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On The Cover —

"Alligator Fossil" and Other Oklahoma Pseudofossils

EIGHT-YEAR OLD DISCOVERS WORLD'S LARGEST PETRIFIED ALLIGATOR IN SOUTHERN OKLAHOMA—A headline that one would expect to see in the tabloids displayed in a supermarket check-out lane. However, a more scientific statement is that the crocodilian-appearing rock is, in reality, nothing more than a pseudofossil.

The cover photograph was taken at one of the stops featured on the spring field meeting of the Oklahoma Academy of Science (see Suneson, 1997, stop 2, p. 14). Jesse Hemish, son of LeRoy Hemish (Oklahoma Geological Survey staff geologist) is standing by an outcrop of the Goodland Limestone (Cretaceous), exposed along the north shoreline of Lake Texoma. The Goodland Limestone is well known for its abundance of invertebrate fossils, particularly *Gryphaea* sp. (oysters) (Suneson, 1997), but not for crocodilian species, as the pseudofossil might suggest.

A pseudofossil is defined in the *Glossary of Geology* as "a natural object, structure, or mineral of inorganic origin that may resemble or be mistaken for a fossil" (Bates and Jackson, 1987, p. 535). Naturally formed shapes that resemble fossils are relatively common and are best characterized as accidents of erosion. Erosional features such as the "alligator fossil" may legitimately be referred to as pseudofossils (Monroe and Dietrich, 1990, p. 155). Discovery of a huge Cretaceous-age alligator fossil is not beyond the realm of possibility. Members of the crocodilian order first appeared in the Triassic, ~240 million years ago, and a great wave of evolutionary progress began at the dawn of the Cretaceous, ~100 million years later. Fossils of crocodilians found in Cretaceous rocks in Texas and Montana indicate that they reached lengths of 45–50 ft and 35–40 ft, respectively, vastly larger than living crocodilian species, which seldom exceed

(continued on p. 134)

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OKLAHOMA GEOLOGY *Notes*

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ADDITIONS TO THE VERTEBRATE FAUNA OF THE ANTLERS FORMATION (LOWER CRETACEOUS), SOUTHEASTERN OKLAHOMA

Richard L. Cifelli[1], *James D. Gardner*[2], *Randall L. Nydam*[1], *and Daniel L. Brinkman*[3]

Introduction

The record of nonmarine vertebrates from the Early Cretaceous (i.e., about 144 to 99 Ma [Gradstein and others, 1995]) is extremely poor in terms of the number of fossil taxa, specimens, and sites (see, e.g., Clemens and others, 1979; Weishampel, 1990). In North America, significant faunas of this age are known (albeit poorly) from such diverse units as the Arundel Clay of Maryland and the District of Columbia (e.g., Kranz, 1996), the Cedar Mountain Formation of Utah (e.g., Cifelli and others, in press), and the Cloverly Formation of Montana and Wyoming (e.g., Ostrom, 1970). The most taxonomically diverse vertebrate assemblages—which include both dinosaurs and a variety of smaller vertebrates such as fish, amphibians, turtles, lizards, and mammals—yet known from the North American Early Cretaceous derive from the Aptian- to Albian-aged Trinity Group of Texas (e.g., Thurmond, 1974; Langston, 1974; Winkler and others, 1990).

In central Texas, the Trinity Group includes (in ascending stratigraphic order) the Twin Mountains, Glen Rose, and Paluxy Formations. The Trinity Group is widely considered to be Aptian-Albian in age, based on the presence of marine invertebrates of Aptian age in the basal Twin Mountains Formation and of mid-Albian age in the Walnut Formation, the latter of which overlies the Trinity Group (e.g., Winkler and others, 1990; Jacobs and others, 1991). The Glen Rose Formation, which lies in the middle of the Trinity Group, has yielded marine invertebrates suggesting an age of late Aptian to late early Albian, depending on location (Jacobs and Winkler, 1989; Winkler and others, 1990). The Trinity Group extends through north-central Texas and into southern Oklahoma, where it is represented by an entirely terrigenous unit, the Antlers Formation (*sensu* Fisher and Rodda, 1966; Winkler and others, 1990). In Oklahoma, the Antlers Formation thickens to the southeast and crops out in a roughly east-west belt, from Carter and Love Counties in the west, to McCurtain County in the east (Fig. 1). This formation consists largely of sandstones and claystones interpreted as having been derived from highlands to the north and west, and deposited in fluvial, deltaic, and strand-plain environments on a broad coastal plain bordering the proto–Gulf of Mexico (see Manley, 1965; Hart and Davis, 1981; Hobday and others, 1981). In extreme southeastern Oklahoma and

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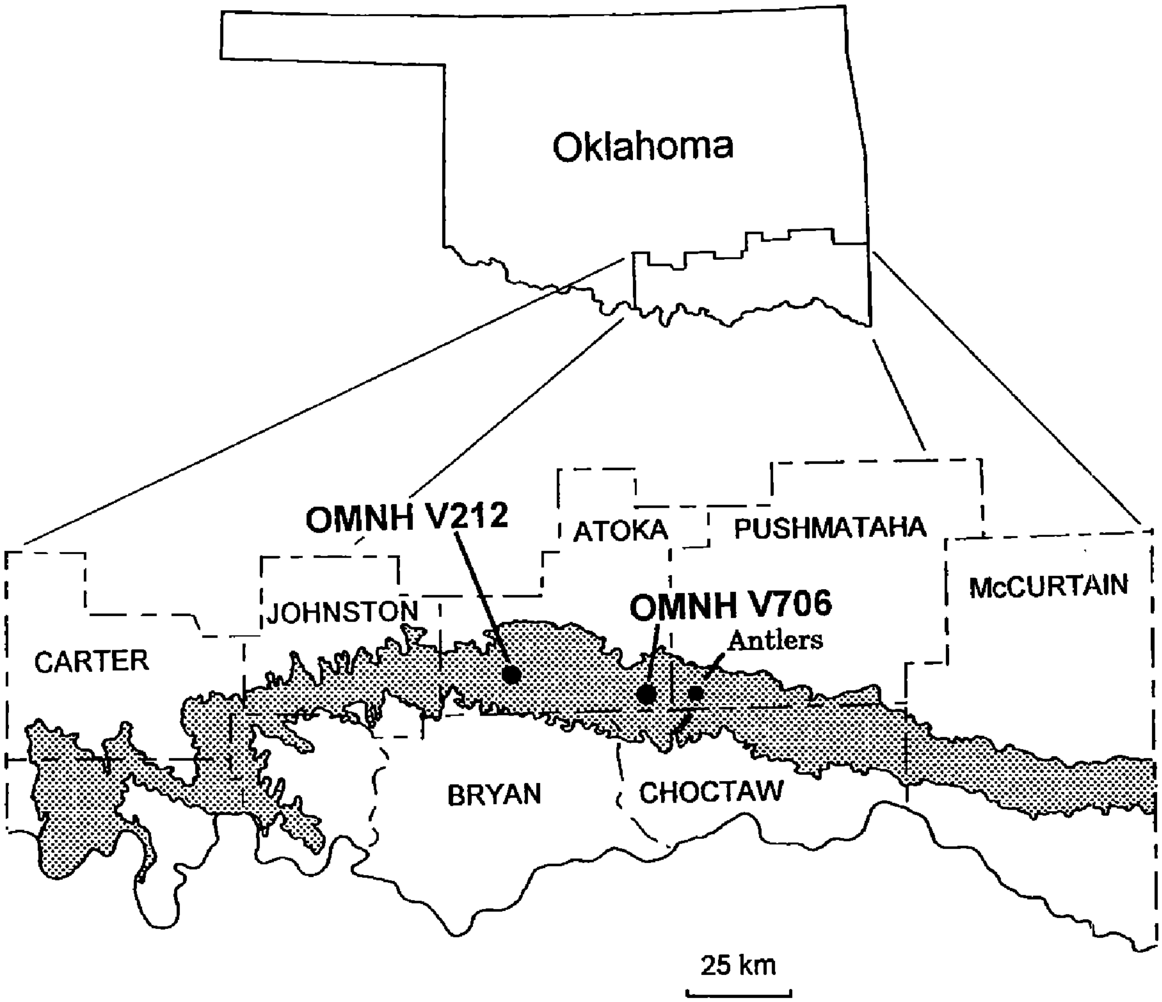

Figure 1. Map showing the distribution of the Antlers Formation (stippled) in southeastern Oklahoma and the positions of OMNH localities V212 and V706 (modified from Hart and Davis, 1981, fig. 7).

southwestern Arkansas, the Lower Cretaceous series includes (in ascending order) the Holly Creek, DeQueen, and Antlers Formations; the Holly Creek and DeQueen Formations may be the lateral equivalents of the Twin Mountains and Glen Rose Formations, respectively (Darling and Lock, 1984; Pittman, 1989; C. J. Rennison, personal communication, 1996).

Although fossil vertebrates from the Trinity Group have been known for more than a century (Winkler and others, 1989) and have been extensively studied since (see reviews by Langston, 1974; Thurmond, 1974; Winkler and others, 1989, 1990), many components of this assemblage remain poorly known. Even less is known about contemporaneous vertebrates from the Antlers Formation of Oklahoma. The first general review of so-called Comanchean (named for the series that includes the Trinity Group) vertebrates is that of C. N. Gould (1929), founder of the Department of Geology at the University of Oklahoma and first director of the Oklahoma Geological Survey (see Ham, 1983), who reported but one occurrence in the state—a coracoid of an indeterminate sauropod dinosaur found near Tushka, Atoka County, and published nearly 20 years earlier by Gould's former student, Pierce Larkin (1910). Discovery of additional dinosaur bones in Atoka County in 1940 prompted systematic but limited investigation by J. W. Stovall, also of the University of Oklahoma, resulting in a total collection of about ten specimens, including partial skeletons of the ornithopod *Tenontosaurus* sp. and the theropod *Acrocanthosaurus atokensis* (Stovall and Langston, 1950; Ostrom, 1970; Langston, 1974; Czaplewski and others, 1994). These occurrences are noted by Langston (1974), who provided the most recent summary of vertebrate fossils from the Antlers Formation of Oklahoma.

With the discovery in 1949 of a taxonomically diverse assemblage of vertebrates in the Trinity Group of Texas, including the first Early Cretaceous mammals known from the Western Hemisphere (Zangerl and Denison, 1950), paleontological investigations in the Trinity Group shifted into that state. The fossils from two well-known sites in the upper Antlers Formation of north-central Texas, Greenwood Canyon and Butler Farm, have proven critical for documenting and interpreting the evolution of North American Early Cretaceous nonmarine vertebrates (see, e.g., Patterson, 1956).

Over the past ten years, field parties from the University of Oklahoma (Oklahoma Museum of Natural History [OMNH]) have once again been actively collecting in the Antlers Formation of Oklahoma. To date, there have been encouraging results, including the discovery of additional dinosaur specimens (Brinkman and others, in press) and two microvertebrate sites (i.e., accumulations of small bones, teeth, and scales of vertebrates), one of which has yielded a moderately diverse assemblage that includes the first Mesozoic mammals from Oklahoma (Cifelli, 1997). These microvertebrate sites are particularly significant in light of the fact that both the Butler Farm and Greenwood Canyon localities are now covered and no longer accessible (Winkler and others, 1989). Specimens from the newly discovered microvertebrate sites in Oklahoma were obtained using underwater screenwashing and associated techniques described by Cifelli and others (1996); to date, about 200 kg of matrix has been processed from each site. Although many of the microvertebrate specimens are fragmentary or otherwise not particularly informative, a number of identifiable specimens have been recovered.

Our purposes here are (1) to briefly describe the newly discovered fossiliferous sites in the Antlers Formation of Oklahoma, and (2) to provide a provisional list of fossil vertebrates known from these exposures. As our investigations are ongoing and we expect more specimens to result from continued work, formal descriptions and detailed interpretations of these taxa will be deferred until a later date.

Geology and Stratigraphy of Newly Discovered Microvertebrate Sites in Atoka County, Oklahoma

OMNH locality V212, in southwestern Atoka County (Fig. 1), has yielded bones of *Tenontosaurus* from a tan, sandy claystone and, about 40 m distant, a limited number of microvertebrates from a relatively homogenous red mudstone at about the same stratigraphic horizon. OMNH locality V706, in far southeastern Atoka County, consists of two fossiliferous levels. The upper level includes a massive accumulation of articulated and partly articulated skeletons of *Tenontosaurus*, together with associated elements of its presumed predator, the small theropod *Deinonychus* (see Maxwell and Ostrom, 1995; Brinkman and others, in press) in a gray-green to red claystone. A nearby outcrop, at about the same stratigraphic level as the fossiliferous levels at OMNH locality V706, has produced neck vertebrae tentatively referred to the sauropod family Brachiosauridae. The lower level at OMNH locality V706, located about 1.5 m below the dinosaur-bearing horizon, has yielded a richly fossiliferous microvertebrate site within a mottled gray mudstone containing abundant nodules and small, laterally discontinuous sandstone stringers indurated with calcium carbonate. Cifelli (1997) interpreted this microvertebrate accumulation to represent a lag in a fluvial overbank deposit.

The precise stratigraphic positions of OMNH localities V212 and V706 within the Antlers Formation are difficult to determine because the Glen Rose Formation, which forms a convenient marker horizon, pinches out further to the south in north-central Texas. Fisher and Rodda (1966, 1967) have correlated the Twin Mountains, Glen Rose, and Paluxy Formations, respectively, with three unnamed units in the Antlers Formation of north Texas: a lower sand, a middle clay, and an upper sand. However, as observed by Fisher and Rodda (1966, 1967), these units cannot be recognized in outcrops along the Oklahoma-Texas border. Hobday and others (1981) continued to recognize these three informal subdivisions of the Antlers Formation, but it is unclear whether they were referring to sections in Texas, in Oklahoma, or in both. In any case, we have found it difficult to identify these units with certainty in outcrops in Atoka County, which are extremely limited. Based on the dip of the Antlers Formation in Atoka County and its thickness known from a nearby well hole (Hart and Davis, 1981), we believe that OMNH locality V212 lies within the middle part of the unit. Preliminary X-ray diffraction analyses conducted by Dr. Scott Argast (University of Indiana) on claystones from the dinosaur-bearing horizons at both localities indicate that both probably lie within the transitional clay-mineral zone recognized by Manley (1965), and, thus, in the middle part of the Antlers Formation. This placement is supported by the work of Rennison (1996), who estimated the Antlers Formation to be about 150 m thick in the vicinity of OMNH locality V706, and who also placed this site stratigraphically within the middle of the formation, approximately 87 m above its base. Using stable isotope ratios from fossil plants, Rennison (1996) correlated the lower and middle parts of the Antlers Formation in Oklahoma with either the middle part of the Twin Mountains Formation and/or the lower to middle part of the Glen Rose Formation (see also Brinkman and others, in press). To summarize, the limited data now available place both fossil localities in the middle of the Antlers Formation, which suggests that they lie stratigraphically below the Butler Farm and Greenwood Canyon sites, both of which are in the upper part of the Antlers in north-central Texas. Although certain vertebrate taxa (e.g., sharks, dinosaurs, and mammals) have proven useful elsewhere for biostratigraphic correlations, these groups are still too poorly known from the Early Cretaceous of North America to permit meaningful comparisons among sites in Oklahoma and Texas. We note, however, that the stage of evolution in *Tenontosaurus* and, possibly, in *Deinonychus*, as represented by specimens from both areas, is weakly suggestive of a correlation of the middle Antlers of Oklahoma to the middle part of the Trinity Group in Texas (Brinkman and others, in press).

Vertebrate Fauna

Table 1 lists the vertebrate taxa identified to date from the Antlers Formation in Oklahoma. The more fossiliferous microvertebrate site, OMNH V706, has produced remains of as many as 44 taxa, six of which have been identified from the second microvertebrate site, OMNH V212. Considering that prior to our report only four

TABLE 1.—VERTEBRATE FAUNA OF THE ANTLERS FORMATION, OKLAHOMA

- **Chondrichthyes**
  - Hybodontiformes
    - Hybodontidae
      - *Hybodus butleri*[1] (A)
      - ?*Hybodus* sp.[1] (A,B)
    - Polyacrodontidae
      - *Lissodus anitae*[1] (A)
- **Osteichthyes**
  - ?Semionotiformes
    - ?Semionotidae
      - gen. & sp. indet.[1] (A,B)
  - ?Lepisosteiformes
    - ?Lepisosteidae
      - gen. & sp. indet.[1] (A,B)
  - Pycnodontiformes
    - Pycnodontidae
      - ?*Palaeobalistum* sp.[1] (A)
      - *Gyronchus dumblei*[1] (A)
  - Amiiformes
    - ?Amiidae
      - gen. & sp. indet.[1] (A)
  - Order and family indet.
      - gen. & sp. indet.[1] (A)
- **Lissamphibia**
  - Order uncertain
    - Albanerpetontidae
      - *Albanerpeton arthridion*[1] (A)
  - ?Caudata, family indet.
      - gen. & sp. indet.[1] (A)
  - Anura
    - Family indet.
      - gen. & spp. (2) indet.[1] (A)
- **Reptilia**
  - Testudines
    - Family indet.
      - gen. & sp. indet.[1] (A)
    - Pleurosternidae
      - *Naomichelys* sp.[1] (A)
    - Glyptopsidae
      - ?*Glyptops* sp.[1] (A)
  - Squamata
    - ?Paramacellodidae
      - gen. & sp. indet.[1] (A)
    - Teiidae
      - gen. & sp. indet.[1] (A)
    - ?Scincidae
      - gen. & sp. indet.[1] (A)
  - Crocodilia
    - Bernissartiidae
      - *Bernissartia* sp.[1] (A,B)
    - ?Atoposauridae
      - gen. & sp. indet.[1] (A)
    - ?Goniopholidae
      - gen. & sp. indet.[1] (A)
    - ?Pholidosauridae
      - gen & sp. indet.[1] (A)
  - Sauropoda
    - Family indet.
      - gen. & sp. indet.[2] (C)
    - Brachiosauridae
      - *Astrodon* sp.[1] (A)
  - Theropoda
    - Family indet.
      - gen. & spp. (6) indet.[1] (A)
    - Allosauridae
      - *Acrocanthosaurus atokensis*[3] (A,C)
    - Dromaeosauridae
      - *Deinonychus antirrhopus*[1,4] (A,B)
      - cf. *Deinonychus* sp. (5 morphs) (A)
  - Ornithopoda
    - Family uncertain
      - *Tenontosaurus* sp.[1,4,5] (A,B,C)
- **?Aves**
    - Family indet.
      - gen. & sp. indet.[1] (A)
- **Mammalia**
  - Triconodonta
    - Triconodontidae
      - *Astroconodon* cf. *denisoni*[1] (A,B)
  - Multituberculata
    - Family uncertain
      - ?*Paracimexomys crossi*[6] (A)
      - gen. & spp. (2) indet.[1] (A)
  - Tribosphenida
    - Family indet.
      - gen. & sp. indet.[1,6] (A)

Footnotes refer to source of data:
[1]This study. [2]Larkin, 1910. [3]Stovall and Langston, 1950. [4]Brinkman and others, in press. [5]Ostrom, 1970; Langston, 1974. [6]Cifelli, 1997.

Locality designations, shown in parentheses, are (A) = OMNH V706; (B) = OMNH V212; (C) = other site based on literature report.

dinosaurs (*Acrocanthosaurus, Deinonychus, Tenontosaurus,* and an indeterminate sauropod) and two mammals (recently reported from locality V706 by Cifelli, 1997) have been published from the Antlers Formation of Oklahoma, the taxa reported here add significantly to the fauna. Most of the nondinosaurian taxa were recovered using underwater screening methods, demonstrating yet again the necessity of employing this method for obtaining better represented fossil assemblages (e.g., McKenna, 1962). Although the nondinosaurian assemblage presently known from locality V706 is more diverse than those reported by Winkler and others (1990, table 1) from two of the best-known sites in Texas, Butler Farm and Greenwood Canyon, we suspect that these differences reflect publication and/or collecting biases rather than taxonomic or ecological differences. Nonetheless, it is clear that OMNH V706 is comparatively rich in fossils: the assemblage we report herein was obtained from about 200 kg of rock matrix, whereas more than 180,000 kg of matrix reportedly was processed from the best of the five sites at Butler Farm (Clemens and others, 1979).

Conclusion

Recent collecting efforts in the Lower Cretaceous Antlers Formation of Atoka County, Oklahoma, have revealed a hitherto unreported, moderately diverse assemblage of nonmarine vertebrates, including sharks, ray-finned fishes, amphibians, turtles, lizards, dinosaurs, mammals, and, possibly, toothed birds. As vertebrates of this age are generally poorly known, both within North America and from other continents, these Oklahoman discoveries promise to provide further insights into the evolutionary history of Early Cretaceous nonmarine vertebrates.

Acknowledgments

We are pleased to gratefully acknowledge the continuing support and cooperation of personnel of the Howard McLeod Corrections Center, Oklahoma Department of Corrections, particularly, Denise Spears, Frank Rember, Ron Harper, and Bobby Cross. We also thank Oklahoma vo-tech instructor Jack Wilson, who discovered site V706, for his help throughout our field work; Scott Argast for conducting analyses on clay samples; and Nick Czaplewski, Kent Smith, William May, Lisa Hames, and Christy and Estelle Miller for their assistance. We are grateful to Robert Umsted for permission to collect at OMNH site V212, to Elizabeth Larson for processing the rock from that site, and to Patrick Murphy for discovering it. This research was supported by NSF grant DEB-9401094 and NGS grant 5021-93 to RLC.

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GUIDEBOOK 30. ***Stratigraphy and Resources of the Krebs Group (Desmoinesian), South-Central Arkoma Basin, Oklahoma,*** by LeRoy A. Hemish and Neil H. Suneson. 83 pages. Price: $6.

From the authors' preface:

This guidebook is a companion to Oklahoma Geological Survey Guidebook 29, "Geology and Resources of the Eastern Frontal Belt, Ouachita Mountains, and Southeastern Arkoma Basin, Oklahoma," which provided information on the area to the east and southeast of the area covered in this volume. OGS Guidebook 30 reports on the stratigraphy and resources of the south-central part of the Arkoma basin. Recent detailed field mapping of lower Desmoinesian strata in the vicinity of McAlester, Oklahoma, provides an opportunity for detailed examination and stratigraphic analysis of numerous outcrops of rocks comprising the Krebs Group in the area. This guidebook was prepared for a two-day field trip (September 13–14, 1997) conducted in conjunction with the American Association of Petroleum Geologists Mid-Continent Section meeting held in Oklahoma City, Oklahoma, September 14–16, 1997.

Coal and natural gas have long been the principal energy resources in this part of the Arkoma basin. Oil is produced from areas just to the north and northwest, along the margin of the Arkoma basin. A recently developed resource is coal-bed methane. It is hoped that the field trip will promote interest in the resource potential of the Krebs Group and provide occasion for discussion of its depositional environments.

Most of the field-trip area has been mapped recently at a scale of 1:24,000 by the authors. These maps are available as uncolored, author-prepared open-file reports from the OGS. They are the most recent in a series of maps that are part of a 12-year-long mapping project in the Ouachita Mountains and Arkoma basin. [See related announcement below.]

GEOLOGIC MAPS OF THE HARTSHORNE SW, MCALESTER, AND SAVANNA QUADRANGLES, PITTSBURG COUNTY, OKLAHOMA. Scale 1:24,000. Xerox copies. Price: $6 each, rolled in tube.

The Ouachita STATEMAP project, which began in 1993, is a joint effort of the Oklahoma Geological Survey and the U.S. Geological Survey to prepare new 1:24,000 geologic maps of the Ouachita Mountains and Arkoma basin in Oklahoma. STATEMAP is part of the National Cooperative Geologic Mapping Program and replaces the successful COGEOMAP program, which began in 1984. Under COGEOMAP, the OGS completed and published 15 7.5′ geologic quadrangle maps along the northern part of the Ouachita Mountains frontal belt and southern part of the Arkoma basin.

During the first year of STATEMAP, in early 1994, the Oklahoma Geologic Mapping Advisory Committee, chaired by OGS associate director Kenneth S. Johnson, was established to recommend mapping priorities for the State. The committee recommended Pittsburg County, especially near McAlester, as an important area for OGS efforts. The committee chose the McAlester area for several reasons: (1) Coal has been a major resource in the area, and substantial reserves still are present. (2) A number of natural-gas fields have been discovered recently and others are being developed in this part of the Arkoma basin, and the giant Wilburton deep gas field was discovered in 1987 immediately east of the area. (3) Environmental problems resulting from open mine shafts, undocumented underground mines, and poor reclamation practices in the past may impact urban development near McAlester, as well as rural development throughout the region. (4) Several type localities of Arkoma basin formations are in the area, but are unmeasured or otherwise poorly documented.

The Hartshorne SW Quadrangle, by Neil H. Suneson and LeRoy A. Hemish, the McAlester Quadrangle, by Hemish, and the Savanna Quadrangle, by Suneson, are the latest in a series of STATEMAP geologic maps of Pittsburg County. Each map is one sheet, available as a black-and-white, author-prepared xerox copy, comprising geologic map, cross sections, description and correlation of units, and a list of gas wells. These maps are important additions to the series of previously mapped quadrangles because of their proximity to the expanding urban area of McAlester. Planners for new highway construction, building construction, and abandoned coal-mine reclamation will find the maps useful in addressing environmental concerns. Further economic assets of the area include gas reservoirs and documented coal reserves in several of Oklahoma's principal coal beds.

COGEOMAP and STATEMAP maps also are available for the Higgins, Damon, Baker Mountain, Panola, Wilburton, Red Oak, Leflore, Talihina, Leflore Southeast, Blackjack Ridge, Gowen, Summerfield, Hodgen, Hontubby/Loving, Wister, Heavener/Bates, Adamson, Hartshorne, and Krebs Quadrangles.

REVISED SUPPLEMENT TO OGS GEOLOGIC MAP 28, OKLAHOMA OIL AND GAS FIELDS.

78 pages, accompanies 63″ × 40″ map (scale 1:500,000). Price: $6, in envelope.

A new supplement containing data current through December 1996 is now available to update OGS GM-28, *Oklahoma Oil and Gas Fields.* This supplement replaces an older one issued in 1991. New fields, revised descriptions of field locations, consolidated fields, and abandoned fields are listed in the booklet, which was compiled by Michelle Summers, OGS technical projects coordinator. New oil and gas fields were named by the Oklahoma Nomenclature Committee of the Oklahoma-Kansas Division, Midcontinent Oil and Gas Association, in accordance with established guidelines. The booklet is sold in a packet with GM-28, the original four-color map, which was developed in 1985 by former OGS geologist Margaret R. Burchfield.

Guidebook 30, GM-28, and COGEOMAP/STATEMAP geologic quadrangle maps can be purchased by mail from the Survey at 100 E. Boyd, Room N-131, Norman, OK 73019. For Guidebook 30 and GM-28 and its revised supplement, add 20% to the cost for mail orders, with a minimum of $1 per order. For mail orders of 1–10 quadrangle maps, add $2; for 11–25 maps, add $3.

All OGS publications can be purchased over the counter at the OGS Publication Sales Office's new location at 1218-B W. Rock Creek Road, Norman; phone (405) 360-2886; fax 405-366-2882. Parking is free and readily available.

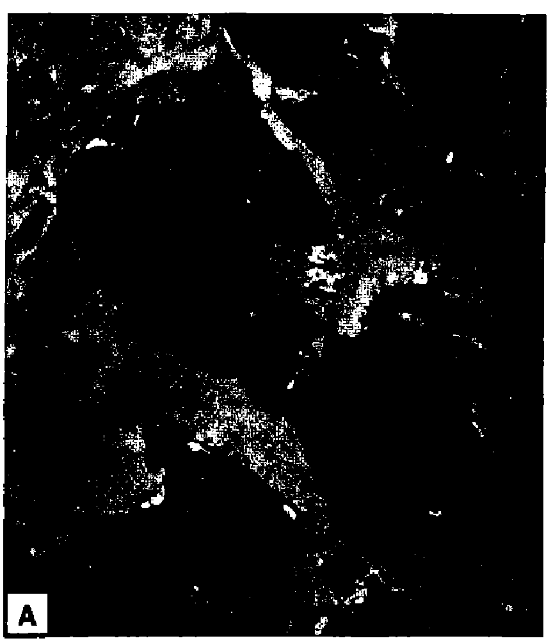
"Alligator Fossil" and Other Oklahoma Pseudofossils *(continued from p. 122)*

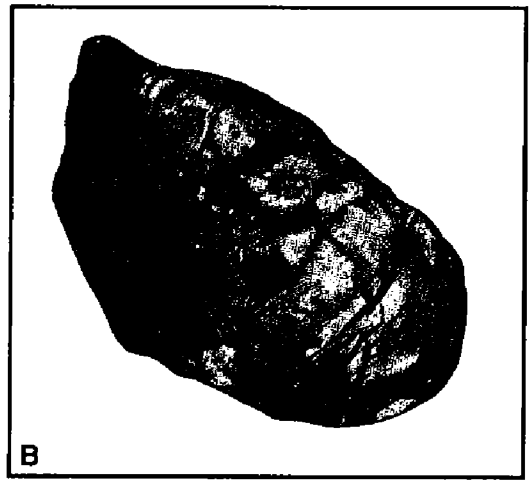
20 ft in length (Fenton and Fenton, 1958). However, the "alligator fossil" found by Jesse is several times larger even than the large Cretaceous crocodilians.

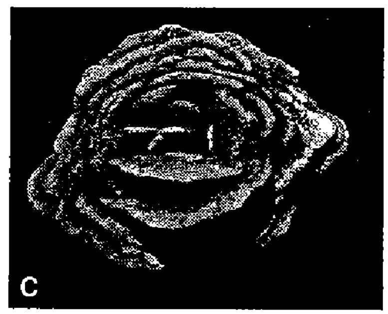
Other accidents of erosion found in Oklahoma have been classified as pseudofossils. One example is the group of depressions left when concretions eroded from Cretaceous Dakota Sandstone in Cimarron County (inset photo A). Features such as these, thought by some people to resemble human footprints, have been used as "evidence" that human beings and dinosaurs coexisted (Monroe and Dietrich, 1990, p. 155).

Another, more common, pseudofossil found in Oklahoma is the septarium; it resembles a fossilized turtle (inset photo B). Septaria are roughly spheroidal concretions, usually of impure argillaceous carbonates, that are crisscrossed by veinlike masses of crystalline minerals (commonly calcite) (Bates and Jackson, 1987, p. 603).

The official state rock of Oklahoma is a pseudofossil (inset photo C). Rose rocks are formed by the growth of a cluster of divergent blades of the mineral barite in red sandstones. Quartz sand grains are incorporated and the red color of the rosettes is acquired from the host rock (Johnson and Suneson, 1996). Because of their resemblance to roses in full bloom, the rosettes often are called "petrified roses" and thus can be considered pseudofossils (Monroe and Dietrich, 1990, p. 152).







References Cited

Fenton, C. L.; and Fenton, M. A., 1958, The fossil book: Doubleday and Company, Garden City, New York, 482 p.

Bates, R. L.; and Jackson, J. A. (eds.), 1987, Glossary of geology (3rd edition): American Geological Institute, Alexandria, Virginia, 788 p.

Johnson, K. S.; and Suneson, N. H. (eds.), 1996, Rockhounding and earth-science activities in Oklahoma, 1995 workshop: Oklahoma Geological Survey Special Publication 96-5, 139 p.

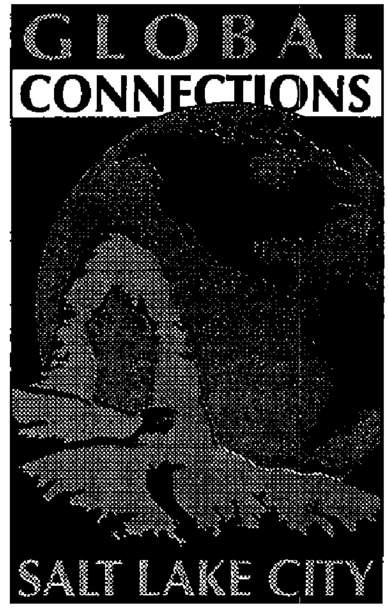
Monroe, J. S.; and Dietrich, R. V., 1990, Pseudofossils: Rocks and minerals, v. 65, no. 2, p. 150–157.

Suneson, N. H., 1997, The geology of the gulf coastal plain in Marshall County, Oklahoma, an introduction and field-trip guide: Oklahoma Geological Survey Open-File Report 1-97, 29 p.

LeRoy A. Hemish

GSA Annual Meeting

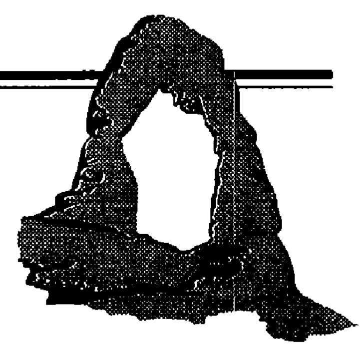
Salt Lake City, Utah
October 20–23, 1997



Because the Rocky Mountains, Great Basin, and Colorado Plateau all come together at Salt Lake City, it is a geologist's paradise. Field trips will introduce you to some of the most spectacular and classic geology in the world. From your hotel window alone, you will see Bingham Canyon, the world's largest open-pit copper mine; Pleistocene beaches from the highstand of ancient Lake Bonneville; the Precambrian spine of Antelope Island in the Great Salt Lake with its herds of wild buffalo; the infamous Wasatch Fault, capable of generating a magnitude 7.5 earthquake at any time; and the magnificent Wasatch Mountains, where the 2002 Winter Olympics will be played out.

In keeping with the growing international prominence of Salt Lake City, the 1997 organizing committee is inviting the geological surveys of every nation to participate for the first time in the GSA Annual Meeting. The meeting theme of "Global Connections" recognizes the increasing role of international research and cooperation in the geosciences. Exhibits, posters, workshops, and speakers will all serve to help us look beyond our borders for new ideas and new challenges.

—M. Lee Allison
1997 General Chair



Agenda

Technical Program

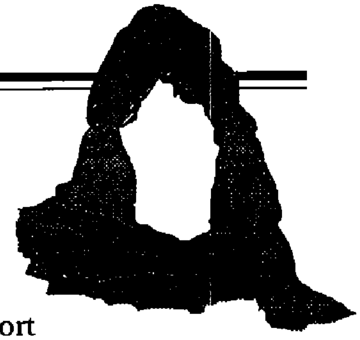
Symposia

Ore Deposits Through Time
Organic Perspectives on Geochemical Processes
IEE Annual Environmental Forum: Concepts in Geoecology and Ecosystem Management: Applying New Knowledge from the Interface of the Life and Earth Sciences
Micropaleontology of the Cretaceous Western Interior Seaway: Integration of the Tethyan and Boreal Record
Geomicrobiology: Interactions Between Microbes and Minerals
Exploring Life in the Solar System
New Developments in Coal and Coalbed Methane Evaluation and Exploitation
Exhumation of High- and Ultrahigh-Pressure Rocks
Engaging the National Science Education Standards
The Anatomy and Attenuation of Chlorinated Solvent Plumes in Granular Aquifers
Hotspots from the Top Down: What Are They?
Process from Pattern in the Fossil Record

Isotopes and Earth Surface Processes
The Costs and Values of Geoscience Information
Recent Advances in Studying Earth from Space: What Students Should Know
Geochemical Records of Hydrologic Response to Climate Change
Tectonic, Climatic, and Eustatic Controls on Sedimentation in Continental Rifts
Archaeological Geology of Arid Environments—Dedicated to the Late Jonathan O. Davis
Iapetus Ocean, Its Birth, Life, and Death: The Wilson Cycle
Geology and Ore Deposits of the Oquirrh and Wasatch Mountains
The Archbishop Ussher Symposium: Quantifying Earth History
Predictive Modeling in the Earth Sciences: Application and Misapplication to Environmental Problems
Celebrating 50 Years of the Engineering Geology Division: The Past, Present, and Future of Geoscience in the Public Interest
Advocacy, Ethics, and the Geosciences: Problems of Facts and Values in Environmental Issues
Recent Advances in Chemical Hydrogeology: A Tribute to William Back's 50-Year Career
Late Ordovician Mass Extinction—Silurian Recovery and Associated Perturbations of Global Earth Systems
Environmental Mineralogy: Science and Politics
Global Connections: Environmental Justice in the Americas and Abroad
Deciphering Exhumation from the Sedimentary Record
Geologic Mapping: Past, Present, and Future
International Surveys

Theme Sessions

Geologic Mapping and GIS: Digital Map Production, Methods of Publication, and Expanded Uses of the Data
Plutons, Volcanoes, and Ore Deposits
Geomicrobiology: Interactions Between Microbes and Minerals
Hydrogeology of Landslides
Trace Metals in the Environment: Sources, Transport, and Fate—A Tribute to Ernest E. Angino
Concepts in Geoecology and Ecosystem Management: Applying New Knowledge from the Interface of the Life and Earth Sciences
Conservation Geology: Restoring and Maintaining Earth's Ecosystems
Plume Tails and Continental Lithosphere: A Multidisciplinary Approach to the Snake River Plain and Other Continental Plume Tracks
Submarine Plateaus and Hotspot Islands, Young and Old: Identification and Role in Continental Growth
Isotopic Mapping: The "0.706 Line" Twenty Years Later—A Tribute to Ronald W. Kistler
Earth Science Education for Pre-Service Teachers
Approaches to Undergraduate Teaching of Geophysics
Earth System Science Laboratories for the Introductory Undergraduate Level
Concepts of Mapping in Geoscience Education
Field-Based Investigations on School or Campus Sites: Examples That Work
Great Geological Vacations in North America—How They Can Enhance Geoscience Literacy
Paleoseismology: Contributions to and Issues in Evaluating Seismic Hazards
Geoscience Information Issues in a Rapidly Evolving Environment
Geologic Mapping: Past, Present, and Future
Linking Fault Zone Architecture and Quantitative Fluid Flow Studies
Hydraulic Properties and Diagenetic Processes of Municipal Solid Waste



Role of Natural Organic Matter in Solute Fate and Transport
Hydrochemistry of Poorly Confined Aquifer Systems
Hydrogeology of Diagenesis
Progress in Dating Young Ground Water
Hydrogeology of Continental Rift Systems
Recent Advances in Density-Dependent Fluid Flow and Solute Transport
Regional Ground-Water Flow and Hydrochemistry of Basins of Internal Drainage
Investigations of Transport Processes in Fractured Rock Using Ground-Water Tracers
Approaches to Understanding Ground-Water Flow and Contaminant Transport in Carbonate Aquifers
Isotopic Tools for Detection of the Origin and/or Fate of Environmental Contaminants
Dense, Nonaqueous Phase Liquids (DNAPL) Migration and Remediation in Fractured Rock
Theoretical Molecular Methods in Earth Sciences
Applications of Plant Taphonomy to Paleoenvironmental, Paleogeographic, and Paleoclimatic Problems
Volcanic Eruptions: From the Deep Oceans to Deep Space
The Galilean Satellites: Exploring Their Connections
Volatiles in Planetary Mantles and Basalts
The Southern Laurentian Late Proterozoic: What Happened?
The Geosciences in Context: Values, Sustainability, Culture, and Curricula
The Sustainability Challenge: A Problem in Geoscience Communication
Natural Background Chemistry and Environmental Decision-Making
Geomorphology in Drylands
The Bonneville Lake Basin from a Global Perspective
Great Basin Aquatic Geology
Environmental Impacts on Western Rivers
Arroyos: Hydroclimatology, Quaternary Geology, and Riverine Processes
Influence of Geomorphic Processes on Biological Communities
Feedbacks Between Tectonic and Surface Processes in Orogenesis
Advances in Deciphering and Modeling Stratigraphic and Depositional Processes of Paleozoic Basins
Origin of Mudrocks: Modern Processes and Ancient Examples
Unexplored Microbial Worlds: Evidence from Occurrences of Unique Microbial Sedimentary Structures
Impact Deposits in the Sedimentary Record
New Perspectives on Neoproterozoic Earth History
Records of Paleoclimate and Tectonic Evolution of Continental Interiors: Latest Results from Scientific Drilling and Coring
Deformation Styles, Stacking Patterns, and Stratigraphic Consequences in Foreland Basins
The Geologic Record of Three-Dimensional Strains in Extended Continental Crust
Processes and Mechanics of Fault Nucleation and Growth
Triassic-Jurassic Structural and Stratigraphic Record of Cordilleran Tectonics: Linking Processes from the Active Margin to the Colorado Plateau
Iapetus Ocean, Its Birth, Life, and Death: The Wilson Cycle
Extreme Continental Extension: Examples from Around the World and New Insights from Quantitative Modeling
Advances of the Neotectonics in Latin America
The Coast Shear Zone (Southeastern Alaska and British Columbia), A Fundamental Crustal Feature
Cenozoic Tectonic Evolution of Northern Tibet
Paleozoic Tectonics of Western China and Adjacent Areas of Central Asia
Advances in the Geology of Mexico

Field Trips

Premeeting

Late Pleistocene–Holocene Cataclysmic Eruptions at Nevado de Toluca and Jocotitlan Volcanoes, Central Mexico, *Oct. 14–18*

Late Devonian Alamo Impact Event, Global Kellwasser Events, and Major Eustatic Events, Eastern Great Basin, Nevada and Utah, *Oct. 16–19*

Grand Tour of the Ruby–East Humboldt Metamorphic Core Complex, Northeast Nevada, *Oct. 16–19*

Late Ordovician Mass Extinction and Glacio-Eustasy—Sedimentologic, Biostratigraphic, and Chemostratigraphic Records from Platform and Basin Successions, Central Nevada, *Oct. 16–18*

Neotectonics, Fault Segmentation, and Geologic Hazards Along the Hurricane Fault in Utah and Arizona, *Oct. 16–18*

Regional Geology of Southeastern Utah, Emphasizing National Parks, *Oct. 16–18*

Sequence Stratigraphy in a Classic Area: Evolution of Fluvial to Marine Architecture in Response to Tectonism and Eustasy, Cretaceous Foreland Basin, Utah, *Oct. 16–18*

Stratigraphy and Structure of Sevier Thrust Belt and Proximal Foreland-Basin System in Central Utah: A Transect from the Sevier Desert to the Wasatch Plateau, *Oct. 16–19*

Bimodal Magmatism, Basaltic Volcanic Styles, Tectonics, and Geomorphic Processes of the Eastern Snake River Plain, Idaho, *Oct. 17–19*

50th Anniversary of the Discovery of the Ghost Ranch Coelophysis Quarry, *Oct. 17–19*

Neoproterozoic Sedimentation and Tectonics in West-Central Utah, *Oct. 17–19*

New Explorations Along the Northern Shores of Lake Bonneville, *Oct. 17–18*

Structure and Kinematics of a Complex Crater, Upheaval Dome, Canyonlands National Park, Utah, *Oct. 18–19*

Geochemistry and Hydrology of the Great Salt Lake, *Oct. 18*

Antelope Island, the Great Salt Lake, and Ancient Lake Bonneville, *Oct. 19*

Examination of Fault-Related Rocks of the Wasatch Normal Fault, *Oct. 19*

Geologic Hazards of the Wasatch Front, *Oct. 19*

Lake Bonneville Classic Depositional Shore Features: Geochronology, Geomorphology, Stratigraphy, and Sedimentology, *Oct. 19*

Sequence Stratigraphy and Paleoecology of the Middle Cambrian Spence Shale in Northern Utah and Southern Idaho, *Oct. 19*

Proterozoic Tidal, Glacial, and Fluvial Sedimentation in Big Cottonwood Canyon, Utah, *Oct. 19*

Half-Day Trip—Concurrent with the Meeting

Bedrock Geology of the Snyderville Basin, *Oct. 22*

Postmeeting

Bimodal Basalt-Rhyolite Magmatism in the Central and Western Snake River Plain, Idaho and Oregon, *Oct. 23–26*

Carbonate Sequences and Fossil Communities from the Upper Ordovician–Lower Silurian of the Eastern Great Basin, *Oct. 23–26*

Depositional Sequence Stratigraphy and Architecture of the Cretaceous (Turonian) Ferron Sandstone: Implications for Coal and Coal Bed Methane Resources, *Oct. 23–25*

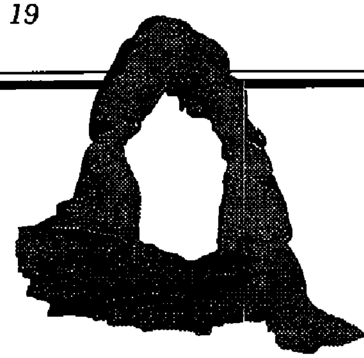
Fluvial-Deltaic Sedimentation and Stratigraphy of the Ferron Sandstone, *Oct. 23–25*

Hinterland to Foreland Transect Through the Sevier Orogen, Northeast Nevada to North Central Utah: Structural Style, Metamorphism, and Kinematic History of a Large Contractional Orogenic Wedge, *Oct. 23–26*

Quaternary Geology and Geomorphology, Northern Henry Mountains, *Oct. 23–25*
Extensional Faulting, Footwall Deformation and Plutonism in the Mineral Mountains, Southern Sevier Desert, *Oct. 23–26*
Triassic and Jurassic Macroinvertebrate Faunas of Utah: Field Relationships and Paleobiologic Significance, *Oct. 23–25*
High, Old, Pluvial Lakes of Western Nevada, *Oct. 24–26*
Triassic-Jurassic Tectonism and Magmatism in the Mesozoic Continental Arc of Nevada: Classic Relations and New Developments, *Oct. 25–26*
Lower to Middle Cretaceous Dinosaur Faunas of the Central Colorado Plateau: A Key to Understanding 35 Million Years of Tectonics, Sedimentology, Evolution, and Biogeography, *Oct. 24–26*
Mississippian Stratigraphy and Paleotectonics of the Antler Foreland, Eastern Nevada and Western Utah, *Oct. 24–26*
Geology and Ore Deposits of the Oquirrh and Wasatch Mountains, Utah, with Visits to the Bingham, Melco, and Mercur Mines, *Oct. 23–25*

Short Courses/Forums/Workshops

Ore Genesis and Exploration: The Roles of Organic Matter, *Oct. 17–18*
Geomicrobiology: Interactions Between Microbes and Minerals, *Oct. 17–19*
Clastic Facies and Sequence Stratigraphy for Graduate Students Only, *Oct. 18–19*
Techniques of Geostatistical Estimation and Simulation Applied to Environmental Geology, *Oct. 18–19*
Computer Visualization of Three-Dimensional Deformation and Application to Upper-Crustal Settings, *Oct. 18–19*
Analysis of Veins in Sedimentary Rocks—An Introduction for Structural Geologists, *Oct. 18–19*
Applications of Environmental Isotopes to Solving Hydrologic and Geochemical Problems, *Oct. 19*
Buck Rogers, Field Geologist: 21st Century Electronic Wizardry for Mapping and Field Data Collection, *Oct. 19*
Dynamical Systems Modeling for Undergraduate Education: From Coleman Coolers to Computers, *Oct. 19*
Environmental Issues at Modern and Historical Mining Sites, *Oct. 19*
Geology of Coal Bed Methane: The Perspective from Basin and Thermal History Studies, *Oct. 19*
Geomorphic Applications of In Situ–Produced Cosmogenic Isotopes, *Oct. 19*
Visualization in the Geosciences, *Oct. 19*
Paleosols for Sedimentologists, *Oct. 19*
Practical Romote Sensing for Geology, *Oct. 19*
Geobiology of Echinoderms, *Oct. 19*
Tidal Rhythmites and Their Applications and Implications, *Oct. 19*
Digital Data Base Forum: Electronic Journals in Earth Sciences, *Oct. 19*



FOR MORE INFORMATION about the annual meeting, contact GSA, Meetings Department, P.O. Box 9140, Boulder, CO 80301; (800) 472-1988 or (303) 447-2020; fax (303) 447-0648; e-mail: meetings@geosociety.org; World Wide Web site is http://www.geosociety.org. The preregistration deadline is *September 19.*

UPCOMING *Meetings*

Society of Petroleum Engineers, Annual Technical Conference, October 5–8, 1997, San Antonio, Texas. Information: SPE, P.O. Box 833836, Richardson, TX 75083; (214) 952-9393; e-mail: techprog@spelink.spe.org.

American Institute of Professional Geologists, Annual Meeting, October 7–11, 1997, Houston, Texas. Information: AIPG, 7828 Vance Dr., Suite 103, Arvada, CO 80003; (303) 431-0831, fax 303-431-1332; e-mail: aipg@netcom.com.

Society for Vertebrate Paleontology, Annual Meeting, October 8–11, 1997, Chicago, Illinois. Information: SVP, 401 N. Michigan Ave., Chicago, IL 60611; (312) 321-3708, fax 312-245-1085; e-mail: svp@sba.com.

Society of Professional Well Log Analysts, Data Quality Conference, October 12–16, 1997, Taos, New Mexico. Information: Vicki King, SPWLA, 8866 Gulf Freeway, Suite 320, Houston, TX 77017; (713) 947-8727, fax 713-947-7181.

Gulf Coast Association of Geological Societies, Convention, October 15–17, 1997, New Orleans, Louisiana. Information: New Orleans Geological Society, 234 Loyola Ave., Suite 932, New Orleans, LA 70112; (504) 561-8980, fax 504-561-8988.

Applications of Emerging Technologies: Unconventional Methods in Petroleum Exploration, Conference, October 30–31, 1997, Dallas, Texas. Information: M. Elisabet Bordt, Institute for the Study of Earth and Man, P.O. Box 750274, Dallas, TX 75275; (214) 768-3762, fax (214) 768-4289; e-mail: ebordt@mail.smu.edu.

Karst-Water Environment Symposium and Workshop, October 30–31, 1997, Roanoke, Virginia. Information: T. M. Younos, Virginia Water Resources Center,

Oklahoma Academy of Science Hosts Fall Meetings

The Geology Section of the Oklahoma Academy of Science invites geology faculty, students, and professionals to participate in two OAS meetings this fall.

The OAS fall field meeting takes place September 19–21 in Hinton, Oklahoma. Participants can choose from a number of field trips during this family oriented event; the geology field trip, led by Neil Suneson of the OGS, explores the geology of Red Rock Canyon State Park.

The OAS technical meeting will be held November 7 at the University of Science and Arts of Oklahoma in Chickasha. Papers are still being accepted; titles are due September 15. Graduate and undergraduate students are encouraged to give presentations at the meeting. **Oklahoma Geology Notes** publishes abstracts of presented papers.

Attendance at the meetings costs $10 when paid in advance and $15 on site; for students, $5 when paid in advance and $10 on site.

For information about the meetings, or about membership in the Geology Section of the OAS, contact John P. Hogan at the University of Oklahoma, 100 E. Boyd, Suite 810, Norman, OK 73019; (405) 325-4428; e-mail: jhogan@ou.edu. Or, visit the OAS web page: http://bmb-fs1.biochem.okstate.edu/OAS/OASHomePage.html

10 Sandy Hall, VPISU, Blacksburg, VA 24061; (540) 231-8039, fax 540-231-6673; e-mail: tyounos@vt.edu.

Society of Exploration Geophysicists, Annual Meeting, November 2–7, 1997, Dallas, Texas. Information: Judy Paull, SEG, 8801 S. Yale, Tulsa, OK 74137; (918) 497-5500, fax 918-497-5557.

International Conference on Advances in Ground-Water Hydrology, November 16–19, 1997, Tampa, Florida. Information: AIH, 2499 Rice St., Suite 135, St. Paul, MN 55113; (612) 484-8169, fax 612-484-8357; e-mail: AIHydro@aol.com.

Applied Geologic Remote Sensing, 12th International Conference, November 17–19, 1997, Denver, Colorado. Information: Robert Rogers, ERIM, Box 134001, Ann Arbor, MI 48113; (313) 994-1200, ext. 3234, fax 313-994-5123; e-mail: raeder@erim.org.

Geological Society of America, South-Central Section, Meeting, March 23–24, 1998, Norman, Oklahoma. *Abstracts due December 1, 1997.* Abstract submission information: Judson Ahern, School of Geology and Geophysics, University of Oklahoma, 100 E. Boyd St., Suite 810, Norman, OK 73019; (405) 325-3253; e-mail: jahern@ou. edu.

American Association of Petroleum Geologists, Southwest Section, Annual Meeting, March 29–31, 1998, Wichita Falls, Texas. *Abstracts due October 1, 1997.* Abstract submission information: Bill Stephens, Gunn Oil Company, P.O. Box GOCO, Wichita Falls, TX 76307; (940) 723-5585.

Bartlesville Play Featured in October Workshops

The Oklahoma Geological Survey will present a one-day workshop, "Fluvial-Dominated Deltaic (FDD) Oil Reservoirs in Oklahoma: The Bartlesville Play," in three Oklahoma cities this fall. The workshop will be held in Tulsa on October 29 at the U.S. Army Corps of Engineers Facility; in Bartlesville on October 30 at the Phillips Research and Development Center; and in Norman on November 12 at the U.S. Postal Training Center.

The registration fee for operators in this play is $15; for other attendees it is $25. (Note: The $15 fee is for only one representative from each company; additional registrants must pay $25.) The cost includes lunch and a copy of the play workbook, *Fluvial-Dominated Deltaic (FDD) Oil Reservoirs in Oklahoma: The Bartlesville Play* (OGS Special Publication 97-6). Bartlesville operators have priority status to attend if registered by October 10. Other attendees must register by October 17.

The workshop is the last in a series of eight presented as part of the Fluvial-Dominated Deltaic Oil Reservoirs project. The FDD project is sponsored by the Oklahoma Geological Survey, in cooperation with the University of Oklahoma's Geo Information Systems and the OU School of Petroleum and Geological Engineering.

For more details or for registration forms, contact Michelle Summers, Oklahoma Geological Survey, 100 E. Boyd, Room N-131, Norman, OK 73019; (405) 325-3031 or (800) 330-3996; fax 405-325-7069.

Geologic and Hydraulic Characteristics of Selected Shaly Geologic Units in Oklahoma

Prepared in cooperation with the Oklahoma Geological Survey, this 25-page USGS water-resources investigations report describes the geologic characteristics and hydraulic-test data of the Dog Creek Shale and Chickasha Formation in Canadian County, the Hennessey Group in Oklahoma County, and the Boggy Formation in Pittsburg County. A generalized geologic log is presented for each unit, and bulk mineralogy and clay types determined by X-ray diffraction are described. Permeameter-derived measurements of hydraulic conductivity, in addition to specific storage, porosity, and water content of selected samples are given. In-place hydraulic conductivity and specific storage of the Hennessey Group and Boggy Formation also are given. The purpose of the project was to gain insight into the characteristics controlling fluid flow in shaly units that could be targeted for confinement of hazardous waste in the State and to evaluate methods of measuring hydraulic characteristics of shales. The report was written by Carol J. Becker, Myles D. Overton, Kenneth S. Johnson, and Kenneth V. Luza.

Order WRI 96-4303 from: U.S. Geological Survey, Water Resources Division, 202 N.W. 66th St., Bldg. 7, Oklahoma City, OK 73116; phone (405) 843-7570, fax 405-843-7712. A limited number of copies are available free of charge.

Middle Proterozoic to Cambrian Rifting, Central North America

Edited by Richard W. Ojakangas, Albert B. Dickas, and John C. Green, this volume includes 18 papers on rifting, with emphasis on the Midcontinent Rift System (MRS), one of the longest Precambrian intracontinental extensional features on earth. Thirteen of the papers deal with the geophysics, tectonics, structure, mineralization, or sedimentary rocks of the MRS. The other five papers in the volume relate to other rifts in the central part of North America. The paper by John P. Hogan and M. Charles Gilbert, "Intrusive Style of A-Type Sheet Granites in a Rift Environment: The Southern Oklahoma Aulacogen," deals specifically with Oklahoma. Another paper, "Role of the Reelfoot Rift/Rough Creek Graben in the Evolution of the Illinois Basin," by Dennis R. Kolata and W. John Nelson, also relates to Oklahoma geology. This 322-page, indexed volume is an outgrowth of the 10th International Basement Tectonics Conference held at the University of Minnesota–Duluth in August 1992.

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Oklahoma ABSTRACTS

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

A Case Study of Implementation of Environmental Justice

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Century-old mining of lead and zinc in the Tri-State Mining District that includes southwestern Missouri, southeastern Kansas and north Oklahoma, resulted in contamination of soil and ground water with lead, zinc, cadmium and other metals. The Environmental Protection Agency (EPA) has put some of the worst contaminated sites in the district on its National Priority List under the Superfund Program. Two of these sites in the states of Missouri and Kansas, in EPA's Region VII, are currently undergoing remediation.

High concentrations of lead, above 2,500 ppm, were found in 300 residential yards in Missouri and Kansas. Of the 2,000 children screened for lead, 230 were found to have lead levels above the limit of 10 microgram/dL in their blood. In order to minimize the health risk to children a remediation program was developed that included: (i) excavation and restoration of all residential yards where lead levels were more than 2,500 ppm, (ii) covering the yards having lead levels of less than 2,500 ppm with grass, mulch or rock aggregate, (iii) health monitoring of children six years or younger, and (iv) educating parents on how to avoid lead exposure to their children.

To implement the remediation plan, EPA worked in close coordination with local groups and citizens. Media was kept informed of all activities and open communication was maintained with citizens, media and the local groups. The project is a successful demonstration of how envirommental justice can be served to people affected by past activities involving hazardous materials. The key to success are: full public participation and open communication among all concerned parties.

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Hydrology, Water Quality and Global Change Research on the Little Washita River Watershed

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The Little Washita River (LWR) Watershed is the largest (230 sq. mi.) of the USDA–Agricultural Research Service's watersheds and one of the best instrumented watersheds in the world. Established in the 1930s, the watershed was used to demonstrate the effectiveness of soil erosion control, soil and water conservation structures, and floodwater retarding reservoirs. Scientific and public concern and a government initiative on global change lead to a major reinstrumentation effort on the LWR watershed beginning in the late 1980's. Reinstrumentation involved upgrading a network of 42 meteorological stations on a 5 km × 5 km grid to provide automated monitoring of air temperature, relative humidity, incoming solar radiation and soil temperature at four depths. Soil moisture is also monitored at selected sites using a resonant frequency capacitance probe. Four "nested" stream gages monitor stream flow. The LWR watershed is strategically located to other large-scale hydrologic and climatologic projects including GCIP-GEWEX, DOE's CART/ARM, and the Oklahoma Mesonet System. It also lies within the coverage of four operational weather surveillance radars (WSR-88D). In 1992 and 1994, cooperative, multi-agency experiments were conducted to collect remotely-sensed data for hydrologic investigations. Remotely-sensed data from hand-held instruments, as well as airborne sensors on board NASA's C-130 and DC-8 aircraft and from equipment aboard the space shuttle, Endeavour, were collected. Future instrument additions include infrared thermometer transducer for measuring surface/canopy temperature, net radiometers and pyrgeometers, automated soil moisture sensors, and weighing lysimeters. An extensive groundwater well network is also planned. Instrumentation will provide data for investigation of scaling and spatial/temporal variability of water and energy fluxes, percolation, interflow, groundwater recharge and discharge, as well as for watershed parameterization, and hydrologic modelling at the mesoscale.

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Interaction of Alluvial Sediments and a Leachate Plume from a Landfill Near Norman, Oklahoma

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Municipal landfills were commonly sited on alluvial plains. Substances leached from these landfills are moving through alluvial sediments toward rivers. During transport these substances are altered by numerous processes, including reactions with detritus in the alluvium. USGS, EPA, and Oklahoma University researchers are investigating processes affecting leachate from an abandoned landfill on the Canadian River alluvium near Norman, Oklahoma.

Canadian River alluvium near the landfill is 0 to 13 meters thick and is underlain by red-brown Permian siltstones and mudstones. Alluvium intersected during coring is medium to very fine sand with less abundant mud and silt. The alluvium is mainly quartz and clay, with minor feldspars. Minor calcite and dolomite cement sedimentary rock fragments. The clay is mainly smectite with minor illite-smectite, illite and kaolinite. Other detritus includes plant fragments and hematite. Authigenic iron-sulfide phases formed near some plant fragments.

Reactions between leachate and solid phases affect dissolved iron, potassium and barium. High dissolved Fe2+ (>30 mg/L) in the plume is attributed to reductive dissolution of iron oxides. However, some hematite grain coatings remain in all samples. Dissolved potassium concentrations decrease from 400 ppm next to the landfill to less than 3 ppm, 100 m down gradient. The decrease is attributed to cation-exchange between the leachate and smectite. The exchangable molar K/Ca ratio in the clay fraction supports the exchange. The ratio is 0.09 at the landfill compared to 0.02 at background sites and 100 m down gradient. High dissolved barium (up to 8 mg/L), is thought to have resulted from barite dissolution. Barite dissolves when sulfate concentrations in the leachate are reduced to <1 mg/L by bacterial sulfate reduction.

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Waulsortian Mound Development Associated with Kinderhookian (Lower Mississippian) Transgressive Systems Tract, Missouri and Oklahoma

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Numerous Waulsortian mounds are developed in a northeast-southwest trending belt associated with Lower Mississippian (Kinderhookian) strata across northeastern Oklahoma and southwestern Missouri, but they have not been recognized in the eqivalent section in adjacent Arkansas. The mounds are small, generally less than 20 m thick and 200 m long, but they exhibit the same facies patterns as those seen in the classic Waulsortian region, Dinant basin, Belgium. The core facies is composed of carbonate mud lacking an obvious framework organism, but containing scattered, disarticulated crinozoan detritus, and fragmental fenestrate bryozoans. *Stromatactis* is common. Crude bedding within some mound cores suggests mud transport and supports an "import model," but the relationships are not unequivocal. Flank beds are composed of grain-supported lithologies dominated by crinozoan detritus that form thin to medium beds, and onlap the core facies. Flank bed dips may reach 45°, while regional dip is less than 1°. Intermound lithologies are composed of grain-supported, crinozoan-bryozoan packstones that exhibit increasing mud contribution toward the top of the section as a reflection of continued transgression.

The Waulsortian mounds in Missouri and Oklahoma formed below effective wave base, but at relatively shallow depths of no more than 30 m in an upper to middle ramp setting that experienced starved conditions along its distal margins and finally passed into shales basinward. The mounds begin in the Compton Limestone, although not at its base. Clastics of the Northview Siltstone onlap, but do not cover any of the mound cores, which by that time may have grown above effective wave base. The mounds were subsequently drowned by continued Kinderhookian and Osagean transgression represented by the Pierson Limestone.

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Possible Carbonate Olistoliths, St. Joe Limestone (Lower Mississippian), Northwestern Arkansas

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Mound-like bodies of bedded, coarse, crinozoan-bryozoan grainstones and packstones occur within the Pierson Member, upper St. Joe Limestone (Lower Mississippian) in northwestern Arkansas. These bodies exhibit sharp but irregular contacts with the overlying Boone Limestone, which is a chert-bearing, fine grained calcisiltite to carbonate mudstone. The Boone interval exhibits pronounced differential compaction and thinning in proximity to the bodies indicating positive relief of as much as three meters over a length of approximately fifteen meters at the time of deposition. These bodies resemble Waulsortian mounds that are well known from the equivalent interval in adjacent Missouri and Oklahoma. Unlike the midcontinent Waulsortian mounds, however, these bodies are not cored by carbonate mud, they exhibit obvious bedding, and they are highly fossiliferous. Conodonts recovered from the mound lithologies are representative of the *Bactrognathus–Pseudopolygnathus multistriatus* Conodont Biozone that indicates a lower Osagean age. Thus, these mound-like bodies are also significantly younger than the upper Kinderhookian age for all the unquestioned Waulsortian mounds developed in the Compton Member of the St. Joe Limestone in Missouri and Oklahoma.

The St. Joe Limestone and its equivalents are a transgressive systems tract developed on a regional type 1 unconformity surface across the southern midcontinent. The location of the Arkansas locality is in a deeper, down-ramp position south of the main Burlington carbonate shelf. We believe that these mound-like bodies may be slump blocks (olistoliths) of the shelf facies that became detached as progradation defined the ramp-shelf boundary, and involve down slope movement of possibly 20 kilometers or more.

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Regional Diagenetic Variation in Maximum-Transgression Phosphates from Midcontinent Pennsylvanian Shales

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Phosphatic, marine, "core" shales in Midcontinent Pennsylvanian cyclothems probably represent examples of condensed sections that preserve more of the original anatomy of a condensed section than many previously described condensed sections. Phosphate is usually not reworked, and can occur in several distinct zones. The association of glaucony and phosphate commonly reported in condensed sections is weak in these cratonic condensed sections. Glaucony sometimes occurs with the phosphate when the shale has been reworked.

Distinct regional differences in phosphate petrology are evident. In eastern Kansas and northeastern Oklahoma, Kansas-type nodules are peloid- *and/or* radiolarian-rich cemented by variable amounts of phosphate, calcite, and silica. In east-central Oklahoma, Oklahoma-type nodules have a distinct, probably fecal nucleus separated from an encasing phosphate and/or carbonate rind by carbonate-filled septarian cracks. The regional petrologic differences may result from differential rates of compaction and/or cementation.

Rare earth element (REE) data from the Kansas-type nodules suggest regional gradients that may be primarily controlled by the degree of masking of middle REE-enriched patterns by flat REE patterns. The middle REE-enriched pattern may reflect the fecal component in these phosphates, whereas the flat pattern is attributed to detrital influence.

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Sequence Stratigraphy Helps to Distinguish Offshore from Nearshore Black Shales in the Midcontinent Pennsylvanian Succession

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Although all Midcontinent Pennsylvanian black shales were once regarded as shallow-water deposits, the widespread, phosphatic, conodont-rich black shales that lack benthic fossils and lie stratigraphically between marine transgressive and regressive limestones in a cyclothem (T-R sequence or stratigraphic sequence) are now recognized as offshore sediment-starved condensed-section deposits, which accumulated slowly in anoxic water below a pycnocline. In contrast, less-widespread (and often overlooked) phosphate- and conodont-poor black shales that typically overlie coals (or other flooding surfaces) tend to grade vertically and laterally into shoreline and/or terrestrial deposits and often contain a sparse benthic fauna, probably formed under conditions of organic overload in nearshore dysoxic environments. However, at least one widespread black shale that overlies a coal contains plant fragments and sparse shallow-water conodonts at the base, but phosphate nodules and abundant offshore conodonts in the top (Anna Shale in an Iowa core). Moreover, R. C. Price showed that the upper Anna in southern Kansas is the more offshore, lower-shelf equivalent of both the overlying limestone-shale sequence (Myrick Station–Mine Creek) and the upper Anna in Iowa. P. B. Wignall and J. R. Maynard reported two stratigraphically distinct black shales in a Namurian cyclothem in England: the lower (Owd Betts Horizon) overlies a marine flooding surface and is conodont poor, whereas the higher (*Gastrioceras cumbriense* horizon) is conodont bearing and ammonoid rich, separated from the lower by a gray shale, and is time-equivalent to distant nearshore highstand deposits. J. R. Hatch reported the Anna Shale in the Iowa core to have two zones of organic enrichment (15%, 19%) in the base and top, respectively, separated by a less-organic-rich (3.5%) zone. The basal Anna and Owd Betts Horizon were probably deposited during early transgression in nearshore environments subject to organic overload, whereas the top of the Anna and the *G. cumbriense* horizon were deposited offshore at maximum transgression beneath a pycnocline.

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Ichnology of Transgressive-Regressive Surfaces in Mixed Carbonate-Siliciclastic Sequences, Early Permian Chase Group, Oklahoma

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Early Permian rocks of the Chase Group in north-central Oklahoma consist of repeated couplets of carbonates and clastics. The carbonates and clastics correlate to major transgressive and regressive events, respectively. Regressive parts of the depositional couplets consist of thicker (10–40 m [33–131 ft]), more clastic-rich marginal-marine and/or continental facies dominantly composed of red and green mudstones and/or shales locally capped by exposure surfaces and paleosols. Transgressive parts of the couplets consist of thinner (1–20 m [3–66 ft]), more carbonate-rich marine and marginal-marine facies dominantly composed of shallowing-upward units of coated-grain, fossiliferous wackestones, packstones, and grainstones.

The sole of the lowest (first) transgressive carbonate bed of each depositional couplet is covered with ubiquitous horizontal boxworks of the trace fossil *Thalassinoides* isp. These burrow systems were constructed as excavations into the underlying regressive mudstones and occur at a discontinuity surface at the culmination of a major regressive event and the initial onset of a major transgressive event. Horizontal forms of the trace fossil *Rhizocorallium* isp. characterize the top bedding-plane surface of the highest (last) carbonate unit of each couplet, and mark the discontinuity surface at the culmination of a major transgression and the initial onset of a major regression.

These trace-fossil associations are assigned to the substrate-controlled *Glossifungites* ichnofacies. In the Early Permian Chase Group of north-central Oklahoma, this ichnofacies is dominated by the ichnogenera *Thalassinoides* and *Rhizocorallium* in association with *Diplocraterion, Arenicolites, Chondrites, Teichichnus,* and *Planolites.* The *Glossifungites* ichnofacies, at least in this particular geographic and stratigraphic setting, characterizes discontinuity surfaces that correlate to hiatuses in deposition, typically concomitant with shallow-water erosion associated with transgressive-regressive events.

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Sequence Stratigraphic, Paleobathymetric, and Tectonic Controls on Reservoir Architecture in Lower Permian (Chase Group), Cyclic Carbonates in the Midcontinent USA

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Ninety-five percent of the 80 TCF of gas reserves in midcontinent Permian rocks is from carbonate reservoirs in the Chase Group (Wolfcampian). Outcrop studies provide model-analogs useful in the characterization of these reservoirs. The section includes 7 depositional sequences, each of which is hierarchally divided into 2 higher-frequency cycles. Cyclic sedimentation reflects glacio-eustatic forcing superimposed on continual subsidence over time. The two principal reservoir-analog facies, subtidal carbonate sands and peritidal dolomudstones, contain different but multiple pore types. Spatial occurrence of these facies in any given stratal unit is predictably related to relatively high-frequency cyclicity, paleobathymetry, and at times, syndepositional tectonism.

It was the hierarchy of cyclicity, however, that exerted fundamental control on reservoir architecture. Marine accommodation increases accompanying relatively high-magnitude eustatic fluctuations were sufficient to maintain marine conditions, and resulted in a dominance of porous sands in the basal Chase Group. These sands are of relatively limited areal extent, and some are associated with type-1 unconformities. Lower-magnitude eustatic fluctuations and accommodation increases instead resulted in areally extensive progradation of progressively more dolomitized peritidal facies in the upper Chase Group; peritidal deposits and dolomites are virtually absent in older beds. The up-section change from laterally heterogeneous limestones to more extensive and laterally homogeneous dolomites reflects depositional history as controlled by the character of cyclicity, and predictively explains the contrasting production characteristics of these gas reservoirs in the subsurface.

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Late Paleozoic Recurrent Structural Movement in the Midcontinent (USA) as Recorded by "Plains-Type Folds"

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"Plains-type folds" are structural features formed in the thin sedimentary package overlying a shallow, cratonic, crystalline basement. The local anticlines are subtle features developed in the thin sedimentary cover over buried basement tilted fault blocks. They are small in areal extent (less than 1 km^2) and their definition increases with depth, which is either the result of (1) differential compaction of the sediments (usually shale units); (2) nondeposition of sediment; or (3) a combination. The development of the anticlines by continuous but intermitted movement of basement blocks in the Late

Paleozoic is substantiated by the alignment of the traces of anticlinal axes to the known basement faults.

The recurrent movement, which reflects adjustment to external stresses, is revealed by computing the structural interval gradient, which expresses the change in thickness of stratigraphic units over the crest of the fold. By plotting the structural interval gradient for different stratigraphic units of individual anticlines on different fault blocks, it is possible to determine the timing of movement of the blocks assuming thinning of sediments over the structure reflect time of structural adjustment. The shale units in the Permo-Pennsylvanian, because of their compactibility, best reflect the times of differential movement. The structural interval gradient for numerous structures in the Cherokee, Forest City, and Salina Basins and on the Nemaha Anticline of the Midcontinent (USA) were determined and compared for location and timing of the adjustments. A similar variability in movement of local structure is shown in these regional geological areas.

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History and Evolution of Reactivated Basement Faults in Kansas and Contiguous Areas, USA

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Northwest- and northeast-trending faults characterize the structural grain of the pre-Paleozoic basement in the Midcontinent. Northwest-trending faults associated with the Central Plains Orogen and the younger granite-rhyolite terrane to the south predate the northeast-trending set of faults related to the development of the 1.1 Ma Midcontinent Rift System.

Precambrian compound vertical displacement of at least several thousand feet is evident from the preservation of younger rocks in grabens or fault-bounded basins in older terranes. Several periods of reactivation can be demonstrated to have occurred in the Paleozoic. Subtle changes in morphology across linear trends known to coincide with tectonic zones mapped in the subsurface are believed to reflect neotectonic activity. The same is true for linear trends of rivers and streams, as well as contacts between geologic formations.

Much of this activity can be related to periodic stress buildup associated with orogenic activity along the margins of the craton. The loci for the release of horizontal, vertical and shear stresses are likely to be preexisting faults. Recurrent activity, coupled with changes in direction of the stress fields, tend to give rise to complex fault systems, more properly referred to as tectonic zones. Interpretation of recurrent activity is a difficult task, because present-day fault configurations exhibit compound movement over time.

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Consequences of Neotectonic Recurrent Movement Along Precambrian Structures on the Stratigraphic Record, Midcontinent U.S.A.

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The early-formed crust of the Earth eventually attained sufficient strength to react in a brittle fashion in response to tensional stresses and was broken into semirectangular blocks bounded by NE- and NW-trending megafractures. These fractures are loci for whatever combination of horizontal, vertical, and shear stresses acted on them throughout geologic time. Precambrian structures of all scales can thus be propagated upward into the overlying sedimentary sequence by recurring movement along these old megashears or tectonic zones. The location of subsurface fractures and faults affecting Paleozoic and Mesozoic sedimentary rocks can be interpreted where abundant drilling records exist. In Kansas and adjacent areas pre-Cenozoic sedimentary rocks dominate the surface geology south of the area covered by glacial till. Neotectonism is difficult to demonstrate in these older rocks, but we believe that relatively recent subtle movement along the older structures has given rise to a variety of features that must be interpreted as being recent. The change from a hummocky to a flat topography across the trace of a mapped subsurface fault in central Kansas can be interpreted as neotectonic uplift of the hammocky block. The linear trend of many rivers and streams, as well as the abrupt change in direction of streams in the Midcontinent shows spatial relationships with mapped subsurface faults. Recent erosional patterns seen in the trend of many geologic outcrop boundaries also are good indicators of young vertical displacement. Recognition of areas affected by possible neotectonic processes has important ramifications with respect to many geologic-engineering projects such at dams, power plants, waste disposal sites, and many others.

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Revised Lower Ordovician Biostratigraphic Framework for the Ozark Region, Midcontinent U.S.A., and Implications for Sequence Stratigraphic Interpretations

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The Ozarks region of central southern Missouri is underlain by one of the classic Lower Ordovician (Ibexian Series) successions in North America/Laurentia. Present are, in ascending order, the Eminence (in part), Gasconade, Roubidoux, Jefferson City, and Cotter/Powell formations. This succession, however, is poorly understood due to pervasive dolomitization, lack of recent study, and an extant biostratigraphy based mostly upon poorly resolved and sparsely occurring molluscan faunas.

Our systematic search for conodonts from these units, beginning with sections of the Gasconade Dolomite and Roubidoux Formation, shows that large dolostone samples from these units can yield collections with stratigraphically useful faunas, all of which are typical of warm, shallow environments of the North American Midcontinent Faunal Realm. Most of the Gasconade Dolomite is assigned to the *Rossodus manitouensis* Zone; the upper part, up to 10 m or more, is assigned to the "Low Diversity Interval" (lowest part of the range of Fauna D). The Roubidoux Formation ranges from the "Low Diversity Interval" through most or all of the *Macerodus dianae* Zone. The base of the Jefferson City is poorly resolved at present, using conodonts, and lies either high in the *M. dianae* Zone or very low in the overlying *Acodus deltatus–Oneotodus costatus* Zone (middle Ibexian). Trilobite faunas, however, effectively constrain the base of the Jefferson City.

Having established that the Ibexian conodont successions from the Ozarks can now be linked with those in other regions, the result is greater precision in inter-regional correlation and better control for long distance sequence stratigraphic analysis. For example, the Gasconade-Roubidoux contact has been correlated with the level of the House-Fillmore contact (Utah), the McKenzie Hill–Cool Creek contact (Oklahoma), and the top of the Stonehenge Limestone (central Appalachians), largely on the basis of the lithologic changes at those levels. Conodonts indicate that the influx of sand marking the base of the Roubidoux is somewhat younger than the base of the Fillmore and the Cool Creek and significantly younger than the top of the Stonehenge.

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Detailed Microbial Reservoir Characterization Identifies Reservoir Heterogeneities within a Mature Field in Oklahoma

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A detailed Microbial Reservoir Characterization (MRC) survey was conducted over a mature producing field in Washington County, Oklahoma. The samples were collected in a 330′ grid pattern over the entire 720 acres of the study area. MRC theory is dependent on observed rapid hydrocarbon microseepage and the direct relationship between surface microbial populations and the pressure regimes within the reservoir. Reduced microbial populations are located above portions of the reservoir in direct communication with producers while elevated populations are associated with injection. When a well is brought into production, the drive mechanism changes from a vertically migrating buoyancy force to horizontal gas streaming to low pressure sinks created within the reservoir in pressure communication with the producing wells. This change in drive mechanism causes rapid reduction of surface microbial populations and defines reservoir drainages, radii and heterogeneities around producing wells. Within single horizon producing fields, areas of elevated microbial values are not in pressure communication with the producers and are isolated from the producer by reservoir heterogeneities. Conversely, in areas where the reservoir is being repressured, as in a waterflood, microseepage is reestablished. The microbial populations increase in response to increasing microseepage coming from the portion of the reservoir in direct communication with the waterflood. Low microbial counts within injection areas indicate depressured regions of the reservoir not in communication with injector and isolated by some heterogeneity. All these patterns were observed in the study area and verified by recent infill drilling.

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The Effect of Brine on the Microbial Degradation of Hydrocarbons: A Progress Report from the Tallgrass Prairie Preserve, Oklahoma

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The Tallgrass Prairie Preserve in Osage County, Oklahoma, represents a unique site for the study of the long term effects of brine and oil contamination. This study examines the role of brine contamination on the bioremediation of hydrocarbons in an abandoned storage pit.

Fifty samples were collected from the pit and the immediate outwash area where brine damage is obvious. Hydrocarbons were extracted from 25 samples and analyzed

using standard gas chromatographic techniques. Each sample was tested for the percentage of total dissolved salts and bio-assayed to determine the microbial content.

The amount of degradation was determined using the least degraded sample as a standard. By comparing the remaining samples, a relative scale of degradation was established. The most degraded samples are along the pit edges where vegetation and soil depth are well established. The least degraded oils are located in areas of high total dissolved salts at the base of the pit where a man-made berm prevents dispersion of the brine. The samples were scored based on turbidity and emulsion. The highest microbial counts were also found along the pit edges, where nutrients and other physical requirements for growth are more abundant. Fungal growth occurred within 12 days of inoculation and was widespread within 30 days. Fungi are more salt tolerant, while the bacteria cannot survive in elevated salt concentrations. The results of the amount of degradation, total dissolved salts and most probable number show that brine is hindering microbial growth thus affecting the amount of oil degradation.

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Reservoir Characterization and Improved Water-Flood Performance in Glenn Pool Field: A DOE Class I Project

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Study of the Glenn Sand (Middle Pennsylvanian) in Glenn Pool field, northeastern Oklahoma, has been a joint partnership between the U.S. Department of Energy, The University of Tulsa, Uplands Resources (operator) and Amoco Production Company. The project goal is to improve water-flood performance in this 90-year-old field through detailed reservoir characterization using conventional and advanced technologies. To date, efforts have focused on a 160-acre tract including about 1-year of implementation of a new reservoir management plan.

Four architectural levels are recognized in the reservoirs that make up the Glenn Sand. (1) Largest scale (rock volume) is multistory discrete genetic intervals (DGI) that comprise the 150 ft thick interval and are traceable across the southern extent of field. (2) Seven DGIs are recognized descending from A through G. Sandstones of each DGI are vertically separated by generally continuous mudstones except for localized areas of erosion. (3) Each discrete genetic interval is composed of facies: braided fluvial (confined to DGI F and G); meandering fluvial channel-fill and crevasse splay (DGI A to D); and overbank mudstones. (4) Channel-fill facies is divided into subfacies: a lower subfacies comprising trough cross-stratified, medium-grained sandstones; a middle subfacies dominated by mudstone draped epsilon cross-stratified, fine-grained sandstone; an upper subfacies composed of mudstone.

From core and borehole-image log analysis it is clear that much of the remaining resource (up to 80% of OOIP) is located in the middle channel-fill subfacies and in crevasse splay complexes. Several management scenarios were evaluated using different reservoir simulations and well configurations. The most economically reasonable for this part of Glenn Pool field involved a reconfiguration of perforations in producers and injectors of existing vertical wells. With only half of the plan in effect to date, increased production is 200% above our projections.

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Sequence Stratigraphic Architecture and Energy Resources of Bartlesville Sandstone

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The Pennsylvanian Bartlesville Sandstone, a main oil producer in Oklahoma and Kansas, is traditionally interpreted as part of a large deltaic complex deposited in essential as a single regressive interval. However, regional scale to reservoir scale investigation in both outcrop and subsurface in an area over 2000 square miles in northeastern Oklahoma reveals that Bartlesville Sandstone is mainly fluvial incised valley-fill deposited in a transgressive manner from a lower braided fluvial to an upper tidal-influenced meandering fluvial depositional systems.

Outcrop survey illustrates that a type-I sequence boundary exists at the base of Bartlesville Sandstone, indicated by subaerial erosion of underlying Savannah Shale and basinward facies shift from marine shale below to braided fluvial deposits above. Core facies and log facies interpretation validates the facies shift. Well log correlation shows Bartlesville Sandstone thickens at the expense of the Savannah Shale. The incised valley extends from north to south over a distance of 120 miles within Oklahoma, and is 4–5 miles wide in Washington County to over 40 miles wide in the Eufaula Lake area. The thickness of Bartlesville Sandstone interval varies from 120–250 ft within the valley to less than 20 ft outside the valley.

Depositional environment interpretation based on outcrop, core, and log curves demonstrates that the whole Bartlesville Sandstone incised valley-fill section consists of two sequence stratigraphic architectural elements: (1) the lower lowstand system tract, 80–150 ft, composed of braided fluvial deposits and distal lowstand delta; (2) the upper transgressive system tract, 70–100 ft, composed of meandering fluvial, estuarine tidal, and shallow marine deposits. The regional Inola Limestone marker, capping the Bartlesville Sandstone interval, is equivalent to a condensed section which represents maximum flooding.

The lowstand systems tract (LST), holding about 75 percent of OOIP discovered in Bartlesville Sandstone, played a key role in the past 90 year development and is almost depleted. The transgressive systems tract much more complex and heterogeneous and less developed in comparison with LST, offers the main potential for further reservoir development.

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Badlands Development in the Humid Environment of Eastern Oklahoma

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Badlands topography has developed in an area adjacent to the Arkansas River flood plain in the SE¼ sec. 33, T. 12 N., R. 22 E., Sequoyah County, Oklahoma. Although on a much smaller scale, owing to different climate, these landscape features (pseudokarst) are similar to those found in the Badlands National Monument in western South Dakota.

The mean annual precipitation in Sequoyah County is >43 in., most of which occurs as rain. During some years, however, extended periods of drought occur. Deep desiccation cracks develop in clayey and silty soils, such as those found in the steep side slopes of the Arkansas River valley. Water from subsequent heavy rain finds a passageway into the ground through these fractures. Swelling of water-saturated clays "heals" the fractures, concealing tunnels formed by lateral flow of water at the bottom of the vertical openings. ("Piping" is the term applied by geomorphologists to this form of concentrated soil-water throughflow in the subsurface.) Initially, sinkholes form by collapse of surface soils into underlying tunnels. Subsequent collapse of surface soil between sinkholes creates a system of closely spaced, narrow gullies with little or no vegetation.

Conclusions are that pseudokarst features form in humid environments, such as eastern Oklahoma, as the result of variations in weather patterns. The rate of erosion is slow in years of normal rainfall and gentle rains; it is greatly accelerated by heavy rains following an extended period of drought, particularly when sinkholes and their associated conduits collapse, exposing unvegetated soil.

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The Evolution of Independent Study Courses in Geology at Oklahoma State University and Elsewhere—New Solutions for Old Problems

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"Correspondence" courses in geology are undergoing a major revolution, changing from read-write mailings to a "distance-learning" experience perhaps more solid than courses offered on campus. In response to a mandate to assess and ensure equivalency of OSU extension courses, we examined our geology offerings and found them to be seriously amiss.

Although students who completed independent study courses tended to perform on par with on-campus students in regards to tests and grades, there were obvious signs of malfunction: (1) Text dependency led to disinterest and/or lack of perseverance such that less than half of the enrollees finished. (2) Students scanned textbooks for answers to exercises rather than thoroughly reading. (3) Students did not obtain an alternative viewpoint or the attitudinal shaping commonly supplied by a "live" instructor. (4) Students were not appropriately exposed to lab skills. (5) Students spent much less time (50–100 hours) with the 4 semester-hour courses than their on-campus counterparts (100–200 hours). (6) Completion required about 280 days. Most lessons were procrastinated till the month before expiration.

We gathered statistics from other schools while looking for ways to improve our offering. Correspondence courses are in greater demand than ever. The demand is being met with high-tech improvements. Many courses have been revised to incorporate television programs or video lessons, notably the Earth Revealed series. The 13 hours of Earth Revealed functions as a vicarious lecture, lab, and field trip. Some courses incorporate laser disks or computer media, but availability of appropriate equipment is cited as a problem. More schools are incorporating laboratory experiences, something easy to accomplish when labs are characterized by modeling and identification rather than experimentation. Finally, communication is improving—from mail, to fax, to e-mail and the internet.

OSU took advantage of most of these options during the development of the new course in physical geology, but we encountered several technologic roadblocks which forced us to delay incorporating the full technologic approach. Until a recording video disk is ubiquitous, individual departments would be advised to adapt commercial products such as Earth Revealed and postpone authoring their own renditions. Initial reaction to our course is mixed—it generates greater enthusiasm, but is more time-consuming and demanding.

Detailed information regarding correspondence course statistics, course malfunctions, revision problems, the OSU physical geology course guide, and a prospectus for future correspondence course design will be presented.

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Reading the Earth's Story

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The College of Geosciences at the University of Oklahoma hosts three summer academies "Exploring the Geosciences: Earth, Atmosphere, and Environment" for school teachers (K–12) and rising 11–12th and 9–10th grade students. Participants study three sections: Meteorology, Geography, and Geology over periods ranging in duration from a week to three weeks. Participants come from diverse backgrounds, from throughout Oklahoma, commonly with little or no knowledge of geology. Two primary goals of the geology section are: (1) increase participants' awareness of the importance of geology in their everyday life, and (2) develop basic skills fundamental to success in the sciences.

These academies are highly valued by teachers for the transfer of ideas and experiences in an informal setting. New labs are trouble-shot and evaluated for practicality from a teacher's perspective. The effectiveness of these labs are assessed during student academies. We integrate labs, designed to demonstrate fundamental geologic principles through "hands-on" experimentation, with geologic field trips in the state to the Arbuckle Mountains and/or Wichita Mountains. Abstract concepts presented in the classroom are immediately reinforced by the reality of geologic field observations. To enhance this experience we have provided participants with disposable cameras and geologic fieldbooks. Geologic sketches of laboratory experiments and field trip stops are used as a means of increasing observational skills and establishing a connection between experimental results and field observations. Photographs and samples supplement these sketches. The final product serves as a portfolio of the participants' summer academy experience.

Learning to read the Earth's story is the end product for teachers and for students. Follow-on evaluations indicate strong teacher appreciation and significantly increased student interest in the geologic sciences.

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Earth System Science—The Framework for Multidisciplinary Education in the Earth Sciences

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Today's university students, both those majoring in one of the traditional Earth science disciplines and those simply taking an Earth science course to meet a general education requirement, can benefit greatly from a broad "systems perspective" of the functioning of Planet Earth. Such a perspective provides a framework that gives context to disciplinary knowledge and aids in integrating such knowledge with that from other disciplines. Tomorrow's social and political leaders, as well as the next generation of Earth scientists, need such a holistic understanding of Earth to address both pressing environmental questions and the increasingly cross-disciplinary nature of cutting-edge research problems.

To provide such educational opportunities, the National Aeronautics and Aerospace Administration, through the University Space Research Association, has undertaken a multi-year effort to nurture the development of Earth System Science courses at universities nationwide. I report on efforts to develop and offer such undergraduate courses, first at Purdue University, and, most recently, at The University of Oklahoma, under the sponsorship of this NASA/USRA initiative. In both cases, the offerings are a lower division introductory (survey) course and an upper division/beginning graduate level course.

Experiences to date suggest that such courses are best team taught, with the lead instructors being an Earth scientist and a Life scientist. Team members should represent the full range of the Earth sciences—geology, meteorology, oceanography—and should be committed to working together to provide a seamless presentation to the students. This last is both a challenge and an opportunity. There are surprising differences in perspective about common subjects; for example, it is instructive to hear a geologist, a meteorologist, an oceanographer, and a biologist each describe the hydrologic cycle! Ideally, the students are a mix of all the Earth and Life sciences.

Modeling is an important tool of Earth scientists for summarizing knowledge and for predicting future events. Indeed, much of "Earth System" knowledge consists of models of the global (bio-)geochemical cycles. When presented on paper or even in the best of lectures, these often come across as static. However, activities with toy models constructed with a user-friendly software such as STELLA (© High Performance Systems) have proved to be effective for illustrating the dynamic, non-linear nature of the Earth System.

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