OKLAHOMA GEOLOGY

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On the cover—

A Diapiric? Fold in the Arkoma Basin

This well-exposed fold was discovered in a cut on a farm road in the Summerfield 7.5′ Quadrangle, Le Flore County, southeastern Oklahoma (SE¼NW¼SE¼SE¼ sec. 22, T. 6 N., R. 23 E.). The lithology consists of thin-bedded shales and sandstones, comprising a shallow marine deltaic facies of the Bluejacket Member of the Boggy Formation (Desmoinesian). The Bluejacket crops out along a north-dipping strike ridge in the southern part of the Arkoma basin. Folds of this magnitude and wavelength are extremely rare, if not unknown, in the Arkoma basin as compared with the Ouachita imbricate zone south of the Choctaw fault. Also somewhat unusual is that the fold axis appears to be perpendicular to the regional fold trend in the area. These features suggest that the fold is not a tectonic feature but rather an early soft-sediment deformation feature involving shale diapirism. Shale diapirs commonly occur in modern delta-front positions where high rates of sediment loading generate excessive fluid pressures below impermeable layers. Localized upward bulging (diapiric uplift) results as fluids and associated sediments, mainly shales, escape toward the surface away from the overpressured layer. The phenomenon is analogous to overinflating an inner tube, with a weak zone bulging disproportionately. If this fold were excavated, it should be circular in plan view.

The base of the fold is not exposed, but the converging downwards nature of the fold edge suggests that a detachment surface (corresponding to the zone of overpressuring) may be only a meter or so below the outcrop (exposure). The exposure is ~2 m high. Note how the fold vergence changes over the height of the fold.

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A LARGE STETHACANTHID SHARK (ELASMOBRANCHII: SYMMORIIDA) FROM THE MISSISSIPPIAN OF OKLAHOMA

Jiri Zidek[1]

Abstract

Remains of *Stethacanthus* cf. *altonensis* preserved in a Caney Shale (Delaware Creek Member, lower Chesterian) concretion consist of a ceratohyal, the brush portion of a spine–brush complex, large teeth, and a variety of small teeth and denticles. The gnathal dentition is represented by a symphysial whorl and three- and five-cusped cladodont teeth; the pharyngeal dentition includes whorls and other compound denticles of the "*Stemmatias*" type. Three-cusped teeth of hitherto undescribed morphology have stout, blunt, noncarinated cusps and bases lacking articulating bosses; they may have been anterior pharyngeal rather than posterior gnathal. Several monocuspid denticles with variously expanded bases are from the top of the head or the brush platform. A relatively large placoid scale of *Petrodus*-like morphology, previously not known to occur in *Stethacanthus*, may be from the lateral–dorsolateral region of the head.

Although the compositions of *Stethacanthus* brush and *Gyracanthus* (Acanthodii: Gyracanthidae) prepectoral spines are different, the resulting surface appearance is the same and so are their stratigraphic ranges. Since the two may occur together in lagoonal and deltaic deposits, caution is called for when identifying imperfectly preserved specimens. The hybodontoid elasmobranch *Trichorhipis* Zangerl, based on a triangular pectoral fin, has been reinterpreted as a gyracanthid prepectoral spine, but its comparison with such spines reveals the reassignment to be incorrect.

Introduction

The remains illustrated in Figure 1A–C and Figure 2A–M were collected in 1982 by David M. Work (then with the Missouri Geological Survey, currently at the University of Iowa) and Allen A. Graffham (Geological Enterprises, Ardmore, Oklahoma) at a tributary of the Jack Fork Creek in NW¼ sec. 5, T. 2 N., R. 7 E., Pontotoc County, Oklahoma. They were found closely associated in a Delaware Creek concretion ~30 cm in diameter and 10 cm thick, and may thus all be regarded as parts of a single fish that can be quite unequivocally assigned to the genus *Stethacanthus* Newberry 1889 (family Stethacanthidae Lund 1974, order Symmoriida Zangerl 1981, subclass Elasmobranchii Bonaparte 1838). A. A. Graffham used a rock saw to remove the larger elements (Fig. 1A–C) and 10% acetic acid to free the minute teeth and denticles (Fig. 2A–M), and has graciously given the material to me. It has been deposited at the Oklahoma Museum of Natural History (OMNH) under the catalogue number 4175a–d. It is the first unequivocal record of *Stethacanthus* for the State, because the Caney Shale spines mentioned by Eastman (1917, p. 255) remain to be reexamined and described. The only other fishes ever reported from the Delaware Creek concretions are two palaeoniscoid (possibly *Rhadinichthys*) frag-

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ments (Eastman, 1913; 1917, p. 273), an indeterminate acanthodian (Zidek, 1975, p. 136, figs. 1,2), and *Holmesella* scales (H.-P. Schultze, personal communication, 1992). This further supports the conclusion that the shark remains belong to a single individual, because the great scarcity of fishes makes the odds of finding two specimens or taxa in one relatively small concretion astronomical.

The Delaware Creek is a member of the Caney Shale, which is Meramecian and Chesterian in age. According to D. M. Work (personal communication, 1992), ammonoid cephalopods found in direct association with the *Stethacanthus* specimen included *Goniatites multiliratus* Gordon, *Girtyoceras meslerianum* (Girty), *Epicanites loeblichi* Miller et Furnish, and *Arcanoceras* sp. Another cephalopod, identified by Work as *Bactrites quadrilineatus* Girty (a michelinoceratoid nautiloid), lies above the ceratohyal shown in Figure 1A. The ammonoid taxa are characteristic of the *Goniatites multiliratus* Zone which is lower Chesterian, equivalent to the P_1c-d Zone of the British Bollandian (Saunders and others, 1977, fig. 2), or, more broadly, to the upper Viséan.

There is a strong disagreement concerning the species and generic diversity within the Stethacanthidae. Zangerl (1981) recognized only the genus *Stethacanthus* and placed all occurrences in *S. altonensis* (St. John et Worthen 1875). Williams (1985, p. 117–118) concurred while recognizing *S. carinatus, S. humilis,* and possibly also *S. proclivus* and *S. erectus* as valid species, whereas Lund (1984;1985a,b; 1986) recognized a number of species placed in the genera *Stethacanthus* Newberry 1889, *Orestiacanthus* Lund 1984, *Falcatus* Lund 1985(a), and *Damocles* Lund 1986. Zangerl (1990) described two new stethacanthid genera, *Stethacanthulus* and *Bethacanthus,* and erected a new family, the Falcatidae, for *Falcatus* and *Damocles.* Fortunately, the unsettled state of stethacanthid taxonomy does not affect the assignment of the Oklahoma specimen, whose morphology fits *Stethacanthus* even according to the more complex scheme of Lund. In terms of species, the specimen appears to differ from *S. altonensis* only in a coarser striation of the tooth cusps, which may or may not fall within the range of intraspecific variation. This difference and fragmentary preservation necessitate labeling the specimen only as *Stethacanthus* aff. *altonensis* (St. Johns et Worthen 1875), but it deserves a description for reasons other than species affiliation—namely the multitude of tooth and denticle morphologies and sizes.

Description and Discussion

The OMNH 4175a–d specimen consists of a ceratohyal, the brush portion of a spine–brush complex, large teeth, and a variety of small teeth and denticles.

The ceratohyal (Fig. 1A) is 13 cm long and lacks the upturned posterior end which attached to the hyomandibular. The slightly expanded anterior end which attached to its antimere (or to a basihyal as in *Cobelodus,* see Zangerl and Case, 1976, fig. 13) is well preserved. The upturned posterior portion amounts to ~20% of the total length, which makes the estimated length of the element 15.6 cm. The largest *Stethacanthus* ceratohyal illustrated by Williams (1985, pl. 9, fig. 8) is 13 cm in total length, and the OMNH ceratohyal thus is the largest hitherto recorded. The ceratohyal/meckelian cartilage length ratio is not known for *Stethacanthus* and can only be guessed from the situation in related genera. The length of the ceratohyal amounts to 70% of the meckelian in *Denaea meccaensis* (Williams, 1985, pl. 3), 81% of the meckelian in *Symmor-*

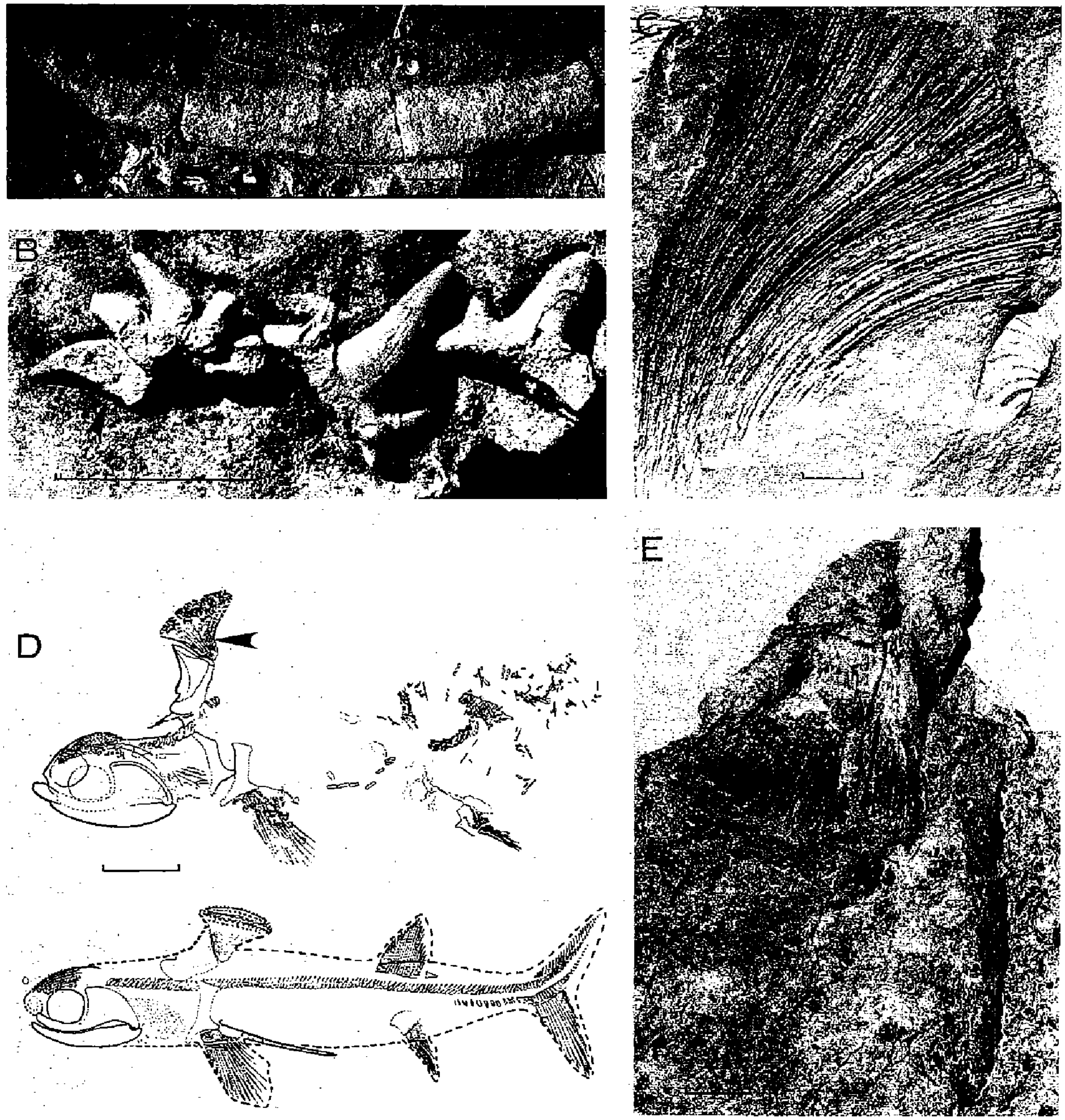

Figure 1. *A–C—Stethacanthus* cf. *altonensis* (St. John et Worthen) from Delaware Creek Member of Caney Shale (lower Chesterian) in Pontotoc County, Oklahoma; scale bars equal 1 cm. *A*—Ceratohyal OMNH 4175a; poorly preserved teeth below its anterior part denoted by arrows. *B*—Symphysial whorl (arrow) and two labially exposed cladodont teeth, OMNH 4175b. *C*—Brush OMNH 4175c (see arrow in *D*) lacking dorsal denticulated platform; detail of surface is shown in Figure 3A. *D*—Preservation and reconstruction of *Stethacanthus altonensis* female skeleton from Mecca Quarry Shale Member of Linton Formation (Desmoinesian) in Parke County, Indiana (from Zangerl, 1981, fig. 81); spine–brush complex denoted by arrow; scale bar equals 10 cm. *E*—PU 20753, associated pectoral and prepectoral spines of *Gyracanthus* sp. (Acanthodii) from Horton Bluff Formation (Tournaisian = Lower Mississippian) in Kings County, Nova Scotia, Canada; scale bar equals 1 cm; detail of surface (prepectoral spine) is shown in Figure 3B.

ium reniforme (Williams, 1985, text-fig. 15), and 93% of the meckelian in *Cobelodus aculeatus* (Zangerl and Case, 1976, fig. 13); thus, 70–90% range is likely for *Stethacanthus*. Zangerl's (1984, fig. 1) restoration of *S.* cf. *altonensis* indicates the meckelian/standard specimen length ratio to be 1:6, which translates to ceratohyal/standard specimen length ratios of 1:6.7 using 90% and 1:8.6 using 70%. The OMNH specimen is therefore estimated to have been between 104.5 and 134.2 cm in standard length, which is in the size range of the Field Museum (FMNH) specimen PF 2207, from the Desmoinesian Logan Quarry Shale at Logan Quarry, Indiana, restored by Zangerl (1984, fig. 1, ~125 cm in standard length).

The brush (Fig. 1C) lacks the dorsal denticulated platform, yet is 8.6 cm tall. In the Logan Quarry specimen restored by Zangerl (1984, fig. 1) the brush is only 6.5 cm tall, which means either that the above calculations based on the ceratohyal underestimate the length of the fish, or that in Zangerl's specimen the brush is relatively smaller because it is a female (see Zangerl, 1984, p. 377; Williams, 1985, p. 122). The brush is only 3–4 mm thick in the Oklahoma specimen, but its radiating tubules are well preserved (see also Fig. 3A), indicating that compaction was not severe and the resulting reduction in thickness probably amounted to only ~30%. Although the denticulated platform is not preserved, some monocuspid denticles derived either from the platform or from the top of the head have been recovered from the acetic-acid residue (Fig. 2L).

The spine–brush complex (arrow in Fig. 1D) has been persistently called "spine–fin complex" by Lund (1974;1984;1985a,b;1986), although Williams (1979,1985) and Zangerl (1981,1984,1990) demonstrated quite conclusively that the brush contains no cartilaginous radials and its tubes are structurally not comparable to ceratotrichia. The function of the complex has not been definitely established, however. Williams (1979;1985, p. 122) regarded it as "a neomorph which probably functioned primarily in sexual display," whereas Zangerl (1984, p. 372, 378) suggested that "the spine–'brush' and head denticle patch may have acted in concert to effect a threat posture simulating a tooth-studded, wide open mouth of a much larger fish," adding (p. 378) that his interpretation does not rule out the possibility that "this elaborate structure may have also served in sexual display and/or courtship behavior."

The gnathal teeth are of four morphologies: symphysial whorl, five-cusped cladodont, three-cusped cladodont, and three-cusped pseudocladodont. The cusps are broadly oval to circular in cross section at the base, but become lenticular and carinated (except for the pseudocladodont type) higher up toward the tip. Ornamentation consists of parallel, vertical cristae that only rarely anastomose and reach all the way to the tip. The spacing of the cristae is twice as wide as that in the teeth studied by Williams (1985, pls. 8,14–16) and about the same as in the teeth studied by Lund (1974, fig. 11a) and Hansen (1986, fig. 27, pl. 4, figs. 16–18).

The symphysial whorl (Fig. 1B, arrow) measures 8 mm in the labio-lingual direction at the compound, strongly concave base which is formed by fusion of five monocuspid teeth aligned in a single plane. There is no appreciable difference in the size of component teeth. The only other symphysial whorl recorded for *Stethacanthus* is from the Sunbury Shale (Kinderhookian = middle Tournaisian) at Berea, Ohio (Williams, 1985, pl. 9, fig. 6). It is incomplete; restored, it probably would be only one-half the size of the Oklahoma whorl, but its morphology appears to be identical.

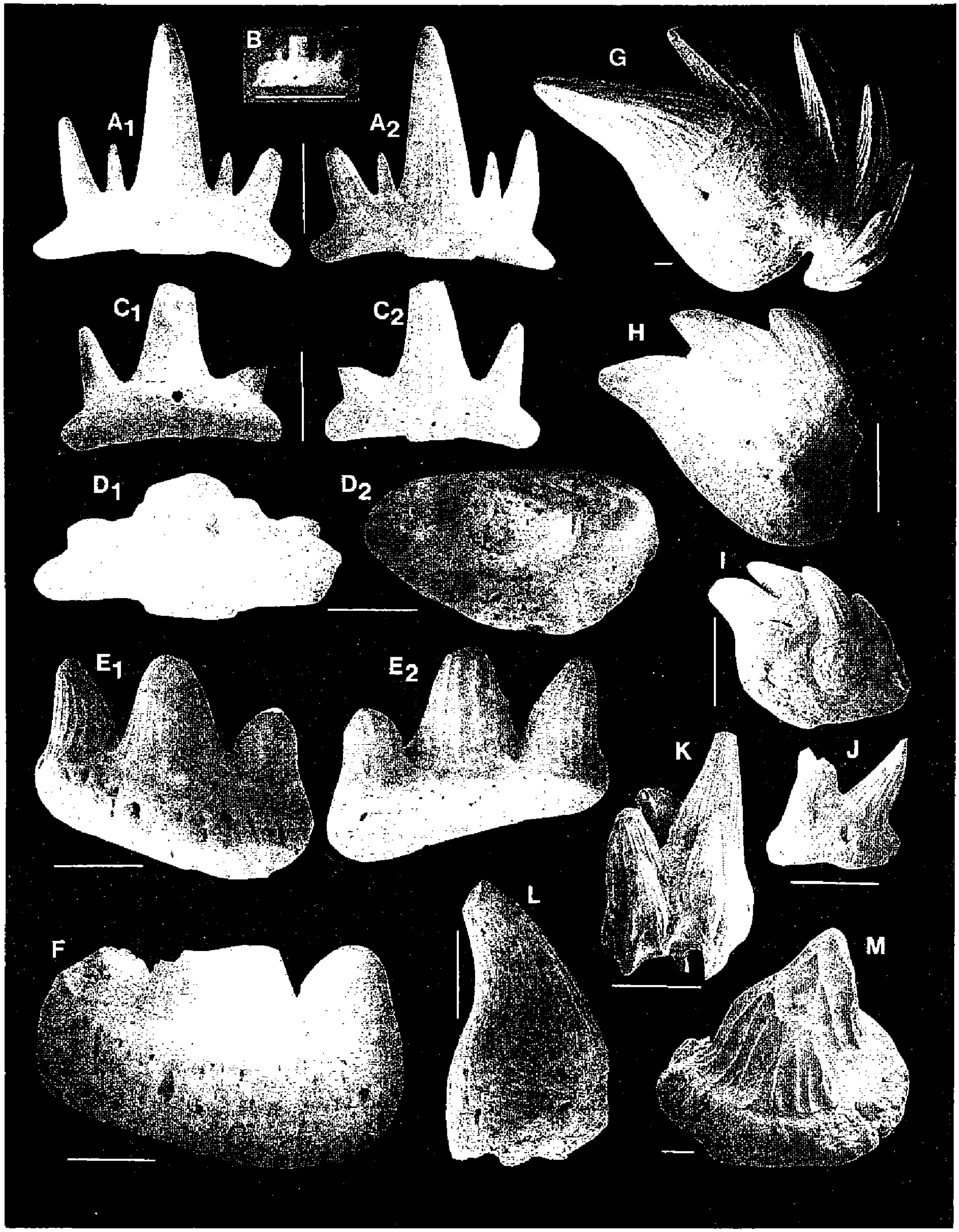

Figure 2. ***Stethacanthus*** **cf.** ***altonensis*** **(St. John et Worthen) from Delaware Creek Member of Caney Shale (lower Chesterian) in Pontotoc County, Oklahoma. OMNH 4175d, teeth and dermal denticles found associated with the ceratohyal, brush, and larger teeth shown in Figure 1A–C. Scale bars equal 1 mm in *A–F* and *H–L*, and 0.1 mm in *G* and *M*. SEM photography courtesy of K. K. Kietzke. *A*—Five-cusped cladodont tooth in lingual (A_1) and labial (A_2) views. *B*—Exceptionally small five-cusped clado-**

(continued on next page)

The cladodont teeth differ only in the number of cusps and size. The lateral cusps reach one-third to one-half the height of the central cusp, and in the five-cusped teeth the intermediate cusps are about one-third shorter than the lateral cusps (Fig. 2A). All the cusps are lingually recurved and the central cusp exhibits a sigmoidal flexure which is best apparent in larger teeth (Fig. 1B). The bases are laterally elongate, with the anteromedial–posterolateral dimension about twice as long as the labial–lingual dimension, their labial margin is nearly straight, the lingual margin is rounded (Fig. $2D_2$), and the aboral surface is slightly concave. On the labio-aboral surface beneath the central cusp is a rectangular basolabial articulating boss as wide as the base of the cusp (Fig. 1B; Fig. $2A, C_2, D_1$), and on the lingual upper margin of the base is a rectangular apical articulating boss which is as wide as the basolabial boss and carries a large lingual foramen that may be centered or laterally offset (Fig. $2A_1, C_1, D$), or rarely paired (Fig. 2B). A row of three to five smaller labial foramina is located between the base of the central cusp and the basolabial boss, and similar but arcuate rows of foramina run below the lateral cusps (Fig. $2A_2, C_2$). Division of the apical boss by the lingual foramen into two squarish prominences, noted by Hansen (1986, p. 229, fig. 27) as common in Ohio *Stethacanthus*, does not occur in the Oklahoma teeth. However, they match the teeth described by Hansen (1986) in all other respects, and those described by Williams (1985) in all respects but one—the density of cristae on the cusps. The teeth described by Lund (1985b, p. 8, fig. 8A–D) as *Stethacanthus* sp. do not belong to this genus (Zidek, 1992, p. 152–153) and therefore are not compared.

The three-cusped cladodont teeth shown in Figure 1B have bases 9 mm long and are the largest teeth found in the specimen, three to four times larger than those in Fig. 2C,D. The largest five-cusped cladodont teeth have bases 2.9 mm long (Fig. 2A), whereas the smallest tooth found has a base only 1 mm long (Fig. 2B). A one-to-nine size range is quite impressive for a single dentition.

The only other cladodont tooth from Oklahoma that could belong to *Stethacanthus* is *Cladodus aculeatus* Eastman from the Johns Valley Formation in Atoka County. The holotype (U.S. Natl. Mus. 8106) was discussed by Zidek (1973, p. 90–91, fig. 1) who labeled it *Cladodus* sp. because of its fragmentary condition. The central cusp is very *Stethacanthus*-like, but the base is visible only in oral view and is so poorly preserved as to render the specimen indeterminate to genus. The other cladodont tooth discussed and illustrated in that paper (Zidek , 1973, p. 92–93, fig. 2) under the name *Cladodus occidentalis* Leidy, from the Superior Clay Products pit near Ada, Pontotoc County (Francis Formation, Missourian), can now be identified with certainty as *Symmorium reniforme* Cope 1893. It is OMNH 00259.

The three-cusped pseudocladodont teeth shown in Figure 2E,F are of hitherto undescribed morphology. The cusps are stout, blunt, lingually recurved, and of round cross section throughout. The lateral cusps are only slightly shorter than the central cusp. The base has nearly straight labial and lingual margins, slightly concave abo-

dont tooth in lingual view. *C*—Three-cusped cladodont tooth in lingual (*C_1*) and labial (*C_2*) views. *D*—Three-cusped cladodont tooth in oblique linguo-basal (*D_1*) and oral (*D_2*) views. *E*—Three-cusped pseudocladodont tooth in lingual (*E_1*) and oblique labio-basal (*E_2*) views. *F*—Three-cusped pseudocladodont tooth in lingual view. *G, H*—Pharyngeal whorls in lateral view. *I–K*—Pharyngeal denticles of *"Stemmatias"* type. *L*—Monocuspid denticle from top of head or brush platform. *M*—Placoid scale.

ral surface, no lingual platform, no anteromedial or posterolateral overlap, and no articulating bosses. Its shape can be characterized as transverse to transverse anguste ellipticus (Systematics Association Committee for Descriptive Biological Terminology, 1962), i.e., a compressed oval with the short to long axes ratio of 1:2.5 to 1:3. The labial margin of the base is very thin (Fig. $2E_2$), but the thickness greatly increases linguad and at the lingual margin the base nearly matches in thickness the height of the cusps and has a well-developed lingual foramen correlable with that in the apical articulating boss of the cladodont teeth (Fig. $2E_1$,F). The lingual foramen and the identical cristation of the cusps relate these teeth to the cladodont type and help to justify calling them pseudocladodont, but the absence of articulating bosses results in the appearance of a dermal-denticle base and suggests that these teeth are anterior pharyngeal (by analogy with *Heterodontus*; see Nelson, 1970, fig. 8) rather than posterior gnathal.

The whorls shown in Figure 2G,H are compound mucous-membrane denticles from the pharynx. They are about six times smaller than the symphysial whorl, from which they differ also in the conspicuous size gradation and often somewhat laterally offset arrangement of the component denticles, and in their variable number (3–8). I am not aware of any pharyngeal whorls previously reported for *Stethacanthus* (although the compound denticle figured by Lund [1974, fig. 11b] comes close), but they are known from all the symmoriid genera, best in *Cobelodus aculeatus* (Zidek, 1973, fig. 3b; Zangerl and Case, 1976, p. 130, fig. 16; Zangerl, 1981, fig. 4B; Hansen, 1986, pl. 11, figs. 15,16), and possibly from *Falcatus falcatus* (Lund, 1985a, p. 5, figs. 5,6A). In *Cobelodus* they occur along the posterior branchial arches and their cusps point anteriorly. The cusps do not differ from *Stethacanthus* in their morphology and size gradation, but the bases are much thicker and only slightly concave (subtypes 018 and 119 of Tway and Zidek, 1983, figs. 36,37). In *Denaea* and *Symmorium* the whorls are poorly preserved (Williams, 1985, p. 96, 109, pl. 7, fig. 17); as far as can be discerned, their bases are indistinguishable from those in *Cobelodus*. The whorls of *Falcatus* differ from those of *Stethacanthus* in having convex, cuplike bases and longer, more slender cusps. The cusps point anteriorly and are only up to 1 mm long, yet form the largest elements of the dentition (the largest specimen of *F. falcatus* is only 14.5 cm in standard length). Lund (1985a) envisioned the whorls as supported by uncalcified labial cartilages, but their position and arrangement would rather seem to suggest that they are pharyngeal.

The Late Pennsylvanian (middle Virgilian) hybodontoid *Hamiltonichthys mapesi* possesses pharyngeal whorls (Maisey, 1989, p. 26–27, figs. 29–31,33) that are less tightly curled and exhibit less progressive size gradation of the component denticles, but are otherwise quite similar to those of *Stethacanthus*. Maisey (1989) found the whorl cusps directed posteriorly and presumed that this had been the orientation in life. Although it certainly is the prevailing orientation of dermal denticles, the above examples of *Cobelodus* and *Falcatus*, and of pharyngeal denticles in modern *Heterodontus* (Nelson, 1970, p. 10, fig. 8), cause me to refrain from speculating on the orientation of pharyngeal whorls in *Stethacanthus*.

Delimiting between pharyngeal whorls and other compound denticles of the pharyngeal (branchial) dentition is quite subjective, as demonstrated by the element in Figure 2I which has the character of a whorl but its two-plane arrangement approaches the *"Stemmatias bicristatus"* denticle type in Figure 2K. The element in Figure 2J, shown in lateral view, has a smaller cusp on each side of the central row that consists of only two larger cusps, but the lateral cusps are not of equal size and the denticle approaches the multiplane condition of the *"Stemmatias cheiriformis"* type. Denticles of similar morphologies are known to occur throughout the Symmoriida. They have been given a multitude of names, chiefly in the 1930s (see Zidek, 1972,1973; and especially Hansen, 1986, p. 441–454, for a list and thorough discussion), but in reality most, if not all, of them are not diagnostic of genera or even families within the order. It may be of interest to note that the dermal denticle "B" of Hansen (1986, p. 417, fig. 79, pl. 11, figs. 1,2; subtype 148 of Tway and Zidek, 1983, fig. 49a,b) has not been encountered in the Delaware Creek material.

The dorsal platform of the brush and the top of the head are covered by monocuspid denticles (Fig. 1D) some of which have been recovered from the concretion, but for lack of space only one is illustrated (Fig. 2L). The cusps of these denticles are recurved or rarely straight, 1–2 mm tall, some of circular cross section throughout but more frequently compressed and carinated, and invariably cristated. The bases are bulbous, in some instances much more expanded than in the figured denticle. Williams (1985, p. 123) noted that some of his specimens suggest a complete gradation between the *"Cladodus pattersoni"* and *"Lambdodus hamulus"* denticle types, which certainly is the case in the Delaware Creek specimen. However, while these denticle types from other localities have smooth cusps, in the Oklahoma specimen they are cristated in the same manner as the teeth and are indistinguishable from some of the stout anterior pharyngeal denticles of *Cobelodus* (Zangerl and Case, 1976, fig. 16 upper right; Hansen, 1986, figs. 86A,88), i.e., the *"Gunnellodus bellistriatus"* and *"Gunnellodus cameratus"* denticle types.

Stethacanthus is thought to have been essentially devoid of squamation (Lund, 1974; Williams, 1985) and the occurrence of a relatively large placoid scale (Fig. 2M) in the Delaware Creek specimen is therefore surprising. It has a flat, roughly circular base 0.9 mm in diameter, which forms a wide rim in all directions. The crown is a deeply ribbed cone somewhat stretched posteriorly but otherwise resembling *Petrodus*. The closest match appears to be subtype 076 of Tway and Zidek (1982, fig. 31a–e) which differs only in having a narrower basal rim and a more fluted crown, but it is ~20 times smaller than the Delaware Creek scale. It also somewhat resembles the dermal denticle "D" of Hansen (1986, pl. 11, figs. 7–9). *Petrodus*-like denticles were reported to occur on the anterodorsal edge of *Stethacanthus* spine (Williams, 1986, p. 124, pl. 15, figs. 5–8), but they are as small or smaller than the subtype 076 scale and exhibit rather variable morphology. The figured scale is the only one recovered from the concretion, which makes it likely that scales of this size and morphology were present only in a very restricted area and their number was low. One potential site is the lateral–dorsolateral surface of the head which is said to have been studded with denticles (Williams, 1985, p. 123).

Ramifications

Figure 1E shows *Gyracanthus* sp. (Acanthodii: Climatiida: Gyracanthidae) from the Horton Bluff Formation (Horton Group, Lower Mississippian) at Horton Bluff, Kings County, Nova Scotia, Canada. The specimen, Princeton University (PU) 20753, is now deposited at the Yale Peabody Museum, New Haven, Connecticut, and represents a rare association of a long, narrow, and heavily ornamented pectoral spine with a large, triangular, and unornamented prepectoral spine. It is in-

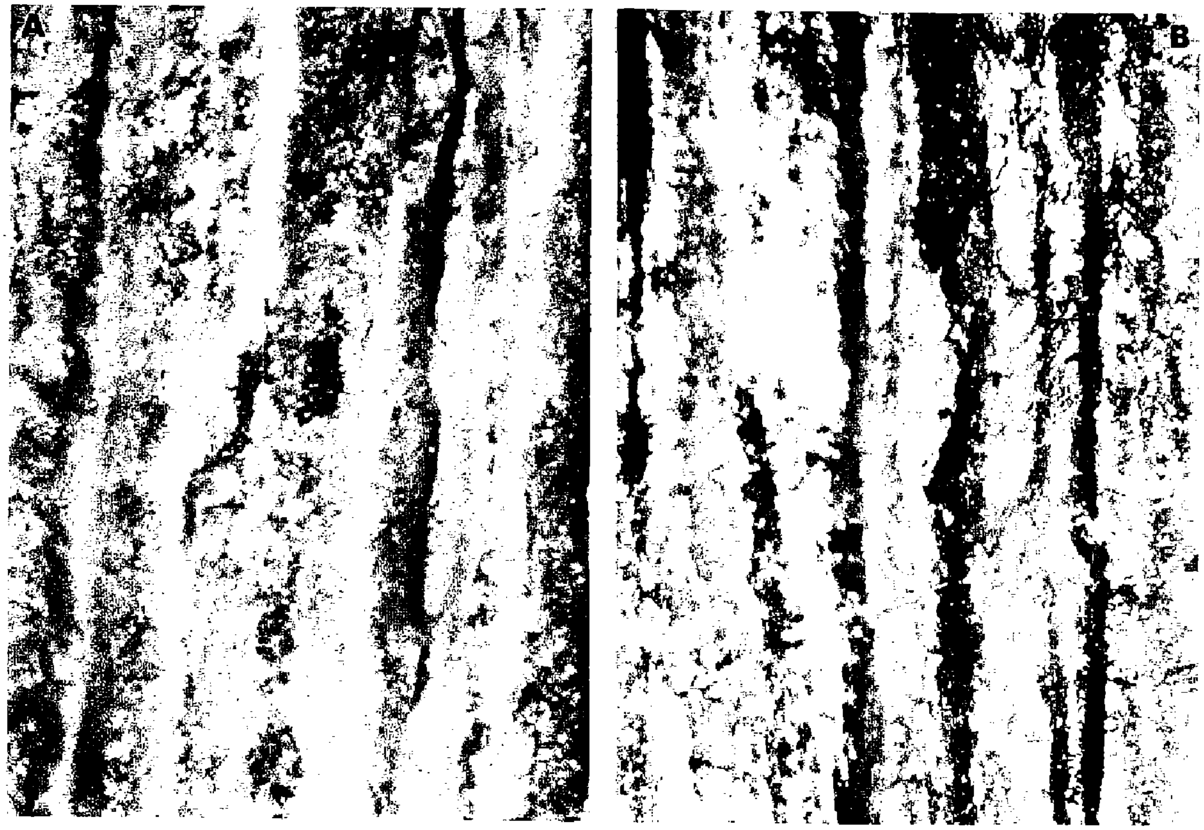

Figure 3. Textures of *Stethacanthus* cf. *altonensis* brush OMNH 4175c (*A*) shown in Figure 1C, and *Gyracanthus* sp. prepectoral spine PU 20753 (*B*) shown in Figure 1E. Scale bar equals 1 cm. Photomicrographs courtesy of A. P. Hunt.

cluded for comparison with the *Stethacanthus* brush (Fig. 1C) because should the prepectoral spine occur isolated, it would be impossible to determine without sectioning whether it is a gyracanthid spine or a stethacanthid brush lacking the denticulated platform. The reason is that the surface texture of the two elements is identical, which is demonstrated in Figure 3. The *Stethacanthus* brush is composed of phosphatic tubes (Zangerl, 1984, p. 375, fig. 5; Williams, 1985, p. 122, pl. 14, figs. 6,7). The histology of *Gyracanthus* prepectoral spines has not been studied, presumably because of their scarcity (see Baird, 1978, p. 13), but spines of *Oracanthus milleri* Agassiz have been so investigated (Patterson, 1965, p. 149, fig. 26) and placed in the Gyracanthidae (Miles, 1973, p. 190), permitting the conclusion that *Gyracanthus* prepectorals consist of osteodentine (as do the pectorals; see Krebs, 1960) and their radiating ridges are the surface expression of dentinal osteons (pallial dentine is absent). Thus, although the compositions of *Stethacanthus* brush and *Gyracanthus* prepectoral spines are different, the resulting surface appearance is the same and the stratigraphic ranges of these genera are very similar. *Gyracanthus* was freshwater, at least predominantly, whereas *Stethacanthus* was marine, and the depositional environment therefore helps in differentiating between isolated prepectoral spines and brushes. However, the two may occur together in lagoonal and deltaic deposits, and caution thus is called for when identifying imperfectly preserved specimens.

Zangerl (1973, p. 13, pl. 1) based a new elasmobranch genus and species, *Trichorhipis praecursor*, on an isolated pectoral(?) fin preserved in an ironstone concretion from Mazon Creek, Grundy County, Illinois (Francis Creek Shale, Carbondale Formation, lower Westphalian D), and later (1981, p. 58) placed it in his superfamily Hybodontoidea. This taxon belongs to the predominantly freshwater Braidwood component of the Mazon Creek fauna. Baird (1978, p. 13) reinterpreted *Trichorhipis* as a gyracanthid prepectoral spine, and I have accepted his opinion until comparing the *Stethacanthus* brush with *Gyracanthus* prepectoral spines. This comparison has convinced me that *Trichorhipis* cannot be synonymous with *Gyracanthus* or an indeterminate gyracanthid and that it indeed is a hybodontoid elasmobranch. The fossil is a flat and very thin, nearly two-dimensional, triangular element that consists of fine rays radiating toward a gently convex margin and rows of denticles that are superposed on the rays and follow their course but do not reach the convex margin. The rays form a compact veil, are unsegmented, straight, very thin, and become the thinnest at the convex margin. The resulting texture is very fine and regular, in contrast to the coarse and rather irregular surfaces shown in Figure 3. The rays in no way differ from those in *Xenacanthus decheni* (Goldfuss) (Xenacanthida), and there can be no doubt that they are ceratotrichia. Triangular pectoral fins very similar to *Trichorhipis* have been described by Maisey (1989, p. 19, figs. 13–15) in articulated specimens of *Hamiltonichthys mapesi*, a Late Pennsylvanian (middle Virgilian) hybodontoid so far known only from the Hamilton quarry complex in Greenwood County, Kansas. Ceratotrichia are not preserved in *Hamiltonichthys*, but "dermal denticles are arranged in rows parallel to where the underlying ceratotrichia would be expected" (Maisey, 1989, p. 19), i.e., in exactly the same manner as in *Trichorhipis* where both are preserved. Zangerl (1981, p. 59) pointed out that gyracanthid prepectoral spines are not covered with placoid scales, and my own examination of *Gyracanthus* prepectorals from Mazon Creek (Field Museum PF 8358 and 8361) and Nova Scotia (Yale Peabody Museum PU 20753, Fig. 1E; PU 21740 from the Port Hood Formation, Westphalian A; and PU 23191 from the Point Edward Formation, Upper Mississippian) confirms the absence of any ornamentation. *Gyracanthus* differs in this regard from *Oracanthus*, whose prepectoral spines bear the ornament of stellate tubercles (Patterson, 1965). It suggests that the prepectoral spines of *Gyracanthus* were covered by the dermis and were not projecting much, if at all, beyond the body outline. In conclusion, the interpretation of *Trichorhipis* as a gyracanthid prepectoral spine rests on its triangular shape which by itself is not diagnostic; in contrast, all its discernible features, including the shape, combine to indicate that it is a hybodontoid elasmobranch. The dubious aspect of the fossil is not its derivation but its name, since an isolated fin whose skeleton is not revealed can hardly be regarded as truly determinate to species nor genus.

Acknowledgments

Allen A. Graffham of the Geological Enterprises, Ardmore, Oklahoma, prepared the specimen and has graciously given it to me. David M. Work of the University of Iowa supplied information on the associated cephalopods and age. Kenneth K. Kietzke and Adrian P. Hunt of the New Mexico Museum of Natural History provided the SEM photos for Figure 2 and the photomicrographs for Figure 3, respectively. Lynne Hemenway of the New Mexico Bureau of Mines and Mineral Resources typed the manuscript. Discussions with Michael C. Hansen of the Ohio Geological Survey, Hans-Peter Schultze of the University of Kansas, and Rainer Zangerl of Rockville, Indiana, were exceedingly helpful and their reviews improved the manuscript. This is contribution 75 to the International Geological Correlation Programme No. 328.

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NEW OGS PUBLICATION

BULLETIN 145. *Special Papers in Paleontology and Stratigraphy: A Tribute to Thomas W. Amsden,* edited by James R. Chaplin and James E. Barrick. 235 pages, 10 contributions. Price: Clothbound, $15; paperbound, $10.

Recently released Bulletin 145 was presented (as a surprise) to retired OGS geologist Thomas W. Amsden at a banquet held in his honor in Norman, Oklahoma, January 28. Jim Chaplin, co-editor of the volume, explains how the book came to be:

> *The idea to publish a bulletin to honor Dr. Thomas W. Amsden was first suggested to me by Dr. James E. Barrick, professor of geology at Texas Tech University, during the 1990 South-Central Section meeting of the Geological Society of America held in Stillwater, Oklahoma. I concurred with Jim that such a tribute volume to recognize Tom's scientific contributions was well deserved and needed. We then proceeded to enlist authors for contributions.*
>
> *The response was most gratifying and all were eager and enthusiastic to have the opportunity to join other colleagues in their expressions of gratitude to Tom for his field assistance, his outstanding contributions to the science and profession of geology, and most importantly, his genuine friendship.*
>
> *Oklahoma Geological Survey Bulletin 145 consists of 10 papers from 16 contributors and contains a wealth of new information in paleontology and stratigraphy from the Ordovician, Silurian, Devonian, and Permian Periods. Also included in the volume are letters submitted by Tom's many friends and colleagues, acknowledging their appreciation and relating their personal experiences with Tom.*

Dr. Thomas W. Amsden at the banquet held in his honor.

OGS Director Charles J. Mankin presenting Tom with Bulletin 145.

The papers and authors included in Bulletin 145 are:

- Proximality Trends in the Red Mountain Formation (Lower Silurian) of Birmingham, Alabama, by B. Gudveig Baarli, Scott Brande, and Markes E. Johnson
- Late Silurian–Early Devonian Conodonts from the Hunton Group (Upper Henryhouse, Haragan, and Bois d'Arc Formations), South-Central Oklahoma, by James E. Barrick and Gilbert Klapper
- The Ordovician Utica Shale in the Eastern Midcontinent Region: Age, Lithofacies, and Regional Relationships, by Stig M. Bergström and Charles E. Mitchell
- *Stringocephalus* (Brachiopoda) from Middle Devonian (Givetian) Rocks of the Baird Group, Western Brooks Range, Alaska, by Robert B. Blodgett and J. Thomas Dutro, Jr.
- New Information on Latest Ordovician to Earliest Silurian Solitary Rugose Corals of the East-Central United States, by Robert J. Elias
- North American Midcontinent Devonian T-R Cycles, by J. G. Johnson and Gilbert Klapper
- Corals from the Turkey Creek Limestone (Lower Devonian), Southern Oklahoma, by William A. Oliver, Jr.
- Lower Devonian Ostracoda in Western Tennessee, by Lee E. Petersen and Robert F. Lundin
- Middle and Late Ordovician Conodonts from Southwestern Kansas and Their Biostratigraphic Significance, by Walter C. Sweet
- Microfacies Correlation of the Early Permian Barneston Limestone, Conoco Test Facility to Vap's Pass, Kay County, Northern Oklahoma, by Donald F. Toomey

Bulletin 145 can be obtained over the counter or by mail from the Survey at 100 E. Boyd, Room N-131, Norman, OK 73019; phone (405) 325-3031, fax 405-325-7069. Add 10% to the cost of publication(s) for mail orders, with a minimum of 50¢ per order.

DELTAIC-RESERVOIRS WORKSHOP
Norman, Oklahoma, March 23–24, 1993

A workshop on "Fluvial-Dominated Deltaic Reservoirs in the Southern Midcontinent," co-sponsored by the Oklahoma Geological Survey and the Bartlesville Project Office of the U.S. Department of Energy, will be held March 23–24, 1993, at the University of Oklahoma in Norman.

The workshop will present discussions and reports on types of deltaic reservoirs, depositional settings, diagenetic history, reservoir characterization, and enhanced oil recovery. The workshop is designed to transfer technical information that will aid in the identification and characterization of oil and gas plays, and thus improve our ability to search for and produce our petroleum resources. Provisional titles and speakers are listed below:

March 23

Distinction, or Indistinction, of Fluvial-Dominated Deltaic Reservoirs, by John W. Shelton, MASERA Corp., Tulsa

Types of Deltaic Reservoirs—A Comparison, by Glenn S. Visher, Geological Services & Ventures, Inc., Tulsa

Pennsylvanian Deltaic-Channel Reservoirs in Oklahoma, by Robert Northcutt, Oklahoma City, and Kenneth S. Johnson, Oklahoma Geological Survey

Evolution of Fluvial Influence on Deltaic Sedimentation, Atokan and Desmoinesian of Arkoma Basin, by David Houseknecht, U.S. Geological Survey, Reston

The Morrowan Reservoirs: A Complex Fluvio-Deltaic Depositional System, by Zuhair Al-Shaieb, J. Puckette, and A. Abdalla, Oklahoma State University

The GYPSY Field-Research Program in Integrated Reservoir Characterization, by Daniel J. O'Meara, University of Oklahoma

Integrated Reservoir Description Using Outcrop Studies: Example from the Bartlesville Sandstone, Northeast Oklahoma, by Dennis Kerr, G. Martinez, I. Azof, and M. Kelkar, University of Tulsa

Mine-Assisted Secondary Recovery of Oil in the Bartlesville Sand in the Cushing Field, Northeastern Oklahoma, by Maynard F. Ayler, Oil Mining Co., Golden, CO

Geometry, Depositional Environment, and Exploration of the Pennsylvanian Red Fork Sandstone, by Richard D. Fritz and Christopher L. Johnson, MASERA Corp., Tulsa

Integrated Perspective of the Depositional Environment, Reservoir Geometry, Characterization, and Performance of the Upper Morrow Buckhaults Sandstone in the Farnsworth Unit, Ochiltree County, Texas, by Richard H. McKay, UNOCAL, Oklahoma City, and Jesse T. Noah, UNOCAL, Houston

March 24

On the Seismic Characterization/Classification of Deltas, by John D. Pigott, University of Oklahoma

Deltaic Facies: Problems, Practices, and Pitfalls, by James R. Chaplin, Oklahoma Geological Survey

Reservoir Characterization and Economic Potential of the Marmaton (Desmoinesian) Sand, Roger Mills County, Oklahoma, by Douglas W. Johnson, and Shahveer P. Kapadia, Grace Petroleum Corp., Oklahoma City

Sequence Stratigraphy, Delta Models, and Fluvial-Deltaic Facies Tracts in the Pennsylvanian Cyclothemic Deposits of North-Central Texas, by Arthur W. Cleaves, Oklahoma State University

River-Dominated Deltaic Reservoirs of the Desmoinesian in Southeast Kansas, by Anthony W. Walton, University of Kansas Reservoir Geochemistry—Concepts, Applications, and Results, by Paul Philp and Andrew Bishop, University of Oklahoma

General Reservoir and Production Characteristics for Fluvial-Deltaic-Dominated Reservoirs, by Ming Ming Chang, Min K. Tham, and Susan R. Jackson, NIPER, Bartlesville

Heterogeneities Related to Deltaic Depositional Processes and Their Effect on Waterflood-Recovery Efficiency, by Susan R. Jackson, Min K. Tham, and Ming Ming Chang, NIPER, Bartlesville

Understanding Reservoir Depositional Environments Contributes to Optimize Oil Recovery—Muskogee Oilfield, a Classical Example, by Jorge M. Perez, E. C. Donaldson, and S. W. Poston, Texas A&M University

Poster Session, March 24

Fluvial-Deltaic Facies Sequences in the Lower Deese Group, Ardmore Basin, by Patricia C. Billingsley, Sanjay Banerjee, R. Douglas Elmore, and Patrick K. Sutherland, University of Oklahoma

Improved Recovery Alternatives for the Alamo SW Field: A Tight Distal-Deltaic-Sand Reservoir, by Roy Knapp, James Forgotson, Tim Collins, Arnaldo Ganuzio, and John Gosling, University of Oklahoma

Mine-Assisted Secondary Recovery of Oil in the Bartlesville Sand in the Cushing Field, Northeastern Oklahoma, by Maynard F. Ayler, Oil Mining Co., Golden, CO

Integrated Reservoir Management to Maximize Oil Recovery from a Fluvial Reservoir, A Case Study of the Sooner Unit, Colorado, by Mark A. Sippel and Ronald W. Pritchett, Research & Engineering Consultants, Inc., Englewood, CO, and Bob A. Hardage, Texas Bureau of Economic Geology

Heterogeneity in Delta-Destructive Oil Reservoirs: Deposition and Diagenesis of Carter Sandstone (Upper Mississippian), Black Warrior Basin, Alabama, by Jack C. Pashin and Ralph L. Kugler, Geological Survey of Alabama

Surface Geochemical Hydrocarbon Signature of the Eastern Colorado and Western Kansas Morrow Formation, by Daniel C. Hitzman, James D. Tucker, and Brooks A. Rountree, Geo-Microbial Technologies, Inc., Ochelata, OK

Reservoir Characterization of Pennsylvanian Sandstones, Nelson Lease, Savonberg Field, Allen County, Kansas, by Tim Phares, Tony Walton, and Lanny Schoeling, University of Kansas

Stratigraphic Characterization from Integrated Core and Well-Log Data of Some Selected Pennsylvanian Sandstone-Producing Reservoirs—Conoco 33-5 Well, Conoco Test Borehole Facility, Kay County, Oklahoma, by James R. Chaplin, Oklahoma Geological Survey

Electrofrac Heatflood Process Demonstration in Peru Sand—A Fluvial-Dominated Deltaic Reservoir, by Shapour Vossoughi, University of Kansas, and Erich Sarapuu and R. H. Crowther, Electrofrac Corp., Kansas City

Cherokee Group (Pennsylvanian) Production in Oklahoma: Data from Fluvial-Dominated Deltaic Reservoirs, by David P. Brown and Mary K. Grasmick, Geological Information Systems, and Robert A. Northcutt, Oklahoma City

Detrital Ore Minerals and Their Significance, Basal Atoka Formation, Northern Arkoma Basin, Arkansas, by Lisa K. Meeks, Arkansas Tech University, and Walter L. Manger, University of Arkansas

Use of Stratamodel Software for Reservoir Characterization of GYPSY Field, by Daniel J. O'Meara and Dirk Seifert, University of Oklahoma

Seismic Exploration for Fluvial-Deltaic Sands in Oklahoma, by Raymon L. Brown, Oklahoma Geological Survey, and Ron Everett, Geobyte Images, Inc., Oklahoma City

Fluvio-Estuarine Facies in the Douglas Group (Virgilian) of Kansas, by Allen W. Archer, Kansas State University, Howard R. Feldman, Kansas Geological Survey, and William Lanier, Emporia State University

Advance registration (prior to February 26) is $50, which includes two lunches and a copy of the proceedings. Late and on-site registration will be $65 per person. Lodging will be available on the OU campus or at local motels.

For more information, contact Kenneth S. Johnson, General Chairman, Oklahoma Geological Survey, University of Oklahoma, 100 E. Boyd, Room N-131, Norman, OK 73019; phone (405) 325-3031; fax (405) 325-7069.

AAPG ANNUAL CONVENTION
New Orleans, Louisiana, April 25–28, 1993

Welcome! The New Orleans Geological Society is delighted to be your 1993 AAPG Convention host.

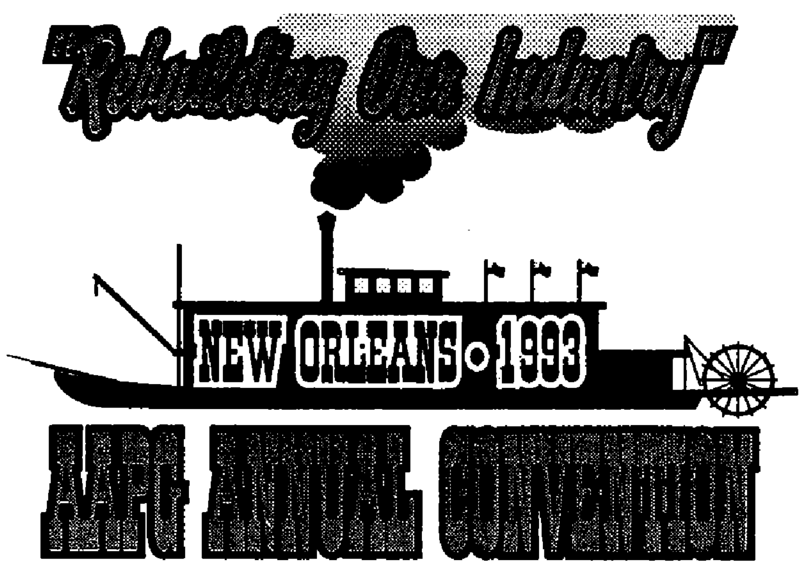
The theme of the AAPG Convention 1993 is "Rebuilding Our Industry." Even as Claude and I draft this message comes compelling evidence that the gas "bubble," persistent through much of the careers of many of our members, finally has burst. However, this important economic incentive is not enough in itself to stimulate investment for domestic petroleum exploration. It is the geologist's obligation to sharpen and apply fundamentals, and avant-garde technology, to the creation of sound petroleum prospects that will reattract capital. We have asked our speakers to help you do this. Technical Program Coordinator Bob Ingram and his committee have provided enough papers, field trips, short courses, and posters to satisfy everybody. Technical exhibits will break records. All these sessions (except, of course, field trips) will be held in New Orleans' incomparable Convention Center.

Your organizers, together with AAPG convention staff, have planned not only a varied technical program, but also enjoyable entertainment events, most of them unique to New Orleans, for you and your spouse. We will send you home full of Creole and Cajun food, with a renewed appreciation of southern hospitality.

Ours has to be a great convention because we are competing against all the delightful things New Orleans visitors like to do. Be sure to leave some time to enjoy our beautiful city. We look forward to seeing you in April 1993!

Bob Sabaté
General Chairman

Claude Baker
General Vice-Chairman



AAPG Annual Convention Agenda

Technical Program

April 26

SEPM/AAPG Carbonate and Evaporite Depositional Systems—Ancient and Modern
EMD/DPA/DEG Get It Out Cleanly—The Environment and Extraction of Energy Mineral
AAPG Domestic Exploration, Emerging Exploration Areas
SEPM/AAPG Geochemical Stratigraphy
AAPG/SEPM Deepwater Depositional Systems, Outcrops, Cores, and Subsurface Examples
SEPM/AAPG Sequence Stratigraphy: A Critical Evaluation—Parts I and II
AAPG/SEPM Carbonate Exploration and Development
AAPG Subsurface Techniques and Analysis
AAPG/SEPM Salt Tectonics
AAPG Domestic Exploration, Opportunities for Independents
AAPG Economics: Synergistic Approach to Exploration and Development
SEPM/AAPG Organic Matters Early Diagenesis Through Catagenesis
SEPM/AAPG Deepwater Depositional Systems—Gulf of Mexico
AAPG Gulf of Mexico: Rebuilding Our Industry Through Integration and Cooperation

April 27

SEPM Carbonate Diagenesis
SEPM Research Conference—Geochronology, Time-Scales, and Correlation: Framework for a Historical Geology—Parts I and II
AAPG International Exploration, Emerging Exploration Areas
DEG Environmental Improvements in Onshore Petroleum Exploration and Development
AAPG/SEPM Geochemistry, New Applications
AAPG Hydrocarbon Habitat—Gulf of Mexico: Geologic Framework
SEPM/AAPG Siliciclastic Depositional Systems—Ancient and Modern
Selected Papers from SEG 62nd Annual International Meeting and Exposition
AAPG International Exploration: Play Concepts
Division of Professional Affairs: The Professional Geologist of the 1990s and Beyond—Adapting to a Changing Market
AAPG/SEPM Geochemistry: Oil-Source Applications—Carbonate and Siliciclastic Source Rocks
AAPG Hydrocarbon Habitat—Gulf of Mexico: Turbidite Plays and Fields
SEPM/AAPG Cretaceous Carbonate Platforms

April 28

SEPM Siliciclastic Diagenesis—Parts I and II
AAPG Reservoirs, Traps, Seal Integrity
AAPG Best of Hedburg Conference on Paleogeography, Paleoclimate, and Source Rocks
EMD Energy Minerals
SEPM/NAMS Symposium: Innovative Analysis of Micropaleontological Data
AAPG Hydrocarbon Habitat—Gulf of Mexico: Development Case Histories
SEPM/AAPG Quantitative Modeling of Petroleum Systems and Fluid Flow
AAPG Structural Analysis and Modeling

AAPG International Exploration, Business Strategies
DEG Hydrogeology and Environmental Issues
AAPG General Interest
AAPG Hydrocarbon Habitat—Gulf of Mexico: Deltaic Plays and Fields
SEPM/AAPG Quantitative Stratigraphic and Structural Modeling

Short Courses

EMD Sequence Stratigraphy of Coal-Bearing Strata: Concepts, Models, and Applications, *April 22* or *April 25*
SEPM Integrated Stratigraphic Analysis: Application of Sequence Stratigraphy and Biostratigraphy to Defining Basin History, *April 23–25*
NOGS Salt Tectonics, *April 24*
NOGS Gulf of Mexico Processes and Environments of Deposition, *April 24*
NOGS Seismic and Sequence Stratigraphy: Its Current Status and Growing Role in Exploration and Development, *April 24*
EMD Detection of Subtle Basement Structures and Related Hydrocarbon Plays, *April 24*
AAPG Analysis of International Oil and Gas Contracts, *April 24–25*
AAPG The Petroleum System—An Investigative Technique to Reduce Exploration Risk, *April 24–25*
AAPG Quick Look Techniques for Prospect Evaluation, *April 24–25*
SEG An Introduction to Reflection Seismic Interpretation, *April 24–25*
SEG Career Goals and Strategies for Geoscientists, *April 24–25*
NOGS Low-Resistivity, Low-Contrast Productive Sands, *April 25*
NOGS Introduction to Ground-Water Hydrology, *April 25*
SEPM Paleokarst-Related Hydrocarbon Reservoirs: A Core Workshop, *April 25*

Field Trips

NOGS Sequence Stratigraphy of the Mississippian Carbonate Ramp, Ozark Mountains, Arkansas and Missouri, *April 22–24*
EMD Testing the Models: Sequence Stratigraphy and Sedimentology of Coal-Bearing Strata, Dolet Hills Lignite Mine, Mansfield, Louisiana, *April 22–24*
GCS–SEPM Sequence Stratigraphy of Paleogene Strata of the Eastern Limb of the Mississippi Embayment, *April 23–25*
NOGS Caprock Structure and Mineralization, Winnfield Salt Dome, Winnfield, Louisiana, *April 24–25*
NOGS Louisiana's Coastal Wetlands and Barrier Islands: Grand Isle and Isles Derniers, *April 24–25*
NOGS Mississippi Delta Overflight, *April 25*
NOGS The Mississippi River Mudlumps at the South Pass Distributary Mouth, *April 25* or *April 29*
NOGS Jackson–Vicksburg–Natchez–Old River, *April 28–30*
NOGS Stratigraphy of the Ouachita Mountain Core Area, Central Arkansas, *April 29–May 1*
GCS–SEPM Holocene Sediments of the Belize Shelf, *April 29–May 5*

For further information about the annual meeting, contact AAPG Convention Dept., P.O. Box 979, Tulsa, OK 74101-0979; (918) 584-2555, fax 918-584-2274. The preregistration deadline is March 15.

UPCOMING MEETINGS

Mantle Composition, Structure, and Processes Workshop, April 4–8, 1993, Soda Springs, California. Information: Jane E. Nielson, U.S. Geological Survey, MS 975, 345 Middlefield Rd., Menlo Park, CA 94025; (415) 329-4948, fax 415-329-4936.

Progress in Geotechnical Engineering Seminar, April 12–14, 1993, Hershey, Pennsylvania. Information: Cari Beenenga, Gannett Fleming, Inc., Box 67100, Harrisburg, PA 17106; (717) 763-7211, ext. 2698.

Geology of Industrial Minerals Symposium, April 25–30, 1993, Long Beach, California. Information: Dave Beeby, Division of Mines and Geology, MS 8-38, 801 K St., Sacramento, CA 95814; (916) 323-8562.

Earthquake-Hazard Reduction in the Central and Eastern United States Meeting, May 3–5, 1993, Memphis, Tennessee. Information: Cathey Stephens, Central U.S. Earthquake Consortium, 2630 E. Holmes Rd., Memphis, TN 38118; 1-800-824-5817 or (901) 345-0932, fax 901-345-0998.

USA/CIS Second Joint Conference on Environmental Hydrology and Hydrogeology: "Industrial and Agricultural Impacts on the Hydrologic Environment," May 15–21, 1993, Arlington, Virginia. Information: American Institute of Hydrology, 3416 University Ave., S.E., Minneapolis, MN 55414; (612) 379-1030, fax 612-379-0169.

Environmental Hydrology and Hydrogeology Meeting, May 16–20, 1993, Washington, D.C. Information: American Institute of Hydrology, 3416 University Ave., S.E., Minneapolis, MN 55414; (612) 379-1030, fax 612-379-0169.

Geological Association of Canada/Mineralogical Association of Canada, Annual Meeting, May 17–19, 1993, Edmonton, Alberta. Information: J. W. Kramers, Alberta Geological Survey, Box 8330, Station F, Edmonton, Alberta T6H 5X2, Canada; (403) 438-7644, fax 403-438-3364.

Midwest Friends of the Pleistocene, May 21–23, 1993, Sturgeon Bay, Wisconsin. Information: Allan F. Schneider, Dept. of Geology, University of Wisconsin—Parkside, Box 2000, Wood Rd., Kenosha, WI 53141; (414) 595-2439.

American Geophysical Union, Spring Meeting, May 24–28, 1993, Baltimore, Maryland. Information: Meetings Dept., AGU, 2000 Florida Ave., N.W., Washington, DC 20009; (202) 462-6900, fax 202-328-0566.

National Ground Water Association, Outdoor Action Meeting, May 25–27, 1993, Las Vegas, Nevada. Information: NGWA, 6375 Riverside Dr., Dublin, OH 43107; (614) 761-1711, fax 614-761-3446.

Geotechnical Engineering, International Meeting, June 1–5, 1993, St. Louis, Missouri. Information: Norma R. Fleming, 119 ME Annex, University of Missouri, Rolla, MO 65401; 1-800-752-5057 or (314) 341-6061, fax 314-341-4992.

The Society for Organic Petrology (TSOP), 10th Annual Meeting, October 9–13, 1993, Norman, Oklahoma. *Submit tentative title by April 30; abstracts due June 30.* Information: Brian Cardott, Oklahoma Geological Survey, 100 E. Boyd, Room N-131, Norman, OK 73019; (405) 325-3031, fax 405-325-7069.

TWO STATE SURVEYS NAME NEW DIRECTORS

Dr. Emery T. Cleaves was recently appointed state geologist and director of the Department of Natural Resources (DNR) Maryland Geological Survey (MGS). Cleaves has been working with the MGS since 1963, serving the agency as field geologist, chief of the environmental geology program, and deputy director and principal geologist.

Dr. James Robertson has accepted the position of director and state geologist of the Wisconsin Geological and Natural History Survey, effective January 1, 1993. Robertson worked 18 years at the New Mexico Bureau of Mines and Mineral Resources, serving as associate director from 1988 to 1991.

NOTES ON NEW PUBLICATIONS

Sequential Extraction Analyses of Drill Core Samples, Central Oklahoma Aquifer

E. L. Mosier, C. S. Papp, J. M. Motooka, K. R. Kennedy, and G. O. Riddle are the authors of this 41-page USGS open-file report.

Order OF 91-0347 from: U.S. Geological Survey, Books and Open-File Reports Section, Federal Center, Box 25425, Denver, CO 80225; phone (303) 236-7476. The price is $4 for microfiche and $6.75 for a paper copy; add 25% to the price for foreign shipment.

Annual Yield and Selected Hydrologic Data for the Arkansas River Basin Compact, Arkansas–Oklahoma, 1991 Water Year

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

Order OF 92-0029 from: U.S. Geological Survey, Books and Open-File Reports Section, Federal Center, Box 25425, Denver, CO 80225; phone (303) 236-7476. The price is $4 for microfiche and $5.25 for a paper copy; add 25% to the price for foreign shipment.

A Petrographic Study of Igneous Rock from Three Drill Holes Near the Meers Fault, Oklahoma

This 25-page USGS open-file report was written by D. S. Collins.

Order OF 92-0411 from: U.S. Geological Survey, Books and Open-File Reports Section, Federal Center, Box 25425, Denver, CO 80225; phone (303) 236-7476. The price is $4 for microfiche and $4.25 for a paper copy; add 25% to the price for foreign shipment.

OKLAHOMA ABSTRACTS

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

Models for the Appalachian–Ouachita Rifted Margin

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University of Kentucky, Lexington, KY 40506

Rifted continental margins preserved beneath intact passive-margin cover strata, as well as modern rift systems, suggest analogs for reconstruction of the late Precambrian–Cambrian Appalachian–Ouachita rifted margin. Paleozoic orogenic events, post-Paleozoic erosion, Mesozoic extension, and post-Paleozoic sedimentary cover have left a complex mosaic of remnants of the Appalachian–Ouachita rifted margin. Reconstruction based on restored balanced cross sections, as well as three-dimensional reconstructions, can be enhanced by identification of key components in generalized models for synrift structures and rocks.

Transform offsets partition rift systems into large-scale segments (rift zones), comparable in scale to promontories and embayments of the Appalachian–Ouachita rifted margin. Smaller components (rift units) of rift systems are similar in scale to the distribution of specific synrift rocks of the Blue Ridge rift (for example, Ocoee and Mount Rogers). Low-angle detachment models for continental rifting require significant differences in structure of the upper and lower plates, and the structural differences are manifest in differences in the stratigraphy and composition of synrift and early post-rift rocks. Transform faults define offsets of rifts and form boundaries between domains of opposite dip of low-angle extension faults. Along-strike variations in the synrift and post-rift rocks indicate upper-plate and lower-plate configurations in different domains along the Appalachian–Ouachita rift. Transform margins have an abrupt transition from continental to oceanic crust (as documented for the Alabama–Oklahoma transform of the Appalachian–Ouachita margin). Some transform margins include transform-parallel fault blocks, and diachronous thermally driven uplifts migrate along continental transform margins as the adjacent ocean opens. Such potentially distinctive, transform-related structures are not yet recognized along the Appalachian–Ouachita margin.

Compressional deformation of old rift structures and synrift rocks, as well as passive-margin cover strata (rifted-margin prism), may be expressed in the re-use of rift-stage fault surfaces. Sense of movement and selection of specific rift-stage faults for re-use are determined primarily by the azimuth of plate motion and by the direction of dip of the subduction zone. For example, compressional deformation of an ancient rifted margin on a subduction plate differs from that on an overriding plate. Although re-use of extensional structures is generally recognized, specific components of a deformed rift system are difficult to identify with certainty.

Reprinted as published in the Geological Society of America *Abstracts with Programs, 1992,* v. 24, no. 2, p. 70.

Progressive Deformation of Slaty Cleavage in the Broken Bow Uplift, Oklahoma

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The oldest rocks of the Ouachita Mountains are exposed in the Broken Bow uplift of Oklahoma. These low grade metasedimentary rocks reveal a polyphase deformational history in which folded cleavages are recorded. A regionally developed slaty cleavage is associated with the first generation folds. This slaty cleavage is pervasive in the shales and more widely spaced in the coarser grained sediments. On a microscopic scale, zones of pressure solution residuals (PSR) consisting of mica, iron oxides, and other insoluble opaque materials are aligned parallel to the cleavage traces. Estimates of shortening across these zones indicate as much as 30–40% volume loss. Evaluation of the PSR has revealed two distinct morphologies: one high frequency spacing (50–100 µm) of narrow PSR (~2 µm) and one low frequency spacing (300–1000 µm) of broader PSR (20–250 µm). Age relationships are difficult to establish; however, the low frequency spacing may be younger based on a few cross cutting relations. The slaty cleavage is folded and is rotated from regional northerly dip to a local southerly dip. These synforms are coaxial with the first generation folds and commonly are truncated by reverse faults on the south dipping limbs. Flattening on these south dipping limbs is apparent in the recumbent buckles; slip on favorable oriented PSR; and the development of local subhorizontal rough cleavage in the sandstones and siltstones as well as pencil structures in the finer grained rocks. These pencil fragments are oriented (310°/30–40°). Using the SEM, weakly developed fabrics can be seen in these fragments: the original bedding, slaty cleavage (1–3 µm PSR), and a third fabric oriented 15–20° to the slaty cleavage. This flattening fabric appears to modify the slaty cleavage by reorienting the micaceous minerals in the PSR and locally truncating and reorienting the PSR. As a result, field observations of cleavage orientation reveal an upper limit to the southerly dipping slaty cleavage of 50–60°. Subsequently, the slaty cleavage is poorly developed, but has a more gentle dip approaching that of the rough cleavage. This cleavage modification in the shales points toward an explanation for the transecting cleavage reported by earlier workers.

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Paleozoic Tectonics of the Ouachita Orogen through Nd Isotopes

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A combined isotopic and trace-element study of the Late Paleozoic Ouachita Orogenic belt has the following goals: (1) define changing provenance of Ouachita sedimentary systems throughout the Paleozoic, (2) constrain sources feeding into

the Ouachita flysch trough during the Late Paleozoic, (3) isolate the geochemical signature of proposed colliding terranes to the south, (4) build a data base to compare with possible Ouachita System equivalents in Mexico. The ultimate aim is to constrain the tectonic setting of the southern margin of North America during the Paleozoic, with particular emphasis on collisional events leading to the final suturing of Pangea.

Nd isotopic data identify 3 distinct groups: (1) Ordovician passive margin sequence with $E_{Nd}(O) = -18$ to -22, $E_{Nd}(t) = -13$ to -16, and $T_{dm} = 1.8$ to 2.1 Ga; (2) Carboniferous proto-flysch (Stanley Fm.), main flysch (Jackfork and Atoka Fms.) and molasse (foreland Atoka Fm.) with $E_{Nd}(O) = -9$ to -13, $E_{Nd}(t) = -6$ to -10, and $T_{dm} =$ 1.4 to 1.7 Ga; (3) Mississippian ash-flow tuffs with $E_{Nd}(O) = -5$ to -6, $E_{Nd}(t) = -2$, and $T_{dm} = 1.0$ to 1.1 Ga. Interestingly, two Silurian samples from the Blaylock Fm. have $E_{Nd}(t) = -7$, showing close affinities with the Carboniferous rather than the early Paleozoic strata.

We interpret the Ordovician signature to be essentially all craton-derived, whereas the Carboniferous signature reflects mixed sources from the craton plus orogenic sources to the east and possibly the south, including the evolving Appalachian Orogen. The proposed southern source is revealed by the tuffs to be too old and evolved to be a juvenile island arc terrane. We interpret the tuffs to have been erupted in a continental margin arc-type setting. Surprisingly, the foreland molasse sequence is indistinguishable from the main trough flysch sequence, suggesting the Ouachita trough and the craton were both inundated with sediment of a single homogenized isotopic signature during the Late Carboniferous. The possibility that Carboniferous-type sedimentary dispersal patterns began as early as the Silurian has important implications for the tectonics and paleogeography of the evolving Appalachian–Ouachita Orogenic System.

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Significance of Detrital Ore Minerals, Basal Atoka Formation, Northern Arkoma Basin, Arkansas

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Detrital galena and sphalerite occur in conglomerates of the Spiro Sandstone, basal Atoka Formation (Middle Pennsylvanian), along the northern margin of the Arkoma Basin in Pope County, Arkansas. Granule to pebble clasts include quartz, chert, shale, quartz arenite, concretionary ironstone, and micritic limestone. Matrix is subangular to rounded, medium to coarse quartz sand with accessory alkali feldspars, many weathered to clays, heavy minerals and rare metamorphic rock fragments cemented by calcite spar. Marine invertebrate fossils are common. Conglomeratic intervals reach more than eight meters. Thicker intervals display channel geometries, truncate underlying strata, but occur above the base of the Spiro. Detrital sphalerite occurs as cleavage fragments and rounded grains in the sand fraction, while galena is a mineralization of limestone clasts.

The feldspars, quartz granules, and metamorphic rock fragments, combined with dispersal directions for the Spiro Sand in central Arkansas suggest the Ozark Dome as its source, although absence of volcanic detritus is puzzling. Uplift of the Ozark Dome and coeval downwarp of the Arkoma Basin produced a broad erosional surface over the southern midcontinent reflected by the Morrowan–Atokan unconformity. The presence of detrital galena and sphalerite in basal Atokan strata suggest that all lead–zinc mineralization in southeastern Missouri may not be related to the Ouachita Orogeny, but some is older and was subjected to Middle Pennsylvanian erosion.

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Regional Depositional Relationships and Fracturing of the Wapanucka Limestone, Frontal Ouachita Mountains

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Although gas production in the Ouachita Mountains has been primarily from the Spiro (Atokan), the Wapanucka (Morrowan) locally is a gas reservoir and thus a secondary objective. Outcrop study of imbricate thrust sheets forms a basis for predicting the character of rocks in the subsurface. Thick successions of repetitive subtidal carbonate cycles of platform, platform margin, and basinal facies characterize the Wapanucka in outcrop, except for most of the basinal outcrops, in which cyclicity is not evident. Each cyclic sequence records aggradation and southward progradation of the ramplike shelf margin. Shoaling marine environments are represented by bryozoan crinoid shallow shelf bars capped by oolites that developed on local and regional topographic highs. These repetitive subtidal cycles are occasionally capped by localized beach deposits (limestone pebble conglomerates with abundant oolites and carbonaceous wood fragments).

Demosponges were the most abundant biota at times when the shallow shelf waters were muddied by fine clastic influx. Sponges commonly grew with the tubular algae, *Donezella*, and were occasionally encrusted with *Archaeolithophyllum*, a phylloid algae. These two algaes form boundstones that dominate the basinward facies with associated encrusting forams. In the eastern portion of the study area, phylloid algae is often the dominant bioclast in arenaceous grainstone shoal deposits. They are also found as the major constituent of algal-mud mounds.

The top of the Wapanucka can be correlated throughout the outcrop region as a stratigraphic sequence boundary. A fine clastic influx, probably from the terrestrial Foster channels to the north, choked out the carbonate production of the Wapanucka. This shaly facies conformably overlies the Wapanucka and is termed either the middle shale or sub-Spiro shale. In this interval, cross-bedded sandy calcarenites within the shale probably represent shelf bars. These local buildups make it difficult to separate the Wapanucka and Spiro. Several of these discontinuous bars occur in outcrop within a few miles laterally, and were also observed in subsurface core. The Spiro Formation conformably overlies the middle shale and represents a return to shallow shelf carbonate deposition similar to the Wapanucka. However, significant

amounts of sand were transported to form sand-dominated shallow-marine bars, in contrast to the bioclastic and oolite shoals of the Wapanucka.

Several facies of the Wapanucka are potential hydrocarbon reservoir rocks. These include limestone pebble conglomerate, oolitic grainstone, algal boundstone, and spiculitic limestone. Spiculitic limestone (often sponge boundstones) often develop fracture porosity. Numerous fractures in the fontal Ouachitas cut through bedding, and most of these are oriented perpendicular or parallel to strike. Fracturing is believed to be of major importance to reservoir potential of the Wapanucka, and probably the Spiro as well.

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Sedimentology and Structure of Polk Creek Shale, Cossatot Mountains, Arkansas

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The Polk Creek Shale (PCS) is an Upper Ordovician shale and chert unit of the pre-flysch system in the Ouachita Mountains of Arkansas and Oklahoma. Little modern information has been published about the formation because of the poor quality of its outcrops due to relative thinness and lack of resistance to erosion. A complete section of the PCS has recently been exposed near Albert Pike Recreation Area in the Cossatot Mountains, part of the southern Benton uplift, Arkansas. Sedimentologic and structural analysis indicates that the lower contact of the PCS is conformable and interfingers with the Bigfork Chert. The lower PCS consists of thin, organic-rich, black siliceous shales interlayered with black chert beds. There are graptolite assemblages in the carbonaceous shales and thin shell beds containing bryozoans, brachiopods, and crinoid fragments that have been totally replaced by silica. Many of the fossils' delicate structures are preserved suggesting a limited transport distance. The upper contact of the formation is conformable with the Blaylock Sandstone. The upper PCS is composed of thin beds of black, siliceous shale interlayered with mottled chert and contains fewer beds of graphtolite-rich, carbonaceous shale relative to the lower part of the unit. Toward the top of the formation, thin laminae of fine-grained siltstone are interbedded with laminae of black shale. The laminae increase in thickness from about 1 mm to 8 cm near the contact with the Blaylock Sandstone. Stratigraphic thickness of the formation is currently unknown owing to extensive deformation characterized by north-vergent, tight to open, westward-plunging, mesoscopic kink folds with near-vertical back limbs. Geometry of mesoscopic folds and thrust faults indicates dominant northward tectonic transport. The PCS in this area has been diagenetically altered during late Paleozoic Ouachita orogenic deformation by the replacement of shale, dolomite, and limestone by silica and iron-bearing minerals. In areas where the rocks are less altered, the formation is a potential source-rock for hydrocarbons. Evidence from the Cossatot Mountains suggests that the PCS was deposited in a quiet-water shelf environment.

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Geochemical Indicators of Provenance and Tectonic Setting of Mississippian Pelites of the Ouachita Fold Belt

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Plate tectonic reconstructions of the southern continental margin of North America during the Peleozoic are inconclusive. Numerous conflicting models have been proposed for the opening and closing of the Iapetus Ocean and the subsequent deposition and deformation of the Ouachita System. Considerable confusion also exists concerning the provenance of the Carboniferous flysch deposits of the Ouachitas.

Trace element geochemistry of shales from the Stanley Group constrain both the provenance of the sediments and the plate tectonic setting during the Mississippian evolution of the southern continental margin. Th/Sc and Cr/Th ratios support a cratonic source for the majority of samples analyzed. However, in several samples the Th/Sc ratio decreases and the Cr/Th ratio increases, suggesting a contribution from a more mafic source. Using element ratio-ratio diagrams, all of the samples plot along a curve consistent with a two-component mixing model between a felsic and mafic source.

Both a tantalum-niobium trough and a strongly negative strontium anomaly are seen in upper-crust-normalized trace element spiderdiagrams. These anomalies are also present in interbedded volcaniclastics within the Stanley. The Stanley shales also exhibit a positive vanadium-chromium-nickel anomaly. The pervasive occurrence of these anomalies is interpreted as inherited from their source, and not from diagenetic alteration or sedimentary processes.

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Ouachita Facies Sm–Nd Depleted-Mantle Model Ages and Detrital Zircon Compositions Consistent with a North American Cratonic Source

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The much-debated source of Ouachita Facies sediments of Arkansas and Oklahoma is constrained by Sm–Nd model age data and detrital zircon compositional data. The Stanley Group rocks vary little in Sm–Nd model ages, with 11 of 14 samples falling between 1525 Ma and 1670 Ma, and are likely derived predominantly from cratonic, probably North American, source areas. The three remaining Stanley samples are all from the southern margin of the exposed Ouachitas and

have model ages of 1395–1425 Ma. This small degree of model age variation extends to some other Paleozoic units exposed in the Ouachitas, including the pre-orogenic Bigfork (1615 Ma) and Womble (1445 Ma) Formations and the post-Stanley Jackfork (1540-1565 Ma) and Atoka Groups (1510 Ma). Two samples of the Stanley-equivalent Tesnus Formation of the Marathon region of West Texas also have model ages (1530 Ma, 1615 Ma) indistinguishable from those of the Stanley Group. The only samples with significantly different model ages are two samples of tuff (1075 Ma, 1100 Ma) interbedded with Stanley.

The three southern margin Stanley samples are surmised to have a small volcanic component related to the interbedded southern-derived tuffs. This volcanic component is borne out not only by their somewhat younger model ages, but also by their slightly elevated radiogenic Nd content. Further, Hf and Y contents of zircons from these samples (mean 1.7 wt.% HfO_2, 0.4 wt.% Y_2O_3) is closer to those of the tuffs (1.6 wt. HfO_2 and 0.3 wt.% Y_2O_3) than are the Stanley samples in general (1.8 wt.% HfO_2 and 0.6 wt.% Y_2O_3), again indicating that only the southernmost samples have a significant south-derived sediment component. Available data on zircon compositions and Rb–Sr age dates from granites of the Ozark uplift and zircon compositions of the Black Warrior Basin suggest the Ouachita Facies sediments have more in common with the Ozark granites than with the possibly southern-derived Black Warrior sediments.

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Remagnetizations, Basinal Fluids, and Paleomagnetic Constraints on the Timing of Dolomitization

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Geochemical and paleomagnetic results from Cambro–Ordovician dolomites in the Arbuckle Mountains, southern Oklahoma, suggest a connection between dolomitization events and magnetizations in two distinct dolomite types. Type I dolomite, which is most common in the vicinity of the Arbuckle Anticline, has a dull cathodoluminescence, low $\delta^{18}O$ values, coeval to slightly lower $^{87}Sr/^{86}Sr$ ratios and contains an easterly early Paleozoic magnetization in magnetite. These results are consistent with nearly syndepositional dolomitization and subsequent alteration by meteoric fluids in the Ordovician.

To the southeast, closer to the Ouachita Mountain front, most of the dolomites (type II) contain a SE and shallow late Paleozoic remagnetization in magnetite. In contrast to type I dolomites, these dolomites contain abundant authigenic k-feldspar and pyrite, radiogenic $^{87}Sr/^{86}Sr$ ratios, high Fe and Mn concentrations, and have a bright red cathodoluminescence, all of which are consistent with alteration by basinal fluids. At one site, a stromatolitic bioherm, dolomites similar to type I are surrounded by type II dolomites. The distribution of specimen directions at this site is streaked between the early Paleozoic and late Paleozoic directions.

The results of this study suggest a connection, either direct (by causing precipitation) or indirect (by increasing permeabilities for another fluid), between a radiogenic dolomitizing fluid and the late Paleozoic remagnetization in magnetite. The type I dolomites at the stromatolitic bioherm apparently escaped the almost pervasive alteration and remagnetization caused by the basinal fluids close to the Ouachita Mountains, one potential source for the fluids.

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Two-Decked Nature of the Ouachita Mountains, Arkansas

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The Ouachita Mountains of Arkansas and Oklahoma are made up of two structural decks. The lower deck of tight to isoclinal folds in pre–Middle Mississippian strata records multiple folding and low-grade metamorphism. The upper deck of open folds in Carboniferous rocks shows no evidence of the multiple folding and metamorphism. Dips of fold limbs in the lower deck are typically more than 60°; dips of fold limbs in the upper deck are generally less than 45°; fold wavelengths in the lower deck are in the range of 0.5 to 3.5 km; fold wavelengths in the upper deck are generally in the range of 12 to 15 km. Estimates of shortening of the folds in the lower deck are five times greater than those of shortening of the upper deck. The change from tight folding to broad folding takes place in the middle part of the Mississippian Stanley Group. The difference in fold style has been attributed to disharmonic folding of a stiff upper deck and a ductile lower deck. However, the boundary between harmonic and disharmonic folds shows no apparent relation to the fold wavelength or the stratigraphic spacing of stiff beds. We hypothesize that the difference in structural style reflects the unconformable deposition of younger folded and faulted foreland-basin strata (the upper deck) over the older lower deck strata, which were stacked in an accretionary wedge.

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Meteoric Modification of Early Dolomite and Late Dolomitization by Basinal Fluids, Upper Arbuckle Group, Slick Hills, Southwestern Oklahoma

GUOQIU GAO, LYNTON S. LAND, and ROBERT L. FOLK, Dept. of Geological Sciences, University of Texas, Austin, TX 78713

Thick, massive dolomite units from the upper Arbuckle (lower Ordovician) peritidal carbonate sequence, Slick Hills, southwestern Oklahoma, provide insight into two important problems: (1) modification of early dolomite, and (2) late dolomitization. Early dolomite, volumetrically dominant, is nonluminescent to dully luminescent. $^{87}Sr/^{86}Sr$ ratios of most early dolomite samples are similar to both Early Ordovician seawater and associated limestones, consistent with an early origin from coeval seawater. All early dolomite samples are characterized by low $\delta^{18}O$ values (–5.1 to –10.0‰, PDB), indicating postdepositional modification. Meteoric water, buffered by younger carbonates with lower $^{87}Sr/^{86}Sr$ ratios, was probably responsible for modification because lower Sr concentrations, $\delta^{18}O$ values, and $^{87}Sr/^{86}Sr$ ratios characterize the more intensively modified early dolomite samples. Meteoric modification probably occurred during emergence of the carbonate platform in the Ordovician.

Late dolomite, volumetrically minor, is brightly luminescent and occurs mainly in transition zones between early dolomite and associated limestone. Late dolomite has high $^{87}Sr/^{86}Sr$ ratios, $\delta^{18}O$ values (+5.9 to –2.5‰, PDB), and Fe and Mn concentrations, relative to early dolomite and associated limestone. ^{87}Sr-, ^{18}O-, Fe-, and Mn-enriched fluids, derived from the Anadarko basin during the late Paleozoic, are proposed to have formed the late dolomite. The fluids migrated through preexisting, early dolomite "aquifers," and dolomitized limestones near the early dolomite–limestone contacts which existed at that time.

Although early dolomite remained more porous than limestone during early burial, burial alteration by solution–compaction and cementation by late dolomite have reduced porosity considerably. Better reservoir quality is expected to be associated with late dolomite in the Arbuckle Group.

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Trapping Mechanisms in the Arbuckle Group Sediments of Eastern Major County, Oklahoma

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A new exploration play in Major County, Oklahoma, has discovered significant reserves of oil and gas in Ordovician Arbuckle sediments. Major County is located on the northern shelf of the Anadarko basin, and oil and gas have been produced in the county since 1945. The newly explored deeper structures are reflected by subtle structural reversals in the shallow sediments.

Arbuckle Group lithotypes are typically dolomitic grainstones and mudstones. Matrix-supported chaotic breccia and collapse breccia facies are present in the upper 170 ft of Arbuckle sediments. Unique to this play is an aphanic rhyolite that also produces oil and gas.

A horst and graben structural fabric is the primary trapping mechanism in the area. Within each horst block, structural reversals and stratigraphic pinch-outs further define reservoir geometry. The Mustang horst in T21N R10W illustrates the trapping mechanisms in the Arbuckle Group sediments. A facies change from a bioclastic grainstone to a very finely crystalline mudstone traps hydrocarbons in the DLB Energy Company 27-4 Cecil oil reservoir. A sucrosic microcrystalline dolomite that subcrops against Oil Creek shale is the trapping mechanism for the Continental

Trend Resources 1-22 Mary Ellen gas reservoir. Porous Arbuckle dolomite juxtaposed to Oil Creek shale by a small normal fault traps hydrocarbons in the DLB Energy Company 28-9 Bierig. A structural reversal on the downthrown side of a normal fault along with the facies change from a collapse breccia to a matrix-supported chaotic breccia traps hydrocarbons in the Continental Trend Resources 1-34 Terry.

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Interbasinal Cyclostratigraphic Correlation of Milankovitch Band Transgressive-Regressive Cycles: Correlation of Desmoinesian–Missourian Strata Between Southeastern Arizona and the Midcontinent of North America

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The cyclic pattern of deposition in the Horquilla Limestone of southeastern Arizona resulted from glacio-eustatic sea-level fluctuations with periodicities within the Milankovitch band. The depositional surface fluctuated from above sea level to below the depth of autochthonous carbonate production. By means of characteristics of the cycles, correlations can be established not only between sections in the Pedregosa basin of southeastern Arizona, but also to the midcontinent of the United States. These correlations exceed the resolution of biostratigraphy and distinguish the eustatic component of relative sea-level fluctuations in widely spaced basins with different depositional settings.

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Ore Microscopic Textures and Paragenetic Sequence of Permian Shale- and Sandstone-Hosted Copper–Silver Deposits at Paoli and Creta, Oklahoma

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Ore microscopic examination of polished thin sections of ores from the sandstone-hosted (Wellington Formation, Leonardian Series, Permian) silver–copper deposit at Paoli in south-central Oklahoma has revealed ore textures that are markedly different from those found in the shale-hosted (Flowerpot Shale, Guadalupean Series, Permian) copper–silver deposit at Creta in southwest Oklahoma. The differences in ore textures have resulted from the selective replacement of different preexisting materials by the copper–silver mineralizing fluids.

At Paoli, part of the chalcocite mineralization occurs as replacement of disseminated, diagenetic, pyritohedral pyrite crystals and as replacements of carbonate cement between clastic quartz sand grains (Thomas, Hagni, and Berendsen, 1991), but most of the copper sulfide grains have formed by the replacement of hermatite

grains. The hermatite itself occurs as a replacement of carbonate cement in the host sandstones. This mode of copper sulfide occurrence at Paoli is greatly different from that at Creta where the copper sulfide grains occur as replacements of megaspores, colloform pyrite, and pyrrhotite crystals.

The replacement of hermatite grains at Paoli results in a paragenetic sequence of ore mineral deposition that consists of: pyrite (oldest)–goethite–hematite–covellite–chalcocite–digenite–bornite–chalcopyrite (youngest). The sequence of copper minerals at Paoli is the reverse order of those deposited at Creta and it is unusual for most copper ore deposits elsewhere. The paragenetic sequence at Paoli indicates that early pyrite and other iron-bearing minerals in the sandstones were first oxidized to hematite (and minor goethite). Subsequent fluids became progressively more reducing during the deposition of the copper sulfide minerals.

The Paoli and Creta copper deposits are interpreted to have formed by epigenetic replacement, but under different conditions of formation.

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Upper Triassic Dockum Formation, West Texas: Stratigraphy and Sedimentation

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Upper Triassic strata exposed in west Texas are assigned to the Dockum Formation of the Chinle Group, which consists of four named members (in ascending order): (1) Camp Springs member, up to 15 m of mostly extrabasinal conglomerate; (2) Tecovas member, up to 67 m of strata dominated by variegated mudstone and siltstone; (3) Trujillo member, up to 76 m of mostly intrabasinal conglomeral and micaceous sandstone; and (4) Bull Canyon member, mostly reddish brown mudstone and siltstone up to 162 m thick. An unnamed member of mudstone and sandstone in the Big Springs area is equivalent to the Camp Springs and lower Tecovas members to the north. Fossil vertebrates, palynomorphs and field stratigraphic data establish the following: (1) the Camp Springs, Tecovas, and unnamed members are of late Carnian age; (2) the Trujillo and Bull Canyon members are of early Norian age; (3) contrary to one recent claim, the Trujillo and Camp Springs cannot be equivalent; (4) no Lower or Middle Triassic rocks are present in west Texas.

Dockum sediments were deposited in the southeastern portion of the Chinle basin, a huge basin that extended from Wyoming to Texas and from Nevada to Oklahoma. Dockum rivers flowed north–northwest from highlands to the south–southeast of the basin (Ouachita and Marathon uplifts). No internally drained large lake basin existed in west Texas during the Late Triassic. Initial Dockum sedimentation was of extrabasinal clastics (Camp Springs member) that filled an incised topography developed in Permian red beds. A major base-level change at about the Carnian–Norian boundary produced an incised topography (and pervasive unconformity) that was subsequently infilled by Trujillo clastics. So, the Dockum is

a tectonosequence composed of two sequences: upper Carnian (Camp Springs–Tecovas) and lower Norian (Trujillo–Bull Canyon), the sequence boundary being the base of the Trujillo.

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Stratigraphic Distribution and Age of Vertebrate Tracks in the Chinle Group (Upper Triassic), Western North America

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Vertebrate tracks have been reported from the Upper Triassic Chinle Group in Wyoming, Utah, Arizona, New Mexico, Oklahoma, and Colorado. These occurrences are in the "Popo Agie" Formation of western Wyoming (*Agialopus*) and northwestern Colorado (*Gwyneddichnium, Rhynchosauroides, Agialopus*), the Bell Springs Formation of northwestern Utah (*Brachychirotherium, Grallator,* tridactyl tracks), the Rock Point Formation of southeastern Utah (*Brachychirotherium, Pentasauropus, Atreipus*), the Petrified Forest Formation of northeastern Arizona (*?Rhynchosauroides*), the Sloan Canyon Formation of northeastern New Mexico (*Chirotherium, Brachychirotherium, Rhynochosauroides, Grallator, Apatopus,* ?therapsid), the Sheep Pen Formation of southeastern Colorado and western Oklahoma (*Grallator, Brachychirotherium*), the Redonda Formation (*Grallator, Apatopus, Brachychirotherium*) and Bull Canyon Formation (undescribed) of east-central New Mexico. Contrary to previous interpretations, all "Popo Agie" Formation tracks are from the Bell Springs Formation and all localities, except for the Petrified Forest Formation and Bull Canyon Formation, are Rhaetian in age. Thus, almost all Chinle tracks are Rhaetian in age, and the pre-Rhaetian record is poor. *Brachychirotherium* and *Grallator* are the most common Rhaetian ichnotaxa in the Chinle. Several localities (Sheep Pen, Redonda) suggest theropod dinosaurs were locally numerous during the Rhaetian, which is supported by the abundance of theropod body-fossils in the Rock Point Formation at Ghost Ranch in north-central New Mexico.

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Temporal Characteristics of Several Large Earthquake Sources in the Central and Southeastern United States

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Four areas in the central and southeastern United States have been identified as locales of large (i.e., magnitude ≥7) earthquakes during the Holocene. These include the Charleston, S.C. and New Madrid, Mo. areas (both locales of large historical earthquakes) as well as the Meers Fault and the Wabash Valley regions (locales where large earthquakes are not present in the historic record but where paleoseismic evidence strongly suggest past large events). How often these sources generate large earthquakes is critical to understanding their long-term seismic hazard. The table below summarizes some of the available data regarding the temporal aspects of past large events in these four areas.

A wide range of temporal behavior is suggested—from time predictable to highly irregular patterns. At one extreme, paleoseismic data for Charleston, S.C. suggest that Holocene siesmicity may have behaved in a time predictable fashion with 600 years between large events (Amick and others, 1991). At the other extreme, studies in the New Madrid region have found no conclusive evidence of past large earthquakes suggesting extremely long return periods (Wesnousky, 1991). Similarly, the Wabash Valley has apparently been the locale of a single large prehistoric event during the mid-Holocene (Obermeier and others, 1991). Data suggest that the Meers Fault lies somewhere between these extremes with episodic seismicity characterized by temporal clustering of large events preceded by a long period of seismic quiescence (Swan and others, 1991).

Location	Largest Historical Earthquake	Paleoseismic Evidence of Large Prehistoric Earthquakes?	Temporal Pattern
Charleston, South Carolina	1886 $m_b = 7.1$	Yes: At least 5 large events in the past 7,000 yrs. Most recent prehistoric events similar to 1886 earthquake.	Time Predicable Model Return Period of 600 yrs.
Meers Fault, Oklahoma	Historically aseismic	Yes: Two mid- to late-Holocene events—1,200 yrs ago and 3,200 yrs ago. At least one much older event.	Episodic Model with temporal clustering of large events.
New Madrid Seismic Zone	1811–1812 $m_b = 7.4$	No: No evidence of earlier 1811–1812 magnitude Holocene earthquakes.	No previous event 5,000+ yr Return Period.
Wabash Valley Seismic Zone	Several m_b 5+	Yes: Single mid-Holocene event much larger than historical events.	Single event suggests 3,500+ yr Return Period.

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Geological Aspects of the Devonian Misener/Sylamore Sandstone in the Central United States

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The Middle to Upper Devonian (Givetian–Famennian) Misener sandstone (subsurface of Kansas and Oklahoma) and its subsurface equivalent, the Sylamore Sandstone (eastern Oklahoma and northern Arkansas) form the basal unit of the Chattanooga/Woodford Shale in the mid-continent area. The thickness of the strata ranges from zero to a reported maximum of 26 m (80 ft). In the study area, the rock body is composed mostly of multicolored fine- to medium-grained quartz sandstone and brown, gray, or green mudstones. At places, the sequence is interbedded with Chattanooga/Woodford-like shale. Detrital components of the sequence are primarily monocrystalline quartz, illitic clay, glauconite, phosphatic fragments, trace amounts of feldspar, rock fragments (chert, dolostone, and metamorphic quartz), tourmaline, and zircon. Reworked faunal elements include abundant conodonts and fish bones and tooth fragments.

Three lithofacies were recognized within the rock body: quartz arenite, quartz and lithic wacke, and mudstone. Sediments composing these rocks, which were probably deposited in a combination of nearshore marine environments, were reworked during transgression of the Chattanooga/Woodford sea. Therefore, the sediments were palimpsest, and some of the sedimentary features relict. Diagenesis began with (1) development of poikilotopic carbonate cement accompanied by syntaxial silica and emplacement of pyrite, (2) dolomitization, (3) stylolitization, (4) creation of secondary porosity, and (5) migration of hydrocarbons.

At some places in Oklahoma, and to a lesser extent in Kansas, the Misener is a prolific hydrocarbon producer. It is thin (generally less than 6 m or 20 ft) and erratically distributed on the post-Hunton/pre-Chattanooga unconformity in topographic lows, making it an elusive target. The porosity of the Misener ranges up to 20%, with permeabilities of several hundred millidarcys.

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The Significance of Clay Fabric in the Devonian–Mississippian Chattanooga (Woodford) Shale of Oklahoma, Kansas, and Nebraska

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The Late Devonian–Early Mississippian Chattanooga (Woodford) Shale of western Oklahoma, Kansas, and southeastern Nebraska includes the basal Misener Sandstone Member and informally defined lower, middle, and upper shale members. Clay fabric of the formation varies systematically with internal stratigraphy and location. Fabric in the middle shale member is more consistently parallel to bedding than that in the lower and upper shale members, although there is a trend to more random fabric in the middle shale member in the northern part of the study area. Geochemical indicators (including kerogen type and Fe/Mn) suggest that the middle shale member was deposited under conditions of greater anoxia than the other shale members, and that the degree of oxygenation during deposition of the middle shale member increased in the north. Correspondence of fabric orientation with anoxia indicates a depositional control on fabric development, as does the fact that more randomly oriented fabric is associated with increased silt content and bioturbation of the shale.

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