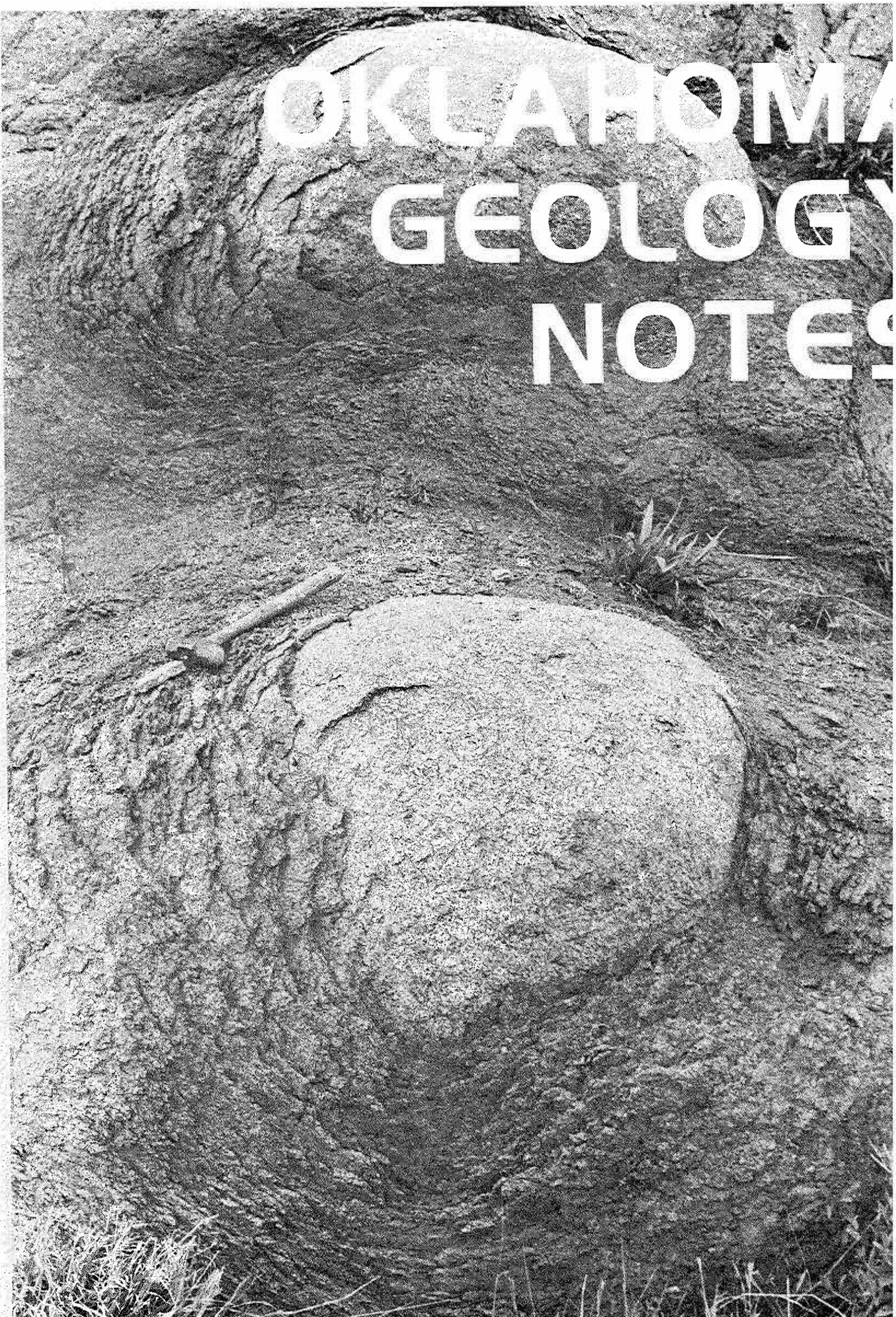
VOLUME 38 NUMBER 3 JUNE

P. K. SUTHERLAND

OKLAHOMA GEOLOGY NOTES



Cover Picture

EXFOLIATION FEATURES IN IGNEOUS ROCKS WICHITA MOUNTAINS

Although not restricted to igneous rocks, most of the well-known examples of exfoliation in the world involve rocks that are typically of the granite-granodiorite-diorite clan. The specific type of exfoliation featured here is called spheroidal weathering where shells of decomposing rock surround a relatively fresh corestone. As hydrolysis is the principal altering agent, this type of weathering goes on underground where water circulation is active.

Approximately 1 mile south-southwest of Saddle Mountain in sec. 8, T. 4 N., R. 14 W., at the contact between the Cambrian intrusive Mount Scott Granite sill and the underlying older rocks of the Raggedy Mountain Gabbro Group, a zone of amphibole-rich hybrid igneous rocks was developed. Apparently this contact served as a channelway for circulating ground waters, so that well-developed examples of spheroidal weathering can be seen where excavations have been made. For scale, the hammer in the photo is 14 inches long.

This weathering process has been important in helping to create the topography of the Wichitas. Most of the boulders scattered over the surface were formed in this way. Commonly, erosion has concentrated corestones into prominent boulder streams, as on Mount Scott. Opportunities for sphereoidal weathering occurred early in the burial of the Wichitas in the Permian and then during more recent geologic time, probably beginning in Late Tertiary, just as the mountains were being exhumed.

—*M. Charles Gilbert*

Editorial staff: William D. Rose, Elizabeth A. Ham, Judy A. Russell

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, seventy-five cents; 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 University of Oklahoma Printing Services, 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. 1,500 copies have been prepared for distribution at a cost to the taxpayers of the State of Oklahoma of $1,990.00.

MICROEROSION PROCESSES AND SLOPE EROSION ON SURFACE-MINE DUMPS AT HENRYETTA, OKLAHOMA

Martin J. Haigh[1]

Introduction

Oklahoma's strippable coal reserves amount to 695 million tonnes, 504 million tonnes net recoverable. Surface-mined-coal production was 2.4 million tonnes in 1974 (Arndt and others, 1974) and has increased steadily. By mid-1973, 14,400 hectares of land in Oklahoma had been affected by surface coal extraction (Johnson, 1974). Nationally each week, strip mining disturbs about 690 hectares, an area approximately the size of Manhattan Island, New York, and it has been claimed that "no single issue concerning the use of our land has so polarized the environmentalists and those whose primary concern is the provision of an adequate supply of energy" (Whitaker, 1976).

A primary contention in the environmentalists' arguments is sediment pollution caused by increasing the sediment in runoff. However, to date, comparatively few quantitative evaluations of sediment yields from surface-mined lands have been prepared (Schumm, 1956; Curtis, 1971; Haigh, 1977a, 1977c). Therefore, a pilot study was initiated to measure the sediment production from selected spoil-bank slopes and to describe the factors and the processes controlling the erosion of some surface-coal-mined orphan lands in eastern Oklahoma.

Site Description

Two contiguous strip-mine spoil-bank complexes located near the town of Henryetta, in southern Okmulgee County (sec. 9, T. 11 N., R. 13 E), were selected for study. One operation, an Alkonak mine, was worked between 1916 and 1924; the other was developed by the McGinnis and Grafe Coal Company in 1948 and closed in the late 1950's.

The two mines used the same technique (fig. 1) to exploit the Henryetta (Croweburg) Coal seam buried beneath a comparable depth (10–12 m) of shale and sandstone overburden. The two sites have a dog-tooth type of topography, which is typical of unreclaimed strip-mined lands (figs. 2, 3).

The disturbed area at Henryetta extends over 72 hectares and includes 36 subparallel, north-south-trending spoil banks. Most of these dumps support a well-developed vegetation cover. However, vegetation is absent from most of the land disturbed by the younger mine and from perhaps an eighth of the area of the older dumps. U.S. Soil Conservation Service aerial photographs indicate that the gross character of these mine dumps has remained unchanged since 1963 (Sparwasser and others, 1968).

Oklahoma presently has an active program for the reclamation of modern strip-mined land. However, relatively little effort has yet been directed to the reclamation of the State's older (pre-1968) disturbed lands (Johnson, 1974).

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This is a rather more vexed environmental question. Many geomorphologists contend that degree of soil loss is a function of, among other things, the density of vegetation cover and the length of time since disturbance. The redisturbance of stable, naturally revegetated, older mine dumps in the name of reclamation is seldom justifiable either in economic or environmental terms (compare with Haigh, 1976; Curtis, 1971; Meleen, 1977).

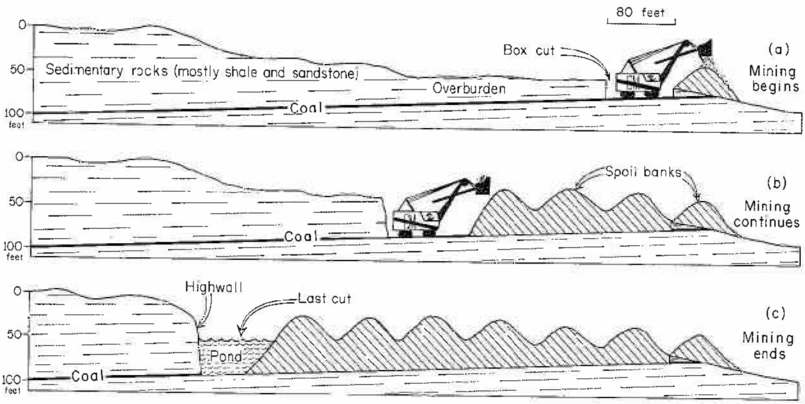

Figure 1. Creation of strip-mine spoil banks (after Johnson, 1974).

Figure 2. View of Henryetta mine dumps, west, across younger site.

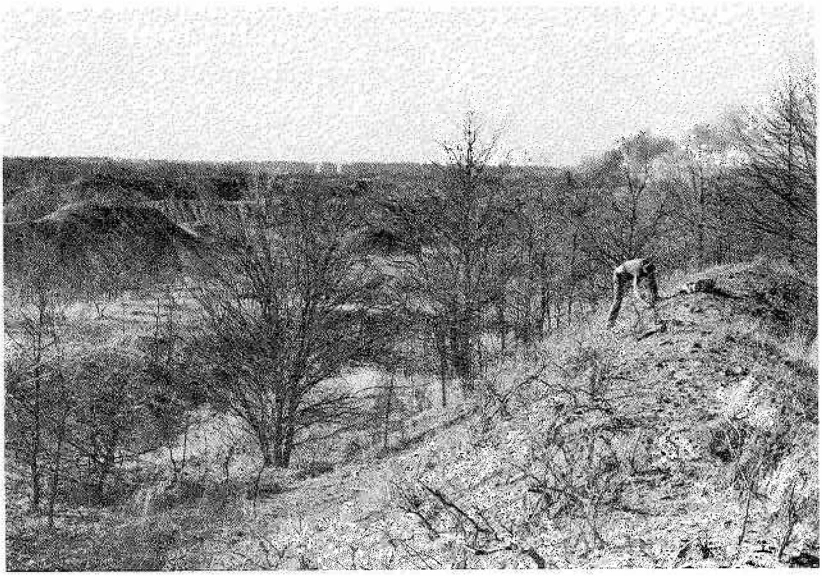

Figure 3. View of Henryetta mine dumps, north, showing collection of soil samples on vegetated section of older site.

Spoil-Dump Geomorphology

The Henryetta spoil banks have a local relief of about 3 m. Slope-angle measurements have been collected from three transverse transits across both sites. Measurements were made by means of a Brunton compass mounted on a raised meter-long bench. Preliminary compilations of these meter-unit slope-angle-frequency data reveal slope-angle-frequency peaks at 34°, 21°, 10–11°, 3° and 0° for the younger site and 27–24°, 10°, 3°, and 0° for the older site (compare with Young, 1961).

Analysis of 60 samples of surface spoil-bank materials indicates a mean-particle-size diameter (D^{50}) of 0.1–1.0 mm. Standard water displacement (pyncometer) tests indicate a bulk density of 2.1–2.2 for spoil on the older site and 1.9–2.0 for the younger site (compare with Smith, 1968). Further measurements suggest that the increased density of surface materials on the older slopes is the consequence of a reduction in the proportion of coal. Coals make up more than half of the stone fraction on the younger site but only an eighth of the stone fraction of samples gathered on the older site. The mean bulk density of these coals is only 1.3; that of the associated shales and sandstones is 2.5 and 2.7, respectively.

Gullies are mainly a feature of the younger mine dumps. Few gullies were discovered even on the unvegetated sections of the older dumps; although a slight crenulation in the plan-profile of these slopes suggests that these slopes had been subjected to gullying at an earlier time. Gullying was conspicuous on most of the newer mine-dump slopes. Ungullied slope sections were far from unusual. Gully dissections were variable but, typically, of the order of 0.2–0.5 m. The morphology of these features is the subject of continuing investigation.

Climate

This area receives an average annual rainfall of 1,040 mm, and about 70 freeze-thaw cycles. Precipitation is frequently associated with thunderstorm activity and may be torrential, especially in the spring and early summer months. Between March 26, 1976, and August 6, 1977, total rainfall was 1,313 mm, including 853 mm for the period July 14, 1976, to August 6, 1977 (fig. 4). There were 108 days when below-freezing temperatures were recorded.

Experiment Design, Procedure, and Results

Two slopes were selected for study. One slope was situated on the older mine dumps, the other on the younger mine dumps. The two slopes were selected as "typical" of ungullied, unvegetated, east-facing slope profiles. The slopes have a local relief of 3.5 m, a ground surface length of 8 m, and a 3-m maximum slope angle of 34°.

Erosion is being monitored by erosion pins (Haigh, 1977b). Three parallel profiles were established on each of the two slopes. The profiles are separated by

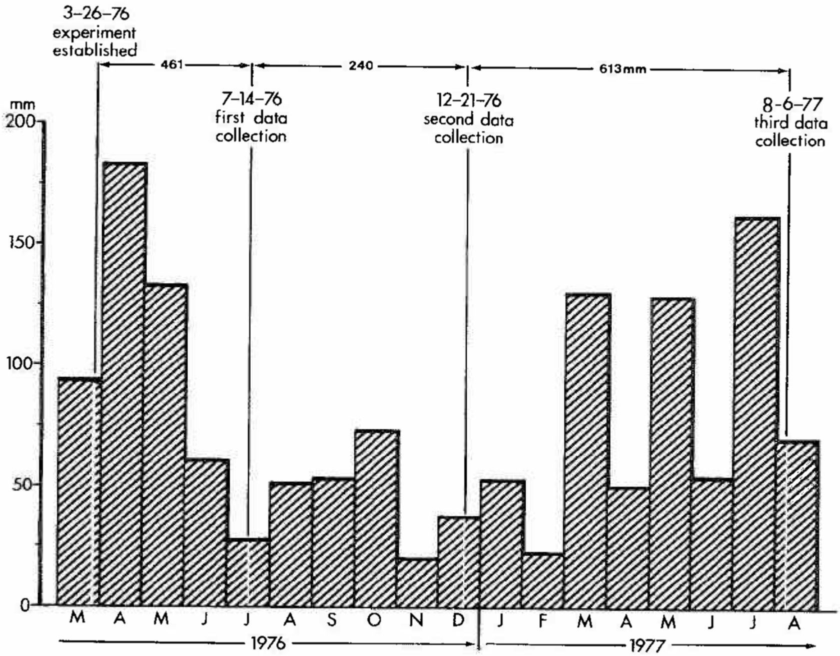

Figure 4. Graph of rainfall at Henryetta (Dewars 2 NE station), March 1976–August 1977, showing history of collection of erosion data, total precipitation between data collections, and monthly total precipitation.

a distance of 0.5 m. Erosion pins (dimensions, 600 mm by 15 mm) were placed at 2-m intervals down the line of steepest slope between slope crest and slope foot. Prior to recording the data, washers were lowered over the erosion pins and down to the ground surface. The function of these washers was to even out irregularities in the ground surface surrounding the pins. Soil is removed or sediment deposited around the pins, and these changes in the exposure of the erosion pins were recorded by means of a depth gauge. Two readings were collected approximately 10 mm from each pin, one to the left and one to the right, and the average results were recorded. Repeated data collection at selected sites suggests that these average results are accurate to about 1 mm.

Experiments were established on March 26, 1976, and the first data were collected on July 14, 1976. A discussion of these preliminary observations was prepared and published (Haigh, 1977c). Subsequent data collections were undertaken on December 21, 1976, and August 6, 1977 (fig. 4).

Results for the period July 14, 1976, to August 6, 1977, corrected to 12-month figures, were plotted as figure 5. These data are averages computed from the three profiles on each site.

The data collected indicate that, during the period of observation, the younger slope underwent slightly more erosion than the older profile. In fact, soil loss from the sloping sections on the older profile was 82 percent of that from the younger slope.

Maximum erosion on the younger slope was recorded at the upper convexity, crest, and midslope. High ground-retreat was also recorded from the crest and upper convexity of the older slope, but maximum erosion was recorded on the lower concavity, possibly in association with a marked incision at the slope foot. The slope-foot site on the younger profile was the only station to record deposition (fig. 5).

A better appreciation of the significance of these data is gained by comparing them with the results collected during the preliminary period of investigation, March 26–July 14, 1976. These results indicate that both slopes had considerable soil loss during this period. The younger slope had an average surface lowering of 6.4 mm, and the older slope, an average lowering of 4.3 mm; these changes were the result of 461 mm of precipitation. Croxton (1928) noted that newly formed strip-mine ridges in Illinois were lowered about 600 mm at the crest by erosion during their first year. At Henryetta, the younger slope had the most erosion at its crest, while the older slope's zone of maximum retreat was the midslope (table 1). Deposition was a feature of both slope-foot sites (Haigh, 1977c).

This preliminary record encompasses most of the period of maximum erosion in the annual cycle. This fact is emphasized by a comparison of these results with those collected during the period July–December 1976 and December 1976–August 1977 (table 1). The bulk of recorded ground retreat—though not necessarily erosion—occurs in the first part of the year (compare with Disecker and Richardson, 1962).

Studies by Schumm and Lusby (1963) and others (see Haigh, 1977b) have described an annual cycle of fluctuations in ground-surface elevation caused by

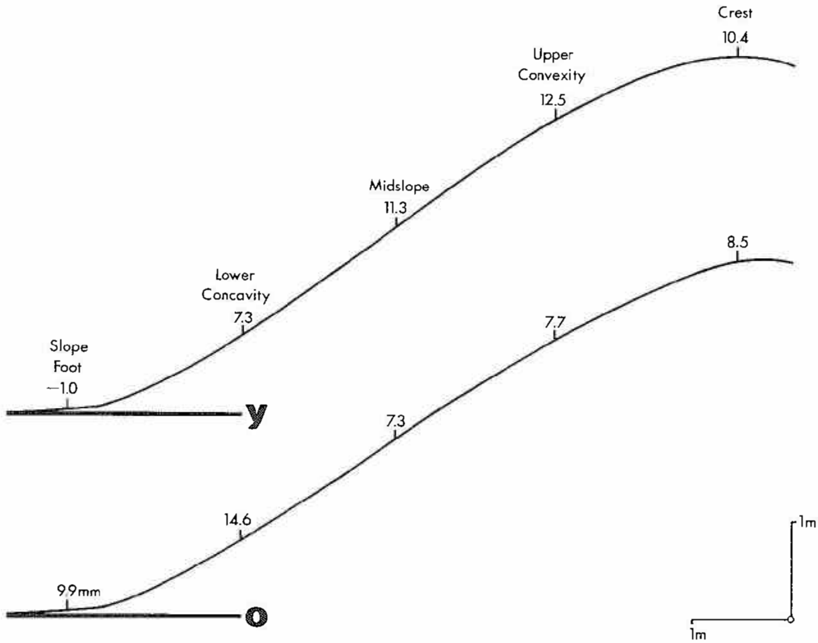

Figure 5. Morphology of experimental slopes, based on 1-m-unit slope measurements. Vertical lines indicate erosion-pin sites, and adjacent numbers indicate total ground retreat (in mm), corrected for 12-month period (autumn 1976–summer 1977). Profile **O** based on data from older mine-dump complex, and profile **Y**, on data from more recently disturbed site.

Table 1.—Ground Retreat Between Data Collections (averages exclude slope-foot data)

	Ground retreat (mm)		
Slope: section	3/26/76–7/14/76	7/14/76–12/21/76	12/21/76–8/6/77
Older: Crest	4.0	–4.3	12.8
Upper convexity	2.7	2.2	5.5
Midslope	7.6	6.7	0.6
Lower concavity	2.9	1.0	13.6
Slope foot	–11.5	–13.4	23.3
Average	4.3	1.5	8.1
Younger: Crest	9.7	–3.6	14.0
Upper convexity	5.8	0.2	12.3
Midslope	7.7	–0.2	11.5
Lower concavity	2.3	–1.5	9.2
Slope foot	–7.1	1.6	–2.6
Average	6.4	–1.3	11.8

seasonal differences in soil moisture and surface compaction. In the winter months, freezing, thawing, and the cyclic segregation of ground-ice and needle-ice crystals cause the surface layers of the ground to become loosened and puffed up (Soons, 1968). In late summer, the ground surface, beaten down by spring and summer rains, becomes more compact and has a lower elevation. This seasonal pattern of ground-surface compaction and changes in surface elevation also controls the seasonal differentiation of erosion. The frost-loosened soils of spring have a far lower shear strength than the compacted soils of summer. Balogh and Matrai (1968) described how soils loosened by plowing may resist erosion by light rainfall because of their increased infiltration capacity, but how, once this infiltration capacity is exceeded and surface wash develops, such soils may erode to the base of the loosened layer. Thus, on the mine dumps of Oklahoma, the frost-loosened soils of early spring may become casualties of the first spring cloudbursts. Subsequently, the ground surfaces of summer and autumn acquire a greater immunity to erosion as they become compacted by rain-splash impacts and planed by surface wash.

Unpredictably, results from the two slopes in the preliminary period of observation are more akin than those from the later period (table 1). During the first months of observation, slopes on both the younger and the older sites experienced slope-foot deposition. In 1977, however, the spring rains activated concentrated wash at the base of the older slope, resulting in incision and the liberation of colluvium from the lower concavity. This differentiation of erosion seems to be a consequence of the geomorphic evolution of these dumps (fig. 6). Spoil banks on the younger site tend to be separated by wide depositional flats. On the older site, these flats have become mantled with colluvium and incorporated into the lower slope profile. Thus, while wash being deposited on the slope foot of the younger site may be dispersed over a wide area, on the older site it tends to become concentrated between the colluvial deposits of opposite slopes and consequently becomes a more effective agency for erosion (fig. 6). The relatively high values for at-a-point, slope-foot deposition on the older slope are another manifestation of the same feature. The younger slopes are next to a larger flat slope-foot area, so even though their sediment yields tend to be higher, at-a-point deposition tends to be less because the colluvium has farther to spread. These slope-foot depositions have a wider environmental significance. Meleen (1977) noted that because the hollows between strip-mine spoil banks are effective sediment traps, unreclaimed strip-mined areas that are unvegetated frequently cause less external sediment pollution than reclaimed and graded areas. (This study was restricted to unvegetated slopes.)

A general feature of the erosion of these spoil dumps is the consistently high erosion rates experienced in the vicinity of the slope crest. Mayer and Kramer (1968), in their computer manipulations of the classical soil-loss equations, relating erosion to slope angle and slope length, demonstrated that convex slopes are innately more vulnerable to erosion than either straight or concave slopes. Empirical verification of this situation was supplied by Young and Mutchler (1967). Thus, the upper convex element of the spoil-bank profile erodes more easily than either the rectilinear midslope or the lower concavity. The situation

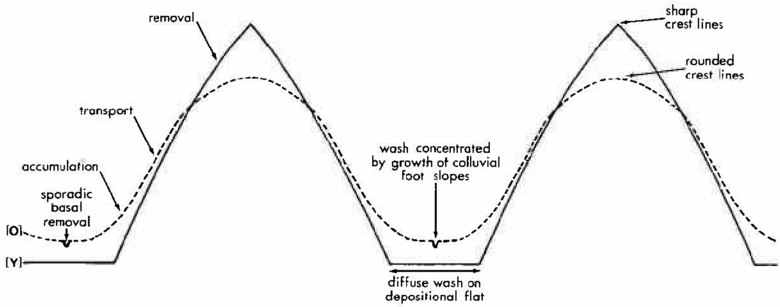

Figure 6. Model for observed evolution of slopes on strip-mine spoil banks. Solid line diagrammatically represents condition of younger slope (Y), and dashed line, condition of older slope (O).

is complicated because the upper convex section of the slope supplies debris to the lower slopes. This debris in turn inhibits further removal from the slope of elements of the lower profile, which have now come to function as transport slopes, or sites for temporary deposition. Strip-mine dumps, thus, in their raw state, might be expected to have most erosion occurring at the crest and upper convexity. Later, as this area becomes eroded and less steep, it supplies less sediment and the zone of maximum erosion migrates toward the area of greatest slope—the midslope.

One further complicating factor may be envisaged. Foster and Martin (1969) and Rowlison and Martin (1971) stressed the effect of variation in soil compaction (expressed as unit weight) on slope erosion. Erosion rates were found to be greatest for low unit weights on flatter slopes and greatest for high unit weights on steeper slopes. Artificial landforms, such as spoil banks, are less compacted at their crests and become increasingly compact toward the slope foot. If one constructs a surface of erosion potential based solely on the unit-weight criterion, one discovers that such a slope's maximum vulnerability would be first at the upper convexity and crest and second in the lower midslope.

Conclusion

Erosion has been monitored on representative slope profiles on two strip-mine dump complexes near Henryetta, in eastern Oklahoma, for a period of 16 months. The major difference between the two dump complexes is their age; one is nearly 20 years old, the other nearly 53 years old. The two areas have similar morphologies and are unvegetated. In the last 12 months of observation, erosion was concentrated on the upper sections of the younger slope and was also quite high on the crest and upper convexity of the older slope. Maximum erosion on the older slope, however, occurred on the lower concavity in response to slope-foot channel incision. The younger slope had more erosion than the older one, losing 10.4 mm to 9.5 mm in the 12-month period ending August 1977. This ground-surface loss, however, converts to an identical loss of 200 tonnes/hectare/

year because of differences in the bulk density of the surface spoil on the two sites.

Slope evolution on surface-mine dumps may be conditioned by the activities of two sets of controls. The first set is the nature of the slope foot and the activity on the basal control; the second is structure and gross morphology. Slope evolution seems to proceed from the soil removal of the crest, via downslope extension of the upper convexity, to the development of a colluvial toeslope, which helps to create a zone of concentrated wash at the slope foot.

Acknowledgments

I wish to thank J. M. Goodman, Department of Geography, The University of Oklahoma, for his advice and assistance in the establishment and maintenance of these experiments; Sammye Parsons, who assisted with data collections during August 1977; Bill Wallace, for his assistance with field work during 1978; Roger Lewis, for his assistance with data compilation and analysis; and Chris Muller-Wille, Cartographic Service Unit, University of Chicago, for drafting the diagrams.

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New Reclamation Fund Receives Almost $34 Million

The Office of Surface Mining of the U.S. Department of the Interior reported payments to the new Abandoned Mine Reclamation Fund totaling $33,925,490 for the first period, which ended January 30. This amount resulted from only 58 percent response to collection forms sent to 9,254 operators listed in the coal-mine-identification system.

Reclamation fees, based on coal-mine production, will be used to reclaim lands that were previously mined but left in inadequate condition before August 3, 1977, the effective date of the Surface Mining Control and Reclamation Act.

Half the amounts collected within a state or an Indian reservation are reserved for 3 years for use by that state or Indian reservation. Uses for the remainder include the Small Operators Assistance Program, the new Rural Lands Reclamation Program of The U.S. Soil Conservation Service, and other reclamation projects. Priority is given to projects involving extreme dangers to health and safety. Oklahoma has collected $445,677 in reclamation fees so far.

Enhanced-Recovery Symposium Announced

The Fourth Annual Symposium on Enhanced Oil and Gas Recovery and Improved Drilling Methods will be held August 29–31 in the Performing Arts Center at Tulsa. The symposium is sponsored by the U.S. Department of Energy, The University of Tulsa, and the *Oil and Gas Journal.* For further information, contact F. S. Manning, University of Tulsa, 600 South College Avenue, Tulsa, Oklahoma 74101 (phone, 918—939–6351).

AGI Releases Publication Guide

Maps and Geological Publications of the United States: a Layman's Guide, issued recently by the American Geological Institute, is a valuable reference for professional geologists as well as for students, teachers, and amateur collectors. Compiled for AGI by William R. Pampe, professor of geology at Lamar University, Beaumont, Texas, the 57-page volume lists nontechnical publications for each state in the Union. Categories covered include general geology, mineral resources, guideboks, rocks and minerals, landforms, maps, water, earthquakes, and bibliographies.

An introductory section gives addresses of federal agencies that offer additional information. A list of publishers from whom the publications can be obtained follows the listing by states. None of the publications are sold by AGI.

Maps and Geological Publications of the United States, an updating of the much-used 1965 *Selected Maps and Earth Science Publications*, which was compiled by AGI's director of education, William H. Matthews III, is available from the American Geological Institute, 5205 Leesburg Pike, Falls Church, Virginia 22041. The price is $3.00.

Professional Day Held at OU

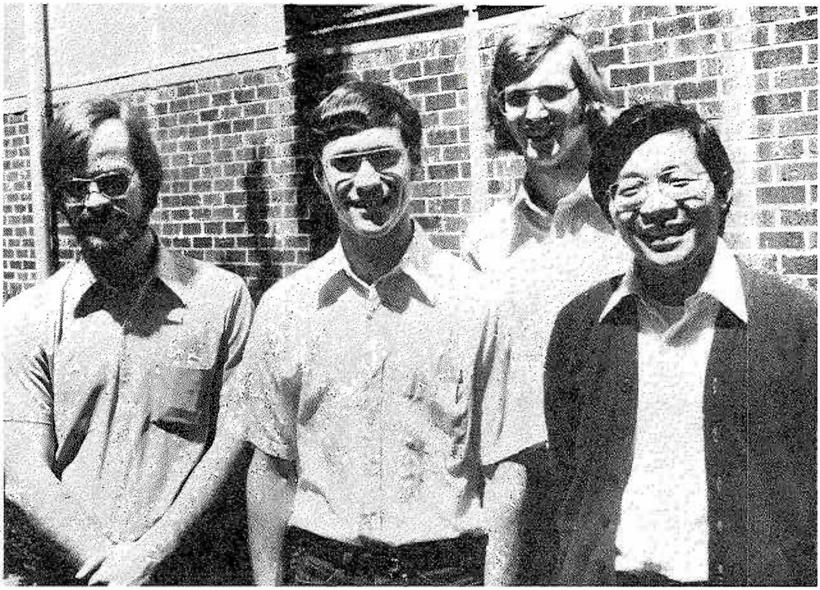
April 14 was the date of the first Professional Day held by the School of Geology and Geophysics at The University of Oklahoma. Plans call for this event to be held annually, thereby giving students an opportunity to present their topics of research before their peers, professors, and others interested in the earth sciences.

Burr Silver, faculty sponsor of Sigma Gamma Epsilon, and Darryl Carter, SGE president, enlisted the aid of the members of SGE and the Geoscience Club to put together a successful program and awards banquet. Deborah Houston was in charge of publicity and assembled the program brochure, and Pam Hudson was in charge of the arrangements for the banquet. John Groves was program chairman and presided over the meeting.

Fourteen students presented a variety of papers. The keynote speaker, Mahlon Ball, director of the U. S. Geological Survey Energy Resource Group at Woods Hole, Massachusetts, set the pace with his talk, "Hydrocarbon Potential of the Eastern Atlantic Shelf." Awards were given to the outstanding papers: two in geology and two in geophysics. The papers were judged by several School faculty members and OGS staff members.

The awards banquet was held the same evening in the Oklahoma Memorial Union, with Drew Goodbread as master of ceremonies. Recipients of awards were: Randy Baker, Outstanding Geology Paper; Grant Zimbrick, Second Place Geology Paper; Tim Hsue, Outstanding Geophysics Paper; Kevin Woller, Second Place Geophysics Paper; Bethany Bye, W. A. Tarr Award (SGE award to a senior geology major); Darryl Carter, E. L. McCullough Award (SGE award to a graduate student); and Becky Pope, $200 scholarship. Faculty and Survey staff members receiving awards were Burr Silver, Certificate of Merit, and John Wickham and Charles Mankin, Faculty Honor Roll.

With the demonstrated success of the first Professional Day, the event is bound to become an annual affair!



Recipients of the Professional Day Awards are (left to right): Randy Baker, Grant Zimbrick, Kevin Woller, and Tim Hsue.

1978 Petroleum Encyclopedia Available

The 11th volume of the *International Petroleum Encyclopedia* has been published by the Petroleum Publishing Co., and orders are being accepted for shipment in July. The 1978 version of this useful reference book contains 50 maps defining oil and gas fields, pipelines, refineries, tanker terminals, and physical and political geography. It also includes numerous tables, charts, and graphs plus reviews of developments in the industry.

International Petroleum Encyclopedia 1978 can be ordered by writing IPE '78, P.O. Box 1260, Tulsa, Oklahoma 74101. The prepaid price is $42.50.

BLASTOIDS FROM WAPANUCKA FORMATION LOWER PENNSYLVANIAN

Steven G. Katz[1] and **Harrell L. Strimple**[2]

Blastoids of the genus *Pentremites*, which were abundant and diverse during most of the Mississippian in North America, suddenly became rare in the uppermost Chesterian (Imo Formation) and in the Pennsylvanian. An exception is a single species, *P. rusticus* Hambach (1903; redefined by Katz, 1975, and Katz, in press). This species occurs abundantly in the Morrowan (Lower Pennsylvanian) Sausbee and McCully Formations in eastern Oklahoma (new stratigraphic nomenclature of Sutherland and Henry, 1977) and in the Bloyd and Hale Formations of northwestern Arkansas. The species is now confirmed to be present, although not common, in the Morrowan Wapanucka Formation of south-central Oklahoma.

References to Wapanucka blastoids in previous literature are limited. Morgan (1924, pl. 33, figs. 6, 7) illustrated an elongate specimen as *P. angustus* Hambach and a short one as *P. rusticus* Hambach. Both of his specimens came from near the base of Wapanucka Formation at his Station 28; both were in an excellent state of preservation. However, Katz (1975, and in press) has shown in recent studies that *P. angustus* is properly a synonym of *P. rusticus*; Morgan's confusion is typical of that encountered by other workers.

Rowett (1962), as well as Morgan, recognized the presence of the genus *Pentremites* but was prudently reluctant to identify the particular species he had found. The present study of some of his material in The University of Oklahoma collections (specimens OU 8444–8449; fig. 1) and of material from The University of Iowa (SUI 43286–43839) has yielded convincing evidence that these specimens are nearly identical to *P. rusticus* from eastern Oklahoma and western Arkansas.

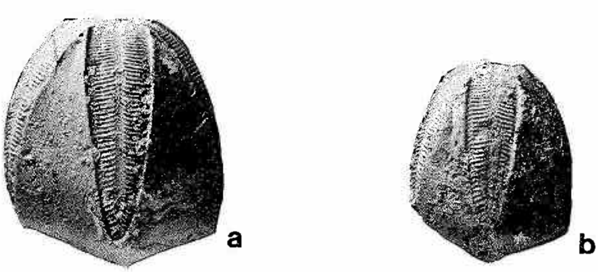


Figure 1. **Pentremites rusticus** Hambach from the Wapanucka Formation, NE1/4 NW1/4 sec. 8, T. 1 N., R. 7 E., Pontotoc County, Oklahoma (locality 3-unit F of Rowett): (a) side view of medium-sized theca (OU 8446), × 2; (b) side view of small individual (OU 8447), × 2.

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The blastoids in these collections were all recovered from various undifferentiated horizons in the Wapanucka Formation in Pontotoc and Coal Counties, Oklahoma, at Rowett's (1962) localities 3-unit A, 3-unit F, 7-unit A, and 4-unit A. (Morgan's, 1924, locality 28 and Moore and Strimple's, 1973, locality 13 are equivalent to Rowett's locality 4-unit A.) The condition of preservation of the blastoids from these localities is generally much poorer than that of specimens of *P. rusticus* from farther east in Oklahoma and from western Arkansas, and a much higher percentage were crushed, broken, badly weathered, and otherwise unsuitable for sectioning and internal study.

Externally, the specimens are remarkably similar to other *P. rusticus* specimens. Infrequently, the basal ends of the ambulacra may extend slightly beyond the base and somewhat axially, making the calyx more globose than barrel-shaped. Also, infrequently, the interambulacra may be more concave than usual. It has been demonstrated, however, that *P. rusticus* is a highly variable species, and it is not surprising that the Wapanucka blastoids also exhibit a high degree of variability.

Internally, *P. rusticus* exhibits a morphologic feature suspected to be unique to the species. The fragile respiratory hydrospires, ten clusters of internal calcite folds that are commonly preserved, have the two posterior (anal) hydrospire groups modified for internal brooding of eggs in the living blastoid (Katz, 1975; Katz and Sprinkle, 1976). These posterior groups are of two types: Type I (females), with a reduced number of folds and an expanded shape (for holding the eggs), and Type II (males), with only the reduced number of folds. All observed Wapanucka specimens that have preserved hydrospires also show one or the other of these two types of posterior hydrospires. This lends support to the identification of these blastoids as *P. rusticus*.

In conclusion, the time range for *P. rusticus* is not extended by confirmation of the occurrence of this species in the Wapanucka Formation, but the geographic extent is firmly established. The species is now known to occur over a 200-mile range from Washington, Crawford, and Carroll Counties, Arkansas, and Muskogee, Cherokee, and Sequoyah Counties in eastern Oklahoma, to Pontotoc and Coal Counties in south-central Oklahoma.

We wish to thank Patrick K. Sutherland, of The University of Oklahoma, for the loan of specimens for this study and A. Allen Graffham, of Geological Enterprises, for providing some of the better preserved specimens for sectioning. Mr. Graffham's specimens are now reposited at the University of Iowa.

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Circular on Information Sources Released by USGS

A new circular issued by the U.S. Geological Survey—*A Guide to Obtaining Information from the USGS, 1978*—is an excellent source of information (and a source for sources of information) on services and products available from this federal agency. The 36-page publication, issued as Circular 777, describes the various USGS offices, groups, divisions, centers, sections, and services and tells what is offered where—or where to find the address you need. It will not tell you more than you want to know, but it does give an insight into the activities and offerings of our national geological agency. The USGS maps, reports, abstracts, bibliographies, indexes, periodicals, and data systems referred to reflect almost 100 years of effort.

Compiled by Paul F. Clarke, Helen E. Hodgson, and Gary W. North, Circular 777 can be obtained free on request from the Branch of Distribution, U.S. Geological Survey, 1200 South Eads Street, Arlington, Virginia 22202.

AAPG Committee Releases Exploratory-Well File

The Committee on Statistics of Drilling (CSD), a standing committee of The American Association of Petroleum Geologists, has released its exploratory-well file for public access through The University of Oklahoma's Information Systems Programs and the General Electric Mark III computer network.

Classifications of exploratory wells include new-field wildcat, new-pool wildcat, deeper pool test, shallower pool test, and outpost (extension) test. Recorded in the file are American Petroleum Institute well number, completion date, depths, well classification, operator identification, section-township-range (where available), geological basin, deepest formation codes, name, pay code and pay name, estimated ultimate yield, field name, and remarks. The file is indexed by state, year reported, basin code, and classification.

The file contains 237,896 well tickets for the years 1954–1976. OU obtained the data for 1954–1963 from the AAPG office in Tulsa, and these data were reduced and added to the file. The data-base name is CSD1, and the dictionary for accessing this file is CSD001.

ORE DEPOSITS OF THE USSR
A REVIEW

Robert O. Fay[1]

Ore Deposits of the USSR, edited by V. I. Smirnov. Translated by D. A. Brown, Australian National University. Fearon-Pitman Publishers, Inc., London–San Francisco–Melbourne. In three volumes: vol. 1, 352 p., 135 figs., $21.75; vol. 2, 424 p., 163 figs., $25.25; vol. 3, 492 p., 174 figs., $29.00, 1977. Special rate for set, $68.50.

The principal metalliferous ore deposits of the Soviet Union are discussed by 42 Soviet geologists. The metals are divided into 28 chapters, with a discussion of the prominent deposits. Volume 1 includes chapters on iron, manganese, chromium, titanium, vanadium, and aluminum. Volume 2 includes nickel, cobalt, copper, lead and zinc, bismuth, antimony, mercury, and uranium. Volume 3 includes gold, silver, platinum, molybdenum, tungsten, tin, lithium, caesium, beryllium, tantalum and niobium, rare earths, germanium, strontium, and dispersed elements (rhenium, selenium, tellurium, cadmium, gallium, thallium, indium, scandium).

Each metal is discussed according to origin: (1) endogenic (involving magmatic and hydrothermal solutions)—either volcanogenic or plutonogenic; (2) exogenic (involving cool solutions in sediments)—either epigenetic (late origin), or diagenetic (early origin), or polygenetic (multiple origin); and (3) metamorphogenic. The deposits are also related to tectonic provinces, such as pre-Palaeozoic, Caledonian, Hercynian, Cimmerian, and Alpine, and are related to sedimentary provinces, such as basins, platforms, deltas, and piedmonts. Most of the articles are descriptive, showing geologic and mineralogic relationships but lacking details on chemistry of solutions.

One example of a typical chapter is that on uranium, which is subdivided into:

A. Metamorphogenic deposits of ancient platforms, associated with sodic and carbonate metasomatism. *B*. Endogenic deposits of folded regions. Class I. Andesite-diorite hydrothermal deposits in dikes, paleo-volcanoes, and along intrusive contacts. Class II. Rhyolite-granite hydrothermal deposits, in volcanic depressions, subvolcanic massifs, and explosion pipes and necks. *C*. Endogenic deposits of active regions. Class III. Trachyte-syenite hydrothermal deposits in subvolcanic massifs and faults in crystalline basement. Class IV. Andesite-rhyolite hydrothermal deposits in erosional tectonic basins. *D*. Exogenic deposits of young platforms. Class V. Epigenetic or polygenetic infiltration deposits in carbonate, terrigenous, and coal deposits, associated with roll fronts and hydrocarbon halos. Class VI. Diagenetic-sedimentational deposits, such as bone beds, black shales, and sabkha deposits.

The work is a welcome addition to general knowledge of Soviet ore deposits.

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OKLAHOMA ABSTRACTS

AAPG-SEPM Annual Meetings
Oklahoma City, Oklahoma, April 9–12, 1978

The following abstracts are reprinted from the March 1978 issue, v. 62, 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 Gary Howell, AAPG publications manager, to reproduce the abstracts is gratefully acknowledged.

Atoka Formation (Pennsylvanian) Depositional Environment and Growth Faulting Southwestern Arkoma Basin, Oklahoma

BRUCE E. ARCHINAL, Houston Oil and Minerals Corporation, Houston, Texas

The Atoka Formation along the southwestern margin of the Arkoma basin in Coal and Pontotoc Counties, Oklahoma, is a shale and mudstone unit interbedded with thin sandstones and thin sandy limestones. Detailed surface mapping and measured stratigraphic sections show that the Atoka was deposited on a marine shelf that received only minor amounts of medium clastic sediments. The sandstones present are lower foreshore beach, submerged barrier bars, or longshore bars and were deposited during brief stillstands or minor regressions that occurred intermittently during a general transgression.

The Clarita anticline was a positive structural feature and the Clarita fault was an active down-to-the-north growth fault during Atoka deposition. A thickened Atoka sequence, deposited just north of these features, thins onto and across them. This relation was unrecognized by previous workers who thought that *Fusulinella* was present 200 ft (60 m) above the top of the Morrowan and only 100 ft (30 m) above *Profusulinella*, when the actual stratigraphic separation might be more than 1,000 ft (300 m).

Petroleum explorationists need to be aware of the possibility of growth faulting in the subsurface along the Clarita and Phillips faults. Multiple reservoirs could be present if closure exists and the downthrown block contains an expanded section with numerous sandstone beds. Hydrocarbon accumulations are possible on the high side of faults, where deposition kept pace with fault growth, and sands were deposited on the upthrown block. [491]

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.

Stromatoporoids—Epic Struggle for Survival (Examples from Devonian of Michigan, Pennsylvanian of Oklahoma, and Modern Jamaican Reefs)

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During the past 10 years, there has been a dramatic change in the interpretation of stromatoporoids. Exploration of the modern deep fore reef resulted in description of Sclerospongiae as a dominant framebuilder at depth. Further investigation revealed the presence of sclerosponges within caves and dark galleries in shallower reef areas.

Examination of the structure of these unique sponges disclosed remarkable similarity to stromatoporoids and to some tabulate corals, suggesting an evolutionary relation.

Several problems are posed by the interpretation of stromatoporoids as sclerosponges. These include the erratic distribution and sudden disappearance of stromatoporoids from the role of a dominant framebuilder after the Devonian Period. The solution to these problems may be found by careful examination of Devonian and later Paleozoic bioherms and comparison with modern reefs. Developmental stages of modern lagoonal reefs and Devonian and Pennsylvanian bioherms are remarkably similar, exhibiting stages of stabilization by stromatoporoids or stromatolitic algae, diversification, and, finally, domination by stromatoporoids, bryozoans, or stromatolitic algae.

Earlier studies of late Paleozoic bioherms have identified only chaetetids and related forms as stromatoporoids. However, careful reexamination of Early Pennsylvanian (Morrowan) bioherms from Oklahoma reveals that stromatoporoids were a significant part of the cavity fauna, indicating that by Morrowan time, at least one group of stromatoporoids had been displaced into the cryptic habitat occupied by modern sclerosponges. Suggestions that stromatoporoid extinction resulted from competition by tabulate or scleractinian corals are not supported. Rather, the answer seems to lie with distribution and development of stromatolitic and calcareous coralline algae as important bioherm stabilizers and binders. [498]

Subsurface Heavy-Oil-Bearing Sandstones in Southeastern Kansas

W. J. EBANKS, JR., Kansas Geological Survey, Lawrence, Kansas

The current interest in minerals which may be alternate sources of fuel for the future has provided the incentive to investigate in greater detail deposits of heavy-oil-bearing Cherokee sandstones in southeastern Kansas and contiguous areas of Missouri and Oklahoma. Although a resource which may be as large as 200 million bbl of heavy oil probably is present in the shallow subsurface beneath the three counties studied, none of this may be considered reserves, that is, recoverable under existing technology and economics. This estimate of resource size severely downgrades earlier estimates which were based on less direct evidence.

The main reason for lowering estimates of resource size is the discontinuity

of individual reservoir sandstones. The earlier impression of these heavy-oil-saturated, "blanket" sandstones is not correct. The composition, texture, internal structures, and distribution of the sandstones suggest that they were formed by alluvial-deltaic systems extending periodically into Kansas from the east. Errors in correlation of these sandstones from Missouri to Oklahoma have resulted from overly simplified assumptions about their continuity through areas of poor exposure.

The geochemistry of these heavy oils is best explained as resulting from contact and washing of the sandstones by natural fresh waters, with accompanying alteration of the oils by bacteria. The heavy oils have almost no light-hydrocarbon compounds, have only small amounts of normal paraffins, and have slightly higher contents of sulfur and nonhydrocarbons than do the lighter Cherokee crude oils in the area. [511]

Stratigraphic Trap Possibilities in Arbuckle Group

LLOYD E. GATEWOOD, Independent-Consultant Geologist, Oklahoma City, Oklahoma

One of the richest oil- and gas-producing areas in the United States is a belt 200 mi (320 km) wide and 850 mi (1,400 km) long, from the Central Kansas uplift across Oklahoma, North and West Texas, to the Central Basin platform, and extending across the Delaware basin into New Mexico. More than 90% of all oil and gas produced from Ordovician and Cambrian rocks has come from this area, and accumulations are present to depths in excess of 24,000 ft (7,300 m) in thick, environmentally complex Arbuckle-Ellenburger carbonate rocks.

The potential of the Arbuckle in this area is emerging in fields such as West Mayfield and Mills Ranch, which have producing wells averaging 15 MMcf of gas per day and gas reserves greater than 20 Bcf per well.

The Arbuckle in its hydrogen sulfide-rich depocenter in Oklahoma is over 8,000 ft (3,400 m) thick, and the dolomite section on the platform is 5,000 ft (1,500 m). Dolomite porosity and production have been localized in an area of predominantly carbonate deposition, where evaporites are related to entrapment.

Data from these fields show that four depositional environments existed, which shifted laterally as the basin subsided. These environments were lagoonal, supratidal, intertidal, and subtidal. The result of this continuous shift in environment was both vertical and lateral, highly complex lithologic and facies relations. Fracture porosity and trapping mechanisms are evident without "benefit" of structure.

As more wells are drilled, it becomes increasingly possible to use subsurface samples for predicting depositional environments and in delineating diagenetic dolomites, reefs, shoals, and porous dolomites interbedded with and capped by evaporites. Thus, many new localities of potential oil and gas production should be located in both the basin area and in the shallower shelf-dolomite areas.

[516]

Depositional Environments and Conodont Biostratigraphy of Wapanucka Formation (Pennsylvanian), Frontal Ouachita Mountains, Oklahoma

ROBERT C. GRAYSON, JR., University of Oklahoma, Norman, Oklahoma

The Wapanucka Formation crops out as a series of two to five subparallel, arcuate ridges along the northern margin of the Ouachita Mountains in southeastern Oklahoma. These thrust-fault exposures provide a unique opportunity for detailed three-dimensional stratigraphic analyses, for both basinward and lateral relations can be examined. Basinward the Wapanucka Formation thickens from approximately 400 to 700 ft (120 to 210 m); shale interbeds become volumetrically important; and shallow-water, marine carbonate rocks are replaced by deeper marine, flaser-bedded spiculites. Laterally, subtidal-lagoon, open-marine-carbonate, oolite-shoal, and skeletal-bar deposits interfinger and grade into a linear system of offshore bar sands and interbar muds. Presumably, the more basinward flaser-bedded spiculites grade laterally and basinward into the shale facies of the Johns Valley Formation in the central Ouachitas.

Evaluation of the conodonts indicates that four faunal subdivisions can be recognized. In ascending order, the faunas are distinguished by the earliest local occurrence of: (1) *Idiognathoides convexus*; (2) *Idiognathoides ouachitensis*, and/or *Neognathodus kanumai*, and *Gondollela clarki*; (3) *Gnathodus orphanus*; and (4) *Streptognathodus* sp. cf. *S. elegantulus*. Fauna 1 indicates a correlation of the lower Wapanucka Formation with the Dye Shale(?) and Kessler Limestone Members of the Bloyd Formation (type Morrowan) in northwestern Arkansas. The absence of faunas 2 and 3 in the Bloyd Formation suggests that an erosional gap is present at or near the base of the Trace Creek Shale Member of the Bloyd Formation in northwestern Arkansas. Fauna 4 occurs in the Trace Creek Shale and in the overlying Atoka Formation in that area. The conodont evidence suggests that the Morrowan-Atokan chronostratigraphic boundary is contained within the Wapanucka Formation in the Ouachitas, where the preserved depositional sequence is more complete than that in the type Morrowan area in Arkansas. [518]

Subsurface Lithostratigraphy of Hunton Group in Parts of Payne, Lincoln, and Logan Counties, Oklahoma

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In the area of investigation, T15-20N, R2E-3W, in Payne, Lincoln, and Logan Counties, Oklahoma, the Silurian Hunton Group consists almost entirely of limestone and dolomite with minor amounts of sandstone and shale. The present areal extent of the Hunton was determined by erosion before deposition of the overlying Woodford Shale. Only Silurian rocks of the Hunton Group are present, and the Hunton was eroded from the northern parts of the study area. The Hunton Group apparently is conformable upon the Sylvan Shale.

At many places the Hunton was eroded to a karst topography, in conjunction with evolution of a dendritic stream drainage system. Solution porosity and dolomitization seem to be particularly well developed where stream valley "heads" were cut into the karst surface.

Folding and faulting, as illustrated by structure of the top of the Sylvan Shale, were determinants in development of porosity and entrapment of hydrocarbons within the Hunton Group. Dolomitization apparently is associated with groundwater that migrated through faults and fractures.

Four types of hydrocarbon-trapping mechanisms are present in the Hunton: (1) folding, (2) faulting, (3) stratigraphic changes in lithology, and (4) a combination of folding and stratigraphic changes. No production in the area has been discovered to be related directly to pinchouts at the subcropping edge of the Hunton. [523]

Development of Mills Ranch Complex, Texas and Oklahoma

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The Mills Ranch complex is fast developing into one of the largest fields in the deep Anadarko basin. This complex is part of a deeply buried granite uplift which extends northwest-southeast for 15 m (24 km) or more from Wheeler County, Texas, into Beckham County, Oklahoma. It is a long narrow anticlinal feature paralleling a northwest-southeast-striking thrust fault and is complicated by numerous faults and unconformities. The discovery well of the deep Mills Ranch–Hunton play which started a large drilling program was the Freeport Oil Co. 1 Sidney Fabian, which was drilled in 1972 to a depth of 21,640 ft (6,596 m) and completed at a calculated open flow rate of 93,050 Mcf/day. Since that time a continuous program, chiefly by the Chevron-Freeport group, has proved at least three separate productive reservoirs in the Hunton. The Hunton section averages 929 ft (283 m) in thickness, and produces from both the Chimneyhill and the Henryhouse sections. Wells in the Hunton on the main structure are capable of producing up to 20,000 Mcf/day.

The deepest commercial production in the world was found from the Arbuckle at 22,918 ft to 23,938 ft (6,985 to 7,296 m) in the Chevron et al 1 James which was completed in August 1976. An offset well, the Chevron et al 1 Ledbetter, has been drilled to 26,500 ft (8,079 m) into the Arbuckle. Deeper production on the Mills Ranch complex could cause increased deep drilling activity in fields presently producing only from the Hunton as well as on nonproducing structures in this part of the Anadarko basin. [526]

Permian Salt Deposits in Texas Panhandle and Western Oklahoma

KENNETH S. JOHNSON, Oklahoma Geological Survey, Norman, Oklahoma

Permian red beds and evaporites are as much as 5,000 to 7,000 ft (1,500 to 2,100 m) thick in the Anadarko, Palo Duro, and Dalhart basins of the Texas Panhandle and western Oklahoma. Leonardian, Guadalupian, and Ochoan rocks of the two-state region contain six principal salt-bearing units, including (in ascending order) the Hutchinson, lower Clear Fork (lower Cimarron), upper Clear Fork (upper Cimarron), San Andres (Blaine Formation), Seven Rivers Formation (Artesia Group), and Salado-Tansill salts. Each of these units typically ranges from 200 to 1,500 ft (60 to 450 m) in thickness and consists of interbedded salt, shale, anhydrite, and dolomite or limestone. Individual salt layers generally are 5 to 50 ft (1.5 to 15 m) thick, and salt typically comprises 30 to 70% of each salt-bearing unit. The oldest of the salt units is limited to the northern part of the region, whereas younger salts are distributed farther south as the site of salt deposition shifted progressively southward during Permian time.

Permian strata dip gently into the three basins, but outcropping rocks are collapsed and disturbed where soluble salt layers have been dissolved by groundwater. These solution and collapse features locally obscure the stratigraphic and structural relations, thus making the identification of deep-seated structures more difficult. The erratic distribution of thick and thin masses of salt in these areas of partial dissolution also makes interpretation of seismic reflection data extremely difficult and risky. [526]

Sandstone Diagenesis in Bromide Formation, South-Central Oklahoma

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Many factors combine to control diagenesis in sandstones. These include (1) composition, (2) depositional environment and associated rock types, (3) migration patterns and chemistry of interstitial fluids, (4) pressure and temperature, (5) time, and (6) local setting relative to faults and folds. Quartzarenites generally are cemented with quartz or calcite; arkoses by quartz, feldspar, kaolinite, or illite; volcanic arenites by chlorite and zeolite; and calclithites by calcite. Depositional environment affects diagenesis through composition of connate water, availability of fossil fragments (a source of calcite), associated shales (a source of magnesium for dolomite, silica for quartz, etc.), and associated evaporites. Fluid migration in the subsurface is a complex variable that may promote cementation by bringing in ions from other areas or may inhibit cementation either by filling pores with an inert diagenetic fluid such as hydrocarbons or by bringing in undersaturated solutions. Pressure affects diagenesis mainly via pressure solution. The role of temperature still is poorly understood.

Sandstones in the Ordovician Bromide Formation of south-central Oklahoma were deposited in shallow-marine shoreface and tidal-flat environments in a sporadically transgressing sea. The sandstones are supermature quartz arenites with quartz, calcite, and dolomite cements. In these sandstones depositional environment acted in conjunction with composition as the primary control on diagenesis. Dolomite cement is most commonly associated with algal mats in tidal-flat sediments. Shoreface sandstones with common fossil fragments generally contain calcite cement. Thin unfossiliferous shoreface sandstones enclosed by shale tend to be cemented with quartz. Porosity is preserved locally in thick unfossiliferous shoreface sandstones where relatively early migration of hydrocarbons inhibited late-stage cementation by quartz. [538]

Contemporaneous Faults—Mechanism for Control of Sedimentation in Southwestern Arkoma Basin, Oklahoma

MICHAEL WILLIAM MCQUILLAN, Edwin L. Cox Oil and Gas Producer, Oklahoma City, Oklahoma

Basal Atokan-Morrowan deposition in the Arkoma basin was influenced by down-to-the-basin growth faults similar to those reported from the Gulf Coast. There are abrupt increases in thickness of the lower Atokan and Morrowan strata on the downthrown sides of the faults. Stratigraphic changes in proximity to faults also occur subjacent to the minor faults within the major blocks. The distribution and thickness of the basal Atokan (Spiro) sandstone were controlled by contemporaneous faulting (i.e., growth-fault-controlled sand accumulation).

The Spiro sandstone is subdivided into two facies: (1) a local north-south-trending delta distributary channel sandstone (Spiro B) and (2) an overlying transgressive marine sandstone (Spiro A). The Spiro B represents local seaward-building delta distributary channel systems that may extend up to 20 mi (32 km) in length and range from 1 to 6 mi (1.6 to 10 km) in width. The transgressive marine facies (Spiro A) is believed to be a submarine sand deposited in trends subparallel with paleodepositional strike. The source of the Spiro sand was on the east and southeast with a limited contribution of sediment from the north.

The growth faults probably originated by movement in the basement and were perpetuated by additional basement movement and/or sedimentary loading and slumping. Contemporaneous movement along the faults began as early as Morrowan time, continued throughout deposition of the Atokan sediments, and apparently ceased by the time of Hartshorne sand (Desmoinesian) deposition.

[543]

Petroleum Potential and Stratigraphy of Simpson Equivalents in Arkansas and Adjacent Areas

RAYMOND W. SUHM, Texas A&I University, Kingsville, Texas

The Simpson Group (Middle Ordovician) in Oklahoma is well known because of its petroleum potential; however, little is known about its equivalents in Arkansas and Missouri. Uncertainties with correlation, lack of published studies, and formational names that change at state lines hinder an understanding of these strata.

To alleviate this gap, an intensive effort was initiated in 1968 to describe and correlate the Everton-St. Peter from exposures in the Arkansas Ozarks and to study equivalent units, as well as the Joachim and Plattin, in the subsurface of petroleum-producing regions in the Arkoma basin of Arkansas and Oklahoma and the Black Warrior aulacogen in northeastern Arkansas.

The subsurface project involved the study of more than 60 wells in Arkansas, Missouri, and Oklahoma that spanned the Simpson succession. Seven regional stratigraphic cross sections trending east-west and north-south were constructed to show complex facies relations of potential sandstone and carbonate reservoirs. Major cycles of transgressions and regressions were defined and compared with those of the type Simpson in Oklahoma. Eustatic sea-level fluctuations over a stable craton and geosyncline margin provide a means by which these cycles may be recognized on a regional basis.

Despite facies complexity, lithostratigraphic units were traced satisfactorily throughout most of the subsurface. Exceptions, however, were the thick Arbuckle-Simpson carbonate successions in the Black Warrior aulacogen of northeastern Arkansas where cratonic unconformities and lithologic contrasts are absent. Insoluble residue analyses provide a means for differentiation. Here, too, the Smithville Formation "fills" the unconformable gap between the Arbuckle (Powell) and Simpson (Everton, St. Peter, Plattin).

Regional stratigraphic synthesis of the Simpson in Arkansas and surrounding regions is derived from isopach maps, percentage maps, and reconstructed cross sections. Geologic histories and paleogeography are also explained. The data suggest that the carbonate materials and lobate to sheet sands accumulated in a barrier island–shelf sea. The sands were partially reworked and modified by marine processes in transgressing seas. Secondary dolomitization of limestone was effective in producing intercrystalline porosity in selected areas of the Black Warrior basin.

Trends of favorable reservoir facies in the Everton and St. Peter are established in regions where production is from shallower and younger strata. Deeper targets in the Simpson therefore are suggested. [565]

Reevaluation of Morrowan-Atokan Series Boundary in Northwestern Arkansas and Northeastern Oklahoma

PATRICK K. SUTHERLAND, ROBERT C. GRAYSON, JR., and GRANT D. ZIMBRICK, University of Oklahoma, Norman, Oklahoma

In the area of the type Morrowan Series in Washington County, Arkansas, the boundary of that series with the overlying Atokan traditionally has been placed at the base of the first cliff-forming sandstone above the Kessler Limestone Member of the Bloyd Formation. This horizon is the arbitrary location of the base of the Atoka Formation and the top of the Trace Creek Shale Member of the Bloyd Formation. Sandstones locally as thick as 20 ft (6 m) within the Trace Creek Shale in Washington County have been ignored. The assumption has been that deposition is regionally continuous from the Bloyd to the Atoka Formation in this area although it has been recognized that the base of the Atoka Formation becomes a regionally truncating surface within 20 mi (32 km) west, in Oklahoma.

New field evidence indicates that (1) the Trace Creek Shale in Washington County, Arkansas, is a facies of the lower part of the Atoka Formation in Oklahoma and (2) the regionally truncating unconformity at the base of the Atoka Formation in Oklahoma passes eastward not into a horizon at the base of the cliff-forming Atoka sandstones but into one at or near the base of the underlying Trace Creek Shale.

The presence of a regionally significant hiatus at or near the base of the

Trace Creek Shale in Washington County, Arkansas, and Adair County, Oklahoma, also is indicated by a gap in the conodont faunal succession, as compared with other, more complete, stratigraphic sequences in the Ardmore basin and in the frontal Ouachitas in southern Oklahoma. Conodont faunas from as few as 10 ft (3 m) above the base of the Trace Creek Shale correlate with occurrences in the Atokan Series in southern Oklahoma, whereas those in the underlying Kessler Limestone Member of the Bloyd Formation are Morrowan in age. Consequently, the Morrowan-Atokan boundary in northwestern Arkansas and northeastern Oklahoma should be redefined to conform with these new data. [566]

Economic Potential of Canyon-Fan Unit in Anadarko Basin, Oklahoma

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The Cunningham sandstone (Springer) can be interpreted as an inner canyon-fan deposit in the Anadarko basin in Oklahoma. Integrated subsurface methods including sedimentary structure analysis, subsurface mapping techniques, log motifs, and paleogeographic patterns were used to interpret the depositional environment.

The sandstone was deposited in a restricted area with onlap occurring across the continental slope. The source of clastic material was from erosion of Chester and older rocks present on the northeast margin of the basin. Later erosion and truncation reflected by Morrowan strata obscure submarine-canyon deposits, but inner canyon-fan deposits are preserved in the Anadarko basin. Cross sections illustrate both truncation and updip onlap of the Cunningham sandstone.

Sedimentary structures from the Cunningham sandstone exhibit a variety of mass- and fluid-flow characteristics. Log motifs show a blocky pattern with sharp basal contacts. Thin alternating sandstones and shales are present in interchannel areas. Sandstone geometry illustrates inner channel-fan patterns. In cross sections depocenters are indicated by a convex-upward bulge in areas where stacking of channels has occurred.

Morrow-Springer sandstone deposits in the Anadarko basin are economically important. Gas reserves in these units approximate 20 Tcf. Traps are generally stratigraphic, but with updip truncations and depositional pinchouts. Other Springer sandstones similar to the Cunningham are important exploration objectives within the Anadarko basin and in similar tectonic basins and borderlands. [566]

Southern Oklahoma Oil Country in Context of Plate Tectonics

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The Anadarko and Ardmore basins represent parts of the southern Oklahoma aulacogen, a Paleozoic tectonic complex that formed transverse to the ancient continental margin of North America. The aulacogen parallels Precambrian structural trends and extends at least 700 km (420 mi) into the Mid-

Continent from its junction with the Ouachita foldbelt in southeastern Oklahoma.

The history of the southern Oklahoma aulacogen includes rifting, subsiding, and deforming stages with reasonable present-day analogies in the Afar region of east Africa (rifting), the Niger delta region of western Africa (subsiding), and the Timor Sea between Australia and Indonesia (deforming). Rifting affected much of North America about 550 m.y. ago and in southern Oklahoma perhaps occurred by right-slip extension as suggested by offset of the Grenville orogenic belt and the N60°W orientation of late Precambrian dikes. Silicic igneous activity followed mafic intrusions and extrusions. During the Late Cambrian through Early Devonian this igneous "basement" subsided below sea level and the aulacogen accumulated 5 to 10 times more marine sediment than adjacent areas, thus forming a structural trough buried with sediment about 10,000 to 15,000 ft (3,000 to 4,500 m) thick. Apparently guided by old normal faults, Devonian to Early Permian deformation included lateral as well as prominent vertical displacements, both reasonably explained by east-west compression related to plate convergence along the Ouachita orogenic belt.

Studies of southern Oklahoma that could lead to new discoveries of oil and gas include: (1) early Paleozoic relations among extensional faulting, sedimentation, magmatic heat, and fluid migration; (2) late Paleozoic structural style and sedimentation relative to remigration of early Paleozoic oil and gas accumulations; and (3) post-Paleozoic extensional fractures related to formation of the Gulf of Mexico. [567]

GSA Annual Meeting, Rocky Mountain Section Provo, Utah, April 28-29, 1978

The following abstract is reprinted from the *Abstracts with Programs* of The Geological Society of America, v. 10, no. 5. Page number is given in brackets below the abstract. Permission of the authors and of Jo Fogelberg, managing editor of GSA, to reproduce the abstracts is gratefully acknowledged.

"Naked" Species of Gondolella (Conodontophorida)—Their Distribution, Taxonomy, and Evolutionary Significance

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The oldest "naked" (absence of broad platform), indeed, the oldest known species of *Gondolella* s.s. is *G. gymna* of earliest Desmoinesian age from northwestern Illinois and rocks of similar age from Japan. This species represents the only "naked" gondolellid from pre-Missourian rocks. *Gondolella denuda*, upon which the concept of "naked" gondolelliform conodonts was originally based, occurs in rocks of early Missourian age—in the Hushpuckney Shale of the Kansas City Group, the Cramer Limestone of the McLeansboro Group, and very rarely

in the Lower Brush Creek Member of the Conemaugh Group. Similar elements occur in rocks of Virgilian age, most commonly in the Queen Hill Shale, but also very rarely in the Heebner Shale, both of the Shawnee Group. The more common species, *Gondolella* n.sp. A, appears to be a direct phylogenetic derivative of *G. denuda*. *Gondolella* n.sp. B is known only from the Heebner Shale at a single locality in northern Oklahoma and seems to be a direct evolutionary descendant of *G.* n.sp. A, derived by a drastic shortening of the blade-like platform. In eastern and central North America *Gondolella* s.s. is unknown higher than the Queen Hill Shale. Thus both the oldest and youngest species of *Gondolella* in this part of North America are "naked." This may have important phylogenetic implications, both for the origin of the broad-platformed species of *Gondolella* and possibly for those of *Neogondolella*.

The multielement apparatuses of *G. gymna*, *G. denuda*, and *G.* n.sp. A have the same element plan of up to six pairs of elements and a bilaterally symmetrical element. *Gondolella* n.sp. B is based only on platform elements at the present time. [240]

The University of Oklahoma

Nannofossils of the Ozan Formation (Cretaceous), McCurtain County, Oklahoma

ANTHONY EDWARD KRANCER, The University of Oklahoma, M.S. thesis, 1975, 6425 Westheimer #401, Houston, Texas

A stratigraphic and micropaleontologic study, concentrating on nannofossils was made of the Ozan Formation of Upper Cretaceous (Gulfian Series) in southeastern McCurtain County, Oklahoma, from a previously described section 2½ miles east of the town of Tom (Morgan, 1967).

Samples of the Ozan Formation were obtained from locations in Oklahoma and Arkansas for laboratory analysis. Standard laboratory procedures were used in the preparation of calcareous microfossils from the sediments. No attempts were made to extract the carbonaceous forms as these had been previously studied by Morgan (1967).

A wide variety of fossils were encountered in the study. Invertebrates occur abundantly and include representatives of Pelecypoda and Cephalopoda in these sections of the Ozan Formation. Also found abundantly throughout the Ozan Formation are representatives of Foraminifera, Ostracoda, spores, pollen, dinoflagellates, acritarchs, and nannofossils. Scanning Electron Microscope and Light Microscope studies revealed thirty-one genera and forty-nine species of nannofossils. Seventeen genera of microforaminifera were distinguished and were similarly examined as the nannofossils.

Analysis of the fossils assemblages show that the Ozan Formation is a transgressive marine unit. Spores and pollen indicate a tropical climate, Marine invertebrate filter feeders indicate quiet water conditions, and the microforaminifera indicate a depositional depth of less than 600 feet.

A correlation with the nannofossil zonations determined from Deep Sea Drilling Project cores indicate that the Ozan Formation was deposited during the *Broinsonia parca* zone of the Early Campanian Stage.

Areal Geology of the Cordell Area, Central Washita County, Oklahoma

REZA MOUSSAVI-HARAMI, The University of Oklahoma, M.S. thesis, 1977, Department of Geology, University of Iowa, Iowa City, Iowa

This report describes an area of 288 square miles in central Washita County, Oklahoma. Rocks cropping out in this area are sedimentary in origin and belong to the Permian System (Guadalupian and Ochoan Series). Total thickness of the outcropping rocks is about 1,000 feet. The oldest formation exposed is the Dog Creek Shale, which is 166 to 203 feet of reddish-brown blocky shale interbedded with thin beds of greenish-gray shale. Unconformably overlying the Dog Creek is the Whitehorse Group, consisting primarily of orange-brown to reddish-brown fine-grained sandstone that is 400 to 600 feet thick. The Whitehorse Group is overlain conformably by the Cloud Chief Formation which is about 400 feet thick and has been divided into two parts. The lower portion of the Cloud Chief is a massive bed of white to gray gypsum, and the upper portion is mostly reddish-brown sandstones and siltstones interbedded with greenish-gray siltstones. The Doxey Shale conformably overlies the Cloud Chief Formation. It consists mainly of reddish-brown mudstones, siltstones, sandstones, claystones, and shales that are 160 to 180 feet thick in central Washita County. The upper part of this unit has been eroded in all parts of the Cordell area. Terrace and alluvial deposits of Quaternary age occur along the course of past- and present-day major streams and consist of gravel, sand, silt, and clay.

These Permian sediments probably had a source area to the east in the Ouachita and Ozark Mountains. They apparently were deposited in shallow-marine environments with some restricted evaporite basins along the border of the sea.

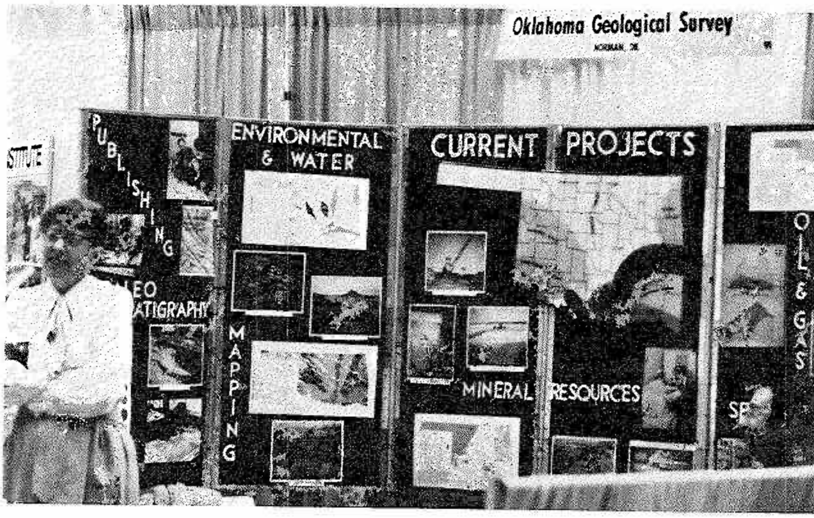
Strata in the Cordell area are exposed on both flanks of the Anadarko basin, the major structural feature in the study area. Outcropping rocks are disrupted and show evidence of collapse due to the solution of salt or gypsum beds that underlie the area.

Surface and Subsurface Study of the Southwest Davis Oil Field, Sections 11 and 14, T. 1 S., R. 1 E., Murray County, Oklahoma

ELLIOTT W. WILTSE, The University of Oklahoma, Norman, Oklahoma M.S. thesis, 1978, Amoco International Oil Co., Chicago, Illinois

That a wrench system provides traps for hydrocarbons has been shown but that production from such a system is possible on the flanks of the Arbuckle Mountains, Oklahoma, is new. Hydrocarbon accumulation is shown to result from a convergent wrench system which shows characteristic en echelon folds, a main wrench fault, thrust faults, the dip of which steepen with depth, and possible antithetic strike-slip faults and extension joints. The thrusting is particularly interesting since it provides the major trapping mechanism by sandwiching the producing unit between impermeable rocks. This complex system is further complicated by the existence of a buried high.

OGS Exhibit at AAPG–SEPM Convention



Betty Ham and Ken Luza at the Survey's booth during the convention held in Oklahoma City in April.

USGS Publishes CRIB Information Circular

USGS Circular 755–A, *Description of CRIB, the GIPSY Retrieval Mechanism, and the Interface to the General Electric MARK III Service*, is an indispensable handbook for those who wish to use the federal agency's Computerized Resources Information Bank.

CRIB, a data-storage system covering the world's mineral resources, was established in 1972 and was made available to the public in 1976 (see *Oklahoma Geology Notes*, v. 33, p. 199; v. 36, p. 59). Access to the data bank is gained through the computer facilities of The University of Oklahoma's General Information Processing System (GIPSY). General Electric's MARK III service, when linked with GIPSY, allows users to communicate directly with the computer. Authors James A. Calkins, Eleanor K. Keefer, Regina A. Ofsharick, George T. Mason, Patricia Tracy, and Mary Atkins discuss the content of the data bank and the mechanism of the retrieval system and offer detailed instructions for recovery of desired information.

Circular 755-A can be obtained on request from the Branch of Distribution, U.S. Geological Survey, 1200 South Eads Street, Arlington, Virginia 22202.

New Theses Added to OU Geology Library

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

Mineralogic and Textural Dispersal Patterns within the Permian Post Oak Formation of Southwestern Oklahoma, by William B. Stone, Jr.

Computer Modeling of Fracture Pattern in a Single Layer Fold Using the Finite Element Method, by Gayle Standridge Tapp.

Pennsylvanian Ichthyoliths from the Shawnee Group of Eastern Kansas, by Linda Elaine Tway.

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