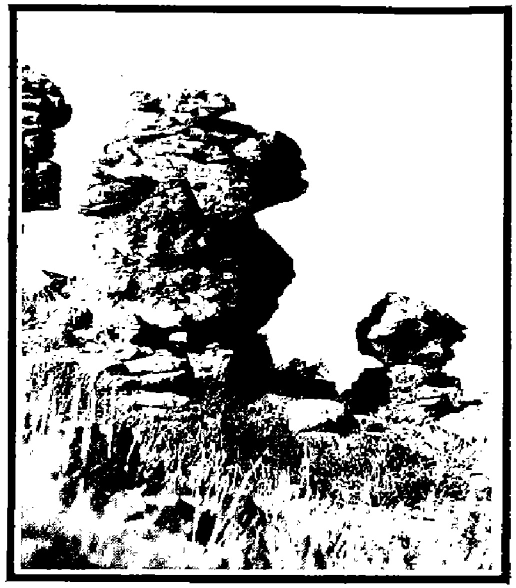
OKLAHOMA GEOLOGY NOTES

ISSN 0030-1736 VOLUME 40 NUMBER 5 OCTOBER 1980

OKLAHOMA GEOLOGICAL SURVEY / THE UNIVERSITY OF OKLAHOMA / NORMAN, OKLAHOMA 73019

Cover Photo

BLACK MESA STATE PARK



Black Mesa State Park is situated in Cimarron County, in the extreme northwest corner of Oklahoma. It is but 7 miles east of New Mexico, 10 miles south of Colorado, and 4 miles south of the Cimarron River. The park measures slightly over ½ square mile and includes Lake Carl Etling, an attractive body of water that provides an opportunity for fishing and boating. The park has adequate camping facilities but is otherwise rather primitive and isolated. The nearest town, Boise City (population 2,000), is also in Cimarron County.

Physiographically, the park lies on the High Plains, or the Llano Estacado. Topographic relief is low. The average annual precipitation is a scant 16 inches, which, with a sandy, shallow soil development, results in a ground cover of low shrubs underlain by golden buffalo and grama grasses.

The exposed bedrock is composed principally of Cretaceous sandstones, mostly of the Dakota Formation but also of the Cheyenne Sandstone Member of the Purgatoire Formation along Carrizozo Creek. These sandstones are strongly jointed by an orthogonal, vertical fracture system. As a consequence, the bedrock often erodes into grotesquely shaped hoodoos, which are further enhanced by a strong pattern of crossbedding (above, right).

Certainly, the most unusual aspect of the park is the large segments of petrified tree trunks that have been freed from the sands by weathering (cover photo). Placed to resemble the tumbled columns of an ancient Roman ruin, they are left to stand sentinel over the quiet solitude of the park.

—Donald A. Preston

Editorial staff: William D. Rose, Elizabeth A. Ham, Connie Smith

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

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

This publication, printed by the Transcript Press, Norman, Oklahoma, is issued by the Oklahoma Geological Survey as authorized by Title 70, Oklahoma Statutes 1971, Section 3310, and Title 74, Oklahoma Statutes 1971, Sections 231-238. 1,800 copies have been prepared for distribution at a cost to the taxpayers of the State of Oklahoma of $2,395.

OKLAHOMA OBSERVATIONS OF EFFECTS OF MAY 18, 1980, ERUPTION OF MOUNT ST. HELENS

Jim Lawson[1]

The eruption on May 18, 1980, at 8:32 PDT, of Mount St. Helens, 45 miles north-northeast of Vancouver, Washington, and the accompanying earthquakes produced several effects that were recorded 2,482 km (great circle) away in southern Tulsa County, at the Oklahoma Geophysical Observatory, a branch of the Oklahoma Geological Survey. The Observatory was transferred from The University of Oklahoma to the Survey on July 1 of 1978, and since that time it has become an important segment of the agency's statewide research programs.

Seismological Observations

Five minutes and 2 seconds after the eruption, several observatory seismographs recorded a longitudinal body wave, called a P wave, from the principal earthquake. This wave is best shown on the SPNBZ (short-period narrow-band vertical) seismogram (fig. 1), which was recorded on a seismograph with a peak magnification of 200,000 for waves of 1.0-second period (1.0-hertz frequency). The peak-to-trough ground amplitude of 167 nanometers, which occurs on the third cycle of the P wave, indicates a body-wave magnitude of 5.2.

Four minutes after the arrival of the P wave, a transverse body wave (S wave) was prominently recorded (see fig. 2) on the LPHIZ-2 (long-period high-gain vertical seismogram, with a peak magnification of 10,000 for waves of 35-second period, 29-millihertz frequency).

About 3½ minutes after the S-wave arrival, a surface wave called a Rayleigh wave was recorded. Only its first cycle is traced, as later cycles were clipped. The vertical ground amplitude (peak-to-trough) of 8.19 micrometers, which was measured on a different seismogram, indicated a surface-wave magnitude of 4.9.

The small difference (0.3 magnitude units) between body-and surface-wave magnitudes is strong evidence that the waves emanated from an earthquake involving slip along a planar fault rather than being simply waves from the explosion that initiated the eruption. A blast, such as the

[1]Chief geophysicist, Oklahoma Geological Observatory, Leonard, Oklahoma 74043.

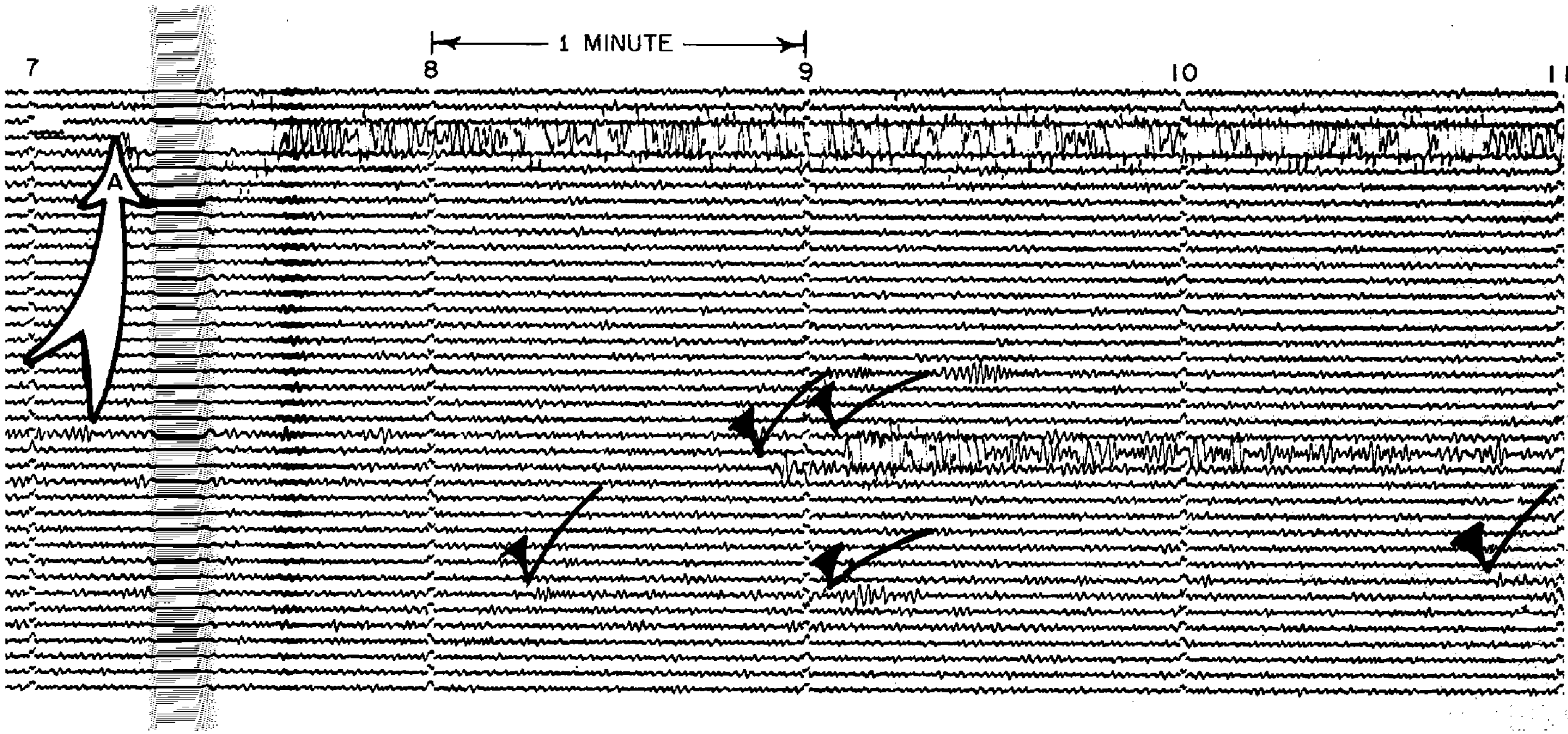


Figure 1. Part of SPNBZ (short-period narrow-band vertical) seismogram for May 18-19, 1980. P wave from principal-eruption-associated earthquake arrives at *A*. Because of scattering of waves within earth, P wave is followed by many minutes of vibration called a coda. Each successively lower line represents portion of seismogram recorded 15 minutes later. Check marks indicate P waves from aftershocks occurring between 4 and 7 hours after main earthquake. On complete seismogram, about 30 aftershocks are visible.

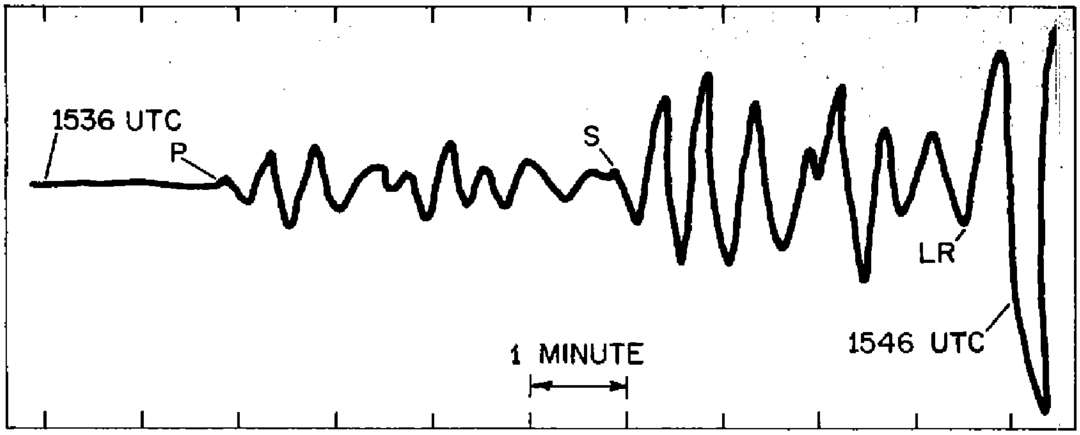


Figure 2. Tracing of LPHIZ-2 (long-period high-gain vertical no. 2) seismogram, showing P, S, and LR waves. Peak magnification is 10,000 for waves of 35-second period. UTC is Coordinated Universal Time, 6 hours later than CST. Main earthquake occurred at 15:32:11 UTC.

Cannikin underground nuclear test that was discussed in *Oklahoma Geology Notes* (v. 32, no. 1, February 1972, p. 11–15), produces mostly P waves. Blast transverse body waves (S waves) are usually not detectable, and blast surface waves are so small that the surface-wave magnitude is usually 2.0 magnitude units below the body-wave magnitude calculated from P-wave amplitudes.

There was relatively little seismic activity during the 3 hours following the eruption. During the next 3 hours, about 30 aftershocks were recorded on the SPNBZ seismogram. Some of the aftershocks are indicated in figure 1. The aftershocks, which did not produce detectable S or surface waves, were so small that a few of them could only be differentiated from ground noise by comparing the observatory records to the SPNBZ seismogram recorded from a radio-telemetry station, Rose Lookout Tower (RLO), 75 km northeast of the observatory.

The public can obtain full-size copies of these seismograms from NOAA/EDS/NGSDC, Solid Earth Data Services Division, Boulder, Colorado 80302. The cost of each seismogram is $1.50. Enclose a check payable to NOAA/EDS/NGSDC and request SPNBZ and/or LPHIZ-2 components from TUL for May 18, 1980, 153211 UTC. Other Observatory seismograms showing at least the principal earthquake are the SPZ, SPN, SPE, LPZ, LPN, LPE, HPZ, and LPLOZ components, which are also available through NOAA/EDS/NGSDC. Besides full-size copies, NGSDC will also provide microfiche.

Infrasonic Sound

The explosion of Mount St. Helens produced sound that was heard (according to press reports) at distances of 200 km or more. At farther distances, the atmospheric waves from the blast constituted infrasonic sound, frequencies too low to be detected by the human ear.

Among the Observatory's equipment is a microbarograph with a coiled bourdon tube that twists as pressure changes. It is similar to the bourdon tube in some dial barometers. However, instead of turning a needle, the coiled tube turns a mirror that reflects a light beam onto two adjacent photocells. As the light beam moves, one photocell is illuminated over a greater area and the other photocell over a lesser area. The difference in the voltage of the photocells is amplified and recorded on a paper chart moving 20 mm per hour.

An enlarged tracing of a microbarograph recording (fig. 3) shows the beginning of the infrasonic sound-wave train arriving at Leonard 2 hours, 9 minutes, and 20 seconds after the Mount St. Helens explosion. The wave train had traveled at 320 m per second over the 2,482-km distance.

The initial waves had a period of 360 seconds, a frequency of 0.0028 hertz, or about one-ten-thousandth of the lowest audible frequencies (20-30 hertz). The peak-to-trough amplitude of the initial cycles was 350 microbars, or about 0.01 inches of mercury. The initial impulse was an increase in pressure (downward on the graph), which is to be expected from an explosion. Much of the subsequent wave train was generated because the shorter period (higher frequency) waves travel more slowly through the atmosphere, a phenomenon called dispersion. Dispersion also affects seismic surface waves.

The wave train became shorter in period and smaller in amplitude until 37 minutes after the initial arrival, when it could no longer be seen above the background noise. The apparent large pressure drop after the first one and one-half cycles was due to a steady weather-related pressure decrease upon which the infrasonic sound is superimposed.

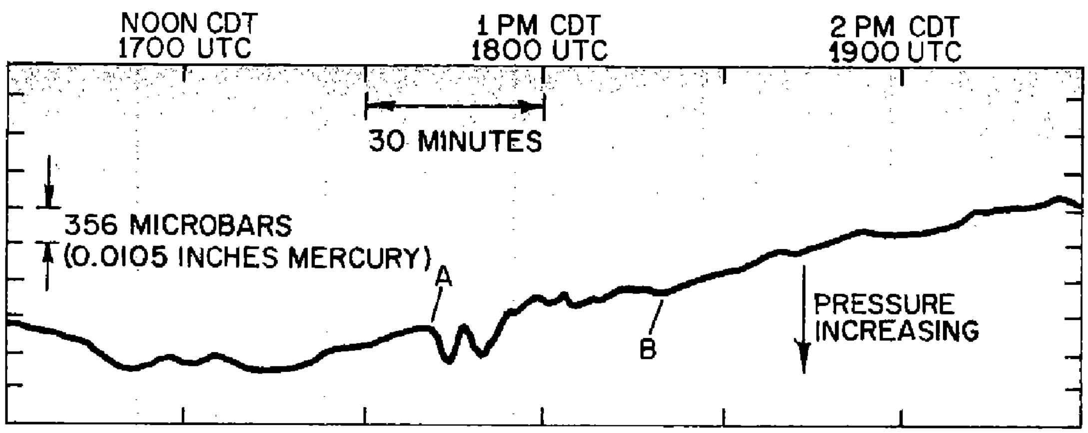


Figure 3. Infrasonic sound-wave train recorded by Oklahoma Geophysical Observatory microbarograph. At point *A*, beginning of wave train arrives, after traveling for 2 hours, 9 minutes, and 20 seconds, at an average velocity of 320 m per second, to cover the 2,482 km from Mount St. Helens. Initial waves have a period of 360 seconds (frequency, 0.0028 hertz) with a peak-to-peak pressure-fluctuation amplitude of about 350 microbars (0.01 inches of mercury). Wave train continues with decreasing periods and amplitudes for 37 minutes, when waves become too small to be recorded by microbarograph (point *B*).

The Tulsa City-County Health Department operates high-volume particulate samplers that pump 1.13 m^3 of air per minute through a filter to trap particulate matter. The samplers pump for 24 hours (midnight to midnight CST) every six days. High-volume samplers throughout the United States operate on the same days on a schedule set by the U.S. Environmental Protection Agency.

Mr. Ron Johnson, of the Tulsa City–County Health Department, gave the Observatory parts of the particulate filters from the May 19 and May 25 samplings from six sites within the city of Tulsa. Their only rural sampler, a few kilometers from the Observatory, was not operating. The health department also provided the Observatory with particulate weights reduced to weight per cubic meter of air filtered.

The May 19 samples were taken before the volcanic ash could reach Tulsa. The collection was made on a weekday, when particulate pollution should have been higher. The particulates measured at the six sites averaged 65 micrograms per cubic meter of air filtered. On Sunday, May 25, when particulate pollution should have been low, the particulates averaged 146 micrograms per cubic meter of air. Presumably, this larger quantity of particulates included some volcanic ash. The filters have been sent to Todd Hinkley, of the U.S. Geological Survey, for geochemical analysis. (It is known that volcanic ash did, in fact, reach Oklahoma, because Dr. Charles J. Mankin, director of the Oklahoma Geological Survey, found volcanic-glass shards during a microscopic examination of dust collected from the windshield of a car parked in Norman.)

In addition to air samples, rainwater samples from the Observatory were sent to the USGS for geochemical studies. After each rainfall, the contents collected from a two-compartment tipping-bucket rain gage were bottled and shipped to the USGS for volcanic-ash analysis.

Wichita Uplift Region Hydrogeochemical and Stream-Sediment Reports Available

The Grand Junction, Colorado, office of the U.S. Department of Energy has placed on open file "Hydrogeochemical and Stream-Sediment Detailed Geochemical Survey for Wichita Uplift Region, Oklahoma."

The report contains 161 pages plus two microfiche sheets of basic data and eight oversized plates. Uranium concentration ranges from less than 0.20 to 197.20 parts per billion in water samples and from 0.74 to 32.00 parts per million in sediments.

Copies of the report can be seen at the Oklahoma Geological Survey, 830 Van Vleet Oval, Room 163, Norman.

DOE Issues Aerial Radiometric Report

A U.S. Department of Energy National Uranium Resource Evaluation report covering 3,155.7 line miles on the Texarkana Quadrangle, which includes part of southeastern Oklahoma, has been placed on open file at the Oklahoma Geological Survey office.

The aerial survey was flown and compiled as part of a program to gather geologic and other information to aid in assessing the magnitude and distribution of uranium resources in the United States.

Volume I of the final report includes sections on instrumentation, data reduction, geology, and data analysis as well as appendixes that contain statistical data, single and average record listings, and a production summary for the Tyler, Texarkana, and Waco Quadrangles.

Volume II contains record locations; geologic maps; radiometric profiles for potassium, uranium, thorium, and their ratios; and magnetic profiles and anomaly maps for potassium, uranium, thorium, and their ratios. Separate copies of volume II are issued for each quadrangle.

The materials are available in three purchase options from GeoMetrics Inc., Attn: Robert Fowler, 395 Java Drive, Sunnyvale, California 94086.

Open-file reports can be seen at the Oklahoma Geological Survey, 830 Van Vleet Oval, Room 163, Norman.

Geographic Names Decisions Announced

The U.S. Board on Geographic Names has announced the following decisions:

Boone Creek: stream, 1.6 km (1 mi) long, heads at the junction of its East and West Branches at 35°05′56″N, 97°21′56″ W, flows S to the Canadian River 8 km (5 mi) N of Purcell; named for Captain Nathan Boone, U.S. Dragoons, who with a contingent of 87 soldiers camped along this stream on July 20, 1843; Cleveland County, Oklahoma: sec. 13, T 7 N, R 2 W, Indian Mer.; 35°05′12″ N, 97°22′14″ W.

Crystal Lakes: populated place, 5.6 km (3.5 mi) SW of Ames; Major County, Oklahoma; sec. 13, T 20 N, R 10 W, Indian Mer.; 36°12′45″ N, 98°13′25″ W. Not: Magruder.

East Branch Boone Creek: stream, 4.8 km (3 mi) long, heads at 35°08′25″ 97°21′28″ W, flows S to join the West Branch to form Boone Creek 9.7 km (6 mi) N of Purcell; Cleveland County, Oklahoma; sec. 12, T 7 N, R 2 W, Indian Mer.; 35°05′56″ N, 97°21′56″ W.

West Branch Boone Creek: stream, 5.6 km (3.5 mi) long, heads at 35°08′40″ N, 97°21′58″ W, flows S to join the East Branch to form Boone Creek 9.7 km (6 mi) N of Purcell; Cleveland County, Oklahoma; sec. 12, T 7 N, R 2 W, Indian Mer.; 35°05′56″ N, 97°21′56″ W.

NEW OCCURRENCES OF THE PETALODONTIFORM CHONDRICHTHYAN *MEGACTENOPETALUS* IN THE PENNSYLVANIAN OF OKLAHOMA AND KANSAS

Michael C. Hansen[1]

The petalodonts were a group of sharklike fishes that appeared in the Early Mississippian, reached their zenith in the Late Mississippian, and persisted with decreased diversity until the end of the Permian. Preliminary studies (Hansen, in press) indicate that 17 described genera are valid. The systematic position of the petalodonts is uncertain; with only a few exceptions, they are known by isolated teeth which are relatively common in upper Paleozoic marine rocks of North America and Europe. Teeth of petalodonts have received little attention in this century and, accordingly, the taxonomy of this group is in need of revision and its stratigraphic occurrences require analysis within a modern framework.

Perhaps one of the rarest petalodont taxa is *Megactenopetalus kaibabanus,* until recently known only by the holotype from the Lower Permian Kaibab Limestone of the Grand Canyon, Arizona (David, 1944). In recent years, several additional specimens have been discovered in the Upper Permian of Iran (Golshani and Janvier, 1974) and in the Permian of the southwestern United States (Ossian, 1976; Cys, 1977; Hansen, 1978). Two other specimens, from the Permian of China, that were named *Petalodus shingkuoi* by Young (1950; see also Liu and Hsieh, 1965) were reassigned to *Megactenopetalus kaibabanus* by Hansen (1978).

Recently, two additional specimens have come to light: one from Oklahoma, sent to me for identification by H. L. Strimple, The University of Iowa, and one from Kansas, sent to me for identification by John Chorn, The University of Kansas. These two fragmentary teeth extend the geographic distribution of *Megactenopetalus* and are the first reported occurrences of this taxon from Pennsylvanian strata.

The following report adds to the list of chondrichthyan remains recorded by Zidek (1972, 1973, 1976, 1977).

[1]Geologist, Ohio Division of Geological Survey, Columbus, Ohio 43224.

Systematic Paleontology

Class CHONDRICHTHYES

Subclass ELASMOBRANCHII

Order PETALODONTIFORMES

Family PRISTODONTIDAE

Genus **Megactenopetalus** David, 1944

Megactenopetalus kaibabanus David, 1944

(For synonymy, see Hansen, 1978)

Fig. 1

Oklahoma specimen.—SUI 33449; 1 mile east of Burbank, Osage County, Oklahoma. Red Eagle Limestone, Oscar Group, Gearyan Series, Upper Pennsylvanian. Collected by William M. Furnish.

This specimen of *Megactenopetalus kaibabanus* is reposited at the Department of Geology, The University of Iowa. It is an incomplete lower dental element that lacks a small part of the right lateral part of the crown, most of the left part of the crown, and the basal part of the attachment surface. The sharp coronal margin descends from the apex of the tooth at an angle of 30° and exhibits a narrow, even band of wear, along which the distal ends of exposed vascular canals form longitudinal striations. The orthodentine of the crown preserves a peculiar pattern of dark, narrow, horizontal bands that are more numerous lingually and are irregular in spacing (fig. $1A_1$). The origin of these bands is uncertain; however, they may be a preservational artifact formed at the sediment/water interface during successive stages of burial of the specimen. The dimensions of SUI 33449 are: labial crown height, 11 mm; maximum width (estimated), 26 mm; total height, 16 mm; height of mandibular attachment surface, 5 mm; lingual crown height, 14 mm.

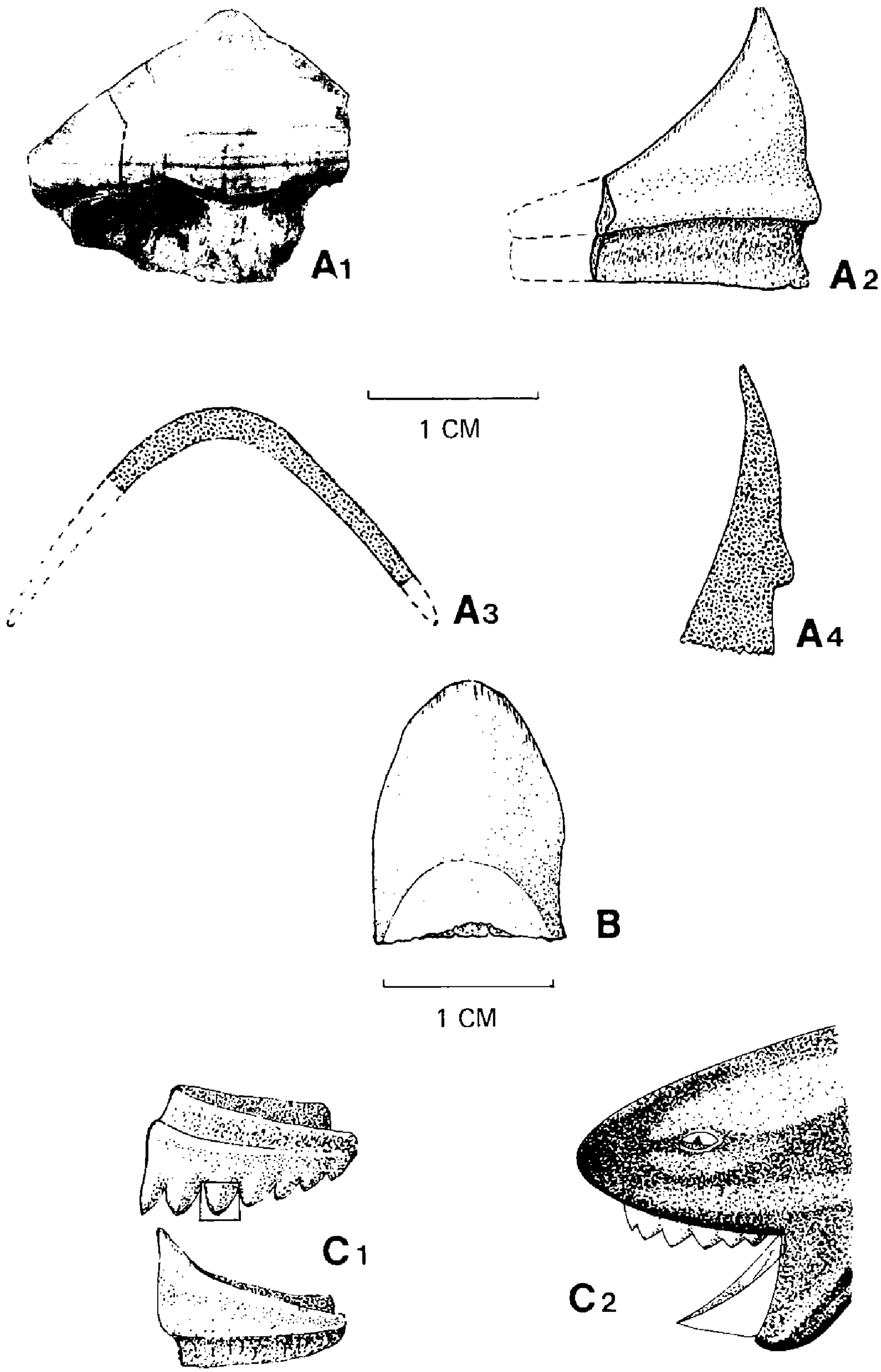
Kansas specimen.—KUVP 57433 (cast); T. 12 S., R. 18 E., SW¼ sec. 13, Douglas County, Kansas. Road cut on road just north of and parallel to I-70. Beil Limestone Member, Lecompton Limestone, Shawnee Group, Virgilian Series, Upper Pennsylvanian.

This specimen, *Megactenopetalus kaibabanus,* a cast of which is reposited in the Museum of Natural History at The University of Kansas, is a single cusp of an upper dental element, possibly the second or third cusp

Figure 1A. *Megactenopetalus kaibabanus,* lower dental element, SUI 33449, labial view (A_1), lateral view (A_2), transverse section (A_3), sagittal section (A_4). Red Eagle Limestone (Gearyan), Osage County, Oklahoma. (All figures ×2.)

Figure 1B. *Megactenopetalus kaibabanus,* cusp from upper dental element, KUVP 57433, labial view (×2). Beil Limestone Member, Lecompton Limestone (Virgilian), Douglas County, Kansas.

Figure 1C. *Megactenopetalus kaibabanus,* reconstruction of dental elements with square enclosing probable position of cusp illustrated in *B* above (C_1), reconstruction of *M. kaibabanus* (C_2) (after Hansen, 1978). Features other than dentition are purely conjectural. (×⅓).


A1
A2
1 CM
A3
A4
B
1 CM
C1
C2

from the midline on the left side of the dentition (fig. $1C_1$). This cusp shows wear along its distal margin. The length of this specimen is 15 mm, and its maximum width is 12 mm (fig. 1B). The original specimen is retained by the collector, a student at The University of Kansas.

Discussion.—The Oklahoma specimen of *Megactenopetalus* represents only the fourth known lower dental element of this rare petalodont. The dentition of *Megactenopetalus kaibabanus* was reconstructed by Hansen (1978); these single-cusped lower dental elements were associated with the better known multicusped upper dental elements. *Megactenopetalus* was a highly specialized petalodont with only a single dental element in each jaw (fig. $1C_1$, C_2).

Megactenopetalus kaibabanus is known from almost all of the Permian sequence and now, with the discovery of these specimens from Oklahoma and Kansas, can be recorded with certainty from the uppermost Pennsylvanian as well. Although the Gearyan Series has been previously regarded as Early Permian (Wolfcampian) in age, the Oklahoma Geological Survey, on the basis of palynological evidence (Shelton, 1979, p. 5–7), now places it in the Upper Pennsylvanian.

References Cited

Cys, J. M., 1977, Lectostratotype of North American Leonardian Series, Glass Mountains, West Texas: Geological Society of America Abstracts with Programs, v. 9, p. 14.

David, L. R., 1944, A Permian shark from the Grand Canyon: Journal of Paleontology, v. 18, p. 90–93.

Golshani, F., and **Janvier, Philippe,** 1974, Tooth fragment of a petalodontid fish (Elasmobranchii, Bradyodonti) from the Permian of central Iran: Geological Survey of Iran, v. 31, p. 55–61.

Hansen, M. C., 1978, A presumed lower dentition and a spine of a Permian petalodontiform chondrichthyan, *Megactenopetalus kaibabanus:* Journal of Paleontology, v. 52, p. 55–60.

———in press, Systematic relationships of petalodontiform chondrichthyans: Ninth International Congress of Carboniferous Stratigraphy and Geology, Urbana, Illinois, Proceedings.

Liu, H. T., and **Hsieh, H. H.,** 1965, The discovery of bradyodont from Yangsin Series, the Lower Permian of Liangshan, Shensi: Vertebrata Palasiatica, v. 9, p. 280–283.

Ossian, C. R., 1976, Redescription of **Megactenopetalus kaibabanus** David, 1944 (Chondrichthyes: Petalodontidae) with comments on its geographic and stratigraphic distribution: Journal of Paleontology, v. 50, p. 392–397.

Shelton, J. W., 1979, Geology and mineral resources of Noble County, Oklahoma: Oklahoma Geological Survey Bulletin 128, 66 p.

Young, C. C., 1950, Notes on the first occurrence of the order Bradyodonti in China: Science Record, v. 3, p. 243–246.

Zidek, Jiri, 1972, A review and commentary, *pt. 1 of* Oklahoma paleoichthyology: Oklahoma Geology Notes, v. 32, p. 171–187.

———1973, Elasmobranchii (*Cladodus,* minute elements of cladoselachian derivation, *Dittodus,* and *Petrodus*), *pt. 2 of* Oklahoma paleoichthyology: Oklahoma Geology Notes, v. 33, p. 87–103.
———1976, Chondrichthyes, *pt. 5 of* Oklahoma paleoichthyology: Oklahoma Geology Notes, v. 36, p. 175–192.
———1977, Addendum to part 5, Oklahoma paleoichthyology: Oklahoma Geology Notes, v. 37, p. 151–156.

WASTE DISPOSAL EFFECTS ON GROUND WATER
A REVIEW

Ginia Wickersham[1]

Waste Disposal Effects on Ground Water, David W. Miller, editor, 1980, 512 p. Premier Press, P.O. Box 4428, Berkeley, California 94704. $16.

In the past 10 years, ground water has achieved status as a major natural resource. The use of ground water is increasing at a rate of 25 percent per decade, and over half the population of the United States is now served by ground water. However, along with the recognition of ground water's importance as a major resource has come the evidence of ground-water contamination. Pollution of ground water has occurred on a local basis in all parts of the nation.

This book is a first step in the assemblage of the latest scientific facts known about ground-water contamination. It is described as a comprehensive survey of the occurrence and control of ground-water contamination resulting from waste-disposal practices. Ground-water-pollution practices delineated include: industrial-waste-water impoundments (pits, ponds, lagoons), septic tanks, waste-water sludges and effluents, oil-field brines, mine wastes, animal feedlots, and injection wells. Each of these potential pollution sources is described in detailed sections that average 40 pages in length. Each section contains a summary, description of the practice, characteristics of the contaminants, extent of the problem, technological considerations, and legal constraints on the pollution source.

For the reader who is not familiar with ground water, the book contains five sections listing the important facts of ground-water occurrence. Most noteworthy is section III, which defines the extent of ground-water usage. Texas, New Mexico, Arizona, Utah, Nevada, Kansas, and Nebraska all rely on ground water as the major source of drinking water. Oklahoma would have been included in the list of states using more ground water than surface water if the latest (1975) U.S. Geological Survey figures had been utilized by the editor. Section IV describes the geographic extent of the resource. More than one-third of the nation is underlain by aquifers capable

[1]Geologist, National Center for Ground Water Research, Norman, Oklahoma 73019.

of yielding at least 100,000 gallons per day. One of the largest aquifers is the Ogallala, which extends from Texas to South Dakota. In the text, the Ogallala is mentioned as alluvium, which is misleading; most alluvial deposits are thin, limited in width, and not as prolific as the Ogallala. How fresh ground water is contaminated is described in a simple scientific manner in section V.

The basic accomplishment of this book is that it unites in one reference many of the factors surrounding ground-water contamination. The physical and chemical sources that lead to pollution of ground water are given detailed treatment in the text. However, the discussion does not end with the technological aspects. Included also are legal, political, and economic constraints on the development of adequate ground-water-protection programs. Section XVII is entitled "State and Local Alternatives for Ground Water Quality Protection" and includes recommendations that all ground-water officials should review. The alternatives may be too simplistic for states where ground-water control is split among more than one agency—e.g., in Oklahoma, in which the State Department of Health, the Water Resources Board, the Corporation Commission, the Pollution Control Board, and the Department of Agriculture all have responsibilities for ground-water protection. However, the goal of ground-water protection should receive high priority.

This book will serve as a useful guide for those working to prevent ground-water contamination. As a reference text, the book should be on the desk of every ground-water professional, student, and regulatory official dealing on a daily basis with ground water.

STRATABOUND COPPER IN LOWER PERMIAN RED BEDS NORTH-CENTRAL OKLAHOMA

Roy Cox[1] and Zuhair Al-Shaieb[2]

A previously unreported copper deposit has been discovered in the upper Wellington Formation (Lower Permian) of Grant County, Oklahoma. This copper-sulfide occurrence is found within several thin mineralized beds in the shallow subsurface of the upper shale member of the Wellington Formation. Less distinct zinc and lead zones are also present, having a limited lateral distribution.

A zonal relationship exists between copper and zinc, with the copper zone occurring stratigraphically higher and extending deeper into the Permian Basin. Up to four distinct copper-mineralization zones can be recognized within a 250- to 320-foot interval in the uppermost part of the Wellington Formation.

A geochemical map has been prepared, based on these copper zones (fig. 1), which reveals the following: (1) the body has an irregular blanket geometry; (2) the boundaries of the body extend beyond the study area in both the down-dip (west) and strike (north-south) directions; and (3) the eastern limit is truncated by an erosion surface.

The copper anomalies occur within thin beds of fine- to medium-grained carbonates and gray-green shales. Chalcocite is the principal ore mineral and occurs in various forms: (1) fine-grained disseminations, (2) veinlet fillings, (3) irregular patches, (4) growths in carbonate vugs, and (5) replacements (pseudohexagonal and cubic morphologies) after pyrite.

The genesis of the Grant County deposit is probably related to diagenetic processes. Although a sabkha model (Renfro, 1974) is indeed plausible and has already been applied to the Midcontinent copper-shale deposits by Smith (1974), the depositional environment of the host rock cannot be clearly defined as sabkha.

As an alternative to the sabkha model, Rose (1976) proposed that cuprous chloride complexes, which increase the solubility of copper in water, may be an effective mineralization agent. Copper mineralization in north-central Oklahoma is consistent with Rose's (1976) hypothesis. The chalcocite zones of the upper Wellington form part of a major regressive sequence that is underlain by a thick wedge of evaporites and marine shales. During compaction, chloride-rich connate water formed copper complexes and mi-

[1]Phillips Petroleum Co., London, England.
[2]Department of Geology, Oklahoma State University, Stillwater, Oklahoma 74074.

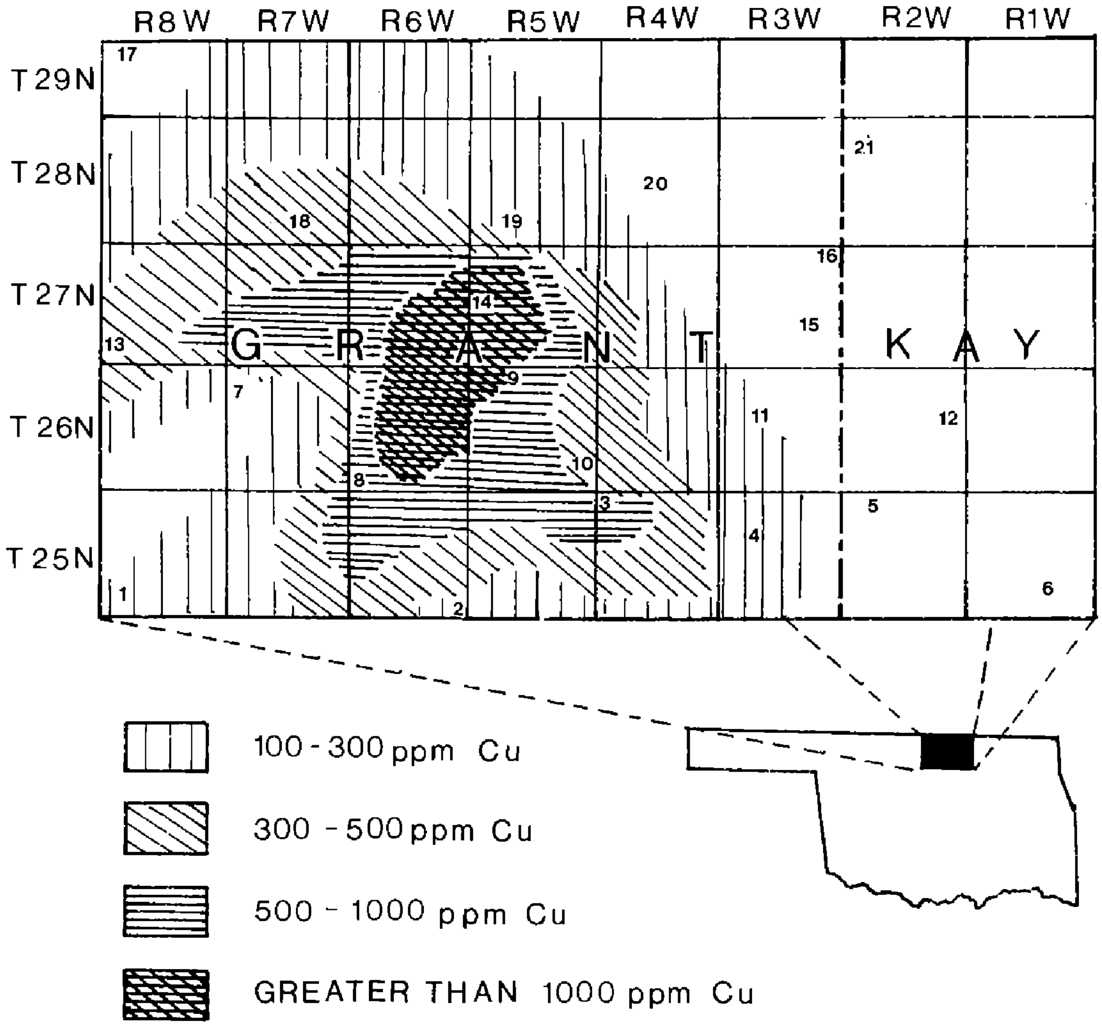


Figure 1. Copper distribution and well locations (nos. 1-21) Grant and Kay Counties, Oklahoma.

grated upward through the organic-rich and terrigenous Wellington sediments. This reducing environment caused copper precipitation as open space fillings within several beds and as replacements of organic matter and pyrite. The copper may have had its source from weathering and erosion of numerous sulfide deposits in the Ouachita Mountains (Fay, 1975).

References Cited

Fay, R. O., 1975, A possible origin for copper in Oklahoma: Oklahoma Geology Notes, v. 35, no. 4, p. 151–153.

Renfro, A. R., 1974, Genesis of evaporite-associated stratiform metalliferous deposits—a sabkha process: Economic Geology, v. 69, p. 33–45.

Rose, A. W., 1976, The effect of cuprous chloride complexes in the origin of red-bed copper and related deposits: Economic Geology, v. 71, p. 1036–1048.

Smith, G. E., 1974, Depositional systems, San Angelo Formation (Permian), north Texas—Facies control of red-bed copper mineralization: University of Texas, Bureau of Economic Geology, Report of Investigations 80, 74 p.

Volume on Carboniferous of Western U.S. Available

A publication of interest to many geologists, particularly those of Oklahoma and the surrounding region, was issued recently by the U.S. Geological Survey.

USGS Professional Paper 1110—M–DD describes surface and subsurface occurrences, historical development, geologic setting, and economic geology of Mississippian and Pennsylvanian rocks in 20 states west of the Mississippi River. The 18 summary chapters that make up the volume were contributed through arrangement with the state geologists of the area covered. Chapters were prepared by the directors of the agencies and their colleagues, by academic personnel, and by geologists working in industry.

Oklahoma's 35-page section was authored by Robert O. Fay, S. A. Friedman, Kenneth S. Johnson, John F. Roberts, and William D. Rose, of the Oklahoma Geological Survey staff, and Patrick K. Sutherland, professor in the OU School of Geology and Geophysics.

With as much as 7,000 m of Carboniferous sediments deposited in Oklahoma's basins, with Carboniferous rocks cropping out in more than half the State, and with Oklahoma's three major mountain systems formed during the Pennsylvanian, the time period represented constitutes a significant segment of Oklahoma's geologic history. Carboniferous rocks account for 60 percent of the State's cumulative production of oil and natural gas, all coal production, the lead and zinc production of northeastern Oklahoma, and much of the State's industrial-mineral production. Thus, these rocks have played a significant role in Oklahoma's economic history.

USGS Professional Paper 1110—M–DD is a companion volume to Professional Paper 1110—A–L, which covers the Carboniferous of 12 states east of the Mississippi. The project developed from a request of the permanent committee of the International Congress on Carboniferous Stratigraphy and Geology that a summary of American Carboniferous geology be prepared for the ninth session of the Congress (IX–ICC), which met in the United States in the spring of 1979. Ellis L. Yochelson, geologist with the U.S. Geological Survey and secretary-general of IX–ICC, served as coordinator for the publications.

Professional Paper 1110—M–DD, *The Mississippian and Pennsylvanian (Carboniferous) Systems in the United States,* can be ordered from Eastern Distribution Branch, U.S. Geological Survey, 604 South Pickett Street, Alexandria, Virginia 22304. The price per copy is $11.00, postpaid (in the United States). A limited number of copies of separates of the Oklahoma chapter are available from the Oklahoma Geological Survey.

The Greatest Gamblers: The Epic of American Oil Exploration

The second edition of Ruth Sheldon Knowles' *The Greatest Gamblers: The Epic of American Oil Exploration* has been published recently by The University of Oklahoma Press. Knowles, who says she "was born in the oil patch," has gained a special insight into the oil industry through her experience as a journalist, petroleum specialist, independent oilwoman, and consultant.

The Greatest Gamblers traces the industry from its beginnings in 1859 to the 1970's and the "thousands of hunters still at work." Twelve pages of photos provide a delightful look back at the industry's early days. A new last chapter and a new preface have been added to the original 1959 version of the book.

Available from: The University of Oklahoma Press, Norman, Oklahoma 73019. Price: $10.95 hardcover; $7.95 paperback.

Land Use and Land Cover and Associated Maps for Oklahoma City

This data set includes one map keyed to the USGS topographic map of Oklahoma City at 1:250,000 (1 inch = about 4 miles). The map is coded for statistical data development. The map is land use and land cover, and the set also includes one positive of the cultural base for Oklahoma City at 1:250,000. Lat 35° to 36°, long 96° to 98°.

Available from: U.S. Geological Survey, Midcontinent Mapping Center (NCIC–M), 1400 Independence Road, Rolla, Missouri 65401.

Report on Water Programs in Oklahoma

The Oklahoma City office of the U.S. Geological Survey's Water Resources Division has issued a comprehensive summary report of its water-resources activities completed and in progress during 1980.

The 128-page publication describes current programs and gives the status of projects in aquifer studies, sediment studies, water-quality investigations, flood analyses, coal hydrology and hydrologic effects of reclaiming orphaned coal-mine lands, and Watstore and Nawdex (computerized water-data storage and exchange systems). Also, the book contains a bibliography of published and open-file reports on Oklahoma hydrology issued from 1901 to the present. Numerous tables present detailed data on gaging stations.

The report, *Oklahoma—a Summary of Activities of the U.S. Geological Survey Water Resources Division for 1980,* is available on request from the U.S. Geological Survey, Water Resources Division, Room 621, 215 Northwest 3d Street, Oklahoma City, Oklahoma 73102 (phone, 405–231-4256).

USGS Water-Resources Data Reports

Water Resources Data for Oklahoma—Water Year 1978, v. 2, Red River Basin, 1979, 258 p., $15. (PB-80 143 001)

Water Resources Data for Oklahoma—Water Year 1978, v. 1, Arkansas River Basin, 1980, 531 p., $26. (PB-80 143 829)

Available from: National Technical Information Service, U.S. Department of Commerce, Springfield, Virginia 22161. When ordering, use the NTIS number in parentheses. Microfiche copies are available for $3.50.

USGS Open-File Reports

Report of the Annual Yield of the Arkansas River Basin for the Arkansas River Basin Compact, Arkansas—Oklahoma, 1979 Water-Year, by G. L. Ducret, Jr. Microfiche, $3.50; paper copy, $3.50 (80-333)

Leasable Mineral and Waterpower Land Classification Map of the Dalhart Quadrangle, Texas, New Mexico, Oklahoma, Colorado, Kansas, compiled by D. A. DeCicco, E. D. Patterson, and K. M. Robinson. One oversize sheet, scale 1:250,000 (1 inch = about 4 miles). Microfiche, 50c; paper copy, $2.25. (80-496)

Both available from: Open-File Services Section, Branch of Distribution, U.S. Geological Survey, Box 25425, Federal Center, Denver, Colorado 80225. When ordering, use full title and number in parentheses.

Colorado Geology

The Rocky Mountain Association of Geologists has recently published a 264-page volume of 23 papers on Colorado geology. Editors Harry C. Kent and Karen W. Porter have divided the book into sections on "Structural and Tectonic Framework," "Geologic History," "Resources," and "Engineering Geology."

Order from: RMAG, 1615 California Street, Denver, Colorado 80202. Price: $28.

Roadside Geology Series

Mountain Press Publishing Company of Missoula, Montana, is continuing publication of its series of guidebooks to the geology of a number of areas in the United States. Published so far are books on Colorado, Texas, Oregon, Northern California, Waterton–Glacier National Parks, and the Northern Rockies. A number of other books are scheduled for later publication.

Order from: Mountain Press Publishing Company, P.O. Box 2399, Missoula, Montana 59806. Price: $6.95 each.

Index to Water-Data Acquisition

This second volume of a planned five-volume set comprises 950 pages and lists more than 10,500 water-data-acquisition activities in parts of several states, including Oklahoma, making up the Interior Coal Province. Volume I, which covers the Eastern Coal Province, is also available. Copies of volumes I and II are available for inspection and reference at offices of the U.S. Geological Survey, Water Resources Division, and the Office of Surface Mining, U.S. Department of the Interior, serving these respective regions.

For further information, contact P. E. Ward, Office of Water Data Coordination, U.S. Geological Survey, 417 National Center, Reston, Virginia 22092.

Lithostratigraphic Analysis of Sedimentary Basins

Topics covered in this recent publication include analysis of outcrops, subsurface samples and data, physiochemical properties of rocks, and other subjects of interest as reference material for senior students and practicing earth scientists interested in sedimentary-basin analysis.

Order from: Academic Press, 111 Fifth Avenue, New York, New York 10003. Price: $39.50.

Deltaic Sand Bodies

A new AAPG publication by James M. Coleman and David B. Prior has been printed in conjunction with a short course at the recent AAPG annual meeting in Denver. The book is AAPG catalog no. 889.

Order from: AAPG, P.O. Box 979, Tulsa, Oklahoma 74101. Price: $8; 10 or more copies, $7.

USGS Names New Mapping Chief

R. B. Southard has been named chief of the newly organized National Mapping Division that was formed by the U.S. Geological Survey to map the nation and expand applications of cartographic and geographic sciences in resource management.

The National Mapping Division is one of the major divisions of the USGS and is the largest civilian land-mapping operation in the nation. With headquarters at the USGS National Center in Reston, Virginia, the Division has about 2,260 cartographers, geographers and other specialists and a budget of about $90 million per year, or 14 percent of the Survey's total budget. Regional mapping centers are operating at Reston; Rolla, Missouri; Denver, Colorado; and Menlo Park, California.

Oklahoma's Geological Societies Announce New Officers

New Officers and executive committees for the 1980–81 year have been announced by the following geological and geophysical societies in Oklahoma:

Ardmore Geological Society

President, **J. D. Garrison,** Westheimer-Neustadt Corp.
Vice-President, **Jim R. Hallett,** Quinton-Little Co.
Secretary-Treasurer, **Fred B. Jones, Jr.,** independent
Past President, **Jim R. Hallett**
Councilors: **Robert W. Allen,** independent; **Lawrence S. Morrison,** independent

Geophysical Society of Oklahoma City

President, **Clint Hutter,** Texas Pacific Oil Co.
First Vice-President, **Bill Hazelwood,** Energy Reserves Group
Second Vice-President, **Marc Pottorf,** Terra Resources Inc.
Secretary, **Peter Silkworth,** Champlin Petroleum Corp.
Treasurer, **Cliff A. Hanoch,** Union of Texas Petroleum
Past President, **B. B. (Bo) Ferrell,** Data Finders

Geophysical Society of Tulsa officers for 1980–81. Seated, left to right: John N. Gallagher, second vice-president; R. A. "Bob" Wyckoff, president; W. O. "Bill" Heap, first vice-president. Standing, left to right: M. E. "Mo" Arnold, past president; J. W. "Jim" Smith, secretary; Garry Timm, editor; John L. Blum, editor elect; Jon A. Ferris, treasurer. Not present: S. W. Fruehling, past president.

Geophysical Society of Tulsa

President, **R. A. "Bob" Wyckoff,** Conoco, Inc.
First Vice-President, **W. O. "Bill" Heap,** Seismograph Service Corp.
Second Vice-President, **John N. Gallagher,** Amoco Production Co.
Secretary, **J. W. "Jim" Smith,** Amoco Production Co.
Treasurer, **Jon A. Ferris,** Amerada Hess
Editor, **Garry Timm,** Texaco, Inc.
Editor-Elect, **John L. Blum,** Mapco Production, Inc. (1979-80)
Past President, **S. W. Fruehling,** consultant
Past President (1978-79), **M. E. "Mo" Arnold,** Amoco Production Co.
District Representatives: **R. A. Wyckoff, S. W. Fruehling,** and **M. E. Arnold**

Oklahoma City Geological Society

President, **W. P. Anderson, Jr.,** Exok, Inc.
First Vice-President, **Jerry E. Upp,** Tenneco Oil Co.
Second Vice-President, **John G. Borger, II,** Walter Duncan, Inc.
Secretary, **G. Phil Spurlin,** consultant
Treasurer, **Carol L. Kinney,** Mewbourne Oil Co.
Shale Shaker Editor, **Patricia P. Potts,** R. J. Walker Oil Co.

Oklahoma City Geological Society executive committee for 1980–81. Seated, left to right: Jim W. McHugh, Library Director; John G. Borger, II, second vice-president; W. P. Anderson, Jr., President; Jerry E. Upp, first vice-president; Harold W. Hanke, presidential appointee. Standing, left to right: G. Phil Spurlin, secretary; Gary W. Hart, past president; Carol L. Kinney, treasurer; Patricia P. Potts, *Shale Shaker* editor; John V. Hogan, presidential appointee. Not present: Jake L. Hamon, presidential appointee.

Tulsa Geological Society officers for 1980–81. Front row, left to right: Kenneth E. Proctor, treasurer; Edward D. Pittman, president; Roger Berg, councilor. Middle Row, left to right: Richard W. Behling, second vice-president; Lyle G. Bruce, councilor; J. Glenn Cole, past president. Back row: Susan P. Ennis, councilor; Peter M. Duggan, secretary; Dan R. Schenck, first vice president. Not present: Norman J. Hyne, editor; James E. Cunliffe, newsletter editor.

Library Director, **Jim W. McHugh,** consultant
Social Chairmen, **John V. Hogan** and **Jake L. Hamon**
Public Relations Chairman, **Harold W. Hanke,** consultant
Past President, **Gary W. Hart,** independent

Tulsa Geological Society

President, **Edward D. Pittman,** Amoco Production Co.
First Vice-President, **Dan R. Schenck,** Cities Service Co.
Second Vice-President, **Richard W. Behling,** consultant
Secretary, **Peter M. Duggan,** Texaco, Inc.
Treasurer, **Kenneth E. Proctor,** consultant
Editor, **Norman J. Hyne,** University of Tulsa
Newsletter Editor, **James E. Cunliffe,** Cities Service Co.
Past President, **J. Glenn Cole,** Amcana Oil Corp.
Councilors: **Roger Berg,** Phillips Petroleum Co.; **Susan P. Ennis,** Amoco Production Co.; **Lyle G. Bruce,** Essex Exploration Co.

Three Oklahomans Among AAPG's New Leaders

Myron K. Horn, Cities Service Co., Tulsa, is serving the second year of a 2-year term as editor for The American Association of Petroleum Geologists.

Other members of AAPG's 1980–81 executive committee are Robey H. Clark, Diamond Shamrock Corp., Amarillo, Texas, president; Frank W. Harrison, Jr., consulting geologist, Lafayette, Louisiana, president-elect; E. F. (Bud) Reid, Sunburst Exploration, Bakersfield, California, vice-president; Donald R. Boyd, Edwin L. Cox Co., Corpus Christi, Texas, secretary; John S. Runge, consulting geologist, Casper, Wyoming, treasurer; and H. Victor Church, consulting geologist, Bakersfield, California, chairman of the House of Delegates.

S. A. Friedman, senior coal geologist with the Oklahoma Geological Survey, has been named vice-president of AAPG's Energy Minerals Division for 1980–81. Other EMD officers are John A. Pederson, U.S. Geological Survey, Lakewood, Colorado, president, and Robert L. Fuchs, GeoSystems Corp., Westport, Connecticut, who is serving his second year of a 2-year term as secretary-treasurer.

George R. Bole, Amoco Production Co., Tulsa, has been elected secretary-treasurer of the association's Division of Professional Affairs. Serving with him in the DPA are Jerome J. C. Ingels, ERGCO, Dallas, president, and Charles A. Brinkley, Maralo, Inc., Houston, vice-president.

With more than 25,000 members, AAPG has now strengthened its hold as the world's largest organization of geologists.

New Theses Added to OU Geology Library

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

A Numerical Analysis of Fistulipora *(Bryozoa) from the Henryhouse Formation (Silurian) in Southcentral Oklahoma,* by John William Bartley. 78 p., 5 figs., 7 tables, 1979.

The Misener Sandstone in Portions of Lincoln and Creek Counties, Oklahoma, by Paul Edward Bauernfeind. 72 p., 10 figs., 15 pls., 3 tables, 1980.

Subsidence and Thermal History of the Southern Oklahoma Aulacogen, by Shimon Feinstein. 84 p., 17 figs., 1 table, 1979.

Mineral Dispersal Patterns in the Pierre Shale, by Richard Lewis Jones. 270 p., 50 figs., 33 tables, 1979 (Ph.D. dissertation).

Near-Surface Seismic Properties for Permian Rock Formations at Selected Sites in Oklahoma, by Muharrem Türkarslan. 78 p., 23 figs., 13 tables, 1979.

A Gravity and Magnetic Study of the Medford Anomaly, North-Central Oklahoma, by Donald J. Santiago. 105 p., 33 figs., 1979.

Upper Eocene–Lower Miocene Planktonic Foraminiferal Biostratigraphy of Wells JS 25-1 and JS 52-1, Offshore Eastern Java, Indonesia, by Miguel K. Graetzer. 112 p., 12 figs., 6 pls., 4 tables, 1980.

Significance of Silicified Carbonate Rocks Near the Devonian–Mississippian Boundary, Ouachita Mountains, Oklahoma, by Carolyn D. Murgatroyd. 65 p., 26 figs., 6 pls., 1980.

OKLAHOMA ABSTRACTS

AAPG–SEPM–EMD Annual Meeting Denver, Colorado, June 8–11, 1980

The following abstracts are reprinted from the May 1980 issue, v. 64, no. 5, of the *Bulletin* of The American Association of Petroleum Geologists. Page numbers are given in brackets below each abstract. Permission of the authors and of Myron K. Horn, AAPG editor, to reproduce the abstracts is gratefully acknowledged.

Fresh Look at Some Ouachita Problems

J. KASPAR ARBENZ, Shell Oil Co., Houston, Texas 77001

Numerous new geologic and geophysical data collected in recent years in the Ouachita province by industry, government, and academic institutions allow an updated synthesis of events that shaped the southern margin of North America in the Paleozoic.

Some new key observations include: (1) radiometric data indicate both Devonian and late Paleozoic metamorphic events affected the core areas of the Ouachita Mountains; (2) long-suspected pre-Desmoinesian orogenic uplift that supplied detritus into the foreland basins of the Ouachita system is well displayed on seismic data and has been confirmed by the drill. Weakly deformed Desmoinesian and younger, shallow marine to continental successor basin sediments overlie with angular unconformity the folded and

---

OKLAHOMA ABSTRACTS is intended to present abstracts of recent unpublished papers relating to the geology of Oklahoma and adjacent areas of interest. The editors are therefore interested in obtaining abstracts of formally presented or approved documents, such as dissertations, theses, and papers presented at professional meetings, that have not yet been published.

thrusted Ouachita facies rocks beneath the Gulf coastal plain as far south as the Sabine uplift; (3) high-quality field work, especially in Arkansas, has yielded ample data that support a polyphase deformation in the core areas of the Ouachita Mountains. Movements consisted of at least one north-vergent thrust and fold phase primarily of Pennsylvanian age. Initial folding and thrusting were followed (probably in Permian time) by a south-vergent overturning of previous geometries, additional folding and thrusting, and the development of north-dipping cleavage; and (4) plate tectonic reconstructions of the opening and closing of the Iapetus Ocean and the formation and breakup of Pangea have added to the understanding of the events that led to the origin of the Ouachita system. Nevertheless, big data gaps remain. [670]

Promising Morrow Sandstone Discoveries in Southeastern Colorado

LOREN E. AVIS and D. R. BOOTH, Texas Oil & Gas Corp., Denver, Colorado

Eight new Morrow oil and gas fields have been discovered in southeastern Colorado during the past two years. The latest discovery resulted in a well flowing oil from a Morrow sandstone at an initial rate of 700 bbl of oil per day and 750 Mcf of gas per day. The trapping mechanism in this well, as in most, is a stratigraphic and structural combination.

The depositional history of Morrow sandstones in southeastern Colorado was strongly influenced by regional tilt into the Anadarko basin, established at the close of Mississippian time. Mississippian rocks were subject to truncation in the area of the Las Animas arch and development of karst topography on the erosion surface. Transgression of the sea from the southeast in Morrowan time resulted in the deposition of a sandstone and shale sequence.

The Morrow series consists of a basal transgressive sandstone member (Keyes sandstone) overlain by at least three sandstone units deposited during regressive pulses in an overall transgressive sequence. These Morrow sandstones generally trend from northwest to southeast toward the Anadarko basin; their source is inferred to have been the ancestral Rocky Mountain uplift for the upper sequence and the Amarillo uplift for the basal Keyes member. The environment of deposition appears to have been fluvial delta plains and associated tidal channels which were alternately created and destroyed by regression and transgression of the Morrowan seas. Distribution of these elongate sandstones is generally erratic and meandering; individual sand bodies have an estimated width of up to 1 mi (1.6 km) and a maximum thickness of 42 ft (12.8 m).

The nature and distribution of these sandstones leave many areas essentially unexplored. Southeastern Colorado has had substantial Morrow discoveries which justify a closer look at the area. [672-673]

Distribution and Alteration of Ogallala Volcanic-Ash Deposits and Their Possible Relation to Uranium Mineralization in Western Oklahoma

SALMAN BLOCH and KENNETH S. JOHNSON, Oklahoma Geological Survey, Norman, Oklahoma 73019

Diagenesis of the Ogallala (upper Miocene-Pliocene?) and Pearlette (Pleistocene?) rhyolitic volcanic ash in western Oklahoma was studied. The Ogallala ash ranges from relatively fresh to highly altered. Chemical changes during its devitrification are characterized by a loss of silicon, sodium, potassium, and uranium, and addition of magnesium to the ash. The thorium to uranium ratios range from 4:1 to 10:1 for relatively unaltered ash to 16:1 to 64:1 for the highly altered ash. The average loss of uranium due to devitrification is greater than 3 ppm. Migration of the released uranium in the alteration system was made possible by carbonate complexing agents.

Study of the Ogallala Formation in the high plains and equivalent formations in the Gulf coastal plain indicates that these strata originally were widespread over most of Oklahoma but that the sediments were removed from all but the western part of the state during late Pliocene-Pleistocene erosion. The volcanic-ash beds that had existed in the eroded Ogallala are a potential source for some of the uranium occurrences.

Analyses of the Pearlette ash did not disclose any alteration trends or a downward decrease in the uranium concentration. The uranium content of the Pearlette is significantly higher than that of the altered Ogallala ash. The minimum ash of the Pearlette is 0.6 m.y. which suggests that efficient release of uranium from volcanic glass, at least in some examples, is not a geologically contemporaneous process. [677–678]

Subsidence and Thermal History of Southern Oklahoma Aulacogen—Implication for Petroleum Exploration

SHIMON FEINSTEIN, The University of Oklahoma, Norman, Oklahoma 73019; WILLIAM E. HARRISON, Oklahoma Geological Survey, Norman, Oklahoma 73019; THOMAS L. THOMPSON, The University of Oklahoma, Norman, Oklahoma 73019.

Evolution of the southern Oklahoma sedimentary basin has been constructed from the stratigraphic record in deep wells, using the backstripping method, and by analysis of the rate of subsidence. For this analysis, rate of subsidence has been considered a significant recorder of the cumulative effect of the factors which control basin subsidence. Similarity of subsidence curves constructed in this study to other models indicates, in general, the application of the concept of thermally-controlled isostatic subsidence for the evolution of the southern Oklahoma basin.

Two distinct mechanisms of subsidence are proposed for the evolution of the basin. First, elastic flexure of the lithosphere controlled the initial 20 m.y. of subsidence. Second, reactivation of aulacogen boundary faults may account for differential subsidence.

An anomaly in the rate of subsidence curve suggests a short phase of sediment compaction and fluid migration near the termination of the subsidence stage. This compaction might be a sensitive indication of change in the state of stress from extension to compression, possibly related to the regional tectonic setting. [705]

Depositional and Tectonic Evolution of a Basement-Bounded, Intracratonic Basin, Palo Duro Basin, Texas

C. ROBERTSON HANDFORD, MARK W. PRESLEY, and SHIRLEY P. DUTTON, Bureau of Economic Geology, The University of Texas at Austin, Texas, 78712

Continental collision along the southern margin of the North American continent during Pennsylvanian time created northwesterly directed compressional stress that was transmitted to the continental interior along boundary faults of the southern Oklahoma and Delaware aulacogens. As a result, numerous basins and uplifts were formed in the aulacogens and edges of the craton, including the Anadarko, Delaware, Midland, and Palo Duro basins, the Amarillo-Wichita uplift, Matador-Red River arch, and Central Basin platform.

The Palo Duro basin is a basement-bounded, or yoked, shallow intracratonic basin filled largely with Pennsylvanian and Permian strata. Its tectonic-depositional history may be divided into four stages: (1) formation of the basin between basement blocks (Matador arch, Amarillo uplift) that were uplifted along boundary faults of the southern Oklahoma aulacogen during Early Pennsylvanian time, and subsequent deposition of basement-derived, fan delta "granite wash" around uplifts flanking the basin; (2) planation and burial of uplifts through Early Permian time, and infilling of the deep basin with shelf-margin carbonate and basinal facies; (3) encroachment of continental red-bed facies from sources in New Mexico and Oklahoma and deposition of thick Middle to Upper Permian marine evaporites in sabkha environments; (4) marine retreat during Late Permian time and development of a Triassic lacustrine basin brought about as a result of continental rifting and drainage reversal. [717]

Petroleum Geology in 1980's

JOHN D. HAUN, Colorado School of Mines, Golden, Colorado 80401

At no time in the history of petroleum geology has the need for marshaling our scientific knowledge and professional skill been more necessary than it is today. As a result of the mature stage of development in most

United States petroleum-producing areas and recent concentration on close-in exploration targets, the barrels of oil equivalent (BOE) discovered per foot of newfield wildcat drilled has declined from 350+ in the late 1940s to 53 in the late 1970s.

If the decline in discovery per unit of drilling continues, and approximately the same rate of drilling is maintained, by 1990 the discoveries per foot in newfield wildcat wells are projected to be 24 BOE. If the rate of exploratory drilling is increased in the early 1980s, the discovery rate will decline more drastically.

Our knowledge of oil and gas source materials, source-bed maturation, mechanisms and time of primary migration has expanded greatly during past decades and new insights will be added in the 1980s. Stratigraphic and sedimentational concepts, methods of identifying depositional environments, tectonic and structural principles, and details of geologic history will continue to play prominent roles in our intensive probing of the frontiers of geologic knowledge. Pressure-temperature relations, origins of abnormally high or low pressures, and the delineation of hydrodynamic versus hydrostatic conditions have become increasingly important in understanding trap formation; more precise measurements and interpretation are essential in future exploration.

The role of the geologist in interpreting geophysical measurements, especially in seismic stratigraphy and mechanical logs, will grow in importance. Knowledge of the principles of petroleum geology will continue to be important in oil- and gas-field development, in enhanced recovery, and in uranium, coal, geothermal, and tar-sands exploration or exploitation.

With these increasing complexities and the resulting professional opportunities, it is unfortunate that so few universities have a meaningful program specifically designed for educating petroleum geologists. The developing surplus of bachelor-level geology graduates probably will be followed in the late 1980s by a shortage, i.e., another supply/demand cycle. The opportunities for advanced-degree graduates probably will continue during this decade and the energy crisis should guarantee a long and exciting professional career.

The intense search for non-Arab, non-OPEC oil-producing areas in the world will continue. The present 28/1 reserves/production ratio of world oil probably will not decline rapidly as long as OPEC nations restrict production to levels significantly below capacity. Other nations with recently expanded oil-production capacity may choose also to maintain moderate export levels. High import prices, supply insecurity, and balance-of-payments problems will keep extreme pressure on production of domestic oil and gas, coal, atomic energy, hydroelectric power, synthetic fuels, and other energy alternatives. In addition, strong compulsory conservation measures probably will be imposed. Rapidly rising leasing, exploration, and production costs and their relation to wellhead prices (minus tax) may result in a deterrent to U.S. oil and gas production.

The outcome of environmental, political, and economic constraints on domestic energy production is more problematic than are the scientific and technologic questions. Three-fourths of our oil and gas reserves and production are in giant fields. Most future discoveries of large fields will be in the frontier areas, largely offshore and in Alaska. National energy policy should encourage exploration in frontier areas, in addition to conservation and development of other energy sources. [720-721]

Paleogeography of Eustatic Model for Deposition of Mid-Continent Upper Pennsylvanian Cyclothems

PHILIP H. HECKEL, The University of Iowa, Iowa City, Iowa 52242

The hypothesis that eustatic sea level changes formed Upper Pennsylvanian cyclothems in Mid-Continent North America has been supported by recent documentation of many episodes of Mississippian through Permian glaciation in Gondwanaland. Changes in Mid-Continent paleogeography and sedimentation during a single eustatic advance and retreat are described in 6 phases. (1) At maximum transgression, deep water promoted development of a thermocline, quasi-estuarine circulation, and upwelling, all leading to widespread deposition across the Mid-Continent of phosphatic black shale, which graded in shallower peripheral areas to gray marine shale and carbonates. (2) Progressive shallowing during early regression destroyed the thermocline, restored bottom oxygenation, and caused deposition of gray shale, and then algal-skeletal calcilutite. Deltas began prograding from Oklahoma and the Appalachians, and shoreline carbonates began prograding southward from the Dakotas. (3) During late regression extensive shoal-water calcarenites developed over most of Kansas, carbonate shoreline facies prograded into southern Nebraska and Iowa, and deltas of Appalachian origin prograded across Illinois. (4) At maximum regression, the sea was confined to the deep basins of west Texas and Oklahoma. Karst, caliche, and residuum developed on the exposed carbonate terrane to the north. The extensive deltaic deposits to the east underwent channeling alluviation, and soil formation. (5) Expansion of the sea during early transgression restored shoal-water calcarenite deposition across western Kansas, caused gray shale deposition in embayments and lagoons along the inundated deltaic terrane to the east, and impounded Appalachian-derived streams flowing westward across the immense alluvial plain to form widespread coal swamps in Illinois. (6) During late transgression deeper seas restored skeletal calcilutite deposition across the Mid-Continent, caused marine shell accumulations over coals in Illinois, and shifted coal swamp formation eastward into the Appalachian region. [721]

Recent Advances in Helium Analysis as Exploration Tool for Energy "Deposits"

G. M. REIMER, A. A. ROBERTS, and M. E. HINKLE, U.S. Geological Survey, Denver, Colorado 80225

Recent research by the U.S. Geological Survey demonstrates that helium-gas analysis of waters and soils holds great promise as a cost-effective exploration technique for uranium, oil and gas, and geothermal energy sources. The technologic advances include assembling a helium analyzer, almost entirely from commercially available equipment, and packaging the equipment into a mobile laboratory capable of performing as many as 100 analyses a day at a field location. Helium is an attractive indicator element for many exploration programs because of its unique properties: it is highly diffusive, chemically inert, radioactively stable, and not produced or affected by biologic activity. Many associations of helium with uranium have been observed, in which helium is produced by natural radioactive disintegration; with oil and gas, where helium is trapped by structural and stratigraphic features; and with hot-water geothermal systems, in which the cooling and reduced pressure of rising water causes dissolved helium to be released. The following are examples of distinctive helium anomalies found associated with energy "deposits": for uranium, the Ambrosia Lake district, New Mexico; for oil and gas, the Cement oil field, Oklahoma, and the Cliffside gas field, Texas; and for geothermal, the East Mesa known geothermal resource area in the Imperial Valley, California. With respect to an ambient air background of 5.24 ppm helium, the highest observed concentrations of excess helium in soil and soil gas were typically 0.5 ppm for uranium, 10 ppm for oil and gas, and 100 ppm for geothermal; water samples usually had several hundred parts per million helium for all types of energy deposits. Helium analysis can be used as a rapid and inexpensive reconnaissance tool and as complementary support for other geophysical and geochemical prospecting techniques. [771]

Oswego Limestone, Aline-Lambert Fields, Oklahoma—Source, Reservoir, and Trap

BURR A. SILVER, BERNIE B. BERNARD, and TIMOTHY DREXLER, The University of Oklahoma, Norman, Oklahoma 73019

The unitized Aline-Lambert field covers about 150 sq mi (241 sq km) in Alfalfa County, Oklahoma. Aline field produces oil from two or more porous zones in the Oswego Limestone whereas the Lambert field produces primarily gas but locally contains a thin oil column. Porous and permeable zones are discontinuous in this gas-solution drive reservoir. Gas-water and oil-water contacts in the field drop to the southeast at about 20 to 45° in the direction of regional dip. The trap is a porosity pinch-out.

The Oswego Limestone is composed of intercalated mudstones, wackestones, and packstones that range in thickness from 30 to 40 m. Maximum production in the field is from wells that penetrate a complex system of phylloid algal mounds. Distribution of the mounds is controlled by a break in slope from shallow shelf waters into a deeper water, northeast-trending embayment. Porosity values within the field range from 6 to 12%; permeabilities vary from 2 to 300 md. Porosity and permeability in nonproducing wells in the area average 5% and 4 md. Five stages of cementation and partial dissolution have been recognized. Texture and isotopically light carbon values of the later stage cements suggest that they were in part formed during biochemical degradation of organics.

Initial correlation of hydrocarbons produced from the reservoir suggests that the Oswego was the source. Samples of the Oswego, juxtapositional strata, and oil and gas were processed and analyzed chromatographically for correlation studies. Organic extraction schemes involved the standard separation of alkane and aromatic fractions by column chromatography. Hydrocarbon fractions were analyzed by gas chromatography using glass capillary columns and flame ionization detection. In addition, total organic-carbon percentage in rock samples was determined by combustion and the resulting carbon dioxide was analyzed for its carbon isotopic composition. The resulting $\delta^{13}C$ values suggest a relation between indigenous organic matter and the later stage cements. [784]

United States Province Overviews

JOHN STOUT and RETA BRADLEY, Petroleum Information, Denver, Colorado 80202

Basin folios which compile computerized well data, updated biannually, serve as a ready reference in the event of a new discovery.

Folios are available for the following basins: Appalachian, Arkoma, Black Warrior, Denver-Julesburg, Bend–Fort Worth–Strawn, South Georgia–North Florida, Great Basin and Range, Green River, Overthrust, Powder River, San Juan, Williston, and Lower Great Lakes.

In each folio is a list of exploratory wells with basic information and geologic tops, including a statistical analysis of formations penetrated in the basin. Additional statistics include the discovery-success percentage and hydrocarbon shows tabulated by formation name. An index map shows the states and counties included in the geologic province accompanied by a computer-posted and contoured map to represent the productive horizon of the basin. A thickness or structural datum corrected to sea level is given with each control point. [789]

Anticipating Coal Mining Problems in Hartshorne Formation, East-Central Oklahoma, Using Sedimentary Facies Analysis

DAVID W. HOUSEKNECHT, University of Missouri, Columbia, Missouri 65201; ANTHONY T. IANNACCHIONE, U.S. Bureau of Mines, Pittsburgh, Pennsylvania

A study of sedimentary facies associated with the Hartshorne coal beds of east-central Oklahoma provides an opportunity for preventive planning to minimize mining problems.

Sedimentary facies within the Hartshorne formation include delta distributary sandstones and interdistributary bar-fill shales, siltstones, and sandstones. One distributary channel sandstone body displays a "shoestring" geometry, over 12 mi (19.2 km) long and 1 mi (1.6 km) wide, with an average maximum thickness of 200 ft (61 m). This sandstone rests directly on and locally replaces the Lower Hartshorne coal bed. Three major mining problems are related to this sandstone body: (1) the Hartshorne sandstone in this area is a natural gas reservoir which might emit gas into adjacent coal mines; (2) the sandstone body is directly related to local discontinuities and rolls in the Lower Hartshorne coal bed; and (3) an unstable roof may be locally associated with trough cross-bedding and jointing near the base of the sandstone, and with facies changes and slickensides along the lateral margins of the sandstone body.

In contrast to this sandstone body, interdistributary bay deposits, because of their relative homogeneity and lateral persistence, do not present potential facies-related mining problems. Potential mining problems associated with these facies are local and are directly related to structural and stress-release features which are difficult to predict in advance of mining.

To insure safe and economic coal production from the Hartshorne formation, the distribution of major sandstone bodies overlying the coal beds must be considered when planning degasification programs and shaft, slope, and main entry locations. [724-725]

Oil Production from Fractured Cherts of Woodford and Arkansas Novaculite Formations, Oklahoma

LAWRENCE S. MORRISON, Lamima Corp., Ardmore, Oklahoma 73401

The chert section of the Woodford Formation has been known to be productive of oil and gas for at least 30 years. However, little was known about the chert as a reservoir until 1969 when Jones and Pellow Oil Co. and Westheimer-Neustadt Corp. jointly developed the Northeast Alden pool extension in T. 7 N., R. 13 W., Caddo County, Oklahoma. Cores, thin sections, X-ray analyses, and combustion tube studies indicate that the Woodford Chert is a prime-source bed for hydrocarbons, and when fractured is an excellent reservoir.

In February 1977, Westheimer-Neustadt Corp. drilled the No. 1 Wallace in Sec. 2, T. 8 S., R. 5 E., to test the Arkansas Novaculite, which is similar to the Woodford Chert, and completed the well for a potential flow of more than 1,000 bbl of oil per day. The significance of the discovery has not been fully realized by industry in that it may have opened a new petroleum province in the Ouachita facies that extends from southeastern Oklahoma in a broad arch for over 600 mi (966 km) to the Marathon Mountains near the Mexican border. [754]

Student Papers from AAPG Annual Meeting in Denver

The following abstracts are reprinted from a program listing of student papers that were presented in the student paper contest session at the 1980 AAPG–SEPM–EMD annual meeting in Denver. Page numbers are given in brackets below each abstract. Permission of the authors and of Myron K. Horn, AAPG editor, to reproduce the abstracts is gratefully acknowledged.

Structural Mechanisms and Oil Accumulation along the Wayne Fault, South Central Oklahoma

TYRRELL CHARLES AXTMANN, The University of Oklahoma, Norman, Oklahoma 73019

The west-northwest trending Wayne Fault in the Criner–Payne–East Lindsay Area of Oklahoma is being examined to determine the timing and type of movement associated with the formation of the Wayne and related faults. Patterns of oil fields and subsurface faults suggest that left-slip wrench faulting has occurred in this area with structural overprinting caused by the formation of the Nemaha Ridge, Pauls Valley Uplift and Anadarko Basin. The formation of all these features are related. Possible piercement features on either side of the Wayne Fault will be used to determine the amount of offset along the fault zone through time and to aid in a more complete understanding of the timing of the faulting. Pressure information from Simpson drill-stem tests will be examined to locate the underpressure–normal pressure boundary described by Powley (1979). Understanding of the timing, type and amount of movement along the Wayne Fault may lead to an explanation for the pressure boundary. Knowledge of movement along the Wayne Fault, when combined with demonstrated left-slip displacement along the Washita Valley Fault (Carter, 1979) and Washita Valley Fault system (Tanner, 1967), will allow for a more comprehensive picture of the evolution of the Southern Oklahoma Aulacogen. [6]

The Diagenesis and Environments of Deposition of the Oswego Limestone, Aline-Lambert field, Alfalfa and Grant Counties, Oklahoma

TIMOTHY DREXLER, The University of Oklahoma, Norman, Oklahoma 73019

The Aline-Lambert field is located in Alfalfa and Grant Counties in northwestern Oklahoma. The field produces oil and gas from two or more zones in the mid-Pennsylvanian Oswego Limestone. The porosity and permeability in these zones are highly variable and discontinuous. The trap is a porosity pinchout and gas-water and oil-water contacts are unpredictable.

The productive zones in the Oswego Limestone are located in the transgressive limestone elements of cyclothems. These are analogous to the cyclothemic sequences that typify the midcontinent during mid-Pennsylvanian time. Core analysis indicates a generally quiet water to subaerially exposed nature. The limestones are composed of mudstones, sparsely to abundantly fossiliferous wackestones and packstones and a few thin grainstones. These carbonate units are interbedded with thin coals, marls, siltstones, fossilferous gray shales and fissile nonfossiliferous black shales.

Diverse cement mineralogies and diagnetic processes form the complex history of the Oswego Limestone. Marine and meteoric phreatic as well as vadose textures have been preserved. Cements include calcite, ferroan calcite, anhydrite and ferroan dolomite. [6]

Significance of Silicified Carbonate Rocks near the Devonian–Mississippian Boundary, Ouachita Mountains, Oklahoma

CAROLYN D. MURGATROYD, The University of Oklahoma, Norman, Oklahoma 73019

The Ouachita Foldbelt extends from western Arkansas, through southeastern Oklahoma, south then west through Texas into the Marathon Region of southwestern Texas. Plate tectonic models of the Ouachita Mountains suggest that these sediments were deposited in a remnant ocean basin with the North American craton to the north and an arc-trench system to the south. A thin (2-5m thick) carbonate unit which has been partially replaced by silica occurs near the contact of the Arkansas Novaculite of Devonian-Mississippian age and the overlying Stanley Formation of Mississippian age in the area of Broken Bow, McCurtain County, Oklahoma. There has been a controversy concerning the origin of bedded chert as to whether it is deep versus shallow water. A shallow or deep water origin of the carbonate unit could be significant in interpreting the tectonic history of the region. The study was conducted to determine the distribution, thickness, and depositional history of the carbonate in relation to the tectonic history of the Ouachita Mountains. Field work and measured sections concentrated around McCurtain County, Oklahoma, with reconnaissance work done in Oklahoma and Arkansas. Petrographic and thin section studies were done on selected samples from the measured sections.

The carbonate unit near Broken Bow, Oklahoma, was found to be partially silicified limestone. The preserved limestone was a recrystallized packstone or grainstone; grains included fine to medium crystalline echinoid fragments in various stages of alteration, broken mollusk fragments, and minor amounts of brachiopods, forams, and unrecognizable fragments. The cement was irregularly crystalline, clear neomorphic sparry calcite; when stained with alizarin red, the cement appeared to be ferroan calcite. Silicification began at random locations in the carbonate; extensive silicification resulted in a rock with a chert matrix and 15-25% irregular to rhombic isolated crystals of sparry calcite.

Trace amounts of detrital quartz silt and authigenic euhedral quartz was also seen in the carbonate; detrital andesine plagioclase (up to 5% of the rock) and quartz grains were in various stages of replacement by calcite. Outside of the area around Broken Bow, the unit was a porous, soft chert with 20-25% voids where carbonate had been leached out by weathering. The unit thinned to the north and west in McCurtain County and regionally in Oklahoma and Arkansas; it was not seen outside of McCurtain County in Oklahoma or along the northern Ouachita Mountains in Arkansas. The unit is suggested to be a carbonate debris flow deposited in an arc-trench system of a mid-Paleozoic southward-dipping subduction zone. A suggested southern source for the carbonate is consistent with a southern source suggested for the lower Stanley Formation (Niem, 1977). Presence of detrital plagioclase may represent volcanic activity to the south which is consistent with a similar interpretation for the origin of the lower Stanley rhyodacitic tuff beds (Niem, 1977). [8-9]

Correlation of Landsat Lineaments with Basement Structure and Earthquake Epicenters in Oklahoma

ROBERT C. SHOUP, The University of Oklahoma, Norman, Oklahoma 73019

Lineaments produced by natural features of the earth's surface as viewed by remote sensors are often interpreted as expressions of subsurface geologic control. This interpretation may not always be correct as lineaments can also be produced by other features not related to geologic control.

Using a rotational linear enhancement technique, a lineament map will be constructed for north-central Oklahoma. A prominent lineament will be selected and both the subsurface and the surface will be mapped to demonstrate geologic control. Computer classification techniques will be employed to determine if the computer can be trained to locate other lineaments related to subsurface control. The locations of those lineaments will then be compared to the locations of Oklahoma earthquake epicenters to determine if a significant correlation exists. [13]

Environmental Pollutant Management Case History: Oil Well Production Pollution in the George M. Sutton Urban Wilderness, Section 20, Township 9 North, Range 2 West, Cleveland [County], Oklahoma

SUSAN L. SMITH, The University of Oklahoma, Norman, Oklahoma 73019

The George M. Sutton Urban Wilderness is located on 160 acres of undeveloped land in Norman, Oklahoma. The land was owned by the State Hospital until 1978 when it was bought by the State and leased to the Oklahoma Parks and Recreation Department for use as an Urban Wilderness. From November, 1978, until August, 1979, Oklahoma regulatory agencies (Oklahoma Pollution Control Board and Oklahoma Corporation Commission) received complaints of pollution by an oil well located in the urban wilderness. The oil well (State Hospital #1) produces from the Oil Creek Formation, an Ordovician sand from the Simpson Group. Current production is approximately 8-10 BPD of oil and 200 BPD salt water. Most problems were related to salt water production leakage, presence of an old earthen evaporation pit, and small oil spills. Salt water disposal was accomplished by injection into a disposal well. Oil field brines and oil cause several environmental problems including corrosion, scale deposition, pollution of ground-water, poisoning of fish, and impaired growth in vegetation. Resolution of the problem involved several parties with conflicting points of view, such as Oklahoma regulatory agencies, local government, municipal planning committees, the operators of the well, environmental groups, and members of the press. [14]

Society for American Archaeology Annual Meeting
Vancouver, British Columbia, April 23–25, 1979

The following abstract is reprinted from the April 1979 issue of *Program and Abstracts* of the Society for American Archaeology, 44th Annual Meeting, which was held in Vancouver, British Columbia. Page numbers are given in brackets below each abstract. Permission of the author, and of the Society, to reproduce the abstract is gratefully acknowledged.

Pollen Evidence for Late Holocene Environments in the Southern Plains

STEPHEN A. HALL, North Texas State University, Denton, Texas 76201

The numerous attempts to obtain pollen sequences from late Holocene archaeologic sites in the Southern Plains have resulted in dated pollen

diagrams from only three sites, all in northeastern Oklahoma. The pollen record from these sites, representing the time interval A.D. 300 to 1250, indicates an oak forest vegetation such as exists at these localities today. Increased hickory pollen frequencies during the period A.D. 400 to 1050, with maximum hickory abundance occurring about A.D. 600, may reflect a period of more moist climate. The decline of hickory beginning A.D. 600 shows a return to drier conditions, a climatic trend that may have persisted to the present. Dated pollen records from both archaeologic and non-archaeologic sites in the Southern Plains are essentially absent for the time periods A.D. 1300 to present and 3000 B.C. to A.D. 300. [45]

Geophysical Observatory Establishes Continuous Time Synchronization

In August, the Oklahoma Geophysical Observatory, operated by the Oklahoma Geological Survey, installed a computerized timing system that is continuously synchronized to the National Bureau of Standards' low-frequency (60 kilohertz) pulse-coded timing signals transmitted from Fort Collins, Colorado, on radio station WWVB.

The timing system is synchronized at two levels. At a basic level, the frequency of the system's own oscillator is phase-locked to the WWVB radio frequency. At a higher level, the sytem's microprocessor, which makes exactly 1 million computations per second, reads each minute-long train of time-code pulses to verify continually the date-hour-minute-second display. If the radio signal is lost, the system continues to operate on its own oscillator.

Each minute, the timing system makes a time mark on the Observatory's 17 drum-recorded seismograms. The timing-system computer has been set to advance the time mark by 8 milliseconds. A 3-millisecond advance compensates for the time taken by the radio signal to travel 977 km from Fort Collins, Colorado, to the Observatory at Leonard, Oklahoma. The remaining 5 milliseconds compensates for the time delay in time-mark relays between the timing system and the recorders.

From 1961 to about 1972, the Observatory used a tuning-fork-operated clock that was checked daily with Bureau of Standards' high-frequency voice-timing signals from station WWV. Later, a crystal-controlled clock, which was set electronically each morning from WWV signals, was used. These clocks are now being kept running as backup systems.

Between settings, the earlier systems drifted from 10 to 30 or more milliseconds. The new system will never be more than 500 microseconds away from the time kept by the Bureau of Standards' ensemble of nine cesium-beam atomic clocks.

—*Jim Lawson*

OAS to Meet in Norman

The Oklahoma Academy of Science will hold its annual technical meeting in the Physical Sciences Building at The University of Oklahoma on Friday, November 14, 1980. The Geology Section, to be chaired by Kenneth S. Johnson, associate director of The Oklahoma Geological Survey, will be held in the morning and will present the following talks on Oklahoma geology:

8:30: "Measurement of Sulfur and Trace Elements in Coal-Derived Liquids by Neutron Activation Analysis," by Charles W. Terrell.
8:50: "Surface Eruptions of Natural Gas in Northwest Oklahoma," by Donald Preston.
9:10: "Subsidence Problems Associated with the Extraction of Pb-Zn Ores in the Tri-State District, Northeast Oklahoma," by Kenneth V. Luza.
9:30: "An Evaluation of Earthquake Risk at the Proposed Arcadia Dam Site in Central Oklahoma," by James E. Lawson, Jr.
9:50: Geology Section business meeting.
10:00: "Landslide Studies Along Talimena Drive in Southeastern Oklahoma," by Curt J. Hayes.
10:20: "Radioactive Springs in the Watershed of a Proposed Reservoir in Sequoyah County, Oklahoma: Environmental and Economic Evaluation," by Salman Bloch and Robert Craig.
10:40: "Geology and Its Relation to Ground Water in the Arbuckle Mountains, Oklahoma," by Roy W. Fairchild.
11:00: "Species Identification of the Hobart, Oklahoma, Mammoth by the Statistical Method of Aguirre," by Edwin T. Green.

Appalachian–Basin Index Available

A new cross-referenced bibliographic index of over 3,000 theses, dissertations, and papers from 120 institutions in the United States and Canada has recently been published by the Appalachian Geological Society. Entries are cross-referenced by title, author, subject, and school, and are concerned exclusively with geology of the Appalachian Basin.

Copies of the index can be obtained through the Appalachian Geological Society, P.O. Box 2605, Charleston, West Virginia 25329. The price of the index is $12.00.

OKLAHOMA GEOLOGY NOTES

Volume 40 October 1980 Number 5

Page