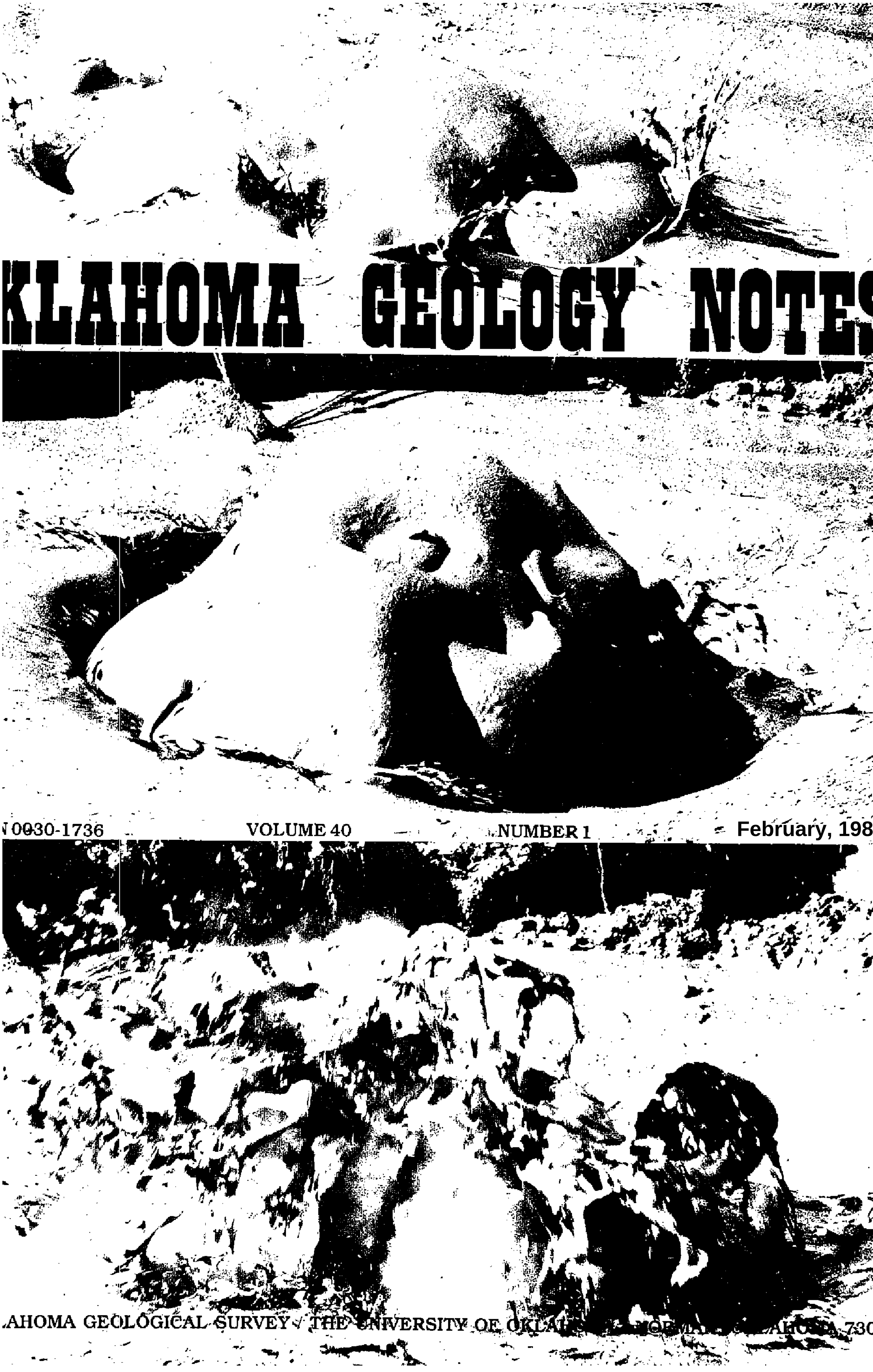

KLAHOMA GEOLOGY NOTES

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Cover Picture

BURSTING NATURAL-GAS BUBBLE WOODS COUNTY, OKLAHOMA

On January 31, 1980, natural gas erupted to the surface in the Edith area along the southwestern boundary of Woods County, Oklahoma, roughly 30 miles west of Alva, the county seat. The venting was first observed from a large mud-filled crater (right) that sprang up along a section-line road (SW¼SW¼SW¼ sec. 19, T. 27 N., R. 18 W.). Venting quickly spread eastward, eventually covering an area of 1 by 1½ miles.

A volume estimate of the total gas vented daily was made during the second week. For the crater shown, the gas was vented in discrete bubbles through the viscous mud (cover photo). The estimated average bubble diameter (5 feet) and measured average count (46 bubbles per minute), with a 50-percent correction for non-sphericity, yield a calculated daily flow of more than 2 million cubic feet of gas. The flow from other vents was captured and metered, and then all other perceptible vents were categorized by relative size. On this basis, the total gas flow was estimated to be more than 20 million cubic feet per day.

Detailed analyses of the vented gas are almost identical to those of gas produced from the Chester and Morrow formations (Upper Mississippian and Lower Pennsylvanian) at depths of 5,000–5,800 feet from wells within the area. A temperature survey of a nearby well suggests that the vented gas is coming directly from an evaporite section associated with the Cimarron anhydrite of Permian age at a depth of 600–650 feet. The migration path from the Chester-Morrow sequence to the evaporite is currently unknown. However, the migration path from the evaporite to the surface appears to be through natural fracture systems developed in the Flowerpot Formation of Permian age, as a strong lineation shown by many of the vents corresponds to fracture orientations observed in surface exposures.

—*Donald A. Preston*

Editorial staff: William D. Rose and Elizabeth A. Ham

Oklahoma Geology Notes is published bimonthly by the Oklahoma Geological Survey. It contains short technical articles, mineral-industry and petroleum news and statistics, an annual bibliography of Oklahoma geology, reviews, and announcements of general pertinence to Oklahoma geology. Single copies, $1.00; yearly subscription, $4.00. All subscription orders should be sent to the address on the front cover.

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

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STRATIGRAPHY OF THE WOODBINE FORMATION (UPPER CRETACEOUS), SOUTHERN OKLAHOMA

George G. Huffman[1]

Abstract—The Upper Cretaceous Woodbine Formation crops out in several counties of southern Oklahoma, reaching its maximum development in Bryan County, where it forms the surface rock in an area covering more than 350 square miles. Here, the Woodbine consists of a polylithic sequence of chert-pebble conglomerate, sandstone, shale, siltstone, volcanic tuff, and lignite. Four named members are recognized, which are, in ascending order: (1) Dexter Member, consisting of a basal shale unit, overlain by 85 to 90 feet of ferruginous sandstones and interbedded clays, and a topmost layer of 40 feet (Rainbow clay); (2) Red Branch Member, made up of 60 to 70 feet of lenticular beds of tuffaceous sandstone, carbonaceous shale, and lignite; (3) Lewisville Sandstone Member, composed of 70 to 90 feet of brown sandstone and interbedded shale; and (4) Templeton Shale Member, comprising 60 to 70 feet of smooth, gray-black shale with lenses of sand and phosphatic concretions.

Exposures in Choctaw County are poor, and no attempt was made to differentiate and map the individual members. Outcroppings of the Dexter sandstone, the Rainbow clay, the Red Branch Member, and the Lewisville Sandstone were observed, but their linear continuity was obscured by windblown sand from the Red River alluvium, from various terrace deposits, and from the Woodbine itself.

In southern McCurtain County the Woodbine Formation includes two unnamed members, a lower tuffaceous unit and an upper sandstone member. The tuffaceous member, which is 155 feet thick, resembles the Red Branch Member of Bryan County, but it may include strata equivalent to the Dexter Member that have been replaced by volcanic tuff from the volcanic centers in Arkansas during Woodbine time. The upper sandstone member (100 feet thick) resembles the Lewisville Sandstone Member of Bryan County. The Woodbine in McCurtain County lies unconformably on the Bokchito, Caddo, and Kiamichi Formations (Lower Cretaceous).

Only the basal 50 feet of the Dexter sandstone has been reported in eastern Marshall County, and no Woodbine has been observed in Love County to the west.

Introduction

The Woodbine Formation was named by Hill (1901, p. 293) from strata cropping out beneath the Eagle Ford Shale near the town of Woodbine, Cooke County, Texas. Taff (1902, p. 6) applied the term Silo to partially equivalent beds near the town of Silo, in western Bryan County, Oklahoma. The term Silo did not gain general acceptance, and the name Woodbine has been adopted. Hill (1901, p. 297) subdivided the Woodbine into three members, which are, in ascending order: (1) Dexter, (2) Lewisville, and (3) a unit of upper sands and clays, later assigned in part to the Eagle Ford.

Bergquist (1949) subdivided the Woodbine of Cooke, Fannin, and Grayson Counties, Texas, into four named units of member rank: (1) Dexter Member, with a total thickness of 100 to 140 feet of nonmarine, white to ferruginous sandstone and silty clay lenses, with some basal carbonaceous clays that contain scattered leaf and wood prints, and a topmost persistent bed of varicolored clay (Rainbow clay); (2) Red Branch Member, consisting of 60 to 70 feet of lenticular beds of crossbedded, tuffaceous sandstone or ferruginous sandstone

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containing abundant leaf prints, some carbonaceous shale, and beds of lignite; (3) Lewisville Sandstone Member, composed of 70 to 90 feet of fossiliferous and glauconitic brown sandstones and lenses of shale, some local tuffaceous material, and oyster beds with *Crassostrea soleniscus* (Meek) common; and (4) Templeton Shale Member, consisting of smooth, gray-black shale with lenses of glauconitic clay and tan sand and containing large, rounded concretions filled with mollusk shells. Bergquist also recognized an unnamed shale unit consisting of 11 feet of gray shale and 6 feet of brown, glauconitic clay, which he thought was transitional from the underlying Grayson Formation into the Woodbine but more closely related to the Woodbine.

Figures 1 and 2 show the outcrop of the Woodbine Formation in Marshall and Bryan Counties and in Choctaw and McCurtain Counties, respectively, going from west to east. Figure 3 shows the Woodbine stratigraphic sequence in southern Oklahoma.

Bryan County Section

The Woodbine Formation crops out over an area of approximately 350 square miles in the southern one-half of Bryan County, Oklahoma. Most but not all of the exposures are south of U.S. Highway 70, which connects Durant, Blue, Bokchito, and Bennington. About 25 square miles of Woodbine terrane is found north of U.S. Highway 70 and west of Durant in the vicinity of Silo, Oklahoma. Thick alluvium covers the Woodbine along major streams, and Quaternary terrace deposits overlie it in much of southwestern Bryan County.

The Woodbine Formation in Bryan County is a polylithic sequence consisting of chert-pebble conglomerate, shale, siltstone, sandstone, volcanic tuff, calcareous reefoid sandstone, and lignitic coal beds. Following the classification established by Bergquist (1949) for beds in northern Texas, four named members—Dexter, Red Branch, Lewisville, and Templeton—are recognized (see Huffman and others, 1978).

Dexter Member

The Dexter Member in Bryan County, as herein designated, consists of a basal shale unit (0 to 37 feet), the Dexter sandstone (85 to 90 feet), and the Rainbow clay (40 feet).

Basal shale unit.—At places in western Bryan County, a few feet of clay shale separates marlstone of the Grayson Formation from the overlying sandstone of the Dexter Member of the Woodbine Formation. Stratigraphically similar clays were reported by Taff and Leverett (1893, p. 282), Hill (1901, p. 297, 300, 303–305, 307), Bullard (1931, p. 48, 49–51, 55), and Bergquist (1949) at several localities in Texas. A detailed discussion of these clay shales and their correlation with rocks in other areas has been presented by Hart (1970, p. 122–129) and will not be repeated here.

In Bryan County, the basal shale unit consists of gray to brown, platy shale containing carbonaceous fragments. It lies unconformably on and channels into the Grayson Formation at places; elsewhere the contact with the underlying Grayson appears to be conformable. The basal shale unit grades upward into and intertongues with the overlying Dexter sandstone.

The best and most extensive exposure of the basal shale unit is on Newberry Creek in the NE¼ sec. 25, T. 6 S., R. 7 E. There, the uppermost 2.5 feet of Grayson contains specimens of *Gryphaea* which were mutilated by boring organisms (Hart, 1970, p. 122), suggesting a post-depositional break at the top of the Grayson. The basal shale unit ranges from 29 to 37 feet in thickness on Newberry Creek, and the uppermost 7 to 8.5 feet is interbedded with sandstones of the Dexter type, suggesting close affinity to the Woodbine Formation. Unweathered exposures of the clay shale below the sandy interbeds range in color from light gray to brown to dark gray to black, depending in part on the moisture content of the beds. The brown clay contains sparse, black, carbonaceous fragments. The lower 10 feet of the Newberry Creek section consists of platy shale with scattered beds of ferruginous, sandy, clay-ironstone.

Additional exposures were observed by Hart (1970, p. 124) along Chukwa Creek in sec. 24, T. 6 S., R. 8 E., approximately 1 mile north of Durant; in gullies in adjacent sec. 23; and in a limited 8-foot exposure in the NE¼ sec. 35, T. 6 S., R. 9 E. Channeling of the basal shale unit into the Grayson was observed by Hart (1970) in the SW¼ sec. 19, T. 6 S., R. 9 E., and along Chukwa Creek. Currier (1968, p. 69–70) noted a 4.5-foot section of brownish-black, fissile shale between the Woodbine (Dexter sandstone) and the Grayson Formation on Little Sand Creek, NE¼NE¼ sec. 11, T. 8 S., R. 7 E.

Final age assignment and formal naming of the basal shale unit awaits additional work in Bryan County. The author has placed this unit in the Dexter Member of the Woodbine Formation on the basis of a local disconformity at the base and interbedding with the Dexter sandstone at the top.

Dexter sandstone unit.—The Dexter sandstone unit crops out along the northeast flank and the northwest end of the Cumberland Syncline, forming a belt ranging in width from 3 to 6 miles and extending across Bryan County in a northwesterly direction from R. 13 E. to R. 7 E., where it turns abruptly southeastward and passes beneath extensive terrace cover.

The Dexter sandstone unit consists of 85 to 90 feet of yellow-brown sandstone and subordinate amounts of shale. At places, a ferruginous, chert-pebble conglomerate marks the base. The contact with subjacent beds is unconformable except in areas where the basal shale unit is present. In these localities the contact seems to be gradational, and the basal shale appears to channel into the Grayson Formation. Eastward, the Dexter sandstone lies unconformably on the Bennington Limestone, and along the Bryan–Choctaw County line it lies on the Pawpaw Sandstone Member of the Bokchito Formation. Sandstones in the Dexter Member are quartzose and fine to medium grained, angular to subrounded with a silt or clay matrix. Ferruginous concretions, clay-ironstone layers, crossbedding, and carbonized wood are common. The sandstone is typically soft and friable.

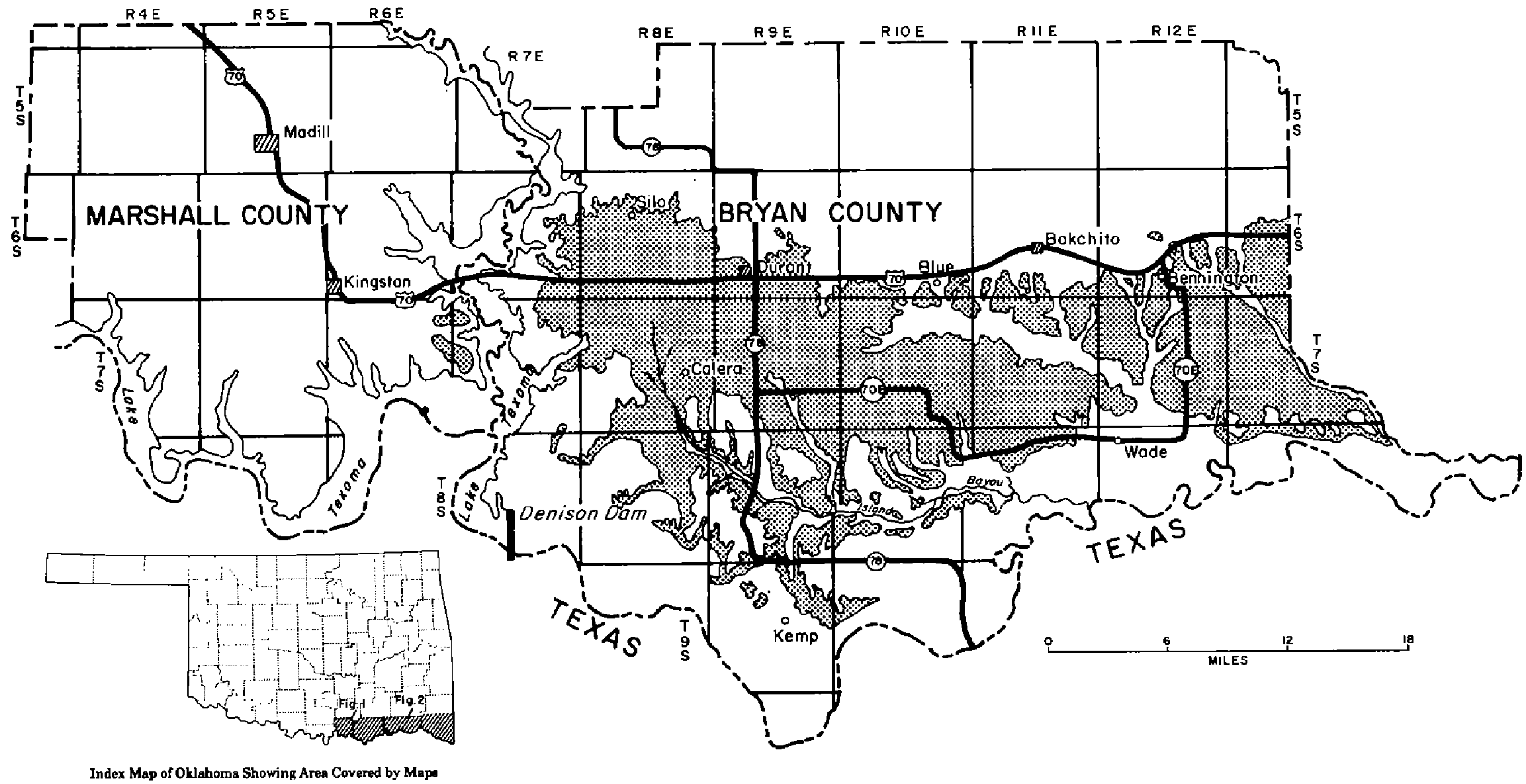

Figure 1. Map showing outcrop of Woodbine Formation (stippling) in Marshall and Bryan Counties, Oklahoma.

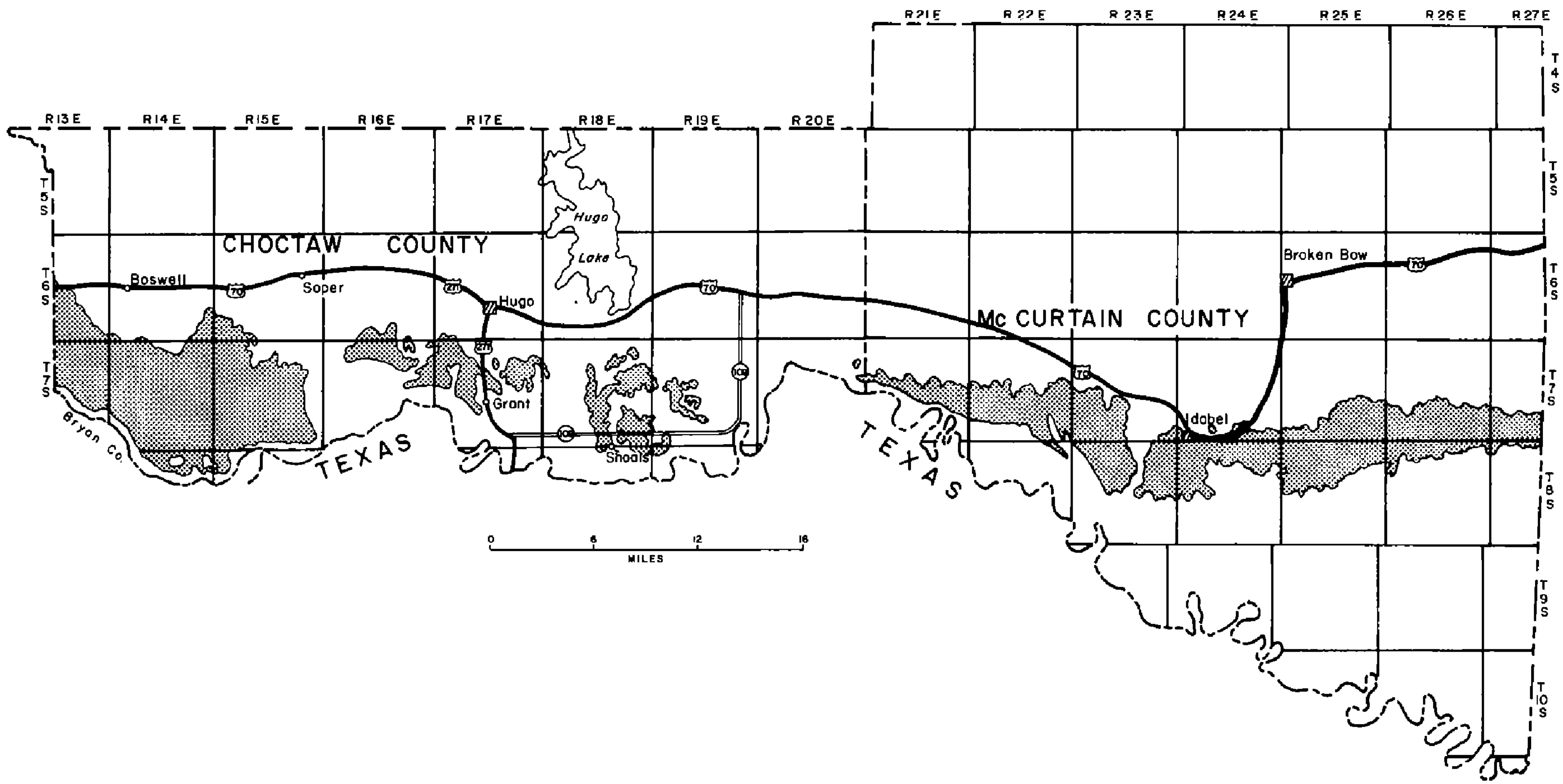

Figure 2. Map showing outcrop of Woodbine Formation (stippling) in Choctaw and McCurtain Counties, Oklahoma.

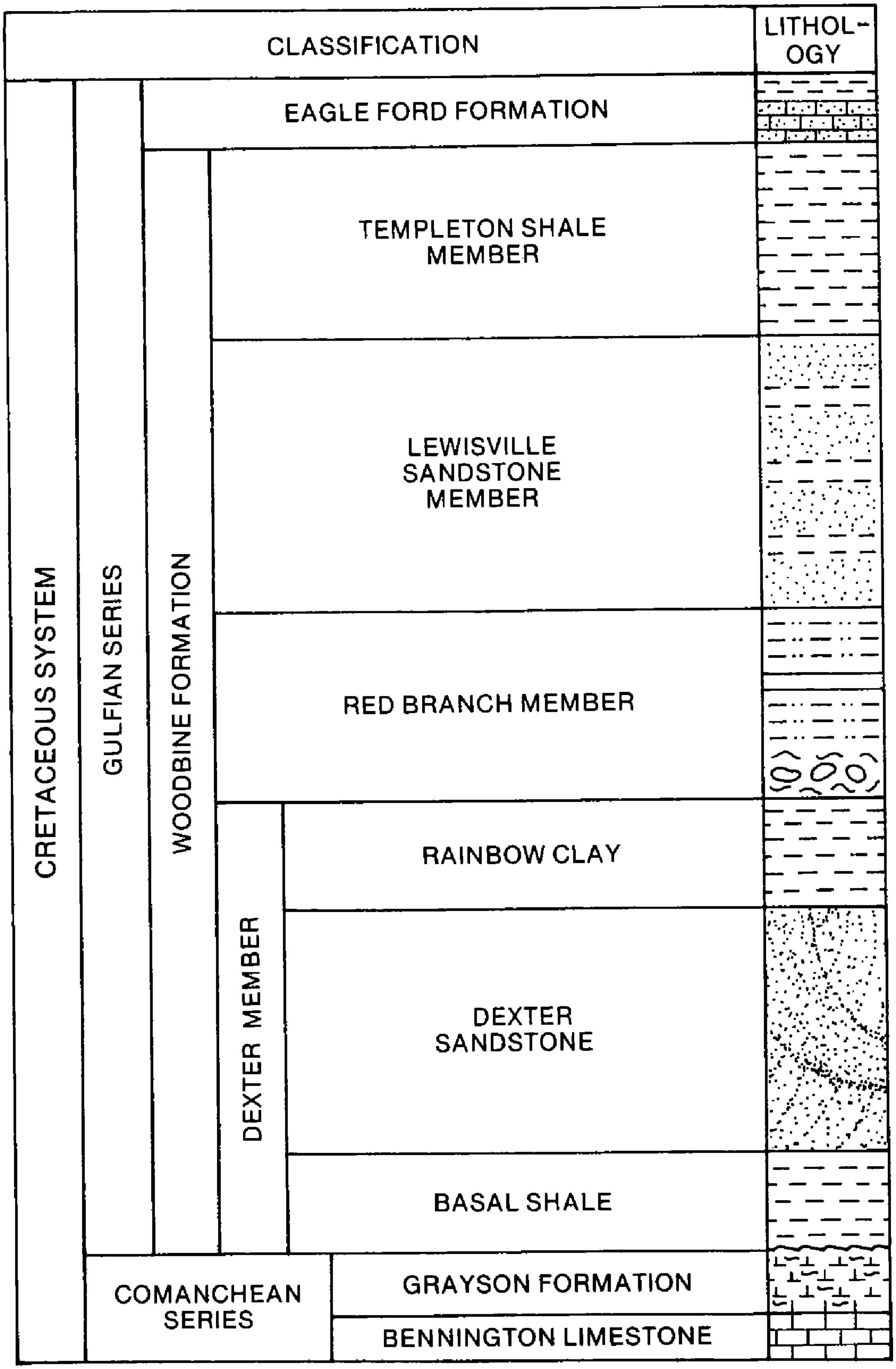

Figure 3. Chart showing stratigraphic sequence of Woodbine Formation and adjacent units in southern Oklahoma.

THICK-NESS	DESCRIPTION OF UNITS
25	Blue-gray, thin bedded, flaggy, silty limestone, weathers yellow and silty; thin beds of blue, calcareous siltstone and blue silty shale.
60-70	Blue-gray to black, fissile shale with thin beds of yellow sandstone, clay ironstone, phosphotic nodules, concretions, some septaria, weathers iron-stained.
90-100	Yellow to reddish-brown, ferruginous, glauconitic sandstone interbedded with tan to brown shale, sandstones generally cross-bedded.
60-70	Comprises yellow-brown, ferruginous, tuffaceous sandstone; gray to yellow to black silty shale; thin beds of lignitic coal, thin-bedded to platy siltstones.
40	Includes approximately 40 feet of soft, varicolored clay which weathers readily.
85-90	Yellow-brown, ferruginous, fine-to medium grained, cross-bedded sandstone with ferruginous concretions and clay ironstone; some carbonized wood.
0-37	Includes a maximum of 37 feet of brown; carbonaceous shale which grades upward into overlying sandstone.
0-27	Olive-gray to light greenish-gray marlstone with interbeds of white, nodular limestone, fossiliferous with *Ilymatogyra arietina* (Roemer) and *Texigryphaea roemeri* (Marcou).
7-13	Blue gray, heavy-bedded to massive, fine-to-medium crystalline limestone, weathers yellow-brown, pitted and honeycombed, fossiliferous with *Ilymatogyra arietina* (Roemer) and *Kingena wacoensis* .

Beds of green, tuffaceous sandstone were reported by Hart (1970, p. 140) at two localities, one an outlier along U.S. Highway 70 west of Durant in sec. 5, T. 6 N., R. 8 E., the other a local development south of Durant, where he thought the tuffaceous beds were about 10 feet below the base of the Rainbow clay. These exposures were reexamined in 1973 and, based on observations made along new highway cuts, were assigned to the Red Branch Member, which here channels into the underlying Dexter Member.

Vertical pipes lined with clay-ironstone and filled with soft clayey sand were observed at several localities within the Dexter Member. Similar structures were observed by Huffman and others (1975) in Choctaw County and were reported earlier by Gibbs (1950).

Rainbow clay unit.—The upper 40 feet of the Dexter Member makes up the Rainbow clay, a unit so-named informally for its colorful appearance in weathered outcrop. The clay is gray in fresh exposures but weathers to shades of purple, violet, red, orange, and brown. Tiny pellets of limonite and siderite litter the exposed surfaces. Rounded pebbles of quartz and quartzite, let down from some previous level, are abundant on weathered exposures.

Topography on the Dexter Member is typically rolling to hilly. Weathering produces a sandy to loamy soil, which is loosely consolidated and is subject to wind activity unless stabilized by vegetation. Pimple mounds characterize the Woodbine surface west of Durant; these are most often associated with terrace sands.

Red Branch Member

The Red Branch Member consists of tuffaceous sandstones, ferruginous sandstones, carbonaceous shales, and lignitic coal. The long, narrow outcrop extends northwestward from the eastern edge of Bryan County (T. 7 S., R. 13 E.) to a point southwest of Durant, where it turns abruptly southward along the south limb of the Kingston-Cumberland Syncline. Exposures are discontinuous, especially along the southern limb, where terrace deposits overlap it from the southwest. Island Bayou has cut through the upper Woodbine along the axis of the Cumberland-Kingston Syncline, where local flattening and erosion have exposed the Red Branch.

Presence of the Red Branch Member in Oklahoma was noted by Curtis (1960), and preliminary but partially incorrect mapping was done by him. Hedlund (1966) measured and collected samples from several exposures along the outcrop, and, based on evidence from a study of the spores and pollen, he assigned that part of the Woodbine Formation to the Cenomanian Stage. Olson (1965) remapped the Red Branch Member across eastern Bryan County and measured and described a 24-foot vertical exposure in the SE¼ sec. 24, T. 7 S., R. 12 E., where three lignite beds were observed.

Currier (1968) studied the Red Branch along Island Bayou, where a stream has cut through the upper Woodbine, exposing a sequence of carbonaceous shales and lignitic coals that underlie a sandy, calcareous bed carrying a pelecypod fauna, including *Crassostrea soleniscus* (Meek), which is thought to mark the base of the overlying Lewisville Sandstone Member. The abundance of coal and plant remains, interbedded with sandstones, siltstones, and silty clays, supports an assignment of these beds to the Red Branch Member. Only the upper 8 to 10 feet is exposed. (See Currier, 1968, p. 39.)

Exposures along the southwest flank of the Kingston-Cumberland Syncline complex are poor because of extensive terrace cover. Huffman (1976) mapped the Red Branch in this area on the basis of large, tuffaceous concretions, which characterize the Red Branch.

Lewisville Sandstone Member

The Lewisville Sandstone Member occupies a large part of the Cumberland-Kingston Syncline, dipping southward north of Island Bayou and northeastward in the area southwest of Island Bayou. It includes the beds above the Red Branch Member and those below the Templeton Shale Member.

The Lewisville consists of red to yellow, ferruginous, glauconitic sandstones and tan to brown clay shales. Sandstones are fine to medium grained and range from thin-bedded to massive, crossbedded units. Shales that alternate with sandstones produce a gentle escarpment and dip-slope topography with ridges supported by the sandstone layers. Shales predominate in the upper part but are poorly exposed. The best exposures of Lewisville in Bryan County are along Moore Creek, a tributary of Island Bayou south of Calera, and in a series of road cuts along State Highway 70E northeast of Wade in T. 7 S., R. 12 E. The estimated thickness is 100 feet.

Templeton Shale Member

The Templeton Shale Member was named by Bergquist (1949) from exposures along Templeton Branch near Bells, Grayson County, Texas. In that locality he described it as a sequence of smooth gray shale with lenses of gray to tan, soft, glauconitic sand. Embedded in both sand and shale are numerous calcareous concretions, some with septarian structure. Phosphatic concretions characterize the basal shale. The Templeton Shale Member is overlain by sandy-limestone flagstones that mark the base of the Eagle Ford Formation.

The presence of the Templeton Shale in Bryan County, Oklahoma, was established by the author in August 1973 following extensive investigations. Oklahoma exposures were studied and sampled, and a trip to the type section in Texas was made for comparison purposes. The conclusion was that the Oklahoma beds are lithologically like those in Texas, and the units in Texas and Oklahoma are correlative. Beds herein assigned to the Templeton Shale Member of the Woodbine Formation had been previously mapped as Red Branch by Curtis (1960) and as Eagle Ford by Olson (1965).

To date, only five representative exposures have been observed. Exposed parts consist of soft, gray-black shale, which weathers fissile, and thin beds of yellow sandstone and clay-ironstone (siderite). Lower beds carry a thin, yellow coating of sulfur or jarosite(?). Phosphatic nodules, calcareous concretions, and septaria are common in lower parts. The upper shales are gray to brown, iron stained, and contain partings of platy siltstone and thin, reddish-brown, sideritic concretions. The estimated thickness is 60 to 70 feet. The Templeton weathers to form a miniature "badland" topography devoid of vegetation. Exposed surfaces are littered by small fragments of gray, platy shale.

The southernmost exposure observed in Bryan County is about 2½ miles east of Kemp and about ¼ mile west of a small creek in the SE¼ sec. 13, T. 9 S., R. 9 E., along the north roadside. A second section along a tributary stream of Island Bayou on the north side of State Highway 78 in the SW¼ sec. 35, T. 8 S., R. 9 E., marks the westernmost exposure. A third exposure was observed along a small stream tributary to Island Bayou in secs. 17 and 20, T. 8 S., R. 10 E. A fourth exposure is on the south wall of Long Creek in the SE¼ sec. 16, T. 8 S., R. 10 E. (assigned by Olson to the Eagle Ford Formation). A fifth exposure lies directly below the terrace in the NW¼ sec. 19, T. 8 S., R. 11 E., where about 8 feet is exposed. Additional exposures are believed to be present along the walls of Island Bayou and in the lower parts of its tributaries.

The contact of the Templeton Shale Member with the overlying calcareous flagstones of the Eagle Ford was observed in a ravine in the pasture west of the road in the SW¼ sec. 27, T. 8 S., R. 10 E. The estimated thickness for Bryan County is 60 feet.

Choctaw County Section

The Woodbine Formation crops out in a wide belt across southern Choctaw County, reaching a maximum width of 10 miles south of Boswell. It passes beneath the terrace cover along Muddy Boggy Creek south of Soper and reappears only in a few scattered exposures from that point eastward. The Woodbine is deeply weathered throughout the county, forming a thick, red, sandy and clayey soil, which at places is difficult to differentiate from terrace materials. Exposures are exceptionally poor, and no attempt was made to delineate and map the individual members during the course of study (Huffman and others, 1975, p. 19–21). The estimated Woodbine thickness for the southern part of the county is between 300 and 400 feet.

The easternmost exposure of the Woodbine in Choctaw County is in secs. 12 and 13, T. 7 S., R. 20 E., adjacent to the McCurtain County line. Here, the basal Woodbine is composed of well-rounded quartzite and chert pebbles in a matrix of coarse-grained, ferruginous quartz sand. Overlying the conglomerate are brick-red to brown, slightly calcareous, fine- to very fine-grained, angular to subangular, iron-stained, friable sandstones. Sieve analyses of these sand grains reveal a grain size ranging from 2.0 ϕ to 3.5 ϕ on the phi scale (Duarte-Vivas, 1968, p. 41). The sandstones contain a small amount of feldspar and magnetite. The basal conglomerate rests on the Caddo Formation. The exposed thickness of the Woodbine here is 25 feet.

An excellent exposure of sandstone of the Woodbine Formation occurs along a country road passing through the center of sec. 12, T. 7 S., R. 18 E., where the basal Woodbine appears to overlap the Bokchito Formation, although terrace cover makes precise relations difficult to establish. The exposed Woodbine at this locality is a red to yellow, poorly cemented, medium-grained, crossbedded sandstone. This basal sandstone is succeeded by mottled gray to reddish-brown sandy clay. Vertical clay "pipes" ranging in diameter from 3.0 to 10 inches are characteristic. Succeeding beds, poorly exposed, resemble the Rainbow clay of Bryan County, Oklahoma, and beds near the top of the Dexter Member in Texas.

A 32.5-foot section of basal Woodbine north of Grant, on the south bank of Horse Creek, sec. 14, T. 7 S., R. 17 E., was measured and described by Gibbs (1950, p. 52). Inasmuch as that exposure is now largely concealed by vegetation, Gibbs' description must be relied upon. At this locality the Woodbine rests directly on the Bennington Limestone. The contact is visible in the road cut along U.S. Highway 271. The lower 10 feet consists of red to yellow, fine-grained, crossbedded quartz sand. Fifteen inches of red clay and sandy clay overlie the sand. The succeeding 13 feet consists of light-brown, medium-grained, crossbedded sandstone. Succeeding beds are composed of red sand and sandy clay characterized by numerous "clay pipes."

The tuffaceous phase of the Woodbine (possibly Red Branch equivalent) is exposed along a small creek in secs. 16, 21, and 22, T. 7 S., R. 19 E., where it lies on a thin remnant of the Bennington Limestone. Here, the unit consists of yellow-brown, crossbedded, poorly cemented, medium-grained, tuffaceous sandstone. Locally, calcite cementation has formed large, green, concretionary masses or lenses ranging in size from a few inches to several feet. The concretionary lenses are surrounded by yellow-brown, thin-bedded, tuffaceous sandstone containing a large amount of magnetite. This exposure resembles the concretionary beds in the Red Branch Member of the Bryan County section and the tuffaceous member of the McCurtain County section.

Closely related or similar tuffaceous beds have been observed in other scattered localities in southeastern Choctaw County. Small, green, probably tuffaceous boulders are present along State Highway 109 east of Shoals in secs. 27 and 34, T. 7 S., R. 18 E. Thin-bedded, tuffaceous sands were observed along a farm road south of Shoals in secs. 2 and 3, T. 8 S., R. 18 E., and in a tributary stream in the NW¼ sec. 17, T. 7 S., R. 19 E.

Tuffaceous, concretionary beds are well exposed at the intersection of State Highway 109 and the Crowder Springs Road at the junction of secs. 13, 14, 23, and 24, T. 7 S., R. 14 E. At the crossroads, the green, calcareous, concretionary, tuffaceous beds are overlain by gray to black shale. This section resembles an exposure on the south side of the Red River east of the bridge leading to Arthur City, Texas, where both the concretionary and shaly facies are well exposed beneath the terrace cover. Another exposure of the concretionary beds can be seen along a creek crossing the road between sec. 24, T. 7 S., R. 14 E., and sec. 19, T. 7 S., R. 15 E. In all these exposures, the general lithology and sequence suggest that these beds occur at the stratigraphic position of the Red Branch Member.

There are numerous other exposures of the Woodbine Formation in road cuts that run normal to the strike of some of the more resistant beds. The interrelationship of many of these isolated exposures has not yet been established. The largest single exposure covers 100 square miles in the southwestern corner of the county, although much of it is masked by loose sand derived from the flood plain of the Red River, by various terrace remnants, and by the Woodbine itself. This makes subdivision of the Woodbine and delineation of the Bryan County members difficult in Choctaw County.

McCurtain County Section

Heilborn (1949) and Davis (1960) determined the stratigraphy of the Woodbine and mapped the formation in McCurtain County. There, the Woodbine forms a long, continuous or nearly continuous belt of outcrop extending completely across the county from west to east, occupying a 2- to 4-mile-wide belt in Tps. 7 and 8 S. from R. 21 to 27 E. in southern McCurtain County. Davis (1960, p. 39–42) subdivided the Woodbine of McCurtain County into two unnamed members, a lower tuffaceous member and an upper sand member and assigned a thickness of 255 feet to the formation.

Davis (1960, p. 41) described the lower, tuffaceous member of the Woodbine as consisting of highly crossbedded, coarse-grained, poorly consolidated, dark-green, tuffaceous sand that weathers yellowish green to yellowish red and is cemented locally by calcite into lenses or rounded masses. At the base, in a few places, he noted a white sand and a few gravel lenses. Interbedded with the tuffaceous sands are beds of brownish-red clay, which are lenticular and noncalcareous. The upper member was described by Davis as composed principally of gray to brown, crossbedded sand and sandy gravel with some brown or reddish-brown clay lenses. A thickness of 100 feet was assigned to the upper member.

Heilborn (1949, p. 9–16) described the Woodbine Formation as a sequence of yellow-green, sandy, volcanic tuff, thin sand lenses, gray shales, red and purple clay, and an occasional layer of gravel. The basal part of the formation was described as consisting largely of yellow-green volcanic tuff. A thin bed or lens of sand marks the base at places; locally a bed of ferruginous conglomerate occurs at the base. Above the basal sand and tuff beds, Heilborn described a sequence of gray shales containing an abundance of fossil plant leaves. Above the gray shale, which is 17 feet or more in thickness, Heilborn described green volcanic tuffs containing rounded or concretionary masses of calcite-cemented tuff. The volcanic member is everywhere crossbedded and at places contains beds of gravel. Overlying the tuffaceous beds is a sequence of 24 feet of red and purple clays interbedded with lenses of tuff. Marcasite, pyrite, and siderite were reported from the red-clay beds. From his lithic studies, Heilborn concluded that the Woodbine of McCurtain County is a water-laid volcanic tuff, derived from volcanic centers in Arkansas, that is interbedded with red and gray clays and shales.

The Woodbine Formation in McCurtain County is unconformable above beds of Early Cretaceous age. In western McCurtain County, it overlies the Denton Member of the Bokchito Formation; in eastern McCurtain County, it lies on the Kiamichi Shale. It is succeeded unconformably by the Tokio Sand, which occupies the stratigraphic position of the Austin Chalk of Texas (Davis, 1960, p. 45).

Marshall County Section

Bullard (1926, p. 48) described an area of Woodbine in eastern Marshall County, Oklahoma, where about 50 feet of basal Woodbine sandstone (probably the Dexter Member) forms an outlier east of Woodville in secs. 6, 7, and 18, T. 7 S., R. 7 E. Kenneth Bridges (personal communication, 1979), a master's student at The University of Oklahoma, mapped this outcrop as two small outliers, and in secs. 6 and 7, T. 7 S., R. 7 E., and secs. 1 and 12, T. 7 S., R. 6 E., and a second in secs. 7 and 18, T. 7 S., R. 7 E., and secs. 12 and 13, T. 7 S., R. 6 E. (fig. 1). In this locality, the Woodbine caps hills that are preserved in the trough of the Kingston Syncline. These outliers are separated by erosion from the main outcrop of the Woodbine in Bryan County. The Woodbine overlies the thin, fossiliferous Grayson Formation in eastern Marshall County.

Summary and Conclusions

The Woodbine Formation reaches its maximum development in Bryan County, Oklahoma, where it is represented by four named members (ascending): (1) the Dexter Member, including a basal shale unit, the Dexter sandstone, and the topmost Rainbow clay; (2) the Red Branch Member, consisting of shales, siltstones, lignitic coal, and beds of concretionary and crossbedded volcanic tuff; (3) the Lewisville Sandstone Member; and (4) the Templeton Shale Member. These units have been mapped in Bryan County (Huffman and others, 1978).

Exposures are poor in Choctaw County (Huffman and others, 1975), and no attempt was made to map the individual members. The basal shale unit and the Templeton Shale Member were not observed in Choctaw County, although the Dexter sandstone, the Rainbow clay, the Red Branch Member, and the overlying Lewisville Sandstone Member were recognized. The Woodbine truncates the Lower Cretaceous eastward, and in extreme southeastern Choctaw County a basal Woodbine conglomerate lies on the Caddo Formation.

The Woodbine forms a long, narrow belt of outcrop across southern McCurtain County, where two unnamed members, a lower tuffaceous member and an upper sandstone member, are present. The lower tuffaceous member resembles the Red Branch Member of Bryan County on a purely lithologic basis. The thickness of the tuffaceous member in McCurtain County and the interbedded sands and clays suggest that the lower tuffaceous member of McCurtain County is equivalent to both the Dexter and Red Branch Members of Bryan

County and that the typical Dexter facies is replaced by volcanic tuff as the Cretaceous volcanic centers or sources in Arkansas are approached. The upper sandstone member (100 feet) of the Woodbine of McCurtain County occupies the position of the Lewisville Sandstone Member as recognized in Bryan County, Oklahoma, and northern Texas.

Only the basal 50 feet of the Dexter Member is present in eastern Marshall County, where the Woodbine caps two small outliers in the trough of the Kingston Syncline.

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The safety panel of the International Phase of Ocean Drilling of the Deep Sea Drilling Project (DSDP) met last November 18–20 at Woods Hole Oceanographic Institution, near Falmouth, Massachusetts. The purpose of the session was to review seismic records and other geologic data acquired on DSDP's Leg 67, a cruise taken off the western seaboard of Central America last May–June. Such data are used to assess the likelihood of encountering petroleum deposits, which can constitute serious problems both for the marine environment and drillship safety, and information obtained on Leg 67 will be used to evaluate future drill sites.

One of the most hazardous contingencies in subsea drilling is the possible penetration of sedimentary strata that contain gas hydrates, which are ice-like materials that form under special conditions of temperature, pressure, and gas content (see fig. 1). The gas molecule most often found is methane, the major component of natural gas. These molecules of gas occupy the cavities or voids in particular ice structures, and when the ice thaws or melts, the volume of the gas increases and creates pressure conditions that might be similar to the high-pressure gas pockets that sometimes cause "blowouts" in drilling wells. Many

Figure 1. Vitric sand from core recovered during Leg 67 of DSDP–IPOD program (actual size). Core taken at site with water depth of 17,973 feet and sub-bottom penetration of 471 feet. Sand grains are held together by ice-like gas hydrates, and when samples are recovered quickly from core barrel, material is well indurated. After a few minutes' exposure at surface, hydrate melts, and rock collapses completely at slightest touch.

parts of the world's oceans have suitable conditions for gas hydrates, and some consideration has been given to tapping this potential source of energy.

For a ship like Global Marine's *Glomar Challenger*, which is the vessel that was used on Leg 67, penetration of one of these gas pockets would create a hazardous situation. The *Glomar Challenger* has drilled more than 500 sites in the world's oceans; the ship is not, however, equipped with a drilling-mud system or blowout preventers, and it must avoid areas that might contain petroleum deposits.

Gas hydrates have been known for a long time from a theoretical standpoint and have been observed in natural-gas pipelines in cold climates, but only a few specimens from ocean sediments had been noted prior to DSDP's Leg 67. Recovery of these icy samples was often quite good in cores taken on Leg 67. Joseph A. Curiale, also of the Oklahoma Geological Survey staff, and I served as geochemists for the cruise and were able to conduct several experiments in the laboratories aboard the *Glomar Challenger*.

In one experiment, a 100-cc sample was placed in a 232-cc sample vessel equipped with a pressure gauge and was permitted to thaw and release the trapped gases. After about 5 minutes the gauge indicated a pressure of 172 pounds per square inch; the gas tested to contain 99-percent methane and 1-percent carbon dioxide.

Several tentatively scheduled drill sites for Leg 67 had to be abandoned because of the presence of these materials. Recent press releases, however, indicate that the *Glomar Explorer* (the Howard Hughes vessel used to recover a Russian submarine a few years ago) may be brought into the DSDP program and equipped as a conventional drillship. Such a ship would be capable of drilling almost anywhere in the world's oceans, thus increasing the probability that additional gas hydrates will be encountered.

DSDP, a function of Scripps Institute of Oceanography in La Jolla, California, operates through the support of the National Science Foundation and six foreign countries. The cooperative venture is known as JOIDES, for Joint Oceanographic Institutions Deep Earth Sampling, and Leg 67 was one of several cruises to be dedicated to the International Phase of Offshore Drilling (IPOD) of the project.

—*William E. Harrison*

New Theses Added to OU Geology Library

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

Structural Analysis of a Portion of the Reagan Fault Zone, Murray County, Oklahoma, by Eugene Anthony Haas, 1978. 52 p., 19 figs., 1 pl., 2 charts.

The Lithostratigraphy and Depositional Environments of the Pitkin Formation (Mississippian) in Adair County, Northeastern Oklahoma, by David R. Clupper, 1978. 115 p., 8 figs., 8 pls., 1 table.

DISTRIBUTION OF LOWER ORDOVICIAN *CERATOPEA* (GASTROPOD OPERCULA) IN THE KINDBLADE FORMATION, WICHITA MOUNTAINS SOUTHWESTERN OKLAHOMA

Donald Francis Toomey[1]

Abstract—Silicified gastropod opercula, referred to the form genus *Ceratopea* Ulrich 1911, are important zonal fossils useful for differentiating intervals within the Lower Ordovician and for interregional correlations. A summary of the occurrence of species of *Ceratopea* found in the Kindblade and West Spring Creek Formations of the Arbuckle Mountains of southern Oklahoma was presented by Yochelson (1973). This paper, which is based on collections made by the late W. E. Ham and myself, summarizes the occurrence of Kindblade *Ceratopea* in the Wichita Mountains of southwestern Oklahoma. Occurrences of *Ceratopea* are plotted for three key stratigraphic sections, including the section at the Kindblade Formation type locality. In addition, a previously unpublished section, which was measured and sampled at the type locality and which delineates various faunal zones, is also included.

Introduction

The recognition of Lower Ordovician gastropod opercula, referred to the genus *Ceratopea,* is important to any stratigraphic study of the Arbuckle Group. Fossils of this gastropod are typically found as massive opercula that have been replaced by silica and are usually lying partially exposed on bedding-plane surfaces. These can be readily acid-etched and freed from the host carbonate. Life associations of the gastropod shell and the operculum are exceedingly rare (Yochelson and Wise, 1972). Still, numerous *Ceratopea* collections from the Arbuckle Group (Yochelson and Bridge, 1957; Yochelson, 1973) have demonstrated clearly that the vertical distribution of various *Ceratopea* species can provide a useful stratigraphic framework for subdividing at least a portion of the relatively fossil-free carbonates of the Oklahoma Arbuckle Group.

In the early 1960's the late Dr. William E. Ham of the Oklahoma Geological Survey and I initiated a long-range study of the organic buildups present in the Lower Ordovician Kindblade Formation that is exposed in both the Arbuckle and Wichita Mountains of southern Oklahoma. Field work was essentially completed by 1970, when Bill Ham suddenly passed away in July of that year. Some years were to elapse before I was able to devote the necessary time to complete the final report. This report, which has only recently been published (Toomey and Nitecki, 1979), incorporates most of the joint field efforts of Ham and Toomey. In the meantime, Yochelson (1973) published a detailed

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account of *Ceratopea* occurrences in both the Kindblade and West Spring Creek Formations of the Arbuckle Mountains. Since notes and collections regarding the Ham-Toomey collections of Kindblade Formation *Ceratopea* occurrences in the Wichita Mountains were available, it was thought desirable to publish the information at this time.

Geologic Setting and Stratigraphy

The Wichita Mountains (fig. 1) are situated approximately 90 miles northwest of the Arbuckle Mountains, where they crop out as a series of relatively low hills and ridges with a relief generally less than 500 feet that emerge from a nearly flat plain. The most recent published geologic mapping of the Wichita Mountains was done by Chase, Frederickson, and Ham (1956). However, later study of the so-called Precambrian rocks of this area by Ham and others (1964) demonstrated conclusively that these "Precambrian" rocks that form the northwest-trending cores of the Wichita Mountains, and that are the dominant rock elements of the range, are of Early and Middle Cambrian age.

Much of the sedimentary rock that was originally deposited on these igneous knobs has subsequently been removed by erosion from the central, and structurally highest, part of the mountain range. This erosion occurred following intense orogeny and uplift during Pennsylvanian and Early Permian time (Chase and others, 1956, p. 36), and, as a consequence, older Paleozoic rocks are exposed in ridges and isolated hills on the eastern-plunging end of the uplift. The exposed rocks are primarily carbonates of Late Cambrian and Early and Middle Ordovician age, and these, in certain areas, are covered with clastics of Early Permian age that form prominent plains around the Wichita Mountains.

Rocks of Early Ordovician age are exposed in the eastern part of the Wichita Mountains, centering around the common corner of Comanche, Caddo, and Kiowa Counties and in central Comanche County. All the data available on the Lower Ordovician sequence of this region has been accumulated over a number of years in a series of geological reports (Decker, 1933, 1939a, 1939b; Chase and others, 1956; Ham and Frederickson, 1947; Ham and others, 1949; Ham and others, 1957), culminating in the latest report by Toomey and Nitecki (1979). From these studies it has been determined that no complete sections of the Kindblade Formation are exposed in the Wichita Mountains.

Decker (1933) originally named the Kindblade interval the Alden Limestone and chose as the type locality the Kindblade Ranch in Kiowa County, southwestern Oklahoma. Later, in 1938, Grace Wilmarth of the U.S. Geological Survey informed Dr. Decker that the name Alden was preoccupied, and Decker (1939a) substituted the name Kindblade Formation for the preoccupied name. Later that same year he designated a more precise location for the type locality on the Kindblade Ranch and presented a measured section of 975.5 feet of Kindblade Formation (Decker, 1939b, p. 47–48). Significantly, he recorded the occurrence of the gastropod *Ceratopea* and the lithistid sponge *Archaeoscyphia* and even listed small algal buildups which he referred to as "*Stromatocerium*." Later, in 1962, Ham and Toomey measured a Kindblade section at the type locality (described in this paper) and reported a thickness of 775 feet. Pertinent outcrop photographs of this sequence are shown in figures 2 and 3. The differences in Kindblade thicknesses reported by Decker and by us is due primarily to later, refined mapping, with delineation of a more precise top of the underlying Cool Creek Formation plus the recognition of Lower Permian sediments overlying the Kindblade at this locality. The work of Ham and Toomey on Kindblade organic buildups, which has been reported on by Toomey and Nitecki (1979), utilized three key Kindblade sections in the Wichita Mountains (see fig. 1). These are (1) Kindblade Ranch (type locality), (2) Longhorn Mountain, and (3) Unap Mountain. It is these sections that form the basis of this report on *Ceratopea* occurrences and distribution in the Wichita Mountains.

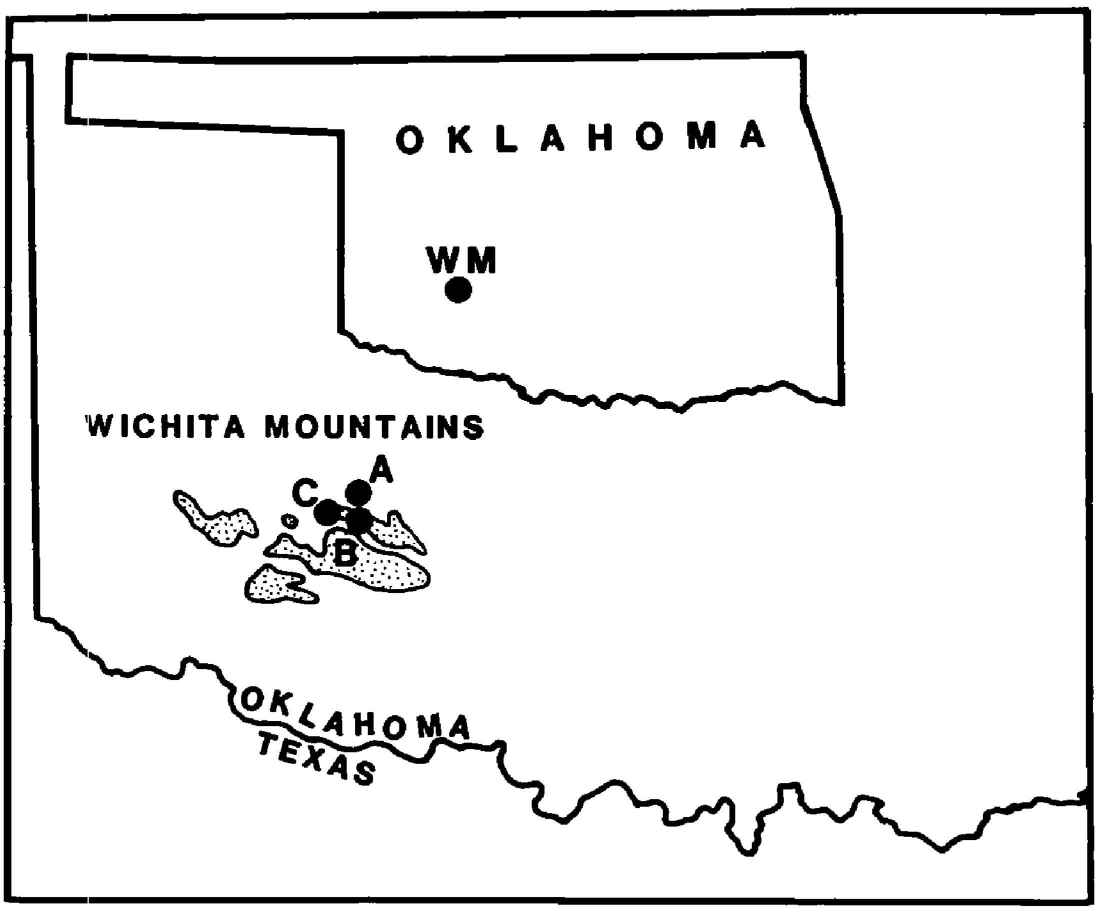
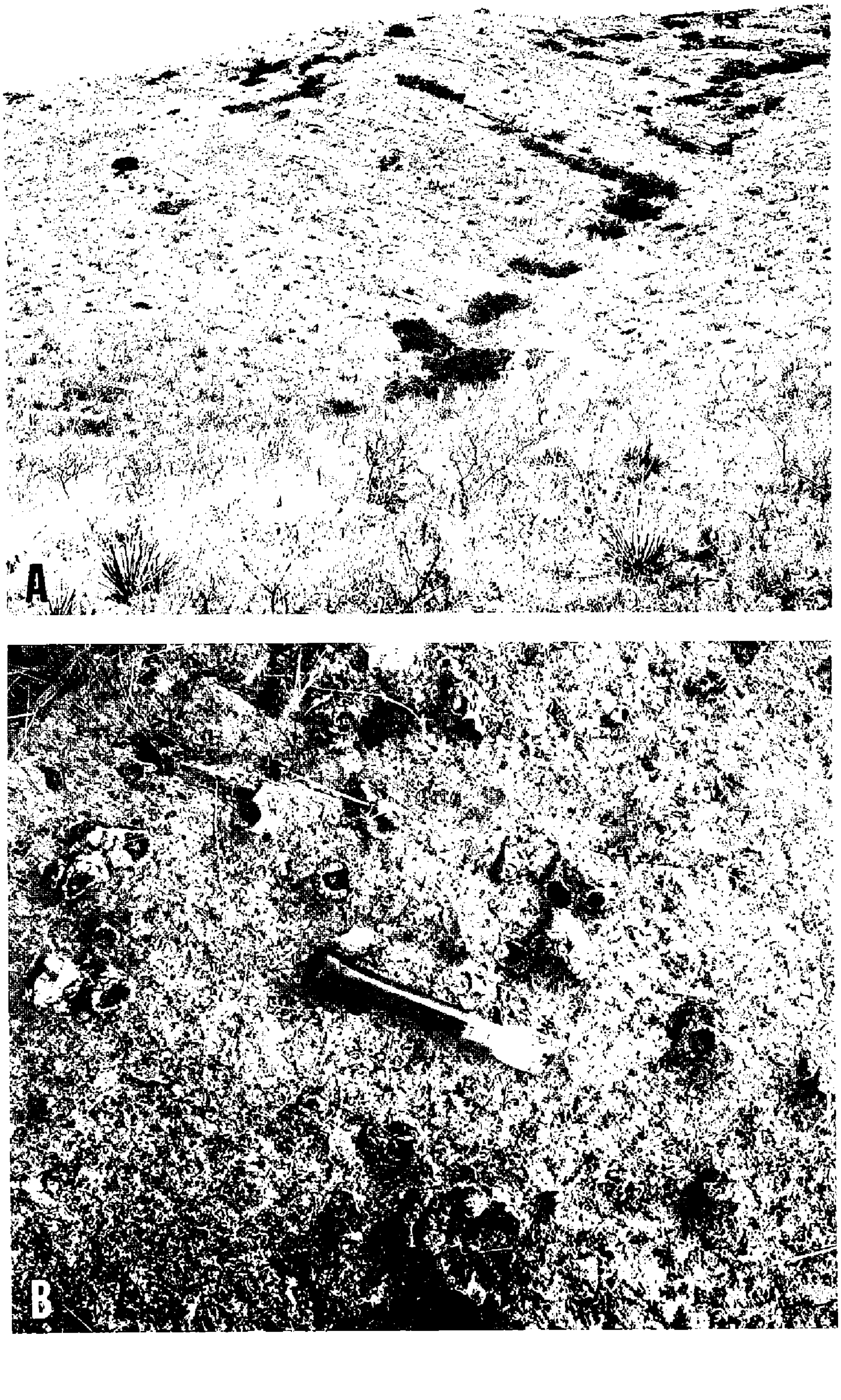


Figure 1. Index map showing location of Wichita Mountains in southwestern Oklahoma, with key stratigraphic sections designated: **A**, Kindblade Ranch (type locality); **B**, Longhorn Mountain; and **C**, Unap Mountain. All sections are in Kiowa County.


A
B

In their comprehensive review of the Lower Ordovician gastropod *Ceratopea*, Yochelson and Bridge (1957) noted that these opercula can be divided into five more or less distinct groups. They were able to construct a diagram (fig. 104) based on gross morphology and stratigraphic succession of the form that suggests the phylogeny of *Ceratopea* species. On the basis of this evidence, they were able to subdivide the Kindblade and West Spring Creek Formations into a useful stratigraphic *Ceratopea* succession for the Arbuckle Mountains (fig. 103). As a result, gastropod opercula grouped under the genus *Ceratopea* are perhaps the best stratigraphic indices for a definitive Early Ordovician relative-age sequence. The succession *Ceratopea capuliformis-incurvata-corniformis-keithi-tennesseensis* does have meaningful stratigraphic value. This fact was reinforced by Yochelson (1973) when geographic locations and stratigraphic positions of large collections made earlier by Ham were documented and plotted for the Arbuckle Mountains. These *Ceratopea* zones independently confirm interregional correlations based on stratigraphic succession supplemented with the use of other fossil groups. Several *Ceratopea* species have a broad geographic distribution; more geographically restricted species, however, do appear to have a local usefulness in mapping. As a result, the stratigraphic succession of *Ceratopea* zones has been documented for the Ellenburger Group of central Texas, the Lower Ordovician sequences of the Ozark Uplift, Missouri, and the east Tennessee section (Yochelson and Bridge, 1957, p. 292). More recently, Toomey and Nitecki (1979) discussed the occurrences and made comparisons of the *Ceratopea* zones in the El Paso Group of far West Texas with those of the Arbuckle Group of southern Oklahoma.

The occurrences and distribution of *Ceratopea* species found in three stratigraphic sections in the Wichita Mountains of southwestern Oklahoma are plotted in figure 4. Included on this diagram are the stratigraphic zones from which various *Ceratopea* species have been identified, the numbers of specimens found in each collection, and the zonal range for each of the pertinent *Ceratopea* species. This diagram is based upon data derived from 28 collections representing a total of 83 specimens.

It should be emphasized that there are no complete sections of the Kindblade Formation exposed in the Wichita Mountains. In fact, Kindblade thicknesses in the Wichitas are just about half what they are in the Arbuckle Mountains.

Figure 2. Outcrop photographs of lower part of Kindblade Formation exposed at type locality on Kindblade Ranch, Kiowa County, Oklahoma. **A**, approximate contact of Cool Creek–Kindblade Formations marked by first occurrence of well-exposed, relatively thin-bedded units; note presence of lower algal-sponge-mound interval occurring as massive beds within an interval 37 to 82 feet above base of Kindblade Formation. **B**, close-up photograph of lower Kindblade algal-sponge-mound surface showing abundant chert-replaced **Archaeoscyphia annulata** Cullison (lithistid sponges) typically strewn over buildup surface; chisel, 7 inches long.

Figure 3. Outcrop photographs of upper part of Kindblade Formation exposed at type locality on Kindblade Ranch, Kiowa County, Oklahoma. **A**, typical outcrop expression of thin-bedded carbonate units marking upper part of formation. **B**, bedding surface in upper Kindblade Formation showing abundant silicified high-spired snails (**Hormotoma** sp.); this horizon is present within upper mound interval in principal zone of **Calathium** (receptaculitid alga)–sponge buildups 435 to 467 feet above base of formation.

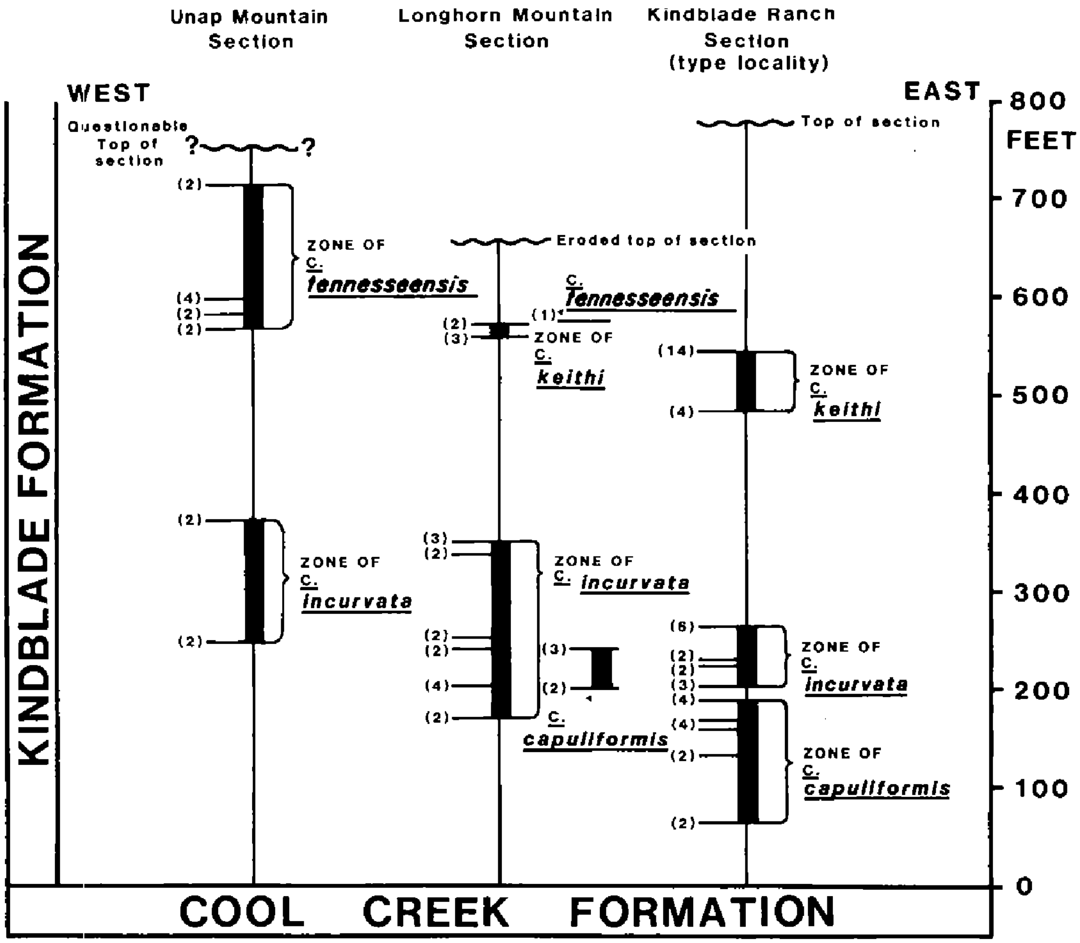


Figure 4. Occurrences of **Ceratopea** opercula in three stratigraphic sections of Kindblade Formation exposed in Wichita Mountains, southwestern Oklahoma. Numbers in brackets indicate numbers of collected silicified specimens (data derived from previously unpublished notes of W. E. Ham dated prior to 1962, supplemented by field data of joint work by W.E.H. and D.F.T. in 1962).

The Kindblade Ranch section was perhaps the most thoroughly searched interval in the hunt for *Ceratopea* specimens. Here, the *Ceratopea* succession followed the progression *C. capuliformis-incurvata-keithi*, with a rather conspicuous "barren" interval of a little more than 200 feet in the approximate middle of the formation. This generally barren interval has been shown by Yochelson (1973, fig. 2) to be present in the Arbuckle Mountains in an equivalent stratigraphic position. *Ceratopea* specimens have not been found in any of the units overlying a zone 545 feet above the base of the formation.

At the Longhorn Mountain section a *Ceratopea* succession consisting of *C. incurvata-capuliformis-keithi-tennesseensis* was found. *Ceratopea* was first noted within a zone 172 feet above the base of the formation. This occurrence marked the base of the zone of *C. incurvata*. Specimens of *C. capuliformis* do not appear until we reach a zone approximately 205 feet above the base of the

Kindblade Formation. In this section, the stratigraphic ranges of these two *Ceratopea* species overlap, a fact previously demonstrated in other areas (Yochelson and Bridge, 1957, fig. 103; Yochelson, 1973, fig. 1). There follows a "barren" interval of a little more than 200 feet, similar to what is found in the Kindblade Ranch section, before the next overlying *Ceratopea* zone is encountered. Beginning at an interval of 560 feet above the base of the formation there is a short 12-foot interval containing specimens of *C. keithi*. Directly overlying the zone of *C. keithi* we have found only one specimen of *Ceratopea tennesseensis*. Stratigraphic units directly above were searched diligently for additional *Ceratopea* specimens, but to no avail. It should be noted, however, that previous *Ceratopea* ranges given by Yochelson and Bridge (1957) and Yochelson (1973) for the Arbuckle Mountains and other regions show overlapping ranges for these two *Ceratopea* species.

At Unap Mountain, lower Kindblade exposures are not well developed, and no *Ceratopea capuliformis* specimens were found. The first occurrence of *Ceratopea* marked by the base of the *C. incurvata* zone is in a zone 250 feet above the base of the Kindblade Formation. This zone extends upward to the top of the zone approximately 375 feet above the base of the formation. Overlying the *C. incurvata* zone is a "barren" interval 185 feet thick, similar to that seen at both the Longhorn Mountain and the Kindblade Ranch sections. The next overlying *Ceratopea* zone occurs in a stratigraphic zone 570 feet above the formation base. This zone marks the base of the *C. tennesseensis* zone, which at this section extends upwards to near the questionable top of the formation.

The succession and distribution of Kindblade *Ceratopea* species in the Wichita Mountains of southwestern Oklahoma appears to be similar to those described by Yochelson (1973) for the Kindblade section in the Arbuckle Mountains of southern Oklahoma, with the only major exceptions being the absence of two *Ceratopea* species, *C. corniformis* and *C. germana*, in the Wichita Mountains and the rarity of occurrences of these species in the Kindblade sequence of the Arbuckle Mountains. Nonetheless, a rather useful and meaningful Kindblade *Ceratopea* stratigraphic succession for the Wichita Mountains has now been documented.

Measured Section

The following measured section of the Kindblade Formation, at the Kindblade Ranch type locality, Kiowa County, southwestern Oklahoma, shows the occurrence of distinctive faunal zones occurring throughout the section. This type section is approximately 10½ miles south of the town of Carnegie. The section was measured with Brunton compass and Jacob's staff, beginning at the base of the Kindblade Formation on a saddle and south slope of the main ridge, SE¼NW¼ sec. 25, T. 6 N., R. 14 W., and continuing to the highest exposed beds in the NE¼SE¼SW¼ sec. 24 of the same township and range. The strata are mostly well exposed and strike N. 40° to 50° W., with a northeast dip of 24° to 27°; an averaged dip of 25° was used for stratigraphic measurement. The section was measured with the aid of aerial photographs, scale 1:20,000. This section was measured September 10–12, 1962, by W. E. Ham and D. F. Toomey.

WICHITA FORMATION (LOWER PERMIAN): Limestone-cobble conglomerate and red shales.

— — — — — — — — — — —*Angular Unconformity*— — — — — — — — — — —

KINDBLADE FORMATION (LOWER ORDOVICIAN): Exposed thickness of 775 feet; approximately upper half of formation covered. Observed fossils, silicified unless otherwise noted. *Fossil collection obtained.

Feet above base	
760	*Orospira* sp., *Tarphyceras* sp.
740	*Orospira* sp.
735	*Tritoechia delicatula* Ulrich and Cooper,* *Orospira* sp., endosiphuncle (cf. *McQueenoceras* sp.), indet. trilobites.
700	*Orospira* sp.
670	*Orospira* sp.
640–645	endosiphuncle (cf. *McQueenoceras* sp.).
620–625	*Orospira* sp.
615	*Tritoechia delicatula* Ulrich and Cooper, endosiphuncle (cf. *McQueenoceras* sp.).
605	*Orospira* sp., endosiphuncle (cf. *McQueenoceras* sp.).
595	*Orospira* sp.
585–590	*Orospira* sp., endosiphuncle (cf. *McQueenoceras* sp.).
555–560	*Orospira* sp.
542–545	*Tritoechia delicatula* Ulrich and Cooper, *Ceratopea keithi* Ulrich,* *Orospira* sp., *Hormotoma* sp., endosiphuncle (cf. *McQueenoceras* sp.); TOP OF *C. KEITHI* ZONE.
538	*Tritoechia delicatula* Ulrich and Cooper.*
505	*Orospira* sp.
495–500	*Orospira* sp.
480–485	*Ceratopea keithi* Ulrich*; BASE OF *C. KEITHI* ZONE.
435–467	Upper mound interval (algal-sponge buildups); small mounds, not well developed; principal contributor is receptaculitid alga *Calathium* sp. (mostly silicified on surfaces); polished slabs from this interval show common calcified specimens of lithistid sponge *Archaeoscyphia annulata* Cullison; at base of this interval abundant *Orospira* sp. and *Hormotoma* sp. concentrated along bedding surfaces in pockets between small stromatolitic heads; *Girvanella* sp., *Renalcis* sp., and solenoporoid-type algal colonies; conodonts,* sponge spicules,* and many trilobite (*Peltabellia*? sp.*), brachiopod, and echinoderm fragments. Specimens of *Calathium* much scarcer here than in equivalent intervals in Arbuckle Mountains.
425	endosiphuncle (cf. *McQueenoceras* sp.).
410	*Orospira* sp.
400	*Tritoechia delicatula* Ulrich and Cooper, *Orospira* sp., *Hormotoma* sp., ?chiton plate.
385–390	*Orospira* sp.
370	*Orospira* sp.
350	*Hormotoma* sp., endosiphuncle (cf. *McQueenoceras* sp.).
345	*Tritoechia delicatula* Ulrich and Cooper, *Orospira* sp., *Hormotoma* sp.
325	*Orospira* sp.
318	*Orospira* sp.
310	*Orospira* sp.

282 *Tritoechia delicatula* Ulrich and Cooper, *Orospira* sp., *Hormotoma* sp.

260–265 *Ceratopea incurvata* Yochelson and Bridge*; TOP OF *C. INCURVATA* ZONE.

245 *Tritoechia delicatula* Ulrich and Cooper.

230–232 *Ceratopea incurvata* Yochelson and Bridge,* *Orospira* sp., *Hormotoma* sp., endosiphuncle (cf. *McQueenoceras* sp.).

225 *Tritoechia delicatula* Ulrich and Cooper, *Ceratopea incurvata* Yochelson and Bridge, *Orospira* sp.

205–210 *Ceratopea incurvata* Yochelson and Bridge, *Hormotoma* sp.; BASE OF *C. INCURVATA* ZONE.

190 *Ceratopea capuliformis* Oder*; TOP OF *C. CAPULIFORMIS* ZONE.

170 *Ceratopea capuliformis* Oder, *Orospira* sp.

160 *Ceratopea capuliformis* Oder.*

150–152 *Archaeoscyphia annulata* Cullison,* *Orospira* sp.

135 *Ceratopea capuliformis* Oder.*

67–82 Lower mound interval (algal-sponge buildups); organic buildups well developed, up to 10 feet high; principal mound contributor is calcified and silicified specimens of lithistid sponge *Archaeoscyphia annulata* Cullison* with sparse *Calathium* sp.*; scarce *Ceratopea capuliformis* Oder* at base of mound interval along with endosiphuncles (*McQueenoceras* sp.) in beds along strike to southeast. Mound rock contains *Renalcis* sp., *Girvanella* sp., sponge spicules, snails, chiton plates, trilobite debris, pelmatozoans, and conodonts. One of best developed intervals of *Archaeoscyphia* buildups present in both Arbuckle and Wichita Mountains. BASE OF *C. CAPULIFORMIS* ZONE.

59–62 *Archaeoscyphia annulata* Cullison* in small mounds, associated with scarce *Calathium* sp.

55 *Archaeoscyphia annulata* Cullison* in small mounds.

37–39 Lowest bed of abundant *Archaeoscyphia annulata* Cullison* in small mounds; 300 feet to southeast this bed is base of an *Archaeoscyphia*-dominated mound 28 feet high; many *A. annulata* Cullison specimens are calcified.

20 *Archaeoscyphia annulata* Cullison.

7 *Archaeoscyphia annulata* Cullison,* widely scattered though well preserved.

0 Rare *Archaeoscyphia annulata* Cullison*; basal 25 feet of Kindblade Formation is dolomitized along strike, but silicified specimens of *A. annulata* Cullison are rather common in dolomite.

COOL CREEK FORMATION (LOWER ORDOVICIAN): Consists mostly of unfossiliferous calcilutite, calcarenite, and intraformational conglomerate, interbedded with prominent stromatolite zones. Strata are irregularly dolomitized along strike. Approximately 300 feet below top of Cool Creek Formation is distinctive zone containing abundant specimens of brachiopod *Diaphelasma oklahomense* Ulrich and Cooper and *Lecanospira* sp. Specimens of lithistid sponge *Archaeoscyphia*, which occurs in middle Cool Creek Formation of Arbuckle Mountains, were searched for at this section but not found.

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Cohen Named Chief of USGS Water Resources Division

H. William Menard, director of the U.S. Geological Survey, has announced the appointment of Philip Cohen to the position of chief hydrologist for the federal survey.

A native of New York City, Cohen received a B.S. degree *cum laude* in geology from the City College of New York, and an M.S., also in geology, from the University of Rochester. He began his career with the USGS in 1956 in the Nevada branch of the Water Resources Division and was named chief of the Humboldt Research Project in northern Nevada. Later assignments were with the Long Island, New York, subdistrict office, where he became chief in 1968, and with the office of the director at USGS headquarters, where he functioned as staff scientist and later as associate chief for research and technical coordination.

Cohen received the USGS Meritorious Service Award in 1975 and is in line to receive the Interior Department's highest honor, the Distinguished Service Award. His professional memberships include the Society of the Sigma Xi, the American Institute of Professional Geologists, and the American Water Resources Association. He is a fellow of The Geological Society of America.

In his new assignment, Cohen will administer the largest of the survey's operating divisions, which has 4,000 members working with state, local, and other federal agencies to appraise the quantity and quality of the nation's surface and ground water through monitoring of more than 40,000 stations.

Cushing Field Monument Dedicated

Braving a cold north December wind for the dedication of an 8-foot-high granite monument commemorating the Cushing–Drumright petroleum area were, left to right: John Steiger, chairman of the Oklahoma Petroleum Council's Historical Committee; Forrest S. Fuqua, an OPC director; H. Glenn Jordan, executive director of the Oklahoma Historical Society; and Warren L. Jensen, OPC president. The monument, the 15th of Oklahoma's petroleum historical markers, stands on the west side of Cushing's City Hall and memorializes a field that opened in 1912 and still contributes about 2½ million barrels a year.

Rocky Mountain Coal Meeting Scheduled

The 1980 Symposium on the Geology of Rocky Mountain Coal will be held April 27–May 1 in Golden, Colorado. Sponsors are The American Association of Petroleum Geologists' Energy Minerals Division, the Colorado Geological Survey, the U.S. Geological Survey, and the Colorado School of Mines.

Technical sessions will cover all aspects of coal geology in the Rocky Mountain, Northern Great Plains, Interior, and Pacific Coast coal-bearing provinces. A two-day field trip will be offered to the Raton Mesa coal region of Colorado and New Mexico.

For information, contact Keith Murray, co-general chairman, Colorado School of Mines Research Institute, P.O. Box 112, Golden, Colorado 80401 (phone, 303–279-2581, extension 256).

OKLAHOMA ABSTRACTS

Ninth International Congress of Carboniferous Stratigraphy and Geology Pander Society, 13th Annual Meeting Urbana, Illinois, May 19–26, 1979

The following abstracts are reprinted from the *Abstracts of Papers* of the Ninth International Congress of Carboniferous Stratigraphy and Geology, held in Urbana, Illinois. The page numbers are given in brackets below each abstract. Permission of the authors and of Mackenzie Gordon, Jr., president of the congress, to reproduce these abstracts is gratefully acknowledged.

Preserved Mineralogy and Ultrastructure in Two New Pennsylvanian Bivalves

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An asphaltic shell breccia from a Pontotoc County, Oklahoma drill core has yielded two new molluscan taxa showing preserved mineralogy and ultrastructure. Surrounding well data suggest Des Moinesian (mid-Pennsylvanian) age, for the cored interval. Etched sections of cf. *Nuculopsis* n. sp. (Family Nuculidae) examined with a scanning electron microscope show the shell to be largely composed of unaltered aragonite with the characteristic lenticular nacreous structure seen in Recent *Nucula.* However, the outer prismatic layer so prominent in modern nuculids is comparatively thin in *Nuculopsis* n. sp. The remaining bivalve is a new genus and species with affinities to the Grammysiidae. The ultrastructure here shows strong similarities to that mysiids among the Pholadomyacea. Mineralogically aragonitic, it consists of an inner layer composed of sheet nacre separated by pallial myostracum from an outer layer of step-like "treppen" nacre. The thin outermost prismatic layer reported in *Pholadomya* is lacking.

The ultrastructure of these bivalves is fundamentally similar to that of their Recent counterparts except for the poor development of outer prismatic layers, a tendency also noted in certain Devonian taxa. This suggests that the character of the inner layers is phylogenetically older than the outer layers and suggests that the addition of an outer prismatic layer may have been a convergent phyletic trend among unrelated late Paleozoic bivalves. [8–9]

Mobile Basin-Shelf Border Area in Northeast Oklahoma during Desmoinesian Sedimentation

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Desmoinesian coal cycles and marine limestone banks episodes in northeastern Oklahoma are related to the mobility of the basin-shelf border area. This border area during its northernmost advance was apparently near the Kansas border, whereas, during its southern retreat it was near the Choctaw Fault in east central Oklahoma. Initial phase of Desmoinesian sedimentation, the Hartshorne coal cycle, represented such a retreat of the shelf front over the basinal Atoka deposits and this broad regression continued through many other oscillatory coal cycles, including, in upward sequence, the McAlester, Savanna, Boggy, Thurman, Stuart and Senora deposits. Toward the end of Senora time basinal deposits spread northward as large progradational sedimentary wedges, known as the Calvin, Wetumka and Wewoka Formations. The shelf became the occasional site of large limestone banks of the Marmaton Group such as the Fort Scott, Oologah and the Mesolobus bearing Lenapah Limestones, separated by variable thicknesses of prodelta clastics. The latter limestone grades southward into the Dawson coal cycle which represents the lower phase of another shelf edge retreat and the beginning of the three coal cycles previously correlated with the Seminole Formation. The upper cycle (Checkerboard) represents the beginning of the Missourian Stage and of the Coffeyville transgression. Widespread extent of Desmoinesian lithogenetic units over the shelf and deep into the basin suggests that upstream source conditions may be a greater determinant of sediment types than even the varying environments of shelf and basin. [16]

Coalbed Derived Natural Gas in Conventional Gasfields

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Coalbed gas is considered to be an "unconventional" gas for several reasons:
It is adsorbed gas;
It is produced readily only when associated water is removed;
It is composed mainly of methane with less than 2 percent higher hydrocarbons;
It contains no hydrogen sulfide; and
It is usually produced in small volumes as compared with conventional gas sources.

The total gas content of coalbeds may be very high. Resource estimates of more than one trillion cubic feet of gas have been established for part of the Pittsburgh coalbed in northern West Virginia and southwestern Pennsylvania, part of the Hartshorne coalbed in Oklahoma, and part of the Mary Lee coalbed in Alabama. Like most Carboniferous coalbeds, these occur in the same geographic area as conventional oil and gas fields.

The relationship between coalbeds and conventional gasfields is not clear although there are supporting data for the relationship for one small gasfield in Oklahoma. During coalification the vast amount of disseminated coalified wood debris in the coal measures rocks yielded large amounts of methane which migrated into reservoir rocks now recognized as conventional gasfields. Where the plant material was thoroughly degraded and intimately intermixed with clay minerals and fine silt in thick sequences, the gas formed may be trapped by sorbtion on the organic residue. This gas is another form of unconventional gas, the Devonian shale gas of the eastern United States. [51]

Species-Level Bryozoan Assemblages in the Wreford Megacyclothem (Lower Permian) of Kansas, Oklahoma, and Nebraska

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The Lower Permian Wreford Megacyclothem, from southernmost Nebraska down across Kansas into northern Oklahoma, contains abundant and diversified bryozoans, which have been extensively sampled, identified to species, and now counted from the various facies developed at each horizon distinguishable within the Wreford succession. The fauna includes 20 species—2 ctenostomes, 7 fenestrates, 4 pinnates, 2 rhomboporoids, 1 trepostome, and 4 fistuliporoids—which are distributed in complexly intermingled fashion. Several techniques are being employed to detect significant patterns in the co-occurrences and distributions of these species; such patterns when confirmed may possibly reflect variations in particular paleoenvironmental factors, bottom sediments, invertebrate communities, or biogeographic areas at individual horizons, within the predominant overall framework of cyclothemic recurrence of faunas. The techniques include simple mapping, cluster analysis, and Fourier analysis; in this last, the distribution and abundance of each species is considered a periodic function, decomposable into its harmonic constituents, which indicate both periodicities and possible noise within the data set. [84]

Distribution of Zinc and Cadmium in Coals from the Eastern and Western Regions, Interior Coal Province

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Trace element analyses of more than 800 coal samples collected from cores and mines in the Eastern and Western regions of the Interior coal province outline areas where coals of Pennsylvanian age contain as much as 11,500 ppm zinc and 60.2 ppm cadmium. These areas are in northwest, northeast, and southeast Illinois (Eastern region–Illinois Basin); and southeast Iowa, northeast, north-central and southwest Missouri, southeast Kansas, northeast Oklahoma and southeast Nebraska (Western region–Forest City and Arkoma Basins). Within the areas mentioned, Zn and Cd contents in the coals are irregularly distributed with differences in contents as much as 1000% between beds that are closely related stratigraphically or between parts of the same bed. The Zn and Cd occur in the coal as sphalerite (ZnS), which is found along cleats and fractures, in association with calcite, pyrite, kaolinite, barite, and quartz. These coals also have relatively high contents of Pb, Ni, Co, Mo, and Ag.

The geographic distribution of these areas appears related to the 38th parallel lineament and to the major positive structural features of the midcontinent area; the LaSalle anticlinal belt, Mississippi River arch–Lincoln anticline, and Nemaha anticline. Many of the areas are near mining districts containing Mississippi Valley-type lead-zinc-barite-fluorite ores. Proximity and similarity in mineralogy suggest a common origin. [86]

Geologic Association of Coalbed Gas and Natural Gas from the Hartshorne Formation in Haskell and Le Flore Counties, Oklahoma

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The Hartshorne formation contains a complex association of gas reservoirs and source rocks. Geological and geochemical data are provided in an attempt to arrive at possible solutions of the origin, migration, and retention of gases within the formation. The close association of the Hartshorne coalbed and sandstone complicates an understanding of the origin and subsequent migration of the gas. Possible source rocks are the Hartshorne coalbed, the marine Atoka shales below, and the carbonaceous McAlester shales above the Hartshorne formation.

The Hartshorne coalbed is estimated to contain between 1.1 and 1.5 trillion cubic feet of gas. In the same area, the Hartshorne sandstone has been producing natural gas from the Quinton, Poteau-Gilmore and Camaron gasfields for approximately 65 years. These gasfields are produced from small combination traps (structural and stratigraphic). Gas samples were collected from nine production wells in the three different gasfields, several gas drainage holes in the Hartshorne coalbed, and two Hartshorne coal cores. The δC^{13} content in the methane, ranging from —34 to —44 per mil, and the amount of ethane, propane, and butane were found to be dependent on the rank of the coal associated with each gasfield. Coalbed gas, sampled from a mine near the Quinton field, contained more methane and less ethane, propane, and butane than natural gas from the Quinton field. This may be due to the high sorption properties of coal. The heavier hydrocarbons remain adsorbed on the surface of the coalbed micropore structures, with higher proportions of methane released into coalbed macropore structures. Data collected so far indicate that the gas from the Poteau-Gilmore and Camaron fields is derived from associated coalbeds, while the gas from the Quinton field may have another origin. [94–95]

Lower Mississippian Carbonate Shelf, Southern Missouri, Eastern Oklahoma and Northern Arkansas

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A carbonate shelf system was established in Middle Kinderhookian time and probably existed into early Meramecan time as part of a larger shelf complex extending from the eastern interior to the Rocky Mountain region. Following a Middle Kinderhookian transgressive phase represented by thin clastics, shallow water carbonate deposition was characterized by a predominance of light-colored, muddy facies associated with crinoid–fenestrate bryozoan assemblages. Small, isolated, crinoidal bioherms lacking mud and measuring several meters thick and several tens of square meters in areal extent developed in eastern Oklahoma and Waulsortian-like "reefs" are present in southwestern Missouri.

Both types appear to be absent in northern Arkansas. Biohermal growth appears restricted to late Kinderhookian time in the Missouri Waulsortian-like "reefs", whereas the crinoidal bioherms of Oklahoma appear to be early Osagean in age. Upper Kinderhookian time was marked by prograding fine-grained siliciclastics which interrupted carbonate deposition. The Kinderhookian-Osagean boundary occurs in a continuous carbonate sequence identical to that found below the clastic influx. In north-central Arkansas, no clastics are present and the entire interval is bright red. Environmental significance of this color change is unclear. Carbonate deposition during Osagean time is represented by unpredictable alternations of mud-supported and grain-supported carbonate lithologies characterized by penecontemporaneous and later diagenetic chert development. Maximum thickness of the carbonate interval approaches 100 meters with marked thinning due to starved basin conditions in deeper areas to the south of the shelf. In addition, dolomitization and silicification more extensively alter the depositional record in these areas. The top of the present sequence is a significant regional unconformity that removed record of the final stages of carbonate shelf development. [125–126]

The Mississippian-Pennsylvanian Boundary in the Southern Midcontinent, United States

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Sequences of the Chesterian and Morrowan Series are separated in the southern Midcontinent by an unconformity of variable magnitude when compared to the type Namurian Series of Europe. The Grove Church Shale of the type Chesterian region, southern Illinois, yields *Adetognathus unicornis* Zone conodonts, Mamet Zone 19 foraminifers, but no ammonoids, suggesting equivalency to the Namurian Arnsbergian Stage (upper E_2a-lower E_2b). The overlying Caseyville Formation contains plants of middle Morrowan age, equivalent to upper Westphalian A.

In the type Morrowan region, northern Arkansas, the Imo Formation, highest Chesterian Series, contains upper Arnsbergian (E_2b-c) ammonoids with Mamet Zone 19 foraminifers and *A. unicornis* Zone conodonts. The Cane Hill Member, Hale Formation, basal type Morrowan, yields lower Kinderscoutian Stage (R_1a) ammonoids with *Millerella* (Mamet Zone 20) and *Rhachistognathus primus* Zone conodonts. In northwestern Arkansas, the Cane Hill Member may overlie the older Chesterian Pitkin or Fayetteville Formations of lower Arnsbergian (E_2) or Pendleian (E_1) age.

In northeastern Oklahoma, the Morrowan Braggs Member, Sausbee Formation, contains *Idiognathoides sinuatus* Zone conodonts of Kinderscoutian (R_1) or Marsdenian (R_2) age in contact with the Pitkin Formation of presumed lower Arnsbergian (E_2) age. [126]

The Mississippian/Pennsylvanian Boundary in the Ouachita Mountains and Ardmore Basin, Oklahoma and Arkansas

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An uninterrupted succession of approximately 7,000 m. of Chesterian and Morrowan clastic rocks crop out in the Ouachita Mountains. These rocks are subdivided into the Stanley, Jackfork and Johns Valley lithic units. Each is dominated by rapid depositional rates, chiefly gravity-flow sedimentation across an unstable slope/rise/abyssal plain system. The sparse, unevenly-distributed fossil content is dominated by redeposited fossils (mollusks with minor plants, brachiopods, and crinoids) in limestone and shale blocks intermittently slumped from a south-sloping, fault-controlled continental slope. Poor exposure, complex structure, similar appearing stratigraphic units, and the rarity of indigenous fossils have led to heated debate about the age of these units. The Stanley contains both Meramecian and Chesterian fossils with transported fossiliferous blocks bearing late Chesterian ammonoids occurring near the top. The lowermost beds of the Jackfork have yielded a Chesterian flora but small allochthonous Morrowan marine faunas occur at several localities in the middle and upper Jackfork. Thus the Mississippian-Pennsylvanian boundary falls in the lower part of the Jackfork. The Johns Valley also contains Morrowan marine fossils.

To the west, in the northern Arbuckle Mountains, the upper "Caney" (Rhoda Creek Shale Member) contains a well developed late Chesterian ammonoid fauna but the Mississippian-Pennsylvanian boundary occurs in an overlying poorly exposed and presumably continuous shale interval, for which no faunal information is available. At a higher horizon, the Union Valley Formation contains an abundant middle Morrowan *Branneroceras* goniatite assemblage. In the Ardmore Basin, presumably continuous deposition across the boundary is found in the Springer Group, in a poorly fossiliferous, predominantly clastic sequence, which contains latest Chesterian *Rhachistognathus muricatus* Zone conodonts succeeded by earliest Morrowan *R. primus* Zone conodonts.

[143–144]

Late Mississippian–Early Pennsylvanian Miospore Assemblages from Northern Arkansas

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The compositions of miospore assemblages recovered from the Fayetteville, Imo, Pitkin and Hale Formations from various localities in northern Arkansas are compared with those from formations of comparable age in southern Oklahoma. An attempt is made to relate the sequence of miospore populations recovered from the Arkansas succession to that known in Namurian deposits of comparable age in Northwest Europe in an attempt to establish the position of the Mississippian-Pennsylvanian boundary within the palynological zonation of the Namurian. [155]

The Mississippian-Pennsylvanian Boundary in North America

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On the North American craton, the Chesterian and Morrowan Series are bounded by a major unconformity that separates alternations of shale and shelf carbonates of Mississippian age from terrigenous, coal-bearing facies of the Pennsylvanian. Transition from craton margin to geosynclines reduces duration of the unconformity through more nearly continuous deposition and marine faunas become associated with sediments of the boundary interval.

Three faunal groups, ammonoids, conodonts, and calcareous foraminifers, figure prominently in boundary analysis in both cratonic and geosynclinal areas. The standard ammonoid succession is the Namurian Series of western Europe, divided into 19 zones representing seven stages. The boundary occurs at the top of the Arnsbergian (E_2) Stage, although neither the succeeding Chokierian (H_1) nor Alportian (H_2) Stages has been recognized in North America from ammonoids. The North American conodont succession has been based on sections in Oklahoma and the Great Basin. There the *Rhachistognathus muricatus* Zone, highest Chesterian, is succeeded by the basal Morrowan *R. primus* Zone. This zonal boundary occurs within the *Streptognathodus lateralis-Idiognathoides noduliferus* Zone of the type Namurian, approximately at the Arnsbergian (E_2)-Chokierian (H_1) boundary. No ammonoids are associated with conodonts of this interval in North America. The succession of calcareous foraminifers was synthesized from sections in the Rocky Mountains. The Mississippian-Pennsylvanian boundary coincides with the boundary between Mamet Zone 19 (eosigmoilinid-dominated) and 20 (*Millerella*). Foraminifers are absent in the type Namurian and age determinations are based on correlations of conodonts and ammonoids through the Russian Platform and Urals. [211–212]

Comparison of the Compression and Palynological Floras of the Henryetta (Pennsylvanian) Coal of Oklahoma

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The Henryetta coal in Okmulgee County, Oklahoma is equivalent to the Croweburg coal (Desmoinesian, Pennsylvanian) also in Oklahoma, Kansas, and Missouri. It is considered to be correlative with the Colchester (No. 2) coal of Illinois, coal IIIa of Indiana, Schultztown coal of Kentucky, and the Whitebreast coal of Iowa. The Lower Kittanning coal of the northern Appalachian field appears to be approximately contemporaneous, consequently the Henryetta coal and its correlatives probably make up the most extensive coal deposit known. In Oklahoma the only abundant compression flora of the Croweburg coal occurs at Henryetta, Oklahoma. This locality is near the southwestern boundary of the coal deposit. The compression flora consists of 18 genera and 34 species. A tally, based upon 1,757 compression specimens, indicates that the Lycopsida consti-

tute 11.5%, the Spenopsida 13.7%, and the Filicineae and Pteriodspermae combined 74.8%. The most abundant representatives of each group are *Lepidodendron obovatum*, *Asterophyllites equisetiformis*, and *Neuropteris scheuchzeri* respectively. No compression fossils of *Cordaites* were found although the pollen (*Florinites*) is abundant in the top coal levels. The palynological flora consists of 21 genera and 49 species. The top four inches of coal consists of Lycopsida 75%, Sphenopsida 4%, the Filicineae and Pteridospermae combined 12.7%, and Cordaitales 8.3.% The palynological flora represents both plant assemblages of the coal swamp and the adjacent higher ground, whereas the compression flora is that of the swamp and possibly the immediate vicinity. Those geographic factors and the fact that relative production of palynomorphs in Paleozoic plants is unknown, appears to explain floristic differences of the compression and palynological floras. [234]

Palynological and Plant Compression Evidence for a Desmoinesian–Missourian (Pennsylvanian) Series Boundary in Northeastern Oklahoma

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Palynological and plant compression bearing coal and shale deposits in Tulsa County (NE Oklahoma) contain floristic evidence for separating the Desmoinesian and Missourian Series at the base of the Checkerboard Sandstone (Upper Seminole Ss.). Three coal seams, Dawson (below), Seminole, and Checkerboard were formerly placed in the Missourian Series. The two lower seams and their associated shales and sandstones are here removed to the Desmoinesian Series. Dawson coals contain approximately 42% *Thymospora pseudothiessenii* spores and 17% those of *Lycospora* sp., whereas the Seminole coals contain none of the former and only 1% of the latter. Sphenopsid spores increase from 4% in the Dawson to 25% in the Seminole. Filicineae and Pteridospermae palynomorphs are 65% in the Dawson and 37% in the Seminole. More abundant in the Seminole are the genera *Endosporites*, *Calamospora*, *Triquitrites*, and *Laevigatosporites*. Checkerboard coals and shales contain the Missourian genera *Centonites*, *Trivolites*, *Plicatisporites*, and *Tuberculatosporites*. Compression floras associated with the Dawson and Seminole coals contain only 9 known species of which *Calamites suckowii*, *Annularia stellata*, *Pecopteris pseudovestita(?)*, *Alethopteris serlii*, and *Neuropteris scheuchzerii* are common. The Checkerboard shales contain possibly 29 species. [234–235]

Correlation of Early Pennsylvanian Conodont Sequences between Europe and North America

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Knowledge of European and North American conodont sequences allows correlation of the major stratotypic successions. Although some faunal differences are apparent (*i.e.*, European assemblages are dominated by *Declinognathodus* and *Idiognathoides* and North American ones by *Adetognathus* and *Rhachistognathus*), certain species are common and easily distinguished from underlying Mississippian faunas. Earliest Pennsylvanian Strata (base of *Declinognathodus noduliferus* Subzone of Higgins in the British Isles; D_5^8 limestone in the Donetz Basin; near the base of the Target Limestone, type Springeran, southern Oklahoma; and near the base of the Cane Hill Formation, type Morrowan, Arkansas), are recognized globally at the first appearance of *Declinognathodus noduliferus inaequalis* and *Declinognathodus lateralis*. Significantly, the typical Mississippian genera *Gnathodus* and *Cavusgnathus* disappear at about this level. The appearance of *Idiognathoides corrugatus* and *I. sinuatus* corresponds with basal Rla in Europe, but in North America basal Rla strata have been interpreted using ammonoids to occur somewhat below the first appearance of these species. Strata of definite Atokan age first occur in limestone K_1 of the Donbass Bashkirian succession. [247]

Correlation of Conodont Biofacies with Lithofacies in the Core Members of the Oread Megacyclothem (Virgilian), Southern Kansas and Northern Oklahoma

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The Leavenworth Limestone, the Heebner Shale and the Plattsmouth Limestone, all of Virgilian age, in southern Kansas and northern Oklahoma provide a rare opportunity to examine lateral lithofacies relationship of core members of Pennsylvanian cyclothems as they approach a palaeo-shoreline, and to document accompanying faunal changes. Of great interest is the distribution of conodonts in these, particularly in the Heebner Shale—the core shale of the Oread Megacyclothem. This member contains a characteristic black fissile shale as far south as Chautauqua County in southern Kansas. Further south, in northern Oklahoma, the black facies is replaced by both soft green shales of a "normal" marine aspect as well as by coarser clastics.

Cavusgnathus, numerical dominance of which is indicative of nearshore, marine conditions, is conspicuously absent in the Heebner Shale of southern Kansas in lithologies indicative of deep-water anoxic depositional environments. In nearby northern Oklahoma where both lithofacies and megafauna support a shallow-water, normal marine interpretation for the Heebner Shale *Cavusgnathus* increases noticeably. Parallel trends can be demonstrated for *Cavusgnathus* in the underlying and overlying Leavenworth and Plattsmouth limestones, respectively, although the different outcrop limits of these members causes their trends to be modified.

The distribution of other conodont genera, relative to a postulated northern Oklahoma shoreline during Virgilian deposition, is not as well defined. For example, abundant *Streptognathodus*, *Idiognathodus* and *Idioprioniodus* in the most southerly outcrop of the Heebner Shale known are anomalous in terms of previously proposed biofacies models. [249]

AAPG Mid-Continent Section Meeting
Tulsa, Oklahoma, October 7–9, 1979

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Geochemical Prospecting for Stratigraphic Traps

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Petroleum geochemistry has received considerable attention in recent years and has emerged as a useful tool in exploration efforts. Most of the methods currently being used find maximum benefit and application in frontier exploration areas. Such studies generally provide information on source-rock quality, maturity level, and migration history. Some techniques, however, are especially suited for stratigraphic-trap exploration efforts. One such method involves pyrolysis of samples (well cuttings) and measurement of the quantity of hydrocarbons that are volatilized. Detecting, quantifying, and mapping hydrocarbon content of samples from specific stratigraphic units help to assess proximity to oil accumulations.

As oil moves to a trap, small quantities of hydrocarbons are invariably left in the rocks which served as avenues of migration. Concentrations of these hydrocarbons are highest near an oil accumulation and become progressively lower at greater distances from an accumulation. Concentration gradients can be mapped and interpreted in much the same way as conventional subsurface data and thus can provide the exploration geologist with a quantitative tool. Data are rapidly obtained, and information derived from initial boreholes can be used to help position subsequent tests. Preliminary results from several Mid-Continent study areas have been encouraging. [2117]

Geochemistry of Small Lacustrine Delta, Great Salt Plains, Alfalfa County, Oklahoma

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A shallow lacustrine delta is forming at the northern end of the Great Salt Plains reservoir in Alfalfa County, north-central Oklahoma. Although sediment is supplied solely by the river, organic matter may be derived from the land surface (and transported by the river) or derived from the lake itself. The total amount of organic carbon in the surface sediments increases with distance from the river mouth and is accompanied by a decrease in mineral grain size as expected. However, within a single sediment sample, organic carbon content is not a strong function of grain size over the range from 5 to 11ϕ. Visual examination

of the separated insoluble organic matter showed that structured, wood-derived organic matter predominates in the coarser fractions ($>62\mu$) but the finer fractions ($<62\mu$) contain mainly microorganisms and amorphous material. Pyrolysis experiments gave a ratio of (total response/organic carbon content) that increased from low values in the coarse fractions to higher values in the fine ones—a trend consistent with the visual kerogen observations because high ratios are usually produced by amorphous organic matter. However, infrared spectra of the organic matter from coarse and fine sediments closely resemble that generally observed for the humic substances associated with soils, suggesting that even the finer grained, amorphous organic matter is derived largely from the terrestrial organic matter. X-ray diffraction indicated the presence of quartz, feldspars, calcite, dolomite, mica, kaolinite, illite, and montmorillonite in the sediments. The composition was rather uniform with no major variations due to clay size or areal distribution. [2118–2119]

Controls on Pennsylvanian Hydrocarbon Accumulations in Mid-Continent

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Approximately 8.8 billion bbl of oil and about 31.5 Tcf of gas have been found in Pennsylvanian reservoirs in the Mid-Continent as of January 1, 1978. Although these volumes of hydrocarbons were trapped in thousands of fields throughout the region, most of these resources were emplaced in a relatively few fields: about 6.4 billion bbl of oil has been found in 90 significant and giant oil fields, and 18.5 Tcf of gas has been discovered in 50 significant and giant gas fields. Our calculations of the total oil and gas accumulations in Pennsylvanian reservoirs were extrapolated from these data.

Most oil and gas accumulations of Pennsylvanian age in the Mid-Continent were stratigraphically trapped in lenticular sandstone bodies; the environments in which most of the clastics were deposited range from fluvial to deltaic to shallow marine. Even though this region is now in a late mature stage of exploration and development, important stratigraphic accumulations of oil and gas remain to be found. These fields will be discovered through detailed subsurface analysis, the reconstruction of depositional environments, and the application of high-resolution seismic data to stratigraphic problems. [2119]

Stimulation Design for Upper Morrow Reservoirs in Reydon–Cheyenne Area, Western Oklahoma

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Recent deep, high-pressure upper Morrow reservoir completions in the western Oklahoma part of the Anadarko basin indicate the area to be a major natural gas producing area. These Morrow sandstone reservoirs consist of poorly sorted medium to coarse-grained feldspar-rich sandstones to chert-pebble conglomerates. Diagenetic minerals present include calcite, siderite, and quartz overgrowths. Clay minerals present include small to moderate amounts of iron-rich chlorite, mixed-layer clays, and illite. Generally, the diagenetic minerals and the clays tend to fill the intergrain pore space. Resevoir porosity ranges from 6 to 12%, and effective reservoir permeabilities range from 0.1 to 10 md.

Wells are generally drilled to total depth, logged, and a 5-in. (12.7 cm) OD liner is cemented back to the intermediate casing. Once perforated and cleaned up, the well is allowed to flow and a pressure buildup test is performed. Buildup-test analysis commonly indicates that a fracture-stimulation treatment may be needed to obtain satisfactory production rates. With bottom-hole temperatures in excess of 260°F (127°C), potassium chloride treated water in a cross-linked gel system is being used as the treatment fluid. Use of high-strength proppant instead of sand appears to help provide sustained production increases after fracturing.

Treatment designs must consider the following parameters: depth, bottom-hole temperature, reservoir pressure, and bottom-hole treating pressure, as well as surface-pressure limitations, tubing size, job volume, and type of proppant system used with respect to closure stresses expected.

Following the stimulation treatment and fluid cleanup, another pressure-buildup test is performed to evaluate the treatment. Field results indicate that stimulation treatments have been successful. [2119]

Oklahoma State University

Coal Geology of the Chelsea Quadrangle in Parts of Craig, Mayes, Nowata, and Rogers Counties, Oklahoma

WALTER ROBIN KEASLER, Oklahoma State University, M.S. thesis, 1979

Scope and Method of Study: The coal geology of the Chelsea area was mapped by using records of coal-test borings, aerial photographs, and by field mapping. Information potentially valuable for coal mining is shown on structural contour maps, isopach maps, and cross sections. Estimates of coal reserves were based on information from the maps and cross sections. Proximate and ultimate analyses were made of samples of coals in order to determine their suitabilities for various uses.

Findings and Conclusions: Pennsylvanian rocks of the surface and shallow subsurface of the study area include units of the Boggy, Senora, and Fort Scott Limestone Formations. These formations are part of the Krebs and Cabaniss Groups, Desmoinesian Series. Seven coal beds were observed; the Weir-Pittsburg, Mineral, Croweburg and Iron Post coals of the Senora Formation are economically important.

Rocks of the study area are moderately faulted and folded. Sediments of the Cabaniss Group were deposited in or near shallow seas. Coal swamps developed on deltas that built into the seas repeatedly and were submerged repeatedly.

Bulletin on Noble County Issued by Survey

A new bulletin on the *Geology and Mineral Resources of Noble County, Oklahoma* has been released by the Oklahoma Geological Survey.

The 66-page report, issued as OGS Bulletin 128, describes the surface and subsurface stratigraphy, structure, paleontology, petrography, economic geology (including petroleum), and water resources of the 747-square-mile north-central Oklahoma county. It represents the 30th stage toward the Survey's long-term goal to provide geologic information on each of Oklahoma's 77 counties.

The principal author of the bulletin is John W. Shelton, professor of geology at Oklahoma State University. Roy H. Bingham, hydrologist with the U.S. Geological Survey's Water Resources Division, now at Tuscaloosa, Alabama, prepared the section on water, and William A. Jenkins, independent geologist of Durango, Colorado, collaborated with Shelton for the section on petroleum.

Surface rocks in Noble County are of Late Pennsylvanian and Early Permian age and are characterized by red beds and cyclic deposits that dip gently westward. Subsurface sedimentary rocks are approximately 6,500 feet thick and were deposited on the stable Central Oklahoma platform, with the dominant depositional environment being an arid tidal flat. Faulted anticlinal structures are the most prominent subsurface expressions, with faulting paralleling the buried block-faulted Nemaha ridge to the west.

It is these structural traps that have yielded most of the petroleum in the county. Since the discovery 50 years ago of the Tonkawa field, about 186 million barrels of oil and 75 billion cubic feet of natural gas have been produced. Although recovery has come from 25 stratigraphic units ranging in age from Cambrian through Permian, most of the production has been from Ordovician and Pennsylvanian formations.

Other resources of economic potential include sandstone, sand and gravel, mudrock for brick and tile manufacture, and stone for road metal. Copper mining has seen early, limited activity, and copper minerals have been observed at a number of localities.

Surface water of a quality acceptable for household and some industrial usage is obtained from lakes formed by damming tributaries of major streams. Only 1.5 inches of the average annual precipitation of 32 inches is available to recharge the county's ground-water aquifers.

The new bulletin is accompanied by three large plates folded in a pocket. These include a new geologic map in color, at a scale of 1:63,360 (1 inch to the mile), with superimposed structure contours of the Herington Limestone of Late Pennsylvanian age; a subsurface structure map of the county; and three electric-log correlation sections.

Bulletin 128 can be obtained by writing to the address on the front cover. The price is $15.00 for clothbound and $11.00 for paperbound copies.

USGS Issues Circular on Thorium

U.S. Geological Survey Circular 805, *Principal Thorium Resources in the United States*, summarizes the findings of the USGS and the U.S. Bureau of Mines on this radioactive fuel–mineral resource and represents the first comprehensive assessment of thorium deposits in the country. It shows an estimated 693,000 tons in known deposits and an additional 2.2 million tons in disseminated deposits.

Circular 805 is free on request from the Branch of Distribution, U.S. Geological Survey, 1200 South Eads Street, Arlington, Virginia 22202.

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