arlington). Probably it is a reddish-brown and greenish-gray sandstone or siltstone south of Arlington.

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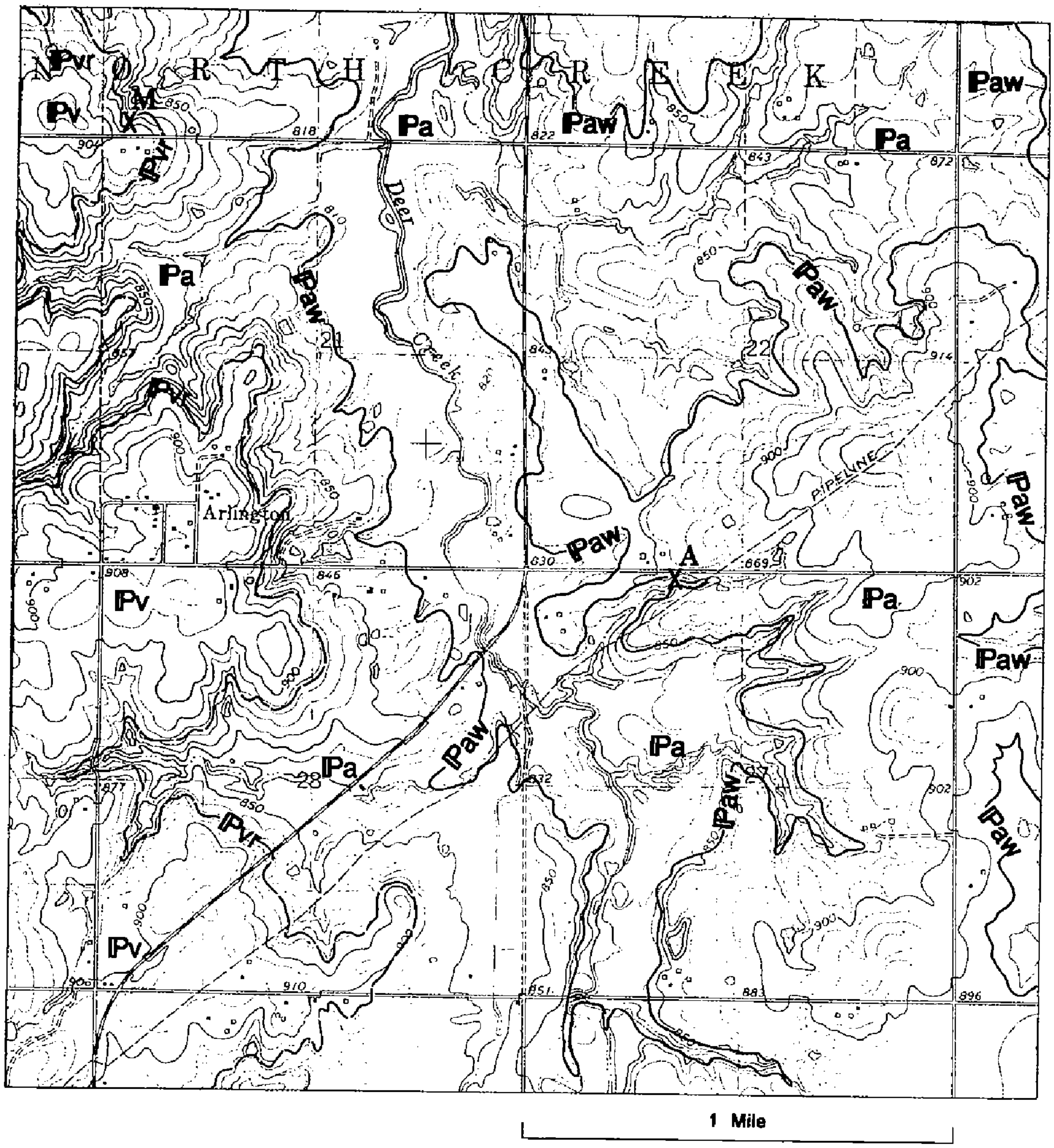

EXPLANATION

IPv —— IPvr ——	VANOSS GROUP (IPv). Red-brown shale and sandstone; with lower part of *Reading Limestone* (IPvr) at base, consisting of red-brown and greenish-gray limestone and siltstone, ~1 ft thick.
IPa —— IPaw ——	ADA GROUP (IPa). Red-brown shale and sandstone, ~150 ft thick; base absent; with lower *Wakarusa Bed* (IPaw), consisting of red-brown and greenish-gray limestone and siltstone ~2 ft thick, ~80 ft below top.

X[A] - East Arlington prospect   X[M] - Max B. Martin prospect

Figure 7. Geologic map of Max Martin Prospect and East Arlington Prospect areas. Base is U.S. Geological Survey Arlington Sheet (1974), scale 1:24,000. The Martin Prospect (M) is in the SW¼SW¼ sec. 16, T. 13 N., R. 6 E., and the East Arlington Prospect (A) is in the NE¼NW¼NE¼NW¼ sec. 27, T. 13 N., R. 6 E., in Lincoln County, Oklahoma.

Figure 8. View looking east at the Martin Prospect (March 29, 1973) in Reading Bed at base of Vanoss Group, 400 ft east and 225 ft north of the southwest corner of sec. 16, T. 13 N., R. 6 E., Lincoln County, Oklahoma.

Figure 9. Close-up view of Martin Prospect (March 29, 1973), looking north, showing malachite lentils in basal Reading siltstone. Geology hammer is 12 in. long.

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——— 1974, Arlington quadrangle, Lincoln County, Oklahoma, 7.5-minute series (topographic), scale 1:24,000.

Gertrude Selma Sober *(continued from p. 134)*

find and formed the Indian Mining and Development Company, with capital stock of $1,000,000 and shares priced at $1 each. Gertrude was president and general manager, and Hope (who financed the venture) was a director. The boom years for the Southwest Davis Zinc Field were 1909–1912. Mining declined after 1913 and stopped about 1918. A total of about 1,500 tons of ore was mined (Fay, 1981).

Gertrude pursued her interest in geology even after her involvement in mining ended. A few years after a brief marriage to Chester E. Field in 1918 (she was widowed within eight months), she moved to Norman in 1924 and enrolled at the University of Oklahoma to study geology. She received her Bachelor of Science degree in 1933 at the age of 63. After graduation, Gertrude moved to Oklahoma City, where she lived until her death on November 1, 1949.

Gertrude Sober's achievements were noted during her lifetime. According to an article in a Davis newspaper from about 1909, a monument of zinc ore was proposed to honor her, to be inscribed "Queen of the Arbuckles" (Fay, 1981). No such monument was ever raised, but on September 26, 1988, Gertrude Selma Sober was inducted into the National Mining Hall of Fame in Leadville, Colorado.

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Robert O. Fay

Note: See John W. Hook's related article in this issue (p. 147), about his study of the zinc deposits in the same geographical area for the American Zinc Company in the early 1950s.

A Personal History of the American Zinc Company's 1951–52 Explorations for Zinc in the Arbuckle Mountains, Oklahoma

John W. Hook[1]

In the early spring of 1951, the American Zinc Company transferred me from the East Tennessee Zinc District to Davis, Oklahoma, to explore the zinc deposits in the Arbuckle Mountains. The original three-month assignment was to map and assess the prospects on the Butterly Ranch (secs. 20, 21, 28, T. 1 S., R. 1 E., Murray County, Oklahoma). This work led to a major drilling project and extended my stay in Oklahoma to a year and a half.

The chief geologist for American Zinc, Dr. Charles Oder, and I drove to Joplin, Missouri, the location of the company's office for its Tri-State Zinc District (Missouri, Kansas, and Oklahoma). The company had acquired leases on the zinc prospects on the Butterly Ranch, and the project was operated out of the Joplin office, under the direction of Dan Stewart, district geologist.

In Joplin, I had my first look at aerial photographs of the Arbuckles. The Arbuckle photos were a real eye-opener for me, after working with photos of the heavily wooded hills of the East Tennessee Zinc District. The photos of the Arbuckles' rocky terrain in a semi-arid climate had the appearance of geologic maps. The zinc prospects were in Paleozoic carbonate sediments on the crest of the Arbuckle anticline, 6 mi southwest of Davis. The row after row of dipping formations on the south flank of the anticline were beautifully exposed, in places having the look of rows of tombstones. The crest of the anticline was broken by extensive faulting. In the photos, the faults were marked by well-defined dark lines cutting across the formations. (Later, I discovered in the field that these dark lines were the more lush growth of grass and other vegetation in the weathered fracture zones, in contrast to the more sparse growth on less weathered bedrock.) The north flank of the anticline was nearly vertical.

Dan and Charlie spent a day with me in the field to examine the zinc prospect and to meet John and Rose Butterly, the owners of the ranch (Fig. 1). Sphalerite was exposed in a number of small-scale mines and prospect pits (Fig. 2). We also met Tom Davis, a local realtor who was assisting with the land and mineral acquisition. The town of Davis had been named for one of his ancestors.

I spent the next day in the field with Bill Ham of the Oklahoma Geological Survey. Bill had recently mapped the Arbuckles on aerial photographs (scale: 1 in. = 660 ft) and drafted a geologic map (on a scale of an inch to a mile). I would be mapping the area of zinc deposits on photographs of the same scale, 1 in. to 660 ft, but in much greater detail. I was especially impressed with Bill's ability to hold stereo pairs of photos in front of his eyes and see the relief. For this I needed a stereoscope. I had worked only in the eastern United States up to that time and was delighted by how much of the geology in this new area could be seen on stereo pairs of air photos. The Butterly Dolomite, in which the sphalerite deposits occur, showed up much

[1]Salem, Oregon.

Figure 1. John and Rose Butterly, with a bowl of rattles from rattlesnakes killed on their ranch.

darker than the limestone formations on either side. In outcrop, the dolomite weathered to a dark brown, whereas the limestone was bleached to a very light gray.

Bill and I spent the full day examining the structure and stratigraphy of the prospect area. The formations on the gently dipping south flank of the Arbuckle anticline were relatively simple pancake geology with few faults. The crest was highly faulted, as was the steeply dipping north flank. He left copies of his unpublished geologic map and measured sections with me.

My first objective in mapping the geology was to establish good stratigraphic control. By using Bill Ham's geologic map in conjunction with the aerial photos, I was able to locate a full section of the Butterly Dolomite that was unbroken by faulting. The McKenzie Hill Limestone at the top of the Butterly Dolomite and the Signal Mountain Limestone at the base were clearly visible on the photo. The next morning I proceeded to the base of this unbroken section and started measuring the section. Using the contact with the Signal Mountain Limestone as the 0 bed, I numbered the lithologic contacts within the Butterly to correspond to the number of feet above the base. Thus, a contact 10 ft above the base would be the "10 bed." Charlie Oder had used this method in describing the stratigraphy of the ore zone in the Knox Dolomite in the East Tennessee Zinc District. It had proved to be especially useful in prospecting and mining.

In measuring the section, I found that the Butterly Dolomite contains both fine-grained and coarsely crystalline beds. Some of the very fine grained beds have thin, closely spaced streaks of silt, which give it the appearance of a varved clay. Chert beds in the dolomite often are distinctly different in color and size. Some dolomite beds have sandy zones and small conglomerate pebbles of quartz and feldspar. There was no sphalerite in the measured section; subsequent mapping and core drilling found zinc only in the upper part of the Butterly.

The stratigraphy of the Butterly proved to be remarkably consistent throughout the zinc area. From the initial measured section, it was possible to identify exact stratigraphic units even where only small portions of the Butterly were exposed. However, while the sedimentary features such as the chert beds, sands, and varved zones showed good consistency, the dolomitization did not. The same stratigraphic units could be either limestone or dolomite. In one extensive exposure, which could be traced several hundred feet along strike, the limestone-dolomite contact cut across the bedding. For example, a distinctive varved bed changed from dolomite to limestone along the strike. The abrupt change from the brown weathering of the dolomite to the light gray bleaching of the limestone gave me a textbook example of epigenetic dolomite mineralization.

The *Geologic Map of the Southwest Davis Zinc Field, Arbuckle Mountains, Oklahoma,* compiled by Robert O. Fay (1981), describes the Butterly Dolomite as follows:

> Dolomite, tan, micritic to coarsely granular (dololutite to dolarenite to dolorudite), sandy, jointed, fractured, with many sphalerite veins in upper part; grades into beds above and below and is absent in southwest part of area. Sargent (1969, 1974) treated part of this unit as tectonic dolomite, which contains 2 to 13 percent $FeCO_3$, in contrast to stratigraphic dolomite, which contains 0.7 percent or less $FeCO_3$. Thickness, 210–300 feet.

The field mapping proceeded very rapidly in spite of the complex faulting. The combination of Bill Ham's geologic map and the aerial photos provided an excellent base on which to fill in the details of the stratigraphy and structure.

My initial mapping in the vicinity of the zinc prospects was done on foot. However, as I became familiar with the formations—and after I encountered several large rattlesnakes—I graduated to horseback (Fig. 3). The faults and contacts that I had observed on the aerial photos were easy to confirm from the saddle. My horse, "Ole Wolf," was a gentle animal; when I stopped to take strike and dip measurements, he would stand wherever I dropped the reins.

The structural picture of the prospect area that emerged from my mapping was one of extensional tectonics. The crest of the anticline appeared to

Figure 2. John Hook examining a boulder of zinc ore at the main open pit on the Butterly Ranch.

Figure 3. John Hook on "Ole Wolf" on the West Timbered Hills. The Butterly Ranch is in the background (east).

have been stretched, creating small-scale horst and graben block faulting. The favorable ore beds of the upper part of the Butterly Dolomite occurred only in the down-faulted graben blocks. This important ore zone had been eroded from the horst blocks.

The sphalerite occurs both as bedding replacement and as breccia filling, in association with gangue dolomite. In the breccia deposits, the sphalerite tends to be in direct contact with the blocks of country rock and the dolomite gangue fills the remaining open space in the breccia (Fig. 4). The breccia seems to be of the foundered type caused by solutions, similar to that in the East Tennessee zinc deposits, but I found no exposures sufficient to confirm this observation.

(As an aside, in the East Tennessee district, I had mapped the ore-bearing breccia bodies in great detail as mining progressed. I had been able to demonstrate the downward migration of blocks of country-rock dolomite into voids created by the removal of limestone beds by solutions. Additional control from the mapping of drifts below the breccia zones and drill hole control above demonstrated that these breccias were along slight anticlinal flexures. The opening of tension fractures along the crests apparently created the fracture permeability to permit hydrothermal solutions to dissolve the more soluble limestone beds. The less soluble dolomite beds collapsed into the voids. Blocks of dolomite were sometimes found as much as 25 ft lower in the middle of the stopes than in the undisturbed wall rock on either side.)

The breccias in the main open pit on the Butterly Ranch were very similar to those I had mapped in Tennessee, but the exposure was too limited to adequately demonstrate collapse structures. In any case, the zinc deposits seemed to be strata-bound (now referred to as Mississippi Valley type deposits). Later drilling confirmed the limited stratigraphic range of the ore-bearing breccia.

We had recognized from the beginning of the project that exploratory drilling would be needed to calculate the tonnage of zinc ore present. A program of more than 100 core drill holes was planned on the basis of the detailed geologic mapping. The Minerva Oil Company, which had extensive fluorite, lead, and zinc mines in the Illinois-Kentucky Fluorspar District, and the United States Defense Minerals Administration (DMA) joined American Zinc in funding the explorations.

In September 1951, the DMA program was approved and we hired the Joy Manufacturing Company to do the contract drilling (Fig. 5). We started the project in October with three Joy 12B core drills, which were worked on a single shift through the fall and winter. The following spring we went to two shifts.

The drills were skid mounted and usually pulled from site to site with a pick-up truck. If traction was insufficient for pulling, the pick-up was parked with its brakes set, and the drill rig was skidded toward the truck with the rig's own hoisting cables running through pulleys in the front of the skids. On site, the cables would raise a tubular steel tripod or mast, with which to hoist 20-ft sections of drill pipe. A working platform of wooden planks on railroad cross-ties kept the driller and his helper out of the mud (Fig. 6). The drill pipe was placed in racks along one side of the platform.

We used standard 10-ft core barrels, which had to be pulled after every run. The holes were started with an NX bit for conductor pipe, and a BX bit was

Figure 4. Sphalerite (dark gray) in the main open pit (NE¼NE¼NE¼NW¼ sec. 28, T. 1 S., R. 1 E.) on the Butterly Ranch surrounds boulders of country rock (light gray). White gangue dolomite fills the remaining open space between breccia fragments. This seems to be a foundered breccia caused by hydrothermal solutions dissolving the rock below. Similar breccia bodies are found in the East Tennessee Zinc District. Scale: 3 in. = 1 ft.

used for the casing. The holes were completed with AX tools. The drilling fluid was clear water, piped from ponds on the ranch.

In the first drill holes, we tested the full thickness of the Butterly Dolomite and soon confirmed my field mapping, which limited the ore zone to the Upper Butterly. We therefore switched to testing only that upper zone. One of the first holes was a deep test to penetrate the Royer Dolomite of Cambrian age. Both lead and zinc had been found in this formation in the old Goose Nest Mine, about a mile north of the main open pit on the Butterly Ranch.

The equipment was operated by three experienced drillers who were capable and pleasant to work with. Earl Hayes (an old timer with a severe hearing loss from having listened to too many high-pitched, whining core drills) headed the group. Melvin Eklund ("The Swede," as Earl called him) soon became my hunting and fishing buddy when we were not on the job. Red Vowel, the third driller, sometimes joined Melvin and me on the fishing expeditions to Lake Murray. Local men were hired as helpers on the rigs. Later, Earl had Wally Woodcock come out from Tennessee to act as his helper. In the spring, he moved Wally up to driller when we added the second shift. (At the AIME/SEG meeting in Chicago in 1973, I had dinner with Wally, then a vice president of the Longyear Drilling Company.)

We had good success in finding zinc in the graben blocks on the crest of the Arbuckle anticline, which still contained the favorable upper unit of the Butterly Dolomite. By late spring, we had drilled all of these blocks, but there was not enough ore to justify the construction of a mill in that part of Oklahoma. The obvious target for additional tonnage was the downdip projection of this formation on the south flank of the anticline, but the drilling there proved very disappointing. The holes on the flank showed that the same stratigraphic section was limestone rather than dolomite. All of those holes were barren of zinc.

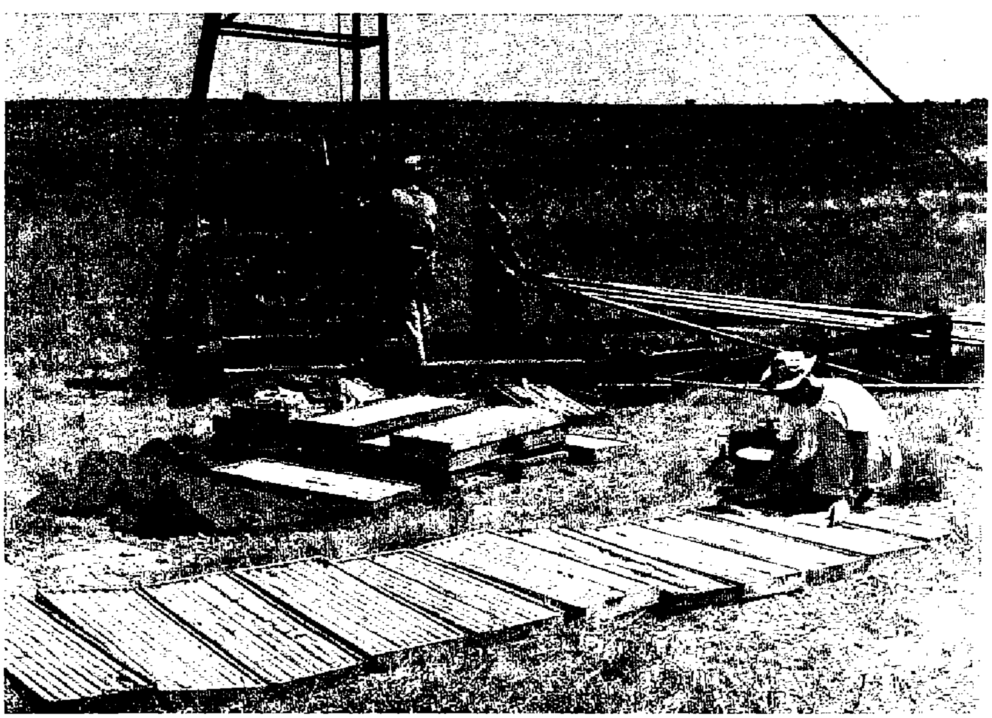

Figure 5. Core drilling on the Butterly Ranch.

Figure 6. Wally Woodcock (left) and helper, with a Joy 12B core drill.

We concluded that both the dolomite and the sphalerite mineralization were of hydrothermal origin confined to the crest of the anticline. Any zinc deposits that might have been in the horst blocks had been eroded away, and the zinc that remained in the graben blocks was not sufficient to justify development. After no zinc was found in multiple test holes along the flank, we terminated the project in late summer 1952.

The text that accompanies the *Geologic Map of the Southwest Davis Zinc Field, Arbuckle Mountains, Oklahoma* (Fay, 1981) lists subsequent interest in the Arbuckle zinc prospects by Eagle-Picher, Cominco-American, Texas Gulf Western, and others. The map was compiled from Bill Ham's mapping on aerial photographs. The photos had been the starting point for the more detailed mapping I did in the vicinity of the zinc prospects. My mapping had subdivided the Butterly Dolomite into units. The upper unit containing the ore-bearing breccia deposits was of much more limited extent than the Butterly Dolomite as a whole.

The Arbuckle zinc prospect was my first major exploration project. Because of the excellent rock exposure, the geology so easily visible on the aerial photographs, and the previous work done by Bill Ham, it was a fun project. While the final results were disappointing in that we did not find enough ore to justify development, it was a job to be proud of. Eventually, I hope that all of the work from this project, including the maps, sections, and drill logs, can be made public.

Author's Postscript—I have been told that the successors to American Zinc will not release my maps or drill logs. However, since the American Zinc-Minerva project was carried out in conjunction with a DMA program, administered by the U.S. Bureau of Mines, the maps and logs may well be public information in some government file. The Bureau of Mines required that we save all of the core. I delivered some cores to American Zinc's Joplin office when the project closed, but, as I recall, most of the cores were left in storage in my field office on the Butterly Ranch.

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Fay, R. O., 1981, Geologic map of Southwest Davis Zinc Field, Arbuckle Mountains, Oklahoma: Oklahoma Geological Survey Map GM-20, 1 sheet, scale 1:7,920; accompanying text, 16 p.

Sargent, K. A., 1969, Geology and petrology of selected tectonic dolomite areas in the Arbuckle Group, Arbuckle Mountains, south-central Oklahoma: University of Oklahoma unpublished M.S. thesis, 84 p.

_______ 1974, Chemical and isotopic investigation of stratigraphic and tectonic dolomites in the Arbuckle Group, Arbuckle Mountains, south-central Oklahoma: University of Oklahoma unpublished Ph.D. dissertation, 182 p.

NEW OGS *Publication*

SPECIAL PUBLICATION 96-3. ***Oklahoma Oil and Gas Production by Field, 1992–95.*** 439 pages. Price: $12.*

This annual publication provides data on reported oil and gas production and related information for each formally recognized field in the State. The volume contains the following types of field data:

- Field name
- County or counties in which the field is located
- Total acreage of the field
- Date the Oklahoma Nomenclature Committee named the field and date of the last revision of field boundaries
- Annual production from 1992 through 1995 by type of product: oil, condensate, total liquids, associated gas, natural gas, and total gas
- Cumulative production from 1979 through 1995 by type of product

Part 1 of this publication includes oil and gas production by county; Part 2 is a summary of production within each county that is not assigned to any formally recognized field. Part 3 is an alphabetical list of all fields, districts, and gas areas that have been formally recognized by the Oklahoma Nomenclature Committee. Part 4 is a listing of discontinued field names.

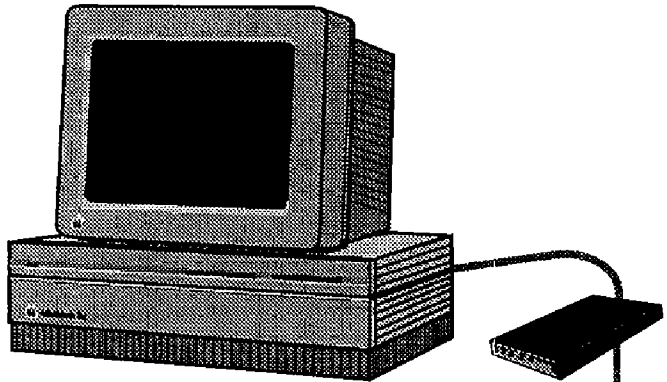
This publication has been developed from data contained in the Natural Resources Information System (NRIS), a computerized data base of oil and gas information for the State of Oklahoma. NRIS currently contains data files of monthly oil and gas production by lease that can be aggregated by such categories as field, producing interval, geologic play, petroleum province, and political area (e.g., county). NRIS also contains digitized records for almost 40,000 well completions and recompletions dating from statehood (1907) to present. The well records include latitude/longitude coordinates that permit plotting and use in a GIS system.

SP 96-3 can be purchased by mail from the Survey at 100 E. Boyd, Room N-131, Norman, OK 73019; fax 405-325-7069. Add 20% to the cost for mail orders.

All OGS publications can be purchased over the counter at the OGS Publication Sales Office's new location at 1218-B W. Rock Creek Road, Norman; phone (405) 360-2886; fax 405-366-2882. Parking is free and readily available.

**Special Offer:* Anyone who purchases SP 96-3 also may receive the past two volumes of *Oklahoma Oil and Gas Production by Field* FREE OF CHARGE, if purchased over the counter (a charge for *postage only* is required for mail orders). Production data for the years 1991–94 are contained in SP 95-2 (postage is $2.40); SP 94-4 (postage $8 for the entire 5-part set) covers the years 1990–93.

OGS Home Page Now Up and Running on the World Wide Web



The Oklahoma Geological Survey now has a World Wide Web home page that lets Internet users access information and send comments back to the Survey. The site contains a calendar of events, list of available publications, earthquake statistics, detailed information about OGS facilities, tectonic and geologic maps, and activities of the South Midcontinent Region of the Petroleum Technology Transfer Council (PTTC).

A comment function makes it easy to send mail directly to the OGS. Connie Smith, OGS promotion and information specialist, hopes that users take advantage of this function to let her know what other information would be interesting and helpful to them.

"We really want to put useful information on these pages and make it quick and easy to access, even with a minimal computer system," Smith said. "So far, we have added information to the Web almost weekly, and other pages are being developed. We are planning a section on geographic names in Oklahoma and already have reproduced an *Oklahoma Geology Notes* article on the geology of Lake Murray (June 1996, p. 106–115). We want to have educational material and items for the general public, as well as technical material for the geological community."

Take a look at the OGS pages at http://www.uoknor.edu/special/ogs-pttc/ and let us know what you think.

Other Geological Organizations with Web Sites:

- **American Association of Petroleum Geologists:** http://www.geobyte.com/
- **American Geological Institute:** http://jei.umd.edu/agi/agi.html
  AGI's list of state geological surveys: http://jei.umd.edu/agi/state.html
- **American Institute of Professional Geologists:** http://www.nbmg.unr.edu/aipg/
- **Association of American State Geologists:** http://www.kgs.ukans.edu/AASG/AASG.html
- **Department of Energy Fossil Energy Program:** http://www.fe.doe.gov/
- **The Fossil Company—Earth Sciences Internet Sites in America:** http://www.gold.net/users/dt89/sites_north_america.html#United_States
- **Geological Society of America:** http://www.geosociety.org
- **Minerals Management Service:** http://www.mms.gov/
- **Petroleum Technology Transfer Council:** http://www.msc.edu/hq/
- **U.S. Geological Survey:** http://info.er.usgs.gov/
  USGS list of Internet resources: http://info.er.usgs.gov/network/science/earth/index.html

OKLAHOMA GEOLOGICAL SURVEY
www.uoknor.edu/special/ogs-pttc/

In Memoriam

LOUISA JOY HAMPTON

OGS Petroleum Geologist

Joy Hampton
(1920–1996)

Louisa Joy Hampton, a petroleum geologist with the Oklahoma Geological Survey since 1981, died Monday, June 3, in Norman. While with the OGS, Joy worked diligently to catalog and file the Survey's collection of well logs, guiding this collection through two major moves. Joy retired from the OGS on August 1, 1992, but continued to help with activities at the Well Log Library. Before joining the Survey staff, she worked for the University of Oklahoma's Energy Resources Institute (ERI).

Joy was born June 4, 1920, in Meeker, to Daniel Duvall and Ethel Myrle Sheese Hampton. She graduated from Central High School in Oklahoma City, then attended the University of Oklahoma, graduating in 1941 with a degree in petroleum geology.

Joy was a pioneer in the Oklahoma petroleum industry—female geologists were almost unheard of in the 1940s. Following her graduation from OU, she spent three and a half years on a seismic crew, working throughout Texas, Georgia, Louisiana, Arkansas, and Oklahoma. She was the only woman in a crew of 10 that tested for favorable oil drilling locations. Her account of this experience was featured in the 1994 book *A Mouthful of Rivets: Women at Work in World War II*, by Nancy Baker Wise and Christy Wise (see accompanying sidebar on next page).

Joy worked with Halliburton in Duncan, Stanolind Oil in Oklahoma, and Mud Control Laboratories in Oklahoma City before joining the Corporation Commission, where she spent 13 years. She moved to Norman from Oklahoma City in 1964.

She was appointed by five Oklahoma governors to serve on the Interstate Oil and Gas Compact Commission, and was an outspoken supporter of the petroleum industry in Oklahoma. She enjoyed working with and encouraging students who were planning careers in petroleum. She was a member of the American Association of Petroleum Geologists, American Institute of Professional Geologists, Oklahoma City Geological Society, University of Oklahoma Associates, and the Norman Business and Professional Women's Club.

Joy loved cooking and entertaining, and hosted many breakfasts and other events for the OGS staff and her friends and extended family. She even cooked breakfast and delivered it to the students who worked on Saturdays at the Log Library.

Her unique perspective and keen wit always made Joy an interesting dinner companion—especially for those who needed an education about the good side of the petroleum business. She was not afraid to speak her mind, but also knew how to "meet and greet" (as she called it), after many years of interaction with other professionals.

Despite some physical problems left from an early bout with polio, Joy had a tremendous amount of energy—both physical and mental. She loved to travel, crochet, decorate her office and home, and plan and implement various building projects for her house. At lunch time, she almost always could be found at the University Club in the Union at the University of Oklahoma, having the "Joy Hampton Special" sandwich at her own reserved table. Joy's zest for life and bright personality will be missed by her many friends and colleagues.

—*Connie Smith*

A Woman in the Oil Patch

When Joy Hampton worked on a seismic crew in 1941, a woman geologist was quite an oddity. Her reflections on her experience as the only woman on a 10-member team were featured in the book *A Mouthful of Rivets: Women at Work in World War II*, by Nancy Baker Wise and Christy Wise (Jossey-Bass Publishers, San Francisco: 1994, p. 60–62). The following passages are reprinted with permission:

I knew how to get along with them. I just became that charming girl who insulted them and giggled. I could throw that line around as good as they could. And we all made the honky-tonks at night. We were transients and people treated us that way. We weren't particularly welcome either. The guys took their families with them. You don't have any social life unless you take it with you.

We didn't stay in motels. Let me tell you that. If you did, you would be that woman who stayed in motels. I got a room in a private home. One woman told me, "Now you can fix your own breakfast here, but I'm not fixing breakfast for anybody." And she fixed it on Sunday and had the hardest old burned-up waffles I ever ate in my life. I just couldn't stand eating those waffles. The men stayed in different homes, too. A lot of people have rooms for rent. A lot of these old maids in Texas wouldn't rent to a woman, they want a man. So I'd go around and they'd have a sign out, and I'd go in and she'd say, "No, I don't have anything." And the boys would follow me around and rent up all the rooms behind me.

The men were deferred for what was considered a defense industry. We got the culls. You could tell just by looking at them.

The crew itself would go out and get the log, the electric log, made on a recorder, right in the truck, in the field, and then we spent the next day working on it. You look for anomalies, and structures. A structure is a formation below the surface. You must have something before you spend all that money drilling.

I was called a junior computer. That was my title. I worked on the records and did the geology work. I really enjoyed that. I got to make maps. There was a guy on the crew who didn't like to make maps and I did. We did all the work in an area and submitted all the maps to the client. There were people who employed us, and their responsibility was to keep us working. I was gone three and one half years, from one job to another.

We had computers and we had special electronic men that ran the records. The electronic gear was all in special trucks. We just moved around. I didn't even have a car. . . .

I had a piece of dynamite luggage. They called the boxes flat 50s because they weren't very deep and they carried fifty pounds of dynamite. So my father turned them inside out, because they wouldn't let you on the train with a box that said "dynamite." And he hinged two of those boxes together, put a lock on it. I still have it. I carry it around. Everybody on the crew had dynamite luggage.

OGS Director Receives Award for Participation in "Clean Cities" Program

Dr. Charles J. Mankin, OGS director, was honored with a certificate for his role in the Clean Cities program that was coordinated by the Association of Central Oklahoma Governments in conjunction with the Department of Energy, Oklahoma Department of Commerce, and Office of the Governor. The program began in 1995, at the urging of Senator Don Nickles and the late Congressman Mike Synar.

The Clean Cities Stakeholder awards were presented at Tinker Air Force Base on May 19, as Tinker Earth Day and the Clean Cities Inauguration were both celebrated at the "Partners on the Prairie" festivities. The celebration featured exhibits, alternative-fuel vehicles for visitors to examine, and speakers who addressed the group in a large aircraft hangar.

The grass-roots Clean Cities program is patterned after the national effort begun by DOE in 1993 to expand the use of alternative-fuel vehicles. To date, 48 cities or regions have created program plans and signed Memorandums of Understanding, as well as created local "stakeholder" committees similar to the one that Dr. Mankin joined.

In central Oklahoma, some 8,000 mail trucks, city and school buses, airport shuttles, police cars, fire trucks, and other vehicles are powered by alternative fuels.

In 1990, the Oklahoma Legislature created some of the nation's first and most innovative alternative-fuel vehicle legislation, providing a revolving loan fund program to public fleets and a 50% tax credit to qualifying citizens. In 1991, Tinker Air Force Base launched an aggressive Alternative Fuels Program. Under partnership agreements, the base tested a variety of clean-burning fuels such as solar, electric, propane, natural gas, and biodiesel. Today, the base has the Department of Defense's largest fleet of alternative-fuel vehicles.

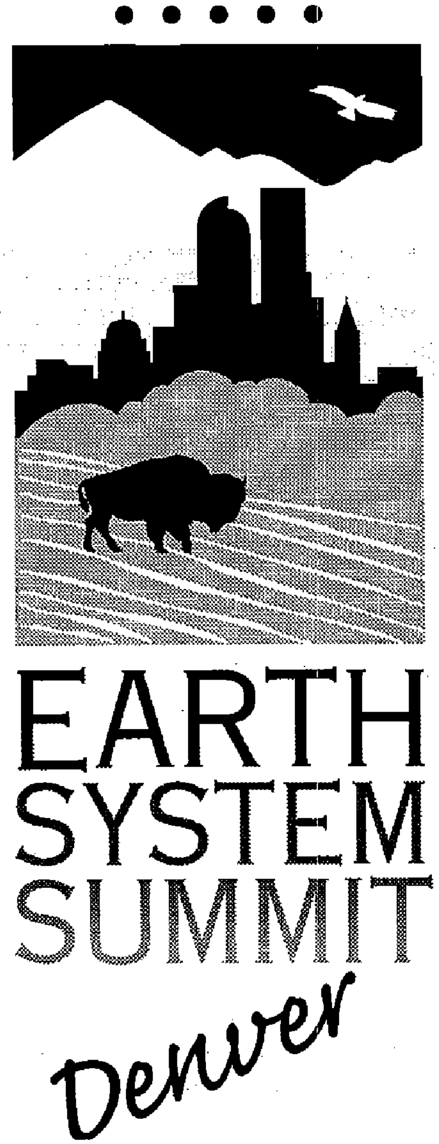
Dr. Charles J. Mankin (left), OGS director, accepts a certificate for his part in the Clean Cities effort from Tommy Folz, National Clean Cities director.

Central Oklahoma is home to one of only six regional alternative-fuel vehicle training centers in the nation, located at the Francis Tuttle Vehicle Training Center in Oklahoma City. Research also is ongoing at the University of Oklahoma, which sponsors programs in electric and propane vehicle research.

The designation of Central Oklahoma to the Clean Cities list was through the cooperation of businesses, major corporations, community leaders, government officials, and state agencies such as the Oklahoma Geological Survey.

—Connie Smith

GSA Annual Meeting
Denver, Colorado
October 28–31, 1996



The theme for the 1996 Denver meeting is Earth System Summit. *The Earth is a complete system whose processes are complexly interrelated at a variety of scales. We are all inhabitants of this amazing system, and our actions can significantly impact, or be impacted by, its dynamic behavior. The gathering of scientists and engineers for the GSA Annual Meeting in Denver, at the base of the Rocky Mountains, will be an intellectual summit, focusing on the Earth System.*

Our keynote symposium, convened by E-an Zen and Karen Prestegaard, considers "Linkages Among Dynamic Processes of Oceans, Continents, and Atmosphere" on a global scale. The Annual Meeting Committee has also recruited symposia on the geologic development of the southern Rocky Mountains, ecosystems and the role of science in their management, and Earth system processes at the last glacial maximum.

Every geologist knows Denver, founded on mining and still known as the Queen City of the Plains. Colorado is booming, and Denver, its capital, is more than keeping pace. It's only a few miles west to the foot of the Rockies. There will be opportunities to get out and to enjoy the scenery. Come to Denver this autumn, to stimulate your mind, to see your colleagues, and to enjoy Colorado.

—Gregory S. Holden and Kenneth E. Kolm
1996 General Co-Chairs

Technical Program

Symposia

Keynote Symposium: Linkages Among Dynamic Processes of Oceans, Continents, and Atmosphere
Tectonic Development of the Southern Rocky Mountains
Dinosaurs, Asteroids, Spotted Owls and Humanity: An Evolving View of Ecosystems and the Role of Science in Their Management
Earth System Processes at the Last Glacial Maximum
Dimensional Scaling and the Stratigraphic Record of Episodic and Periodic Forcing
Interdisciplinary Strategies for Teaching About Earth as a System
Coalbed Methane—From Micropore to Pipeline
The Geoarchaeology of Caves and Cave Sediments
IEE Annual Environmental Forum: Prospects for the Future: Gold and Water in the Earth System
Earth Systems Education: K–16
Recent Advances in Plate Tectonics—What Students Should Know
Geochemical Constraints on Seawater Composition and the Coupled Ocean-Atmosphere System: The Precambrian Revisited
Organic Geochemistry—Linking the Biosphere and Geosphere
Engineering Geology Applications of Geologic Maps
Farvolden Hydrogeology Symposium
Perspectives on Soil-Based Information for Investigating Earth Surface Processes
Planets as Complex Systems
Expanding Boundaries: Geoscience Information for Earth System Science
Seismic Investigations Along the Western Margin and Cordillera of North America: Tectonic Implications
Active Tectonics of Intracontinental Mountain Belts with Implications for Ancient Systems
Alteration Geochemistry: Genetic and Exploration Perspectives
Geoscience Information for Tomorrow's Markets: What Is Wrong with the Present Products
Tectonic Evolution of the Urals and Surrounding Basins
Earth Science–Environmental Justice Summit
Environmental Mineralogy: Science and Politics
The Role of Preferential Flow in the Unsaturated Zone
Biology of the Foraminiferida: Applications in Paleoceanography, Paleobiology, and the Environmental Sciences
Evolutionary Paleoecology
Impact of the Western Surveys
Applications of Reactive Transport Modeling to Natural Systems

Theme Sessions

The U.S. Atlantic Passive Margin: Tectonics, Eustasy, and Sedimentation—A Memorial to James Patrick Owens
History of the Equatorial Atlantic
High-Resolution Glacial Records from Marine and Lacustrine Basins
Application of Soil-Based Information for Understanding Earth Surface Processes
Cretaceous of the Western Interior Seaway, North America
The Rockies Across the Southern Border
Paleozoic and Mesozoic Tectonic History of Central Asia

Appalachian and Cordilleran Melanges: Comparisons and Contrasts
Laramide Sedimentation and Tectonics in the Rocky Mountains
History of Recurrent Basement Faulting in Cratonic North America and Its Orogenic Margins
Geologic and Hydrologic Studies of Fluid Flow in Faults
Evolution of the Neogene Strain Field in the Southeastern Great Basin: Roles of Faults, Folds, and Magmatism
Neogene and Quaternary Geology of the Yucca Mountain Region, Nevada, and Its Relevance to Long-Term Nuclear Waste Isolation
Seismic Investigations Along the Western Margin and Cordillera of North America: Data and Earth Models
Cenozoic Uplift of the Western United States
Precambrian Lithosphere I: Proterozoic Tectonics—Modification of Archean Cratons and Additions of Juvenile Crust
Precambrian Lithosphere II: Mid-Proterozoic Magmatism and Tectonics of Western North America
Precambrian Lithosphere III: Middle Crustal Processes
Volcanism, Tectonism, and Sedimentation in the Rio Grande Rift and Its Margins in New Mexico and Colorado
Magma Generation and Evolution at Convergent Margins
High and Ultrahigh Strain Rate Processes in the Earth and Planetary Sciences
Mapping Other Worlds
Jupiter: Solar System Exploration Continues
Application of Reactive Transport Modeling to Natural Systems
Mineralogy of Planetary Surfaces Using In-Situ Analysis and Remote Sensing
Environmental Mineralogy
Hydrogeology of Confining Units I: Sampling, Analysis, and Interpretation
Hydrogeology of Confining Units II: Physical and Biogeochemical Processes
Field-Scale Investigations of Biodegradation
Scale Effects of Fluid Flow and Fractures
Geofluids: The Role of Fluids in Crustal Processes
Applications of Isotopes for Understanding Hydrologic Systems
High Plains Hydrogeology
Physical and Chemical Heterogeneity: Impact on Reactive Transport
Innovations and Applications of Inverse Ground-Water Models
Evaporite Karst: Origins, Processes, Landforms, Examples, and Impacts
The Death Valley Hydrogeologic System
Physical and Chemical Heterogeneity: Impact on Samples and Measurements at Wells
Diagenetic Processes at Waste-Disposal Sites
Global Impacts of Mining and Urbanization on Fluvial and Coastal Systems
Environmental Geology: The Voice of Reason
Clean-Up at Rocky Flats, a Former Nuclear Weapons Plant: Application of Science to Site Remediation Plans
Integrated Site Characterization for Waste Disposal
Interpretation of Continental Sedimentation Patterns Using Surface and Subsurface Data
The Impact of Geologic Heterogeneities on Characterization, Transport, and Remediation of Non-Aqueous Phase Liquids (NAPLs) at Hazardous Waste Sites
Rates of Geologic Processes in the Holocene
Mechanics of the Riverbed: Hydrology, Sedimentology, and Geomorphic Consequences
Integrated Digital Databases in Tectonics and Geomorphology
Improving Geoscience Courses Through the Use of the Internet and the World Wide Web
Roles of Multiple Intelligences and Creativity in Teaching, Learning, and Doing Geoscience

National Parks as Classrooms for Geoscience Education
The Role of Geology Field Camp in the Geology Curriculum: An Appraisal
Geology Field Camp Exercises in the Rocky Mountains
Linking Natural and Social Systems in Geoscience Education: Pedagogy, Content, and Context
Organics-Ore Interactions in the Field and Laboratory
The Magmatic-Hydrothermal-Epithermal Transition and Associated Alteration and Mineralization
Quantifying the Environmental Impacts of Mining

Field Trips

Premeeting

The Absaroka Range: A Fifty-Million-Year Fascination with Gravity, North-Central Wyoming, *Oct. 23–26*
Geology of the Solitario Dome, Laccolith, and Caldera System, Trans-Pecos Texas, *Oct. 23–27*
A New Look at the Laramide Orogeny in the Seminoe and Shirley Mountains, Freezeout Hills, and Hanna Basin, South-Central Wyoming, *Oct. 24–27*
Hayden's Lakes Revisited: The Origin and New Stratigraphic Interpretations of the White River Sequence, South Dakota, Nebraska, and Wyoming, *Oct. 24–27*
Permian-Triassic Deposystems, Paleogeography, Paleoclimate, and Hydrocarbon Resources in Canyonlands and Monument Valley, Southeastern Utah, *Oct. 24–27*
Proterozoic Magmatism in Southeastern Wyoming: Evidence for the Cogenetic Relationship Between Anorthosites and Rapakivi Granites, Laramie Mountains, South-Central Wyoming, *Oct. 24–27*
Synchronous Oligocene and Miocene Extension and Magmatism in the Vicinity of Caldera Complexes in Southeastern Nevada, *Oct. 24–26*
Geology and Geologic Hazards of the Glenwood Springs Area, Central Colorado, *Oct. 25–27*
Geology of the Western San Juan Mountains and a Tour of the San Juan Skyway, Southwestern Colorado, *Oct. 25–26*
Sequence Stratigraphy of the Muddy Sandstone and Equivalent Rocks from North-Central Colorado to Northeastern New Mexico, *Oct. 25–27*
Kinematics of the Slumgullion Landslide, Lake City, Colorado, *Oct. 26–27*
Petroleum System, Sequence Stratigraphy, Wrench Faulting, and Reservoir Compartmentalization, Central Denver Basin, Colorado, *Oct. 26*
Laramide Orogeny and Cenozoic Erosional History, Front Range and Denver Basin, Colorado, *Oct. 27*
State Line Kimberlite District, Colorado, *Oct. 26*
Field Workshop—Innovative Techniques for Shallow Soil and Ground-water Investigations, *Oct. 26*

Half Day—Concurrent with the Meeting

Geology Tour of Denver Buildings and Monuments, *Oct. 28* or *Oct. 30*
Dinosaur Ridge and Reconnaissance Along Alameda Parkway, *Oct. 29* or *Oct. 31*
Proterozoic Crystalline Rocks of Clear Creek Canyon, *Oct. 29* or *Oct. 31*
Tour of the U.S. Geological Survey Mapping and Geologic Facilities, Denver Federal Center, *Oct. 29* or *Oct. 30*

Postmeeting

Dunes, Rivers, Lakes, and Wetlands: Tales from the Nebraska Sand Hills of Western Nebraska, *Oct. 31–Nov. 2*

Evidence for Early Proterozoic Reworking of Archean Rocks in the Central Laramie Range, Southeastern Wyoming, *Oct. 31–Nov. 3*
Hydrogeology of the San Luis Valley and Summitville Mine, South-Central Colorado, *Oct. 31–Nov. 2*
Jemez Volcanic Field and Valles Caldera–Middle Rio Grande Rift, *Oct. 31–Nov. 3*
Cretaceous-Tertiary Boundary in the Southern Peninsula of Haiti, *Nov. 1–Nov. 3*
Depositional Environments of Codell–Juana Lopez Sandstones and Regional Structure and Stratigraphy of Cañon City and Huerfano Areas and Northern Raton Basin, South-Central Colorado, *Nov. 1–3*
Geology and Paleontology of the Gold Belt Back Country Byway: Florissant Fossil Beds and Garden Park Fossil Area, *Nov. 1–2*
Oblique Laramide Convergence in the Northeastern Front Range of Colorado: Regional Implications from the Analysis of Minor Faults, *Nov. 1*
Precambrian Tectonics and Metallogeny of the Hartville Uplift, Wyoming, *Nov. 1–3*
Soil-Geomorphic Relationships Near Rocky Flats, Boulder and Golden, Colorado Area, with a Stop at the Pre-Fountain Formation Paleosol of Wahlstrom (1948), *Nov. 1*
Tertiary Intrusive Rocks of the Spanish Peaks and the Laramide Structure of the Western Margin of the Raton Basin, South-Central Colorado, *Nov. 1–2*
Upper Cretaceous Coals of the Western Interior Seaway, Northwestern Colorado, *Nov. 1–3*
Cresson Mine, Cripple Creek District, Colorado, *Nov. 1*

Short Courses/Forums/Workshops

Geophysical Map Interpretation on the PC, *Oct. 24–26*
Reactive Transport in Porous Media: General Principles and Application to Geochemical Processes, *Oct. 25–27*
Geomorphic Expression of Active Tectonics, *Oct. 26–27*
How to Do Anything with Mohr Circles (Except Fry an Egg): A Short Course About Tensors for Structural Geologists, *Oct. 26–27*
New Numerical Techniques for Sedimentary Data: Fractals and Nonlinear Dynamics, *Oct. 26–27*
Applications of Microanalytical Techniques to Understanding Mineralizing Processes, *Oct. 26–27*
Systematics of Fluid Inclusions, *Oct. 26–27*
Biology and Paleobiology of Corals, *Oct. 27*
Digital Database Forum, *Oct. 27*
Applications of Environmental Isotopes to Solving Hydrologic and Geochemical Problems, *Oct. 27*
Applications of GPS in the Earth Sciences, *Oct. 27*
Effective Teaching of Hydrogeology: How to Make Do with Scant Real World Data, *Oct. 27*
Recognition, Investigation, and Mitigation of Landslides, *Oct. 27*
Vadose Zone Hydrology: Introduction and Applications to Water and Solute Transport, *Oct. 27*

For more information about the annual meeting, contact GSA, Meetings Dept., P.O. Box 9140, Boulder, CO 80301; (800) 472-1988 or (303) 447-2020; e-mail: meetings@geosociety.org; World Wide Web: http://www.geosociety.org. The preregistration deadline is *September 20.*

UPCOMING *Meetings*

Society of Petroleum Engineers, Annual Meeting, October 6–9, 1996, Denver, Colorado. Information: AAPG Convention Dept., P.O. Box 979, Tulsa, OK 74101; (918) 584-2555.

American Institute of Professional Geologists, Annual Meeting, October 8–12, 1996, Columbus, Ohio. Information: AIPG, 7828 Vance Dr., Suite 103, Arvada, CO 80003; (303) 431-0831, fax 303-431-1332.

Society of Vertebrate Paleontology, Annual Meeting, October 16–19, 1996, New York, New York. Information: SVP, 401 N. Michigan Ave., Chicago, IL 60611; (312) 321-3708, fax 312-245-1085; e-mail: svp@sba.com.

AAPG/EAPG International Research Symposium, "Compartmentalized Reservoirs: Their Detection, Characterization, and Management," October 20–23, 1996, Houston, Texas. Information: Education Dept., American Association of Petroleum Geologists, P.O. Box 979, Tulsa, OK 74101; (918) 560-2621, fax 918-560-2684.

Society of Exploration Geophysicists, Annual Meeting, November 10–14, 1996, Denver, Colorado. Information: AAPG Convention Dept., P.O. Box 979, Tulsa, OK 74101; (918) 584-2555.

Workshop on Tuffs—Their Properties, Uses, Hydrology, and Resources, November 10–15, 1996, Santa Fe, New Mexico. Information: Grant Heiken, Earth and Environmental Sciences Division, EES-1, Los Alamos National Laboratory, Los Alamos, NM 87545; (505) 667-8477, fax 505-665-3285.

Next FDD Workshop Features Cleveland and Peru Plays

The Oklahoma Geological Survey will present a one-day workshop, "Fluvial-Dominated Deltaic (FDD) Oil Reservoirs in Oklahoma: The Cleveland and Peru Plays," on October 17, 1996, at the Phillips Petroleum Company Research and Development Center in Bartlesville.

The registration fee for operators in these plays is $15; for other attendees it is $25. (Note: The $15 fee is for only one representative from each company; additional registrants will need to pay $25.) The cost includes lunch and a copy of the play workbook, *Fluvial-Dominated Deltaic (FDD) Oil Reservoirs in Oklahoma: The Cleveland and Peru Plays.* Cleveland and Peru operators have priority status to attend if registered by October 3; the registration deadline for other attendees is October 14.

The workshop is the fifth in a series of eight workshops to be presented as part of the Fluvial-Dominated Deltaic Oil Reservoirs project, which involves participation from the OGS, the University of Oklahoma's Geo Information Systems, and the OU School of Petroleum and Geological Engineering.

For more details or for registration forms, contact Michelle Summers, Oklahoma Geological Survey, 100 E. Boyd, Room N-131, Norman, OK 73019; (405) 325-3031 or (800) 330-3996; fax 405-325-7069.

Oklahoma ABSTRACTS

The Oklahoma Geological Survey thanks the American Association of Petroleum Geologists and the Geological Society of America for permission to reprint the following abstracts of interest to Oklahoma geologists.

Age and Source Characteristics of Mount Scott Granite, OK

M. DEGGELLER and *J. E. WRIGHT*, Dept. of Geology and Geophysics, Rice University, Houston, TX 77005; *J. P. HOGAN, M. C. GILBERT*, and *J. D. PRICE*, School of Geology and Geophysics, University of Oklahoma, Norman, OK 73019

The A-type Mount Scott Granite is the largest member of the Wichita Granite Group of the Cambrian Southern Oklahoma Aulacogen. It is a medium-grained leucocratic alkali-feldspar, amphibole, biotite granite. Magmatic plagioclase is present but not abundant. Primary accessory minerals include magnetite, ilmenite, titanite, zircon, apatite, and fluorite. Mount Scott Granite crystallized from a high T (900–950°C), H_2O-poor and F_2-rich magma emplaced non-explosively at low P (10^2 bar range) beneath an ≈coeval rhyolitic volcanic pile. Preliminary U-Pb zircon data indicate an emplacement age of 535±3 Ma. Although BSE and cathodoluminescence indicate complex zircon populations, there is no evidence of an older inherited component in the U-Pb isotopic systematics.

Mount Scott Granite is distinctive for its subhorizontal sheet-like form and its compositional homogeneity. The granite is ≈0.5 km thick, yet can be traced for over 50 km in length and 17 km in width. Despite its size, it is remarkably uniform exhibiting narrow ranges in SiO_2 71.0–73.6 wt.%, CaO 1.0–1.5 wt.%, and Rb/Sr ≈ 1.3 and εNd +3.3 to +3.7 for nine samples spread out over the entire 55 km. REE patterns for these samples are nearly identical. Mount Scott Granite is characterized by enrichment in Ba (799–1180 ppm) and HFSE such as Zr (415–554 ppm) and has trace element abundances with a "Within Plate" signature, all features typical of A-type felsic magmas.

Compositional and isotopic characteristics of the A-type Mount Scott Granite imply derivation from a homogeneous uniform juvenile source material with little input from older more evolved continental crust. Presumably other members of the Wichita Granite Group have similar origins, suggesting that a significant amount of new material was added to the Laurentian crust during lithospheric extension in the Cambrian.

Reprinted as published in the Geological Society of America *1996 Abstracts with Programs*, v. 28, no. 1, p. 10.

Investigation of Late Diabase Dikes at Lake Elmer Thomas, Wichita Mountains, Oklahoma

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The Cambrian rocks of the Wichita Mountains, southwestern Oklahoma, indicate bimodal igneous activity varied in intensity through time. The most recent activity is evidenced by diabase dikes that cut through granite and rhyolite. Most examples of these dikes are poorly exposed, and marked only by shallow exploratory pits for precious metals. Surface exposures are commonly weathered away, with the diabase forming loose, saprolitic soil.

Adjacent to the dam at Lake Elmer Thomas, a small quarry has exposed three late diabase dikes cutting across the Mount Scott Granite.The westernmost dike is 0.12 m wide with an attitude of N15W, 92°E. It is fine grained (basalt) and has sharp, linear contacts. 4.19 m to the east is a horizontally parallel dike (MD) dipping 96°E. This dike is comprised of two major diabase stringers, separated by a 0.35 ± 0.11 m zone of partially melted granite (PMV) with blocks of unmelted granite. The MD's west stringer is 0.30 ± 0.09 m wide. Its west contact is sharp and linear, with a 0.05–0.75 m chilled margin. Its east contact with the PMZ is sharp, but sinuous to jagged, with a 0.04–0.05 m chilled margin. The MD's east stringer is complex: comprised of both a singular unit towards the south and several limbs separated by partial melt to the north. The southern portion is 0.40 ± 0.13 m wide, the north is 0.85 ± 0.16 m. Its west contact with the PMZ is highly irregular and interrupted by fractures filled with partially melted granite. Many of the filled fractures seen in this east stringer completely cut through the unit. This contact has a 0.03–0.05 m chilled margin. The east contact is sharp, mostly linear, with a 0.05–0.07 m chilled margin. The granite adjacent to this contact is largely unmelted, with only small areas of partial melt (~0.01 m). The third dike, located 5.17 m to the east of MD, is poorly exposed.

Thermal modeling, based on these observations, constrains the nature of dike emplacement. The observed partial melt indicates that the dike's thermal gradient exceeded the granite's "dry" solidus (~850°C) at the contact. Assuming instantaneous emplacement at 1200°C, and accounting for the ΔH_f of the diabase, a half-space model of the MD's east stringer indicates it cooled to its solidus in 2.8 days. Additionally, a granite temperature in excess of 275°C (~200°C over the inferred geothermal gradient) is necessary for the partial melting of the granite at the contact, indicating diking soon after granite emplacement.

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Magmatic Evolution of the Southern Oklahoma Aulacogen

J. P. HOGAN, M. C. GILBERT, and *J. D. PRICE,* School of Geology and Geophysics, University of Oklahoma, Norman OK 73019; *J. E. WRIGHT* and *M. DEGGELLER,* Dept. of Geology and Geophysics, Rice University, Houston, TX 77005; and *W. E. HAMES,* Dept. of Geology, Auburn University, Auburn, AL 36849

Recent petrologic, geochronologic, and isotopic studies are forcing revision of tectonomagmatic models for the evolution of the Cambrian Southern Oklahoma Aulacogen, an ancient rift formed during the breakup of the Laurentian Supercontinent. Earlier models proposed that magmatism associated with the rifting event occurred in two distinct pulses separated by a period of uplift and erosion: (1) An early magmatic event dominated by intrusion of voluminous mafic magmas of the Raggedy Mountains Gabbro Group, and (2) A later magmatic event dominated by voluminous felsic magmatism that formed a substantial volcanic pile, the Carlton Rhyolite Group, and the A-type sheet granites of the Wichita Granite Group, previously thought to be of crustal origin.

In contrast, new geochronologic data indicate a close temporal association of mafic and felsic magmas. Single crystal laser $^{40}Ar/^{39}Ar$ studies of primary hbl/bio from Mount Sheridan Gabbro yielded ages of 535±8 Ma (late hbl), 533±2 Ma (hbl, 533±4 Ma (bio) which are approximately contemporaneous with the age of hbl from Mount Scott Granite 539±2 Ma (hbl). Similarly new isotopic tracer studies of rhyolites and granites [e.g., Mount Scott Granite $^{87}Sr/^{86}Sr)i = 0.7030–0.7043$; $\varepsilon Nd = +3.4 \pm 3.7$] and Late Diabase Dikes [$^{87}Sr/^{86}Sr)i = 0.7033–0.7041$; $\varepsilon Nd +2.8 \pm 4.3$] severely restrict the involvement of older crust and indicate derivation of mafic and felsic magmas from similar primitive source materials.

These data indicate the petrogenesis of mafic and felsic magmas are closely related and that a substantial amount of new material and heat was rapidly transferred from the mantle to the continental crust during formation of the Southern Oklahoma Aulacogen.

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Capability of the Criner Fault, Southern Oklahoma

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Recent investigations have indicated the possibility that recent movement has occurred along the Criner Fault of southern Oklahoma. The Criner Fault is located in Carter County, Oklahoma, approximately 80 kilometers southeast and along strike of the Meers Fault. The Criner Fault separates strongly folded Ordovician limestone of the Criner Hills from more easily eroded Pennsylvanian sandstones and shales of the Marietta Basin to the southwest. The N450W trace of the Criner Fault is visually enhanced by a pronounced vegetation lineament encompassing a surface expression of approximately 9–12 kilometers. In the field, this tectonic feature takes the form of a discontinuous fault-line scarp in the resistant Ordovician limestone of the upthrown block. Where visible, the fault-line scarp has an approximately one meter high vertical profile. The scarp disappears to the northwest where the trace is bounded on both sides by sandstones and shales of equal erodibility. The scarp terminates to the southeast at the junction between the Criner Fault and the more northerly striking Kirby Fault. The Kirby Fault is downthrown to the northeast; thus, the Ordovician limestone of the Criner Hills is upthrown relative to the bounding blocks to the northeast and southwest. Uplift originated in the Criner Hills during the early Pennsylvanian Wichita Orogeny. Renewed deformation is documented to have occurred on the Criner Fault during the late Pennsylvanian Arbuckle Orogeny. Due to its extremely linear surface expression, the fault appears to have been originally generated by dominantly lateral deformation. However. subsequent reactivation along the Criner Fault plane has involved a definite vertical component. Although some ambiguity exists among previous investigations, the predominant conclusion is that reactivation of the fault plane has been of the reverse sense. Concern about the capability of the Criner Fault arises due to its proximal relationship to the Meers Fault, which is documented to have been reactivated within the last 1200 years. Such findings contradict the prevailing view that the inner continent of North America is a stable tectonic regime. Furthermore, numerous geologic and geomorphic features along the Criner Fault trace are suggestive of recent tectonic activity. Some of the potential indicators of recent activity include a vertical scarp profile, fresh faces at the bottom of the scarp in some localities, stream nickpoints, and springs emerging along the limestone escarpment. None of these features are unequivocal indicators of active faulting. In fact, each feature can quite feasibly result from the dynamic relationship between the factors of lithology, structural control and erosion. Therefore, this study will address the true cause of these features, culminating in the age-bracketing of the most recent deformation which has occurred on the Criner Fault. Exposures developed transverse to the fault trace should provide conclusive evidence for determining the age of the most recent activity along the Criner Fault.

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Evaluation of Faulting Characteristics and Ground Acceleration Associated with Recent Movement along the Meers Fault, Southwestern Oklahoma

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Geologic and geomorphic studies along the Meers Fault in southwestern Oklahoma have shown recent deformation of Quaternary deposits along the fault scarp. The possibility of moderate to large earthquake events along the fault has implications for nearby cities such as Lawton, Oklahoma, a medium-sized city, and Fort Sill, a major military base. The existence of a seismic hazard in the area would also affect the future siting of critical facilities in the area.

Although previous work has proven the likelihood of recent fault activity, there is still some uncertainty with regard to the actual amount and direction of offset. Past work performed by others has resulted in the conclusion that offset is dominantly left lateral. This conclusion is based on studies of stream channel pathways across the fault which were identified as left laterally offset. However, recent investigations suggest that many of these streams have been deflected rather than offset as a result of surface warping on the upthrown block and therefore are not good indicators of fault offset direction. Slickensides taken from fault plane exposures suggest that the last movement on the fault was dominantly vertical, which serves to further complicate the understanding of fault history and driving mechanisms.

The history of ground acceleration associated with these movements is also debatable. The fault lies along the northeast flank of the Wichita Mountains, an uplifted Pre-Cambrian to Cambrian age igneous complex. Precariously balanced rocks known as tors have evolved within this terrain and are present unless ground motion from earthquakes has shaken them down. The range of time required for these features to evolve and remain stable is believed to be of the order of thousands of years. If strong earthquakes have occurred along the fault during the last few thousand years, as has been suggested by other studies, we should expect to see few of these precariously balanced rocks still standing. Furthermore, by analyzing tors still standing, an estimation of maximum ground acceleration associated with these earthquakes can he made.

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Deformation of Quaternary Soil Deposits along the Meers Fault, Oklahoma—Paleoearthquake or Creep? A New Method with a Multidisciplinary Approach

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Recent studies confirm that the Meers fault in southwestern Oklahoma moved in Late Holocene creating a maximum 5 meter vertical and some as yet unmeasured left-lateral strike slip displacements. During this movement, the Quaternary age soil deposits along the fault folded ductilly before they were ruptured. In fact, at some places along the fault, almost all of the deformation is accommodated by ductile folding of these soil layers. Having this kind of deformation with no known record of an earthquake associated with the Meers fault during historical times brings up the question whether the scarp we see along the fault today was created by an earthquake event or by a slow deformation (creep) along the fault meaning no earthquake.

In order to determine how the scarp along the Meers fault was formed, a multidisciplinary approach made up of soil mechanical, soil micromorphological, and geological methods was developed and used. Consolidation tests with Casagrande's (1936) method for finding maximum effective stresses were used to determine the states of stresses the soil deposits underwent during the Late Holocene faulting. These states of stresses were then compared to the states of stresses needed to deform or shear these soil deposits in a slow manner in triaxial and direct drained shear tests. Triaxial shear tests were also used to see if these soil deposits can fail in a ductile manner under the natural field moisture contents and the states of stresses found in the consolidation tests. Direction of maximum principal stress was determined by Mohr's circle and soil thin section analysis.

The results show that the Meers fault scarp must have been created by an earthquake event that occurred about 1,100 years ago in Late Holocene not by a slow deformation along the fault. During this event, the soil deposits along the fault were anisotropically consolidated or compacted recording the states of stresses that faulted them in their structure, and the pores, clays, shale clasts, and some other grains got oriented with their long axes perpendicular to the maximum principal stress direction. Ductile folding of these soil deposits along the fault under these states of stresses and natural field moisture contents could have easily happened during this event. The direction of the maximum principal stress is between N. 62° E. to N. 85° E. dipping 10° SW indicating rotation of principal stress axes.

The method developed and used in this study for the first time can be used in similar areas where active faults offset Quaternary soil deposits with relatively unchanging moisture contents below some depth. And, finally, this method might give more reliable young tectonic stress measurements (both magnitude and orientation) for shallow depths since it is used on geologically recent soil deposits which, unlike lithified deposits, have not gone through millions of years of deformation yet.

Reprinted, with author modifications, from the Geological Society of America *1995 Abstracts with Programs*, v. 27, no. 4, p. 5–6.

The Slick Hills of Oklahoma and Their Regional Setting

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Fort Worth, TX 76129

The Slick Hills of southwestern Oklahoma are the exposed portion of the Frontal fault zone, a region of intense Pennsylvanian-age deformation that is located between the contemporary Wichita uplift (to the south) and the Anadarko basin. During the Lower Palaeozoic the area formed part of the N60W trending Southern Oklahoma aulocogen. A thick and structurally anisotropic sequence of thinly bedded rocks (mostly carbonates) was deposited on a thick suite of Cambrian igneous rocks, some of which are thickly layered. Subsequent Pennsylvanian deformation dismembered the aulacogen. Geomorphology of the Hills is essentially of Permian age.

Lower Paleozoic sedimentation took place on a passive margin in a tropical setting south of the equator, carbonates facies dominate some late Cambrian siliciclastic increments may record tectonic adjustments; most are probably associated with global sea level variation. The structural styles developed during Pennsylvanian deformation reflect variation in isotropy between igneous basement (both within and without the aulacogen) and sedimentary cover. In essence the cover incrementally detached itself along numerous horizons of slippage recording progressive phases of deformation, while strain in more massive basement rocks was resolved by large faults.

Various deformation signatures suggest a principal stress oriented approximately NE–SW. This direction is difficult to reconcile with more or less contemporary orogenic deformation in the Oklahoma Ouachitas, but may reflect a reorientation of stress as the result of the final incorporation of the Laurentia plate within Pangaea.

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Rejuvenation of a Permian Aquifer—A Case History from the Slick Hills of Southwestern Oklahoma

KEVIN R. KNAPP, R. NOWELL DONOVAN, NEVEN A. KRESIC, KEN M. MORGAN, and *ARTHUR B. BUSBEY III,* Texas Christian University, Fort Worth, TX 76129

The Slick Hills of southwestern Oklahoma are the exposed portion of an area of complex Pennsylvanian-age tectonism known as the Frontal fault zone. This zone separates the Anadarko basin (to the north) from the Wichita uplift. Both Frontal zone and uplift record the partial inversion of a Lower Paleozoic sequence approximately 12,000 ft thick, most of which consists of carbonates. Syntectonic erosion cut deeply into igneous basement in the Wichita uplift, whereas in the Frontal zone the level of erosion is mostly within the carbonate section. In the Slick Hills a lower Permian topography of rolling hills with ~500 ft of relief and slopes generally less than 10° is preserved. Rocks forming this topography comprise Cambro-Ordovician limestones (the Arbuckle Group) and the top part of the igneous basement (the Carlton Rhyolite Group). This topography, which is gradually being exhumed from beneath a veneer of Permian sediments, owes its preservation to the extreme aridity of the Permian climate. Among Permian features preserved is a fracture-controlled karst drainage system. Architecture of this karst appears to reflect both fracture intensity and contours of the Permian land surface. Many of the fissures have been partly or completely sealed by speleothems.

Modern drainage incision is rejuvenating both the Permian landsurface and the karst system. This is particularly well seen in the area of Blue Creek Canyon. Here the Arbuckle Group is a fissure-controlled aquifer and the Carlton Rhyolite is an aquitard juxtaposed structurally along a major fault. In detail, variations in hydraulic gradients, concentrations of dissolved solids, saturation relationships and flow velocities suggest compartmentalization of the aquifer (perhaps related to structural architecture). In general, in areas where rejuvenation has taken place, flow velocities and porosities are higher than in areas where the basic Permian geomorphology is still intact.

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Folding Style and Deformation Mechanisms in Arbuckle Group Carbonates, Slick Hills, Oklahoma

LINDA LORTZ and *BRYAN TAPP,* Dept. of Geosciences, University of Tulsa, Tulsa, OK 74104

In this study we attempt to document the deformation mechanisms that have contributed to the formation of nearly cylindrical flexural slip folds that formed in response to transpressional strike slip deformation of upper Arbuckle Group Carbonates in the Wichita Mountains, southern Oklahoma. The field area is in the Slick Hills south of Mountain View, Oklahoma. Bedding plane thrusts are evident in the field, and localized slip along bedding planes is documented by slickensides that are perpendicular to the local hinge line. In the field area, there is evidence of hinge migration leading to local into-the-hinge thrusting and marked fold asymmetry. In some cases, folding induced thrusting has developed small duplex features on the limbs of the larger folds. The dominant deformation mechanisms in the area appears to be brittle. Rocks in the area are highly fractured, with these fractures affecting the erosional character of the outcrops. Although deformation is largely brittle, the presence of sigmoidally shaped tension gashes may indicate some ductile component of deformation. Oriented ultra-thin thin sections will be used to document the modes and mechanisms of deformation from all fold domains. Sections are cut with the axes parallel with the local fold hinges, and perpendicular to the local fold hinges. Work to date indicates that the dominant mechanisms of deformation are carbonate cataclasis marked by grain size reduction along microfracture swarms in individual grains. Pressure solution is important in some samples; although the significance of pressure solution is unclear at this time. This work documents the range and control of deformation mechanisms in the formation of flexural slip folds in carbonate rocks.

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Use of Microresistivity Image Logs in Detailed Reservoir Architecture Reconstruction of Bartlesville Sandstone, Glenn Pool Field, Northeastern Oklahoma

LIANGMIAO YE, Dept. of Geosciences, University of Tulsa, Tulsa, OK 74104

The Glenn Sandstone, a fluvial-dominated deltaic system equivalent to the Pennsylvanian Bartlesville Sandstone, has produced for 90 years as the main pay zone of the Glenn Pool field. However, 70% of OOIP remains despite post-primary recovery attempts because of the complex reservoir heterogeneity. Detailed reservoir architecture is critical for further reservoir management. This study is focused on a 160-acre block in the southern part of the field, in which the 130-ft thick Glenn Sandstone is divided into six discrete genetic intervals (DGIs) descending from DGI A to F.

Analysis of microresistivity image logs, calibrated to detailed core description, revealed features including bed boundary, cross stratification and cross strata set boundaries, scour surfaces, mud drapes, and fractures, etc. Orientation of these architectural elements permitted a detailed reservoir architecture reconstruction in the vicinity of the Self No. 82 well. (1) Structural dip azimuth averages 153° and dip angle 4°. (2) DGI C is dominated by lateral accretion bar deposits. Lateral accretion surface dip azimuth shows progressive upward rotation from 200° to 146°. Comparison of azimuthal orientations for cross strata and lateral accretion surfaces indicates that the well is located in downstream side of a lateral accretion bar. Average vertical spacing of lateral accretion surfaces is 1.08 ft, and their average structure-corrected dip angle is 6°. The "exact" spatial configuration of lateral accretion mud drapes within the bar is developed and it is inferred that 19 lateral accretion mud drapes are present between Self No. 82 and 81. (3) DGI D is a 22-ft thick complex of splay sandstones. The image color proportion analysis indicates that only a 4-ft interval appears to have been washed by water flooding. This in turn suggests thin mudstones deposited between splay sandstone depositional events serve to vertically compartmentalize reservoirs. Orientation patterns reveal DGI D actually consists of four splay units, with dipersal direction being, in descending order, 120°, 315°, 70°, and 210°, respectively. (4) 15-ft DGI E splay sandstone is made of two splay units with dispersal direction being 180° (upper) and 30° (lower) respectively. (5) DGI A and B are channel-fill sandstone facies represented by subaqueous medium-scale cross strata sets with numerous mud drapes.

Integration of core study and log facies analysis has resulted in high resolution facies/subfacies architecture models for each DGI, which provide the basis for reservoir simulation and proposed management plan.

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Integrated Reservoir Description and Flow Performance Evaluation: Glenn Pool Field—Self Unit Study

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This paper presents the study of integrated approach to reservoir description as part of the DOE-Class I Projects to improve the oil recovery from a mature oil field. The Self Unit of the Glenn Pool Field (operated by Upland Resources Inc.) was selected as the study area. Geological, geophysical, and engineering information was collected in 160 acres of the Self Unit. An integrated reservoir description was constructed which honors the geological, geophysical, and engineering data using geostatistical (stochastic) as well as the deterministic models. The description was validated by comparing the simulated results with static (well log and well core) as well as dynamic (well test) information.

Both stochastic and deterministic models replicate the geological model very well. The deterministic model predicts an optimistic result whereas the stochastic model follows the field data very well. The incorporation of geophysical information, taken from tomography survey, improves the reservoir description when comparing with the well test information.

Using the description of each models, the flow simulations were conducted to match the historical performance and to predict the future production. Based on the flow simulation and the economic analysis the plan of recompleting the wells and increasing the injection rate was found to be the most feasible to be implemented in the Self Unit to recover more oil.

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A Multidisciplinary Approach for Reservoir Characterization in the Glenn Pool Field, Oklahoma

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Glenn Pool, a mature marginal oil field, is located on the Northeastern Oklahoma Platform. It has been under production since the first discovery in 1905. Several reservoir treatments have been implemented in the last 50 years following the primary production. However, high reservoir complexity resulted in a large volume of oil to be left in place. Our research is focused on a 160-acre block (Self Unit) where a detailed multidisciplinary (Geology, Geophysics, Petroleum Engineering) reservoir study was conducted. The purpose of the study is to improve the secondary recovery performance of the field through the use of proper reservoir description and better reservoir management.

Prior to drilling a cooperative project well (Uplands Self #82) Self Unit was studied with conventional methods. Stratigraphic framework of the Glenn Sand reservoir has been established through a series of stratigraphic cross sections. Based on well log correlations the reservoir was divided into six discrete genetic intervals (DGI). Channel-fill, splay, channel-mouth bar, levee and interdistributary mudstone facies were recognized from well log profiles and core analysis. Attempts were made in simulating geology using simple kriging methods; results were not entirely satisfactory.

Uplands Self #82 was drilled in late December 1993. The project objectives for drilling the well were: (1) evaluate reservoir predictions; (2) collect data using conventional and advanced technologies. Facies architectural characterization before drilling was reasonably successful. Advanced technologies including microresistivity imaging log and crosswell tomography data were acquired as well as the conventional well log suites and core. Simulation of the DGI distribution was undertaken using truncated Gaussian simulation method. Simulation results strongly agree when comparing probability input distributions with the output distributions. Porosity distribution was simulated using the simulated annealing method, and permeability distribution was transformed from porosity using a conditional distribution approach. For a selected well location (Self #82) the comparison between simulated and core porosity/permeability is very good. Crosswell transmission and migrated reflection tomography images between Self #82 and three offset wells constrained lateral reservoir continuity.

A reservoir management plan was developed from reservoir performance simulation, well test data, facies architecture and crosswell tomography.

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Fluvial Architecture of Selected Middle Pennsylvanian Sandstones, Port of Catoosa, Rogers County, Oklahoma

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The facies architecture of fluvial-dominated delta plain systems were reconstructed for several Middle Pennsylvanian sandstones. The study area incorporates approximately 640 acres centered on the Amoco experimental drilling site near Port of Catoosa. Data included conventional logs from 11 wells, and core plus microresistivity images from a single well.

Architecture elements recognized are divided in four hierarchical levels, in order of decreasing rock volume: multistacked discrete genetic interval; individual discrete genetic interval (DGI); facies; and stratification patterns of a single facies. Conventional logs are used to correlate and map multistacked DGI, individual DGI, and facies. Core and microresistivity images are used to resolve facies and stratification pattern in the vicinity of the experimental well. Using azimuthal relationship among architecture elements, the location of the experimental well within the depositional system are determined.

Examples of architectural reconstruction include the following. The Bartlesville sandstone consists of splay facies in the upper part and channel-fill facies on the lower part as two individual discrete genetic intervals. The channel-fill facies shows fining-upward profile with cross strata at the bottom to parallel strata and ripple laminae at the top. The splay facies is made up of small-scale cross strata, climbing ripple laminae, and parallel strata. Lower Skinner sandstone is 50 feet thick and in conventional well logs forms a single bell-shaped log profile. However, the microresistivity log clearly shows that it is composed of two DGIs, each represented by channel-fill facies.

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Characterizing and Modeling the Heterogeneity of Fluvial Reservoirs, A Case Study from Gypsy Outcrop Site, Pawnee County, Oklahoma

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The genetic relationships between lithofacies and depositional environments and between lithofacies and permeability make the heterogeneity of fluvial reservoirs predictable and mappable. Two types of geological models (with/without lithofacies-dominated heterogeneity interpolation) have been simulated to illustrate the impact of geological modelling on predictions of oil recovery and sweep efficiency.

Lithofacies, defined by certain types of constituents and sedimentary textures and structures, are responses to certain depositional flow regimes or local hydraulic conditions. The Gypsy outcrop site in Pawnee County, Oklahoma, which includes well exposed road cuts with 22 cored boreholes behind the outcrop, provides a realistic three dimensional geological site and data base for developing reservoir characterization techniques. Four lithofacies that control permeability are recognized at the Gypsy outcrop site. From bottom to top of a complete channel sequence, these are:

(1) mudclast sandstones (low permeability);
(2) sandstones dominated by cross beds and planar laminated sets (high permeability);
(3) ripple and bioturbated sandstone (low permeability);
(4) mudstone and siltstone (flow barrier).

The lithofacies within each channel were mapped based on the Gypsy outcrop and cored borehole data. These maps provided input to geological modelling software for 3-D visualization. A flow simulator was used to study models consisting of up to 500,000 grid cells.

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Fracture Detection Using Back-Scattered Shear Waves

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Seismic wave tests were performed in the Clinker Mesas of Wyoming's Powder River Basin, at a test site near Tulsa, Oklahoma, and in a sabkha area in Eastern Saudi Arabia. All these tests show improved coherency of signals in common receiver sorted data in remarkable contrast to that in common shot gathers. This phenomenon is interpreted as being due to the conversion of the incident P-waves to S-waves in the vicinity of the receivers. This characteristic ability to convert wave types should also be present in subsurface layers.

In one of the tests performed near Tulsa, a striking event was seen on horizontal component seismometer records. This event was seen at a record time of 3 seconds; the shot-to-receiver offset was in the range of 240 to 720 feet. This situation corresponds to near-vertical propagation of waves; the event is tentatively interpreted to result from conversion of downtraveling P-waves to S-waves in a subsurface layer namely the Viola or the Arbuckle formation. These layers are believed to have the inhomogenous characteristics necessary to effect the conversion.

Tests to support the interpretation were carried out in southern Ontario. The Ordovician Trenton formation has enhanced porosity and permeability in fractured zones; a characteristic which may cause the conversion of waves. Seismic test profiles were run over fractured zones. The results support the concept that fractured zones may be identified by the strength of the converted shear waves. This may be a valuable and economical way to detect fractured reservoirs. The technique may also find applications in environmental and engineering problems.

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Pedogenesis and Significance of Regolith Developed on Lower Mississippian Limestones, Springfield Plateau, Southern Midcontinent

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The Lower Mississippian St. Joe and Boone Limestones and their equivalents are exposed in the Springfield Plateau covering approximately 20,000 square miles across the tri-state region, Oklahoma, Missouri, and Arkansas. The carbonate sequence comprises three depositional packages: lower chert-free grainstones and packstones, middle calcisiltites with penecontemporaneous chert development, and upper packstones with later diagenetic chert development. A bright red, clay-rich, gravelly regolith is developed on the middle and upper limestone sequence and its pedogenic character reflects that of the underlying bedrock. Regolith developed on both the middle and upper intervals exhibits relict bedding preserved by chert layers, but the middle interval contains a greater contribution of the silt fraction compared to that of the upper interval. In contrast, the chert-free grainstones and packstones exhibit karst features and colluvium transported from the succeeding intervals.

The regolith and associated cave development reflect pluvial conditions established by glacial advance, and probably span the entire Pleistocene. Most of the regolith reflects in situ removal of the soluble fraction, but some exposures suggest alluviation reflected in the lack of relict bedding, rounding of chert gravel, higher sand content, and more uniform lithology throughout the interval of accumulation.

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Thermal Insulation by Low Conductivity Coal: An Important Mechanism for Formation of Mississippi Valley-Type Ore Deposits

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Coal and carbonaceous mudstone were once common in many sedimentary basins in the mid-continent of North America during the Late Paleozoic. Carbonaceous rocks are characterized by thermal conductivities in the range of 0.25 to 1.0 $W/m^{-1}K^{-1}$, lower by a factor of 5 to 10 than other common rocks. Thus, carbonaceous rocks act as a thermal blanket retaining heal energy within basin sediments. A two-dimensional finite element model of fluid flow and heat transport has been used to study the insulating effect of a coal layer on an uplifted foreland basin. Our model section cuts through the Arkoma Basin to Ozark Dome and terminates near the Missouri River, west of St. Louis. A few hundred meters of carbonaceous rocks are placed on the top of the model basin. Topographically driven recharge is assumed to be the major driving force for regional groundwater flow. Our model results show that thermal gradient in the coal layer can be up to 0.14°C/m, much higher than that in normal sediments. High temperatures in underlying sediments are caused by the thermal insulation and high rates of advective heat transport associated with basin-scale fluid flow along basal aquifers (Darcy velocities of up to 5 m/yr). Our model results show high temperatures (~150°C) in the groundwater discharge region at shallow depths (<1.5 km), even with a typical continent basal heat flow of 60 m W/m^2. High temperatures (100–150°C) at shallow depths (<1.5 km) are inferred from homogenization and freezing temperatures obtained from fluid inclusions associated with Mississippi Valley-type (MVT) ore deposits in the midcontinent of North America (Sverjensky, 1986). Thus, thermal insulation by an overlying coal layer can explain the temperature regime believed to be required for MVT ore deposits without imposing unrealistic thermal constraints, such at high basal heat flow (90 to 100 m W/m^2). After the coal layer is removed by subsequent uplift and erosion and fluid flow stops or slows down, the model basin slowly returns to a normal geothermal gradient of about 0.028°C/m.

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Na-Cl-Br Systematics of Mineralizing Brines in Mississippi Valley-Type Deposits

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New and published analyses of fluid-inclusion leachates from Mississippi Valley-type (MVT) deposits can be divided into two groups on the basis of Na/Br and Cl/Br ratios. MVT leachates from the Illinois-Kentucky and Cincinnati arch districts and from cubic galena in the Viburnum Trend have Na/Br and Cl/Br ratios that extend to values significantly above that of seawater, which are characteristic of evaporite-dissolution brines. MVT leachates from Polaris and octahedral galena in the Viburnum Trend have Na/Br and Cl/Br ratios that plot below seawater and along the compositional trend formed by evaporation. Solubility-volume constraints require that brines formed by seawater evaporation had high dissolved metal contents. Preliminary correlation of leachate compositions allows delineation of two brine provinces in the midcontinent United States: (1) an early, high-Br province found only in southeastern Missouri, and (2) a later, low-Br province of probable Permian age that extended from the Cincinnati arch to the TriState district. These observations, along with Na-Cl-Br data for modern brines from the Illinois basin, argue against models for single-stage midcontinent MVT brine flow based on recharge from late Paleozoic (Arkoma) foreland basins to the south.

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