OKLAHOMA GEOLOGY NOTES

Oklahoma Geological Survey Vol. 52, No. 5 October 1992

On the cover—

South Potato Hills Thrust, Western Potato Hills

The cover photograph shows the westernmost exposure of the South Potato Hills thrust, located east of Oklahoma State Highway 2 in the western Potato Hills (NE¼SE¼SE¼ sec. 5, T. 2 N., R. 19 E., Pushmataha County, Oklahoma). In the outcrop area, the South Potato Hills thrust strikes N. 82° W. and dips ~54° S. The thrust juxtaposes shale of the Mississippian Stanley Group on both sides of the fault, which indicates displacement decreased on the fault from east to west (see fig. 3 of a related article in this issue, p. 173–183).

At the fault trace, hanging wall strata are brecciated and bedding is contorted. To the south, beds dip moderately S and strike oblique to the thrust. The difference in strike between the thrust and bedding resulted from the bedding, originally with at NNE strike and WNW dip, being reoriented by the South Potato Hills thrust. To the north, scattered outcrops along the exposure indicate Stanley beds in the footwall of the thrust have been folded into one or more north-verging folds (Fig. 1) oriented 292°/2°, which is approximately parallel to the strike of the South Potato Hills thrust.

Brecciated strata, reoriented beds, north-verging folds, and the difference in strike indicate a fault with north-directed transport. From recent mapping, I have determined that the fault is the South Potato Hills thrust, which indicates the fault extends beyond the western end of the Potato Hills proper.

Mark W. Allen
MASERA Corp., Tulsa

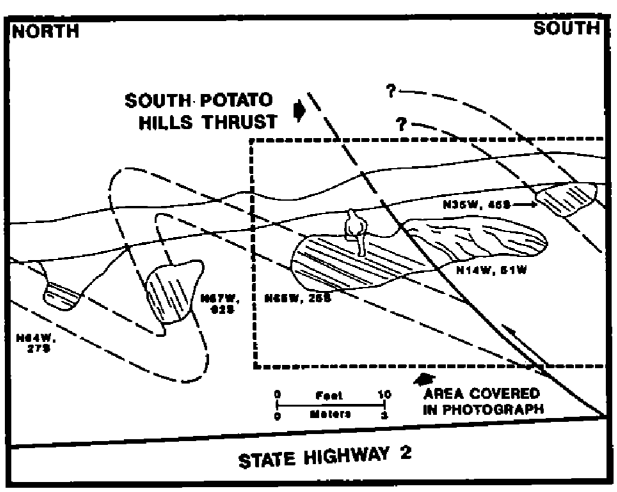

Figure 1. Interpretation of the exposure shown in the cover photograph.

OKLAHOMA GEOLOGICAL SURVEY

CHARLES J. MANKIN
Director

KENNETH S. JOHNSON
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Editor
Christie Cooper

Publications Assistant
Jo Lynn Pierce

Cartography
T. Wayne Furr, *Manager*
James H. Anderson
Charlotte Lloyd

Oklahoma Geology Notes, ISSN 0030-1736, is published bimonthly by the Oklahoma Geological Survey. It contains short technical articles, mineral-industry and petroleum news and statistics, abstracts, notices of new publications, and announcements of general pertinence to Oklahoma geology. Single copies, $1.50; yearly subscription, $6. Send subscription orders to the Survey at 100 E. Boyd, Room N-131, Norman, OK 73019. Short articles on aspects of Oklahoma geology are welcome from contributors; general guidelines will be sent on request.

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OKLAHOMA GEOLOGICAL SURVEY

VOL. 52, NO. 5

OCTOBER 1992

PETROLEUM GEOLOGY OF AN UNCONVENTIONAL UPPER HUNTON GROUP RESERVOIR, SOUTHWEST RINGWOOD AREA, MAJOR COUNTY, OKLAHOMA

***Charles E. Mear*[1] *and Keith A. Hutton*[1]**

Abstract

Geologists and engineers working as a team at Cross Timbers Oil Co., L.P., are developing an unconventional stratigraphically trapped Hunton gas pool in Major County, Oklahoma. The reservoir consists of fine- to medium-crystalline dolostone that contains silt, mica, illite, and solid hydrocarbons. Microporosity averages 12%, and permeability is <0.1 millidarcy (mD). The producing zone must be artificially fractured at low pump rates in order to avoid fracturing beyond the zone of gas entrapment.

Introduction

Many geologists do not have access to seismic data and computer-derived maps with which to recommend the drilling of oil and gas wells. As discussed by Mear (1992), some geologists continue to cause fields to be extended and significant new reserves to be developed. Most manage to do this by working with engineers and by integrating geological and engineering data. In some cases, the geological/engineering team has to overcome unreliable log analyses and avoid miscorrelations of reservoirs that result from the use of incorrect geological models. They determine the lithology of the reservoir rocks, including minor constituents, in order to avoid completion techniques that damage producibility. In other words, they manage to develop and extend oil and gas fields through hard work and rational thinking, using basic engineering and geological concepts. One such project by Cross Timbers Oil Co., L.P., is underway in the Southwest Ringwood area in Major County, Oklahoma.

Stratigraphy of the Upper Hunton Group

The Southwest Ringwood Area is located on the northern shelf of the Anadarko basin (Fig. 1). In the Ringwood area (Fig. 2), the Hunton Group consists of limestone and dolostone beds that were deposited as calcite mud and, subsequently, altered to dolostone on a shallow-marine shelf during Silurian and Devonian time. Dolomitization probably occurred soon after deposition. In Oklahoma, the Hunton Group has been divided into several formations; but no paleontological data are available in the area of interest, and no attempt was made to define the formations.

Following deposition of the Hunton, the northern shelf area was uplifted, and the Hunton and older units were exposed to erosion. Later, in Devonian time, ~50 ft of Woodford Shale was deposited on the truncated Hunton. Following deep burial in Mississippian through Permian time, the Woodford generated oil and gas that migrated into the porous upper Hunton.

[1]Cross Timbers Oil Co., L.P., Fort Worth, Texas.

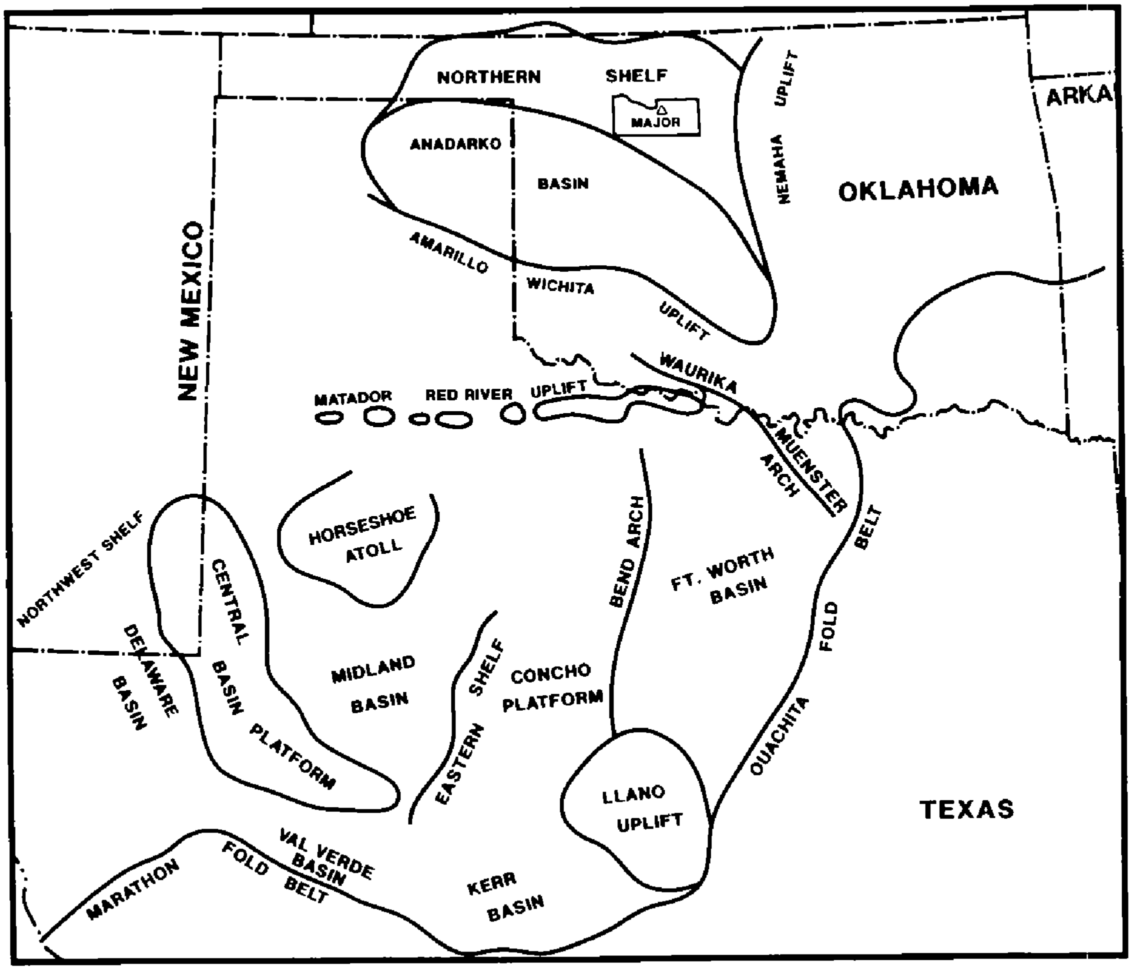


Figure 1. Regional tectonic setting of Major County, Oklahoma.

Reservoir Description

The upper Hunton reservoir attains a net maximum thickness of 66 ft in the Southwest Ringwood area. A core of the lower part of the upper Hunton was obtained from the Cross Timbers No. 4 Rankin, SW¼SW¼ sec. 17, T. 21 N., R. 11 W. As shown by this core, the lower part of the upper Hunton is light brown, bioturbated, finely crystalline dolostone. It contains as much as 20% quartz as silt grains, 5–10% clay, and varying amounts of calcite (Fig. 3). As shown by SEM analysis (Fig. 4), the clay is largely illite, although muscovite is locally present. Thin sections reveal the presence of abundant solid hydrocarbon residue in the intercrystalline porosity. Little intercrystalline porosity can be seen at <50 magnification; thus much of the reservoir is composed of microporosity. Core analysis of part of the reservoir interval in the Rankin No. 4 well shows that the lower part of the upper Hunton has a porosity of 12%, and an arithmetic mean permeability of 0.095 mD. One foot of the core has 0.36 mD, and half of the pay zone has <0.10 mD permeability.

The upper part of the upper Hunton pay zone is light brown, fine- to medium-crystalline dolostone, having ~12% porosity. It contains little or no silt. Core is not available for this part of the zone, but pressure transient analyses show that this part of the pay zone also has permeability of <0.1 mD.

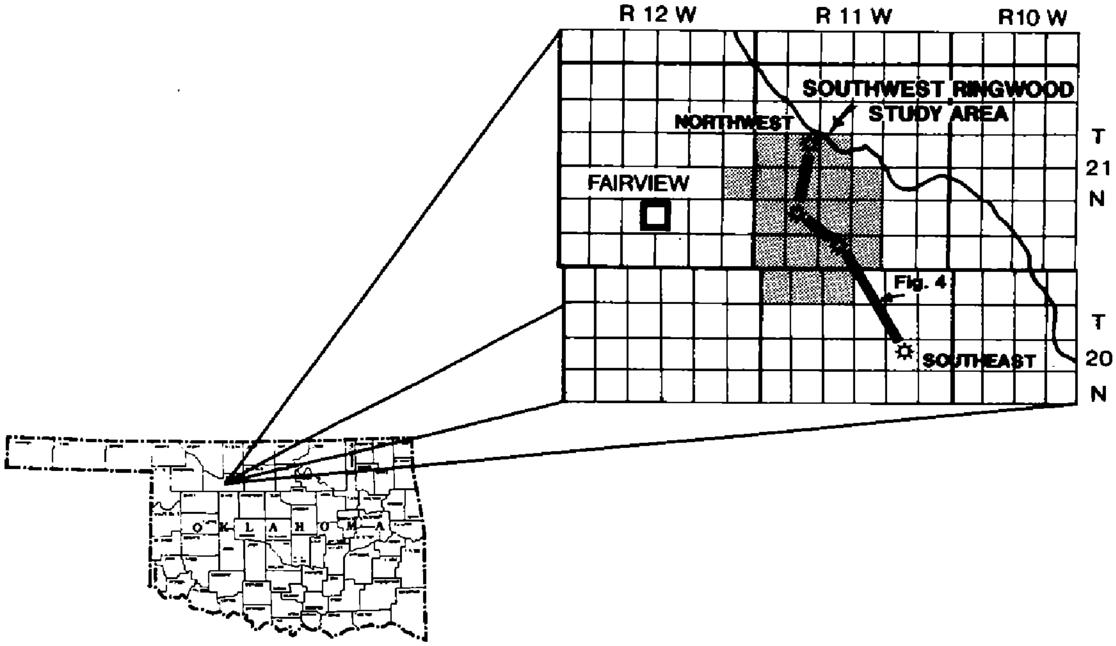


Figure 2. Southwest Ringwood study area, showing line of section northwest–southeast (Fig. 4).

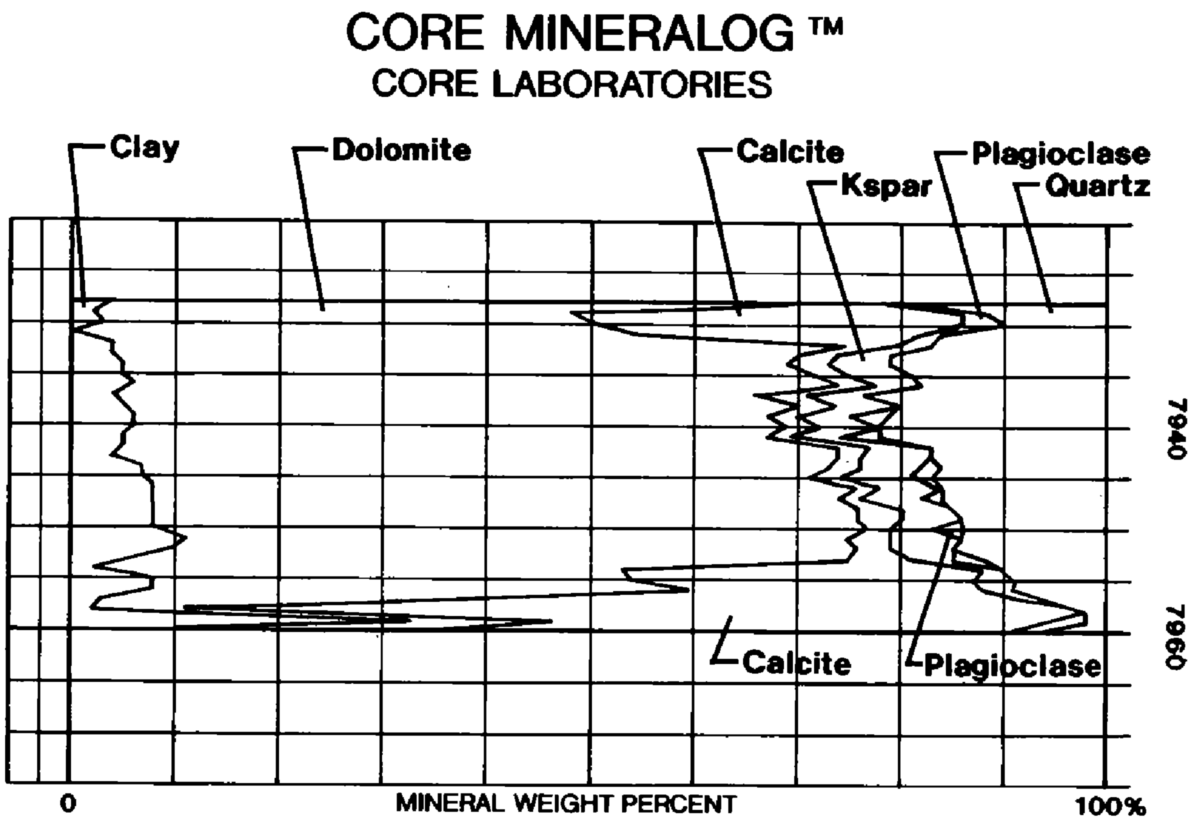


Figure 3. Core Mineralog™ (Core Laboratories) of the lower upper Hunton in the Cross Timbers No. 4 Rankin well, SW¼SW¼ sec. 17, T. 21 N., R. 11 W. Core depths are 12 ft shallower than log depths.

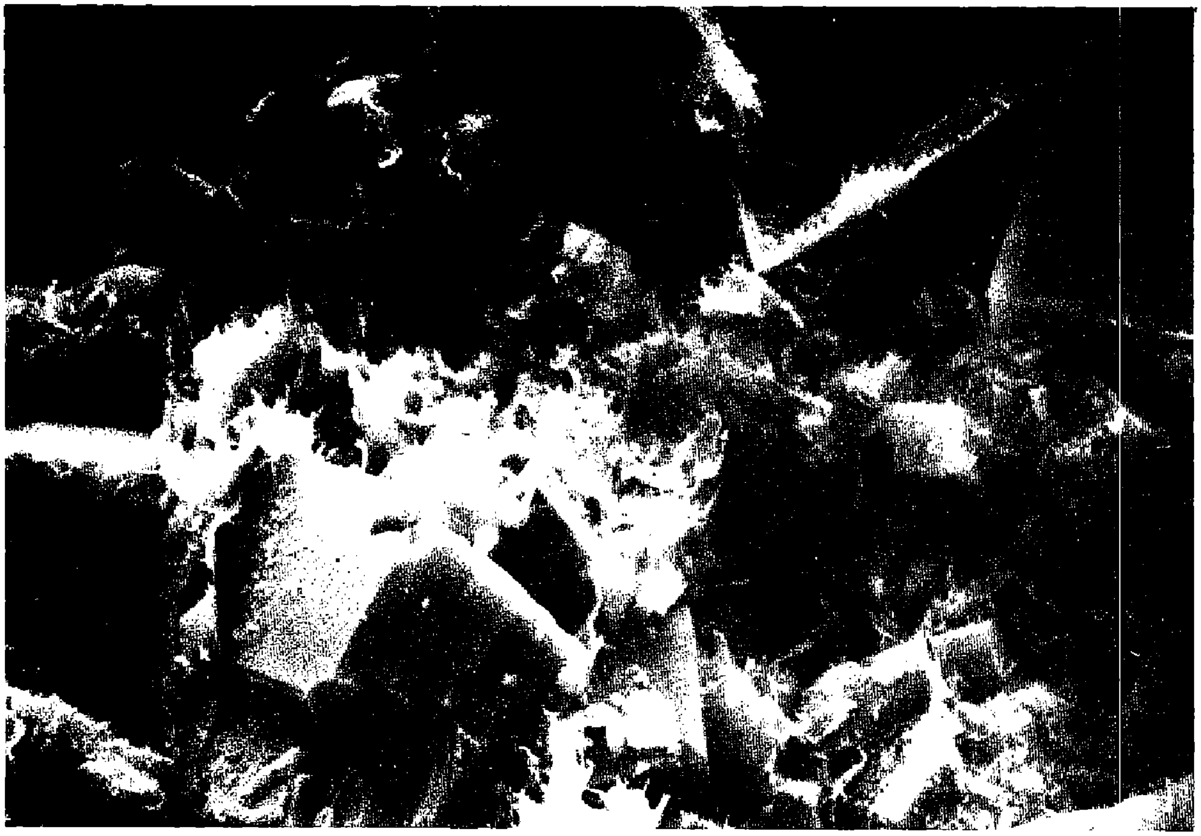


Figure 4. Scanning electron microscope image of lower upper Hunton dolostone, core depth 7,940 ft (7,952 log depth) in the Cross Timbers No. 4 Rankin, enlarged 2,000×. Euhedral dolomite rhombs with authigenic illite fibers.

Discussion

Oil and gas production in the area (Fig. 2), in order of increasing depth, is from Oswego lime (Pennsylvanian), Red Fork sand (Pennsylvanian), Mississippian age limestone and sandstone, and Hunton Group (Silurian and Devonian) carbonate units. All produce from stratigraphic traps.

Cross Timbers Oil Co., L.P., is actively developing upper Hunton gas wells in the southwest part of T. 21 N., R. 11 W. (Fig. 2), where the top of the Hunton ranges from 7,900 to 8,200 ft in depth. Regional dip at the Hunton level is 1–2° SSW (Fig. 5).

Truncated in the updip direction, the Hunton rocks range in thickness from 300 to 240 ft in the area of interest (Fig. 6). The Woodford Shale of Devonian age unconformably overlies dolostone of the Hunton Group. The Woodford is both a source of, and seal for, hydrocarbons in the Hunton.

During a regional study of the Hunton in 1987, it was determined that a gas-producing zone of porosity subcrops updip beneath the Woodford, and grades laterally to dense carbonate. The porosity zone is called the upper Hunton in this paper and covers parts of three townships.

It was noted during the study that one well, the Ferguson No. 1 Reese (Fig. 5), CSE¼ sec. 18, T. 21 N., R. 11 W., had produced ~1 BCF of dry gas from upper Hunton perforations, after being completed as a single-zone gas well in March of 1974. In this well, the Hunton was perforated from 7,955 to 7,966 ft, and the zone was acidized with 3,000 gal 15% acid. It was then artificially fractured with 17,000 gal 1% acid, 8,000 gal 28% acid, and 9,000 lbs of sand. Log analysis of the zone

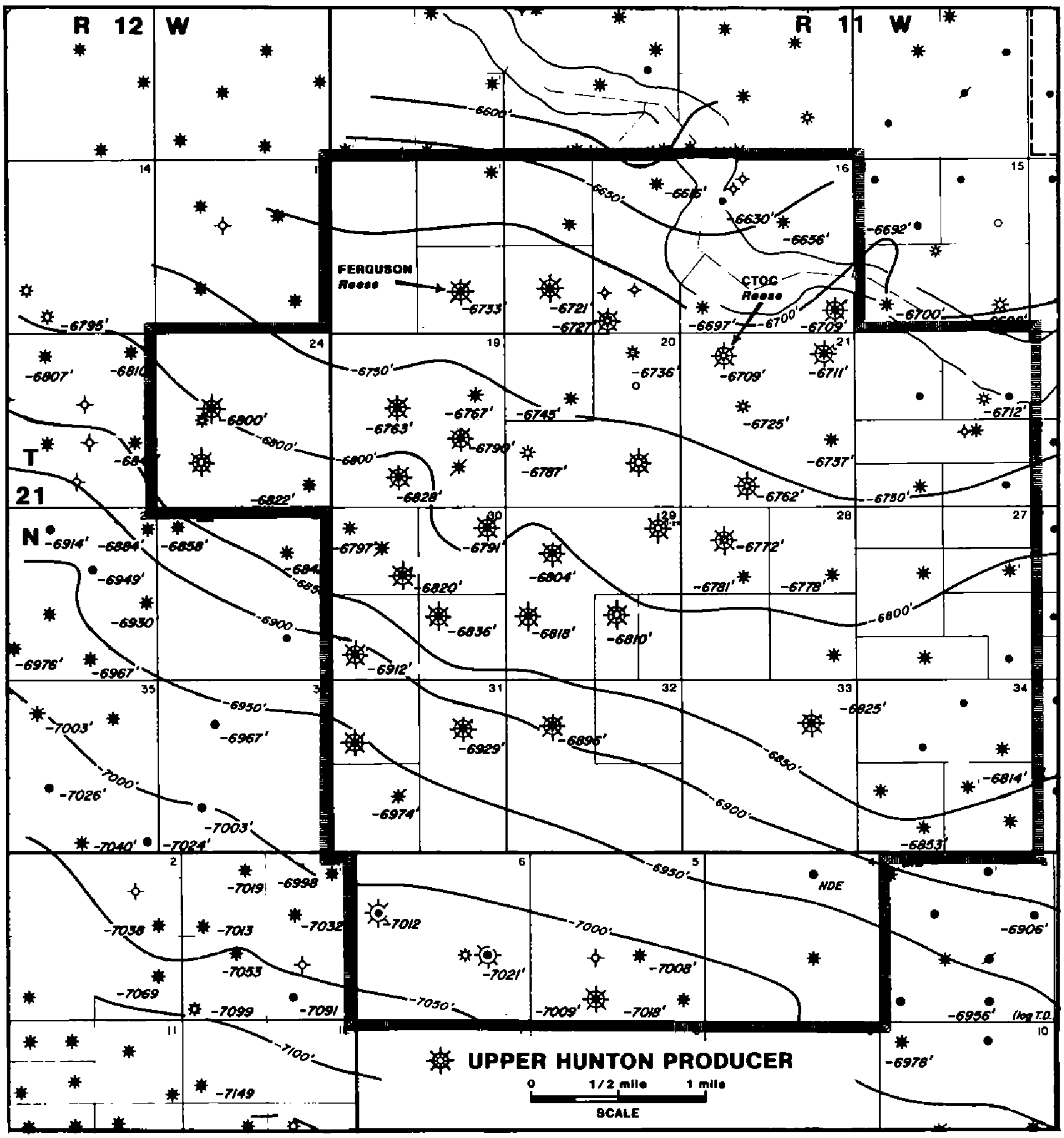


Figure 5. Subsurface structure map, Southwest Ringwood area, showing location of the Ferguson No. 1 Reese and the Cross Timbers No. 1 Ted Reese. Map datum is top of Hunton Group. See Figure 7 for log of Cross Timbers well.

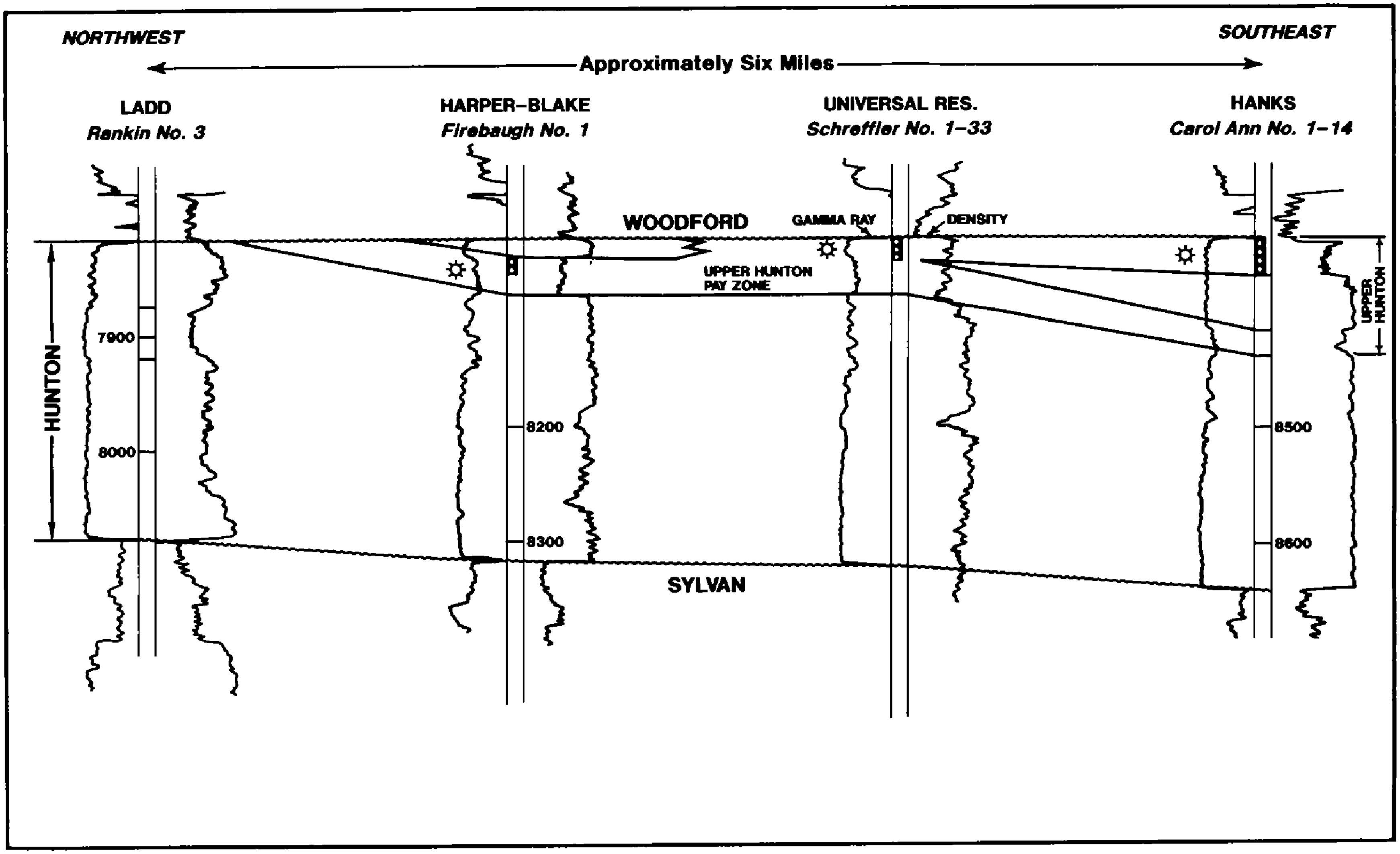


Figure 6. Northwest–southeast stratigraphic section of Hunton Group in Southwest Ringwood area. Datum is base of Woodford Shale and top of Hunton Group. Line of section shown in Figure 2.

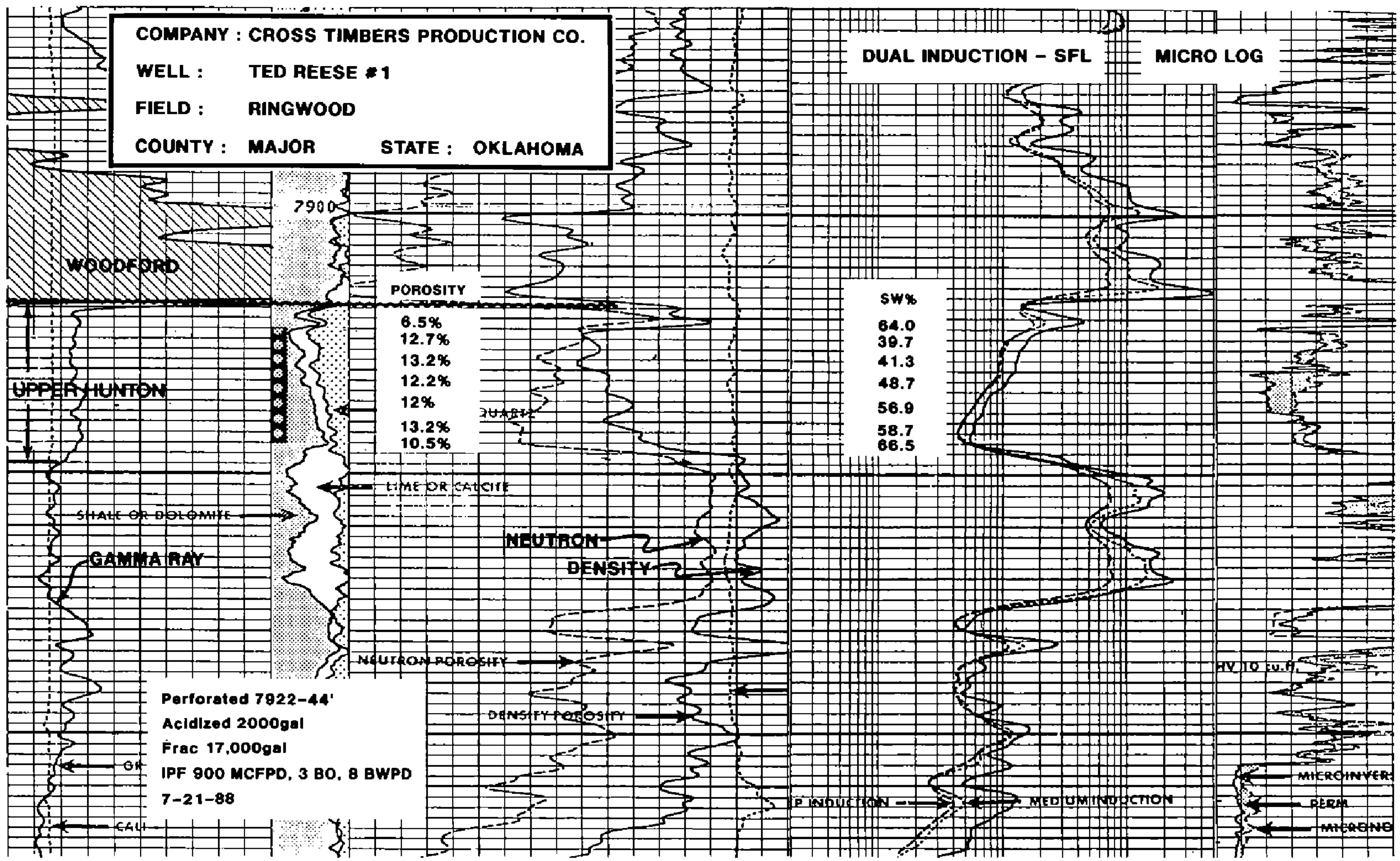


Figure 7. Wireline logs of an upper Hunton producing interval in the Cross Timbers No. 1 Ted Reese. The measurements are typical of the lower upper Hunton throughout the extent of the pay zone in the area.

indicates that it has ~12% porosity and that gas occurs above water. Producing characteristics indicate that the zone has low permeability. The indicated water zone was not perforated, but it probably was in communication with the perforated interval, due to the artificial fracture treatment. Nevertheless, the zone produced dry gas and no water.

By 1987, several wells had been drilled through the upper Hunton along strike and downdip from the Reese well. Each well has a similar log signature, showing gas on water. Most of the wells that had been completed from the upper Hunton were perforated in the uppermost part of the zone above the apparent water level. The zone had been either acidized or lightly fractured, and production was commingled with that from the overlying Mississippian limestone. In most wells the Mississippian pay was artificially fractured with large quantities of fresh water, and produced oil, gas, and water. Logs run to show the vertical extent of induced fractures on wells in the area show very little stress contrast between the Hunton and the overlying Woodford Shale and Mississippian limestones. This indicates that a high-rate stimulation would extend the fracture into adjacent intervals. This can be seen in wells throughout the area, many of which had good gas rate tests from the Hunton prior to stimulation of the Mississippian limestone. The Hunton produced at very low rates after commingling with the Mississippian pay zone, and, based on the low gas production, the zone did not appear to be economically attractive.

The lower part of the upper Hunton has low resistivity in all the wells that have been drilled in the area of interest, and log calculations indicate that the zone should be water productive. This indicates that the water table dips several hundred feet across the area. This part of the pay zone has decreased density porosity and increased neutron porosity (Fig. 7). As a result of these data, the geologist and engineer team concluded that the apparent water table was the result of a change in rock composition, and that the zone probably would not produce water.

Based on recommendations from the team, Cross Timber's management agreed to drill and test the entire zone, which resulted in a commercial dry gas well (Fig. 7). Additional gas wells have been drilled, and several wells have been recompleted from the upper Hunton. These wells are anticipated to have reserves that are similar to the original well in the area, the Ferguson Reese, and there are plans for additional drilling.

Conclusions

A large accumulation of gas occurs in a stratigraphic trap within upper Hunton dolostone in the Southwest Ringwood area of Major County, Oklahoma. The reservoir is unconventional, having an average permeability of <0.1 mD. A false water table is indicated for the zone by log analysis, which detects the irreducible water present in micropores and in the illite. The zone must be artificially fractured in order to produce at commercial rates. The fracture fluid should include as little water as possible, in order to avoid reservoir permeability degradation due to imbibition into the micropores and movement of the illite with the aqueous solution. Care must be taken to avoid fracturing into water-bearing zones.

Key to the exploitation of this gas reserve was teamwork by the engineer and geologist, who used their slow mammalian brains to evaluate basic subsurface geological and engineering data.

Additional hydrocarbon reserves contained in stratigraphic traps will be developed by operators who realize that some hydrocarbons cannot be found by seismic data and computers, but only by the integration and careful analysis of basic subsurface geological and engineering data.

Acknowledgments

The writer is grateful to Steffen E. Palko of Cross Timbers Oil Co., L.P., for permission to publish this paper. Jerry Parks drafted the illustrations, and Sonya Ramerth typed the manuscript.

Core Laboratories of Western Atlas International produced the thin section, SEM image, and Core Mineralog™ data. Mr. Drew Dickert, petrologist with Western Atlas, provided the thin section and SEM analysis of the Hunton Core.

Reference Cited

Mear, C. E., 1992, Developing and extending oil and gas fields without use of computers, remote sensing, seismic and non-conventional methods: Transactions Southwest Section, American Association of Petroleum Geologists, West Texas Geological Society Pub. SWS 92-90, p. 261–266.

STRUCTURAL ANALYSIS OF THE WESTERN POTATO HILLS, OUACHITA MOUNTAINS, OKLAHOMA

Mark W. Allen[1]

Abstract

Structural relationships in the western Potato Hills indicate the South Potato Hills thrust extends westward and does not curve to the north. This supports evidence that the Potato Hills are not a window. A newly identified fault, herein named the Buffalo Creek thrust, is a diverging splay from the Jackfork Mountain thrust. West of the Potato Hills, the strike of the Buffalo Creek thrust changes as it approaches a transverse structure, interpreted as the northern extension of the Clayton horst.

Geologic Setting and Location

The Potato Hills, located in southern Latimer and northern Pushmataha Counties, Ouachita Mountains, southeastern Oklahoma (Fig. 1), are a structurally complex area comprised of lower and middle Paleozoic strata. Rocks exposed in the study area, which encompasses the western end of the Potato Hills, range from upper Ordovician Bigfork Chert to the Mississippian Stanley Group (Fig. 2). Situated in an anticlinal valley ~3 mi south of the Windingstair fault, the Potato Hills form a series of low, isolated hills rising between 200 and 500 ft above the surrounding valley.

Structural Geology

The western Potato Hills (Fig. 3) is one of two important areas for interpreting the structural geology of the Potato Hills; the other is the northeastern area. I mapped the northeastern Potato Hills (Allen, 1991a) and indicated that a window, first proposed by Miser (1929), was nonexistent based on the intersection of the North Potato Hills thrust by the South Potato Hills thrust. This new mapping created a need to re-evaluate the structural geology in the western Potato Hills.

The study area contains two major traceable faults: the South Potato Hills thrust and the Cedar Creek thrust. A previously unidentified fault, the Buffalo Creek thrust, was inferred in the western Potato Hills and identified in the north-central Potato Hills. I have interpreted the Buffalo Creek thrust, which loses displacement to the west and southwest, as a diverging splay from Jackfork Mountain thrust (Fig. 1). My interpretation of a proprietary seismic line through the north-central Potato Hills indicated two faults, the Jackfork Mountain and Buffalo Creek thrusts, between the Windingstair fault and the North Potato Hills thrust. The name "Buffalo Creek thrust" is chosen because of the approximate location of the thrust to the location of Buffalo Creek, now covered by the Sardis Reservoir. Hendricks and others (1947) mapped a fault that strikes NE on the western side of the Potato Hills (Fig. 3). The trace of this fault is now covered by Sardis Reservoir also; therefore, its existence

[1]MASERA Corp., Tulsa, Oklahoma.

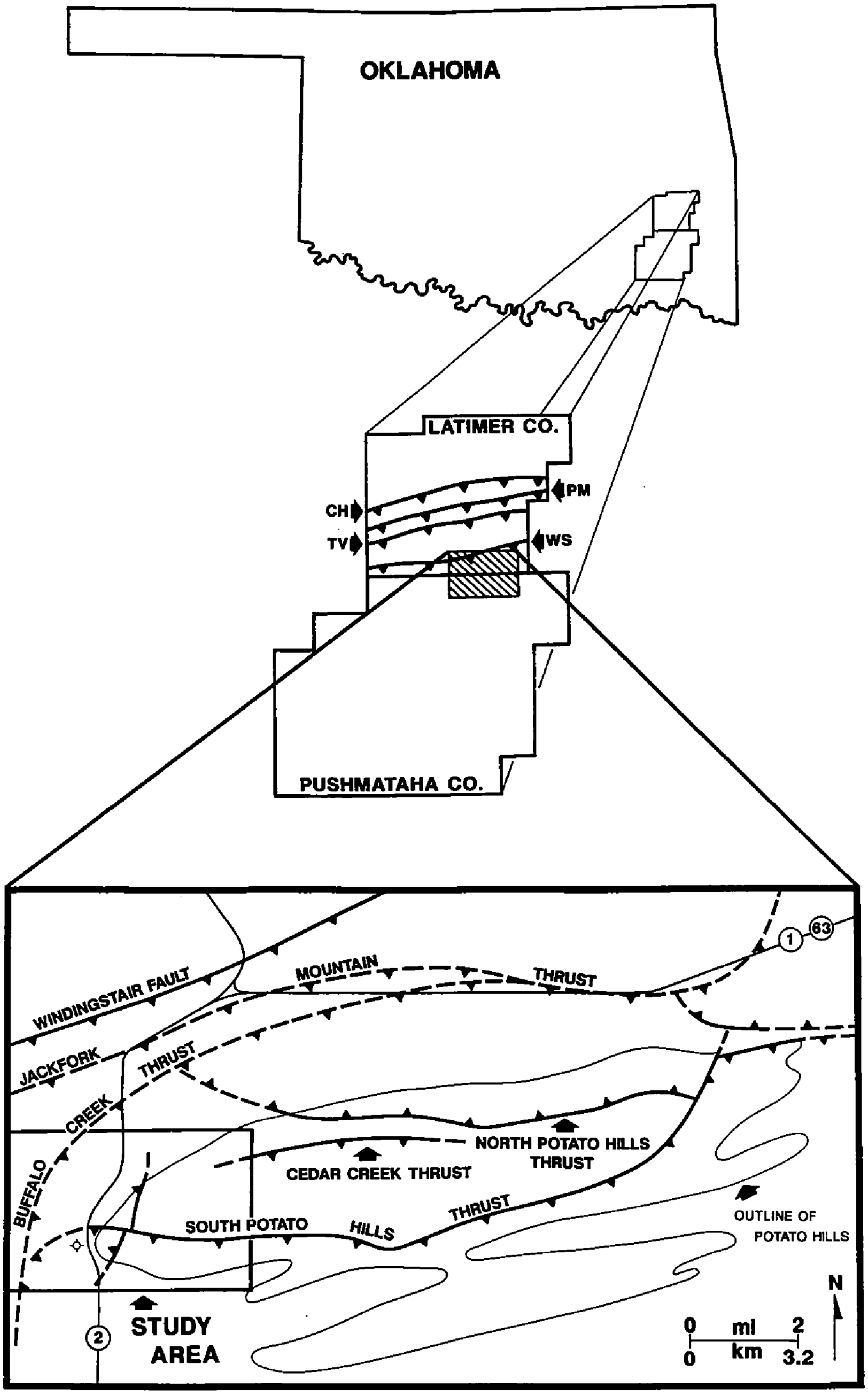


Figure 1. Location map of the study area in the western Potato Hills. CH = Choctaw fault, PM = Pine Mountain fault, TV = Ti Valley fault, WS = Windingstair fault.

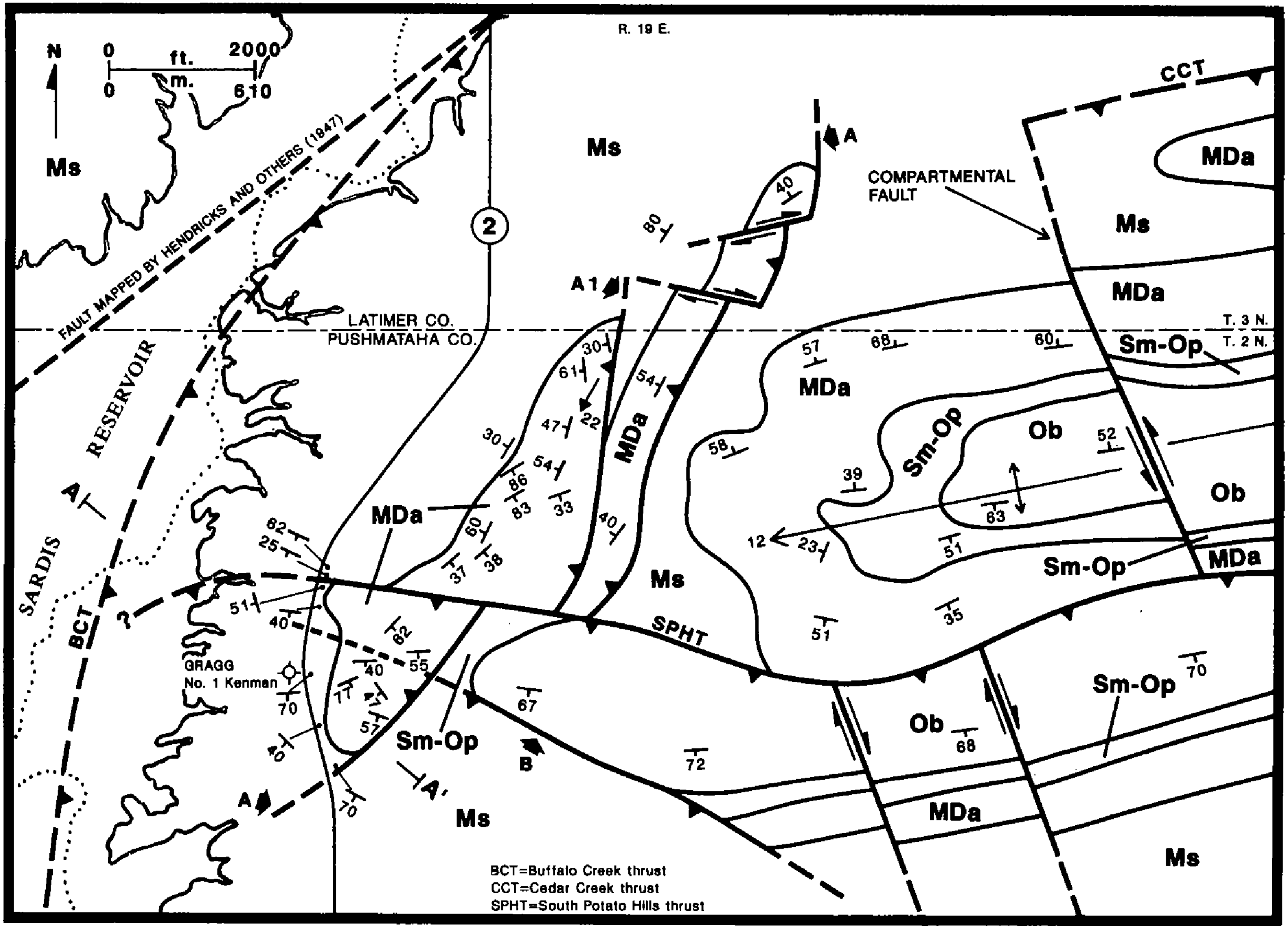
	SERIES	FORMATION
MISSISSIPPIAN	Chesterian	STANLEY GROUP
	Meramecian	
	Osagean	ARKANSAS NOVACULITE
	Kinderhookian	
DEVONIAN	Upper	
	Lower	
SILURIAN	Upper	MISSOURI MOUNTAIN SHALE
	Lower	
ORDOVICIAN	Upper	POLK CREEK SHALE
		BIGFORK CHERT
	Middle	
		WOMBLE SHALE[1]

Figure 2. Stratigraphy in the western Potato Hills. 1 = subsurface only. Modified from Suneson and others (1990).

can be neither verified nor denied. Three minor thrusts (A, A1, B) are also present (Fig. 3).

Two interpretations previously proposed for the western Potato Hills are (1) the South Potato Hills thrust curves to the north supporting the window hypothesis (Miser, 1929; Miller, 1955; Arbenz, 1968); and (2) the South Potato Hills thrust extends westward (Pitt, 1974, fig. 6 by Bennison and Johnson). These interpretations did not incorporate the Gragg Drilling Co. No. 1 Kenman well (NE¼NE¼ sec. 8, T. 2 N., R. 19 E.), drilled in 1961 (Fig. 3).

The Gragg No. 1 Kenman reached total depth at 3,898 ft and is important for defining the subsurface geology in the study area. Log analysis identified four repeated intervals suggesting the following subsurface relationships illustrated in Figure 4: (1) a normal sequence of Stanley through Polk Creek–Missouri Mountain shale above fault A at 830 ft; (2) repeated Arkansas Novaculite and Missouri Mountain Shale above fault B at 1,345 ft; (3) repeated Stanley through Polk Creek Shale above the South Potato Hills thrust at 2,285 ft; and (4) Arkansas Novaculite through Bigfork Chert apparently above the Buffalo Creek thrust (not penetrated). The Bigfork inter-


N
0 ft. 2000
0 m. 610
Ms
FAULT MAPPED BY HENDRICKS AND OTHERS (1947)
SARDIS RESERVOIR
BCT
A
R. 19 E.
2
LATIMER CO.
PUSHMATAHA CO.
T. 3 N.
T. 2 N.
CCT
COMPARTMENTAL FAULT
MDa
Sm-Op
Ob
SPHT
A1
A'
B
GRAGG No. 1 Kenman
BCT=Buffalo Creek thrust
CCT=Cedar Creek thrust
SPHT=South Potato Hills thrust

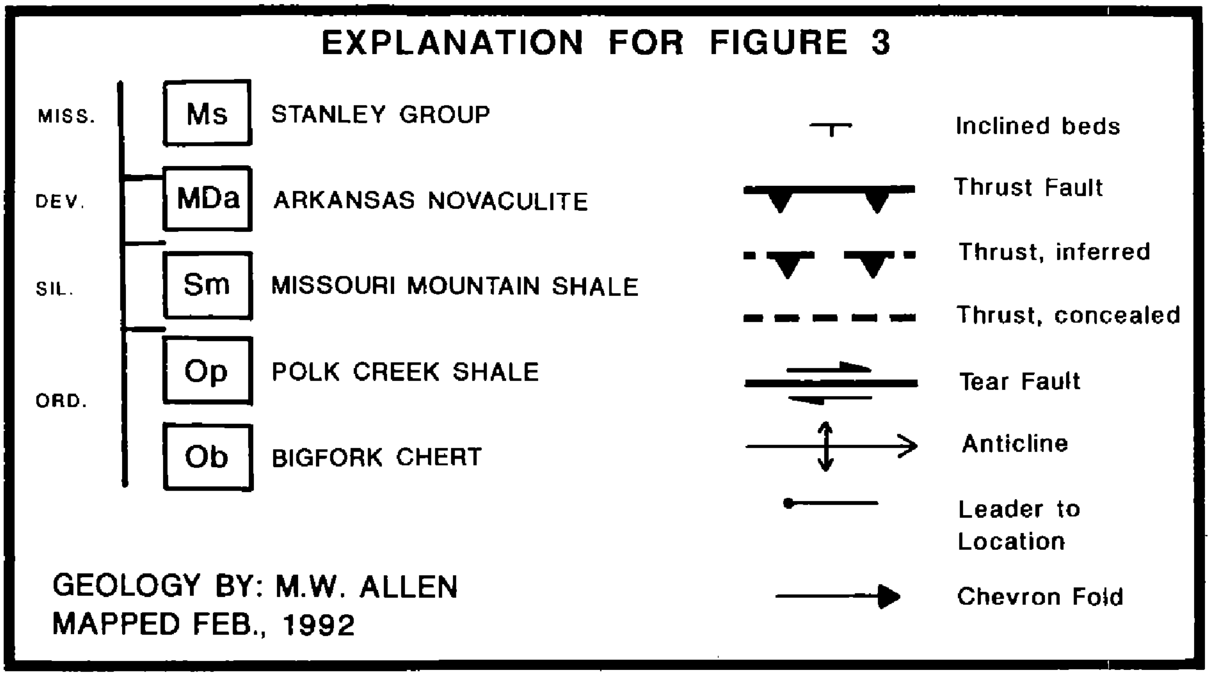


Figure 3 (opposite page and above). Geologic map of the study area. Refer to box in Figure 1 for location and to Figure 4 for cross section. Dotted line in Sardis Reservoir is approximate position of Buffalo Creek, now covered by the reservoir.

val is faulted at 3,110 ft, which I have interpreted as the subsurface extension of fault A (Fig. 4). This interpretation indicates the South Potato Hills thrust extends westward beyond the Potato Hills and does not curve to the north and helps support the existence of the Buffalo Creek thrust. To the best of my knowledge, this is the first published use of the name "Buffalo Creek thrust" for a fault at the location presented in this study.

In the study area, the South Potato Hills thrust strikes EW, juxtaposing Bigfork Chert against Arkansas Novaculite for most of its trace, and loses displacement to the west. The thrust intersects faults A and A1 and extends westward beyond the Potato Hills (Allen, 1992b [cover photo, this issue]). Also, the South Potato Hills thrust possibly intersects the Buffalo Creek thrust (Fig. 3). Therefore, movement on the South Potato Hills thrust postdated movement on the Buffalo Creek thrust and the two minor faults.

Fault A, originally identified by Pitt (1974), is a minor back thrust as determined by displacement oblique to the regional transport direction and is analogous to, but not structurally associated with, the North Potato Hills thrust. I interpreted the North Potato Hills thrust as a modified pop-up back thrust (Allen, 1991a) that developed by layer-parallel shortening prior to frontal ramp formation (Butler, 1982). The North Potato Hills thrust displays south-directed movement that was approximately parallel to, but opposite of the regional north-directed compressional direction.

Fault A strikes from N. 30° E. to north and displays east- to southeast-directed transport. East–southeast compression is indicated by several ESE-verging folds in the hanging wall of fault A1. The orientation of fault A is dictated by a major thrust from which it originated. The major thrust is west and northwest of fault A with approximately subparallel strike and opposite dip.

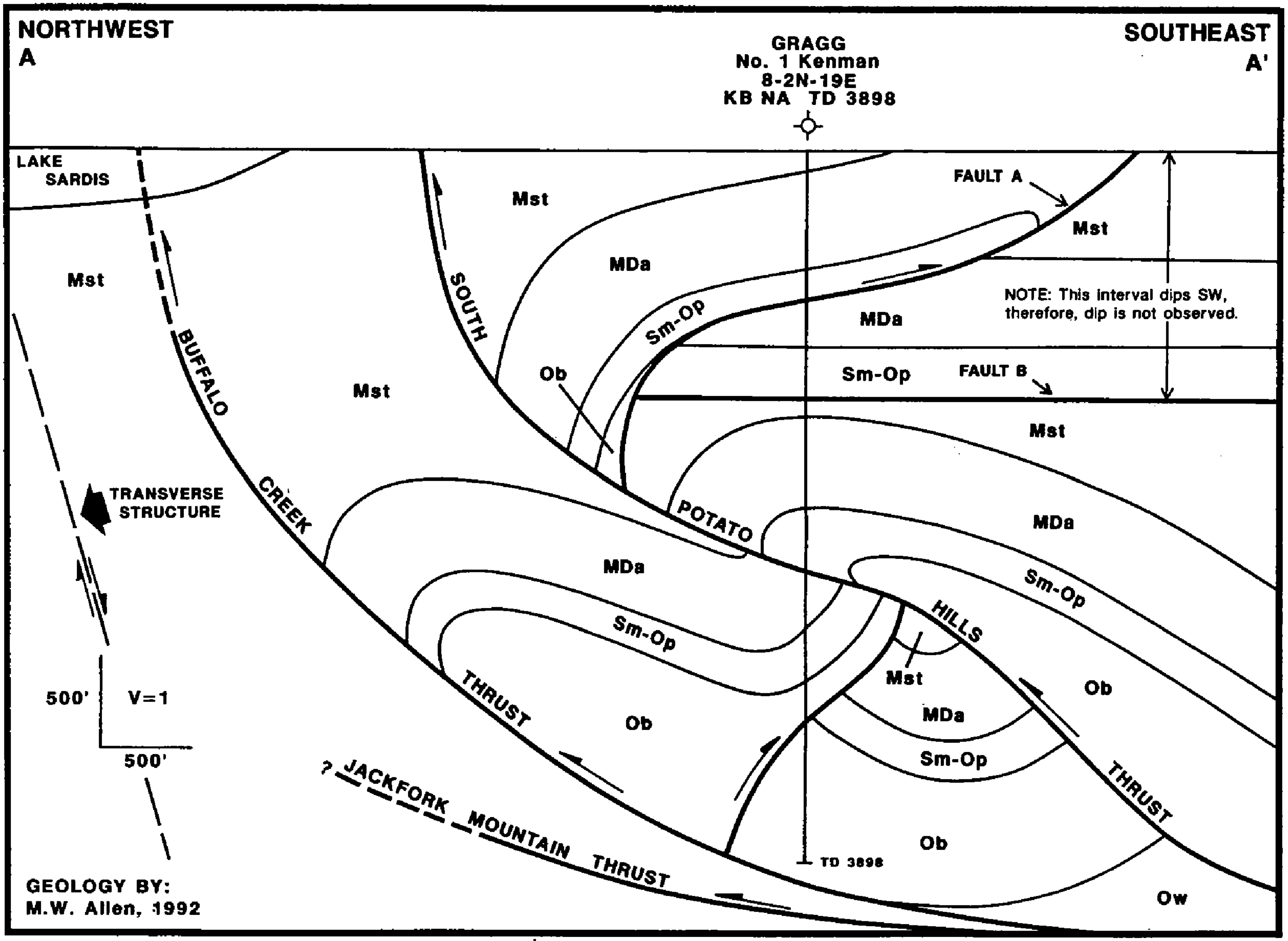


Figure 4. Structural cross section through the Gragg Drilling Co. No. 1 Kenman. Location of A–A′ is shown in Figure 3.

Since displacement on fault A was at an oblique angle to the regional transport direction, it is not a pop-up back thrust. An alternate method of back thrust development is an association with frontal ramp climb (Butler, 1982). I have interpreted fault A as an antithetic back thrust (Fig. 5) because fault A steepens with depth (Fig. 4), and the hanging wall probably rotated above a frontal footwall ramp. The antithetic back thrust model requires a pre-existing ramp. The presence of the Buffalo Creek thrust satisfies this requirement, further supporting its existence.

Strata above fault A on the north side of the South Potato Hills thrust strike NNE and dip NW (Figs. 3,4). However, on the south side of the South Potato Hills thrust, beds strike from NE to NW and dip S. These beds have been reoriented by the South Potato Hills thrust intersection of fault A and possibly from having been thrust upward by fault B.

Fault A1 is a diverging splay from fault A. The branch line has been uplifted and eroded on the south side of the South Potato Hills thrust as indicated by the presence of only fault A. The intersection of faults A and A1 by the South Potato Hills thrust indicates the South Potato Hills thrust extends to the west and does not curve to the northeast as suggested by Miser (1929), Miller (1955), and Arbenz (1968).

Fault B juxtaposes Stanley over older strata (Fig. 3). Thrusts bring older rocks over younger rocks, and they climb up stratigraphic section unless they develop in previously folded strata (McClay, 1987). Therefore, fault B probably originated as a bedding plane thrust in the Polk Creek–Missouri Mountain shale (Fig. 4) during or after folding of strata in the South Potato Hills thrust hanging wall.

Stereographic analysis of bedding in the major west-plunging anticline in the central part of the study area indicates a trend and plunge of 260°/12° (Fig. 3). Fault A, based on its map pattern, was folded by the anticlinal development (Fig. 3). The anticline plunges under fault A and the stratigraphic interval involved in folding corresponds to that above the Buffalo Creek thrust (Fig. 4).

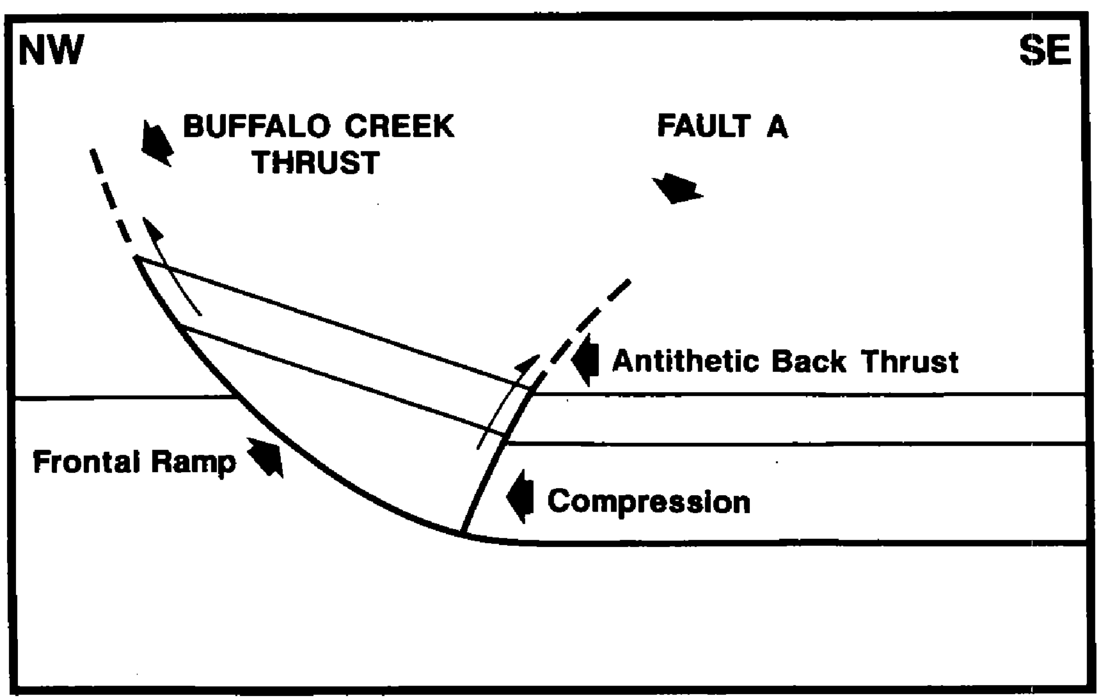


Figure 5. Antithetic back thrust. Modified from Butler (1982).

The origin of this anticline was probably in response to a combination of displacement on the Buffalo Creek thrust, blind thrusting and/or thrust stacking in conjunction with the Cedar Creek thrust, and compression by the South Potato Hills thrust. This is based on the following: (1) the anticline is in the Buffalo Creek thrust hanging wall (Fig. 4); (2) a regional cross section (Allen, 1992a), located ~3 mi to the east, indicates ramping of the Cedar Creek thrust and blind thrusting in the vicinity of this anticline; (3) the anticline is intersected by a tear fault associated with the Cedar Creek thrust (Fig. 3); and (4) the South Potato Hills thrust overrides the south limb of the anticline (Fig. 3).

Discussion

Tectonic Analysis

Tectonic evolution of the Potato Hills was initiated by early, overall layer-parallel shortening directed approximately N. 9° W. (Allen, 1991b). In the western Potato Hills, three separate, generalized events can be recognized in an overall progressive deformation. The first event was the development of the Buffalo Creek thrust and faults A and A1. Concomitant volumetric crowding and hanging wall rotation above the frontal footwall ramp initiated development of back thrusting parallel to the Buffalo Creek thrust. Second, faults A and A1 were uplifted and folded by the major west-plunging anticline. This was followed by the intersection of faults A and A1 by the South Potato Hills thrust.

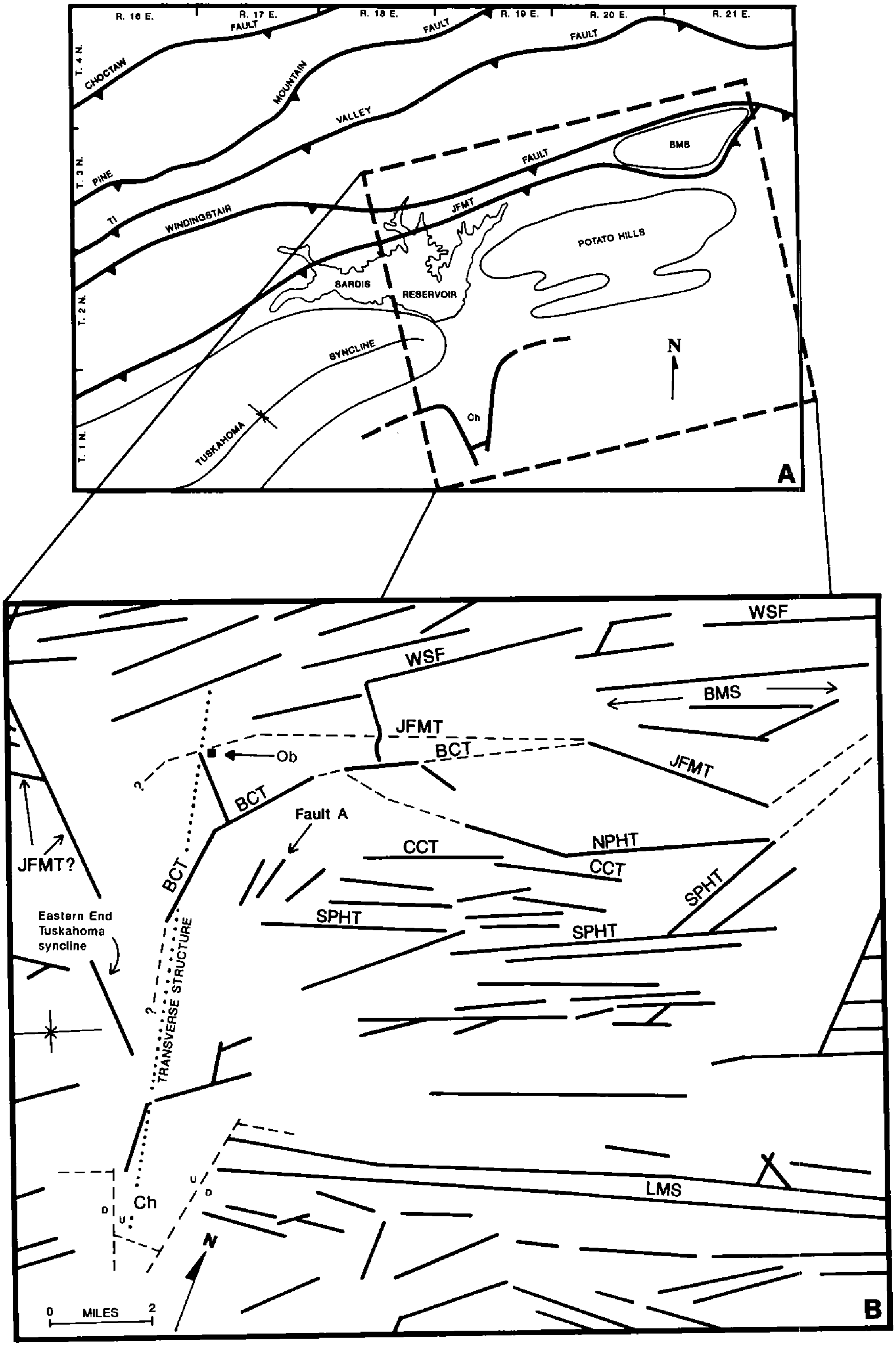
Regional Analysis

Approximately 5 mi southwest of the Potato Hills is the Clayton horst (T. 1 N., R. 19 E.) (Fig. 6A). This structure is significant because it displays >7,000 ft of uplift along near vertical fault planes (Pitt and others, 1982). Cline (1960) mapped the area of the horst and showed that the faults juxtaposed the Atoka Formation and the Stanley Group.

Based on Cline's (1960) map, the two major faults of the horst strike N. 20° W. and N. 10° E. The average of the two faults approximately corresponds to the axis of the horst. The axis of the Clayton horst projected northward crosses the area west of the Potato Hills (Fig. 6) and suggests the presence of a transverse structure. Although transverse structures are *apparently* not common in the Ouachita Mountains, another has been identified in the frontal belt by Suneson (1990). The lineament map (Fig. 6B) indicates a branching of lineaments from the projected line of the Clayton horst. If the lineaments are fault traces, then the branching represents change in strike of these faults as they encountered the transverse structure.

Several indications of the transverse structure are reflected in the surface geology. These include: (1) the branching of lineaments from the northward projection of the

Figure 6 (opposite page). Regional map (A) and lineament map (B) of the Potato Hills region. Dashed lines are modifications added for this study. WSF = Windingstair fault, BMS = Buffalo Mountain syncline, JFMT = Jackfork Mountain thrust, NPHT = North Potato Hills thrust, CCT = Cedar Creek thrust, BCT = Buffalo Creek thrust, Ch = Clayton horst, LMS = Lynn Mountain syncline, Ob = isolated outcrop of Bigfork Chert. Modified from Walsh and Vitek (1981).


R. 16 E.
R. 17 E.
R. 18 E.
R. 19 E.
R. 20 E.
R. 21 E.
T. 4 N.
T. 3 N.
T. 2 N.
T. 1 N.
CHOCTAW
FAULT
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Clayton horst; (2) the change in strike of the Buffalo Creek thrust; (3) a change in the trend of the axis of the Tuskahoma syncline from NE to ENE as the syncline approaches the transverse structure from the west (Fig. 6A); and (4) an isolated outcrop of Bigfork Chert (S½NE¼ sec. 30, T. 3 N., R. 19 E.). The outcrop, originally identified as Arkansas Novaculite (Hendricks and others, 1947), is located in the Jackfork Mountain thrust sheet (Fig. 6B) and is adjacent to the projected line of the Clayton horst; this exposure of older strata suggests that the thrust was forced upward as it encountered the structure.

The exact nature of the proposed transverse structure is unknown; however, surface geology may be reflecting an approximately NNW striking compartmental fault associated with the Windingstair fault. Compartmental faults (a type of tear fault) serve as partitions between domains of rocks in which a common magnitude of shortening has been achieved in different ways (Davis, 1984).

The juxtaposition of the Tuskahoma syncline against the anticlinal valley containing the Potato Hills, plus the termination of these major structures at, and the lack of any structural correlation across the proposed transverse structure are possible indications of compartmental faulting. Brown (1988) indicated structures terminate against, and abrupt changes of asymmetry occur, across compartmental faults. The total area will be deformed together, but the compartmentalization will allow a different structural profile to develop simultaneously and independently so that the overall structural balance is maintained.

Conclusions

Structural analysis of the western Potato Hills has indicated the South Potato Hills thrust extends westward beyond the Potato Hills. Fault A, previously interpreted to represent the curving of the South Potato Hills thrust to the north (Miser, 1929; Miller, 1955; Arbenz, 1968), is a minor back thrust that was intersected and offset by the South Potato Hills thrust. Faults A and A1 were folded by the west-plunging anticline and then intersected by the South Potato Hills thrust; this indicates out-of-sequence faulting in the study area.

The Buffalo Creek thrust is identified in the study area based on surface and subsurface relationships. The existence of this new thrust was confirmed by seismic interpretation in the northern Potato Hills. The orientation of the Buffalo Creek thrust in the western Potato Hills resulted as the thrust encountered a transverse structure.

The exact nature of the transverse structure is not known. A possible explanation for the transverse structure is a compartmental fault juxtaposing two structurally different domains: the anticlinal valley containing the Potato Hills to the east against the Tuskahoma syncline to the west. I favor this interpretation because surface geology displays characteristics of compartmental faulting as seen by the juxtaposition and termination of the major folds at, and the abrupt change in asymmetry across, the transverse structure.

Acknowledgments

I thank K. R. Neuhauser, R. J. Erickson, J. A. Campbell, J. J. Simms, and J. A. Ontko for their constructive criticisms and helpful suggestions that improved and clarified the subject of this paper. I also thank Montgomery Oil and Gas for allowing me access to their proprietary seismic line, Vickie Hulstine for typing the manuscript, and David E. Allen for his assistance in the field.

References Cited

Allen, M. W., 1991a, Structural analysis of the northeastern Potato Hills, Ouachita Mountains, Oklahoma: Oklahoma Geology Notes, v. 51, p. 188–197.

____1991b, Relationship between parasitic folds and tectonic evolution, Potato Hills, Ouachita Mountains, Oklahoma: Shale Shaker, v. 42, p. 66–68.

____1992a, Structural geology, tectonic evolution, and hydrocarbon potential of the Potato Hills, Ouachita Mountains, Oklahoma [abstract], *in* Structural Styles in the Southern Midcontinent Symposium: Oklahoma Geological Survey, Norman, p. 22.

____1992b, South Potato Hills thrust, western Potato Hills: Oklahoma Geology Notes, v. 52, p. 161–162.

Arbenz, J. K., 1968, Structural geology of the Potato Hills, Ouachita Mountains, Oklahoma, *in* Cline, L. M. (ed.), A guidebook to the geology of the western Arkoma basin and Ouachita Mountains: Oklahoma City Geological Society Guidebook, AAPG–SEPM Annual Meeting Field Trip, p. 109–121.

Brown, W. G., 1988, Basement involved tectonic foreland areas: American Association of Petroleum Geologists Continuing Education Course Note Series 26, 92 p.

Butler, R. W. H., 1982, The terminology of structures in thrust belts: Journal of Structural Geology, v. 4., p. 239–245.

Cline, L. M., 1960, Stratigraphy of the Late Paleozoic rocks of the Ouachita Mountains, Oklahoma: Oklahoma Geological Survey Bulletin 85, 113 p.

Davis, G. H., 1984, Structural geology of rocks and regions: John Wiley and Sons, New York, 492 p.

Hendricks, T. A.; Gardner, L. S.; Knechtel, M. M.; and Averitt, P., 1947, Geology of the western part of the Ouachita Mountains in Oklahoma: U.S. Geological Survey Oil and Gas Investigation Series, Preliminary Map 66, scale 1:42,240.

McClay, K. R., 1987, The mapping of geologic structures: Halsted Press, New York, 161 p.

Miller, B. W., 1955, Geology of the western Potato Hills, Pushmataha and Latimer Counties, Oklahoma: University of Oklahoma unpublished M.S. thesis, 55 p.

Miser, H. D., 1929, Structure of the Ouachita Mountains of Oklahoma and Arkansas: Oklahoma Geological Survey Bulletin 50, 30 p.

Pitt, W. D., 1974, Structure of the western end of the Potato Hills, Latimer and Pushmataha Counties, Oklahoma: Oklahoma Geology Notes, v. 34, p. 135–147.

Pitt, W. D.; Fay, R. O.; Wilson, L. R.; and Curiale, J. A., 1982, Geology of Pushmataha County, Oklahoma: Eastern New Mexico University Studies in Natural Science Special Publication 2, 101 p.

Suneson, N. H., 1990, Stop 4—Transverse structures in the frontal belt, *in* Suneson, N. H.; Campbell, J. A.; and Tilford, M. J. (eds.), Geology and resources of the frontal belt of the western Ouachita Mountains, Oklahoma: Oklahoma Geological Survey Special Publication 90-1, p. 32–34.

Suneson, N. H.; Campbell, J. A.; and Tilford, M. J., 1990, Geology and resources of the frontal belt of the western Ouachita Mountains, Oklahoma: Oklahoma Geological Survey Special Publication 90-1, 196 p.

Walsh, S. J.; and Vitek, J. D., 1981, Lineaments in southeastern Oklahoma: detection with LANDSAT data: Oklahoma Geology Notes, v. 41, p. 104–114.

INDUSTRIAL-MINERALS DEVELOPMENT WORKSHOP Norman, Oklahoma, December 1–2, 1992

A major workshop on "Industrial-Minerals Development in Oklahoma" will be held December 1–2, 1992, at the University of Oklahoma, Norman. The workshop is co-sponsored by the Oklahoma Geological Survey, the Oklahoma Department of Mines, and the U.S. Bureau of Mines.

The workshop will present information and discussions to help improve development and use of Oklahoma's industrial-mineral resources. These resources include limestone, granite, gypsum, sand and gravel, clays, cement, silica sand, iodine, etc.; they do not include metals, coal, or oil and gas. The workshop will deal with examples, problems, rules, regulations, and environmental issues drawn from Oklahoma, but most of the issues are applicable to surrounding states as well.

At least 150–200 people are expected to attend the workshop. Proceedings of the workshop will be published and distributed to attendees about six months after the meeting.

Below is a tentative program for the workshop presentations:

- **Overview of Industrial-Mineral Resources of Oklahoma,** by Kenneth S. Johnson, Associate Director, Oklahoma Geological Survey, Norman, OK
- **Exploration and Evaluation of Industrial-Minerals Deposits,** by Charles J. Mankin, Director, and Kenneth S. Johnson, Associate Director, Oklahoma Geological Survey, Norman, OK
- **Ownership and Leasing of Industrial Minerals,** by Robert H. Anderson, Attorney, Oklahoma City, OK
- **Preparation and Issuing of Mining Permits for Industrial-Minerals Operations in Oklahoma,** by Doug Schooley, Administrator, Non-Coal Division, Oklahoma Department of Mines, Oklahoma City, OK
- **Quality Control in Industrial-Minerals Operations,** by Andy Lain, Assistant General Superintendent, Dolese Bros. Co., Oklahoma City, OK
- **Transportation of Industrial Minerals,** by Mike Hagen, President, Midwest Motor Carriers Bureau, Inc., Oklahoma City, OK
- **Marketing of Industrial Minerals,** by Neil J. Dikeman, Former Director, Center for Economic and Management Research, University of Oklahoma, Norman, OK
- **National Markets for Oklahoma Industrial Minerals,** by Dan R. Gorin, Chief Economist, Research and Planning Division, Oklahoma Department of Commerce, Oklahoma City, OK
- **State/Federal Inspections of Industrial-Minerals Operations,** by John W. Pugh, Health and Safety Inspector, Oklahoma Department of Mines, Oklahoma City, OK
- **Water-Related Issues for Industrial-Minerals Operations,** by Patty P. Eaton, Executive Director, Oklahoma Water Resources Board, and Cabinet Secretary of Environment, Oklahoma City, OK

- **Wetlands, Archaeological Sites, and Endangered Species Related to Industrial-Minerals Operations,** by Andrew R. Commer, Environmental Biologist, U.S. Army Corps of Engineers, Tulsa, OK
- **Air-Quality Inspections for Industrial-Minerals Operations,** by Doyle McWhirter, Director, Air Permits and Enforcement Division, Air Quality Service, Oklahoma State Department of Health, Oklahoma City, OK
- **Title V Part 70 Permits; Implementation of the 1990 Amendments to the Clean Air Act,** by Joyce Sheedy, Acting Supervisor, Permits Section, Air Quality Service, Oklahoma State Department of Health, Oklahoma City, OK
- **Reclamation and Sequential Use of Mined Lands,** by Tom Gilbert, Environmental Analyst, Oklahoma Department of Mines, Oklahoma City, OK
- **Public Perception of Industrial-Minerals Operations,** by Leonard A. Solomon, Former Chairman, Oklahoma Mining Commission, Oklahoma City, OK
- **U.S. Bureau of Mines Role in Industrial Minerals,** by Zareh Mozian, Assistant Branch Chief, Branch of Industrial Minerals, U.S. Bureau of Mines, Washington, D.C.
- **Future Outlook for Industrial Minerals in Oklahoma,** by Charles J. Mankin, Director, Oklahoma Geological Survey, Norman, OK

A copy of the final program and registration information can be obtained from the Oklahoma Geological Survey, 100 E. Boyd, Room N-131, Norman, OK 73019; phone (405) 325-3031, fax 405-325-7069.

NEW OGS PUBLICATION

SPECIAL PUBLICATION 92-1. ***Petroleum Core Catalog, Oklahoma Geological Survey—August 1992,*** compiled by Eldon R. Cox and Michelle J. Summers.
150 oversized pages, spiral bound. Price: $5.

Listed in this catalog are the petroleum cores, the largest and most-used group of materials contained in the OGS Core and Sample Library. The Library, established in 1936 by Robert H. Dott, former director of the Oklahoma Geological Survey, is used by petroleum company personnel, geoscientists, and students throughout the United States.

The petroleum group consists of cores taken from more than 2,700 wells drilled in Oklahoma, contained in an estimated 59,100 boxes. This information has been computerized and is now incorporated in the Natural Resources Information System (NRIS) of Oklahoma, which is a group of interrelated data bases that together provide a wide range of information on the State's oil and gas resources. NRIS is being constructed in order to respond to the growing need for access to information on the State's natural resources.

The petroleum core data base presented in this catalog consists of information on section, township, range, well location, county, operator, well name and number, formation name, cored depth interval, cored interval number, number of boxes, diameter of the core, condition, representation, total feet cored, average feet per box, and the library file number.

If you have a need for special information (e.g., a list of all the "Morrow Formation" in the northwest part of Oklahoma or other related computer retrievals), you can contact the Core and Sample Library manager at (405) 325-3031. There is an additional charge for this service.

Although not included in the Petroleum Core Catalog, the Library also contains samples (well cuttings) and non-petroleum cores related to coal, minerals, and special stratigraphic studies. These items are listed in a separate card file at the Library.

SP 92-1 can be purchased over the counter or postpaid from the Survey at 100 E. Boyd, Room N-131, Norman, OK 73019; phone (405) 325-3031, fax 405-325-7069. Add 10% to the cost of publication(s) for mail orders, with a minimum of 50¢ per order.

UPCOMING MEETINGS

American Petroleum Institute, Annual Meeting, November 8–10, 1992, New York City. Information: API, 1220 L Street, N.W., Washington, D.C. 20005; (202) 682-8000.

Water Resources and Environmental Engineering Meeting, November 8–13, 1992, Santa Barbara, California. Information: C. V. Freiman, Engineering Foundation, 345 E. 47th Street, New York, NY 10017; (212) 705-7835, fax 212-705-7441.

International Exploration Seminar, November 13, 1992, Oklahoma City, Oklahoma. Information: Energy Ventures Group, 11210 Steeplecrest Dr., Suite 120, Houston, TX 77065; (713) 890-5952; fax 713-890-4316.

American Nuclear Society, International Meeting, November 15–20, 1992, Washington, D.C. Information: Meetings Dept., ANS, 555 N. Kensington Ave., La Grange Park, IL 60525; (312) 352-6611.

Practical Karst Hydrogeology with Emphasis on Ground Water Monitoring, November 30–December 4, 1992, Cave City, Kentucky. Information: National Ground Water Association, 6375 Riverside Dr., Dublin, OH 43017; (614) 761-1711, fax 614-761-3446.

Industrial-Minerals Development in Oklahoma, A Workshop, December 1–2, 1992, Norman, Oklahoma. Information: Kenneth S. Johnson, Oklahoma Geological Survey, 100 E. Boyd, Room N-131, Norman, OK 73019; (405) 325-3031, fax 405-325-7069.

Sinkholes and Karst Meeting, January 25, 1993, Panama City, Florida. Information: Barry F. Beck, Florida Sinkhole Research Institute, University of Central Florida, Orlando, FL 32816; (407) 823-5645.

Geologic Remote Sensing Meeting, February 8–11, 1993, Pasadena, California. Information: Nancy J. Wallman, ERIM, Box 134001, Ann Arbor, MI 48113; (313) 994-1200, ext. 3234, fax 313-994-5123.

Society for Mining, Metallurgy, and Exploration Annual Meeting, February 15–18, 1993, Reno, Nevada. Information: Meetings Dept., SME, P.O. Box 625002, Littleton, CO 80162; (303) 973-3461.

Geological Society of America, South-Central Section Meeting, March 15–16, 1993, Fort Worth, Texas. Information: John Breyer, Dept. of Geology, Texas Christian University, Fort Worth, TX 76129; (817) 921-7270.

Fluvial-Dominated Deltaic Reservoirs in the Southern Midcontinent, A Workshop, March 23–24, 1993, Norman, Oklahoma. Information: Kenneth S. Johnson, Oklahoma Geological Survey, 100 E. Boyd, Room N-131, Norman, OK 73019; (405) 325-3031, fax 405-325-7069.

Science and Technology Policy Meeting, April 15–16, 1993, Washington, D.C. Information: American Association for the Advancement of Science, 1333 H St., N.W., Washington, D.C. 20005; (202) 326-6400.

Seventh National Outdoor Action Conference on Aquifer Restoration, Ground Water Monitoring, and Geophysical Methods, May 25–27, 1993, Las Vegas, Nevada. *Abstracts due December 4, 1992.* Information: National Ground Water Association, 6375 Riverside Dr., Dublin, OH 43017; (614) 761-1711, fax 614-761-3446.

NOTES ON NEW PUBLICATIONS

Petroleum Geology of the Anadarko Basin Region, Province (115), Kansas, Oklahoma, and Texas

Written by M. M. Ball, M. E. Henry, and S. E. Frezon, this USGS open-file report contains 36 pages.

Order OF 88-0450-W from: U.S. Geological Survey, Books and Open-File Reports Section, Federal Center, Box 25425, Denver, CO 80225; phone (303) 236-7476. The price is $4 for microfiche and $5.75 for a paper copy; add 25% to the price for foreign shipment.

Water Resources Data—Oklahoma, Water Year 1991

Records on both surface water and ground water in Oklahoma are contained in this 449-page report by R. L. Blazs, D. M. Walters, T. E. Coffey, D. K. White, D. L. Boyle, and J. F. Kerestes. Specifically, it includes (1) discharge records for 131 streamflow-gaging stations and 11 partial-record or miscellaneous streamflow stations, (2) stage and content records for 30 lakes and reservoirs, (3) water-quality records for 46 streamflow-gaging stations and two lakes, and (4) water-level records for 27 observation wells.

Order USGS Water-Data Report OK-91-1 from: U.S. Geological Survey, Water Resources Division, 202 N.W. 66th St., Bldg. 7, Oklahoma City, OK 73116; phone (405) 231-4256. A limited number of copies are available free of charge.

Annual Yield and Selected Hydrologic Data for the Arkansas River Basin Compact, Arkansas–Oklahoma, 1990 Water Year

Prepared in cooperation with the Arkansas–Oklahoma Arkansas River Compact Commission, this 31-page USGS open-file report was written by T. E. Lamb and R. L. Blazs.

Order OF 91-0466 from: U.S. Geological Survey, Books and Open-File Reports Section, Federal Center, Box 25425, Denver, CO 80225; phone (303) 236-7476. The price is $4 for microfiche and $5.25 for a paper copy; add 25% to the price for foreign shipment.

Ground-Water Quality of the Central Oklahoma (Garber–Wellington) Aquifer Conference: Proceedings, February 20, 1992

Edited by Scott Christenson and Lyn Carpenter, this 24-page USGS open-file report contains 10 abstracts of papers presented at the conference on the ground-water quality of the Central Oklahoma aquifer.

Order OF 92-116 from: U.S. Geological Survey, Water Resources Division, 202 N.W. 66th Street, Bldg. 7, Oklahoma City, OK 73116; phone (405) 231-4256. A limited number of copies are available free of charge.

Elemental Composition of Surficial Materials from Central Oklahoma

E. L. Mosier, J. H. Bullock, Jr., D. L. Fey, K. R. Kennedy, D. M. McKown, R. B. Vaughn, and E. P. Welsch wrote this 62-page USGS open-file report. The report is also available on one 5¼-in. diskette for MS-DOS.

Order OF 91-0442 from: U.S. Geological Survey, Books and Open-File Reports Section, Federal Center, Box 25425, Denver, CO 80225; phone (303) 236-7476. The price is $4 for microfiche, $9.75 for a paper copy, and $6 for the diskette; add 25% to the price for foreign shipment.

Principal Facts for 1,747 Gravity Stations in Southern Kansas and Central Oklahoma

This 80-page USGS open-file report was prepared by S. L. Robbins, Courteney Williamson, and Meridee Jones-Cecil.

Order OF 91-0335 from: U.S. Geological Survey, Books and Open-File Reports Section, Federal Center, Box 25425, Denver, CO 80225; phone (303) 236-7476. The price is $4 for microfiche and $12.50 for a paper copy; add 25% to the price for foreign shipment.

OKLAHOMA ABSTRACTS

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

Seismic Definition of Sand Lithology by Geologic Setting or by AVO

WILLIAM R. LANDWER, NORMAN S. NEIDELL, and M. SMITH, Neidell and Associates, 2929 Briar Park Dr., Houston, TX 77042

Neidell introduced the idea that sands in relation to shales could occur in three rather distinct environments. The Zone I condition—the bright spot regime—corresponded to young, unconsolidated sands lower in acoustic impedance (density-velocity product) than shales of contemporary age under normal conditions (pressure, temperature, etc.). For Zone III sands (older and consolidated), the acoustic impedance was greater than for shales. Zone II was marked by "inconsistent" relations between sand and shale acoustic impedances. Rutherford and Williams (1989) categorized three sand conditions also showing a relation between amplitude and offset (AVO) in a shale environment. Based on these and other works, many practitioners wish to categorize sands based solely on their AVO responses. Here a detailed prospect-level study involving mapping, seismic inversions with color display, well correlations, and AVO in Grant County, Oklahoma encounters the prospective Bromide (Wilcox) sands. These sands, which are clearly Zone III sands, exhibit Zone II AVO behavior in their host setting of carbonate lithology. Based on this result, it is clear that the definition of sand environments in seismic terms from geologic considerations and from AVO behavior alone are not coincident, and we believe that the geologically based classification is more fundamental.

Reprinted as published in the American Association of Petroleum Geologists, *1992 Annual Convention Official Program*, p. 71.

Geophysical Characterization and Petrographic Analysis of a Chesterian-Age Bioclastic Trap, Major County, Oklahoma

WILLIAM S. COFFEY, Marathon Oil Co., 7301 N.W. Expressway, Oklahoma City, OK 73132

Regional facies mapping of Chesterian age (Mississippian) carbonate buildups through the study area indicates a lenticular geometry of deposition. These carbonate "sands" have regional correlative dimensions of tens of miles in length with maximum thickness values up to 50 ft. This porous facies occurs at or near the Pennsylvanian/Mississippian unconformity and is overlain by a thick Morrowan age shale sequence. The base of this zone is characterized by an equally thick interval

of interbedded tite limestones and shales. A series of northeast–southwest regional normal-faults present in this area creates enhanced porosity-permeability conditions proximal to fault boundaries, in addition to an added structural component to the trap.

The combination of faulting and thick velocity interfaces yielded excellent seismic recognition and characterization of this bioclastic trend. Information collected from the wellsite was input into a synthetic seismic model designed to simulate this carbonate buildup. The model supports this feature as a seismically observable phenomena. The bioherm is noted by a displacement of the overlying Morrow shale interval as an isochron thin over this buildup. Further, at maximum porosity development, a thickening of the wavelet occurs in the Morrow/Chester velocity interface. As porosity/foot values drop, this waveform develops a thinner peak.

Photomicrographic analyses of rotary sidewall cores from this interval provide a descriptive explanation of porosity preservation of this stratigraphic buildup and serves as the basis for the core-poster display.

Reprinted as published in the American Association of Petroleum Geologists, *1992 Annual Convention Official Program*, p. 22.

Depositional History of Lower Cretaceous Strata in Northeastern New Mexico: Implications for Regional Tectonics and Depositional Sequences

JOHN M. HOLBROOK, Dept. of Geological Sciences, Indiana University, Bloomington, IN 47405; ROBYN WRIGHT DUNBAR, Dept. of Geology and Geophysics, Rice University, Houston, TX 77251

Lower Cretaceous strata in northeastern New Mexico reflect deposition during marine transgression and regression associated with the Kiowa–Skull Creek cycle. Development of regionally significant unconformities can be directly related to shoreline shifts during this cycle. Topography related to Early Cretaceous tectonic activity on crystalline basement structures, including the Dalhart Basin, Tucumcari Basin, and the intervening Bravo Dome, also had a direct effect on Early Cretaceous deposition and is reflected by thickness trends in marine strata.

The Kiowa–Skull Creek transgression was preceded by infilling of paleovalleys represented by the Long Canyon and Campana sandstone beds of the Glencairn Formation and Tucumcari Shale, respectively. The Long Canyon and Campana sandstone beds are equivalent to the Plainview Formation of central Colorado, and together they represent an extensive drainage network, developed over a correlative unconformity, that is preserved throughout most of the southern Western Interior. Glencairn and Tucumcari marine shales represent clastic deposition during Kiowa–Skull Creek transgression and early regression.

Base-level drop associated with Kiowa–Skull Creek regression resulted in dramatic shoreline regression and deposition of fluvial channel sandstone in the Dalhart Basin, which maintained a low offshore gradient. This produced an erosional unconformity at the base of Mesa Rica channel sandstone that correlates with the well-documented erosional surface at the base of the Muddy Sandstone in central Colorado. The Tucumcari Basin, which maintained a steeper offshore gradient, accumulated marine-deltaic Mesa Rica Sandstone at this time. Marine strata in both the Tucumcari and Dalhart Basins thin toward the Bravo Dome. Mesa Rica and upper Tucumcari strata represent the only extensive marginal-marine lowstand deposits found on the High Plains to date, associated with the southern arm of the Kiowa–Skull Creek sea.

Major Mesa Rica deposition was followed by transgression that infilled only those Mesa Rica fluvial channels that were active at that time and, also, that deposited marine-influenced strata of the basal Pajarito Formation. This event most likely represents onset of the Greenhorn cycle in northeastern New Mexico.

Other crystalline basement structures in the northern part of the United States Western Interior Basin were active during Early Cretaceous time. Tectonism in these areas may be related to structures in northeastern New Mexico and thus may be expressions of broad-scale crustal strain in the Early Cretaceous Western Interior that is undocumented by present tectonic models.

Reprinted as published in the Geological Society of America *Bulletin*, v. 104, p. 802, July 1992.

Reservoir Characterization of the Deep Upper Morrow Puryear Sequence in the Anadarko Basin, Western Oklahoma and Texas Panhandle

KEVIN E. NICK, PETER N. GALE, BRUCE CARPENTER, and LANNY KING, Target Reservoir Analysis, 6901 N. Robinson, Oklahoma City, OK 73116; CHARLES T. SIEMERS, P. T. Geoservices, Jakarta, Indonesia; CRAIG PECK, The GHK Co., 3030 N.W. Expressway, Oklahoma City, OK 73112; and R. DOUGLAS ELMORE, School of Geology and Geophysics, University of Oklahoma, Norman, OK 73019

The deep Upper Morrow of the Anadarko basin (Western Oklahoma and Eastern Texas Panhandle) is one of the most prolific gas-producing units in the United States. Data from 15 cores and many logs were used to determine the controls on reservoir quality in the Puryear Sequence. The reservoir rocks are chert pebble conglomerates in the central part of the basin and pebbly arkoses in the northwest and southeast. Chert pebbles were apparently derived from uplifted Paleozoic rocks to the south and southeast. The coarse clastics are stacked, highly discontinuous linear sand bodies that rest unconformably on marine shales, terminate abruptly downdip, and are laterally bounded by mudstones. Depositional environments for individual channels are dominantly nonmarine and are interpreted to be rapidly prograding fan deltas with relatively minor delta front deposits and/or valley-fill deposits. Marine shales associated with the conglomerates and sandstones have a characteristic "pedestal" profile in logs, which can be a proximity indicator for channels. Shale conductivity maps also indicate proximity to terrigenous sources. A general paragenetic sequence that incorporates lithologic and geographic variation is early clay, carbonate, and silica cements; selective dissolution of chert and/or feldspar; emplacement of hydrocarbons; and late quartz, clay, ankerite, dolomite, and pyrite cements. The dominant porosity is secondary after the dissolution of chert and feldspar. Porosity in conglomerates shows no direct relation to permeability in the

conglomerates. Dissolution is controlled by the amount of detrital clay and the cleanest, thickest units are most likely to develop significant secondary porosity.

Reprinted as published in the American Association of Petroleum Geologists, *1992 Annual Convention Official Program*, p. 96–97.

Geopressures: Two Distinctly Different Kinds of Conditions

P. E. GRETENER, Dept. of Geology and Geophysics, University of Calgary, Alberta, Canada; and G. Bloch, NAM, Assen, The Netherlands

Published geopressure curves indicate that there exist two distinctly different types of geopressure environments.

In type "A" curves, the geopressures (pressures above the normal hydrostatic value) are limited to the aquitards. Maximum deviation normally occurs near the middle of the aquitard resulting in dewatering gradients both upward and downward into the adjoining aquifers (aquifers are identified by a fluid pressure gradient, dp/dz, near 10.5 kPa/m, 0.45 psi/ft). These aquifers are always at or near hydrostatic pressure (open aquifers). This situation has been described by Chapman in his 1973 textbook as a perfect flow barrier preventing any long-range upward or downward fluid flow. Examples of this situation have been reported from the Anadarko and Williston basins.

In type "B" curves, successively deeper aquifers are under increasing excess pressure (confined aquifers). Within the aquitards the pressure gradient is unidirectional upward and may reach values where dp/dz is in the order of 100 kPa/m (5 psi/ft). When this pressure gradient reaches a critical value, the aquitard may be fractured, permitting periodical upward fluid releases as suggested by Hunt and others. Curves of this type are known from the east coast of Canada, the U.S. Gulf coast, and other places.

The difference of these curves is caused by the absence (A) or presence (B) of effective lateral seals. Where such seals are present, even the aquifers are externally confined and their normal pressure gradient (dp/dz ~10.5 kPa/m or 0.45 psi/ft) is displaced toward higher than normal values. Lateral seals may take the form of sealing faults, facies changes, and/or salt (shale) ridges.

Reprinted as published in the American Association of Petroleum Geologists, *1992 Annual Convention Official Program*, p. 48–49.

Heat Flow and Thermal Conductivity Variations and Their Effect on Thermal Maturation in the Anadarko Basin, Oklahoma

LARRY S. CARTER, Dept. of Geological Sciences, Southern Methodist University, Dallas, TX 75275

Heat flow values have been calculated for seven locations in the Anadarko basin area of Oklahoma. Three of the locations are on the northern shelf, three are in the deep basin, and one is in the frontal part of the Wichita Uplift. The heat flow was calculated from temperature logs run at the seven locations and conductivity measurements from core in or near the sites. High precision temperature logs (0.1–0.5 m measurement interval) were run in wells at or close to thermal equilibrium.

Nearly 300 conductivity measurements were made on vertical core plugs taken from various stratigraphic intervals within the basin. Conductivities range from 0.9 W/m/K for some shales to over 6.6 W/m/K for some sandstones. Permian red shales have a significantly higher conductivity than Pennsylvanian shales and organic-rich shales of the lower Paleozoic. Pennsylvanian "granite" and "carbonate wash" sections have high conductivities ranging up to 6.3 W/m/K, in strong contrast to the laterally equivalent shales away from the uplift.

The heat flow ranges from 39 to 62 mW/m^2 and generally decreases from north to south. Variation of the heat flow is primarily due to the radiogenic content of the basement rock. The lateral lithology changes, and resulting thermal conductivity variations, combined with the heat flow variations, have affected thermal maturation patterns in the basin. For example, vitrinite reflectance values of the Woodford Shale are higher north of the deepest part of the basin. The high thermal conductivity of the "granite wash" sections result in a lower mean gradient along the south (deep) side of the basin. Lower thermal conductivity and increasing heat flow to the north result in a higher mean gradient and increased thermal maturation under the shale sections north of the deepest part of the basin.

Reprinted as published in the American Association of Petroleum Geologists, *1992 Annual Convention Official Program*, p. 17.

Three Levels of Compartmentation within the Overpressured Interval of the Anadarko Basin

Z. AL-SHAIEB, J. PUCKETTE, A. ABDALLA, and P. ELY, School of Geology, Oklahoma State University, Stillwater, OK 74078

Deep basin pressure compartments can be classified on the basis of their size, stratigraphy, and pressure regimes. Detailed investigations of the geologic setting and pressure gradients of numerous reservoirs in the Anadarko basin reveal the presence of three distinct levels of compartmentation.

Level 1 is a basin-wide feature known as the mega-compartment complex (MCC). This complex is an overpressured volume of rocks that is completely enclosed by seals. It is approximately 150 mi long and 70 mi wide and has a maximum thickness in excess of 16,000 ft. Gas reserves of the overpressured reservoirs within the MCC are speculated to be approximately 30 tcf. The other two compartmentation levels are further subdivisions of the internal volume of the MCC.

Level 2 compartmentation consists of multiple, field-sized configurations within a particular stratigraphic interval. These compartments are 20 to 30 mi long, 12 to 20 mi wide, and 400 to 600 ft thick. Their reserve estimates can exceed 2 tcf. An example of this type is the Upper Morrowan Chert Conglomerate reservoirs in the Cheyenne/Reydon field area.

Level 3 consists of a single, small field or a particular reservoir nested within Level 2. These compartments are generally 2 to 4 mi long, <1 to 3 mi wide, and 10 to 100 ft thick. Reserve estimates range from <1 to several hundred bcf. Examples include the Southwest Leedey Red Fork field and the individual channel-fill reservoirs of the "Pierce" chert conglomerate.

The integration of tectonic history, stratigraphic relationships, facies distribution, thermal history, and diagenetic patterns of seal zones suggests that the three levels of compartmentation evolved during the Pennsylvanian orogenic episode. This occurred during the rapid subsidence phase of the orogeny over a period of approximately 30 million years.

Reprinted as published in the American Association of Petroleum Geologists, *1992 Annual Convention Official Program*, p. 2.

Variations in Thick Skin Structural Styles in Southern Oklahoma

W. G. BROWN, Dept. of Geology, Baylor University, Waco, TX 76798

The structural styles of the Arbuckle Mountain region of southern Oklahoma have developed as a result of the late Paleozoic Wichita and Arbuckle orogenies. The location and trends of many of these structures, however, were predetermined by the initial rifting in late Precambrian and early Cambrian during the development of the Southern Oklahoma Aulacogen. Basement-involved compressional structures occur over a wide area in southern Oklahoma, west of the thin-skinned Ouachita thrust belt. Specific sites of deformation are the Arbuckle Mountains, Tishomingo Uplift, Wichita Mountains, and Criner Hills, as well as the Ardmore and Anadarko basins. Hydrocarbons are produced from a variety of structural traps, including: (1) large double-plunging surface anticlines, (2) early formed, deep-basin structures that are not expressed on the surface, (3) large anticlines developed under or immediately in front of major mountain overhangs, (4) anticlines that subcrop beneath the Pennsylvanian on the hanging walls of buried mountain fronts, and (5) overturned beds preserved in the footwall of major reverse faults. Controversy surrounds the interpretation of whether the major faults in the area are wrench-type, with moderate-to-large amounts of strike-slip (both left- and right-lateral), or whether they are primarily reverse dip-slip faults, displaying large amounts of crustal shortening and small amounts of lateral motion. A reinterpretation of the inferred interaction between the basement-involved structures described above, with the thin-skinned Ouachita thrust belt to the east, suggests a different sequence of deformation than generally thought.

Reprinted as published in the American Association of Petroleum Geologists, *1992 Annual Convention Official Program*, p. 14.

Cycle and Sequence Dynamics of Lower Ordovician Platform Carbonates of the Great American Bank (USA): Constraints from Inverse and Two-Dimensional Forward Modeling

R. K. GOLDHAMMER, P. A. DUNN, and P. J. LEHMANN, Exxon Production Research Co., Houston, TX

Lower Ordovician platform carbonates of the Gondwana passive margin (the Great American Bank of the USA) contain several third-order depositional sequences (each 75–200 m thick, 2–5 m.y. duration) correlated from the Diablo plat-

form (El Paso, Texas), southeast to the Diablo arch (west Texas), northeast into the Ardmore basin (Arbuckle Mountains, Oklahoma) and to the Appalachian basin (central Pennsylvania and western Maryland). Correlation utilized biostratigraphy and high-frequency cycle stacking pattern analyses (Fischer plots). Owing to late Paleozoic structuring of the Gondwana margin, present-day exposures occur in updip shelfal positions and lack internal stratal geometries across depositional strike. Thus, sequences and systems tracts are identified by the onlap-offlap third-order facies tongues, the distribution of siliciclastics that straddle third-order sequence boundaries, and via vertical stacking patterns of depositional subfacies and higher-frequency fifth-order cycles (~1–5 m thick; 50–100 k.y. duration). Typically, sequence boundaries are stratigraphically conformable with no evidence for erosion or downward shift in facies.

The origin of fifth-order cycles has been investigated utilizing time series analyses (autocorrelation and maximum entropy spectra) and we conclude that a strict allocyclic, Milankovitch-driven glacio-eustatic mechanism, or a tectonic-reversal model are alone insufficient to account for the origin of fifth-order cyclicity. This, coupled with the progradational nature of peritidal cycles, suggests a Ginsburg-type autocyclic mechanism linked to onshore sediment transport and seaward progradation of tidal flats. The 2-D internal facies architecture of a sequence and cycle stacking patterns have been simulated via computer utilizing an autocyclic mechanism for fifth-order cycle development triggered by third-order accommodation changes. The origin of the third-order sequences appears to be eustatic based on biostratigraphically constrained correlation of Fischer plots for all sections.

Reprinted as published in the American Association of Petroleum Geologists, *1992 Annual Convention Official Program*, p. 46–47.

Pre-Devonian Petroleum Plays in the Southern Mid-Continent

KENNETH S. JOHNSON, Oklahoma Geological Survey, University of Oklahoma, Norman, OK 73019; and ROBERT A. NORTHCUTT, Consultant, 11032 Quail Creek Rd., Oklahoma City, OK 73120

Pre-Devonian sedimentary rocks of the southern Mid-Continent comprise a thick sequence of shallow marine carbonates interbedded with several sandstone and shale units. These strata are remarkably widespread and laterally persistent throughout most parts of the Oklahoma basin, reflecting the stability of this part of the North American craton during early Paleozoic time. Pre-Devonian sediments typically are 1,000–5,000 ft thick in most parts of the area, although they reach 10,000 ft in the deep part of the Anadarko basin. Principal oil-and-gas plays in pre-Devonian rocks include those for the Arbuckle Group (Upper Cambrian–Lower Ordovician), Simpson Group (Middle–Late Ordovician), Viola Group (Late Ordovician), and Hunton Group (latest Ordovician, Silurian, and Devonian). These plays occur chiefly in carbonates (dolomites or limestone), except the Simpson Play, which produces mainly from high-purity silica sands (Oil Creek, McLish, Bromide, and "Wilcox" sands).

General characteristics of these plays are remarkably similar, in that all are related to primary structural traps which have varying degrees of diagenetic overprint. In the Arbuckle Play, porosity enhanced by fracturing, karstification, or dissolution determines where the major accumulations of petroleum occur on structures. The Simpson Play with major accumulation of petroleum is structural, with minimal diagenetic influence; the occurrence of the siliciclastic facies determines the limit of the play. The Viola Play includes areas of significant petroleum production from the fractured and solution-porosity carbonates on structural traps. The Hunton Play can be divided into structural and stratigraphic subplays: Within the Arkoma basin and the deep part of the Anadarko basin, structural trapping predominates in the major fields; in the shelf areas, truncation at the post-Hunton unconformity provides major areas of petroleum accumulation at the resulting stratigraphic traps.

Reprinted as published in the American Association of Petroleum Geologists, *1992 Annual Convention Official Program*, p. 60.

Depositional Compartmentalization of Heavy Oil in Mid-Continent Cherokee Group Fluvial-Dominated Deltaic Sandstones

W. I. JOHNSON and D. K. OLSEN, IIT Research Institute/National Institute for Petroleum and Energy Research, Bartlesville, OK

Integrated geological and engineering analyses of Cherokee Group, Desmoinesian Series, Middle Pennsylvanian System Sandstones, based on published and unpublished reports and theses, were conducted to evaluate the feasibility of recovering heavy oil in the Mid-Continent. Analyses for determining the successful and unsuccessful application of thermal enhanced oil recovery processes were performed on previous projects for both heavy and light oil reservoirs to determine their common characteristics. The primary difference between light and heavy oil reservoirs found in these areas, as shown by integrated reservoir analysis, is the gravity and viscosity of the oil.

Heavy oil reservoirs in the Mid-Continent are found in Paleozoic age carbonates and sandstones from Cambrian through Pennsylvanian Systems. Cherokee Group sandstone reservoirs in the Mid-Continent contain a large portion of these heavy oil resources. Mid-Continent Cherokee Group sandstones are dominated by those deposited as channel filling, multistoried, multistacked, discontinuous, fining-upward, multiple-point-bar fluvial-dominated deltaic sediments. These sandstones commonly have a lower facies that is more homogeneous and an upper facies that is more compartmentalized.

Ultimate recovery of oil from Cherokee Group sandstone reservoirs is affected by facies, small-scale sedimentary structures, bedding boundary and intergranular small-scale permeability barriers, and diagenetic changes, commonly noted as heterogeneities, within the sandstone body. Lower sandstone facies will have the largest volume of heavy oil that is recoverable by thermal processes. Upper sandstone facies will contribute small quantities of oil by thermal processes on a less cost-effective basis. Low recovery in upper sandstone facies is caused by depositional compartmentalization of the heavy oil resource.

Reprinted as published in the American Association of Petroleum Geologists, *1992 Annual Convention Official Program*, p. 60.

The Arkoma Basin—An Overmature Gas Province

WILLIAM G. WERNER, Mobil Exploration and Producing U.S., Inc., Oklahoma City, OK; and CHARLES E. GRIFFITH, Mobil Exploration and Producing Services, Inc., Dallas, TX

The Arkoma basin is a prolific, Paleozoic natural gas province located in eastern Oklahoma and Arkansas. Significant production occurs from "overmature" reservoir rocks that have some of the highest reported maturity levels (R_0's) in the world. These fields serve as productive analogs for other overmature areas. At Red Oak field, the Pennsylvanian Lower Atokan Spiro Sandstone produces from reservoir rocks with projected R_0's up to 4.5%. At Wilburton field, the Cambrian–Ordovician Arbuckle produces from reservoir rocks that have projected R_0's in excess of 3.5%.

Thermal modeling demonstrates that the Arkoma basin and Ouachita area was buried by a thick, thrusted overburden ranging in thickness from less than 10,000 ft to in excess of 30,000 ft. This thick overburden resulted in hydrocarbon generation in late Atokan/Desmoinesian and is the cause of the high thermal maturities present. Substantial removal of section by erosion has occurred during and since the Permian within the area.

The upper thermal exposure limit for significant production is not known for the Arkoma basin; it may be 5.0% R_0 or higher. Deposition, structural development of traps, maturation and generation of hydrocarbons, migration, and trapping preceded the basin's maximum thermal history. Questions of methane stability, trap integrity, reservoir recrystallization, diffusion of gas, thermochemical destruction of gas, and dilution of gas best characterize potential problems in regard to the upper thermal limit of commercial production.

Reprinted as published in the American Association of Petroleum Geologists, *1992 Annual Convention Official Program*, p. 140.

Constraints for Determining the Southern Extent of Overthrusted Platformal Strata in the Ouachita Orogenic Belt, Oklahoma, USA

CHARLES A. FERGUSON, Dept. of Geology and Geophysics, University of Calgary, Calgary, Alberta, Canada

Exploration programs for extending gas reserves south of the Arkoma basin into deeper and more complex areas of the Ouachita orogen should consider an interpretation, proposed herein, that the overthrusted carbonate platform is not as extensive as it is popularly thought to be.

Evidence for location of the platform's south-facing shelf margin is present in the allochthon of the north-vergent Ouachita fold-thrust belt. The allochthon is divided into two sequences by the Ti Valley fault (TVF), a major thrust that runs parallel to and less than 10 km hindward of the frontal thrust. The southern sequence, or Ouachita facies, consists of a deep marine equivalent of the autochthonous platform overlain by a southward-thickening (1 to 8 km) wedge of flysch that contains conspicuous shelf-derived olistostromes. The northern sequences of the allochthon, or

Arkoma facies, is dominated by a thick flysch unit that buried the platform during initial stages of thrusting. The Arkoma–Ouachita facies transition (essentially the TVF) therefore represents an allochthonous trace of the buried shelf margin.

A balanced cross-section of the northern Ouachita Mountains was used to palinspastically restore the Arkoma–Ouachita facies transition and therefore locate the buried position of the shelf margin. This technique places the margin about 25 km south of the frontal thrust, which corresponds to about 60% tectonic shortening. This is 70 km farther north than many other estimates.

A metamorphosed carbonate platformal sequence, structurally buried beneath the southern Ouachita Mountains, is widely interpreted as a southern continuation of the platform that underlies the Arkoma basin. If this were true, it would require unaccountably large amounts of shortening (over 90%) in the frontal Ouachitas. The metamorphosed platform is herein interpreted as part of a terrane exotic to North America. Large areas of the central Ouachita Mountains may not be underlain by platformal rocks of any kind.

Reprinted as published in the American Association of Petroleum Geologists, *1992 Annual Convention Official Program,* p. 40.

Structural Styles and Exploration Strategies Along the Leading Edge of Fold and Thrust Belts: Examples from the Ouachita Fold and Thrust Belt, Southeast Oklahoma

RUSS D. CUNNINGHAM and MARK D. FALK, The GHK Co., 3030 N.W. Expressway, Oklahoma City, OK 73112; and JAY NAMSON, Davis and Namson Consulting Geologists, Valencia, CA 91380

The leading edge of the Oklahoma portion of the Ouachita fold and thrust belt is characterized by a regional surface thrust called the Choctaw fault. Exploration has focused on a complex structural zone in the footwall of the fault, where the structural styles are constrained by subsurface well control, seismic reflection data, and balanced cross sections. Underlying the Choctaw fault is the Choctaw anticlinal trend, which is interpreted to be a fault-bend fold associated with a ramp beginning in Springeran age rocks and progressing through a thick middle Atokan flysch sequence. The thrust has approximately 5 km of slip. Some slip is diverted on a back thrust forming a triangle zone at the front of the anticline, and some slip is transferred into the Arkoma basin foreland where it is consumed in a series of hydrocarbon-producing folds. South of the Choctaw anticline, the structural style in the footwall of the Choctaw fault is characterized by a series of imbricate thrusts or duplex structures with the lower detachment in Springeran age rocks and the upper detachment immediately above the Spiro Sandstone.

The main exploration strategy in the thrust belt has been the imbricate fault traps involving the shallow marine, basal Atokan Spiro Sandstone. A relatively undeveloped play is a middle Atokan submarine fan sandstone in the Choctaw anticlinal trend. These middle Atokan, immature sediments were eroded from the northward-advancing thrust system and deposited in the Atokan age foreland basin formed by a series of down-to-the-south normal faults. These faults control the areal extent of the sedimentary units. Post-depositional thrusting has resulted in a complex hydrocarbon trap consisting of a stratigraphic facies change on the forelimb of a fault-bend fold.

Reprinted as published in the American Association of Petroleum Geologists, *1992 Annual Convention Official Program*, p. 25.

Probable Reservoir Facies, Wapanucka Limestone (Morrowan), Frontal Ouachita Mountains, Southeastern Oklahoma

DARRELL L. MAULDIN, Dept. of Geology, Baylor University, Waco, TX 76798

Although gas production in the Ouachitas has been primarily from the Spiro Formation (Atokan), the Wapanucka Formation is locally a gas reservoir and thus is a secondary objective. Outcrop study of surface imbrications form a basis for predicting the character of rocks in the subsurface.

Thick successions of repetitive subtidal carbonate cycles of platform, platform margin, and basinal facies characterize the Wapanucka Formation in outcrop, except for most of the basinal ridges, in which cyclicity is not evident. Each repetitive sequence records aggradation and southward progradation of the ramp-like shelf margin. Pebble conglomerates were deposited as island beaches. Oolitic and bioclastic calcarenites accumulated as shallow shelf bars, while algal boundstones and wackestones developed near the shelf edge. Spiculitic limestones characterize the platform margin, and slope and basinal depositional environments are inferred for the noncalcareous spiculites and shale.

Several facies are potential hydrocarbon reservoir rocks. These include pebble conglomerate, oolitic grainstone, algal boundstone, and spiculitic packstone. The first two lithologies might preserve primary porosity; the algal units could develop secondary porosity; while the latter facies would develop fracture porosity in certain structural configurations. Thus, mapping the surface is significant because well control and seismic data do not provide this kind of information. Detailed surface work in association with the subsurface geology will aid in locating hydrocarbon reservoirs.

Reprinted as published in the American Association of Petroleum Geologists, *1992 Annual Convention Official Program*, p. 83.

Depositional Facies Distributions, Diagenetic, and Structural Controls on Producing Intervals, Pennsylvanian Spiro Formation, South Hartshorne Field, Latimer County, Oklahoma

STEVEN S. DEMECS and PAUL K. MESCHER, ARCO Oil and Gas Co., Plano, TX; MARK LONGDEN and MARK A. WARD, ARCO Oil and Gas Co., Midland, TX

The Spiro (Pennsylvanian–Lower Atokan) Formation of the Arkoma basin has long been a prolific dry gas reservoir in the southern Arkoma basin of Oklahoma. Inte-

gration of core and petrographic studies with structural mapping from ARCO and partnership wells in the South Hartshorne field area reveals a complex pattern of depositional facies, diagenetic alterations, and structural position control porosity distributions in the Spiro Formation. Depositional facies consist of complex mixed siliciclastic and carbonate depositional systems consisting of shallow shelfal, high-energy barrier system sediments. Primary interparticle porosity and secondary fracture porosity are the main producing pore types. Carbonate sections are dominated by high-energy, cross-bedded bioclastic grainstones having poor fabric selective porosity owing to occluding carbonate cements. Interparticle porosity is present only in quartzarenitic sandstones where early cementation by authigenic chlorite clays prevents a later stage of porosity reduction by diagenetic quartz cementation. Interparticle porosity and secondary fracture porosity is best developed within structurally high areas where late stages of porosity reduction by diagenetic carbonate cementation are not present. Spiro test rates within the field are commonly very high (6–49 MMCFGD).

Pennsylvanian horizons in the area are thrusted and commonly imbricated as the result of Permian–Pennsylvanian (Ouachita) tectonism. Structural analysis demonstrates a positive relationship between ultimate recovery (production) and structural position within closed culminations of a complex regional thrust plate duplex system. South Hartshorne field is anomalous because it produces from a low relief thrust plate, indicating that depositional facies and diagenesis play key roles in reservoir quality.

Reprinted as published in the American Association of Petroleum Geologists, *1992 Annual Convention Official Program*, p. 29.

The Black Warrior Foreland Basin and the Diachronous Appalachian–Ouachita Thrust Belt

WILLIAM A. THOMAS, Dept. of Geological Sciences,
University of Kentucky, Lexington, KY 40506

The Black Warrior foreland basin, a southwest-dipping homocline, extends beneath the northwest-striking Ouachita thrust belt (now covered by postorogenic strata of the Gulf Coastal Plain), and it is bordered on the southeast by the northeast-striking Appalachian thrust belt. A southwestward-thickening, northeastward-prograding, deltaic to shallow marine, Upper Mississippian to Middle Pennsylvanian synorogenic clastic wedge overlies preorogenic, passive-margin shelf facies and fills the foreland basin. Mississippian clastic facies grade northeastward to carbonate, and facies distribution throughout the wedge conforms to northwesterly stratigraphic strike. Structure and stratigraphy indicate that the Black Warrior basin is an Ouachita foreland basin rather than an Appalachian foreland basin. Ouachita thrust loading on the southwest and northeastward dispersal of clastic sediment began in the Meramecian and continued into Middle Pennsylvanian, but the younger (late Early Pennsylvanian) part of the clastic wedge includes some components that prograded northwestward from an Appalachian source, indicating initiation of northwest-directed thrusting. The southeastern part of the southwest-dipping foreland basin subsequently was dismembered and displaced northwestward by

Appalachian thrusting. Mississippian–Pennsylvanian clastic facies in northeast-striking Appalachian synclines are distributed similarly to those in the Black Warrior basin, indicating that the palinspastic location of the Appalachian thrust sheets was within the Ouachita foreland. The clastic succession in deep Appalachian synclines is much thicker than that in the Black Warrior basin, indicating that the foreland basin was partitioned by the down-to-southeast, northeast-striking Birmingham basement fault system (now beneath Appalachian thrust sheets). Strata in the Appalachian thrust belt record the filling of the Black Warrior basin in the Ouachita foreland and the subsequent northwestward thrusting of the original southeastern part of the basin.

Reprinted as published in the American Association of Petroleum Geologists, *1992 Annual Convention Official Program*, p. 131.

An Improved Okcol: A Water-Miscible Mounting Medium

L. R. WILSON, Oklahoma Museum of Natural History, University of Oklahoma, Norman, OK 73019

A water-miscible mounting medium for palynomorphs and similar microscopic objects has been improved over its original formula. Currently it consists of one part glycerine jelly and four parts saturated gum acacia solution. A suggested additional use for Okcol is that of a storing solution for excess microscopic preparations.

Reprinted as published in *Current Perspectives in Palynological Research*, Silver Jubilee Commemoration Volume of the Journal of Palynology 1990–91, p. 321.

Hydrocarbon Source-Rock Evaluation of Desmoinesian (Middle Pennsylvanian) Coals from Part of the Western Region of the Interior Coal Province, U.S.A.

JOSEPH R. HATCH, U.S. Geological Survey, Box 25046, Denver, CO 80225

Coals in the Desmoinesian (Middle Pennsylvanian) Cherokee Group and Marmaton Group in the Western Region of the Interior Coal Province, U.S.A., are potential source-rocks for methane and liquid hydrocarbons. To help evaluate this potential, 85 samples were collected from cores and surface-mines at 21 locations in southeastern Iowa, Missouri, southeastern Kansas, and northeastern Oklahoma. Analyses of these coals are summarized from three areas defined by increasing thermal maturity. Organic matter in coals from area 1 (southeastern Iowa and northern Missouri) is marginally mature with respect to petroleum generation (Rock-Eval $T_{max} = 430 \pm 4°C$, $n = 48$; $R_o \leq 0.55\%$, $n = 9$); in area 2 (southwestern Missouri, southeastern Kansas and northeastern Oklahoma near the outcrop) organic matter is mature ($T_{max} = 446 \pm 5°C$, $n = 25$; $0.57\% \leq R_o \leq 0.80\%$, $n = 7$); and in area 3 (Osage County, northeastern Oklahoma) organic matter is near peak oil generation ($T_{max} = 460 \pm 5°C$, $n = 12$; $0.8\% \leq R_o \leq 1.0\%$, $n = 3$).

For coals from area 1, mean genetic potential (Rock-Eval $S_1 + S_2$ mg HC/g sample) is 126 ± 41 mg/g; from area 2, 139 ± 46 mg/g; and from area 3, 115 ± 35 mg/g, which shows that coals from the three areas all have excellent potential to generate hydrocarbons. For coals from area 1, mean carbon-normalized volatile hydrocarbon content (S_1/TOC, mg HC/g TOC) is 4.4 ± 3.1 mg/g; from area 2, 6.8 ± 4.6; and from area 3, 12 ± 5 mg/g, which indicates that some hydrocarbon generation has taken place.

For coals from area 1, mean content of $CHCl_3$ extractable organic matter is 27 mg/g sample (geometric deviation [GD] = 1.7; $n = 14$); from area 2, 15 mg/g (GD = 1.6; $n = 9$); and from area 3, 9 mg/g (GD = 1.1; $n = 5$). This decrease is thought to be caused by a decrease in micropore interconnections with increased thermal maturity, which results in lower extraction efficiencies. For coals from areas 1 and 2, saturated hydrocarbon distributions are dominated by pristane with low relative amounts of n-C_{25} to n-C_{31}; in area 3, relative amounts of n-alkanes and isoprenoids are similar. Extracts from Desmoinesian coals immediately overlain by marine black shales are intermediate in composition between those of black shales and other coals. This may result from the addition or preservation of bacterial biomass in the upper layers of the peat during early diagenesis or from migration of hydrocarbons from the overlying shale down into the coals.

All of the coal extract compositions are dissimilar to oils produced from the Cherokee Group, suggesting minimal generation or migration of liquid hydrocarbons from these coals. There is, however, active exploration for coalbed methane in southeastern Kansas, and at least 74 gas wells have been completed.

Reprinted as published in the American Association of Petroleum Geologists, *1992 Annual Convention Official Program*, p. 53.

High-Resolution Correlation of Mid-Cretaceous Sequences in the Gulf Coast and Western Interior

R. W. SCOTT, Amoco Production Co., P.O. Box 3385, Tulsa, OK 74101

Four scales of depositional cycles are developed within the mid-Cretaceous section: about 8.1, 4.1, 2.0, and 0.81 Ma. Major transgressions marked by significant onlap and regional unconformities, such as the Washita Group, are approximately 8.1 Ma in duration. Within these cycles are packages of limestone-shale and sandstone-shale, such as the Pearsall Formation, about 4.1 Ma in duration. These units can be divided further into complex shale-limestone bed sets of about 2.0 Ma duration. The thinnest conformable shale-limestone cycles are parasequence sets about 0.81 Ma long, such as several pairs of formations in the upper Washita Group in north Texas.

Graphic correlation techniques applied to the mid-Cretaceous section in north Texas and the southern Western Interior show that the same scale of cycles is developed. The basal Washita drowning unconformity correlates with the unconformity/transgressive surface at the base of the Cheyenne/Kiowa formations in Kansas. Other regional erosional unconformities in one basin correlate with drownings of the shallow shelf in the other basin. The Western Interior erosional unconformity between the Purgatoire–Kiowa and Dakota formations correlates with the drowning event between the Fort Worth and Denton formations in north Texas. The regional erosional contact within the Dakota in the Denver basin correlates with the drowning of the Mainstreet Formation shelf by the shelf-basin facies of the Grayson Formation. The major Gulf Coast erosional unconformity at the base of the Woodbine Formation correlates with the flooding of the Dakota by the Graneros Formation.

Regional lowstand unconformities in one basin may correlate with transgressive surfaces in another basin. High-precision correlation provides a tool to test the relative interactions of eustasy, differential basin subsidence, and sediment supply.

Reprinted as published in the American Association of Petroleum Geologists, *1992 Annual Convention Official Program,* p. 116.