OKLAHOMA GEOLOGY

otes

August 1998
Vol. 58, No. 4

On The Cover —

Hartshorne Formation, Green Country Stone Quarry, Rock Island, Oklahoma

At the Green Country Stone Quarry in northern Le Flore County, Oklahoma, sandstone from the Hartshorne Formation is quarried for a wide variety of uses, including building veneer, retaining walls, and patio flagstone. Large slabs of sandstone are pried from the quarry floor by a Gradall 880, pictured in the cover photo. The Gradall, which was intended to dig and clean bar ditches and grade the sides of highways, was modified to remove sandstone by Bob Thompson, father of the quarry's current owner.

Most of the Hartshorne sandstone at the Green Country quarry is medium gray in color and fine grained. Individual sandstone beds range from 1.5 in. to 1 ft thick and are separated by thin shale beds. The sandstone flagstones and blocks are shipped to more than 20 states, as far away as Oregon and Pennsylvania. Recently sandstone from the quarry was used to build the retaining walls for the garden at Boyd House, the residence of University of Oklahoma President David L. Boren. (*Oklahoma Geology Notes* features the first in a series of papers on rocks of the OU campus in this issue; see introduction on p. 138.)

Green Country quarry is one of several successful stone quarries to open in northern Le Flore and Haskell Counties in recent years. All of the quarries operate in Desmoinesian (Middle Pennsylvanian, about 310 million years old) strata in the Arkoma basin. Several operate in the Hartshorne Formation; others quarry sandstones from the Savanna and Boggy Formations, which are slightly younger.

Magnificent outcrops of very well stratified, lower-delta-front bar sandstones and shales (cover photo) are exposed in the quarry, and two "classic"

(continued on p. 155)

OKLAHOMA GEOLOGICAL SURVEY

CHARLES J. MANKIN
Director

KENNETH S. JOHNSON
Associate Director

OKLAHOMA GEOLOGY NOTES

Editor
Christie Cooper

Associate Editor
Tracy Peeters

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.

This publication, printed by the Oklahoma Geological Survey, Norman, Oklahoma, is issued by the Oklahoma Geological Survey as authorized by Title 70, Oklahoma Statutes 1981, Section 3310, and Title 74, Oklahoma Statutes 1981, Sections 231–238. 1,500 copies have been prepared for distribution at a cost of $1,471 to the taxpayers of the State of Oklahoma. Copies have been deposited with the Publications Clearinghouse of the Oklahoma Department of Libraries.

OKLAHOMA GEOLOGY
Notes

CONTENTS

August 1998
VOL. 58, NO. 4

BAEOTHERATES FORTSILLENSIS, A NEW CAPTORHINID REPTILE FROM THE FORT SILL FISSURES, LOWER PERMIAN OF OKLAHOMA

William J. May[1] *and Richard L. Cifelli*[2]

Abstract

A new genus and species of multiple-tooth-rowed captorhinid, *Baeotherates fortsillensis,* is established on a partial right mandible collected from the Lower Permian fissure-fill deposits (equivalent in age to the Arroyo Formation, Clear Fork Group, Texas) near Fort Sill, in southwestern Oklahoma. Previously, only two other captorhinids were known from the site: *Captorhinus aguti* and an unnamed, basal captorhinid recently described by Modesto (1996). The dentition of *Baeotherates fortsillensis* exhibits several unique characteristics in which it differs greatly from the other multiple-tooth-rowed captorhinid from the site, *Captorhinus aguti,* whose skeletal remains dominate the diverse vertebrate assemblage. At least some of these characters appear to be convergent with those in some microsaur amphibians. Although *Baeotherates fortsillensis* has multiple rows of posterior teeth, as in *Captorhinus* and other advanced members of the family, it lacks other captorhinid features, such as a differentiated canine region and a reduced number of anterior teeth. The unusual combination of features found in *Baeotherates* suggests that mandibular and dental evidence, used by itself, must be interpreted cautiously when evaluating relationships among these early reptiles.

Introduction

The Dolese Brothers Limestone quarry at Richards Spur, near Fort Sill, Oklahoma (Olson, 1967), is the richest deposit of Lower Permian vertebrate fossil remains in the State of Oklahoma, and one of the richest in the world. The fossils occur in fissures in the Ordovician Arbuckle Limestone, which are infilled with Lower Permian sediments that are equivalent in age to the Arroyo Formation, Clear Fork Group, of Texas (Olson, 1967). The fillings consist of soft clays to coarse conglomerates. Some of the fissure fills are literally packed with both articulated and disarticulated fossil remains, while others are completely void of fossils. The vertebrate remains from the fissures are generally well preserved and are frequently complete, with only minor chips or breaks, but some have extensive wear, which indicates that they were transported before they were deposited in the fissures. The majority of the vertebrate remains are disarticulated, but a few articulated skeletons and skulls have been recovered. In the most recent faunal review of the site, Olson (1991) recognized 21 vertebrate taxa, including one shark, 12 amphibians, and eight reptiles. The faunal assemblage is made up of small animals, the majority of which are terrestrial. The most common taxon found at the site is the captorhinid *Captorhinus aguti,* which is known in exquisite detail (see Fox and Bowman, 1966). Although the site has been actively worked for more than 50 years and thousands

---

[1] Oklahoma Museum of Natural History, Norman, Oklahoma.

[2] Oklahoma Museum of Natural History and Department of Zoology, University of Oklahoma.

of specimens have been obtained by a number of institutions, discovery of the new taxon described below underscores the need for continued work there. The new species is referred to the reptilian family Captorhinidae. This group is of special interest to evolutionary morphologists because captorhinid anatomy is thought to closely approximate the primitive conditions for Amniota (Romer, 1966; Carroll, 1988; Laurin and Reisz, 1995). Captorhinids are known from other deposits of nearly equivalent age in Oklahoma, Texas, and New Mexico; the family as a whole ranges from the Early Permian of North America to the Late Permian of Africa, Asia, and Eastern Europe (Ivachnenko, 1990; Benton, 1997) .

Note: The institutional abbreviation, OMNH, is used in this paper for the Oklahoma Museum of Natural History, University of Oklahoma. The descriptions "multiple tooth-rowed" and "single tooth-rowed" are hereafter abbreviated "multiple rowed" and "single rowed," respectively.

Systematics

Reptilia Linnaeus, 1758
Captorhinidae Case, 1911
***Baeotherates fortsillensis*,** new genus and species

Holotype

OMNH 55758, partial right mandible.

Etymology

Baois, Greek, little or small; *therates,* Greek, hunter; in allusion to the size and inferred habits of this reptile. The species is named for a nearby U.S. Army post, Fort Sill, commonly used as the name of the site from which the type was collected (Olson, 1967).

Locality and Horizon

OMNH locality V51, Dolese Brothers Richards Spur quarry, ~6 mi north of Lawton, Comanche County, Oklahoma. Fissure-fill deposit equivalent to the Arroyo Formation (Leonardian: Lower Permian) of Texas.

Diagnosis

Small, multiple-rowed captorhinid distinguished by having a mandibular dentition with extensive fluting, particularly on labial sides of tooth crowns, and lacking a canine region; symphysis differs in having a more robust, undivided dentary contact and reduced or lost splenial contribution (Meckelian canal not participating in symphysis); anterior part of coronoid attachment to dentary differs in being broad and in having a low angle with respect to the occlusal plane. Differs from advised captorhinids (e.g., *Captorhinus, Eocaptorhinus*) in having a greater number of anterior teeth and a longer, more slender mandible with a lesser degree of sculpturing.

Description

The type of *Baeotherates fortsillensis* (Figs. 1, 2) consists of a partial right dentary preserving the symphysis and 15 teeth, the posterior four being arranged in two

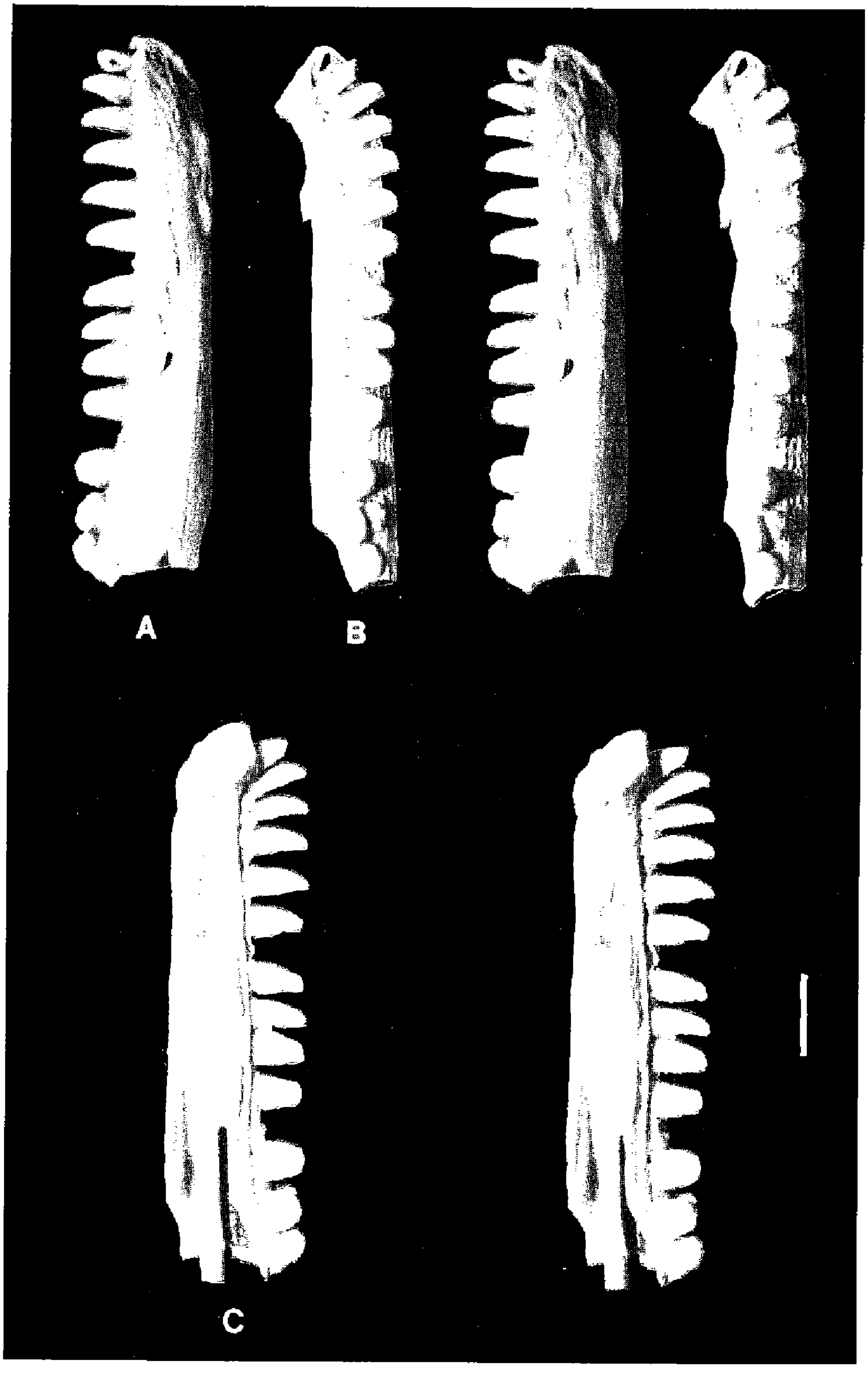
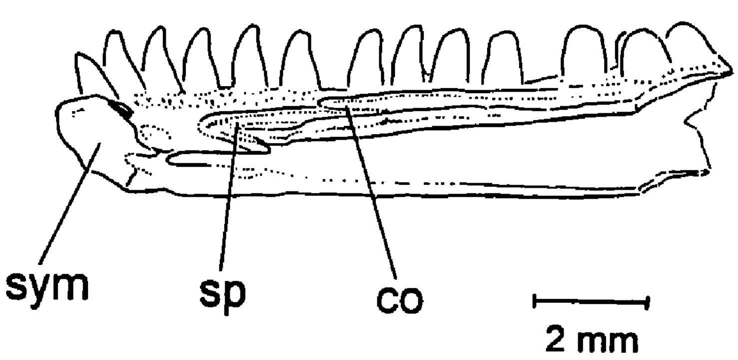


Figure 1. *Baeotherates fortsillensis*, new genus and species. OMNH 55758 (holotype), right mandible in labial (A), occlusal (B), and lingual (C) views (stereopairs). Object protruding from the posterior edge of the dentary in C is a mounting pin affixed to the lingual side of the jaw. Scale bar = 2 mm.

Figure 2. *Baeotherates fortsillensis*, new genus and species. OMNH 55758 (holotype), right mandible in lingual view, showing positions for attachment of the coronoid and splenial to the dentary (see description in text). Abbreviations: co, facet for coronoid; sp, facet for splenial; sym, symphysis. Scale bar = 2 mm.



rows that appear to be diagonally aligned with respect to the long axis of the dentary, as in *Captorhinus aguti.* The anterior two teeth are broken, and there is room for two additional teeth along the middle portion of the jaw. The mandible is broken and the full extent of the tooth row cannot be determined. The jaw is small compared to those of other multiple-rowed captorhinids, such as *Captorhinus, Labidosaurikos,* and *Captorhinikos.* (*Captorhinikos parvus* is also rather small [see Olson, 1970], although it may well represent a juvenile of another captorhinid [J. R. Bolt, personal communication, 1998]). As preserved, the jaw is 12.98 mm long, 1.77 mm high at the symphysis, and 2.92 mm high at the posterior end. The jaw is slender and sculpturing is only weakly developed, unlike the condition in typical captorhinids such as *Captorhinus.* The anterior part of the dentary is expanded where it forms the symphysis, which appears to lack contribution from other mandibular elements such as the splenial and Meckel's cartilage. In general, the symphysis is vaguely reminiscent of the microsaur *Cardiocephalus* (see Gregory and others, 1956). There is a line of foramina on the lateral surface of the dentary, starting at the symphysis and extending to a point below the 13th tooth. The foramina are small and most abundant anteriorly (beneath the first five teeth); posteriorly, they are more elongate and less densely placed. The medial surface of the dentary bears a clear scar for the splenial, which extends anteriorly to the ventroposterior margin of the symphysis (Fig. 2). The jaw slightly deepens posteriorly, beneath the multiple-rowed positions, though not nearly as much as seen in other multiple-rowed captorhinids. The coronoid platform is parallel to the occlusal (horizontal) plane and begins below the gap between the seventh and eighth teeth; it forms a long, thin shelf for the articulation of the coronoid. Posteriorly, the coronoid platform progressively narrows and continues to the broken posterior margin of the jaw. Anterior to the coronoid is the splenial platform, which begins below the fifth tooth and broadens to its maximum width below the sixth tooth, where the dentary bears a small, posteroventrally directed bony process that probably helps support the enlarged splenial. The splenial platform extends to below the coronoid and tapers out below the ninth tooth. The splenial is orientated at a high angle (~45°) to the occlusal plane of the jaw. The splenial scar indicates that the splenial reached the height of the dorsal coronoid-dentary suture. This characteristic is seen in several microsaurs (see Carroll and Gaskill, 1978). In *Captorhinus,* the height of the splenial only reaches the bottom edge of the coronoid. In this respect, *Baeotherates fortsillensis* differs from typical captorhinids and resembles, instead, the microsaurs *Cardiocephalus* and *Euryodus.*

The mandibular dentition of *Baeotherates fortsillensis* is continuous, with only two small gaps; one gap is between the seventh and eighth teeth, and the other is between the 11th and 12th teeth. The lengths of both gaps are smaller than the adjacent teeth. The dentary surface in both gaps shows scarring and impressions of tooth loss. Both of the teeth appear to have been lost well before death. Resorption pits, as found in most primitive tetrapods (Bolt and DeMar, 1975), are not present. The anterior-most tooth is broken off at the level of the dentary, and the second tooth has part of the tip broken off; both of the breaks were post-mortem. All of the tooth bases are robust. The bases of teeth 1–4 are compressed mesiodistally; teeth 5–9 have rounded bases; and teeth 10–15 are labiolingually compressed. The broken base of the first tooth is only slightly smaller than the base of the second tooth. The alveolar margin of the jaw and the orientation of the partial second tooth (which is nearly parallel to the first tooth in most other captorhinids [D. L. Brinkman, personal communication, 1998]) suggest that the first tooth was not procumbent, as it is in *Captorhinus, Eocaptorhinus,* and an unnamed basal captorhinid from the same site (Modesto, 1996). A canine region, found in all other captorhinids (Dodick and Modesto, 1995), is lacking. Teeth 3–10 bear a mesial keel that extends from the apex downward one-fourth to one-half the length of each crown. Smaller, distal cutting edges extend only about one-fourth or less of the tooth length. The tips of teeth 2–10 are labiolingually compressed and recurved; the anterior keel is progressively more horizontal at posterior loci. Tooth 11 is labiolingually compressed and has a chisel-shaped crown; in these respects, it is intermediate in design between the anterior teeth and the posterior, multiple-rowed teeth. The overall crown shapes of teeth 3–11 show a gradual change from the recurved, anterior teeth to the chisel-shaped posterior, multiple-rowed teeth. The crowns of the multiple-rowed teeth (teeth 12–15) resemble those of the multiple-rowed posterior teeth of *Captorhinus aguti* (see Fox and Bowman, 1966). The lingual surface of the crowns of teeth 2–11 have fluting produced by enamel ridges radiating from the tips of the crowns to just less than one-half the length of each tooth. There is light fluting on the labial surface of teeth 2–7 and strong fluting, matching the lingual surface, on teeth 8–11. The posterior, multiple-rowed teeth (teeth 12–15) form two irregular rows; faint fluting is present labially and lingually, but it is restricted to the top one-third of the tooth crowns. Teeth gradually decrease in height (measured on the lingual surface) from the first unbroken tooth, tooth 3 (0.91 mm high), to the 15th tooth (0.49 mm high).

Comparison and Discussion

Baeotherates fortsillensis possesses a complex mix of characters that establish it as a new taxon and, at the same time, make its affinities rather puzzling. We place *Baeotherates fortsillensis* among the captorhinomorphs, in the family Captorhinidae, based on the presence of multiple-rowed posterior teeth (the most distinctive feature found within the family [de Ricqlès and Bolt, 1983]) and aspects of tooth morphology, as discussed below. Captorhinomorphs have been traditionally regarded as "stem" reptiles because of their generally primitive morphology (e.g., Romer, 1966; Carroll, 1969). Phylogenetic analyses have placed captorhinomorphs (and constituent taxa) variably among the Amniota, including in a basal, ancestral position (e.g., Carroll, 1991); as anapsids being related to turtles (e.g., Clark and Carroll, 1973; Gaffney and McKenna, 1979; Gaffney and Meylan, 1988; Gauthier and others, 1989); or as basal diapsids (Gauthier, 1994). Two families of captorhinomorphs are generally recognized (Heaton and Reisz, 1986), with more advanced forms being placed in the Captorhinidae. We follow Laurin and Reisz (1995) in their placement of various captorhinomorph taxa and in their recognition of Captorhinidae as basal members of Eureptilia, including proterothyridids, diapsids and their relatives. Other multiple-rowed captorhinids from the Lower Permian are *Labidosaurikos* (see Stovall, 1950; Dodick and Modesto, 1995), *Captorhinoides* (see Olsen, 1951) and *Captorhinikos* (see Olson, 1954), the latter of which may be represented at nearby Bally Mountain (D. L. Brinkman, personal communication, 1997). Both single- and multiple-rowed captorhinids are known from the Fort Sill locality (Fox and Bowman, 1966; Modesto, 1996).

Before comparing *Baeotherates fortsillensis* to captorhinids, it is worthwhile to note that certain features of the dentary appear to be atypical for that family and, instead, are variably encountered among microsaur amphibians. For example, the mandibular symphysis is expanded in comparison to the condition in *Captorhinus*, and the dentary lacks the bipartite symphysial connections (reflecting the presence of a Meckelian canal and, presumably, Meckelian cartilage) seen in that and similar taxa, such as *Eocaptorhinus* (see Heaton, 1979, fig. 31A) and the basal, unnamed captorhinid from Fort Sill (Modesto, 1996, fig. 3). Unfortunately, the condition cannot be determined in most other captorhinids (see, e.g., figures in Clark and Carrol, 1973). Additionally, the splenial appears to have been virtually excluded from the symphysis; in most captorhinids, the dentary and splenial make approximately equal contributions to the symphysis, and in certain genera, such as *Labidosaurikos*, the splenial is dominant (Dodick and Modesto, 1995). A splenial contribution to the symphysis is widespread among early amniotes and is presumed to be a primitive feature for reptiles (Romer, 1956). The expanded dentary symphysis and limited extension of the splenial anteriorly in *Baeotherates fortsillensis* are similar to the condition seen in the gymnarthrid microsaur *Cardiocephalus* (e.g., OMNH 55779); however, in the closely related *Euryodus* (Carroll and Gaskill, 1978, fig. 40), the dentary symphysis is much less extensive. In *Baeotherates fortsillensis*, the scar for the splenial also differs substantially from the condition in captorhinids for which this region of the jaw is well known. In *Baeotherates fortsillensis*, as in *Euryodus*, the splenial scar on the dentary begins anteriorly as a platform that is only slightly angled with respect to the occlusal plane. In *Captorhinus* and *Eocaptorhinus*, however, the splenial has a much more vertically oriented facet on the dentary. As with the symphysis, microsaurs appear to be variable in the extent and placement of the coronoid and splenial; *Euryodus* (e.g., OMNH 03043) contrasts with *Cardiocephalus* and *Baeotherates* in having a vertically oriented coronoid scar on the dentary. *Baeotherates fortsillensis* also differs from *Captorhinus* and *Eocaptorhinus* in lacking extensive sculpturing on the lateral surface of the dentary. The significance of the foregoing differences of *Baeotherates fortsillensis* from well known captorhinids is difficult to evaluate because of uncertainties regarding these characters in basal captorhinid taxa. Given the known variability among microsaurs, however, we are inclined to regard the similarities to *Cardiocephalus* as less compelling than the dental similarities—particularly the presence of multiple-rowed posterior teeth—of *Baeotherates fortsillensis* to advanced Captorhinidae. *Baeotherates fortsillensis* is a small captorhinid, but its differences from the typical members of the family are not due to size or ontogenetic age: It differs from juvenile *Captorhinus aguti* (Fig. 3) in the same ways that it differs from adults of that species.

Laurin and Reisz (1995) included 12 genera in the Captorhinidae and diagnosed the group as monophyletic on the basis of 12 synapomorphies (see also Berman

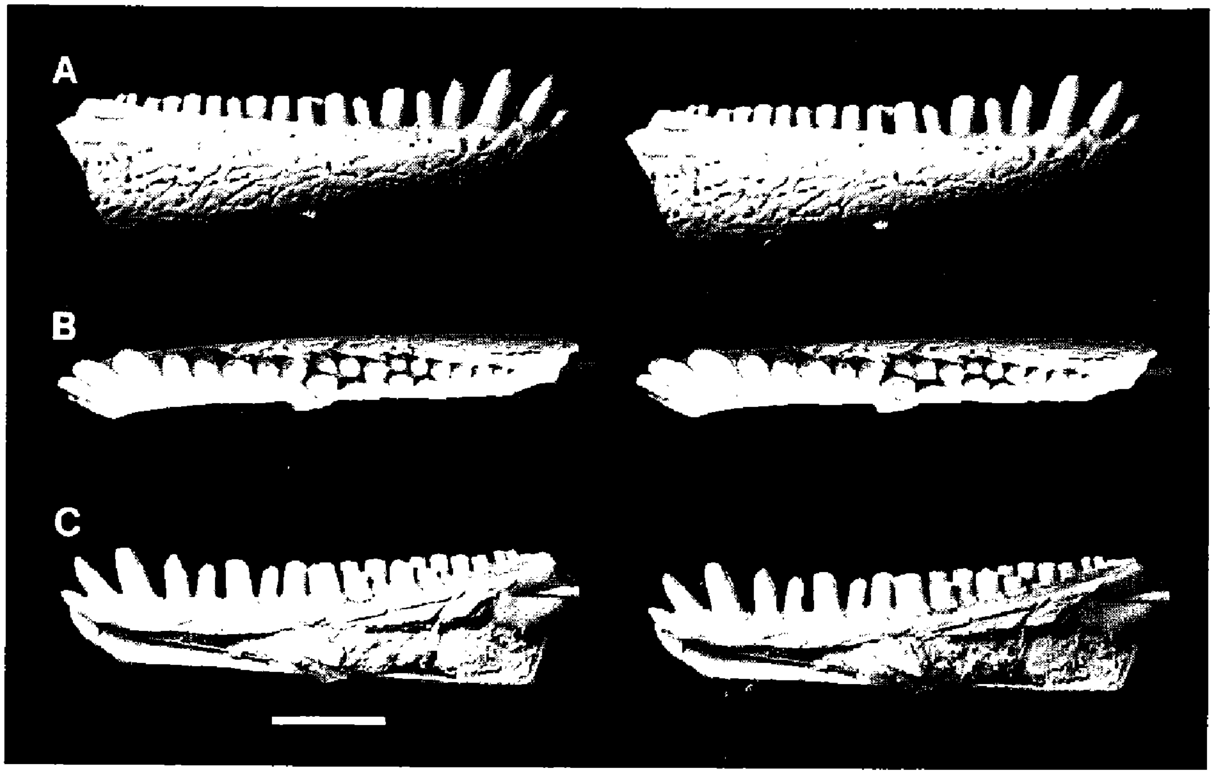


Figure 3. *Captorhinus aguti*. OMNH 55809, right mandible of juvenile individual in labial (A), occlusal (B), and lingual (C) views (stereopairs). Object at the posterior edge of the dentary in C is a mounting pin affixed to the lingual side of the jaw. Scale bar = 5 mm.

and Reisz, 1986). Of these, 10 are cranial and two are postcranial characters; hence, none are observable in *Baeotherates fortsillensis*. However, mandibular and dental characteristics known for the various captorhinid genera, coupled with existing hypotheses on character polarity and relationships within the group (Clark and Carroll, 1973; Gaffney and McKenna, 1979; Berman and Reisz, 1986; Dodick and Modesto, 1995), offer the basis for some limited comparisons and commentary.

The dentition of *Baeotherates fortsillensis* includes anterior teeth that are recurved, are mesiodistally compressed, and bear mesial and distal cutting surfaces; these grade into posterior teeth that have chisel-shaped, labiolingually compressed crowns. Recurvature of tooth crowns may be a plesiomorphy retained in captorhinids; however, the presence of anterior and posterior cutting surfaces may be an advanced feature characterizing the family Captorhinidae (Modesto, 1996). The presence of multiple tooth rows and labiolingually compressed, chisel-shaped tooth crowns would appear to ally *Baeotherates fortsillensis* with advanced captorhinids such as *Captorhinus* and *Eocaptorhinus* (see, e.g., Clark and Carroll, 1973; Heaton, 1979), to the exclusion of proterothyridids and basal captorhinids such as *Romeria, Protocaptorhinus,* and *Rhiodenticulatus* (Dodick and Modesto, 1995). Berman and Reisz (1986, p. 18) grouped *Captorhinus* with *Eocaptorhinus, Labidosaurus,* and presumably all multiple-rowed captorhinids based on the presence of "blunt post-canines," which appear to refer to the same character. Based on analysis of cranial and dental characters, Dodick and Modesto (1995) have suggested that multiple tooth rows evolved twice among captorhinids: (1) in a clade including *Labido-*

saurikos with single-rowed *Labidosaurus* and (2) independently in a clade including *Captorhinus* and single-rowed *Eocaptorhinus* (distinctiveness at the generic level is debated [see, e.g., Clark and Carroll, 1973; Bolt and DeMar, 1975; Heaton, 1979]). To which group is *Baeotherates fortsillensis* related—if either? In terms of tooth morphology, *Baeotherates fortsillensis* is very similar to *Captorhinus* and *Eocaptorhinus*, except that the fluting is more extensive than in those taxa and is present labially as well as lingually. Because the first tooth in the type of *Baeotherates fortsillensis* is broken, it cannot be determined whether or not it was procumbent, as in those taxa (Dodick and Modesto, 1995), although the relationship of the tooth base to the alveolar margin of the jaw suggests that it was not. *Baeotherates fortsillensis* also differs from *Captorhinus* and *Eocaptorhinus* in having a relatively high number of morphologically anterior teeth. Fox and Bowman (1966) (see also, Bolt and DeMar, 1975) recognized three tooth regions in the mandibular dentition of *Captorhinus aguti*: an anterior region, in which the teeth are sharply pointed and mesiodistally compressed; a posterior region, characterized by labiolingually compressed, chisel-shaped teeth (multiple-rowed in *C. aguti*; morphologically similar teeth are seen in single-rowed *Eocaptorhinus*), and an intermediate region. Whereas the anterior region of *Captorhinus* generally includes four or five (rarely up to six or seven) teeth, the first nine teeth of *Baeotherates fortsillensis* can be placed in this region. *Eocaptorhinus* resembles *Captorhinus* in having a low number of teeth in the anterior region (see Heaton, 1979, fig. 31A). *Labidosaurikos meachami* only has four anterior teeth (Stovall, 1950; Dodick and Modesto, 1995); both *Captorhinikos valensis* and *Captorhinikos chozaensis* have six or seven (Olson, 1962). Another puzzling feature of *Baeotherates fortsillensis* is that it lacks enlargement of anterior lower teeth into canines. Canines are found not only in *Eocaptorhinus* and *Captorhinus*, but in other multiple-rowed taxa and in more primitive members of the family, including *Romeria* and *Protocaptorhinus* (Dodick and Modesto, 1995; Modesto, 1996). Finally, the overall shape of the jaw of *Baeotherates fortsillensis* is distinct from that of all other captorhinids: It has a more slender and delicate form and an apparent lack of sculpturing on the labial surface.

Baeotherates fortsillensis is unique in its unusual combination of dental (e.g., extensive fluting) and mandibular (e.g., mandibular symphysis, coronoid facet) morphology. The taxonomic position of *Baeotherates fortsillensis* within the Captorhinidae—assuming that referral to the group is correct—remains uncertain because its morphology is at odds with characteristics currently used to evaluate relationships within the family. Despite the presence of multiple tooth rows in *Baeotherates fortsillensis* and the similarity of its teeth to those of advanced captorhinids such as *Captorhinus* itself, *Baeotherates fortsillensis* lacks at least one presumably derived feature (restriction of the anterior tooth region to the first few tooth positions) possessed not only by the clade including *Captorhinus* and *Eocaptorhinus*, but also by taxa widely believed to be closely related, including *Labidosaurus* and presumed relatives (e.g., Clark and Carroll, 1973; Berman and Reisz, 1986). The lack of a canine region in *Baeotherates fortsillensis* poses a more serious character conflict, as this feature has been identified as a synapomorphy of the Captorhinidae (Dodick and Modesto, 1995). Collectively, the character combination seen in *Baeotherates fortsillensis* implies hitherto unappreciated variability in the mandibular and dental morphology of Captorhinidae and suggests, in turn, that caution be used in relying upon such features in phylogenetic analysis within this group of early reptiles.

Acknowledgments

The authors are grateful to the Dolese Brothers Company and, in particular, to Jim Allen (General Manager of Operations) and Wayne Moran (Plant Superintendent) of the Richards Spur quarry, for their continued support of the Oklahoma Museum of Natural History in our endeavors to collect and preserve the exquisite fossils from this unique site, and for their cooperation in the ongoing research being conducted by many different institutions. We also thank Kyle Davies (OMNH), who found the above specimen, and Dan L. Brinkman (Yale University) and Drs. Robert Reisz (Erindale College, Ontario, Canada) and John R. Bolt (Field Museum of Natural History, Chicago) for helpful information and comments on an earlier version of this paper.

References Cited

Berman, D. S.; and Reisz, R. R., 1986, Captorhinid reptiles from the Early Permian of New Mexico, with description of a new genus and species: Annals of the Carnegie Museum, v. 55, p. 1–28.

Benton, M. J., 1997, Vertebrate paleontology: Chapman and Hall, London, 452 p.

Bolt, J. R.; and DeMar, R. E., 1975, An explanatory model of the evolution of multiple rows of teeth: Journal of Paleontology, v. 49, p. 814–832.

Carroll, R. L., 1969, Problems of the origin of reptiles: Biological Reviews, v. 44, p. 393–432.

_____ 1988, Vertebrate paleontology and evolution: W. H. Freeman and Company, San Francisco, 698 p.

_____1991, The origin of reptiles, *in* Schultze, H.-P.; and Trueb, Linda (eds.), Origins of the higher groups of Tetrapods—controversy and consensus: Comstock Publishing Associates, Ithaca, New York, p. 331–353.

Carroll, R. L.; and Gaskill, Pamela, 1978, The Order Microsauria: Memoirs of the American Philosophical Society, v. 117, 211 p.

Clark, John; and Carroll, R. L., 1973, Romeriid reptiles from the Lower Permian: Bulletin of the Museum of Comparative Zoology, v. 144, p. 353–407.

de Ricqlès, Armand; and Bolt, J. R., 1983, Jaw growth and tooth replacement in *Captorhinus aguti* (Reptilia: Captorhinomorpha)—morphological and histological analysis: Journal of Vertebrate Paleontology, v. 3, p. 7–24.

Dodick, J. T.; and Modesto, S. P., 1995, The cranial anatomy of the captorhinid reptile *Labidosaurikos meachami* from the Lower Permian of Oklahoma: Palaeontology, v. 38, p. 687–711.

Fox, R. C.; and Bowman, M. C., 1966, Osteology and relationships of *Captorhinus aguti* (Cope) (Reptilia: Captorhinomorpha): University of Kansas Paleontological Contributions, Vertebrata, art. 11, p. 1–79.

Gaffney, E. S.; and McKenna, M. C., 1979, A Late Permian captorhinid from Rhodesia: American Museum Novitates, no. 2688, p. 1–15.

Gaffney, E. S.; and Meylan, P. A., 1988, A phylogeny of turtles, *in* Benton, M. J. (ed.), The phylogeny and classification of the Tetrapods: Clarendon Press, Oxford, p. 157–219.

Gauthier, J. A., 1994, The diversification of the Amniotes, *in* Spence, R. S. (ed.), Major features of vertebrate evolution: Short Course in Paleontology 7: The Paleontological Society, p. 129–159.

Gauthier, J. A.; Cannatella, David; De Queiroz, Kevin; Kluge, A. G.; and Rowe, T. B., 1989, Tetrapod phylogeny, *in* Fernholm, B. O.; Bremer, Karen; and Jornvall, Hans (eds.), The hierarchy of life: Elsevier Science Publisher, Amsterdam, p. 337–353.

Gregory, J. T.; Peabody, F. E.; and Price, L. I., 1956, Revision of the Gymnarthridae, American Permian microsaurs: Peabody Museum of Natural History Bulletin, v. 10, p. 1–77.

Heaton, M. J., 1979, Cranial anatomy of primitive captorhinid reptiles from the Late Pennsylvanian and Early Permian, Oklahoma and Texas: Oklahoma Geological Survey Bulletin 127, 84 p.

Heaton, M. J.; and Reisz, R. R., 1986, Phylogenetic relationships of captorhinomorph reptiles: Canadian Journal of Earth Sciences, v. 23, p. 402–418.

Ivanchnenko, M. F., 1990, Elements of the early Permian tetrapod faunal asemblages [*sic*] of eastern Europe: Paleontological Journal, v. 24, no. 4, p. 104–112.

Laurin, Michel; and Reisz, R. R., 1995, A reevaluation of early amniote phylogeny: Zoological Journal of the Linnean Society, v. 113, p. 165–223.

Modesto, S. P., 1996, A basal captorhinid reptile from the Fort Sill fissures, Lower Permian of Oklahoma: Oklahoma Geology Notes, v. 56, p. 4–14.

Olson, E. C., 1951, A new Captorinomorph [*sic*] reptile, *part 2 of* Fauna of upper Vale and Choza: Fieldiana: Geology, v. 10, p. 97–104.

_____ 1954, Captorhinomorpha, *part 9 of* Fauna of the Vale and Choza: Fieldiana: Geology, v. 10, p. 211–218.

_____ 1962, The osteology of *Captorhinikos chozaensis* Olson, *part 2 of* Permian vertebrates from Oklahoma and Texas: Oklahoma Geological Survey Circular 59, p. 49–68.

_____ 1967, Early Permian vertebrates of Oklahoma: Oklahoma Geological Survey Circular 74, 111 p.

_____ 1970, New and little known genera and species of vertebrates from the Lower Permian of Oklahoma: Fieldiana: Geology, v. 18, p. 359–434.

_____ 1991, An eryopid (Amphibia: Labyrinthodontia) from the Fort Sill fissures, Lower Permian, Oklahoma: Journal of Vertebrate Paleontology, v. 11, p. 130–132.

Romer, A. S., 1956, Osteology of the reptiles: University of Chicago Press, 772 p.

_____ 1966, Vertebrate paleontology: University of Chicago Press, 468 p.

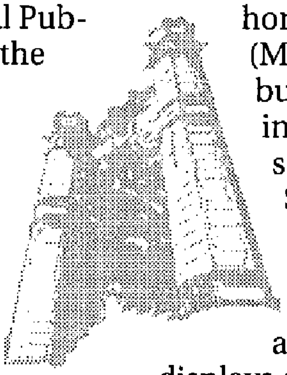
Stovall, J. W., 1950, A new cotylosaur from north central Oklahoma: American Journal of Science, v. 248, p. 46–54.

Introducing a Series of Articles—

Building and Ornamental Stones on the OU Campus

The Norman campus of The University of Oklahoma (OU) is rightfully known for its beautiful plants and trees and its interesting architecture; it should also be known for the fascinating geological stories that its building and decorative stones have to tell. In addition, a number of extraordinary mineral and fossil exhibits on campus deserve recognition.

To encourage people to visit the OU campus and appreciate the geologic features around them, the Oklahoma Geological Survey plans to compile and publish a book in its Educational Publication series that will focus on the building and ornamental stones and geological exhibits of the Norman campus. The publication will be a guidebook format and offer a self-guided tour for visitors to the OU campus and for beginning geology students. It will include a map of the Norman campus showing the location of the subject buildings and monuments. It also will identify the stones, describe the visible geologic features and textures, and explain the geologic history and/or significance of the stones.



It was determined that OU geology students could benefit from the experience of writing for this publication, so Professors Tom Dewers and Dave London, OU School of Geology and Geophysics, and I coordinated a one-credit-hour course titled "Building Stones of the OU Campus." The course was first held in the Spring 1998 semester. Each student selected a topic from a variety of interesting geologic subjects, investigated it, and wrote a paper about it. Subjects ranged from the rocks that make up the Ada Louis Sipuel Fisher fountain, to the Indiana Limestone (the principal building stone for many of the older structures on campus), to concrete and aggregate.

As a preview of the Educational Publication, *Oklahoma Geology Notes* will publish some of the outstanding papers written for the class. Some articles, like the one on the Wapanucka oolite (the first in the series; it starts on the next page), describe stones that tell a story about the State's geologic history. Others will feature stones that are native and unique to Oklahoma, such as the "Birdseye" (McLish) Limestone; or common building materials with an interesting geologic component, such as the gravel walkways. Some papers will highlight remarkable exhibits, such as the fossils in the Laurence S. Youngblood Energy Library, and the rock and mineral displays of the OU School of Geology and Geophysics.

The OGS hopes that this series of articles and the upcoming Educational Publication will inspire geologists and earth science teachers to look at building stones elsewhere in the State as educational resources.

We gratefully acknowledge the assistance of Mr. Red Dennis, stonemason (OU Landscape and Grounds), and Mr. Dave Stapleton, assistant director of OU Architectural and Engineering Services, for sharing their extensive knowledge of the building materials on campus. Their help was invaluable, and they deserve much of the credit for enabling us to identify many of the rocks on campus for this project.

Neil H. Suneson

Building and Ornamental Stones on the OU Campus

WAPANUCKA OOLITIC LIMESTONE

Sharon D. Woods[1]

Introduction

The George Lynn Cross Statue (Fig. 1) is dedicated to the seventh and longest-serving president (1944–1968) of The University of Oklahoma (OU). This bronze statue, unveiled in 1996, is located on the lawn of the Parrington Oval (also called the "North Oval") in front of Evans Hall (Fig. 2). It was sculpted by Paul Moore, an Oklahoma artist formerly working in Santa Fe, New Mexico, and now an artist-in-residence at OU. The white stone blocks that support the statue are carved out of an oolitic limestone known as the Wapanucka oolite, a native rock of Oklahoma. This oolite, along with other kinds of limestone from the Wapanucka Formation, also are used at Boyd House and at the new Sam Noble Oklahoma Museum of Natural History on OU's Norman campus.

The name Wapanucka comes from "Wapanachki," which means "easterner" or "eastern land people" (Wright, 1986); it is the name by which the Delaware Indians and other Algonquian tribes relocated to the west were known. The stone received its name from the town of Wapanucka, where the Wapanucka Formation was first described (Taff, 1901). The Wapanucka oolitic limestone is part of the Lower Limestone Member of the Wapanucka Formation. The Wapanucka oolite, which goes by the trade name of Bromide or Wapanucka, is found only in the State of Oklahoma (Lent, 1925). The quarry for this stone is located in south-central Oklahoma ~3.5 mi northwest of the town of Wapanucka; it is cut into a 100-ft-high ridge just north of Delaware Creek (Figs. 3, 4).

In the Wapanucka limestone ridge across the creek from the quarry are several naturally formed caves. Local legend has it that Jesse James and the Dalton Gang took refuge in these caves at various times (Cecile Gillespie, personal communication, 1998), and the initials "J. J." and the year "1880" are carved on the wall of one of the caves and also in rock above the quarry (Fig. 5).

Limestone from the Wapanucka Formation was first quarried in 1851, when the Chickasaw Rock Academy was built for the Chickasaw Indians. Remnants of this school still remain on the property across Delaware Creek from the quarry. Frank Alpine Gillespie, the grandfather of the current owners of the quarry, purchased the land where the quarry is located from the Chickasaw Nation around 1910. The quarry, then named the Bromide Oolitic Stone Company, operated from 1910 to 1915; the present-day Wapanucka Oolitic Limestone quarry operates only intermittently, on a contract basis (Cecile Gillespie, personal communication, 1998).

The Wapanucka oolite was, and still is, an economically important ornamental stone. The quality of ornamental stone is based on uniform texture, uniform hardness, and color, and the Wapanucka oolite is considered by some to be superior in quality to the world-famous Indiana Limestone of Bedford, Indiana, and the Bath

---

[1] Graduate student, School of Geology and Geophysics, University of Oklahoma.

Figure 1. Statue of George Lynn Cross, the seventh and longest serving president (1944–1968) of The University of Oklahoma (OU). The bronze statue was sculpted by Paul Moore, currently an artist-in-residence at OU, and was unveiled in 1996. The base of the statue is constructed of Wapanucka oolite.

Limestone of Bath, England (Wallis, 1915). Unlike most limestones, which turn a dull gray color (similar to that of cement) after being quarried, the Wapanucka remains a chalky white. That chalk-white color is the Wapanucka oolite's most distinctive and valuable quality. In 1934, the average cost for block stone was 20¢–30¢ per cubic foot (Bowles, 1934). Today, the cost per cubic foot is $10–$12 (Cecile Gillespie, personal communication, 1998). Since 1951, however, this rock has had limited use as a building stone because some of this stone has multiple fractures. Great care must be taken in quarrying so that blocks are not broken up.

Description of the Wapanucka Oolite in the Base of the George Lynn Cross Statue

Ooliths

Upon close inspection of the statue base, you will notice that the limestone is packed with millions of tiny white spheres called ooids or ooliths (Fig. 6). Ooliths are spherical, or nearly spherical, inorganic grains, usually formed of calcium carbonate ($CaCO_3$); they have a concentric structure produced during their growth, while they are suspended and rolled about in agitated water (Eicher and McAlester, 1980). Most ooliths have a nucleus of a shell fragment, an algal pellet, or a quartz grain that is coated by $CaCO_3$ (Boggs, 1995). The $CaCO_3$ comes from currents of cold ocean water that is supersaturated with dissolved $CaCO_3$; as the water warms in shallow seas, the $CaCO_3$ is precipitated and coats the suspended grains (Press and Siever, 1982).

Fossils

Other prominent features of this oolitic limestone are the various fragments of fossils. These remnants of once-living organisms that existed in shallow-marine waters were broken apart by constant wave motion. The fauna of the Wapanucka oolite consists principally of brachiopods, ostracods, gastropods, spicules, bryozoans, crinozoan columns, solitary rugose corals, bivalves, and foraminifers (Rowett and Sutherland, 1964; Grayson, 1980; Brown, 1987). A few large fossil fragments can be seen in the statue base (Fig. 6). Pieces of crinoid stems, corals, brachiopods, and bryozoans also can be identified within the limestone blocks of the base.

Trace fossils also add to the beauty of this ornamental stone. Trace fossils are tracks, trails, burrows, borings, and other structures made by organisms that lived upon, or dug through, bedding surfaces or sediment layers (Boggs, 1995). One of these biogenic structures, a burrow, can be identified within the base; notice how the burrow cuts through the bedding-plane surfaces (Fig. 7).

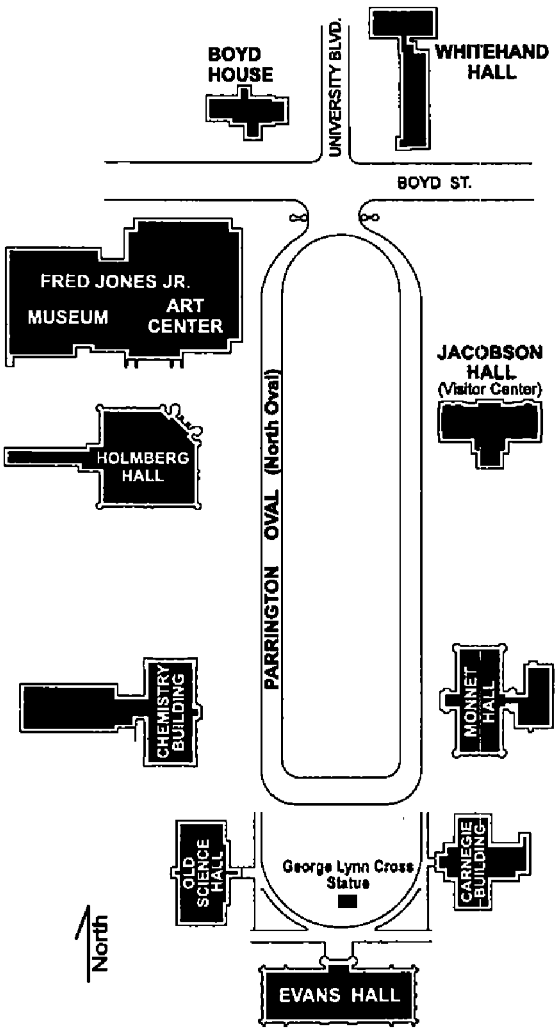


Figure 2. Map of the OU campus (Norman), showing the location of the George Lynn Cross Statue on the Parrington Oval, north of Evans Hall.

Gaps, Fractures, and Stylolites

As you continue to examine the base of the statue, you will notice what appear to be horizontal and vertical fractures in many of the blocks. Not all of these features are actual fractures. The horizontal features are parallel to the bedding planes and occur in areas of the rock that are dark gray in color. In these areas, the clay content of the oolite is high and the clay is beginning to weather out. Where the clay has weathered out completely, a gap remains in the rock. The vertical features in these blocks appear to be of two types. One vertical feature is fairly linear in nature and has been cemented with calcite; it is a possible fracture. The other vertical feature has a sawtooth pattern and is known as a stylolite.

A stylolite is a surface that transects the whole rock and results from pressure and dissolution. The zigzag form of the surface is presumed to be a consequence of stress-enhanced solubility variations within a rock (Bathurst, 1975). This means that, under stress, more soluble parts of a rock dissolve and less soluble parts replace them. Stylolites can be oriented horizontally or vertically. Horizontal stylo-

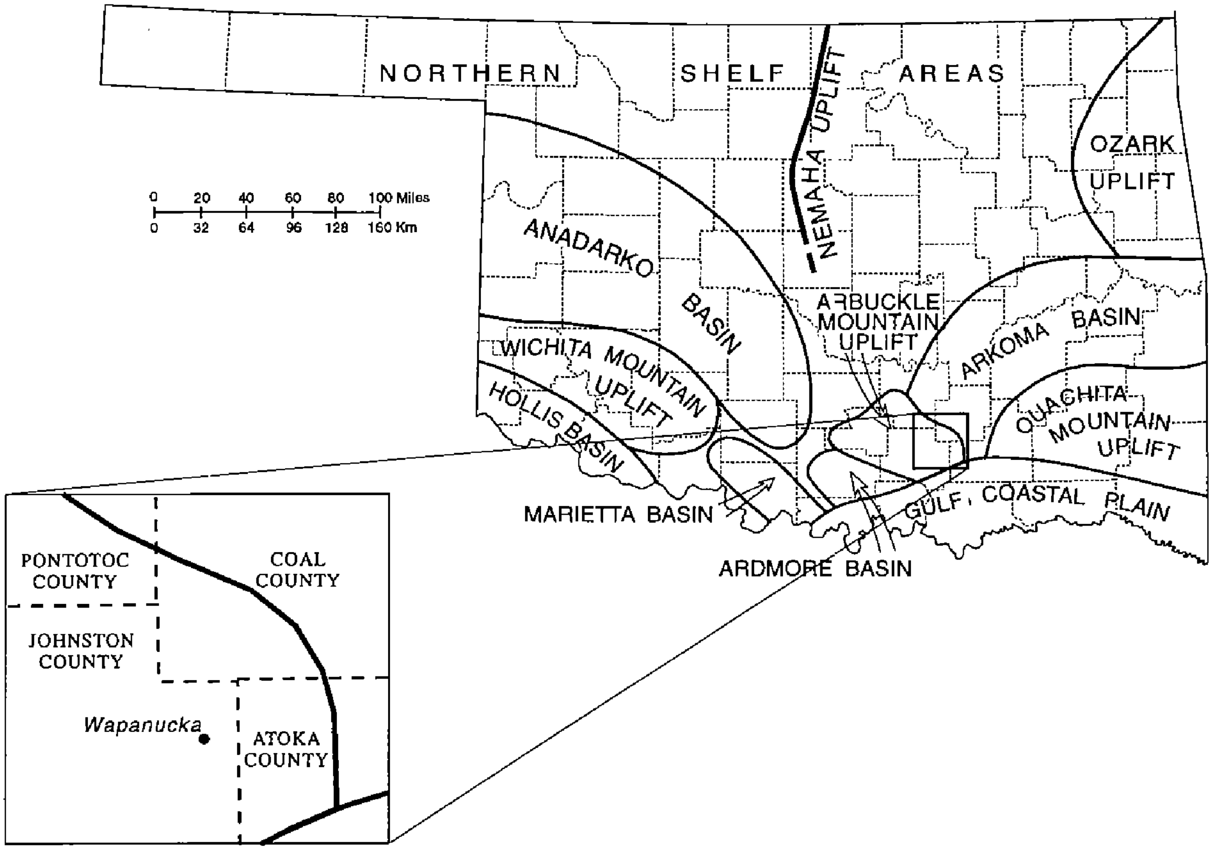


Figure 3. Map of Oklahoma showing the location of the town of Wapanucka. The present-day Wapanucka Oolitic Limestone quarry is ~3.5 mi northwest of town.

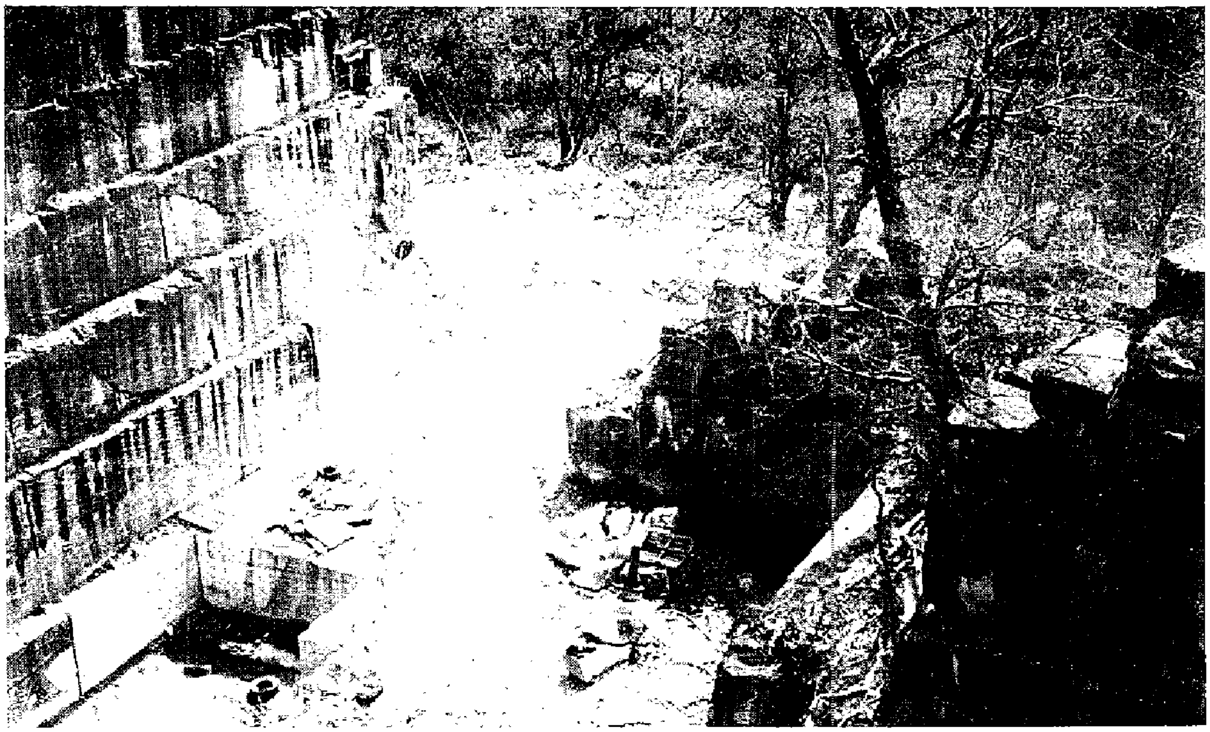


Figure 4. The present-day Wapanucka Oolitic Limestone quarry. Terraces on the walls, each ~8 ft high, mark the floor level of the quarry at different stages.

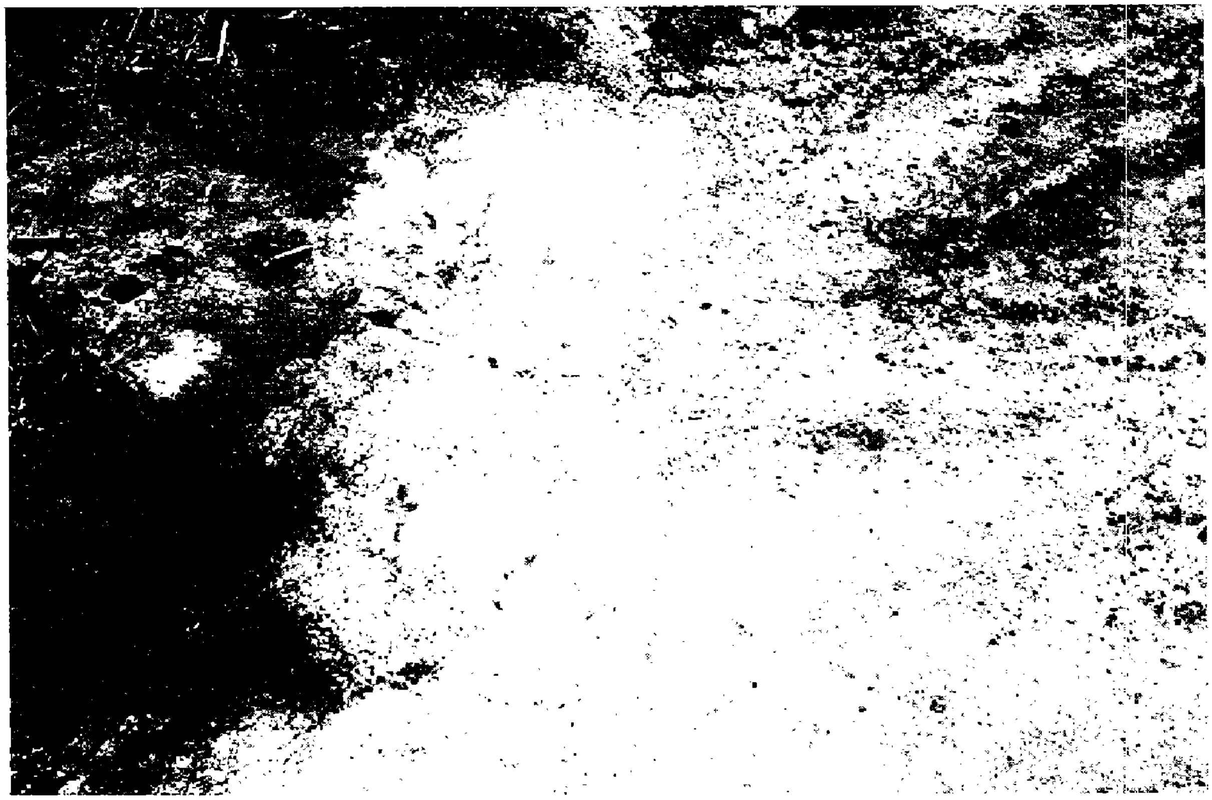


Figure 5. The initials "J. J." and the year "1880" are carved in rock above the quarry and also on the wall of one of the caves nearby. Local legend tells that Jesse James and the Dalton Gang took refuge in the area. Weathering of the limestone has made the initials difficult to see.

lites are so oriented because the dominant stress was vertical. Vertical stylolites are produced when the dominant stress is horizontal. The multiple vertical stylolites in the Wapanucka oolite suggest that the oolite has undergone some type of horizontal compression, which may have occurred during the Pennsylvanian Period of geologic time (290–330 million years ago), when the Arbuckle and Ouachita Mountains were formed.

Bedding

Gently tilted streaks of dark gray against the white background add a pleasing effect to the stone. These streaks are tilted foreset laminae or layers, and two types can be identified within the oolite: those that are planar and those that are curved. The planar laminae are tabular cross-beds, and the curved laminae are trough cross-beds. Cross-beds are evidence for ripples or dunes, which form in a current when grains move up the stoss (upcurrent) side of a ripple or dune and avalanche down, or settle on, the lee (downcurrent) side. The presence of these bed forms indicates that the Wapanucka oolite was deposited in agitated or moving water.

Close inspection of the base will reveal a small seam of coal. At a glance, it looks like one of the many horizontal gaps. (Hint: It is on the west side of the statue.) The presence of this feature is somewhat unusual in an oolitic limestone. Coal usually forms in a swampy environment, whereas oolites form in a high-energy marine environment. (See the discussion of the depositional environment of this oolite under the Geology heading, p. 145.)

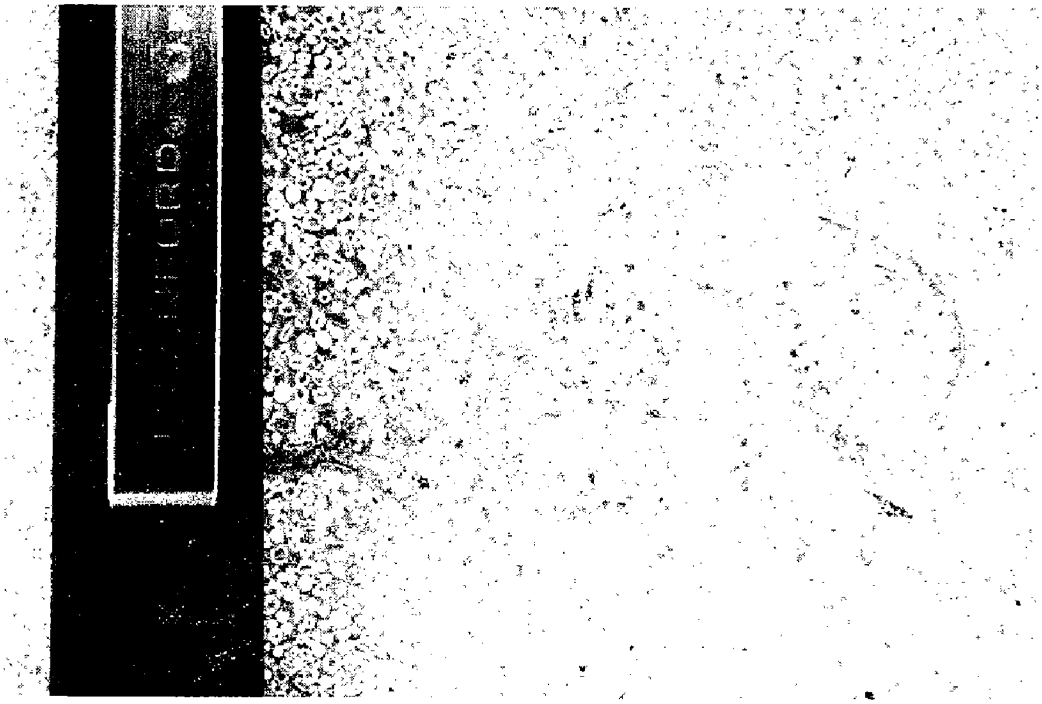


Figure 6. Most of the rock that makes up the base of the George Lynn Cross Statue is composed of small spherical grains called ooliths. The large circular fossil closest to the pen is a solitary coral (~0.6 in. in diameter); to the right is a brachiopod. These fossils can be found on the east side of the statue.

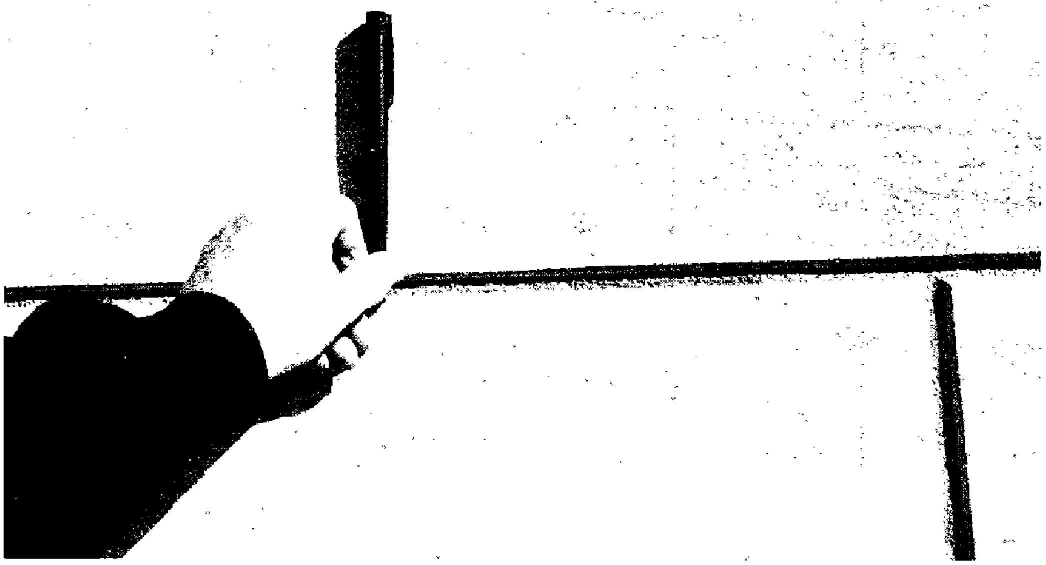


Figure 7. The horizontal layers in the oolite are bedding planes, formed by the successive accumulations of sediment. The structure to the right of the pen (5.4 in. long) is the burrow of an animal that dug through the sediment when it was still soft. The burrow is located on the west side of the statue.

Geology of the Wapanucka Oolite

Outcrop Area of the Wapanucka Formation

The Wapanucka oolite is part of the Wapanucka Formation, an Early Pennsylvanian rock unit (~330 million years old). The Wapanucka Formation crops out on the eastern flank of the Arbuckle Mountains and in the northwestern part of the Ouachita Mountains in southeastern Oklahoma. The Ouachita Mountains are thought to be part of an ancient continental margin that was compressed to form a mountain range in Middle or Late Pennsylvanian time, after the Wapanucka Formation was deposited (Wickham and others, 1976).

Geologic Significance of the Wapanucka Formation

During the Misissippian (about 330–365 million years ago) and Pennsylvanian (about 290–330 million years ago) Periods, what is now Oklahoma was mostly covered by shallow seas. Limestone was deposited during the first half of the Mississippian Period in most of Oklahoma, and that deposition continued into the Early Pennsylvanian Period in some areas. South-central Oklahoma, where the Wapanucka oolite was deposited, was one of these limestone areas.

The Pennsylvanian Period was a time of major crustal unrest in Oklahoma. The uplift of the Wichita Mountains, Nemaha Ridge, Ouachita Mountains, and Arbuckle Mountains occurred during this period, as did the downwarping in the Arkoma, Ardmore, Marietta, and Anadarko basins. The rocks of the Pennsylvanian Period are different from those of the Mississippian and consist mostly of marine shale and sandstone; minor limestone, conglomerate, and coal also is present (Johnson, 1971). The Wapanucka oolite was deposited during the last phase of Pennsylvanian crustal stability in southern Oklahoma.

Composition

Grayson (1980) subdivided the Wapanucka Formation in the Ouachita Mountains into four members: (1) Chickachoc Chert, (2) Lower Limestone, (3) Middle Shale, and (4) Upper Sandstone-Limestone. The oolite, of which the statue base is constructed, is correlated with the Lower Limestone Member and has been classified by geologists as an oolitic calcarenite. The texture of this stone is that of a uniformly fine (Wallis, 1915) grainstone and packstone (Brown, 1987).

Grainstone and packstone are textural terms from Dunham's (1962) classification of limestones. A grainstone is identified as a limestone without mud in the matrix and that is grain supported; that is, the grains are so abundant that they are in three-dimensional contact and support each other. A packstone is identified as a limestone with some mud in the matrix and that contains lots of grains that are mostly in contact. Packstones do not have as many grains as grainstones. Which of these two textural types of limestone is formed depends on wave and current energy in the depositional environment, and whether all, or only some, of the mud has been washed or winnowed away.

Depositional Environment

Ooliths commonly form in shallow-marine, high-energy environments at water depths of less than 10 ft, where the bottom sediments are in constant motion due to waves and currents. Thus, ooliths are moved about by the waves and tidal currents until they are deposited. When ooliths grow too heavy to remain suspended in the water, they settle to the sea floor with other sediments. Eventually the sediments are deeply buried beneath younger sedimentary layers and are lithified to become limestone.

The textural properties of grainstone and packstone assist in identifying the depositional environment of this oolite. In general, oolitic grainstones are indicative of high-energy environments ranging from shoals to tidal channels, and that is likely to be the case for the Wapanucka oolitic grainstone (Brown, 1987). Specifically, the depositional environment of the Wapanucka oolitic sequence has been interpreted as a tidal channel (Brown, 1987). The appearance of small coal seams in the oolite is evidence that vegetation was close by, which supports interpretation of the depositional environment as tidal.

Packstones, on the other hand, are deposited in environments where water flow has slowed enough for micrite (carbonate mud) to settle out of suspension. Petrographic analysis of the Wapanucka oolitic packstone indicates that it formed in two ways: (1) ooliths surrounded by micrite suggest that deposition of ooliths and micrite occurred at the same time; (2) micrite only on the tops of ooliths suggests that the micrite was deposited after the ooliths were in place (Brown, 1987).

Afterword

The Wapanucka oolite, a beautiful ornamental stone, and other members of the Wapanucka Formation have been used elsewhere, as well as on the OU campus: the Marshall County Court House in Madill, Oklahoma; the court house in Abilene, Texas; the Petroleum Club in Tulsa, Oklahoma; and the Holy Family Cathedral in Tulsa, Oklahoma. (It was used in many more localities, but the records of the Bromide Oolitic Stone Company are no longer available to provide this information.) So, the next time you are out and about, take a close look at the stone used in the construction of buildings and statues. You might find some of the Wapanucka oolite.

References Cited

Bathurst, R. G. C., 1975, Developments in sedimentology 12: Carbonate sediments and their diagenesis [2nd edition]: Elsevier Scientific Publishing Company, New York, 658 p.

Boggs, Sam, Jr., 1995, Principles of sedimentology and stratigraphy [2nd edition]: Prentice Hall, Englewood Cliffs, New Jersey, 774 p.

Bowles, Oliver, 1934, The stone industries: McGraw-Hill Book Company, New York, 519 p.

Brown, D. L., 1987, The stratigraphy and petrography of the Wapanucka Formation along the northeastern flank of the Arbuckle Mountains in southern Oklahoma: University of Oklahoma unpublished M.S. thesis, 127 p.

Dunham, R. J., 1962, Classification of carbonate rocks according to depositional texture, *in* Ham, W. E. (ed.), Classification of carbonate rocks: American Association of Petroleum Geologists Memoir 1, p. 108–121.

Eicher, D. L.; and McAlester, A. L., 1980, History of the earth: Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 413 p.

Grayson, R. C., Jr., 1980, The stratigraphy of the Wapanucka Formation (Lower Pennsylvanian) along the frontal margin of the Ouachita Mountains, Oklahoma: University of Oklahoma unpublished Ph.D. dissertation, 319 p.

Johnson, K. S., 1971, Introduction, guidelines, and geologic history of Oklahoma. *Book I of* Guidebook for geologic field trips in Oklahoma: Oklahoma Geological Survey Educational Publication 2, 15 p.

Lent, F. A., 1925, Trade names and descriptions of marbles, limestone, sandstones, granites and other building stones quarried in the United States, Canada and other countries: Stone Publishing Company, New York, 41 p.

Press, Frank; and Siever, Raymond, 1982, Earth [3rd edition]: W. H. Freeman and Company, San Francisco, 613 p.

Rowett, C. L.; and Sutherland, P. K., 1964, Biostratigraphy and rugose corals of the Lower Pennsylvanian Wapanucka Formation in Oklahoma: Oklahoma Geological Survey Bulletin 104, 124 p.

Taff, J. A., 1901, Geologic atlas of the United States, Coalgate Folio, Indian Territory: U.S. Geological Survey, Washington, D.C., 6 p.

Wallis, F. A., 1915, The geology and economic value of the Wapanucka limestone of Oklahoma: Oklahoma Geological Survey Bulletin 23, 102 p.

Wickham, J. S.; Roeder, Dietrich; and Briggs, Garrett, 1976, Plate tectonic models for the Ouachita foldbelt: Geology, v. 4, p. 173–176.

Wright, M. H., 1986, A guide to the Indian tribes of Oklahoma: University of Oklahoma Press, Norman, 300 p.

HARTSHORNE PLAY, SOUTHEASTERN OKLAHOMA, FOCUS OF UPCOMING WORKSHOP AND FIELD TRIP

Richard D. Andrews[1]

Introduction

The Oklahoma Geological Survey (OGS), in cooperation with the Southern Midcontinent Petroleum Technology Transfer Council (PTTC), this fall will sponsor a workshop and field trip on the Hartshorne play. The one-day workshop will be presented in Oklahoma City on September 30 and again in Muskogee on November 4. The two-day field trip, headquartered in McAlester, will be held November 10–11 and again November 12–13. (For registration information, see sidebar below.)

This cooperative effort will focus in detail on the natural gas and coalbed-methane resources of the Hartshorne play, regional geology, stratigraphy, depositional environments, subsurface geology, field studies, and log-to-surface correlations. Cores and hand samples that support the interpretations of specific depositional environments and sedimentary structures will be displayed. A guest lecturer will discuss the Hartshorne play in Arkansas and its relationship to the play in Oklahoma; another speaker will discuss the drilling and completion practices of Hartshorne gas wells.

Following is a brief discussion of the information that will be covered during the upcoming workshop and field trip.

The Hartshorne Formation

The Hartshorne Formation was chosen as the topic for the workshop and field trip because it is one of the most important gas-producing horizons in the Arkoma basin of southeastern Oklahoma. (Only a small amount of oil is produced from the Hartshorne in the extreme western part of the play.) Its prominence as a gas producer is due to relatively large reserves and to the shallow depth of production. Most Hartshorne gas fields have producing intervals at depths of <3,500 ft, and many producing intervals are at depths of <2,000 ft. The play was first recognized in 1910 when the Poteau-Gilmore field was discovered. Through 1990, >655 BCF of gas has been pro-

Pricing and Registration Information for Hartshorne Play Workshop and Field Trip

Workshop: Cost is $30; price covers coffee breaks, lunch, and the workshop publication (OGS Special Publication 98-7).

Field trip: Cost is $75 before October 23 ($95 after that date). Price includes transportation, coffee breaks, lunch, and the field-trip publication (OGS Guidebook 31). Participants are responsible for their own accommodations; a block of rooms has been reserved at the Days Inn Conference Hotel in McAlester, phone (918) 426-5050.

To register or for more information: Contact Michelle Summers or Tammie Creel at the OGS, 100 E. Boyd, Room N-131, Norman, OK 73019; (405) 325-3031 *or* (800) 330-3996; fax 405-325-7069; e-mail: jlcoleman@ou.edu; Web site: www.ou.edu/special/ogs-pttc.

---

[1] Oklahoma Geological Survey.

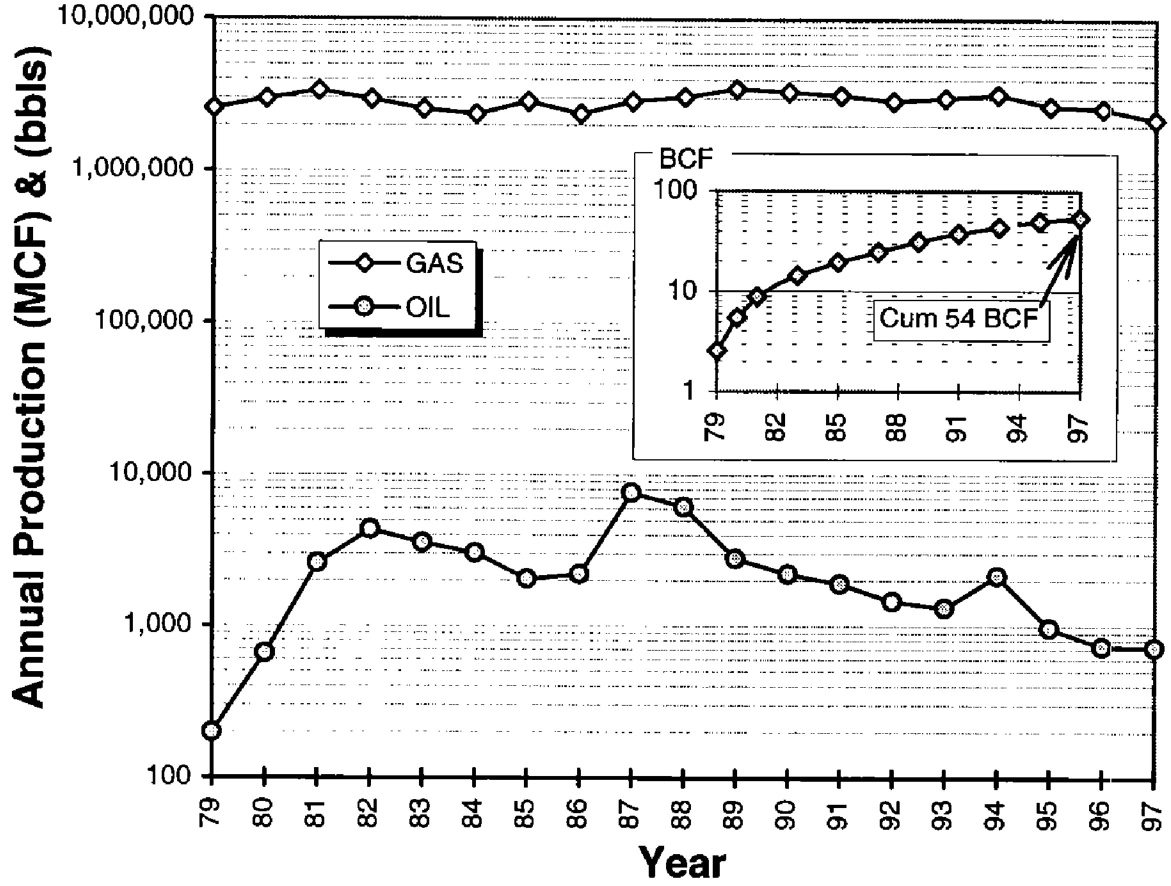


Figure 1. Annual gas and oil production from the Hartshorne Formation in Oklahoma, 1979–97. Inset graph shows cumulative gas production.

duced from the Hartshorne (Brown and Parham, 1994). Since 1991, the Hartshorne has produced ~20 BCF of gas and production has averaged 2–3 BCF of gas per year (Fig. 1) over the past 19 years.

Sandstone is the principal reservoir in the Hartshorne Formation, and production is attributed to a variety of facies originating from many different depositional environments, including marine and nonmarine. The generalized distribution of sandstone and depositional environments in the Hartshorne Formation, southeastern Oklahoma, is shown in Figure 2. The most productive reservoirs within the Hartshorne Formation are the thick channel deposits, which may have >150 ft of net sandstone. New wells completed in these thick channel reservoirs commonly have recoverable reserves of 0.5 to >1.0 BCF of gas per well; many of the wells completed early in the history of the play have cumulative gas production of several BCF. The thinner marine sandstone reservoirs in areas adjacent to the thick channel deposits typically have reserves of <250 MMCF of gas per well. In many parts of the Arkoma basin, there also is active exploration for Hartshorne coalbed methane.

Stratigraphy

The Hartshorne Formation is Middle Pennsylvanian in age and is the lowest formation within the Krebs Group. It is conformably overlain by the McCurtain Shale Member of the McAlester Formation and underlain by the black shale of the

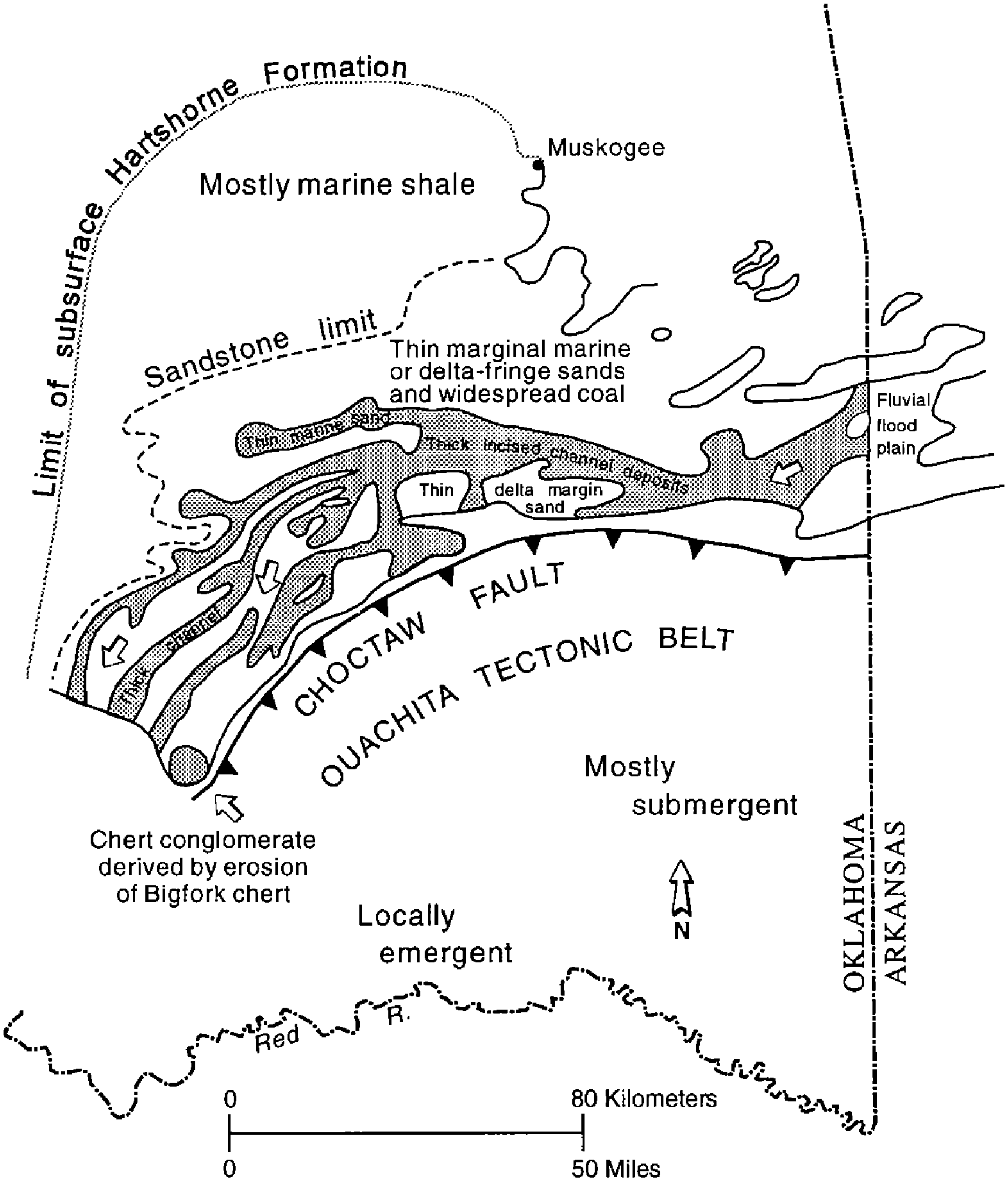


Figure 2. Generalized distribution of sandstone and depositional environments in the Hartshorne Formation, southeastern Oklahoma.

Atoka Formation. In places where the Hartshorne was deposited in deeply incised channels, the basal contact with the underlying Atoka is sharp and disconformable.

The stratigraphic nomenclature of the Hartshorne Formation has changed since it was first named for exposures of coal, sandstone, and shale near the town of Hartshorne. Detailed field work and subsurface correlations can now be used to show the relationship of different stratigraphic units that constitute the Hartshorne Formation (Fig. 3). Simply stated, the Hartshorne Formation includes two members: the Upper Member consists of the Upper Hartshorne coal plus sandstone and shale above the Lower Hartshorne coal, and the Lower Member consists of the Lower Hartshorne coal plus all sandstone and shale above the Atoka Formation. Limestone is not found anywhere in the Hartshorne Formation except in the extreme southwestern part of the play.

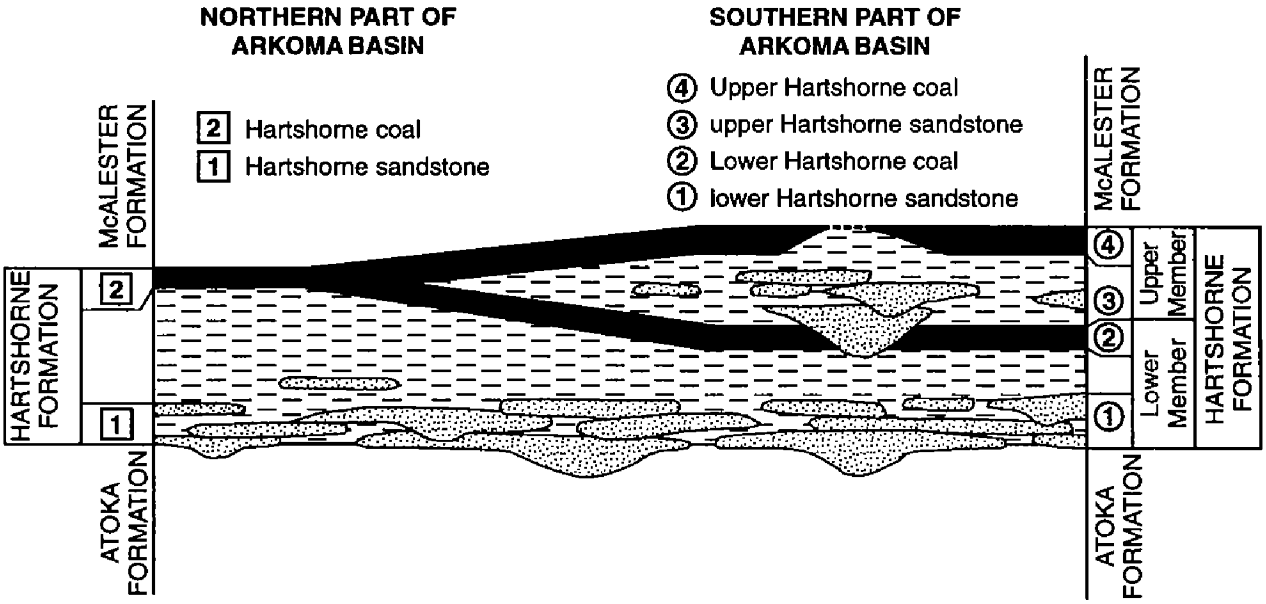


Figure 3. General relationship of different stratigraphic units (formal and informal) that constitute the Hartshorne Formation in the northern and southern parts of the Arkoma basin in Oklahoma. Note that the Upper Hartshorne coal merges with the Lower Hartshorne coal in the northern part of the Arkoma basin and that the Upper Member of the Hartshorne Formation appears to pinch out. From Hemish and Suneson (1997, fig. 3).

Field Studies

Three field studies illustrating the typical sandstone and coal reservoirs of the Hartshorne Formation will be covered in detail at the workhop and in OGS Special Publication 98-7. These field studies are briefly introduced below.

Cabaniss NW Field

This study encompasses 48 sections primarily in northwestern Pittsburg County in T. 6 N., R. 12 E. (Fig. 4). The geology within the field is typical of a progradational fluvial-dominated delta system and is unrelated to the development of a deeply incised, falling-stage channel complex located in the southeastern part of the field study area. The field was discovered in 1974 by KWB Oil Company but was not fully developed until the mid-1990s. The Hartshorne reservoir consists of relatively thin channel sandstone, thin marine deposits, and possibly coal. Cumulative gas production to date is ~3.6 BCF. Maximum sandstone thickness in the channel facies is 40 ft, whereas maximum thickness of the producing marine facies is generally <10 ft. Some field wells have gas production from intervals perforated and stimulated (fractured) in the Hartshorne coal in addition to zones containing no net sandstone. Currently, there are 21 wells producing from the Hartshorne Formation in this field study area.

Reservoir characteristics of the channel facies that are productive in the field are much more favorable than reservoir characteristics in the marine facies. The channel sandstone is typically 10–40 ft thick, and the porosity is 8–14%, averaging ~10%. Calculated water saturation is generally 5–34% and averages ~14%. Over 2- to 13-year periods, cumulative gas production for wells producing from channel reservoirs has been 175–848 MMCF.

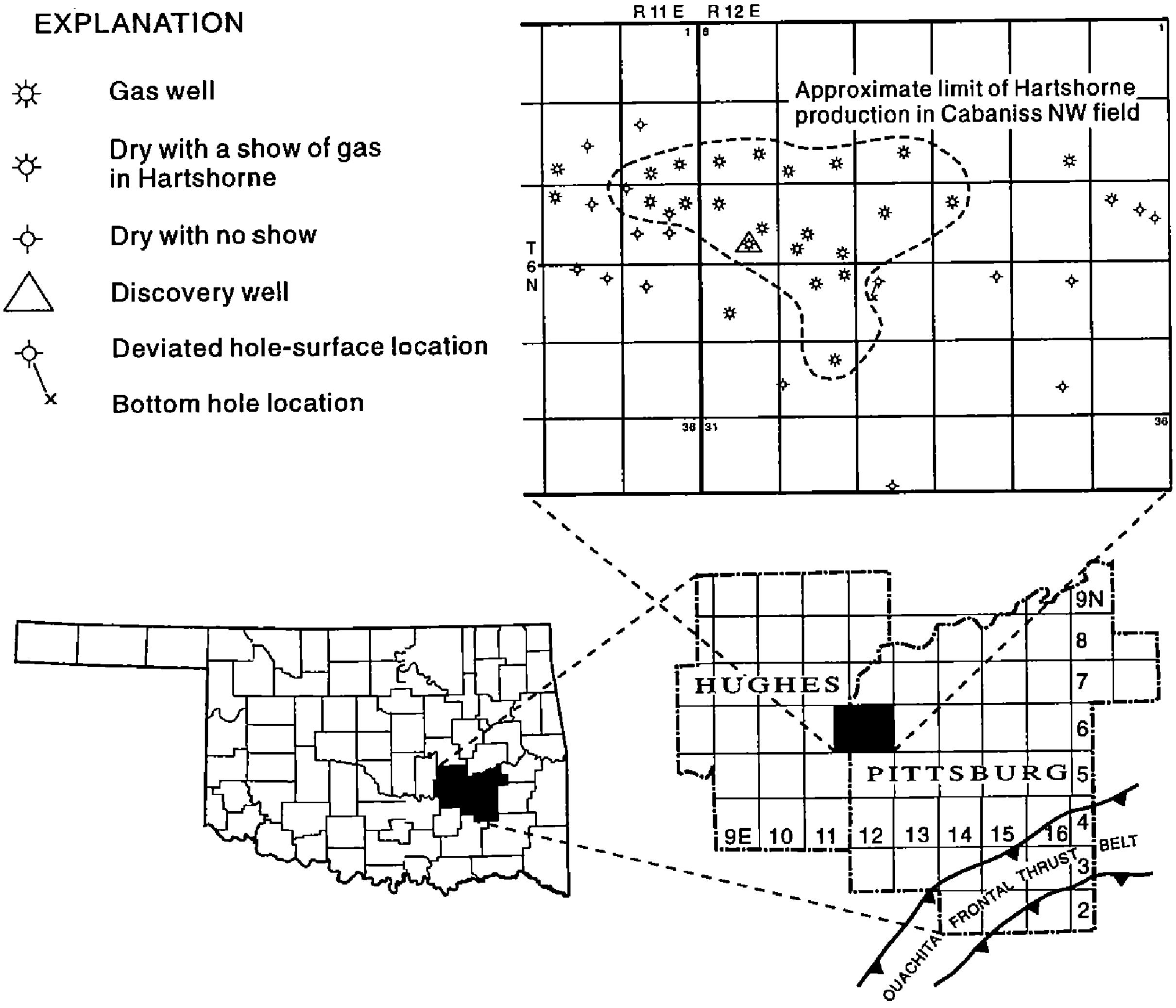


Figure 4. Generalized location map of the study area for the Cabaniss NW field in northwestern Pittsburg and eastern Hughes Counties, Oklahoma.

Marine sandstones form the poorest reservoirs in the field because of low average porosity, high clay content, and low permeability. Sandstone comprising the marine reservoirs is typically 5–15 ft thick (average ~8 ft), and porosity is rarely more than 10% (average ~7.4%). Calculated water saturation is 11–43% and averages 26%. Cumulative gas production over 12- to 19-year periods generally has been <50 MMCF per well, except for three wells with cumulative production of 161–257 MMCF per well.

Kiowa NW Field

This 15-section study area is located in southwestern Pittsburg County in T. 3 N., R. 12–13 E. (Fig. 5). In this study area, Hartshorne production was first discovered in 1981 by Texland Petroleum, but the channel trend was overlooked until 1995 when it was "rediscovered" by Enron Oil and Gas. The producing reservoir consists of channel sandstone deposited within an incised valley, and the geology is typical of the principal major channel trends that characterize the Hartshorne play regionally. Cumulative gas production for the field is ~4 BCF.

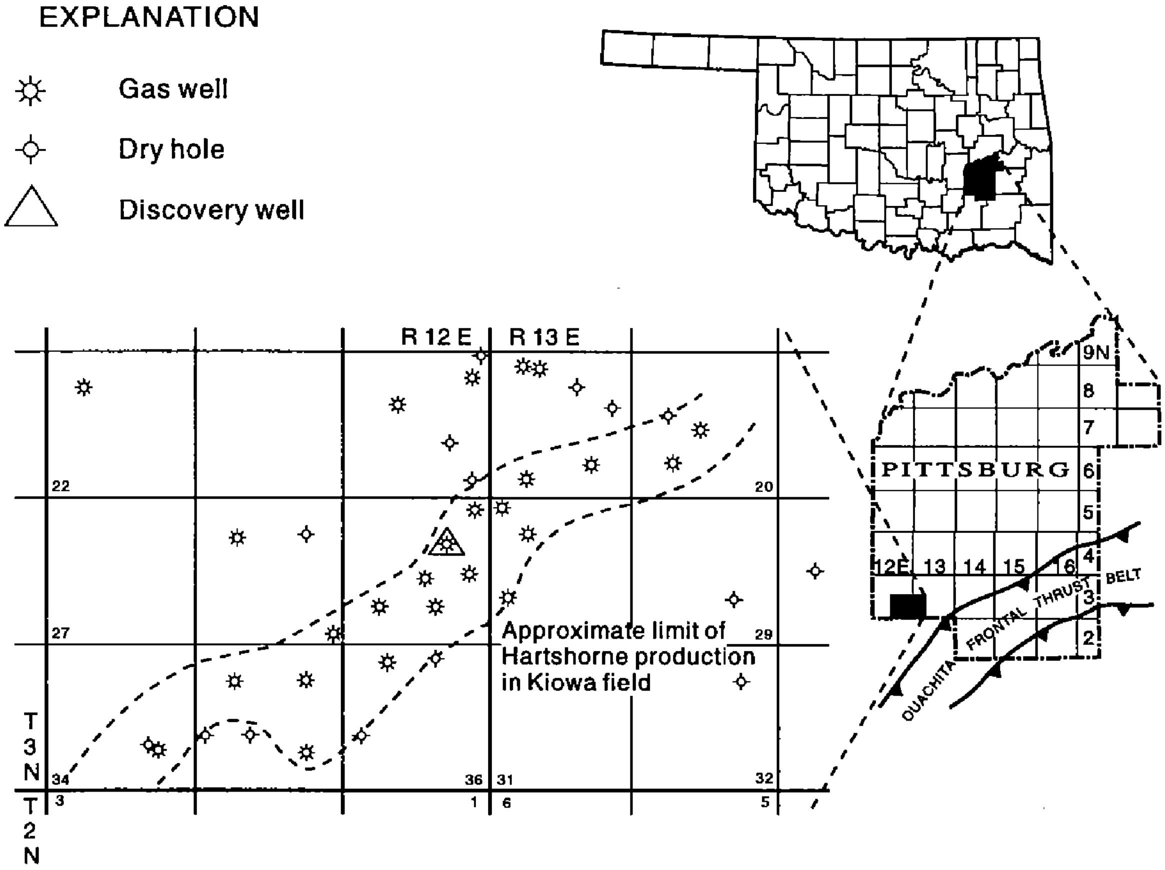


Figure 5. Generalized location map of the study area for the Kiowa NW field in southwestern Pittsburg County, Oklahoma.

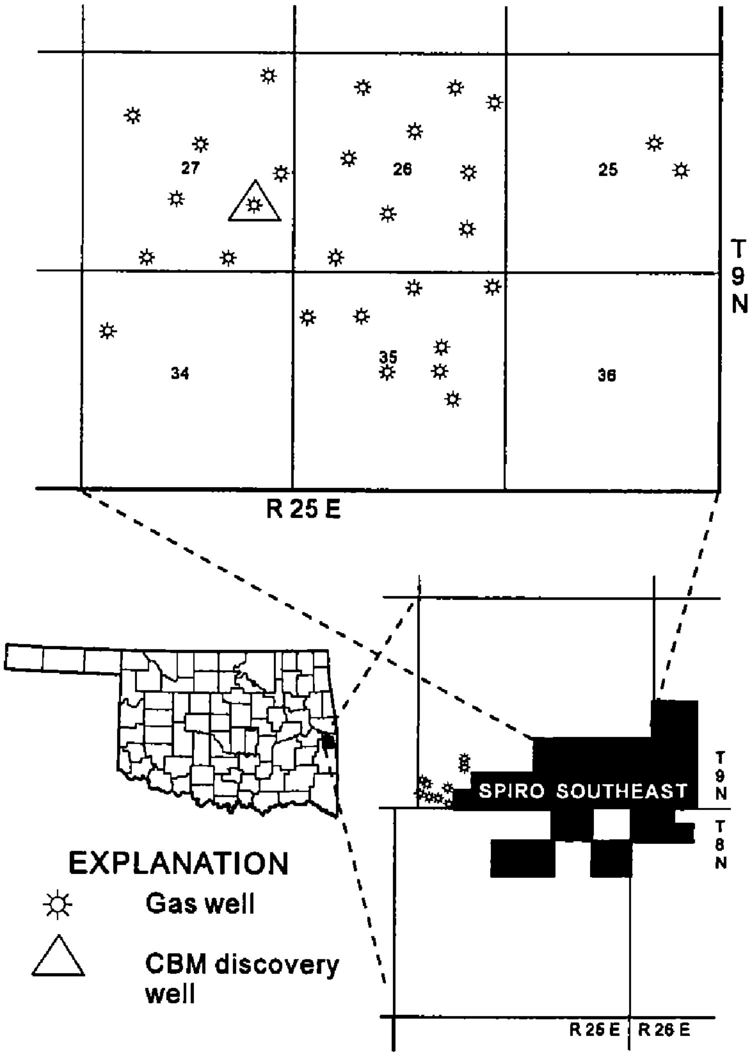
The incised channel complex in the Kiowa NW field consists of stacked or amalgamated channel sandstones with a maximum sandstone thickness of ~100 ft. The sandstone has a considerable amount of interbedded and interstitial clay. Nevertheless, several wells have highly favorable reservoir characteristics, which include thick net sandstone, averaging 26 ft (many areas have thicknesses of 40–60 ft); low average water saturation (~15%); and porosity of about 9–11%. Gas production is generally proportional to the quality of reservoir as interpreted from well logs. Some of the initial wells with at least 40 ft of net sandstone are expected to produce 0.5 to >1.0 BCF of gas. Currently, there are 19 wells completed and producing from the lower Hartshorne sandstone, and the limits of the field are undefined on both ends.

Coalbed-Methane Study in Spiro SE Field

The following brief description of the Spiro SE coalbed-methane field is a summary of a detailed study by Brian Cardott of the OGS. This study, to be published in the workshop publication (OGS SP 98-7), includes regional coal information, literature review, gas composition, coal chemistry, and fractures (cleat) analysis.

This six-section study area is located in the Spiro SE field in northeastern Le Flore County in T. 9 N., R. 25 E. (Fig. 6), just north of the Backbone anticline. Coalbed-methane production is attributable entirely to Upper and Lower Hartshorne coal beds that are about 1,000–1,500 ft deep. Net coal thickness varies from

Figure 6. Generalized location map of the study area for the Hartshorne coalbed-methane field in the Spiro SE gas field in northeastern Le Flore County, Oklahoma.



about 4 ft to 7 ft. The field was discovered in 1962 by Sunray DX with production in the deeper Atoka and Spiro sands. However, coalbed methane wasn't discovered in the Spiro SE field until 1991 by CWF Associates.

Production of coalbed methane from the Hartshorne Formation is highly variable throughout the field and ranges from about 6 to 127 MCFGPD. Gas production from all 28 wells currently is ~1,400 MCFGPD, and cumulative production through March 1998 is almost 1.2 BCF. All wells have been fracture treated; best results were achieved using a freshwater sand frac rather than nitrogen foam. The reservoir properties of the Hartshorne coals include a porosity of 1%, permeability of 3 md, initial shut-in pressure of 550 psi, and gas-in-place estimated at 8 MMCF/acre.

Hartshorne Field Trip

One of the most important parts of the Hartshorne workshop will be the field trip, which will focus on relating reservoir characteristics to specific facies and depositional environments. Additional features of the field trip will be log-to-surface correlations of many depositional environments recognized in the Hartshorne Formation and stratigraphy of the Hartshorne and bounding formations. The field trip is designed to increase participants' understanding of depositional environments, reservoir quality, and stratigraphic relationships of many fluvial and deltaic depositional systems, and its content will have wide-reaching applications. In addition, the field trip definitely will be an enjoyable learning experience in a part of Oklahoma that is particularly beautiful during the fall.

The two-day field trip, by van and field vehicle, will start and end in the southeastern Oklahoma city of McAlester. Nineteen stops have been measured and described for the guidebook and about 12 will be visited on the field trip. Spectacular exposures to be visited include: the Green Country Quarry, which is representative of a deltaic sequence (including distributary channel) (see photograph on this page); the Heavener road cut, which exposes Lower Hartshorne delta-plain deposits such as splays, coal, and lagoonal shale; the Panola section, which exposes the entire Hartshorne Formation including the Upper and Lower Members, both coals, the underlying Atoka shale, and overlying McCurtain Shale; the Red Oak Ridge section, which is a very thick, incised channel complex; the chert conglomerates near Atoka; and many other stops showing marine, channel, and storm deposits.

References Cited

Brown, R. L.; and Parham, K. D., 1994, Desmoinesian fluvial and deltaic sandstone, Arkoma basin, Oklahoma and Kansas, *in* Bebout, D. G.; White, W. A.; Hentz, T. F.; and Grasmick, M. K. (eds.), Atlas of major Midcontinent gas reservoirs: Gas Research Institute, Bureau of Economic Geology, Austin, Texas, p. 36–39.

Hemish, L. A.; and Suneson, N. H., 1997, Stratigraphy and resources of the Krebs Group (Desmoinesian), south-central Arkoma basin, Oklahoma: Oklahoma Geological Survey Guidebook 30, 83 p.

Green Country Stone Quarry *(continued from p. 126)*

distributary channels (one is pictured in photo above) overlie and erode into the bar deposits on the quarry's north side. The quarry is a stop on the second day of an OGS-sponsored field trip that will examine the best-exposed outcrops of the Hartshorne Formation in the Arkoma basin. The two-day field trip, to be held in November, follows a workshop on the natural-gas and coalbed-methane potential of the Hartshorne (see article on p. 148, this issue).

Neil H. Suneson

OGS WORKSHOP HIGHLIGHTS GEOLOGICAL CONSIDERATIONS OF WATERFLOODING

Geologists and engineers turned out June 10 and 11 in Oklahoma City to spend the day discussing factors that can cost an operator time, money, and lost production when implementing a waterflood. This topic is important in Oklahoma, where many producers with limited budgets are trying to recoup oil still in place in areas that already have been worked extensively. Many of these areas are proving that they are worth another look, because primary petroleum production sometimes recovered only about 13–15% of the original oil in place—leaving a large amount still there for the taking.

The Oklahoma Geological Survey and South Midcontinent Region of the Petroleum Technology Transfer Council (PTTC) cosponsored the workshop, which had 68 attendees June 10 and 57 on June 11. The sessions covered reservoir data, analysis of production history, net pay, structure, core and coring results, fractures, water supply, permitting, reservoir modeling and economic issues, and helped integrate modern computer-simulation studies with the "tried and true" methods that geologists and engineers have relied on for decades. As one geologist expressed it: "This workshop is a great review and a reminder of all the many details that need to be examined for a waterflood."

Although the sessions focused on the geological issues involved in waterflooding, the speakers also touched on the engineering considerations. The organizers of the meeting felt it was important to address both the geological and the engineering aspects of waterflood planning, because waterflood material sometimes emphasizes the engineering aspects and overlooks geological issues that can lead to major problems in implementation.

The primary presenter for the workshop was Kurt Rottmann, a consulting geologist from Oklahoma City. Rottmann stressed the need for gathering the most accurate data available and understanding the principles involved in the waterflood process. In addition to talking about the technical aspects of waterflooding, he reminded the audience of the need to examine both the details and the big picture, using their particular set of skills to the best advantage.

Questions were asked at the end of each segment of information, and many participants who had experience with waterflooding shared their own ideas and knowledge with the rest of the group.

"Geologists and engineers tend to view a situation from their individual perspectives," Fletcher Lewis, a geological engineer from Oklahoma City, said during the lunch break. "[The OGS] workshops help remind us all to examine the other person's information and viewpoint. It is especially good for the younger people to see other sides of this issue."

While some of the younger crowd may gravitate more toward computer simulations, the older generation, with its expertise and years of hands-on experience, can offer valuable insight into researching the production history of an area and examining in detail the well data available.

One of the most talked about and appreciated features of the workshop was the price: $30 covered the cost of the sessions, the accompanying publication, lunch, and coffee breaks. The 171-page workshop publication is

Oklahoma City consultant geologist Kurt Rottmann (right) was the primary presenter for an OGS workshop on the geological considerations of waterflooding (above).

bound in a durable three-ring notebook for ease of use.

"All knowledge is useful," Steve Sims, an independent geologist from Norman, Oklahoma, said. "[OGS] workshops have good speakers, great information and written material we can take home, and they are affordable. The price is a major consideration. It is very important to continue your education—to keep learning."

Those who missed the workshop have a chance to attend another session—one is planned for November 19th at the Oil and Brine Museum in Smackover, Arkansas. Or, you can purchase the book, OGS Special Publication 98-3, *Geological Considerations of Waterflooding: A Workshop* ($10), from the OGS Publication Sales Office, 1218-B W. Rock Creek Road, Norman, OK 73069, (405) 360-2886. A videotape of the workshop is also available for sale ($15) or as a loan from the Marginal Wells Commission. Contact Marginal Wells at 1218-B W. Rock Creek Road, Norman, OK 73069, (405) 366-8688 *or* (800) 390-0460, for more information.

These meetings are part of a series of OGS and PTTC workshops that cover a broad range of issues important to operators and others in the petroleum industry. More play-based and Southern Midcontinent workshops are in the planning stages, and the OGS encourages anyone with suggestions for future meetings to contact Charles Mankin, OGS director, at (405) 325-3031 *or* (800) 330-3996; or by e-mail at cjmankin@ou. edu. A comment form also is available on the OGS Web site at <http://www.ou. edu/special/ogs-pttc>. Check the W eb site periodically for news of new meetings and upcoming events and publications.

—Connie Smith

Call for Papers on Silurian, Devonian, and Mississippian Geology and Petroleum

Meeting March 23–24, 1999—Norman, Oklahoma

Next spring, the Oklahoma Geological Survey will hold the 12th in a series of annual workshops designed to transfer information that will aid in the search for, and production of, our oil and gas resources. Silurian, Devonian, and Mississippian rocks in the region include sandstones, limestones, and dolomites that are major petroleum reservoirs; they already have yielded large volumes of oil and gas, and they have great potential for yielding additional hydrocarbons by the use of improved exploration and development techniques. These geologic periods were times of tectonic stability; shallow-marine carbonates and clastics dominate in most of the region, although thick shales, sandstones, and cherts were deposited in the Ouachita basin.

Rock units of special interest are the Hunton, Bois d'Arc, Misener, Woodford, Chat, Osage, Mississippi lime, Chester, Manning, Stanley, Goddard, and Springer, but talks on other rock units are welcome. Papers should be surface or subsurface studies about the geologic setting, depositional environments, and structural and diagenetic history of these strata and/or reservoirs, as well as reservoir characterization, engineering factors that influence hydrocarbon accumulation or production, and specific field studies.

Our workshop will focus on Silurian, Devonian, and Mississippian geology and reservoirs in the southern Midcontinent, including Oklahoma and contiguous parts of Kansas, Missouri, Arkansas, Texas, New Mexico, and Colorado. It will consist of 20 papers presented orally and 15 informal poster presentations, and will be attended by 200–300 participants. The proceedings (including extended abstracts for the posters) will be published by the OGS about one year after the meeting: manuscripts will be submitted four months after the workshop.

Please submit a tentative title for your presentations by *September 1, 1998* (or soon after), to

Kenneth S. Johnson
Oklahoma Geological Survey
100 E. Boyd, Room N-131
Norman, OK 73019
phone (405) 325-3031 *or* (800) 330-3996
fax (405) 325-7069

If you cannot submit a tentative title, but want to attend the meeting or receive information about the final program, please send your name and address to Ken Johnson (as above).

UPCOMING *Meetings*

Association of Engineering Geologists, Annual Meeting, September 29–October 3, 1998, Seattle, Washington. Information: Julie Keaton, annual meeting coordinator, (520) 204-1553; e-mail: aegjuliek@aol.com.

Hartshorne Play Workshop, September 30, 1998, Oklahoma City; held again November 4, 1998; Muskogee, Oklahoma. **Hartshorne Play Field Trip,** November 10–11, 1998; held again November 12–13, 1998; headquartered in Muskogee, Oklahoma. *(Also see article on p. 148.)* Information: Michelle Summers, Oklahoma Geological Survey, 100 E. Boyd, Room N-131, Norman, OK 73019; (405) 325-3031 or (800) 330-3996, fax 405-325-7069.

Society of Vertebrate Paleontology, Annual Meeting, September 30–October 3, 1998, Snowbird, Utah. Information: SVP, 401 N. Michigan Ave., Chicago, IL 60611; (312) 321-3708.

American Institute of Professional Geologists, Annual Meeting, October 3–8, 1998, Baton Rouge, Louisiana. Information: AIPG, 7828 Vance Dr., Suite 103, Arvada, CO 80003; (303) 431-0831, fax 303-431-1332; e-mail: aipg@netcom.com.

Lower and Middle Cretaceous Terrestrial Ecosystems: Filling the Gap, International Symposium, October 7–8, 1998, Fruita, Colorado. Information: James Kirkland, Dinamation International Society, 550 Jurassic Court, Fruita, CO 81521.

Conference on Fossil Resources, October 13–16, 1998, Rapid City, South Dakota. Information: Rachel Benton, Badlands National Park, P.O. Box 6, Interior, SD 57750; (605) 433-5361.

Petroleum Industry Trade Fair, October 15, 1998, Norman, Oklahoma. Information: Linda Nero, Marginal Wells Commission, 1218-B W. Rock Creek Road, Norman, OK 73069; (405) 366-8688 or (800) 390-0460, fax 405-366-2882.

Gulf Coast Association of Geological Societies/Gulf Coast Section of the Society of Economic Paleontologists and Mineralogists, Annual Convention, October 21–23, 1998, Corpus Christi, Texas. Information: Gloria D. Sprague, General Chairman, (512) 882-5750.

Rocky Mountain Federation Show, hosted by Tulsa Rock and Mineral Society, October 23–25, 1998, Tulsa, Oklahoma. Information: Richard Jaeger, 3515 E. 88th St., Tulsa, OK 74137; (918) 481-0249.

American Petroleum Institute, Annual Meeting, November 8–10, 1998, San Francisco, California. Information: Phyllis West, (202) 682-8054.

American Association of Petroleum Geologists, International Meeting, November 8–11, 1998, Rio de Janeiro, Brazil. Information: AAPG, Conventions Dept., P.O. Box 979, Tulsa, OK 74101; (918) 560-2679, fax 918-560-2684.

Silurian, Devonian, and Mississippian Geology and Petroleum in the Southern Midcontinent: A Workshop, March 23–24, 1998, Norman, Oklahoma. *(Also see announcement on p. 158.)* Information: Kenneth S. Johnson, Oklahoma Geological Survey, 100 E. Boyd, Room N-131, Norman, OK 73019; (405) 325-3031 or (800) 330-3996, fax 405-325-7069. *Presentation title submissions requested by September 1, 1998.*

GSA ANNUAL MEETING
TORONTO, ONTARIO
OCTOBER 26–29, 1998

Welcome to Canada! In particular, I welcome you back to Toronto where, in 1889, the Geological Society of America met for the first time under its "new" name and approved its original constitution. There have been nine GSA annual meetings in Canada, one in Montreal (1897), three in Ottawa (1892, 1905, and 1947) and five in Toronto (1889, 1930, 1953, 1978, and 1998).

Canadian geologists have always taken an active role in the GSA and its associated societies. Since Sir William Dawson (McGill University, Montreal) was elected GSA President in 1893, seven other Canadians from both government and university positions have followed in his footsteps, most recently R. E. Folinsbee (1976, University of Alberta), D. J. McLaren (1982, Geological Survey of Canada), and R. A. Price (1990, Geological Survey of Canada and Queen's University). U.S.-based geologists have made many distinguished contributions north of the border, one of which will be recognized in November 1998 when former GSA President Brian Skinner will receive an honorary degree from the University of Toronto. The technical program shows a wide selection of topics with substantial emphasis on continental-scale processes. In addition to your preferred technical sessions or field trip, take time to enjoy some of the local amenities of Toronto and southern Ontario.

Our theme for the Technical Program of this 110th GSA meeting is **Assembly of a Continent**, with both geological and social connotations, and the accompanying logo, based loosely on a Paul Hoffman map, with its lack of political boundaries, emphasizes the international scope of our discipline and our meeting.

— J. Jeffrey Fawcett
1998 General Chair

Technical Sessions

Symposia . . . .

Pardee Keynote Symposium: Tectonic Evolution of Precambrian North America
Pardee Keynote Symposium: Pathfinder and Global Surveyor: New Views of Mars
Pardee Keynote Symposium: Geology and Biology of Early Animal Evolution
Pardee Keynote Symposium: Deep Crustal Processes
Geologic Contexts for Pre-Clovis Archaeological Deposits in the Americas
Controls on Sedimentation and Stratigraphy in Major Coal-Producing Basins of North America
Environmental Quality vs. Economic Development: The Role of Coal in Developing Nations
Accreting the Continent's Collections of Earth Science Information
The Voisey's Bay Ni-Cu-Co Deposit: A World-Class Ore Deposit at the Junction of Two Former Continents
The Lac De Gras Diamondiferous Kimberlite Field, Northwest Territories, Canada
Military Applications of Engineering Geology
Research Issues in Petroleum and Environmental Organic Geochemistry
Geochemical Indicators of Atmospheric Inputs into Terrestrial and Marine Environments
Developing Sustainability Curricula: A Challenge for Earth Sciences Educators
Geoscience Education: Predictions for the 21st Century
Conversations with the Earth: Philosophers and Geoscientists in Dialogue on the Role of the Earth Sciences in Society
Hutton, Lyell, Logan—And Their Influence in North America
IEE Environmental Forum: The Sustainability Challenge: Energy for the 21st Century
Research Opportunities in the Earth Sciences: A Ten-Year Vision
Fault Reactivations, Neotectonics, and Seismicity in the Great Lakes Region
Deformation Mechanisms and Microstructures
Accretionary Margins of North America
Role of Partial Melting During Evolution of Convergent Orogenic Belts
Experimental Petrology and Applications: A Tribute to 35 Years of Research in the Goldsmith-Newton Laboratory at the University of Chicago
Locating Old Mantle Plumes
North American Ice Sheets During Marine Isotope Stages 3 to 1: Extent, Chronology, Data, and Modeling
Application of Cosmogenic Nuclides in Surficial Processes and Global Change Studies
Response to Holocene Climate Change on the Great Plains
Paleoecological and Geochemical Signature of Cretaceous Anoxic Events: A Memorial to William V. Sliter
Understanding Groundwater in Arid and Semi-Arid Environments of North America and Australia
Multimodal Heterogeneity in Clastic Aquifers: Quantifying Permeability and Lithofacies Distributions
Breaking Down Barriers: Communicating Relevant Geoscience Issues to the Public
International Surveys

Theme Sessions . . . .

Gold Deposits Associated with Alkalic Rocks
Natural Sources of Mercury and Arsenic: Significance in Regional Cycles and Environmental Assessments
El Niño 1997–1998: Effects on Earth Surface Processes
Landslides and Transportation Systems
Environmental and Engineering Geology in Quaternary Deposits
Geomicrobiology
Sources, Transport, Fate, and Toxicology of Trace Elements in the Environment
Continent Formation, Growth, and Recycling
Luminescence in Geology
Field Camp Pedagogies: Adjusting to Modern Equipment and the Modern Student
Breaking Down Barriers: Communicating Relevant Geoscience Issues to the Public
Teaching Hydrogeology to Undergraduate and Graduate Students
Creating Learning Environments with the Internet and Multimedia
Teaching Through Inquiry in the Geosciences
Education about the Environment: What Works!
Geotectonics at the Frontier: A Centenary Tribute to Debate, Rejection, and Acceptance of Crustal Dynamics Paradigms in the Geosciences
North American Geology in the Early to Middle Nineteenth Century
Research Opportunities in the Earth Sciences: A Ten-Year Vision
Geophysical Studies of the Crust and Lithosphere
Controls on the Style, Distribution, and Intensity of Deformation Around Faults and Folds
From Cracks To Creep: Evolution, Behavior, and Processes Within Mature Fault Zones
What Are We Dating? Understanding the Crystallogenesis of U-Pb Geochronometers
Deep Crustal Processes
Tectonic Evolution of Precambrian North America
NAFTA: North American Floating Terrane Accretion
Role of Partial Melting During Evolution of Convergent Orogenic Belts
Applied Geological Remote Sensing
Archean Cratons: Evolution and Assembly
Tonalites, Trondhjemites, and Granodiorites and Related Rocks: Ancient Examples and Modern Analogues
Environments and Timing of the Last Interglaciation: Vegetation, Paleohydrology, and Climate
The Power of Paleolimnology: State of the Art and Future Directions
On the Nature and Origin of Stone Lines and Lithologic Discontinuities in Sediments and Soils
Continental Glaciations: Continuing Debates
Terrestrial Records of Late-Glacial and Holocene Climate Change in the Americas
Holocene Climate Change on the Great Plains
Surficial Processes and Landscape Dynamics Within Arid and Desert Environments
Paleontology Solves Geologic Problems
The End-Permian Mass Extinction: Paleozoic Nemesis
Paleontological Databases and Taxonomic Decisions
Sequence Stratigraphic Controls on Organic Facies
Geological Evolution of Mexico: Its Relation to Conterminous North America

Onshore-Offshore Correlation of Cenozoic Strata, Western Margin of North Atlantic
Interpreting Fossil Earthquakes from the Stratigraphic Record
Groundwater Sustainability
Capture Zones in Fractured Rock
Solute Transport in Aquitards: Field Studies
Groundwater Flow and Solute Transport into the Great Lakes
Radionuclide Transport Experiments at Underground Research Laboratories
Hydrogeologic Controls on Ecosystems
From Continental Shelf to Abyssal Plain—Links Between Sediment Transport and Morphology
Paleoecological and Geochemical Signature of Cretaceous Anoxic Events: A Memorial to William V. Sliter
The Lac De Gras Diamondiferous Kimberlite Field, Northwest Territories, Canada
Origin and Transport of Non-Hydrocarbon Gases in Sedimentary Basins
Assembling a New Understanding of Mars

Field Trips

Premeeting

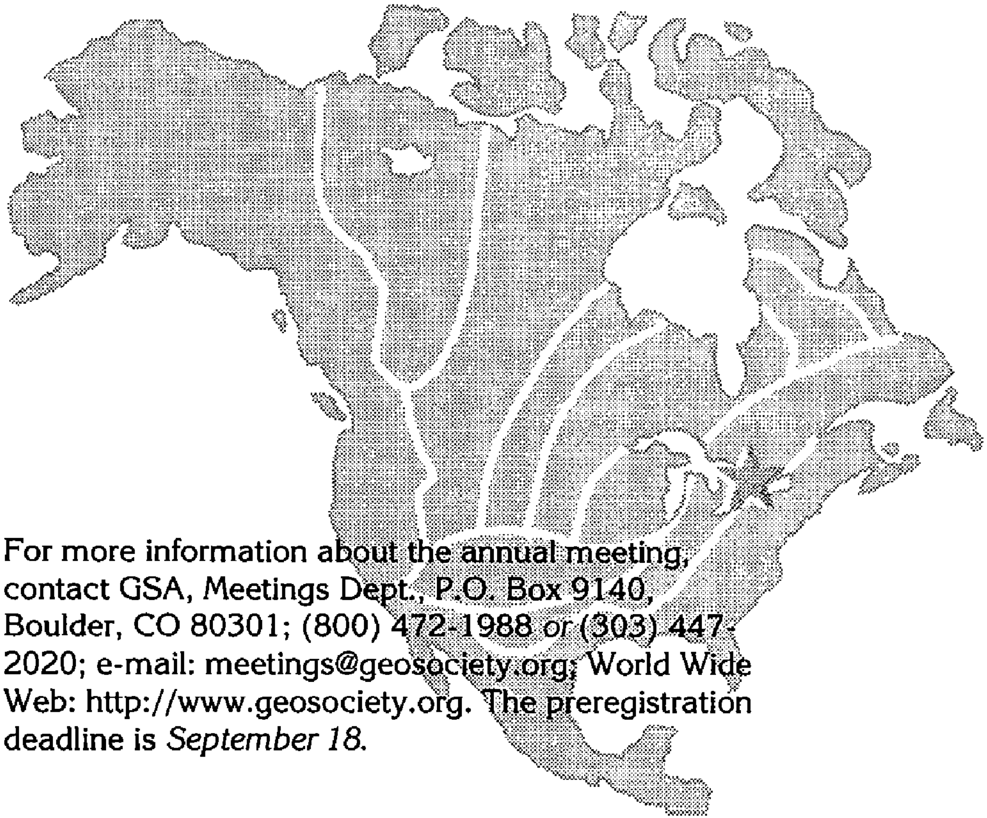
Gold Deposits of Northern Sonora, Mexico, *Oct. 19–Oct. 24*
From Front to Interior: A Southern Ontario Transect of the Grenville Province from Sudbury, Ontario, to the Adirondacks, New York, *Oct. 21–25*
A Western Quebec Grenville Transect, *Oct. 22–24*
Postglacial Surface Processes of Northern New England, *Oct. 22–25*
Allocyclic Controls on Paleozoic Sedimentation in the Appalachian Basin, *Oct. 23–25*
Fenites, Carbonatites, and Other Alkalic Rocks in the Bancroft-Haliburton-Muskoka Regions, Grenville Province, Ontario, *Oct. 23–25*
Stratigraphy, Sedimentology, and Paleocommunities of the Black River and Trenton Limestone Groups (Ordovician), East of Lake Simcoe, Ontario, *Oct. 23–25*
Hydrogeology of the Niagara Falls Area, *Oct. 24*
Classic Quaternary Geology Sites of Toronto, *Oct. 25* or *Oct. 30*
Niagara Falls, *Oct. 25*

Postmeeting

Groundwater Experimental Field Station at Canada Forces Base Borden: Overview of Past and Present Research Activities, *Oct. 30*
Chert, Corn, Environmental Change and Prehistoric Land Clearance: Three Geoarchaeological Studies on the Niagara Escarpment, *Oct. 30–31*
Hydrogeology and Late Quaternary History of Point Pelee National Park, Ontario, *Oct. 30–31*
Late Grenvillian Horizontal Extension and Vertical Thinning of Proterozoic Gneisses, Central Ontario, *Oct. 30–31*
Regional Quaternary Geology and Hydrogeology of the Oak Ridges Moraine and Greater Toronto Areas, Southern Ontario, *Oct. 30–31*
Silurian-Devonian Stratigraphy of the Niagara Escarpment, *Oct. 30–31*

Short Courses/Forums/Workshops

Analysis of Veins in Low-Temperature Environments—Introduction for Structural Geologists, *Oct. 24–25*
Deformation Mechanisms and Microstructures, *Oct. 24–25*
Phase I Environmental Site Assessments, *Oct. 24–25*
Three-Dimensional Seismic Interpretation: A Primer for Geologists, *Oct. 24–25*
Analytical Methods and Applications in Provenance Studies of Lithic Artifacts, *Oct. 25*
Applications of Environmental Isotopes in Groundwater Studies, *Oct. 25*
Buck Rogers, Field Geologist: 21st Century Electronic Wizardry for Mapping and Field Data Collection, *Oct. 25*
Design and Creation of State-of-the-Art, Interactive, Multimedia CD-ROMs for Use in Teaching Geology, *Oct. 25*
Detecting Environmental Effects Using Benthic Foraminifera and Thecamoebians, *Oct. 25*
Geotechnical and Environmental Applications of Time Domain Reflectometry, *Oct. 25*
Teaching Practical Hydrogeology: How to Make Do with Scant "Real World" Data, *Oct. 25*
Techniques in Hydrothermal Ore Deposits, *Oct. 24–25*
Clastic Facies and Sequence Stratigraphy (for graduate students only), *Oct. 24–25*
Isotope Paleobiology and Paleoecology, *Oct. 25*
Radiogenic and Stable Isotopes in Chronostratigraphic, Paleoenvironmental, and Basin Analysis, *Oct. 24–25*
Digital Database Forum, *Oct. 25*



For more information about the annual meeting, contact GSA, Meetings Dept., P.O. Box 9140, Boulder, CO 80301; (800) 472-1988 *or* (303) 447-2020; e-mail: meetings@geosociety.org; World Wide Web: http://www.geosociety.org. The preregistration deadline is *September 18.*

Notes ON NEW PUBLICATIONS

Analysis of Regional Aquifers in the Central Midwest of the United States in Kansas, Nebraska, and Parts of Arkansas, Colorado, Missouri, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming

Large quantities of ground water are available for use from three regional aquifer systems in the central Midwest of the United States. Parts of the lowermost aquifer contain nearly immobile brine and may be hydrologically suitable for material storage or waste disposal. Results of numerical modeling and geochemical analyses confirm general concepts of ground-water flow in the regional aquifer systems. This 67-page USGS professional paper was written by D. G. Jorgensen, J. O. Helgesen, D. C. Signor, R. B. Leonard, J. L. Imes, and S. C. Christenson.

Order P 1414-A from: U.S. Geological Survey, Information Services, Box 25286, Federal Center, Denver, CO 80225; phone (303) 202-4210. Cost is $9, plus $3.50 per order for handling.

Radium and Radon in Ground Water of the Ozark Region in Arkansas, Kansas, Missouri, and Oklahoma

This four-page U.S. Geological Survey fact sheet was prepared by J. C. Adamski.

Order FS 0181-96 from: U.S. Geological Survey, Information Services, Box 25286, Federal Center, Denver, CO 80225; phone (303) 202-4210. Fact sheets are free.

Water-Quality Assessment of the Ozark Plateaus Study Unit, Arkansas, Kansas, Missouri, and Oklahoma—Organic Compounds in Surface Water, Bed Sediment, and Biological Tissue, 1992–95

Prepared by R. W. Bell, J. V. Davis, S. R. Femmer, and R. L. Joseph for the National Water-Quality Assessment Program, this USGS water-resources investigations report contains 30 pages.

Order WRI 97-4031 from: U.S. Geological Survey, Information Services, Box 25286, Federal Center, Denver, CO 80225; telephone (303) 202-4210. Cost is $9 for a paper copy or $4 for microfiche, plus $3.50 per order for handling.

Water-Quality Assessment of the Ozark Plateaus Study Unit, Arkansas, Kansas, Missouri, and Oklahoma—Analysis of Information on Nutrients, Suspended Sediment, and Suspended Solids, 1970–92

J. V. Davis, J. C. Petersen, J. C. Adamski, and D. A. Freiwald prepared this USGS water-resources investigations report for the National Water-Quality Assessment Program. It contains 112 pages.

Order WRI 95-4042 from: U.S. Geological Survey, Information Services, Box 25286, Federal Center, Denver, CO 80225; telephone (303) 202-4210. Cost is $17.75 for a paper copy or $4 for microfiche, plus $3.50 per order for handling.

Summary of Floods in the United States During 1990 and 1991

Edited by P. R. Jordan and L. J. Combs, this volume contains 50 articles describing severe, widespread, or unusual flooding in 28 states during 1990 and 1991. Each article includes one or more maps showing the general area of flooding, as well as hydrology data and descriptions of damages. This 257-page USGS water-supply paper contains a chapter, written by R. L. Tortorelli, describing the floods of April and May 1990 on the Arkansas, Red, and Trinity Rivers in Oklahoma, Texas, Arkansas, and Louisiana.

Order W 2474 from: U.S. Geological Survey, Information Services, Box 25286, Federal Center, Denver, CO 80225; phone (303) 202-4210. Cost is $25, plus $3.50 per order for handling.

Results of Geophysical Investigations Near the Norman, Oklahoma, Municipal Landfill, 1995

J. E. Lucius and R. J. Bisdorf wrote this 125-page USGS open-file report.

Order OF 95-0825 from: U.S. Geological Survey, Information Services, Box 25286, Federal Center, Denver, CO 80225; phone (303) 202-4210. Cost is $18.75 for a paper copy or $4 for microfiche, plus $3.50 per order for handling.

Mineral-Resource Maps Showing Locations of Known Mississippi Valley-Type Deposits and Occurrences in the Ozark Mountains Region

Locations of known Mississippi Valley-type deposits and occurrences in the Ozark Mountains region relative to Late Cambrian shaly lithofacies and other shales in Missouri, Arkanasas, Kansas, and Oklahoma are shown on these 1:1,000,000-scale maps. The maps, printed on one black-and-white sheet, were prepared with the geological surveys of Missouri, Arkansas, and Kansas by J. R. Palmer and T. S. Hayes. *(Also see related publication described below.)*

Order MF-1994-F from: U.S. Geological Survey, Information Services, Box 25286, Federal Center, Denver, CO 80225; phone (303) 202-4210. Cost is $4, plus $3.50 per order for handling.

The Conterminous United States Mineral-Resource Assessment Program—Background Information to Accompany Folios of Geologic and Mineral-Resource Maps

Edited by W. P. Pratt, this 20-page USGS circular contains background information to accompany folios of geologic and mineral-resource maps of the Harrison 1°×2° quadrangle, Kansas and Missouri, which includes map MF-1994-F described above. The circular also contains a page showing ore distribution in the Missouri and Kansas portions of the Tri-State District of Missouri, Kansas, and Oklahoma, prepared by L. M. Nuelle and M. C. McFarland.

Order C 1140 from: U.S. Geological Survey, Information Services, Box 25286, Federal Center, Denver, CO 80225; phone (303) 202-4210. USGS circulars are available free of charge.

Oklahoma ABSTRACTS

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

Microfacies Analysis of the Wapanucka Formation (Morrowan) Frontal Ouachita Mountain, Oklahoma

SUK-JOO CHOH and *BRIAN E. LOCK*, University of Southwestern Louisiana, Lafayette, LA

The early Pennsylvanian Wapanucka Formation exposed in the northern part of the Ouachita Mountain thrust belt was deposited under open marine, outer ramp conditions gently sloping to the south. The formation gradationally overlies late Mississippian to middle Morrowan Springer Shale and is unconformably overlain by sub-Spiro Shale which is also known as the middle shale member of the Wapanucka Formation.

Two stratigraphic sections on the northernmost thrust sheet near the town of Hartshorne were investigated. More than 370 thin sections were petrographically studied from samples collected at an average vertical interval of 0.64 ft (0.2 m) for a total thickness of 240 ft (72 m).

Microfacies range from deep ramp deposits (facies 1 to 3), through shallow subtidal deposits (facies 4 to 7) to shallow ramp shoal deposits (facies 8 to 11). The description of each faces is as follows: (1) silty carbonate mudstones, (2) non-laminated siliceous sponge spicule wackestone/packstone, (3) non-laminated siliceous sponge spicule–benthonic foraminifera wackestone/packstone, (4) benthonic foraminifera wackestone, (5) siliceous sponge spicule–*Donezella*–pellet packstone, (6) *Donezella* packstone/boundstone, (7) benthonic foraminifera–crinoid packstone, (8) coated grain–crinoid–*Donezella* packstone, (9) crinoid–coated grain packstone/grainstone, (10) bioclastic grainstone, and (11) ooid grainstone.

On the basis of vertical stacking patterns of microfacies, it is possible to identify repetitive meter-scale shallowing-upward cycles separated by surfaces marked by sudden change to deeper water facies.

Reprinted as published in the American Association of Petroleum Geologists *Bulletin*, v. 81, p. 866, May 1997.

Blue Mountain Transverse Structures, Latimer County, Oklahoma

CHARLES B. JOHN, U.S. Dept. of the Interior (Ret.), P.O. Box 904007,
Tulsa, OK 74105

This study is located in a 100 square mile area between the Choctaw and Ti Valley thrust faults of the Ouachita Mountains frontal belt of southeastern Oklahoma.

The investigation includes construction of dip and strike cross sections to determine the structural geometry, chronology, and other features. The cross sections are based on surface geology, electric well logs, and published seismic data. The sections are used to determine (1) the fault geometry and chronology, (2) thrust distances, and (3) shortenings at a specific horizon. The following features associated with the frontal belt are addressed.

- The geometry and chronology of the principal thrust fault and the multiple splay imbricates of the Choctaw thrust system.
- Horizontal distance, thrust distance, and shortening distance of the Choctaw thrust system.
- Two northwest-southeast transverse structures (tear faults) that partition the thrust fault into segments.
- Triangle zone, a structural feature found at the transition of the Ouachita frontal belt and the Arkoma basin.

Conclusions:

- Extensional-faulted pre-Mississippian rocks underlie the area.
- The Springer shale is the principal decollement and glide horizon.
- Striking differences of shortening distances of the dip cross sections require that two tear faults be established.
- Timing of the Choctaw thrust system and the tear faults is concurrent, and is at least Late Atokan and possibly Desmoinesian, or later. Triangle structure is defined by inference.

Reprinted as published in the American Association of Petroleum Geologists *1997 Annual Convention Official Program*, v. 6, p. A56.

Sequence Stratigraphy of the Jackfork Sandstone in the Ouachita Mountains and Applications for Petroleum Exploration

RICHARD D. FRITZ, Geological Consultant, Masera Corp., 1743 E. 71st St.,
Tulsa, OK 74136; and *MICHAEL KUYKENDALL*, Geological Consultant,
Solid Rock Resources, Inc., Tulsa, OK

Recent drilling activity for Jackfork reservoirs in southeastern Oklahoma has renewed interest in the structural and stratigraphic framework of the Ouachita Uplift. Structurally the uplift can be divided into two areas: (1) a frontal imbricated zone north of the Ti Valley Fault and (2) the central thrust belt south of the Ti Valley Fault with the dominantly platform sediment to the north and basinal deposits to south.

The Jackfork Group represents an elongate submarine fan complex that extends from Alabama to Oklahoma. The sandstones are composed of slumps, debris flow and turbidites, which were primarily derived from non-volcanic landmass east of the present-day Black Warrior Basin. Secondarily, these sediments were derived from the north from Simpson outcrops and from a large drainage basin to northeast, which terminated with advancing deltas through the Reelfoot Rift area. Some sediment may also be derived from the south from the emergent, advancing Ouachita thrust belt. Multiple fan models have been used to explain Jackfork deposition. A combination of the Walker and Vail models appears to be most applicable to Jackfork deposition. Recent study of Jackfork sequence stratigraphy indicate that the submarine fan may be subdivided into intervals which represent pulses during third-order sea-level changes.

The central Ouachita thrust belt is a largely unexplored zone of over four million acres in Oklahoma and Arkansas. Sohio initiated an exploration program for 1980 to 1988 during which they drilled a large "channel" identified from seismic in a syncline. Although there were multiple gas shows, the well was not economic. In 1990 H&H Star began drilling for Spiro along Ti Valley Faults and found several wells with productive Spiro. This resulted in a marginally economic gas play. Most recently Vastar, Texaco and Chevron have drilled along the Windingstair fault to evaluate Jackfork potential.

Reprinted as published in the American Association of Petroleum Geologists *Bulletin*, v. 81, p. 1350–1351, August 1997.

Jackfork Group, Southeastern Oklahoma: New Gas Play in the Ouachita Overthrust

SCOTT L. MONTGOMERY, 1511 18th Ave. East, Seattle, WA 98112

Recent discovery of natural gas in sandstones of the Jackfork Group of southeastern Oklahoma has led to revised interpretations of hydrocarbon potential in the Ouachita thrust province of eastern Oklahoma. Jackfork reservoirs consist of fine to very fine grained, submarine-fan lobe sandstones with low matrix permeability and porosity. Production is dependent upon natural fractures, enhanced in most cases by artificial stimulation. Individual wells have produced at rates of 1.3–5.7 million cubic feet per day and possess estimated reserves in the range of 2.0–7.6 billion cubic feet. Hyperbolic decline suggests gas contribution from the matrix, possibly due to the presence of microfractures. Drilling has concentrated on two subsidiary thrust blocks in the hanging wall of the Ti Valley thrust, southern Latimer County. However, recent outcrop, petrographic, and sedimentological analyses have shown that traditional depositional models of the Jackfork are overly limited and that potential Jackfork reservoirs exist across a broad area to the south of the current play. Such analyses have revealed the existence of thick, medium-coarse-grained channel sequences at a number of localities in the Lynn Mountain syncline. Similar sequences may also exist well to the south, in the Boktukola syncline, where thick sand intervals have been identified. Petrographic study of samples from the Lynn Mountain syncline suggests that channel sequences may have significantly higher reservoir quality than is found in productive Jackfork sandstones to the north. Traditional assumptions postulating low regional hydrocarbon potential for the Jackfork therefore stand in need of revision.

Reprinted as published in the American Association of Petroleum Geologists *Bulletin*, v. 80, p. 1695, November 1996.

Mineralogical Sites of Trace Elements in Pelitic Rocks

MATTHEW W. TOTTEN and *MARK A. HANAN,* Dept. of Geology
and Geophysics, University of New Orleans, New Orleans, LA 70148

The chemical composition of shales has been of interest to sedimentary petrologists, primarily to establish "average" continental crust composition. In addition, several investigators have established a relationship between the trace element geochemistry of pelites and their provenance and tectonic environment during deposition. All of the trace element data of pelites to date, however, have been of whole-rock compositions. Certain minerals, especially within the heavy-mineral fraction, are known to sequester high concentrations of trace and rare earth elements which may potentially confuse any interpretation based on whole-rock geochemistry.

Shales from the Ouachita Mountains of Oklahoma and Arkansas were analyzed for their whole-rock trace-element compositions and also centrifuged using heavy liquids to separate the heavy-mineral fractions. A strong correlation between whole-rock total REE concentration and aluminum suggests that clay minerals are the dominant site of the rare earth elements. Extension of the regression line to 0% Al_2O_3 gives an Intercept near 70 ppm total rare earths, which is likely to be from heavy minerals. Several of our samples had significant amounts of monazite and apatite in the heavy mineral fraction, minerals which contain a high percentage of light REEs. Other samples had larger percentages of garnet, which fractionates the heavy REEs. Mass balance calculations suggest that enough heavy minerals are present in some rocks to influence the whole-rock trace-element concentrations.

Our results suggest that interpretations based upon whole-rock chemistry of shales might be misleading in some cases.

Reprinted as published in the Geological Society of America *1995 Abstracts with Programs*, v. 27, no. 6, p. A-401–A-402.

Postdepositional Chemical Alteration of Ouachita Shales

S. J. SUTTON, Dept. of Earth Resources, Colorado State University,
Fort Collins, CO 80523; and *L. S. LAND*, Dept. of Geological Sciences,
University of Texas, Austin, TX 78712

Shales belonging to the Carboniferous flysch exposed in the Ouachita Mountains of west-central Arkansas and southeastern Oklahoma have undergone postdepositional alteration that has significantly affected their whole-rock chemistry. Alteration is particularly pronounced in the northeastern Ouachitas and along the Benton–Broken Bow uplift. Altered rocks have lost Ca, Mg, K, Na, Fe, and Si relative to the "conservative" elements Al, Ti, Zr, Cr, and Ni. Some evidence exists for slight loss of Al and Ti relative to Cr, Ni, and Zr. Pyrophyllite- and chloritoid-bearing samples are enriched in ^{18}O relative to less altered samples, and this enrichment is not due to changes in the $\delta^{18}O$ of quartz. Mineralogical and textural evidence support a postdepositional alteration model rather than mixing of sediment from different sources, or sedimentary sorting, to account for the variations in whole-rock chemistry. Development of microscopic foliation-parallel zones enriched in phyllosilicates and in Ti and Al is related to slaty cleavage development and suggests that chemical alteration is coeval with deformation and very low grade metamorphism. Volume-loss calculations based on conservation of "immobile" elements, and on deformation of detrital mica grains, give minimum estimates of ≈30%–50% volume loss in the most altered shales. The postdepositional changes recorded in whole-rock chemistry of these shales may be unique to the Ouachita flysch, but suggest a need for greater caution in the uncritical use of shale chemistry in studies of crustal evolution and provenance.

Reprinted as published in the Geological Society of America *Bulletin*, v. 108, p. 978, August 1996.

Large-Scale Tectonic Constraints on Deposition of North American Devonian–Mississippian Black Shales

FRANK R. ETTENSOHN, Dept. of Geological Sciences, University of Kentucky,
Lexington, KY 40506

During Late Devonian–Early Mississippian time on North America, black-shale deposition was present across nearly one-quarter of the continent's surface. Temporal and distributional patterns of these shales show that their deposition coincides with the timing and location of foreland basins and intracratonic basins yoked to them. Foreland-basin formation and the yoking of intracratonic basins to them were results of deformation loading in adjacent orogens, and the large-scale tripartite distribution of Devonian–Mississippian black shales relative to orogenic belts clearly supports the influence or respective orogenies.

In the Appalachian Basin, the westward to southwestward spread of black-shale deposition, as well as successive westward movement of black shales into the yoked Michigan and Illinois basins, reflect flexural interactions resulting from the Acadian orogeny. The southwestward extension of black-shale deposition beyond the Appalachian Basin into Mississippi, Arkansas, Texas, Oklahoma, New Mexico, Arizona, Kansas,

and western Missouri occurred in the Ouachita peripheral basin and in the yoked Salina and Forest City basins, where shale deposition seems to reflect initiation of subsidence accompanying inception of Ouachita convergence in latest Devonian to Early Mississippian time. On the Cordilleran margin, by Middle Devonian time, subsidence related to the Antler orogeny created ideal conditions for black-shale deposition in parts of the Antler foreland basin, and by latest Devonian to Early Mississippian time, black-shale deposition had spread eastward into the yoked Williston Basin.

Foreland and yoked intracratonic basins like those above make ideal repositories for organic matter, because in their early histories conditions of rapid subsidence and little clastic influx generate sediment starvation and stratification of the water column in which organic-rich sediments are easily preserved. Moreover these conditions may be enhanced during times of coeval convergence on all margins, as in Late Devonian–Early Mississippian time, when large parts of the continent are flexurally depressed allowing black-shale depositional environments to migrate onto adjacent parts of the foreland.

Interpretations suggest that conditions conducive to black-shale deposition may be naturally inherent in the early development of foreland and peripheral basins. Although aspects like depth and production of organic matter can be important controls on black-shale deposition, the generation of suitable repositories is a larger scale, first-order constraint related to regional tectonic regimes.

Reprinted as published in the Geological Society of America *1995 Abstracts with Programs*, v. 27, no. 6, p. A-400.

Conodont Biostratigraphy of Silurlan and Devonian Stratigraphic Sequences in Shelf and Ouachita Facies, Southern North America

JAMES E. BARRICK, Dept. of Geosciences, Texas Tech University,
Lubbock, TX 79409; *PAULA J. NOBLE*, Dept. of Geology, California
State University, Sacramento, CA 95810; and *STEPHEN C. RUPPEL*,
Bureau of Economic Geology, University of Texas, Austin, TX 78713

Conodont faunas permit dating and correlation of Silurian and Devonian shelf successions of southern North America, as well as correlation of these successions with their basinal equivalents. Basinal Ouachita successions in Arkansas-Oklahoma and West Texas correlate more closely with the adjacent shelf and shelf margin sequences than with each other. This suggests that regional tectonic and depositional controls were as important as eustasy in determining the Silurian and Devonian succession.

Intervals of the most extensive carbonate shelf development correlate with novaculite deposition and argillaceous shelf to shelf margin strata often correspond with chert and shale accumulation in the Ouachita facies. In West Texas, the Llandovery Fusselman Limestone and Pragian Thirtyone Formation, both major carbonate shelf units, correlate with the lower and upper novaculite members, respectively, of the Caballos Novaculite. The argillaceous Wenlock to Lochkovian Wink and Frame formations, which accumulated on the margin of the Fasken shelf, correlate with the middle chert and shale member of the Caballos. The upper chert and shale member of the Caballos contains a Middle Devonian lower half that has no platform equivalent; the upper half correlates with the Late Devonian Woodford Shale.

In Arkansas and Oklahoma, the basinal lower novaculite of the Arkansas Novaculite correlates with a widespread Eifelian sheet of siliceous platform carbonates. The thin upper novaculite is equivalent to progradational Osagean shelf carbonates. The lower black chert and shale portion of the middle chert and shale member is older (Middle Devonian) than the Late Devonian Woodford Shale on the shelf, which correlates with

red and green shale higher in the member. Lithological subdivisions of the Llandovery to Pragian shelf carbonates of the Hunton Group cannot be discerned in the equivalent Blaylock Sandstone and Missouri Mountain Shale, except in the frontal Ouachitas.

Reprinted as published in the Geological Society of America *1997 Abstracts with Programs*, v. 29, no. 2, p. 3.

Closing the Ouachita Ocean

GEORGE W. VIELE, Dept. of Geological Sciences, University of Missouri,
Columbia, MO 65211

The hypothesis is offered that the Carboniferous Ouachita ocean closed toward the southeast by subduction of North American oceanic crust beneath a microcontinent or island arc. A southeastward vector of subduction explains many geologic features of the Ouachita Mountains and Arkoma basin of Arkansas and Oklahoma. For example, in the Arkoma basin, fault tip anticlines exhibit a right-stepping en echelon pattern. Many high-angle normal faults trend northeast-southwest and become younger from southeast to northwest. Imbricated and duplexed thrust sheets in the frontal thrust belt of the Ouachita Mountains in Oklahoma disappear eastward into cleaved, tightly folded strata and tectonic melange in Arkansas. In the Broken Bow and western part of the Benton uplifts, hinge lines of folds plunge gently east or west, but in the easternmost Benton uplift, traces of axial surfaces swing 90° to southeastward bearings, and hinge lines are inclined to reclined. Strongly flattened sheath folds and solution cleavage are common. Subsurface loads revealed by analysis of the gravity field in the western Ouachitas are absent in the eastern Ouachitas.

These features are attributed to southeastward subduction of the Ouachita ocean between two transform faults: one parallel to the Wichita Mountains of Oklahoma, the other parallel to the subsurface Ouachita orogenic belt of eastern Arkansas and Mississippi. Apparently, the Ouachita ocean was closed beyond the western transform, for molasse was deposited in the Fort Worth Basin and some Atokan sediments in Oklahoma came from western sources. During subduction, strain was partitioned: thrust faulting predominated in the western Ouachitas whereas strike-slip faulting predominated in the east.

Reprinted as published in the Geological Society of America *1995 Abstracts with Programs*, v. 27, no. 6, p. A-460.

Late Paleozoic Deformation of the Ancestral Rocky Mountains: Result of an Andean Margin Along Southwestern North America?

LEIGH H. ROYDEN and *B. C. BURCHFIEL*, Dept. of Earth, Atmospheric,
and Planetary Science, Massachusetts Institute of Technology, Cambridge,
MA 02139; *HONGSHUAN YE*, University of Texas at Dallas, P.O. Box 688,
Richardson, TX 75083; and *MARTIN SCHUEPBACH*, Danube Inter. Petr. Co.,
2651 N. Harwood St., Dallas, TX 75201

Late Paleozoic deformation within interior North America has produced a series of north-northwest to northwest-trending elongate basins that thicken asymmetrically toward adjacent basement uplifts, from which they are separated by syn-sedimentary faults with large vertical relief. The coincidence in timing, geometry and apparent structural style suggests that these paired regions of basin subsidence and basement uplift form a unified system of regional deformation. Initiation and cessation of subsidence and uplift were approximately synchronous, beginning in Morrowan time and ending

in Wolfcampian time, while the basement uplifts show evidence for folding and faulting in Pennsylvanian to early Permian time. Reverse faults have been drilled over many of the uplifts and extensive basement-involved thrusting can be documented along the margins of the Anadarko, Delaware and Midland basins, suggesting that the entire system region formed by northeast-southwest directed-intraplate shortening. Deformation was coeval with subduction along much of the North American plate margin, and has traditionally been related to emplacement of thrust sheets within the Ouachita-Marathon orogenic belt but we believe that the nature, timing, and orientation of events along the Ouachita-Marathon belt make it difficult to drive the deformation of the Ancestral Rocky Mountains by emplacement of the Ouachita-Marathon belt along the southern margin of North America. We speculate that deformation was driven instead by a late Paleozoic Andean margin along the southwestern margin of North America. Evidence for this previously unrecognized Andean margin comes from east-central Mexico, where a volcanic arc of Pennsylvanian-Permian age indicates a northeast-dipping subduction boundary to the south and west. In this interpretation, the Greater Ancestral Rocky Mountains would be directly analogous to the younger systems of intraplate shortening developed in the Laramide Rocky Mountains of North America and the modern Sierra Pampeanas of South America.

Reprinted as published in the Geological Society of America *1996 Abstracts with Programs*, v. 28, no. 7, p. A-270.

Sm-Nd Constraints on the Nature of Paleozoic "Llanoria" from Mississippian Tuffs and Rhyolites of the Ouachita Orogenic Belt

JAMES D. GLEASON, Dept. of Geosciences and Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ 85721; *B. L. WEAVER*, School of Geology and Geophysics, University of Oklahoma, Norman, OK 73019; and *J. LOOMIS*, Dept. of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131

Mississippian tuffs intercalated with flysch deposits of the Stanley Group (Oklahoma) were erupted from a southern arc source, presumed to be that which collided with North America to produce the Ouachita orogenic belt. The constitution of this late Paleozoic arc, known as "Llanoria," has long been debated. Several lines of evidence indicate that the arc was constructed on older continental basement: (1) Devonian igneous cobbles derived from southern sources in the Pennsylvanian (Haymond Formation) have evolved isotopic signatures ($\epsilon_{Nd} = +1$ to -6; Cameron et al., 1992, *JGR*), (2) trace-element signatures in Mississippian tuffs suggest an evolved volcanic arc setting (Loomis et al., 1994, *GSA Bulletin*), and (3) tuff Nd model ages (t_{DM}) of 1.1 Ga suggest an old crustal component (Gleason et al., 1994, *Geology*). Several more Mississippian tuffs as well as subsurface rhyolite from the study by Loomis et al. (1994) have been analyzed for Nd isotopes to further constrain the isotopic variation and age of the continental basement component in this suite. Nd isotopes in the Oklahoma tuffs (n = 7) are quite homogeneous at 340 Ma ($\epsilon_{Nd} = -1.5$ to -2.9; $t_{DM} = 1.1$ to 1.2 Ga), while a single Mississippian tuff from the Marathon basin in west Texas has $\epsilon_{Nd} = -2.0$ and $t_{DM} = 1.0$ Ga. These small variations between the Ouachita and Marathon regions indicate that arc sources were quite similar in their makeup along ca. 800 km of orogenic strike. Detailed variations suggest, however, that the Hatton tuff ($\epsilon_{Nd} = -1.5$ to -2.0, n = 3) is isotopically distinct from the Beavers Bend and Mud Creek tuffs ($\epsilon_{Nd} = 2.3$ to -2.9, n = 4). The two subsurface rhyolite samples from the Sabine uplift of Texas are isotopically distinct from the tuffs ($\epsilon_{Nd} = -3.5$; $t_{DM} = 1.8$ Ga), suggesting that they are not directly related to any of the Oklahoma tuffs. The anomalously old rhyolite Nd model ages are the result of Sm/Nd fractionation in a highly felsic magma chamber and are not representative of an older basement component. However, the consistent 1.1 Ga model ages in the tuffs strongly suggest a similar petrogenesis involving isotopic mixing between older basement components and mantle-derived material in about the same proportions. The age of this basement component cannot be constrained though it was almost certainly Precambrian, indicating that "Llanoria" consisted in part of ancient crust. Apparently a Devonian arc constructed on the same crust also tapped similar ancient crustal sources, though less homogeneously than the Mississippi tuffs. The paleogeographic affinity of "Llanoria" also is not constrained by the new data, but the inferred presence of a Devonian arc built on older basement suggests an Appalachian origin, similar to that proposed for the Acatlan terrane in southern Mexico and the Central Andean terrane of Colombia.

Reprinted as published in the Geological Society of America *1995 Abstracts with Programs*, v. 27, no. 6, p. A-459.

The Late Paleozoic Ouachita-Marathon-Sonora Orogenic System Along the Southern Margin of North America

FORREST G. POOLE and *WILLIAM J. PERRY, JR.*, U.S. Geological Survey,
P.O. Box 25046, MS 973, Federal Center, Denver, CO 80225

The Ouachita-Marathon-Sonora (OMS) orogenic system is a belt of deformed Paleozoic rocks that borders the present southern edge of the North American craton. The collisional-south-facing-subductional orogenic system extends 3,000 km from Mississippi in the southeastern U.S. westward and southward along a sinuous trace to central Sonora in northwestern Mexico. The belt is concealed for 80 percent of its known length; exposed parts form the Ouachita, Marathon, and Sonora structural salients. Similar sedimentary facies and structural style characterize the three orogens. The OMS system is composed of a folded and faulted sedimentary sequence (3 to 20 km) of distinctive, relatively thin (1 to 3.5 km), lower Paleozoic eugeoclinal dark-gray radiolarian-graptolitic and siliceous mudstone, chert, sandstone, and limestone, and a relatively thick (2 to 16 km), upper Paleozoic dominantly olive-gray flysch sequence, which includes deep water turbidites deposited in rapidly subsiding foredeeps. The eugeoclinal sequence of chert, mudstone, siltstone, limestone, and subordinate sandstone, conglomerate, dolostone, barite, tuff, and pillow lava represents offshelf continental slope and rise and oceanic deposits that were deformed and obducted cratonward (northward) onto the once-continuous southern shelf of paleo-North America in late Paleozoic time. Rocks of the three orogenic salients have many similarities and differ only in stratigraphic detail, structural scale, and degree of metamorphism. They are separated from each other by the Texas and Chihuahua promontories of paleo-North America (Laurentia).

The OMS orogens evolved in late Paleozoic time by collision of Gondwana and North America. Deformation started in mid-Mississippian time in all three orogens and ended in Late Pennsylvanian in the Ouachita Mountains, Early Permian in the Marathon region, and Late Permian to possibly Early Triassic in Sonora. Inferred clockwise rotation of Gondwana during collision with North America is compatible with the diachronous westward younging of OMS orogenic activity along the margins of North America and Gondwana. Foreland basins and attendant uplifts developed along and in front of the advancing allochthons. Thrust faults throughout the OMS orogenic system exhibit profiles characteristic of thin-skinned deformation with thrusting from southeast to northwest; thrusts are stacked in multilevel duplexes and the strata within the thrust sheets are complexly folded in all three segments of the OMS system. The orogens are characterized by tight folds in the pre-orogenic strata beneath broad folds in the synorogenic strata. The overall character and location of the OMS orogenic belt was controlled by the configuration of the southern edge of cratonic basement and by the direction of late Paleozoic plate motion.

Reprinted as published in the Geological Society of America *1997 Abstracts with Programs*, v. 29, no. 2, p. 43.

A Preliminary Stable Isotopic study of Veins and Their Host Rocks from the Paleozoic Ouachita Orogenic Belt, Arkansas and Oklahoma

IAN J. RICHARDS, Dept. of Geological Sciences, Southern Methodist University, Dallas, TX 75275; *JEFFREY B. CONNELLY*, Dept. of Earth Sciences, University of Arkansas, Little Rock, AR 72204; and *ROBERT T. GREGORY*, Dept. of Geological Sciences, Southern Methodist University, Dallas, TX 75275

Over 100 new oxygen isotope analyses from the abundant veins within metasedimentary rocks of the Ouachita orogenic belt provide an opportunity to study fluid-rock interaction associated with deformation. This data can be summarized as follows: (1) Overall, vein quartz spans the range $16.6 < \delta^{18}O < 25.5$‰; (2) Co-existing host rocks span a similar range $13.8 < \delta^{18}O < 25.4$‰; (3) Vein quartz–host rock $\Delta^{18}O$ fractionations vary from 0 in chert and novaculite to +6 in some sandstones and shales; (4) Within large (>100 m) sandstone and shale outcrops, bedding perpendicular, parallel and oblique veins are much more uniform (range of 1.2‰) than their host rocks (range of 2.9‰); (5) Thick (up to 20 cm) quartz veins are extremely homogeneous in composition with traverses along and across veins exhibiting <0.4‰ variation; (6) Both vein and host rock calcite span essentially the same range (±0.2‰) in carbon and oxygen isotopic compositions $0.6 < \delta^{13}C < -12.7$‰, $15.7 < \delta^{18}O < 21.9$‰, however, no recognizable relationship exists between vein and host rock calcite fractionations; (7) Vein quartz–calcite $\delta^{18}O$ fractionations typically cluster between 2.5 and 3.0, but vary between 3.0 and –2.4 indicating that quartz and calcite in veins are not always in isotopic equilibrium; (8) Within a single 5 cm vein, calcite $\delta^{18}O$ values exhibit much greater variation (by as much as 4.1‰) than coexisting uniform quarz $\delta^{18}O$ values, resulting in quartz-calcite fractionations that span the entire range from 2.3 to –2.4. The vein quartz oxygen isotopic data suggests that fluids assiciated with deformation were rock-buffered, even though fluids communicated with the surrounding rocks on scales larger than a single outcrop. Fluid-rock interaction during deformation and low-grade metamorphism enabled the fluid to reach a steady state isotopic composition over scales of 100's of m, but fluid fluxes were not large enough to homogenize host rock $\delta^{18}O$ values.

Reprinted as published in the Geological Society of America *1996 Abstracts with Programs*, v. 28, no. 7, p. A-246–A-247.

Comparison of the Ouachita and Carpathian Fold Belts

TARI C. GÁBOR, Amoco, Houston, TX 77079; and *ALBERT W. BALLY*, Dept. of Geology and Geophysics, Rice University, Houston, TX 77251

The Late Paleozoic Ouachita orogenic belt is a north-vergent thrust-fold belt, related to an A-type subduction of the passive margin of North America. The thin-skinned Ouachitas and their deep foredeep basins were formed during this southward directed subduction. Synchronously with compression in the thrust-fold belt, thick Pennsylvanian to Permian marine sediments were deposited to the south of the Ouachita belt, in the Paleozoic Gulf of Mexico.

The loop of the Late Tertiary Carpathians surrounds the back-arc Pannonian basin and it forms a continuous, thin-skinned thrust-fold belt which is coeval with the Middle Miocene extension on its concave side. The evolution of the Outer Carpathians is dominated by the formation of thick flysch nappes verging toward the foreland and an associated deep foredeep basin.

To compare these systems two maps were compiled based on several sources showing the main structural features in both systems at the same scale. Certain generalizations had to be made to arrive at a compatible legend for both maps. Besides the map-view similarity, the cross-sectional expression of the two systems is also comparable, illustrated by a pair of crustal-scale sections drawn in analogous position through these fold belts. Several specific details are strikingly comparable both in map and in cross-sectional view. The foreland basement promontories are of comparable size and kinematic role, such as the Llano Uplift/Bohemian Massif and the Arbuckle Uplift/Holy Cross Mts. The Arkoma basin finds its counterpart in the Polish sector of the Carpathian foredeep basin. The strongly deformed zone of the Maumelle chaotic zone is directly comparable to that of the Pieniny Klippen Belt.

Reprinted as published in the American Association of Petroleum Geologists *Bulletin*, v. 81, p. 1416, August 1997.

Orogenically Derived Middle Ordovician Clastic Wedge in the Broken Bow Uplift, Ouachita Allochthon, Oklahoma: A Key Link in the Taconian-Famatinian Connection?

MICHAEL C. DIX, DOUGLAS R. REID, and *JOHN F. CASEY,* Dept. of Geosciences, University of Houston, Houston, TX 77204

We have previously recognized an orogenically derived (Taconian) greywacke-shale sequence, informally called the "Mountain Fork sandstone," that occupies the stratigraphic position of the Middle Ordovician Womble Shale in the Broken Bow uplift. This thick (possibly 1500 m), sand-rich submarine-fan complex prograded into the deep Ouachita basin from the southeast. Its northern pinch-out and replacement by cratonically derived Womble Shale in inferred to mark the base of the Laurentian continental slope. Framework modes of the greywackes indicate a recycled-orogenic provenance, and the abundance of labile grains (shale, slate, phyllite) argues for rapid erosion and transport of the sediment to the deep basin. Mountain Fork greywackes also show significant compositional overlap with coeval sandstones of the Taconian Blount clastic wedge of Alabama, Georgia, and Tennessee (Mack, 1985).

A recent hypothesis suggests that the Famatinian orogen of southwestern South America is an extension of the Taconian orogen of eastern North America; orogenesis probably resulted from the Middle–Late Ordovician collision, and then separation, of Laurentia and Gondwana (e.g., Dalziel et al., 1994). The Occidentalia terrane, now exposed mainly in the Argentine Precordillera, represents a continental block believed to have originally bordered the deep Ouachita basin on its southeast side. It supported a Cambrian to Early Ordovician carbonate platform more or less contiguous with that along the eastern Laurentian margin. When Taconian-Famatinian collision began on the outboard side of Occidentalia in the Middle Ordovician, the platform collapsed and was overwhelmed by orogenically derived clastics from the east. We believe the sediment source to be the deformed and uplifted passive margin of southeast Laurentia-

Occidentalia. These sediments prograded northwest across the downwarped platform and eventually spilled into the Ouachita basin, where they are represented by the Yerba Loca, Don Polo, Portoquelo Tontal, and correlative units (Beresi, 1992).

We interpret the Blount, Mountain Fork, and Yerba Loca clastic wedges to be interconnected, broadly correlative elements of an extensive, Taconian-Famatinian sediment-dispersal system. In particular, we speculate that the Yerba Loca clastics may have directly fed the Mountain Fork fan complex, and suggest that petrologic comparison of the two might provide a firm Middle Ordovician linkage between Occidentalia and Laurentia. In addition, mafic flows and ultramafic sills in the Yerba Loca wedge, related to the post-orogenic rifting of Occidentalia away from Laurentia (Ramos et al., 1986), may be precursor analogs for several small, enigmatic, mafic and ultramafic slices enclosed in the deformed Womble Shale and Mountain Fork sandstone of the Ouachita allochthon.

Reprinted as published in the Geological Society of America *1995 Abstracts with Programs,* v. 27, no. 6, p. A-458–A-459.

The American Continents as Morphologic "Twins" Born 400 M.Y. Apart: Break-Up of Pannotia and Pangea

I. W. D. DALZIEL, Institute for Geophysics, University of Texas at Austin,
8701 N. Mopac Expressway, Austin, TX 78759

There is widespread acceptance (Dalziel et al., *GSA Today,* 1996) that the Cambrian–Lower Ordovician carbonate platform constituting the Precordillera of northwestern Argentina (APC) was part of Laurentia until mid- to Late Ordovician times, and that it originated in the Ouachita embayment, as originally suggested by Dalla Salda et al. (*Geology,* 1992). This means that the APC is indeed a critical clue in Paleozoic paleogeography. Astini et al. *(GSA Bulletin,* 1995) followed Thomas *(GSA Bulletin,* 1991) in suggesting that it was detached from Laurentia in the Late Cambrian, docking in South America as a microcontinent rather than as a result of the continent-continent collision hypothesized by Dalla Salda et al. However, comparison with the extensional regime associated with the Mesozoic separation of the Falkland/Malvirsas Plateau fom Africa during the opening of the South Atlantic Ocean basin at 128 Ma suggests that the Birmingham graben, South Oklahoma aulacogen, and Ouachita trough are analogous to the Rawson basins, San Julian basin, and Malvinas basin respectively. Moreover, positioning of the Greenland-Scotland-Labrador promontory of Laurentia within the Arica embayment of South America prior to the opening of the Iapetus ocean basin at ca. 545 Ma, as suggested by Dalziel *(GSA Today,* 1992), places the Ouachita embayment adjacent to the Falkland/Malvinas Plateau and opposite the latest Precambrian to Early Cambrian rifted margins of southern Africa and the Ellsworth Mountains block of the East Antarctic craton. Hence, the Grenvillian basement of the Precordilleran platform may have originated along the present-day southern margin of the Falkland/Malvinas Plateau, and the American continents may have been born ca. 400 m.y. apart as morphologic "twins"—southward tapering cratons with 1000–1500 km long promontories at their southeastern extremities. Opening of the western Iapetus (Laurentia–South America) and South Atlantic ocean basin coincided with the initiation of the first-order Paleozoic and Mesozoic rises in sea level respectively, presumably as a result of displacement of ocean water by new midocean ridge sytems at least 6000 km long in each case.

Reprinted as published in the Geological Society of America *1996 Abstracts with Programs,* v. 28, no. 7, p. A-60.

Gravity Models of Crustal Convergence and Erosion in the Ouachita Embayment: Comparisons with the Carpathian System

ROBERT J. LILLIE, Dept. of Geosciences, Oregon State University, Corvallis, OR 97331

The Ouachita Mountains of Arkansas and Oklahoma, like the Carpathians in central Europe, represent the gentle docking of terranes into a continental embayment. Kinematic models at various stages of continental collision illustrate the evolution of crustal structure, topography, and resulting gravity anomalies in these regions. The models are structural cross-sections that are balanced in terms of continental crust volume, retaining isostatic equilibrium. Widths of Bouguer anomalies indicate the amount of continental crustal shortening that occurred after ocean basin closure; the decay in anomaly amplitude indicates erosion accompanying isostatic rebound.

The Ouachitas and Carpathians represent "soft collisions," where less than 100 km of continental crustal shortening occurred after ocean basin closure. These belts show narrow Bouguer anomaly lows characteristic of the early stages of continental collision. Thick flysch deposits are preserved in the mountains and adjacent foreland basins because the deposits are compensated, isostatically, by shallow mantle of the former continental margin. Less that 10 km of erosion occurred in these mountain ranges because the crust was never thick enough to require large amounts of isostatic rebound.

Adjacent mountain ranges, the Southern Appalachians and Eastern Alps, are examples of "hard collisions," where convergence continued for more that 150 km after ocean basins closed. Bouguer anomaly lows are broad, representing growth of regions of thick continental crust. The underthrusting of full-thickness cratons beneath the mountains resulted in high elevations and large amounts of isostatic rebound and erosion, removing most of the sedimentary deposits.

Reprinted as published in the Geological Society of America *1995 Abstracts with Programs*, v. 27, no. 6, p. A-460.

Derivation of the Argentine Precordillera from the Ouachita Embayment: Rifting History and Kinematics

WILLIAM A. THOMAS, Dept. of Geological Sciences, University of Kentucky, Lexington, KY 40506, and *ROBERT D. HATCHER, JR.*, Dept. of Geological Sciences, University of Tennessee, Knoxville, TN 37996, and Environmental Sciences Division, Oak Ridge National Laboratory, Oak Ridge, TN 37831

The Ouachita embayment and Alabama promontory of the southeastern (present orientation) margin of Laurentia were outlined at ~577 Ma by a ridge shift from the Blue Ridge rift to the Ouachita rift accompanied by initiation of the Alabama-Oklahoma transform fault. Syn-rift intracratonic grabens on the Alabama promontory were filled with fine clastic sediment and minor evaporites of Early to Early Late Cambrian (Dresbachian) age. A passive-margin carbonate shelf was established entirely around the Ouachita embayment and over the synrift grabens by Middle Late Cambrian (Franconian) time. The passive-margin succession (Upper Cambrian–Lower Ordovician Knox Group) is dominated by dolomite; however, in the subsurface on the Alabama promontory, the upper part grades southwestward (toward the transform-bounded continental margin) into a succession that is mostly limestone. In the same area, the hiatus represented by the cratonwide post-Knox (post-Sauk) unconformity decreases southwestward, and the limestone succession probably represents continuous deposition from Early into Middle Ordovician time. A block of Laurentian continental crust (bounded by the Blue Ridge rift, the younger Ouachita rift, and the Alabama-Oklahoma transform fault) was rifted from the Ouachita embayment. Specific similarities in Cambrian-Ordovician stratigraphy and faunas suggest that the block missing from the Ouachita embayment now resides in the Argentine Precordillera. During Early and Middle Cambrian time as the Ouachita rift opened, the Precordillera block moved laterally along the Alabama-Oklahoma transform at the southern margin of Laurentia. In Late Cambrian time, when the separate Precordillera block moved beyond the corner of the Alabama promontory, a passive margin extended around the Ouachita embayment. Faunal similarities suggest that the Precordillera block remained near Laurentia until Middle Ordovician time, possibly reflecting temporal variations in spreading rates of the Ouachita ridge.

Reprinted as published in the Geological Society of America *1995 Abstracts with Programs*, v. 27, no. 6, p. A-457–A-458.

Designation of a Composite-Stratotype for the McAlester Formation (Desmoinesian), Pittsburg County, Oklahoma

LEROY A. HEMISH, Oklahoma Geological Survey, 100 E. Boyd, Room N-131,
Norman, OK 73019

Five sections, measured on the south flank of the Kiowa syncline, ~10 mi southeast of the city of McAlester, Oklahoma, were compiled by the author and designated as the composite-stratotype for the McAlester Formation (Desmoinesian). A formal type section never was specified for the McAlester Formation, although Joseph Taff (the nomenclator) indicated the type locality was in the region of McAlester, Krebs, Alderson, and the basin plain north of Hartshorne.

The McAlester Formation measured ~1,816 ft thick in the composite-stratotype area, which is reasonably close to Taff's original estimated thickness of ~2,000 ft. Taff recognized three lithologically different divisions within the McAlester Formation: a lower, dominantly shale division; a middle division composed of three to four beds of sandstone separated by shale; and an upper division, also predominantly shale, with the McAlester coal ~50 ft above its base. One of the considerations in selecting the composite-stratotype area was to locate outcrops that compared favorably to Taff's original description. In the newly designated composite-stratotype Taff's three divisions are readily distinguishable and closely adhere to the original sense in which the McAlester Formation was defined. Other factors considered in selecting the composite-stratotype area include (1) accessibility of rocks in place; (2) excellent exposures of both the upper and lower formation boundaries as well as good exposures of lithologic units immediately above and below the contacts; and (3) geographic location within the type area (central Pittsburg County).

Establishment of a composite-stratotype for the McAlester Formation fills a gap in the stratigraphic framework of Oklahoma. Investigations carried out as part of the STATEMAP program led to the ultimate publication (and formalization) of the work, which provides benefits additional to those of the basic project.

Reprinted as published in the Geological Society of America *1998 Abstracts with Programs*, v. 30, no. 3, p. 7.

Oklahoma Geological Survey's STATEMAP Program (FY93 to Present)—New 1:24,000 Geologic Maps

NEIL H. SUNESON and *LEROY A. HEMISH,* Oklahoma Geological Survey,
100 East Boyd, Rm. N-1 31, Norman, OK 73019

The Oklahoma Geological Survey (OGS) has participated in the U.S. Geological Survey's COGEOMAP and STATEMAP programs every year since 1984 (FY85). To date, the OGS has released 22 detailed 7.5′ geologic maps (scale 1:24,000) as open-file reports. Originally, the mapping was resource-oriented and focused on the Ouachita tectonic belt–Arkoma basin transition zone, an area undergoing significant natural-gas exploration, discovery, and development. Early STATEMAP proposals emphasized land-use issues near the growing McAlester, Oklahoma, area, which is adjacent to previously mapped areas. In September 1996, the Oklahoma Geologic Mapping Advisory Committee recommended that new detailed geologic maps of the Oklahoma City (OKC) metropolitan area be made. The OGS identified 12 7.5′ quadrangles and developed a 3-year, 4 quadrangles/year mapping program that includes OKC and major suburbs to the west, north, and east. OGS's FY97 STATEMAP proposal (year one) starts with the northern tier of quadrangles (Piedmont, Bethany NE, Edmond, Arcadia) and will provide a basis for addressing environmental concerns as well as Permian stratigraphic problems.

The OGS procedure for producing the geologic maps and supporting information is: (1) Review exisiting data and/or interpret aerial photographs; (2) Map in the field on 1:24,000 topographic bases; (3) Hand-transfer field data to stable-base mylar greenline, including oil- and gas-well locations; (4) Construct cross-section(s); (5) Prepare description and correlation of units, list of wells, symbols, title block, etc.; (6) Lay out map components (mockup); (7) Enlarge or reduce items in step 5 as appropriate; (8) Register base-map negatives to geologic data; (9) Prepare and composite film negatives; (10) Prepare single film positive of entire map sheet; (11) Reproduce as needed on a large-format engineering copier. OGS geologists perform steps 1 through 6; OGS cartographic staff completes steps 6 through 10; and the OGS print shop staff does step 11.

Reprinted as published in the Geological Society of America *1998 Abstracts with Programs,* v. 30, no. 3, p. 33.