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On the cover—

The Everlasting Hills of Oklahoma

The cover photograph shows a view southwestward from the Slick Hills in southern Oklahoma. In the foreground are limestones of the Ordovician Kindblade Formation (Arbuckle Group). Older formations in the group form the folded terrain in the middle ground. In the distance, sunlight highlights the Meers Valley, beyond which rises the rampart of the igneous Wichitas. The tops of the mountains are formed by the Mount Scott granitic sill, below which are outcrops of basic rocks.

The trace of the Meers fault flirts with the nearest edge of sunlight. Although the Recent activity of this fault has attracted a lot of curiosity (and some alarm!), it is the giant beneath that impresses as one of the largest faults on the continent. Stratigraphic downthrow to the north in this area is ~22 mi. The fault reversed its sense of downthrow in early Permian times and has subsequently spluttered on till today.

The landscape of the Wichitas is an anomaly, inherited in its essential details from early Permian times. There is after all a lot of truth in the old hymn which sings about "the everlasting hills of Oklahoma."

The photograph was taken on the Kimbell Ranch. We in the geological community are fortunate to have the support and interest of both the Kimbell family and Ranch manager Charlie-Bob Oliver. To my certain knowledge over a thousand geologists have tramped the Slick Hills in this decade—many have returned for further visits to some of the most continuously stimulating geology in the country. In January, Charlie-Bob will be retiring, one of the last of the real cowboys will ride into the sunset after 42 years. We wish him and his wife Dixie all the very best.

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OKLAHOMA GEOLOGY NOTES

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OKLAHOMA GEOLOGICAL SURVEY

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A PETROGRAPHIC SURVEY OF HIGH-VOLATILE BITUMINOUS OKLAHOMA COAL BEDS

Brian J. Cardott[1]

Introduction

The location of the Oklahoma coalfield is of particular geologic interest because it includes some of the westernmost coal beds of Carboniferous age in the United States (Trumbull, 1960; Wood and Bour, 1988) and because it includes both the edge of the stable craton and a foreland basin. Considerable petrographic information is available on coals from the Eastern Coal Province and eastern region of the Interior Coal Province of the United States, but such information is sparse for coals from the western region of the Interior Coal Province (coal provinces following Campbell, 1929; Friedman, 1988; Friedman and others, 1988).

Published petrographic information on Oklahoma coal beds is limited to a few of the more important commercial coals. There is no published regional study delineating the similarities and differences in maceral composition between coal beds from different areas of the Oklahoma coalfield and from different stratigraphic horizons.

The purpose of this paper is to present a regional overview of the maceral composition of 20 selected high-volatile bituminous coal beds spanning the entire range of coal-bearing strata in the Oklahoma coalfield. These preliminary results of ongoing petrologic investigations of all coal beds in Oklahoma are presented as a basis for future applied studies in regional coal geology and coal utilization.

Description of the Oklahoma Coalfield

The Oklahoma coalfield is in the southern part of the western region of the Interior Coal Province of the United States (Campbell, 1929; Friedman, 1988). The coalfield continues into Kansas on the north and Arkansas on the east. It is bounded on the northeast by the Ozark uplift, on the south by the Ouachita Mountains uplift, on the southwest by the Arbuckle Mountains uplift, and on the west by noncommercial coal-bearing strata of Missourian to Wolfcampian age (Fig. 1). The coalfield was divided into the northeast Oklahoma shelf and the Arkoma basin by Friedman (1974), based on physiographic and structural differences (Fig. 1).

The age of coal-bearing strata in the Oklahoma coalfield is Middle and Late Pennsylvanian (Desmoinesian and Missourian; Fig. 2), although thin, noncommercial coal beds have been reported in Morrowan and Atokan strata (Trumbull, 1957;

[1]Oklahoma Geological Survey.

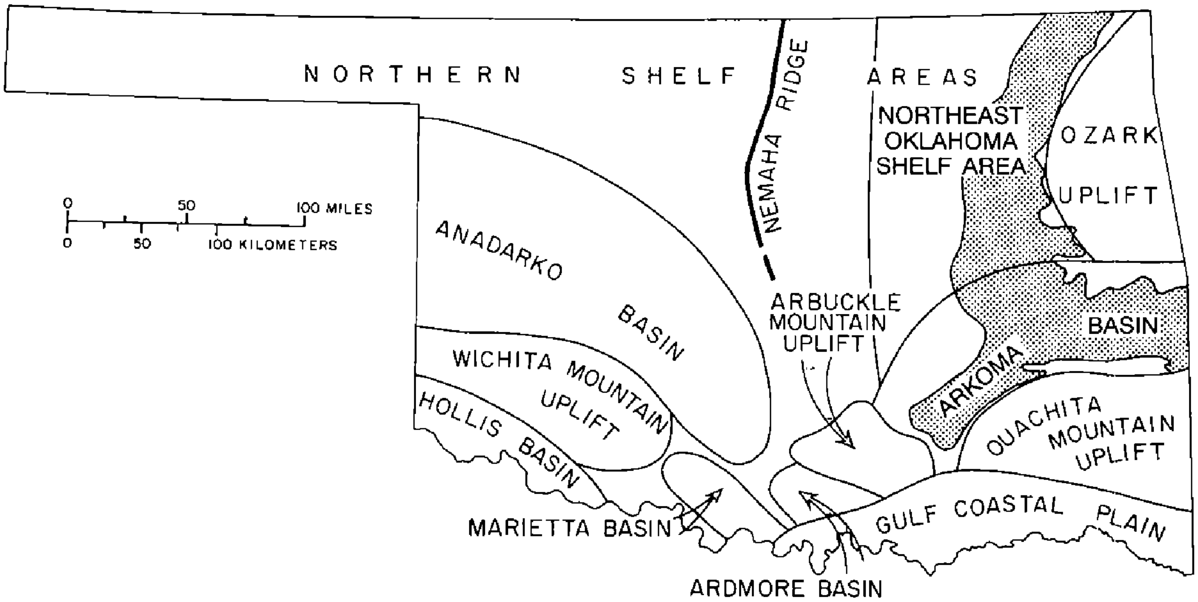

Figure 1. The Oklahoma coalfield in relation to the major geologic provinces of Oklahoma (adapted from Johnson, 1971). The Oklahoma coalfield includes the northeast Oklahoma shelf area and the Arkoma basin; the commercial coal belt is stippled (modified from Friedman, 1974; Friedman and Sawyer, 1982; Hemish, 1987).

Branson, 1965; Wanless, 1975; Hemish, 1987) and Virgilian and Wolfcampian strata (Branson, 1956,1965; Wanless, 1975; Fay and others, 1979). The controversial Desmoinesian/Missourian boundary occurs at the Tulsa coal horizon (Wilson, 1984). Post-Croweburg (Desmoinesian Cabaniss Group) coal beds occur only on the northeast Oklahoma shelf (Friedman, 1978a, p. 5; Hemish, 1988, p. 8–9; Fig. 2) because of erosion or nondeposition of younger stratigraphic units in the Arkoma basin.

Approximately 30 of the nearly 40 named coal beds in the Oklahoma coalfield are of potentially minable thickness—at least 10 in. thick for surface mining. The coal beds in Oklahoma range from 2 in. to 7 ft thick, with an average of approximately 18 in. (Friedman, 1987, personal communication; Hemish, 1988).

The rank of Oklahoma coal beds ranges from high-volatile C to low-volatile bituminous. High-volatile bituminous coals occur in the northeast Oklahoma shelf and western part of the Arkoma basin. Rank increases toward the east in the Arkoma basin to low-volatile bituminous in Oklahoma and to semianthracite in Arkansas (Trumbull, 1960; Friedman, 1974).

Previous Investigations

Although there is considerable palynological (Wilson, 1976) and chemical (Shannon and others, 1926; U.S. Bureau of Mines, 1928; Moose and Searle, 1929; Friedman, 1974; Hemish, 1986) information on Oklahoma coal beds, very few studies have included petrographic information.

The earliest petrographic studies of Oklahoma coals were made using the Thiessen–Bureau of Mines nomenclature system on thin sections. Davis and others

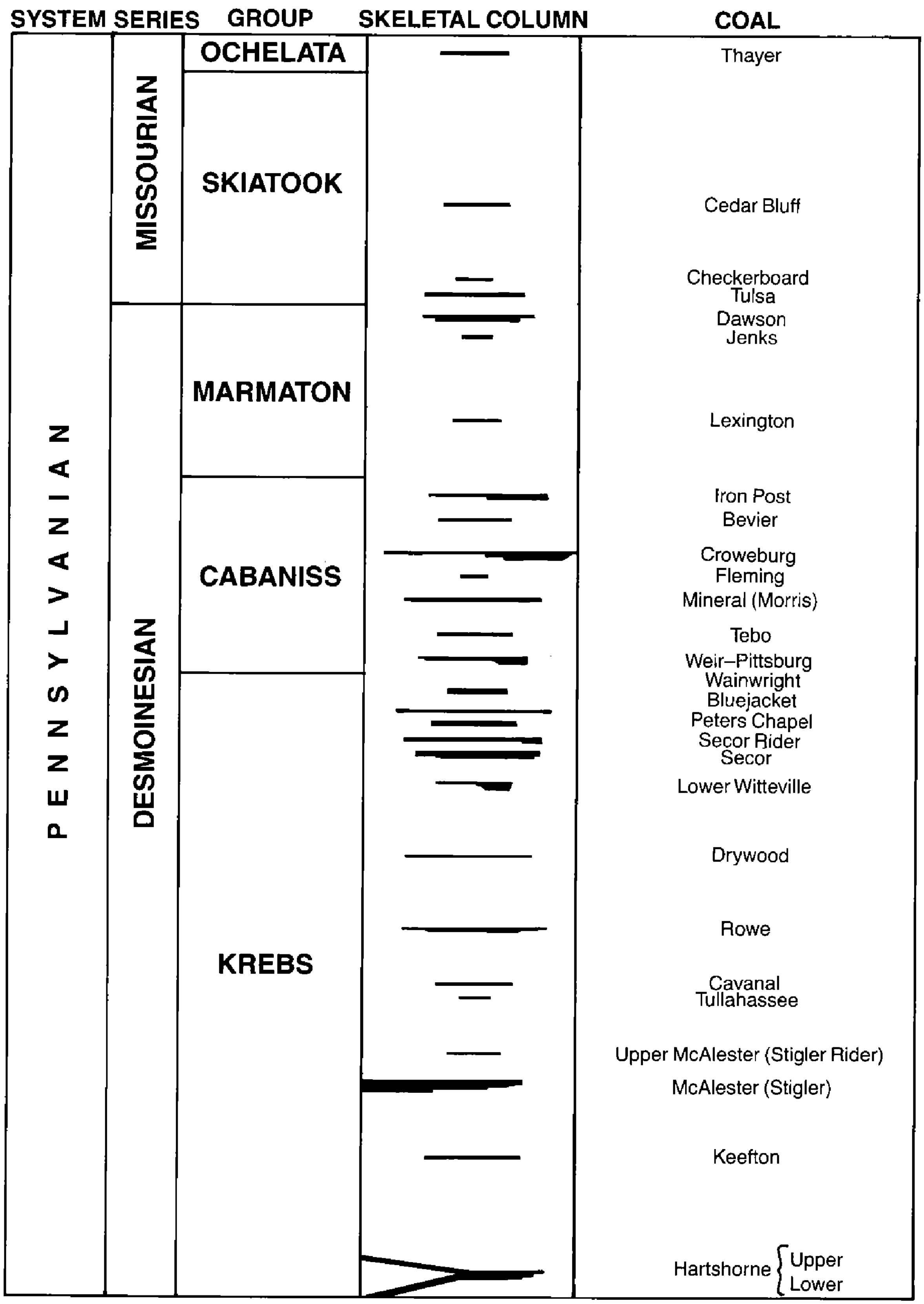

Figure 2. Generalized geologic column showing stratigraphic position, relative thickness, and relative extent of coal beds in the Oklahoma coalfield (modified from Friedman, 1974,1978a; Friedman and Woods, 1982; Hemish, 1988).

(1944) described the petrographic composition of the low-volatile bituminous Hartshorne coal and the high-volatile bituminous McAlester, Henryetta (Croweburg), and Bevier coal beds of Oklahoma as having a similar petrographic composition. The megascopic appearance of the coals is described as being >98% bright coal. The petrographic composition of four coal-column samples was reported to be 68–76% anthraxylon, 17–22% translucent attritus, 4–6% opaque attritus, and 3–5% fusain. Parks and O'Donnell (1956) incorporated the petrographic composition of the Hartshorne, McAlester, and Henryetta (Croweburg) coal beds reported by Davis and others (1944) in their study of the petrography of American coals.

Hambleton (1953, p. 5) described the petrographic composition of the high-volatile bituminous Mineral, Croweburg, and Bevier coal beds of southeastern Kansas as being "relatively uniform in petrographic composition." The megascopic appearance of the coals is described as "bright coals which may contain thin bands of splint or semisplint coal near the top or bottom of the bed" (Hambleton, 1953, p. 71). The petrographic composition of 22 coal-column samples was reported to be 21–54% anthraxylon, 35–69% translucent attritus, 1–11% opaque attritus, and 4–16% fusain.

Dunham and Trumbull (1955, p. 198) stated that high-volatile bituminous Henryetta (Croweburg) and Morris coal beds of Oklahoma consist of "layers of coal having a vitreous appearance, more numerous layers of slightly duller coal, and a few layers of the powdery substance called fusain."

McKinney (1959) presented microscopic and megascopic seam profiles of the high-volatile bituminous Croweburg coal bed of Oklahoma from six coal-column samples. The megascopic appearance of the coal was described as a thin-banded, bright coal with a predominance of clarain and dull clarain. The average petrographic composition was not provided.

Friedman (1978b) determined the megascopic appearance of 15 bituminous coal beds in Oklahoma from 147 channel and 92 core samples. He stated (p. 58) that "the average coal contains sparse (less than 15 percent) to moderate (15 to 30 percent) and thin (0.5 to 2 mm) bands of vitrain, and moderately bright attritus." Referring again to the megascopic appearance of Oklahoma bituminous coal beds, Friedman (1979, p. R25) stated that "most of the coals are moderately dull to moderately bright banded, and the lithotypes are thin banded. Vitrain is sparse, and bright attritus is abundant."

Landis (1985) described the white-light and blue-light maceral composition of the high-volatile bituminous to semianthracite Hartshorne coal bed of Oklahoma and Arkansas. Eleven of 13 samples were from Oklahoma, of which three are high-volatile bituminous. The range in maceral-group composition of the three high-volatile bituminous coal samples of Oklahoma, from the combined-maceral analysis, is 78–82% vitrinite, 13–15% inertinite, and 5–7% liptinite.

Sampling and Methods

For the present study, 20 coal beds have been selected that span the stratigraphic and areal distribution of high-volatile bituminous coals in the Oklahoma coalfield. To allow comparison of the maceral composition exclusive of rank effects, only high-volatile bituminous coal samples were selected. Each coal bed is represented by one site-specific sample that allows for study of compositional variation between coal beds; thus, the data for each bed do not represent a statistical average; each site-specific sample was chosen from an array of 1 to 14 samples per coal bed from a data base of 126 partial or whole-seam channel or core samples from 85 localities. The site-specific samples are considered representative. Future studies will treat compositional variation within single coal beds. Sixteen coal samples are from the northeast Oklahoma shelf area, and four are from the Arkoma basin (Table 1; Fig. 1). All the coal samples are channel samples from mine, outcrop, or exposure, except for drill-core samples of the Hartshorne, Keefton, Tulsa, and Cedar Bluff coals (Table 1). The sampled coal beds are 2–36 in. thick and represent the whole coal bed (data have been averaged by thickness from channel and core samples that have been divided into two or three benches; Friedman, 1978b; Table 1).

The petrographic analyses were performed with a Vickers M17 Research Microscope system adapted for incident white light. The vitrinite-reflectance analysis was carried out on clear areas of vitrinite (vitrinite and pseudovitrinite) at a magnification of 500× in plane-polarized, monochromatic green light and Cargille type-B immersion oil (n_e = 1.5180), in accordance with ASTM D2798 (1988). Mean maximum vitrinite reflectance, based on 100 measurements, is reported and assigned rank according to Davis (1978; hvCb = 0.47–0.57% R_o, hvBb = 0.57–0.71% R_o, hvAb = 0.71–1.10% R_o). The white-light maceral analysis was determined by volume percent on 1,000 points (mineral-free basis) at 625× in oil immersion. Three variations from the ASTM procedure (ASTM D2799, 1988) were: (1) 5 points were counted in each microscopic field, rather than 4 points; (2) 3 additional macerals counted were pseudovitrinite, macrinite, and semimacrinite; and (3) 500 rather than 1,000 points were counted from each of 2 crushed-particle pellets.

Results and Discussion

The results of the petrographic analyses are shown in Table 2, with the coal beds arranged stratigraphically (Fig. 2). The Organic Petrography Laboratory (OPL) numbers designate a whole-seam channel or core sample; more than one OPL number indicates that 2 or 3 petrographic analyses have been averaged (weighted by thickness) from channel and core bench samples.

The vitrinite-reflectance analyses reveal that the coal samples range from high-volatile C to A bituminous rank (mean maximum R_o = 0.50–0.98%).

Maceral Composition

The 20 selected high-volatile bituminous Oklahoma coal beds have a high vitrinite maceral content and low inertinite and liptinite maceral content, illustrated in Figure 3. The vitrinite maceral group, consisting of vitrinite and pseudovitrinite, ranges from 77.6% in the Secor rider coal bed to 92.5% in the Tebo coal bed. Pseudovitrinite ranges from 1.2% to 13.6%, constituting as much as 16% of the total vitrinite maceral group.

TABLE 1.—SAMPLE INFORMATION

Coal Bed	OPL Number(s)[a]	Location[b]	County	Sample Type	Thickness (in.)	Coalfield Division[c]
Cedar Bluff	733	6–22N–13E	Tulsa	Core	14	NE Okla. shelf
Checkerboard	201	34–19N–12E	Tulsa	Channel (exposure)	2	NE Okla. shelf
Tulsa	734	6–22N–13E	Tulsa	Core	2	NE Okla. shelf
Dawson	211–212	2–17N–12E	Tulsa	Channel (outcrop)	24	NE Okla. shelf
Jenks	199–200	30–18N–13E	Tulsa	Channel (exposure)	17	NE Okla. shelf
Iron Post	223	34–23N–16E	Rogers	Channel (mine)	15	NE Okla. shelf
Croweburg	258–260	28–12N–13E	Okmulgee	Channel (mine)	36	NE Okla. shelf
Morris	295	16–14N–14E	Okmulgee	Channel (mine)	16	NE Okla. shelf
Tebo	277	12–13N–15E	Muskogee	Channel (outcrop)	10	NE Okla. shelf
Weir–Pittsburg	275	24–15N–15E	Muskogee	Channel (outcrop)	6	NE Okla. shelf
Wainwright	297	3–14N–16E	Muskogee	Channel (outcrop)	6	NE Okla. shelf
Bluejacket	193	25–17N–16E	Wagoner	Channel (outcrop)	9	NE Okla. shelf
Peters Chapel	280	10–15N–17E	Muskogee	Channel (mine)	10	NE Okla. shelf
Secor Rider	362	14–11N–17E	McIntosh	Channel (mine)	7	Arkoma basin
Secor	279	10–15N–17E	Muskogee	Channel (mine)	13	NE Okla. shelf
Rowe	198	9–18N–17E	Wagoner	Channel (outcrop)	13	NE Okla. shelf
Tullahassee	204	36–16N–17E	Wagoner	Channel (outcrop)	10	NE Okla. shelf
Stigler	323–324	36–11N–17E	McIntosh	Channel (mine)	18	Arkoma basin
Keefton	265	33–12N–20E	Muskogee	Core	7	Arkoma basin
Hartshorne	457–458	12– 5N–20E	Latimer	Core	22	Arkoma basin

[a]OPL designates Organic Petrography Laboratory of the Oklahoma Geological Survey. More than one number indicates bench samples.
[b]Section–township–range coordinate system relative to Indian Meridian.
[c]See Figure 1.

Table 2.—Petrography of Typical High-Volatile Bituminous Oklahoma Coals

Coal Bed	OPL Number(s)	Vitrinite	Pseudovitrinite	Semifusinite	Semimacrinite	Fusinite	Macrinite	Micrinite	Exinite	Resinite	Total Vitrinite	Total Inertinite	Total Liptinite	Vitrinite Reflectance, R_o (%)	Rank
Cedar Bluff	733	77.6	1.2	12.4	1.7	1.2	0.2	3.5	2.2	—	78.8	19.0	2.2	0.60	hvBb
Checkerboard	201	82.3	3.2	3.6	0.6	0.5	—	3.0	6.7	0.1	85.5	7.7	6.8	0.50	hvCb
Tulsa	734	78.6	4.5	0.5	0.1	0.2	—	3.9	12.0	0.2	83.1	4.7	12.2	0.72	hvAb
Dawson	211–212	81.0	10.6	1.6	0.2	1.0	—	1.7	3.8	0.2	91.6	4.5	4.0	0.56	hvCb
Jenks	199–200	85.6	2.6	2.0	0.2	3.0	0.1	3.8	2.5	0.1	88.2	9.1	2.6	0.50	hvCb
Iron Post	223	78.6	7.1	4.7	1.5	1.1	0.1	3.1	3.0	0.8	85.7	10.5	3.8	0.61	hvBb
Croweburg	258–260	81.2	7.8	1.9	1.1	0.3	0.1	1.8	5.6	0.3	89.0	5.2	5.9	0.71	hvAb
Morris	295	81.6	9.7	2.5	0.3	0.4	—	1.1	4.0	0.4	91.3	4.3	4.4	0.69	hvBb
Tebo	277	83.9	8.6	1.3	0.2	0.3	0.1	2.6	2.9	0.1	92.5	4.5	3.0	0.68	hvBb
Weir–Pittsburg	275	85.1	4.9	2.2	0.1	0.6	0.2	3.1	3.7	0.1	90.0	6.2	3.8	0.65	hvBb
Wainwright	297	87.2	5.1	1.9	0.3	1.0	—	2.1	2.4	—	92.3	5.3	2.4	0.61	hvBb
Bluejacket	193	76.9	10.2	3.4	0.8	1.0	—	3.7	4.0	—	87.1	8.9	4.0	0.65	hvBb
Peters Chapel	280	83.4	2.5	3.7	0.7	1.0	0.1	4.5	4.1	—	85.9	10.0	4.1	0.68	hvBb
Secor Rider	362	72.5	5.1	9.1	1.7	1.1	—	5.1	4.7	0.7	77.6	17.0	5.4	0.80	hvAb
Secor	279	75.3	12.6	4.4	0.2	1.1	—	2.8	3.6	—	87.9	8.5	3.6	0.87	hvAb
Rowe	198	72.9	5.3	6.1	—	4.8	0.4	4.1	6.2	0.2	78.2	15.4	6.4	0.65	hvBb
Tullahassee	204	69.4	12.9	4.1	1.2	1.9	—	3.1	7.3	0.1	82.3	10.3	7.4	0.69	hvBb
Stigler	323–324	76.1	13.3	3.2	0.9	0.2	—	2.1	4.2	0.1	89.4	6.4	4.3	0.86	hvAb
Keefton	265	70.7	9.7	10.1	0.8	1.5	0.1	3.3	3.6	0.2	80.4	15.8	3.8	0.98	hvAb
Hartshorne	457–458	70.4	13.6	6.0	0.8	3.3	0.1	2.1	3.6	0.1	84.0	12.3	3.7	0.80	hvAb

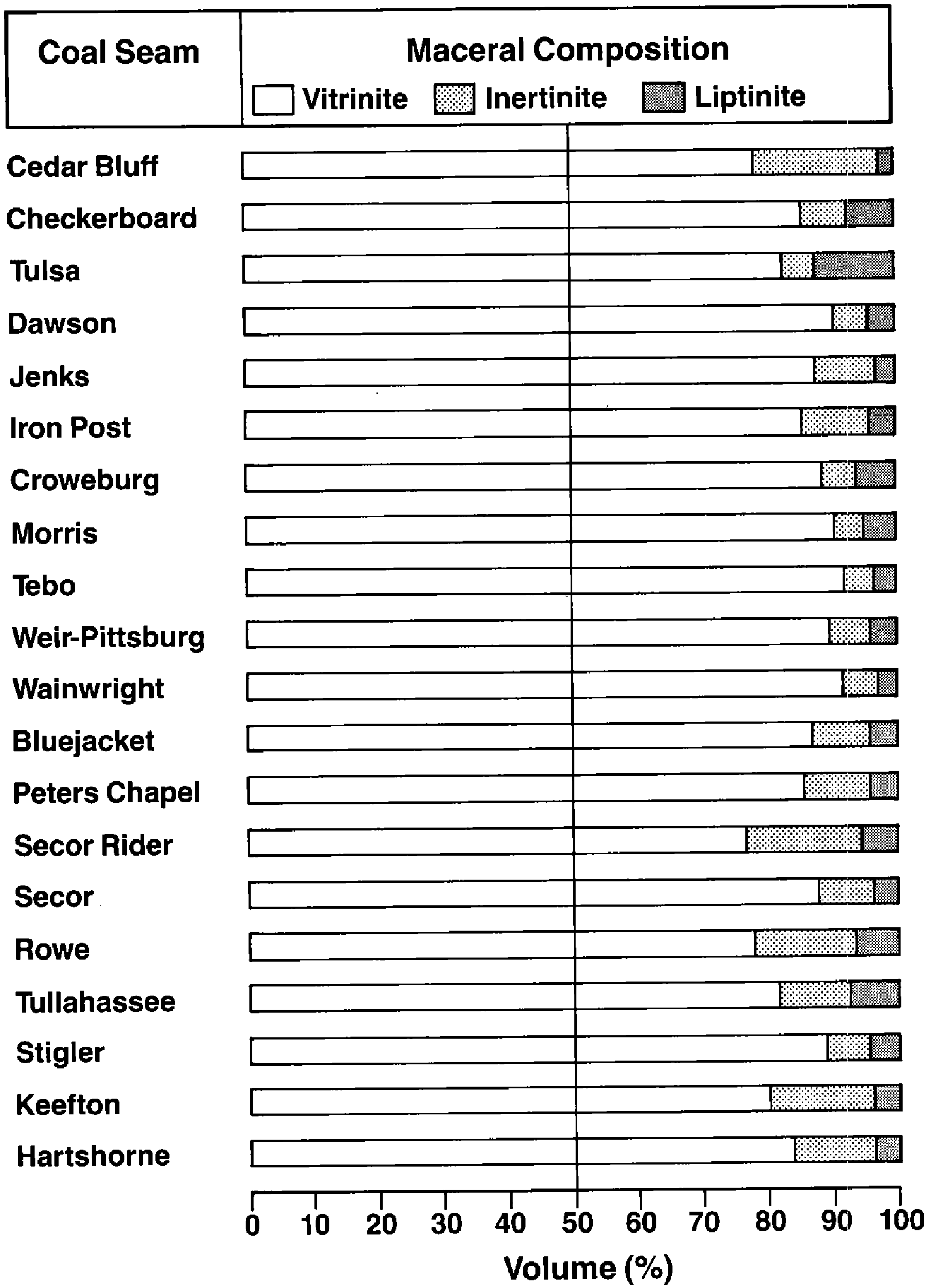

Figure 3. Maceral composition of selected high-volatile bituminous Oklahoma coals, expressed as percentage by volume on a mineral-free basis.

Jones and others (1984) described "patchy" vitrinite in low-reflecting vitrinites from British coal beds in the Fife and Northumberland coalfields of Carboniferous age. They consider the "patchy" vitrinite to be subhydrous in contrast with perhydrous vitrinite and "smear film" on vitrinite described by Stach and others (1982). Jones and others (1984, p. 324) stated that "this same patchy appearance has now been observed in vitrinites from many coal basins and in coals from a wide range of geological age." Salehy (1986) reported "patchy" vitrinite from Jurassic coals in the eastern Surat basin, Australia. Some Oklahoma coals have been found to contain vitrinite with "patchy" texture, particularly the Mineral (Morris), Croweburg, Dawson, and Tulsa coal beds of high-volatile bituminous rank (Fig. 4). These coal beds are late Desmoinesian to early Missourian and occur primarily in the northeast Oklahoma shelf area. The range in vitrinite reflectance for these coal beds from the OPL data base is 0.55–0.79% R_o. Owing to the lower reflectance of the dark patchy areas, only the reflectance of brighter areas in vitrinite was measured in the vitrinite-reflectance analysis.

Jones and others (1984) suggested that the "patchy" vitrinite may be related to a low rate of coalification. They indicate that coals from the Fife and Northumberland coalfields which contain "patchy" vitrinite had a slower coalification rate than

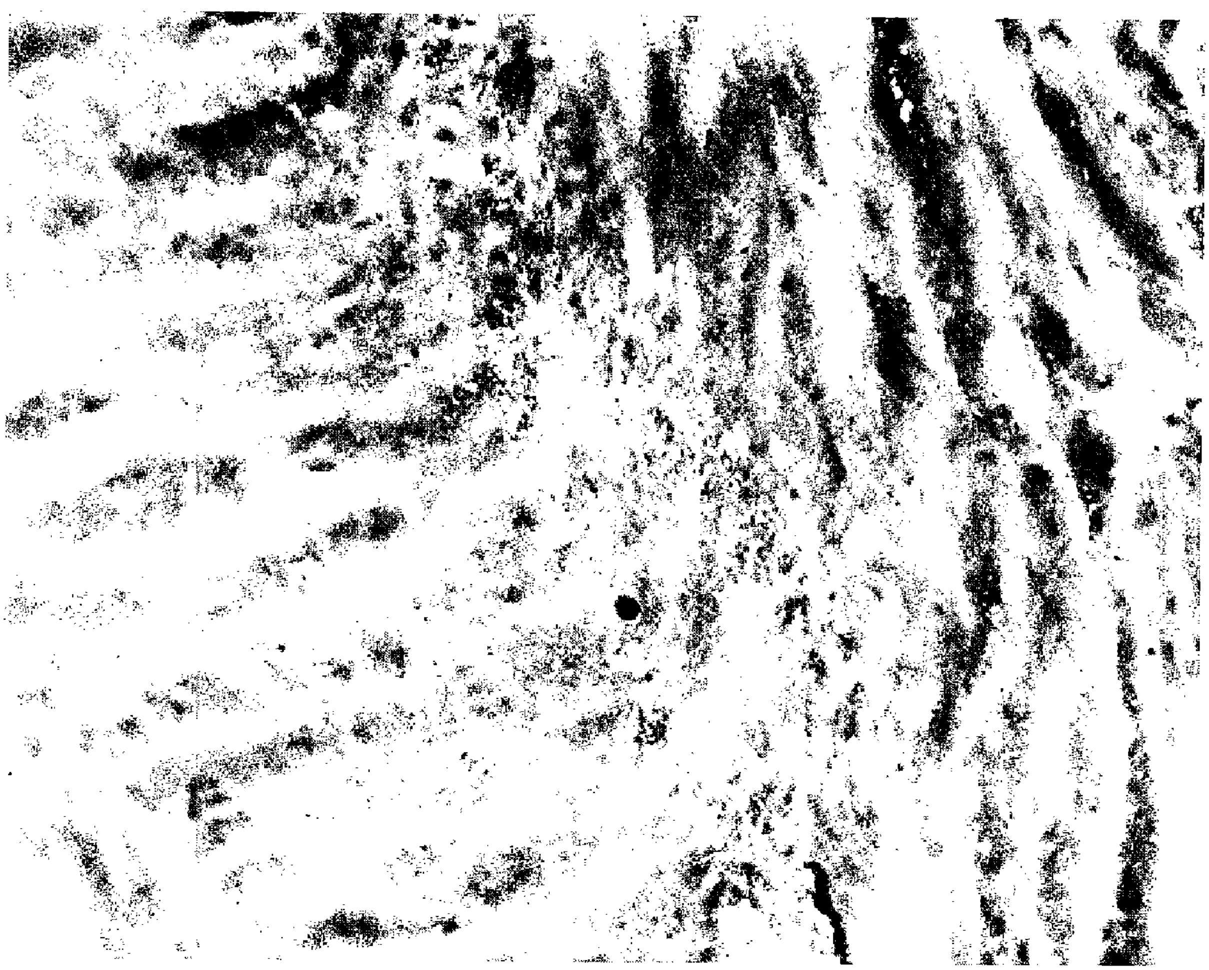

Figure 4. Photomicrograph showing "patchy" texture in vitrinite from the Croweburg coal (mean maximum vitrinite reflectance = 0.75% R_o). Reflected white light, oil immersion, 500×, diameter of field 120 μm.

coals from the Durham coalfield, where "patchy" vitrinite has not been recorded. A similar situation may apply in Oklahoma; the coal beds in the northeast Oklahoma shelf which contain "patchy" vitrinite experienced a slower rate of coalification than coals in the Arkoma basin, where "patchy" vitrinite has not been observed. Further petrographic characterization of Oklahoma's coals may determine which additional coal beds contain "patchy" vitrinite, its association with rank, and its significance as to origin and coalification rate.

The inertinite maceral group, consisting of semifusinite, semimacrinite, fusinite, macrinite, and micrinite, ranges from 4.3% in the Morris coal bed to 19.0% in the Cedar Bluff coal bed. The most common inertinite maceral is semifusinite, ranging from 0.5% in the Tulsa coal bed to 12.4% in the Cedar Bluff coal bed. Semimacrinite, a maceral that "occurs as structureless ovoid bodies with the reflectance of semifusinite" (Crelling and Dutcher, 1980, p. 24), is nearly insignificant, ranging from 0% to 1.7%. Fusinite and micrinite each make up <5%, while macrinite comprises <0.5%.

The liptinite maceral group, consisting of exinite and resinite, typically ranges from 2.2% in the Cedar Bluff coal bed to 7.4% in the Tullahassee coal bed. The Tulsa coal bed has a liptinite maceral content of 12.4%, the highest of any Oklahoma coal studied to date, with a range from 4.4% to 13.2% in 4 samples. The most common liptinite maceral in all the coals is miosporinite, followed in much lesser quantities in most of the coals by tenuicutinite, crassicutinite, megasporinite, and resinite. Megasporinite is particularly abundant in the Tulsa and Checkerboard coal samples. Primary resinite makes up <1.0% of the maceral composition of most of the coals, generally <0.5%. A preliminary survey under blue-light excitation of high-volatile bituminous coals has revealed that (1) fluorinite is present in minor amounts in almost all the coals, and (2) exsudatinite (secondary resinite?) is present in the Weir-Pittsburg and Mineral coal beds (Fig. 5). Landis (1985) found that exsudatinite ranged from 0.1% to 2.4% in 11 high-, medium-, and low-volatile bituminous Hartshorne coal bed samples from Oklahoma. Alginite and bituminite have not been observed in any Oklahoma coal.

Summary and Conclusions

Vitrinite-reflectance and white-light maceral analyses of 20 selected high-volatile bituminous coal beds in the Oklahoma coalfield suggest that the types and quantities of macerals do not vary significantly, either regionally (from shelf to basin) or stratigraphically. The uniform maceral composition suggests that similar conditions of peat accumulation were repeated for each depositional cycle.

The white-light maceral analyses indicate that Oklahoma high-volatile bituminous coals are high (77.6–92.5%) in vitrinite-maceral content, moderately low (4.3–19.0%) in inertinite-maceral content, and low (2.2–12.4%) in liptinite-maceral content. Accordingly, the coals are high (81–95%) in total reactive macerals (vitrinite plus liptinite, excluding reactive semifusinite). All the coal samples in this study plot within the area of predicted optimum liquefaction (conversion) by Davis and others (1976) and Steller and others (1987).

"Patchy-textured" vitrinite appears to be limited to the Mineral through Tulsa coal beds of high-volatile bituminous rank in the northeast Oklahoma shelf area,

Figure 5. Photomicrograph showing flow and granular texture in secondary resinite (exsudatinite?) from the Mineral coal. Reflected light, blue-light irradiation, oil immersion, 500×, diameter of field 120 μm.

and may be associated with a low rate of coalification.

The variety of liptinite macerals is consistent throughout all the coal beds. The most common liptinite maceral in all the coal beds is miosporinite, followed in much lesser quantities in most of the coal beds by tenuicutinite, crassicutinite, megasporinite, and resinite. Fluorinite is present in minor amounts in almost all the coal beds, while exsudatinite is present in only a few. Alginite and bituminite have not been observed in any Oklahoma coal bed.

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RADIAL-DRAINAGE ANOMALY OVER ALEDO GAS FIELD IN THE ANADARKO BASIN: EXAMPLE OF A POOR MAN'S REMOTE-SENSING TECHNIQUE

Lyle G. Bruce[1]

Introduction

Prior to the 1930s most geologic exploration in Oklahoma was conducted using surface mapping (Dott, personal communication, 1985). Today, most oil and gas exploration is managed by making maps of the subsurface directly from electric logs or geophysical data. Few exploration geologists take note of topography or surface geology except for placing a drilling rig or positioning seismic shot points.

Structure and Drainage

It is commonly assumed that northwest Oklahoma has structures too subtle, sediment cover too thick, and unconformities in the stratigraphic section too many to yield surface expression of buried features. Brown (1967) wrote that because of the low angle of dip in northwest Oklahoma, the surface geology reveals little about the shallow subsurface structure. Nevertheless, he concluded that drainage patterns could yield clues to subsurface structure and that the bends in the South Canadian River west of T. 17 N., R. 16 W., Indian Meridian (Fig. 1), were controlled by structural flexures. Harris (1970) disagreed with this conclusion and proposed that these bends were caused by the change in strike between the Tertiary–Cretaceous outcrop (now eroded away) and the Permian outcrop; he asserted that the anomalous flow directions are relict features. The question of whether subsurface geologic structure controls the Canadian River in this area remains unresolved.

Melton (1959) proposed that all drainage in an area is eventually controlled by the structures and fracture patterns of the last major tectonic event; this applies to flat-lying strata and is maintained through or after minor tectonic pulses, inundation, unconformities, etc. The mechanisms by which adjustments to tectonics are reached may be (1) repeated minor uplifts or other movements of buried tectonic features, (2) differential compaction over buried surface topography or tectonic axes, (3) development of joints (fractures) to a degree that will affect weathering and erosion in the overlying rock, and (4) influence on or alteration of groundwater flow because of (1), (2), and (3).

[1]Amoco Corp., Ground-Water Management Section, Tulsa.

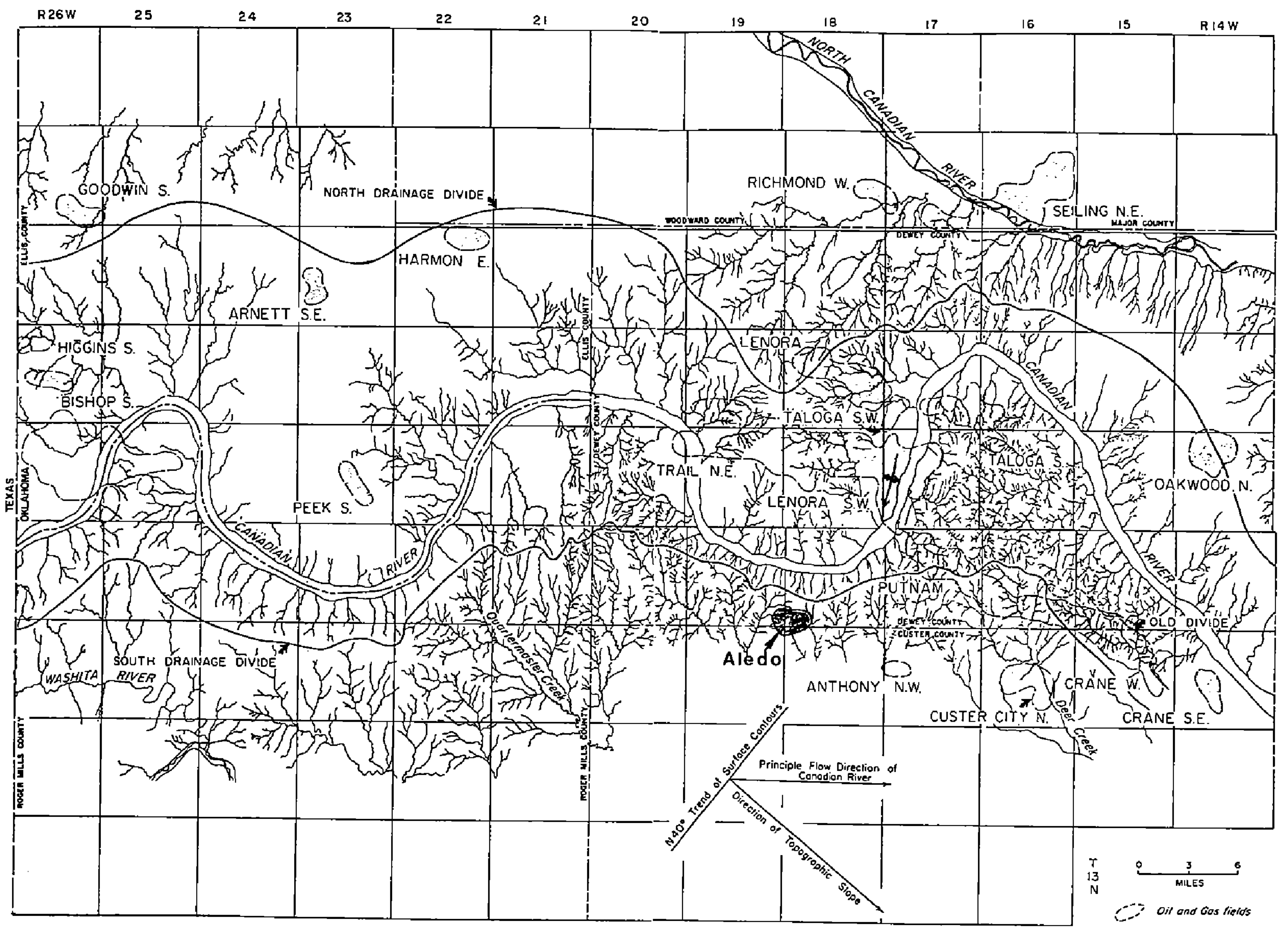

Figure 1. Drainage and oil and gas fields along the Canadian River in northwest Oklahoma (after Brown, 1967).

As a result of extensive drilling for oil and gas, we now have areas in this country with detailed subsurface control. We are fortunate to have many of these areas in Oklahoma. We have the tools to settle old arguments and to start many new ones about the relationship between subsurface and surface phenomena.

Remote Sensing

In areas with little or no subsurface control, remote sensing is often used as an exploration tool. Because remotely sensed data such as satellite imagery and side-scanning radar images have proven useful in exploring inaccessible regions, a few geologists have attempted to integrate this information with subsurface data in "mature," or densely drilled areas (Berger, 1988). More often than not a positive relationship has been demonstrated. Maarouf (1981) used Skylab and Landsat data to show that basement faults have influenced the present surface drainage and structures on the Colorado Plateau through a sedimentary cover of >6 km (nearly 20,000 ft). Unfortunately, satellite and radar imagery can be expensive.

Drainage Technique

Many of us overlook the fact that current (inexpensive) topographic maps are derived from detailed air photos and therefore are representations of some of the best remote-sensing data available. The real challenge is in interpreting what these maps can tell us about subsurface geology.

One technique used to delineate buried structures from a topographic map is the detailed surface drainage map (Ray, 1960). A surface drainage map over the Aledo field of Dewey and Custer Counties shows a radial-drainage pattern centered on secs. 31 and 32, T. 16 N., R. 18 W., Indian Meridian (Fig. 2). The radial drainage overlies the subsurface Aledo structure (Fig. 3). The structure is faulted, with >400 ft of closure at the Hunton interval. The Hunton dolomite, which lies below a depth of 15,000 ft, was the first producing formation at Aledo field. Aledo is now a multi-pay field producing from formations that lie above and below the Hunton. In this field the Hunton alone has produced >218 billion cubic feet of natural gas from six wells. The best well in the field has produced >70 billion cubic feet of Hunton gas.

The Aledo drainage anomaly also can be discerned on a Landsat MSS (Multi-Spectral-Scanner) image using the near-infrared Band 7 (Fig. 4). This band, best suited for distinguishing between land and water areas, yields detailed observations of drainage systems (Richason, 1983). Aledo was first observed on space imagery by Short and others (1976). In this case, a topographic map shows the same feature.

Not all buried structures will look like Aledo field on the surface. Most will be more subtle. But other subsurface features, even geomorphic ones, may have a surface expression or surface signature. We now have the subsurface control to define some areas in detail. This will make our game of "find the hidden picture" easier because we can check the surface expression of known entities in the subsurface. From these observations some generalizations may be possible.

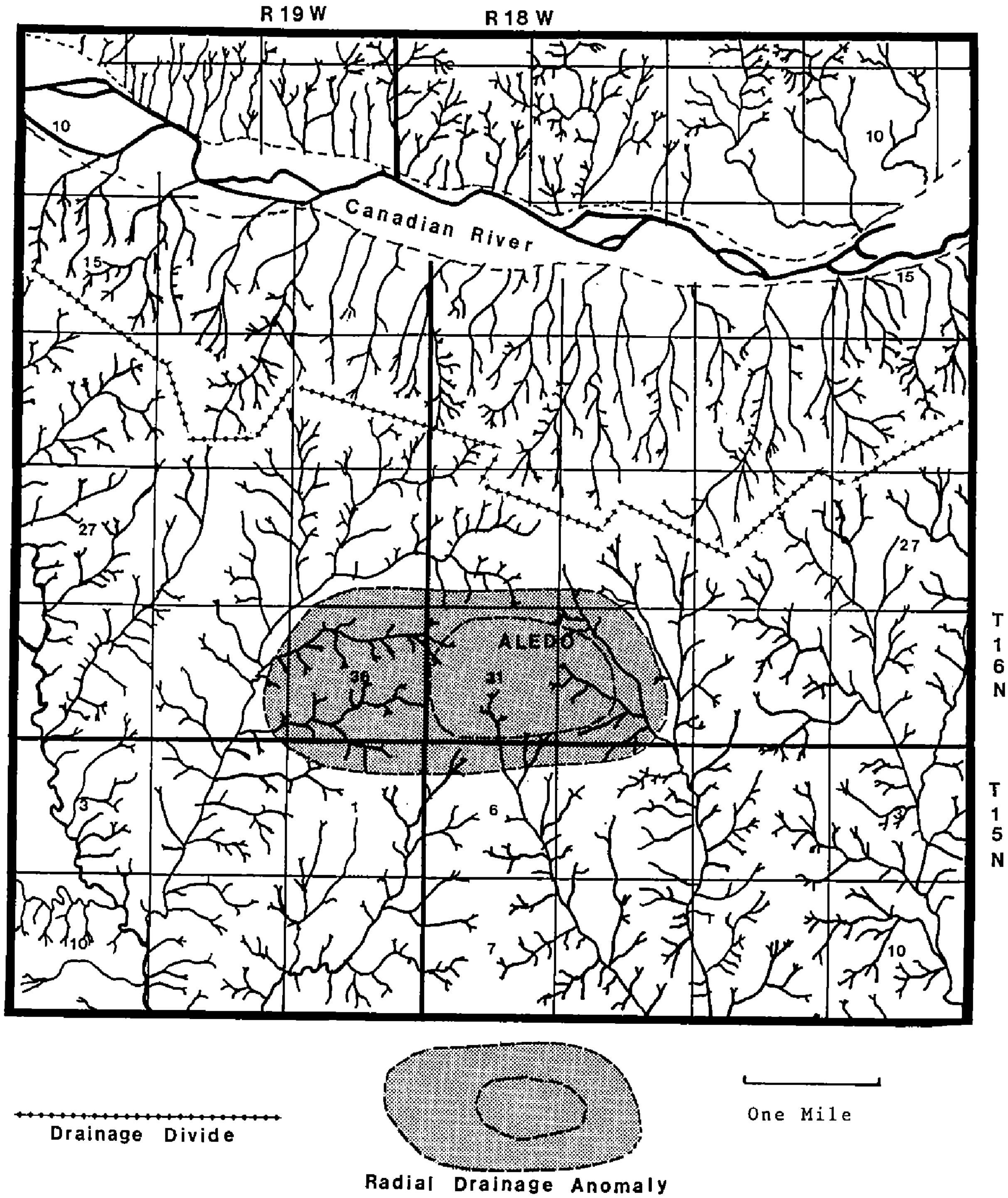

Figure 2. Detail of drainage around Aledo field.

Acknowledgments

Dr. Wayne Pettyjohn, Dr. Jack Vitek, and Richard Behling, J.D., reviewed this paper.

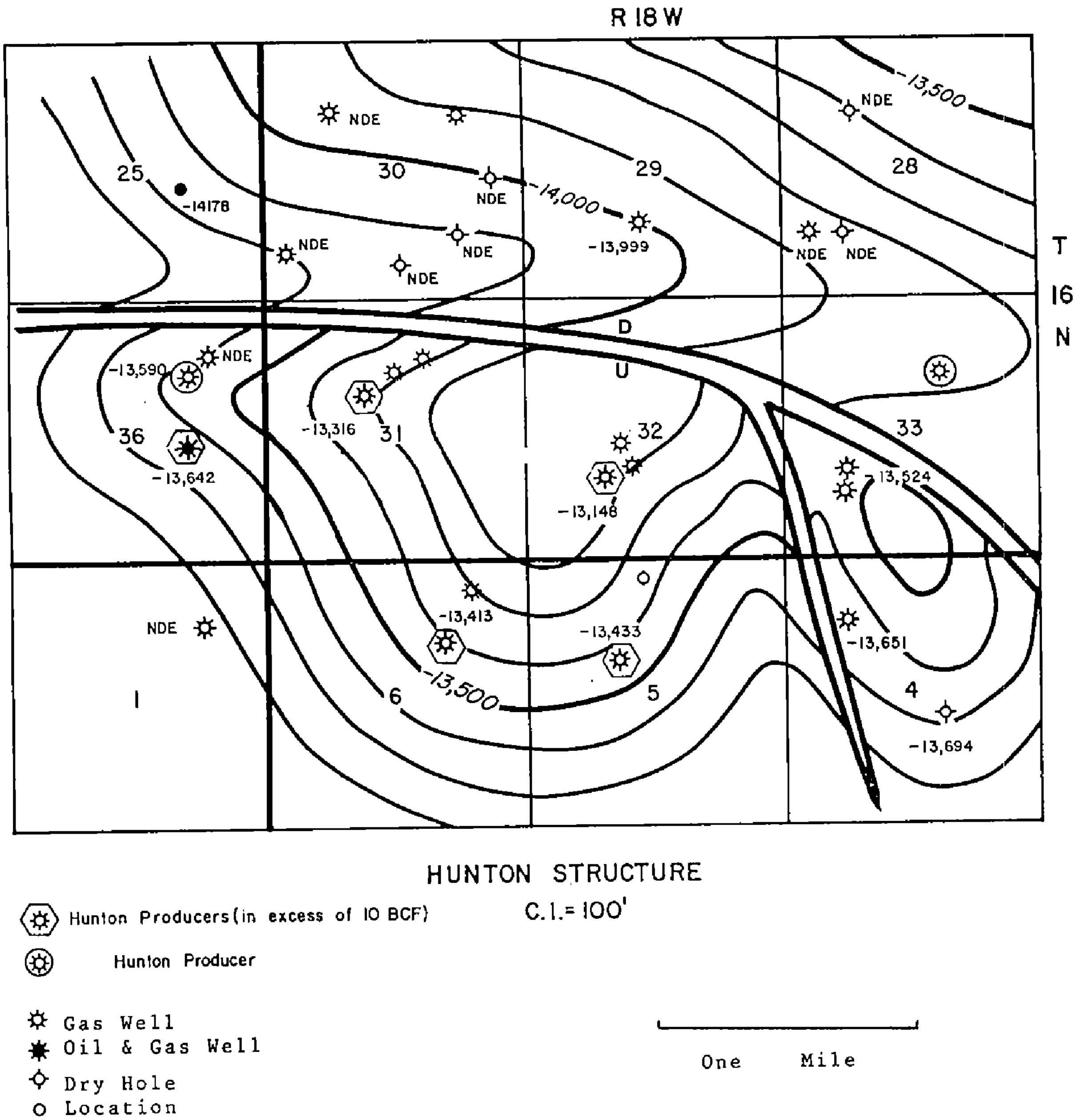

Figure 3. Structure on top of the Hunton at Aledo field.

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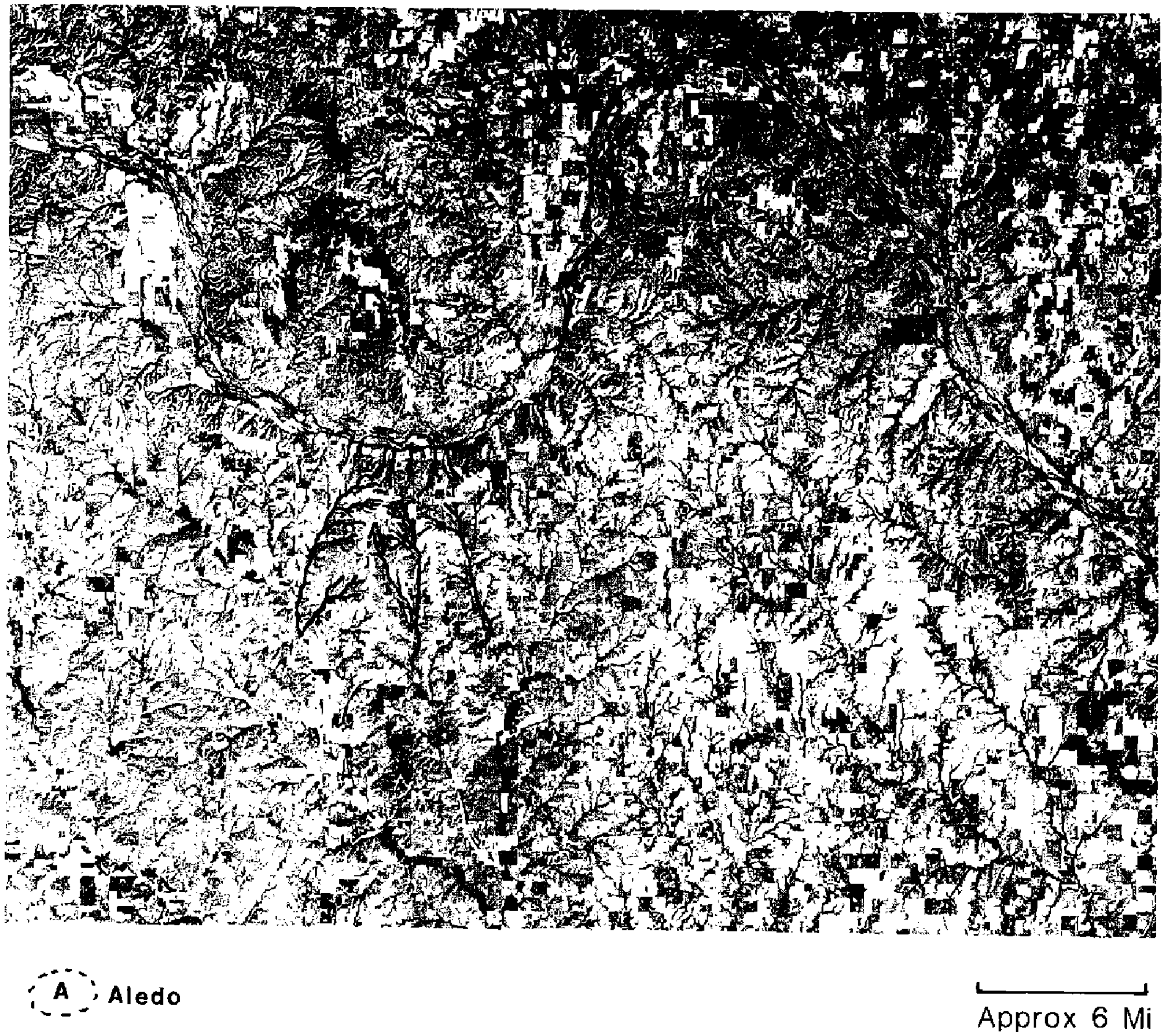

Figure 4. Drainage at Aledo field and surrounding area on Landsat MSS Band 7 image, 4 November 1985.

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CAMBRIAN–ORDOVICIAN SYMPOSIUM
Norman, Oklahoma, October 18–19, 1989

The Oklahoma Geological Survey is sponsoring a symposium on the Cambrian–Ordovician Geology of the Southern Midcontinent. The meeting will be held October 18–19, 1989, at the Oklahoma Center for Continuing Education (OCCE) of the University of Oklahoma in Norman.

The symposium will present current and ongoing research and studies dealing with petroleum exploration and production, depositional environments, petrography, diagenesis, dolomitization, paleokarst, geophysics, and structure.

Provisional titles and speakers are listed below:

October 18

Geologic Overview and Industrial Importance of Late Cambrian and Ordovician Rocks in Oklahoma, by Kenneth S. Johnson

Biostratigraphy of the Timbered Hills, Arbuckle, and Lower Simpson Groups: A Review of Tools and Techniques Available to the Explorationist, by J. R. Derby, W. B. Creath, R. I. Dresbach, R. L. Ethington, J. D. Loch, T. R. McHargue, J. F. Miller, J. E. Repetski, J. H. Stitt, and Mark Williams

Evidence of Paleokarst and Burial Diagenesis in the Ordovician Arbuckle Group of Oklahoma, by Mark Lynch and Zuhair Al-Shaieb

The Arbuckle Group—Relationship of Core and Outcrop Analyses to Sequence Stratigraphy and Correlation, by Richard D. Fritz

Petrography and Geochemistry of Massive Kindblade Dolomite from Arbuckle Group, West Slick Hills, Southwestern Oklahoma, by Guoqiu Gao and Lynton S. Land

Recent Developments at Wilburton Field, Latimer County, Oklahoma, by Richard C. Hook

Seismic Exploration for Arbuckle Objectives in the Wilburton Area, Southern Arkoma Basin, Oklahoma, by Allen J. Bertagne and Tim C. Leising

Arbuckle Group Depositional Cycles, Southern Oklahoma, by Robert F. Lindsay and Kathy M. Koskelin

An Analysis of the Upper Simpson Group in the Slick Hills of Southwestern Oklahoma, by R. Nowell Donovan, Arthur B. Busbey, Dee Jenkins, Roz Ward, Steve D. Bridges, and Kathy H. Collins

October 19

Geology, Geochemistry, and Platinum-Group-Element Mineralization of the Cambrian Glen Mountains Layered Complex and Roosevelt Gabbros, Southwestern Oklahoma, by Roger W. Cooper

Cambrian Basement Rocks and the Setting for Deposition of Late Cambrian Sediments in Western Oklahoma, by M. Charles Gilbert and David A. McConnell

Buried Cambrian Topography in the Slick Hills of Southwestern Oklahoma, by R. Nowell Donovan

Cottonwood Creek—An Oklahoma Oil Discovery Matures, by Robert A. Lamb
The Enigma of Tectonic Dolomitization and Fracturing in Arbuckle Exploration, by John F. Harris
Silica in the Arbuckle Group, Slick Hills, Southwestern Oklahoma, by Deborah A. Ragland and R. Nowell Donovan
The Occurrence of Dolomite in the Arbuckle Group, Slick Hills, Southwestern Oklahoma, by Debra Shelby and R. Nowell Donovan
Depositional and Diagenetic History of the Late Ordovician Montoya Group, Sacramento Mountains, South-Central New Mexico, by David L. Brimberry
Geology of the Arbuckle Group in the Southern Arkoma Basin and Ouachita Mountains of Oklahoma, by Robert O. Fay and Lloyd E. Gatewood

Advance registration (prior to October 1) is $50, which includes two lunches and a copy of the proceedings. On-site registration will be $60 per person. Lodging will be available on the OU campus or at local motels.

Contact Kenneth S. Johnson, Oklahoma Geological Survey, University of Oklahoma, 100 E. Boyd, Room N-131, Norman, OK 73019, phone (405) 325-3031, for registration forms and/or more information.

NEW OGS PUBLICATIONS

CIRCULAR 90. ***Anadarko Basin Symposium, 1988,*** edited by Kenneth S. Johnson. 289 pages, 35 contributions. Price: clothbound, $20; paperbound, $16.

From the editor's preface:

The Anadarko basin is one of the greatest oil and gas provinces in the United States. Cumulative production from the greater Anadarko basin through 1985 was >5 billion barrels of oil and 82 trillion cubic feet of gas, production coming primarily from ~50 significant fields in the basin (Davis and Northcutt, this volume). The Oklahoma Geological Survey and the U.S. Geological Survey have been conducting and sponsoring research programs in the Anadarko basin for a number of years. On April 5–6, 1988, the two agencies cosponsored a symposium comprising invited papers and posters to present data on these programs and other Anadarko basin research. The symposium was held at the Oklahoma Center for Continuing Education, The University of Oklahoma, in Norman, Oklahoma, and this volume contains the proceedings of that conference.

Cooperative efforts of the OGS and USGS to jointly study the Anadarko basin were initiated in 1984 when the USGS began its Evolution of Sedimentary Basins (ESB) program. The ESB program—which utilizes sedimentary basins as natural geologic laboratories to address geologic topics and processes important in assessing our nation's natural resources—meshed perfectly with ongoing OGS studies in the Anadarko basin. Funding of the USGS part of the Anadarko basin program has been from their ESB program and the Onshore Oil and Gas program.

Research reported upon at the symposium includes work on basin history, sedimentation, stratigraphy, tectonics, petroleum exploration, source rocks, thermal history, oil characterization and migration, and hydrogeology. It is our hope that the symposium and these proceedings will bring such research to the attention of the geoscience community, and will help foster exchange of information and increased research interest in the Anadarko basin. Twenty-one invited papers were presented orally, and an additional 20 reports were presented as posters during the two-day session. All 21 of the orally presented papers are presented here as full papers or abstracts, and 14 of the poster presentations are presented as abstracts or short reports.

GUIDEBOOK 26. *Geology of the Arbuckle Mountains along Interstate 35, Carter and Murray Counties, Oklahoma,* by Robert O. Fay. 50 pages, 20 figures, 1 plate. Price: $6.

The geology of part of the Arbuckle Mountains is described in the new edition of this guidebook, prepared cooperatively by the Oklahoma Geological Survey and the Ardmore Geological Society. An earlier version of the guidebook was released under the same title by the AGS in 1969 to accompany an AGS field trip directed by OGS geologist Robert O. Fay. The original book is sold out, and the two organizations agreed to jointly reissue this revised and expanded version of the original guidebook.

Guidebook 26 contains a brief overview of the geology and stratigraphy of the Arbuckle Mountains, but its major contribution is a detailed description of the lithology, on a bed-by-bed basis, of rocks exposed in the 7 miles of deep road cuts through the heart of the Arbuckle anticline. This description of the excellent exposures of Cambrian through Pennsylvanian strata will be widely used by professional geologists, university faculty and students, and many of the general public, all of whom have regarded the Arbuckles as a major geologic field laboratory. People continually journey to the Arbuckles to examine this suite of rocks that are better exposed here than anywhere else in the southwest.

The guidebook contains a large plate with an aerial photograph, colored geologic map, and colored cross section, all at a scale of 1:12,000. The aerial photograph and geologic map cover a 2-mile-wide strip embracing I-35 through the Arbuckle anticline. As an aid to those examining the road cuts, the AGS has placed four-inch brass markers in the rock at stratigraphic contacts, and these brass markers are numbered and keyed to the guidebook.

Index to Topographic Maps of Oklahoma. One sheet, single copies free on request.

The newly printed index to topographic maps of Oklahoma shows the names and locations of U.S. Geological Survey quadrangle maps in four series and gives information on these maps as well as a state base map and a state topographic map.

The 7.5′ topographic maps are published at a scale of 1:24,000 (1 inch = 2,000 feet); the maps show natural and man-made features (streams, towns, roads, lakes and ponds, etc.). Land elevations and the configuration of the terrain are shown by contour lines.

Similar but less-detailed information is shown by the maps in other series published at a smaller scale. The 15′ maps are published at a scale of 1:62,500 (1 inch = ~1 mile). The 30′×60′ maps are published at a scale of 1:100,000 (1 inch = 1.6 miles), and the 1°×2° maps are published at a scale of 1:250,000 (1 inch = ~4 miles). The state maps are published at a scale of 1:500,000 (1 inch = ~8 miles).

Circular 90, Guidebook 26, and the index to topographic maps of Oklahoma can be obtained over the counter or postpaid from the Survey at 100 E. Boyd, Room N-131, Norman, OK 73019; phone (405) 325-3031.

SEPM MIDCONTINENT SECTION PLANS FIELD TRIP

"Regional Upper Cambrian Stratigraphy and Economic Geology of MVT Deposits of Southeast Missouri" is the topic of a two-day field conference for the 1989 SEPM Midcontinent Section Annual Meeting, scheduled for October 13–15 in Rolla, Missouri. The University of Missouri at Rolla, Department of Geology, will host the meeting.

Current plans call for assembly Friday evening, October 13, in Rolla, for dinner and a seminar on Upper Cambrian stratigraphy of the St. Francois Mountains region.

On October 14 participants will leave Rolla at 7 a.m. for an all-day field trip through the St. Francois Mountains, lead by Jay Gregg, University of Missouri—Rolla, and Jim Palmer, Missouri Geological Survey. The group will spend the night in Flat River, Missouri. On October 15 the field trip will continue until noon and will end back in Rolla by 3 p.m.

Stratigraphic units to be studied are the Lamotte Sandstone, Bonneterre Dolomite, and Davis Formation; the Precambrian–Cambrian contact, facies relationships, and Mississippi Valley-type mineralization will be discussed.

A guidebook is being prepared, co-edited by Jay Gregg, Jim Palmer, and Vince Kurtz of Southwest Missouri University. It will be used for this trip as well as for a similar, three-day, post-meeting trip to be lead by Jim Palmer and Vince Kurtz, planned for the GSA annual meeting in St. Louis this November.

For more information contact Jay Gregg, Department of Geology and Geophysics, University of Missouri—Rolla, Rolla, MO 65401; (314) 341-4664.

GSA ANNUAL MEETING
St. Louis, Missouri, November 6–9, 1989

Long known as the "Gateway to the West," St. Louis is the ideal site as GSA's gateway to its second century. St. Louis is a refreshing blend of the traditional and the state-of-the-art in both its social and financial environments. Its unique location has made St. Louis a center that reflects an inventive spirit.

More than one hundred Fortune 500 companies are located in St. Louis, including many that are leading the way in aerospace technologies. This community has a record of public-private cooperation that is the envy of other American cities. In spite of the dynamic influence of the business community, St. Louis remains reasonably priced. Centrally located, it is also easily accessible.

St. Louis made modern history with the spectacular Gateway Arch designed by Eero Saarinen, but it has also preserved the rich treasure of its older architecture. The ornate and authentic restoration of Union Station, a Victorian-era railroad station that was once the nation's busiest, has made this a remarkable place to visit, dine, or shop. Laclede's Landing, once a Mississippi riverbank warehouse district, is now a thriving stretch of eateries and nightclubs.

The city prides itself on being a home for traditional blues and jazz. St. Louis has been home to many musicians, including Scott Joplin, Bix Biederbecke, Miles Davis, Ike and Tina Turner, and Chuck Berry. After all, St. Louis is still the home of the St. Louis Blues.

St. Louis is a city that has combined a rich and varied past with a dynamic future. It is a perfect place to welcome GSA as it experiences its 101st year with a meeting highlighted by the theme "Frontiers in Geoscience."

—GSA

GSA Annual Meeting Agenda

Technical Program

Symposia

Geoscience Research and Public Policy
Cenozoic Deep-Sea Foraminifera: Distribution and Environments
Molecular Approaches to Paleoclimatic and Paleoenvironmental Reconstruction
Frontiers in Geoscience Information
Application of Modern Powder Diffraction Techniques to Problems in Mineralogy and Geology
Remote Sensing and Geographic Information Systems: Techniques on the Frontier of Change
Radiations and Recoveries from Mass Extinctions
Potential for Olympic Dam-Type Cu–Au–U–REE Deposits in the Proterozoic Granite-Rhyolite Terranes, Midcontinent, USA
Mississippi Valley-Type Deposits
Becker and Van Hise's Challenges: Geology and Geophysics since 1904
Geological Exploration of the Solar System: Past, Present, and Future
The Legacy of T. C. Chamberlin
Implications for the Geological Sciences from Recent Developments in Geochemical Techniques and Instrumentation
Sigma Gamma Epsilon Research Symposium
Geological Controls on the Regional Distribution of Archaeological Sites
Modern and Ancient Environments of Coal Formation
Site Characterization for Conditions of Non-Darcian Flow
Intraplate Seismicity and Deformation: Geological and Geophysical Constraints
Rates and Duration of Deformational Processes and Orogenic Events

Theme Sessions

Geological Mapping in the Next Several Decades
The Effects of Man on the Mississippi River and Its Delta
Correlation and Basin Analysis of Nonfossiliferous Sedimentary Rocks
Magma Currents, Melt Migration, and Geochemical Transport in Mafic Igneous Complexes
The Effects of Greenhouse Warming on North American Deserts: Holocene Analogues
Trace Element and Isotopic Studies with the Ion Microprobe
Sub-Mediterranean "Giant Salt" as a Deep-Water Brine *Precipitate*: An Alternative to the Evaporite Hypothesis
Quantitative Structural Geology: The Nature, Mechanism, and Implications of Natural Deformation
The First Half of Earth History
Seismic Tomography and Mantle Dynamics
Global Sedimentary Geology
A Growing Crisis in (Geo)Science Education
The Lunar Science Frontier: Implications for Earth's Past and Future
Tectonometamorphism
Continental Dynamics
Volcanism and Climate
Mantle Plumes and Mass Extinctions
Geoscience and the Arts

New Concepts in Understanding Fluid-Rock Interactions at High Temperatures: Problems and Solutions
Physical Properties of the Lower Continental Crust
Frontiers of Fluid-Inclusion Research
Application of Artificial Intelligence, Expert System, or Knowledge-Based System Methods in Geological Sciences
Determining the Relative Timing of Pluton Emplacement and Regional Deformation
Geomorphic Processes and Landform Evolution
Late Eocene–Oligocene Climatic and Biotic Evolution
Hydrothermal Organic Geochemistry
Cretaceous Record of the Eastern Margin of the Western Interior Seaway
Hydrogeologic Challenges for the Next Decade
Thermal and Hydrologic Evolution of Accretionary Prisms: Modern and Ancient Examples
Origin of Brines in Earth's Crust
Geologic Causes of Natural Radionuclide Anomalies
Rock-Water Interactions in Carbonate Rocks and Sediments

Field Trips

Premeeting Trips

Late Pennsylvanian and Early Permian Cycle Sedimentation, Paleogeography, Paleogeology, and Biostratigraphy in Kansas and Nebraska, *November 3–5*
Depositional Environments and Geology of Coals of the Lower Pennsylvanian of the Western Part of the Appalachian Basin and the Eastern Part of the Illinois Basin in Kentucky, Indiana, and Illinois, *November 3–5*
Geology of the Proposed Nuclear Waste Repository at Yucca Mountain, Nevada, and Surrounding Area, *November 3–5*
Surface Effects of the 1811–1812 New Madrid Earthquake Sequence in Seismotectonics of the New Madrid Seismic Zone, Western Tennessee, Northeast Arkansas, and Southeast Missouri, *November 3–5*
Regional Stratigraphy, Facies, and Paleoenvironments in the Cambrian of Southern Missouri, *November 4–5*
Hydrogeology of Shallow Karst Ground-Water Systems in Southeastern Missouri, *November 4–5*
Engineering and Environmental Geology of the St. Louis Area, Missouri, *November 5*
Archaeological Geology and Geomorphology in the Central Mississippi–Lower Illinois Valley Region, Illinois and Missouri, *November 5*

Half-Day Mini-Trips (during the meeting)

The Geologic Story of the St. Louis Riverfront (A Walking Tour), *November 6*
Aerospace Center, U.S. Defense Mapping Agency, *November 7*
Engineering Geology and Industrial Minerals Aspects of the Greater St. Louis–Illinois Area, *November 7*
Digital Cartography, Map Library, and Data Base Management System of Washington University's Department of Earth and Planetary Sciences, *November 8*

Postmeeting Trips

Quaternary Loess and Glacial Record of Southwestern Illinois, *November 10*

Economic Geology of the Complexly Deformed Cambrian–Mississippian Strata of the Ouachita Mountains, Central Arkansas, *November 10–11*
Cyclic Strata of the Late Pennsylvanian Outlier, East-Central Illinois, *November 10–11*
Transition from Passive Margin to Foreland Basin Sedimentation: The Atoka Formation of the Arkoma Basin, Arkansas and Oklahoma, *November 10–12*

SEG-Sponsored Trips

Precambrian Ore Deposits and Geology of Volcanic and Plutonic Rocks in the Southern St. Francois Mountains, Missouri, *November 2–4*
Mississippi Valley-Type Mineralization of the Viburnum Trend, Missouri, *November 9*

Short Courses/Workshops/Forums

Advanced Powder Diffraction Techniques Short Course, *November 3*
Contaminant Hydrogeology: Practical Monitoring, Protection, and Cleanup, *November 4–5*
Creating Geological Applications with Macintosh HyperCard, *November 4–5*
Current Aspects of Basin Analysis and Sedimentary Geology: A Two-Day Overview, *November 4–5*
Fission-Track Analysis: Theory and Applications, *November 4–5*
Geological Considerations in Hazardous-Waste Site Characterization, *November 4–5*
Planning Hydrologic and Geologic Investigations and Reports, *November 4–5*
Quantitative Interpretation of Joints and Faults, *November 4–5*
Fabric of Cements in Paleozoic Limestones, *November 5*
Glaciotectonic Structures and Landforms, *November 5*
Quaternary Climates: The Ocean Sedimentary Record, *November 5*
The Age of Dinosaurs Short Course, *November 5*
Geology and Public Policy Forum: Geology and Sustainable Agriculture, *November 7*
GIS Geological Field Trip Workshop, *November 7*
GeoRef Beginners Workshop, *November 7*
GeoRef Advanced Workshop, *November 8*
GIS Database Forum, *November 9*

For further information about the annual meeting, contact GSA, Meetings Dept., P.O. Box 9140, Boulder, CO 80301; (303) 447-2020. The preregistration deadline is October 6.

THE GEOLOGICAL SOCIETY OF AMERICA
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UPCOMING MEETINGS

Society for Organic Petrology, Annual Meeting, October 29–31, 1989, Urbana, Illinois; and **Workshop on Fluorescence Microscopy,** November 1–2, 1989, Carbondale, Illinois. Information: Richard Harvey, Illinois State Geological Survey, 615 E. Peabody Dr., Champaign, IL 61820; (217) 244-0836.

NWWA/AGWSE Cluster of Conferences (Agricultural Impacts on Ground-Water Quality; Ground-Water Geochemistry; Ground-Water Management and Well-head Protection; and Environmental Site Assessments—Case Studies and Strategies), February 20–22, 1990, Kansas City, Missouri. Information: National Water Well Association, 6375 Riverside Dr., Dublin, OH 43017; (614) 761-1711.

Society for Mining, Metallurgy, and Exploration, Annual Meeting and Exhibit, February 26–March 1, 1990, Salt Lake City, Utah. Information: Meetings Dept., SME, P.O. Box 625002, Littleton, CO 80162; (303) 973-9550.

OU BENEFITS FROM GRANTS

- **W. M. Keck Foundation** of California has granted the OU College of Geosciences $350,000 for its growing computing network. The Keck funds will upgrade the remote sensing and digital image-processing facilities in the University's Geosciences Computing Network, which in only three years of operation has evolved into a major facility for image processing, graphic visualization, and numerical modeling. Currently housed in Gould Hall, the network will join the College of Geosciences in the new Energy Center next year.

- **Conoco/Du Pont** has established the first endowed professorship in chemical engineering with a $250,000 gift, which is expected to be matched through the State Regents Endowment Program created last year by the Oklahoma Legislature. The first installment of $50,000 was recently presented to OU interim President David Swank.

- **Sun Company** of Radnor, Pennsylvania, has renewed a previous commitment to OU with a $125,000 gift to support the Sun Company Professorship of Ground Water Hydrology. The firm endowed the professorship in 1984 with a $300,000 gift. The professorship is intended to enhance both the teaching and research activities of OU's School of Civil Engineering and Environmental Science, which has conducted ground water/environmental impact studies since 1970.

- **Amoco Foundation** has given the University of Oklahoma the first $15,000 installment of a three-year, $45,000 grant to OU's Environmental and Ground Water Institute. The majority of the grant will support research projects of graduate students associated with the Institute. The Foundation also contributed $2,000 to the School of Accounting for a $1,000 student scholarship and a faculty service award; the School of Petroleum and Geological Engineering received an unrestricted

$4,000. Amoco is also funding a $6,000 fellowship for a University of Oklahoma engineering student.

- **ARCO Foundation** has contributed $49,944 to OU's College of Engineering Minority Programs for the second consecutive year. The grant is to implement and expand activities in the areas of identification, recruitment, and retention of engineering minority students. A gift of $4,000 was also presented by ARCO to OU's School of Petroleum and Geological Engineering; of the total, $3,000 is unrestricted, and the remainder will fund a scholarship for a minority student majoring in petroleum engineering.

- **Phillips Petroleum Foundation** will support several academic disciplines and assist the University of Oklahoma's Centennial Campaign with a gift of $46,575. Of the total, $21,000 is designated for three $7,000 fellowships—one each in geology and geophysics, petroleum and geological engineering, and botany and microbiology. To stimulate student and faculty interest in professional development through activities such as student meetings and visiting speakers, $13,075 will be divided by: arts and sciences ($2,435), business administration ($2,760), engineering ($5,860), law ($1,100), and Career Planning and Placement Services ($920). Also part of the gift was $8,750 for scholarships in engineering, chemistry, and petroleum land management; and unrestricted funds for the College of Business Administration ($1,000), College of Law ($2,500), and the OU Libraries ($250).

NOTES ON NEW PUBLICATIONS

Geohydrology of the Alluvial and Terrace Deposits of the North Canadian River from Oklahoma City to Eufaula Lake, Central Oklahoma

John S. Havens describes the geohydrology of the alluvial and terrace deposits along the North Canadian River between Lake Overholser and Eufaula Lake, an area of ~1,835 mi^2, and determines the maximum annual yield of ground water in this 32-page USGS Water-Resources Investigations Report.

Order WRI 88-4234 from: U.S. Geological Survey, Water Resources Division, 215 Dean A. McGee Ave., Room 621, Oklahoma City, OK 73102; phone (405) 231-4256. A limited number of copies are available free of charge.

U.S. Geological Survey Ground-Water Studies in Oklahoma

This two-page water fact sheet was compiled by John S. Havens.

Order OF 88-0140 from: U.S. Geological Survey, Books and Open-File Reports, Federal Center, Box 25425, Denver, CO 80225. The price is $4 for microfiche and $1.50 for a paper copy; add 25% to the price for foreign shipment.

OKLAHOMA ABSTRACTS

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

Reservoir Characterization, Porosity, and Recovery Efficiency of Deeply Buried Paleozoic Carbonates: Examples from Oklahoma, Texas, and New Mexico

JOACHIM E. AMTHOR, City University of New York, New York, NY 10036; DAVID C. KOPASKA-MERKEL, Dept. of Geology, Brooklyn College, Brooklyn, NY 11210; and GERALD M. FRIEDMAN, Northeastern Science Foundation affiliated with Brooklyn College, Rensselaer Center of Applied Geology, Troy, NY 12181

Capillary-pressure data from the Early Ordovician Ellenburger Dolomite (west Texas and New Mexico) and the Late Ordovician–Early Devonian Hunton Group carbonates (Oklahoma) are used to calculate or infer petrophysical characteristics, such as median pore-throat size, pore-throat size distribution, effective porosity, and recovery efficiency (RE). For both data sets, porosity and RE are inversely related. A positive relationship between RE and porosity has been reported by other workers, but the relative importance of these opposed trends in unknown. The ability to accurately predict which relationship will hold in a given reservoir unit would be of great value for predicting reservoir performance.

RE is also inversely related to median throat size. This is a consequence of two controlling factors: rock characteristics and experimental procedure. Drainage (recovery) from small throats is more efficient than from large throats, and hysteresis limits recovery from large throats because throats filled at very low pressures early in the intrusion process remain filled at comparable pressures upon extrusion. The experimental procedure also suppresses extrusion from large throats because the minimum pressure attained on extrusion is greater than the initial intrusion pressure, due to limitations of the apparatus.

Reservoir rocks are classified in terms of their capillary-pressure curve form, because curve form is controlled by a variety of petrophysical factors which can be measured, and because curve form is strongly correlated with recovery efficiency. Steep-convex capillary-pressure curves correspond to samples with high REs, low porosities, small median throats, and high entry pressures. Steep-concave curves correlate with low REs, high porosities, large median throats, and low entry pressures. Gently sloping curves correspond to samples with moderate REs, intermediate median throat sizes, poorly defined entry pressures, platykurtic throat-size distributions, and variable porosities. Polymodal curves result from polymodal throat-size distributions, and exhibit variable REs and porosities.

Steep-concave and steep-convex curves are interpreted in two quite different ways, as follows. Steep-convex curves indicate reservoir rocks with high REs, but low porosities and small throats, so that production is likely to be economical only under high pressures (or thick oil columns) or from very large hydrocarbon pools. Conversely, steep-concave curves indicate porous reservoir rocks with large throats but probably poor primary recovery efficiency. These reservoirs will be economical even at low pressures and with short oil columns and small total reserves, but will probably need enhanced recovery to produce a significant proportion of reserves. This classification may allow characterization of an "ideal" capillary-pressure curve, which is characterized by a moderate entry pressure, intermediate median throat size, good RE, moderate porosity, and leptokurtic throat-size distribution.

Capillary-pressure plots showing both cumulative and incremental mercury intrusion are more useful than the traditional graphs which show only cumulative intrusion. The incremental intrusion histograms used here highlight modal throat sizes (or modal capillary pressures) which are not well-displayed on cumulative plots. The existence of multiple modes is significant because it affects the relationship between Rwa (water saturation) and oil recovery efficiency, as well as overall nonwetting-phase recovery efficiency.

Reprinted as published in *Carbonates and Evaporites*, v. 3, no. 1, p. 33.

Paleozoic Continent–Ocean Transition in the Ouachita Mountains Imaged from PASSCAL Wide-Angle Seismic Reflection–Refraction Data

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A wide-angle reflection–refraction experiment, sponsored by the Program for Array Seismic Studies of the Continental Lithosphere (PASSCAL), was conducted in the Ouachita Mountains area of southwestern Arkansas and northwestern Louisiana. This experiment employed 400 state-of-the-art seismic recorders and overlapped the southern one-third of the COCORP (Consortium for Continental Reflection Profiling) deep seismic reflection profile in the area. A wide variety of data processing and interpretation techniques was employed to derive an Earth model from these data. The model depicts a preserved early Paleozoic continental margin buried beneath allochthonous Paleozoic strata and younger sedimentary rocks. The southern part of the model indicates the presence of oceanic or highly extended continental crust overlain by about 15 km of mostly Paleozoic sedimentary rock. These results are consistent with little if any shortening of crystalline continental crust during the Ouachita orogeny.

Reprinted as published in *Geology*, v. 17, p. 119.

Megaregional Seismic Approach to New Play Concept Development

ALLEN J. BERTAGNE, CLAUDE VUILLERMOZ, CGG American Services, Denver, CO; and RICHARD A. MAXWELL, CGG American Services, Houston, TX

A megaregional seismic line is a continuous line that traverses more than one basin. After such a line is interpreted using well control, surface geology, and other available data, it serves as a concise expression of our understanding of the geology along a transect and provides a starting point for developing new play concepts.

Megaregional seismic lines aid in the development of exploration concepts by providing new insights into (1) what is and is not basement, (2) maturation history and migration pathways, (3) regional structural geology, and (4) regional stratigraphy.

An ongoing project to prepare a series of interpreted transcontinental megaregional seismic lines uses a segment that starts in the Arkoma basin of Oklahoma, traverses the Ouachita thrust belt, and terminates at the northern Texas Gulf coastal plain. This segment shows that several potential plays exist, both structural and stratigraphic, between areas of current exploration activity. Regional seismic lines from the Sacramento Valley and the Illinois basin further illustrate how interpretation of long seismic lines can lead to new exploration ideas.

Reprinted at published in the American Association of Petroleum Geologists *Bulletin*, v. 73, p. 334.

Role of Diagenesis in Development of Upper Morrow Fan-Delta Reservoirs in Anadarko Basin

ZUHAIR AL-SHAIEB, Oklahoma State University, Stillwater, OK; PATRICIA L. ALBERTA, Pilgrim Exploration Corp., Houston, TX; and MIKE GASKINS, Exxon Co., U.S.A., Houston, TX

Upper Morrow chert conglomerates are prolific natural gas reservoirs in the deeper part of the Anadarko basin. Based on data obtained during the course of this investigation, the conglomerates display several diagnostic features of a fan-delta depositional environment, with various facies representative of middle-fan

and distal parts of the delta-fan complex. These facies were calibrated to suites of wireline logs, characteristic log signatures were identified for each facies, and a map was prepared showing the distribution of facies within the fan-delta complex. Major lithology types of conglomerates are chert, quartz, feldspar, and a combination of these three constituents.

A rather complex diagenetic history includes at least nine cementation episodes reflecting various subsidence stages and thermal regimes.

Reservoir-quality lithofacies are present mainly in the middle-fan channel facies, which consists of stacks and repetitive sequences of braided-stream deposits. Both intergranular primary and secondary porosity types are present in the chert conglomerates. Although intergranular porosity is very common, it was modified by cementation and dissolution. Complete preservation of original porosity is rare. Remnant primary porosity has provided avenues for fluid migration, which resulted in partial to complete dissolution of rock constituents. Siliceous detrital matrix, chert, and feldspar are the major constituents affected by the dissolution processes. A geochemical model emphasizing the role of feldspar hydrolysis is proposed to explain the dissolution of chert and the develoment of productive reservoirs in the chert conglomerates.

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Chamosite: Critical Ingredient in Diagenetic Differentiation of Sandstone Reservoirs

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Chamosite, or iron-rich chlorite, is well documented in sedimentary ironstones and generally agreed to have formed in a particular shallow marine environment with specific geochemical and sedimentological controls. However, chamosite is not restricted to ironstones. For example, chamosite is a common constituent in several productive Pennsylvanian sandstones such as the Spiro and Sells sandstones in the Arkoma basin and Springer sandstones in the Anadarko basin.

Chamosite is a penecontemporaneous to early diagenetic mineral that occurs in several distinct morphologies, including coated grains comprised of concentric laminae around detrital nuclei, granules/nodules, thick pore coatings, and pseudomorphous replacement of bioclastic debris. Under plane-polarized light, chamosite varies in color from light green to light brown. X-ray diffraction analysis shows that the 14Å-basal-spacing variety is very common; however, a 7Å-chlorite (berthierine) is also present in lesser quantity.

The presence of chamosite in sandstone is very significant in determining both depositional environment and postdepositional diagenetic history, including reservoir preservation. In the Pennsylvanian sandstones studied, chamosite-rich facies exhibit very distinct diagenetic patterns compared to other facies with less clay. Preservation of primary porosity is the common denominator in all chamositic sandstones, whereas quartz overgrowths and/or other types of cements tend to occlude the pore space in the cleaner facies. Thus, differentiation of these Pennsylvanian sandstones into reservoir-quality and tightly cemented types is directly related to the presence of chamosite.

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Geochemical and Petrographic Analyses of Travertine-Precipitating Waters and Travertine Deposits, Arbuckle Mountains, Oklahoma

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Waters in Honey and Falls Creeks, Arbuckle Mountains region of Oklahoma, are supersaturated in CO_2 with respect to the overlying atmosphere and are up to 10 times saturated with respect to calcite ($I_{sat} = 10$). Loss of CO_2 from the system results in a downstream increase in saturation levels, with the highest I_{sat} at sites of maximum travertine deposition. High supersaturation is the result of natural kinetic processes (rapid CO_2 outgassing vs. slow precipitation) rather than the effects of foreign ion inhibitors. Temporal variations in the composition of the waters indicate that, contrary to expectations, prolonged periods of heavy rainfall cause a significant increase in I_{sat} levels. At any sample site, no consistent chemical variation occurred between organically mediated and inorganic precipitates. However, all deposits show a significant increase in magnesium concentration in a downstream direction; this may be a result of higher I_{sat} values and corresponding higher rates of precipitation.

Carbon isotopes for creek waters are highly variable, from –0.6 to –12.2%, reflecting a variety of sinks and sources for C^{12}. Oxygen isotopes are relatively constant, from –3.7 to –6.0%, average = –5.2%, indicating an open-water system. Based on calculations from water data, travertine should exhibit a 2% difference in $\delta^{18}O$ values for precipitates formed in the summer vs. those formed in the winter. Algally laminated crusts, which have been postulated to be of seasonal origin, exhibit variation in $\delta^{18}O$ values between laminae, confirming the seasonal origin of the laminae.

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Petroleum Production and Exploration in Ouachita Region of Oklahoma

NEIL H. SUNESON and JOCK A. CAMPBELL, Oklahoma Geological Survey, Norman, OK

Petroleum production in the Ouachita region of southeastern Oklahoma occurs in three geographic areas parallel to regional structure. The frontal gas, central oil, and central gas belts are distinguished by differences in structural setting, reservoir strata, and types of hydrocarbons.

In the frontal belt, nearly 1 trillion ft^3 of dry gas has been produced from thrusted and subthrust Morrowan and Atokan sandstone and carbonate reservoirs. Over 8,000 bbl of oil have been produced in the central oil belt, southeast of the Ti Valley fault. Structures consist of imbricate thrusts and isoclinal to overturned folds. The fields are typically small, associated with asphaltite or tar sands, and produce from Carboniferous sandstone reservoirs. Farther southeast, small fields within the central gas belt have produced minor gas from Ordovician, Devonian, and Mississippian reservoirs.

Six Ordovician through Mississippian Ouachita-facies shales are potential petroleum source rocks and occur in the middle to lower part of the oil window. However, Devonian and Mississippian strata are composed primarily of terrestrial organic matter and are probably gas prone. Oil in Carboniferous reservoirs probably migrated upward stratigraphically from older sources.

Recent exploration has focused on extending production from Pennsylvanian reservoirs in the frontal gas belt. However, a significant Arbuckle discovery (ARCO 2 Yourman) and a Broken Bow uplift test (Sohio 1-22 Weyerhauser) in 1987 indicate that Cambrian–Ordovician Arbuckle Group carbonates may be prospective beneath all of the Oklahoma Ouachitas. Near-future rank-wildcat exploration will probably focus on subthrust, structurally and stratigraphically favorable Arbuckle plays.

Reprinted at published in the American Association of Petroleum Geologists *Bulletin*, v. 73, p. 416–417.

Diagenetic Controls on Primary and Secondary Porosity in Valley-Fill Marine Sandstones—Misener Formation, North-Central Oklahoma

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The Devonian Misener formation in north-central Oklahoma consists of a series of discontinuous sandstone and shale bodies deposited in erosional topographic lows on the post-Hunton unconformity surface of north-central Oklahoma. Paleontological, mineralogical, and sedimentological evidence supports a marine valley-fill depositional setting including both channel and nonchannel facies. Abrupt changes in sandstone thickness and reservoir properties are characteristic of Misener sandstones. These sandstones were episodically deposited, fine upward and commonly interfinger with an equivalent shale facies. The basal contacts of the Misener sandstone bodies are erosional with the inclusion of shale, phosphate, and sandstone clasts in a medium-grained, dolomitic quartzarenite sandstone. A combination of primary and secondary porosity makes Misener sandstone reservoirs prolific hydrocarbon producers.

Reservoir porosity is best developed in the poorer sorted, medium-grained, dolomitic quartzarenites of the channel facies. A mixed-mineralogy sandstone is critical to the preservation of primary porosity as well as the development of later secondary porosity. Well-sorted, fine-grained quartzarenite sandstones (nonchannel) have been extensively quartz cemented and represent a nonreservoir facies. Early dolomitization in the mixed-mineralogy sandstones prevented quartz cementation from preserving primary porosity. Sandstones containing preserved primary porosity served as preferential pathways for the movement of subsurface fluids. These fluids generated secondary porosity by the selective dissolution of glauconite, phosphate, and lithic grains. Significant posthydrocarbon diagenesis in the form of bitumen precipitation, dedolomitization, and calcite cementation has occurred in the water leg of several Misener sandstone reservoirs.

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Gravitational Compaction, A Neglected Mechanism in Structural and Stratigraphic Studies: New Evidence from Mid-Continent, USA

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Compaction of sedimentary rocks over basement hills was first recognized as a cause of structural closure in 1919. In the ensuing decade, many leading petroleum geologists espoused and expanded the concept to include compaction over hills on unconformity surfaces higher in the sedimentary section, compaction over sand buildups within the sedimentary section, and compaction over carbonate reefs. However, following the initial flurry of interest, compaction as a cause of structure was relegated to a minor role in petroleum exploration or was dismissed altogether by most workers. In 1983, studies undertaken at Applied Geophysics, Inc., indicated that many oil fields on structural closure in Oklahoma and Kansas coincided with basement fault blocks deduced from high-resolution residual aeromagnetics. A literature search, followed by a geological library search for closely spaced basement penetrations in the Mid-Continent, has located 30 basement hills, all of which show structural closure in the overlying sedimentary rocks. One must conclude that compaction as a cause of structure is a pervasive geological phenomenon. Additional findings of the ongoing study have been that (1) thinning over structural highs can be explained by compaction of lower beds surrounding basement hills while the overlying strata were being deposited, that is, by syndepositional compaction, (2) flank fracturing can result by compaction over dense underlying hills if lithification takes place prior to deposition of overlying beds, (3) crestal porosity on compaction structures can result when deposition proceeds slower than compactional settling, (4) salt domes may be localized over the top of compaction structures, and (5) much "tectonic" disturbance is not tectonic at all but is the result of compactional tilting followed by erosion and deposition of flat beds over the tilted ones on the flanks of compaction structures.

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Cottonwood Creek–Hewitt Trend Arbuckle Play (Southern Oklahoma): Example of Complexly Faulted and Fractured Karst Trap

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The Hewitt field (T4, 5S, R1, 2W), located along the northwest–southeast-trending Wichita–Criner Hills anticlinorium, is the ninth largest field in Oklahoma with ultimate recovery projected to exceed 250 million bbl. The development of the anticlinorium was initiated by the Wichita orogeny during the Morrowan, forming north–south-trending folds. During the Atokan, extensive erosional forces removed thick sequences and exposed the Ordovician Arbuckle Group. The uplift was subsequently covered by Deese and Hoxbar clastic sediments during the Middle Pennsylvanian. The Late Pennsylvanian Arbuckle orogeny produced compressional stress from the southwest and resulted in refolding of the uplift features and movement along high-angle faults.

The recent discovery of prolific hydrocarbon reserves in Ordovician carbonates (Canadian, Arbuckle Group) has renewed interest along this prolific trend. The productive reservoir in the Hewitt–Cottonwood Creek area is the dolomitic Brown zone (Kindblade Formation), located approximately 1,000 ft below the top of the Arbuckle Group. The zone consists of crystalline dolomite, 500–600 ft thick, with adequate porosity and permeability developed to form significant reservoirs due to karstification of the extensive fracture systems. The Bray zone (West Spring Creek Formation–upper Arbuckle Group) has production in the Healdton and southwestern Lone Grove fields from fractured, arenaceous, finely granular dolomite and may be an additional possible reservoir.

The combination of good untested reservoirs located on structural features associated with block faulting, as illustrated by seismic sections across the Criner fault, gives an excellent indication that the trend may have great future potential within a mature province.

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