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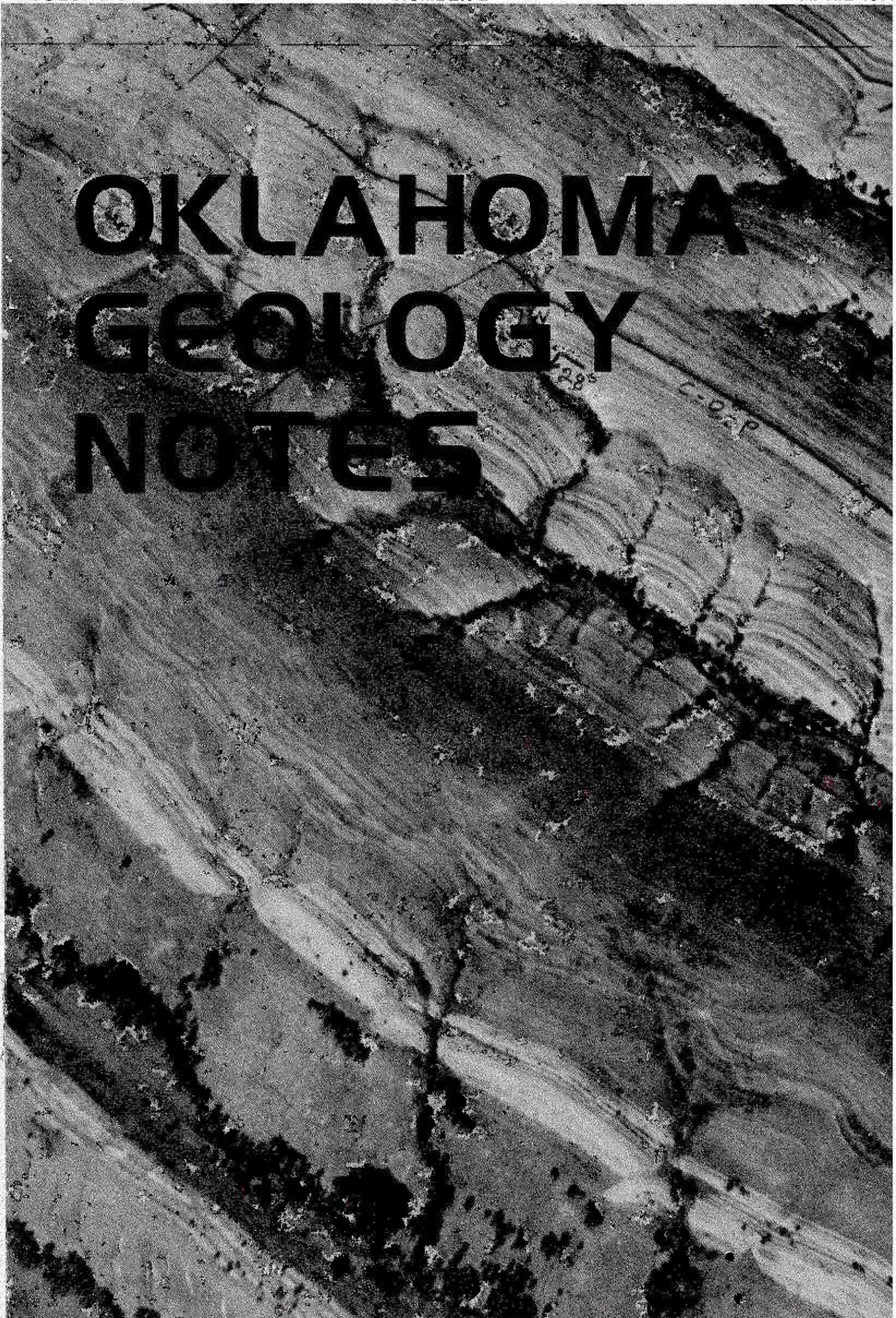
OKLAHOMA GEOLOGY NOTES



Cover Picture

HOMOCLINAL DIP ON SOUTH FLANK OF ARBUCKLE MOUNTAINS

The cover photograph for this issue shows homoclinal southwestern dip of about 3,000 feet of early Paleozoic carbonates on the south flank of the Arbuckle anticline. Lighter colored rocks in the northeast half are limestones of the upper part of the Arbuckle Group (Early Ordovician Kindblade and West Spring Creek Formations), and overlying strata to the southwest are limestones, sandstones, and shales of the entire Simpson Group (Middle Ordovician Joins, Oil Creek, McLish, Tulip Creek, and Bromide Formations).

Strata dip 25 to 30 degrees to the southwest as a result of folding during the Late Pennsylvanian Arbuckle orogeny. Although a number of major faults cut other parts of the Arbuckle anticline, only a few small faults are seen offsetting conspicuous marker beds in this photograph.

The photograph centers on sec. 15, T. 2 S., R. 1 W., in Murray County, and the long axis of the picture is 1 mile. The photograph was taken by the U.S. Department of Agriculture, Agricultural Stabilization and Conservation Service.

—Kenneth S. Johnson

Editorial staff: William D. Rose, Rosemary L. Croy, Elizabeth A. Ham

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 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. 1,500 copies have been prepared for distribution at a cost to the taxpayers of the State of Oklahoma of $1,887.60

BASINWARD FACIES CHANGES IN THE WAPANUCKA FORMATION (LOWER PENNSYLVANIAN) INDIAN NATION TURNPIKE OUACHITA MOUNTAINS, OKLAHOMA

Patrick K. Sutherland[1] and Robert C. Grayson, Jr.[2]

Introduction

The Wapanucka Formation is exposed in a series of arcuate thrust-fault slices about 16 miles south of McAlester, Oklahoma, on the Indian Nation Turnpike in the frontal Ouachita Mountains (fig. 1). The formation and its lateral equivalents are repeated 4 or 5 times in a lateral distance of approximately 2 miles. The frontal-faulted ridge has earned the local name Limestone Ridge from the predominance of limestone and its ridge-forming nature; Wapanucka exposures southward from Limestone Ridge are subdued topographically by the greater shale content. Gordon (1976) correlates the Wapanucka with the Johns Valley Shale (which outcrops in the central part of the Ouachita structural belt), by means of goniatites. There is no information available, however, as to how the facies represented by these two formations are specifically related. The two measured sections examined in this study (fig. 2) represent, to our knowledge, the first documentation of a basinward facies change southward from the frontal Wapanucka Limestone Ridge (Sutherland and Grayson, 1976).

Conodont faunas recovered from the Wapanucka provide a useful biostratigraphic framework for a correlation of the predominantly dissimilar lithologies encountered in the two measured sections. In addition, a correlation based on conodont and goniatite ammonoid occurrences can be suggested with the type Morrowan sequence in northwest Arkansas.

Lithologic Analysis

Locality 1 (fig. 2) represents the typical Wapanucka Formation as recorded at many points along the frontal Ouachita belt, from near the town of Atoka northeastward to Red Oak, Oklahoma (Wallis, 1915; Rowland, 1974). The exposure consists of interbedded spiculiferous packstone and wackestone, carbonate mudstone, and crinoidal-bryozoan, oolitic grainstone and packstone. A few shale interbeds are present, particularly in the upper part of the section. Spiculiferous wackestone and packstone with a siliceous

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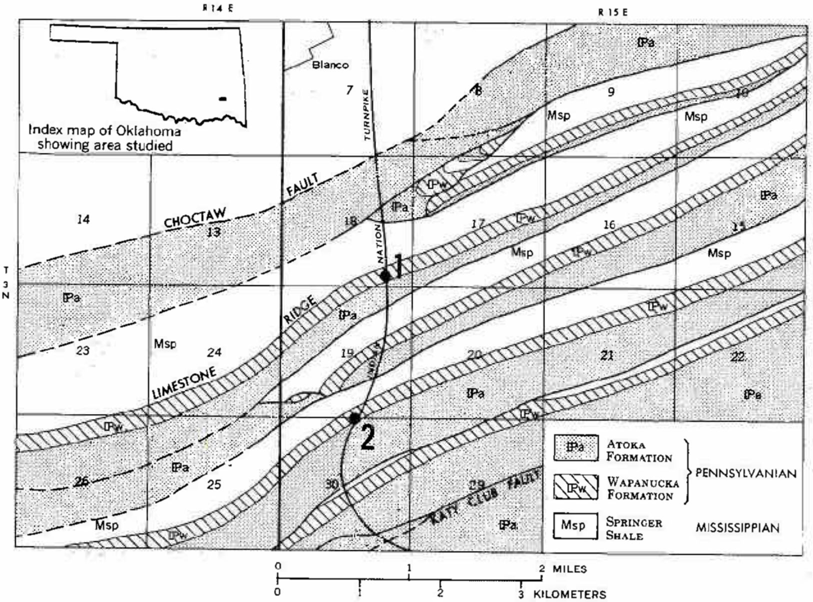

Figure 1. Generalized geologic map showing location of measured sections 1 and 2. (Formations northwest of Choctaw fault not shown; map modified from Hendricks and others, 1947.)

micritic matrix are important in the basal 90 feet (units 2-8). The spiculiferous limestones generally contain an interwoven mass of unoriented siliceous sponge spicules, although weak current action is probably responsible for the minor development of wavy and lenticular bedding. It is not uncommon, however, to find globular concentrations of spicules that are presumed to be in near-life position. A thin, intraclast-bearing grainstone occurs at the base of the predominantly spiculiferous interval and rests with a sharp and slightly irregular contact on the Springer Shale.

Above the spiculiferous interval, nearly 200 feet of the Wapanucka at locality 1 consists of packstones, grainstones, carbonate mudstone, and shale interbeds (units 9-28). The carbonate packstone and grainstone units carry an abundant and varied fauna. Crinozoan detritus and ramose bryozoans are the conspicuous faunal components. Disarticulated valves of brachiopods and bivalves, millirellid and agglutinated forams, and michelenid corals and algal fragments constitute a less abundant but significant volume of bioclastic grains. Ooliths and intraclasts occur sporadically as thin beds or lenses. The carbonate mudstones are sparsely fossiliferous, although crinozoan debris, ostracodes, brachiopods, and algal fragments are found.

Units 29 to 31 consist primarily of sandy to very sandy, oolitic grainstone. Bioclasts in this interval are generally rounded and well sorted. Cross-bedding is common. This interval is overlain by a distinctive carbonate mudstone (unit 33), capped by a black, spiculiferous chert (units 34 and 35) that marks the top of the Wapanucka Formation in this exposure. This carbonate mudstone and the spiculiferous chert are the only units that can be correlated lithologically between localities 1 and 2 (fig. 2).

The measured thickness of the exposure at locality 1 is 310 feet, which is a marked contrast to the measured thickness of 714 feet at locality 2. Locality 2 is about 1 mile south of the frontal ridge at locality 1, on a third faulted ridge. At this exposure, strata equivalent to the Wapanucka consist predominantly of shale. Spiculites form an important element in the lower

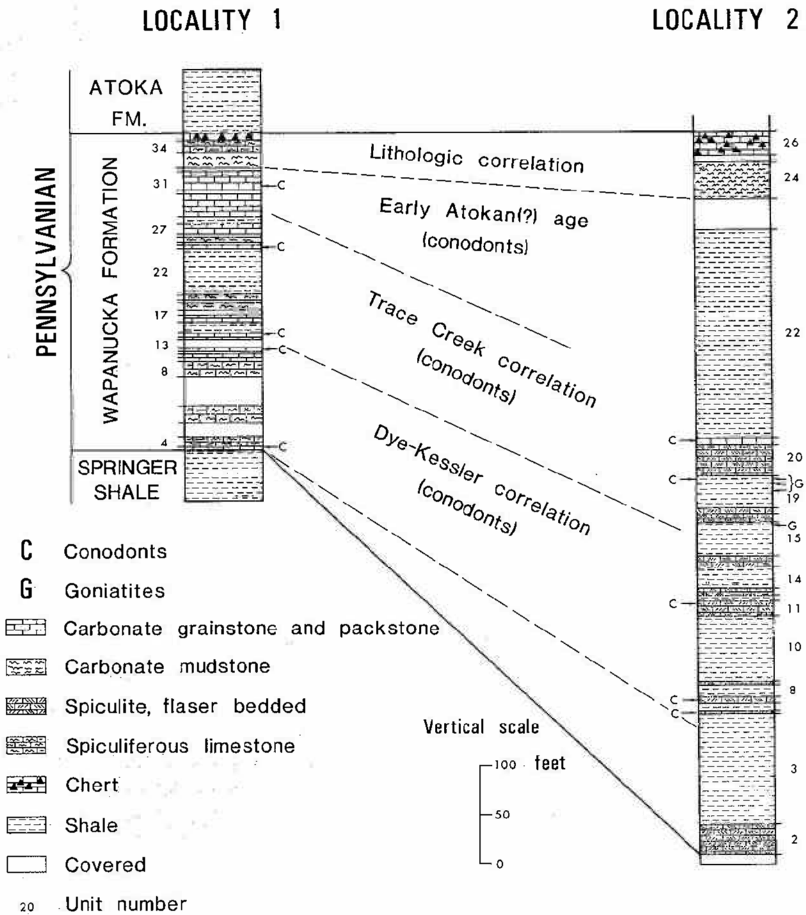

Figure 2. Correlation of formations exposed at localities 1 and 2, Indian Nation Turnpike (see location map, figure 1).

360 feet of the section (units 2-20). The spiculites are composed of current aligned siliceous sponge spicules interbedded with clay in a complex pattern of flaser, wavy, and lenticular bedding. All the spiculites are dark gray or black due to abundant disseminated clay and iron sulfide in the siliceous matrix. A few very thin crinoidal packstones occur within or at the tops of spiculite beds. Commonly, the bases of these carbonates are in sharp contact with spiculite units, but minor irregularities may develop. Above a relatively thick shale and covered interval (units 22 and 23), is a carbonate mudstone that is lithologically similar to the highest carbonate mudstone at locality 1 (fig. 2). This carbonate mudstone is also capped by a unit consisting of spiculiferous black chert (unit 26).

Correlation

The conodont form-species recovered from the Wapanucka at locality 1 and the equivalent strata at locality 2 indicate that the sequence ranges in age from late Morrowan to, possibly, early Atokan (fig. 2). Conodonts from the lower portion of both sections suggest a correlation with the Dye and Kessler Members of the Bloyd Formation of the type Morrowan sequence in Arkansas, based on published data (Lane and Straka, 1974). A goniatite fauna from the upper-middle portion of section 2 has been placed in the *Diaboloceras neumeiri* zone (Gordon and Sutherland, 1975). This zone also occurs in the Trace Creek Member of the Bloyd Formation. The Trace Creek Member is the highest unit in the type Morrowan sequence. Conodonts in this interval of the measured sections are compatible with this correlation, although conodont faunas are not well known in the upper type Morrowan. Conodonts from the highest sample at locality 1 (unit 31)) could indicate an early Atokan age based on the occurrence of *Streptognathodus sp.* cf. *S. elegantulus* and *Gnathodus coloradoensis*. This interval at locality 2 has not produced conodonts, but a lithologic correlation is possible.

Depositional History

Paleozoic depositional environments provided a unique combination of physical and biological interactions. Their interpretation presents special problems because of the uncertainty in establishing recent-ancient analogues. Particular difficulties exist in assuming similar distribution of ancient populations and their presumed modern-day counterparts. An example of special relevance in understanding Wapanucka depositional history is that of evaluating the environmental significance of siliceous sponges. In modern marine environments, hyalosponges, the dominant producers of siliceous spicules, are characteristically associated with deep and cold water. Carboniferous spiculites have traditionally been interpreted as indicating deep-water deposition. Ham and Rowland (1971) concluded that thick spiculiferous limestones found in the Wapanucka Formation (frontal ridge) accumulated in depths of water in excess of 600 feet. Alternatively, siliceous sponge spicules have been described as occurring in abundance in quiet, shallow, near-shore environments in Pennsylvanian strata in the Appalachian Plateau (Cavaroc and Ferm, 1968).

The occurrence of sponge-spicule masses in a near-life position in the Wapanucka at locality 1, in a siliceous, micritic matrix, suggests deposition either below wave base in a moderately deep environment or in a shallower but quiet, possibly lagoonal, environment. We postulate that loose spicules were derived from this environment and transported basinward into deeper water. The abundance of black, flaser-bedded spiculites at locality 2 might indicate deposition below the zone of effective oxygenation. The uncommon, thin beds of crinoidal grainstone at locality 2 may also represent basinward transport by more energetic currents that scoured pre-existing but unlithified spiculiferous surfaces, thereby accounting for the sharp contacts exhibited between these two lithologies.

We expect to make a more precise interpretation of the spiculiferous facies in the Wapanucka Formation after the completion of a detailed regional investigation. We have concluded, however, that the exposure at locality 2 represents, except for the highest strata, a deeper water, more basinward deposit than the equivalent strata at locality 1, although original depositional distances between these faulted exposures cannot be determined.

The distinctive carbonate mudstone at the top of the exposures at both localities 1 and 2 is thought to have accumulated above wave base in a shallow-water, protected, carbonate, mud-bank environment. We do not have sufficient control, currently, to explain the restricted occurrences of bioclastic and oolitic grainstones at locality 1. Presumably, this area was relatively less sheltered from wave action than the equivalent strata at locality 2. Regardless of the exact control, the shallow-water origin of these rocks and the distinctive carbonate mudstone indicate a significant shallowing of the Ouachita trough in late Morrowan and (or) early Atokan time.

References Cited

Cavaroc, V. V., Jr., and **Ferm, J. C.**, 1968, Siliceous spiculites as shoreline indicators in deltaic sequences: Geological Society of America Bulletin, v. 79, p. 263-272.

Gordon, Mackenzie, Jr., 1976, Correlation chart of Carboniferous rocks in Arkansas and Oklahoma: U.S. Geological Survey Bulletin 1422-A.

Gordon, Mackenzie, Jr., and **Sutherland, P. K.**, 1975, Ammonoids of the upper Wapanucka Limestone and their bearing on the Morrowan-Atokan boundary in Oklahoma: American Association of Petroleum Geologists, Annual Meetings Abstracts, v. 2, p. 30.

Ham, W. E., and **Rowland, T. L.**, 1971, Burial cementation in the Wapanucka Limestone (Pennsylvanian) of Oklahoma, *in* Bricker, O. P. (editor), Carbonate cements: Johns Hopkins University Studies in Geology no. 19, p. 198-204.

Hendricks, T. A., **Gardner, L. S.**, and **Knechtel, M. M.**, 1947, Geology of the western part of the Ouachita Mountains of Oklahoma: U.S. Geological Survey Oil and Gas Investigations Preliminary Map 66, sheet 1 of 3.

Lane, H. R., and **Straka, J. J., II**, 1974, Late Mississippian and Early Pennsylvanian conodonts, Arkansas and Oklahoma: Geological Society of America Special Paper 152, 144 p.

Shelton, J. W., and **Rowland, T. L.**, 1974, Guidebook to the depositional environments of selected Pennsylvanian sandstones and carbonates of Oklahoma: Oklahoma State University and Oklahoma Geological Survey, Guidebook for GSA Field Trip (1974 South-Central Section annual meeting), 75 p.

Sutherland, P. K., and **Grayson, R. C., Jr.,** 1976, Basinward facies changes in the Wapanucka Limestone (Lower Pennsylvanian), Indian Nations Turnpike, Ouachita Mountains, Oklahoma: American Association of Petroleum Geologists Bulletin, v. 60, p. 727.

Wallis, B. Franklin, 1915, The geology and economic value of the Wapanucka Limestone of Oklahoma: Oklahoma Geological Survey Bulletin 23, 102 p.

AAPG Sponsors Field Seminars

The American Association of Petroleum Geologists is sponsoring a series of field seminars in geology as part of its continuing-education program. Five field seminars have been set up. Each will run approximately 5-7 days and consist of lectures, laboratory exercises, and field work—with principal emphasis on field observations. Information about the date, course title, person presenting the seminar, location, cost, and maximum enrollment appears below.

May 12-19, 1977

Modern Clastic Depositional Environments (South Carolina Coastal Plain), MILES O. HAYES, Coastal Research Division, Department of Geology, University of South Carolina ($900). Includes $50 registration fee, guidebook, lodging, and some meals. Limit: 18.

May 22-28, 1977

Ancient Clastic Depositional Environments (southwestern West Virginia and eastern Kentucky), JOHN HORNE, Department of Geology, University of South Carolina ($725). Includes $50 registration fee. Limit: 25.

May 9-15, 1977

Modern Carbonate Sediments and Their Diagenesis (Great Bahama Bank aboard research vessel *Goldenrod*), CONRAD GEBELEIN, Department of Geological Sciences, University of California at Santa Barbara ($1,000). Includes $50 registration fee, living costs aboard *Goldenrod,* and guidebook. Limit: 16.

May 16-21, 1977

Ancient Carbonate Rock Sequences and Their Diagenesis (Lower Cretaceous in Central Texas), CLYDE H. MOORE, Department of Geology, Louisiana State University ($635). Includes $50 registration fee, lunches, and guidebook. Limit: 18.

June 27-July 1, 1977

Modern Deltas (Mississippi Modern Delta), JAMES M. COLEMAN, Coastal Studies Institute, Baton Rouge ($675). Includes $50 registration fee, lodging, guidebook, and lunches in field. Limit: 25.

For further information about the field seminars, please contact the Department of Educational Activities, The American Association of Petroleum Geologists, P.O. Box 979, Tulsa, Oklahoma 74101.

OGS Issues Trilobite Bulletin

A bulletin describing trilobites in the vicinity of the Wichita Mountains, southwestern Oklahoma, has just been released by the Oklahoma Geological Survey. Written by James H. Stitt, chairman of the Department of Geology at the University of Missouri-Columbia, the study has been issued as Bulletin 124 and is entitled *Late Cambrian and Earliest Ordovician Trilobites, Wichita Mountains Area, Oklahoma.*

Jim Stitt is no stranger to Oklahoma biostratigraphy, having authored a report on trilobites from rocks of the same age in the Arbuckle Mountains to the east—published as Bulletin 110 by the Survey in 1971. Like Bulletin 110, the present study focuses on trilobites from the Timbered Hills and Arbuckle Groups, which crop out along the northwest-trending Blue Creek Canyon anticline, directly north of the Wichita Mountains.

Among the 66 trilobite genera and 98 species the author identifies in his study are 1 new genus, *Reaganaspis*, and 2 new species, *R. parva* and *Stigmacephaloides verticalis*.

Bulletin 124 contains 6 pages of carefully reproduced plates of trilobite photographs and a large chart folded in a pocket giving stratigraphic occurrences and ranges of identified trilobites from a section measured in the vicinity of Chandler Creek. Other parts of the text, in addition to the systematic descriptions, include discussions of lithostratigraphy, biostratigraphy, and depositional history as well as a description of the Chandler Creek section with a list of its taxa.

The 79-page bulletin can be ordered from the Survey by writing to the address on the front cover. Paperbound copies sell for $5.00 apiece, and clothbound copies, $7.00.

OU Plans Energy Center

The University of Oklahoma has secured approval from the OU Board of Regents to establish an Energy Resources Center. Its purpose, according to Provost Barbara Uehling, is to organize and direct the efforts of the university in helping to solve energy-resources problems. She reports that OU has already done considerable research in energy-related areas, and the center is expected to reinforce this emphasis and fuse all of the university's energy research into one central program.

The center will inventory research in progress, facilitate the development of further research, promote liaison with the industries of our state, and help develop technology that will be beneficial to industry. Emphasis will be on improving understanding and practices for exploration, exploitation, production, processing, and utilization of energy resources. Economics will be stressed along with science and technology.

The University of Oklahoma plans to hire a director and have the new Energy Resources Center in operation by the fall of 1977.

Colorado Coal Resources Summarized

The Colorado Geological Survey has released Special Publication 9, *1975 Summary of Coal Resources in Colorado,* by A. L. Hornbaker, Richard D. Holt, and D. Keith Murray. The 17-page booklet is an expanded and updated version of Special Publication 3, prepared by Hornbaker and Holt and printed in 1973, and it was prepared in March 1975 by D. K. Murray for incorporation into the *1976 Keystone Coal Industry Manual.*

The summary contains information on all coal-bearing regions and rocks of Colorado, their geology, structure, and stratigraphy; comments on the chemical and physical properties of Colorado coal; production statistics; detailed descriptions of each coal region and field, listing representative coal-bed thicknesses and analyses, recent industry activity, and coal utilization; an estimate of coal resources to depths of 6,000 feet by coal region; an updated list of selected references on Colorado coal; a table showing ranges of analyses for the major coal beds in each field and region; and a stratigraphic chart highlighting the coal-bearing rocks in Colorado.

Special Publication 9, priced at $1.00 postpaid, can be ordered from the Colorado Geological Survey, Room 715, State Centennial Building, 1313 Sherman Street, Denver, Colorado 80203. Prepayment is requested.

Colorado Survey Sponsors Coal Symposium

The Colorado Geological Survey is sponsoring the "1977 Symposium on the Geology of Rocky Mountain Coal," to be held May 9-10 at the Cecil H. and Ida Green Graduate and Professional Center, Colorado School of Mines, Golden.

The schedule calls for presentation of 10 papers, all of which deal with the role of depositional environments in the understanding of the occurrence, geometry, correlation, and character of coal beds and the recognition of other geologic factors that are important to mine planning. In addition, workshops are planned on (1) lithologic classification of core and computer data retrieval, (2) interactive computer mapping, (3) recognition of depositional environments from coal cores, and (4) petrography of western coals.

Symposium speakers include geologists from industry, government, and academic institutions. In addition to area geologists, experts from several coal-producing regions outside the Rockies will discuss aspects of coal geology that are applicable to stratigraphic problems that characterize Tertiary and Late Cretaceous coal-bearing sequences in the Rocky Mountain region.

Symposium sessions will be followed by a field trip, by bus, to the important coal mines and fields of northwestern Colorado. (Field trip headquarters will be in Steamboat Springs, Colorado). Attendance on the field trip will be limited to approximately 200.

For further information and registration forms, please contact: D. Keith Murray, Coal Symposium Chairman, Colorado Geological Survey.

GEOCHEMISTRY OF THE FAYETTEVILLE SHALE NORTHWESTERN ARKANSAS

Kenneth F. Steele[1] and Garland C. Lamb[2]

Abstract—Reconnaissance data for this study indicate that there was no significant difference in the source or environment of deposition for the Upper Mississippian Fayetteville Shale along a sampling profile in northwestern Arkansas that probably parallels the depositional shoreline, and although shale deposition was interrupted by deposition of the Wedington Sandstone Member, the same or a similar source and environment of deposition was reestablished with respect to the elements analyzed in this study.

The composition of the Fayetteville Shale appears to be typical, and it is approximately the same as that of the Chattanooga Shale (of Devonian age), except that the former may have a higher strontium content. Median concentrations for constituents of the Fayetteville Shale are given in parts per million by weight (ppm), except for iron, magnesium, sodium, potassium, and manganese, which are in weight percent: iron (2.7), magnesium (1.3), sodium (0.13), potassium (2.2), manganese (0.1), chromium (100), nickel (160), rubidium (360), strontium (270), yttrium (50), zinc (280), zirconium (150), cadmium (0.3), cobalt (4), copper (37), and lead (44).

Introduction

The Fayetteville Shale, consisting of lower and upper shale units and a middle sandstone unit where present (fig. 1), crops out along the southern flank of the Ozark uplift in a belt approximately 80 miles wide (from north to south) and 225 miles long (from east to west). The eastern end of the belt is near Batesville, Arkansas, and the western end of the belt is bounded by the Neosho River in Oklahoma (Croneis, 1930). The thickness of the formation ranges from 10 feet in the south to 400 feet in the north. In the area studied (fig. 2), the thickness ranges from 50 to 300 feet (Cate, 1962). The Fayetteville Shale is of Late Mississippian (Chesterian) age. It appears to be conformable on the Batesville Formation where it is present and disconformable on the Boone Formation where the Batesville is absent. The contact with the overlying Pitkin Formation (Mississippian) is disconformable, and where the Pitkin is absent the Fayetteville Shale is overlain by the Hale Formation. Fayetteville Shale exposures are sparse because of dense vegetation and a mantle of soil, but the shale is exposed along streams, road cuts, excavations, and on steep slopes.

Description

The lower shale unit of the Fayetteville formation is black to gray shale containing numerous orange-brown concretions. The unweathered shale

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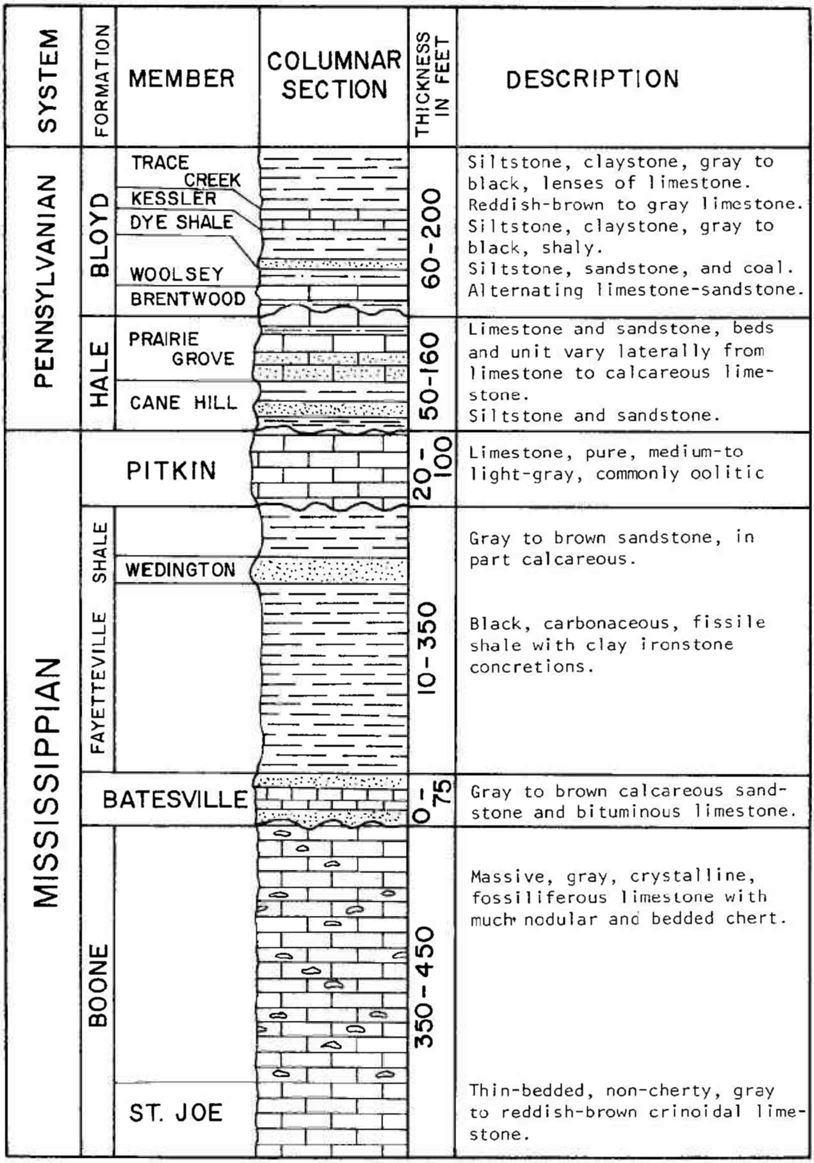

Figure 1. Stratigraphic column for northwestern Arkansas.

appears massive and nonfissile. Where the shale has been subjected to weathering for some time, fissility is pronounced and the shale is light brown to tan. The lower shale unit includes about two-thirds of the total thickness of the formation. In some areas, only the lower shale exists (Cate, 1962). The black color of the shale, the bituminous odor released when it is broken, and the amount of dark-brown material in thin sections suggest that the organic content is high. Some workers have referred to it as a kerogen shale. However, the carbon content reported varies only from 2 to 3 percent organic carbon, which comprises about 97 percent of the total carbon (Zangerl and others, 1969). Diffraction data indicate that the shale is about 70-percent clay and 15-percent quartz. The clays present are kaolinite, chlorite, illite, and predominantly a mixed-layer clay partly expandable with ethylene glycol (Zangerl and others, 1969). The shale also contains water, pyrite, and gypsum and at places is sufficiently calcareous to effervesce in acid (Zachry, 1964). The upper shale unit is generally lighter in color, more silty, and generally not as fissile as the lower unit. Some concretions similar to those in the lower unit occur in the upper interval (Cate, 1962).

The Wedington Sandstone Member of the Fayetteville Shale consists principally of compact, brown, medium- to fine-grained quartz sandstone that generally contains cross-bedding and ripple marks. The Wedington attains a thickness of 150 feet in the northwestern part of Washington County, Arkansas, but is absent to 5-feet thick in the Fayetteville area (Cate, 1962).

The lower shale unit of the Fayetteville contains marine fossils, some of which are pyritized. Remains of terrestrial plants also have been collected from the lower unit. Rapid sedimentation for the shale has been suggested to explain the observed burial aspects of small goniatite and cephalopod shells (Zangerl and others, 1969). The presence of pyrite and organic material and the paucity of bottom faunal fossils indicate a reducing environment.

Method

Fifteen samples were collected at the points shown in figure 2. The sampling trend is roughly parallel to the shoreline at the time of deposition. Two samples of the Chattanooga Shale were collected for comparison, and only 1 sample was collected from the upper Fayetteville Shale (fig. 2). The Chattanooga, a marine shale, is Late Devonian (or Early Mississippian) in age. The uppermost part of the Chattanooga that was sampled is a medium-gray, nonfissile shale. It also contains pyrite and is calcareous in places.

The shale samples were powdered and pressed into pellets with boric acid as a backing. The samples were analyzed (table 1) using a Philips-Norelco Vacuum Path X-ray Spectrograph equipped with a tungsten tube, a lithium-fluoride analyzing crystal, and a scintillation detector. Concentrations were determined using U.S. Geological Survey rock standards. Mass-absorption corrections were made for zirconium, rubidium, strontium, and yttrium. The accuracy and the precision are each about ± 10 percent of the value for each element. Three samples (a high-iron sample, a low-iron sample, and a Chattanooga Shale sample) were also analyzed by atomic-absorption spectrometry (table 2) after treatment with HF, HNO_3, and HCl.

Geochemistry

As might be expected of a group of samples collected parallel to shoreline, there are no systematic chemical variations for the samples. The data for one sample (no. 3) from the upper unit consistently fall within the same ranges as the lower-unit samples (tables 1 and 2). The similarities between the upper and lower Fayetteville shales can be attributed to the same or a similar source and (or) environment of deposition because the intervening Wedington Sandstone Member is thin. However, it is somewhat surprising to note the chemical similarity of the Fayetteville Shale and the Chattanooga Shale (table 1), because the Boone and Batesville formations are

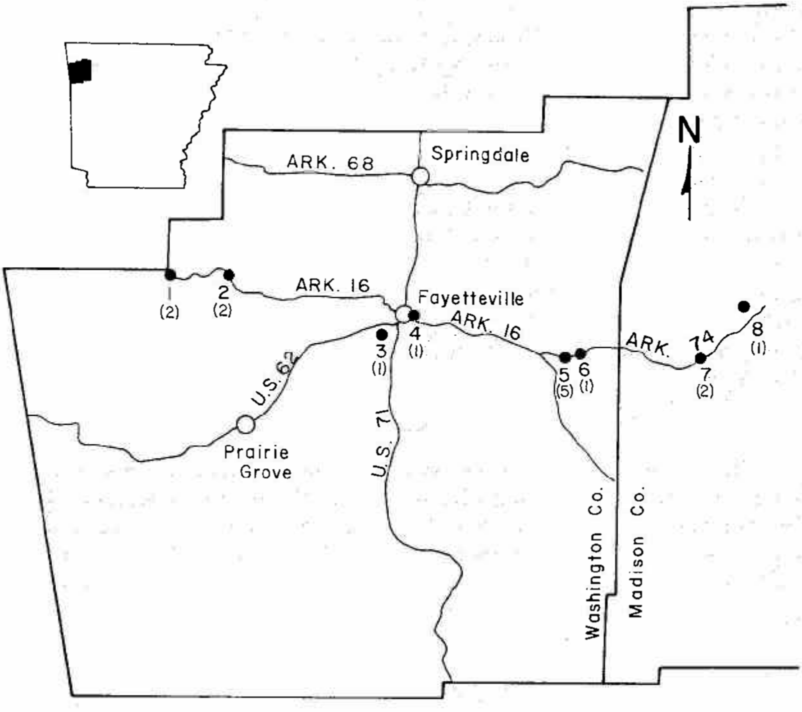

Figure 2. Map showing sample information. Inset shows location of study area in northwestern Arkansas. Upper number is sample-location designation; number in parentheses indicates how many samples were collected. Two samples were collected at point 2 from the Chattanooga Shale; 1 sample was collected at point 8 from the upper shale unit of the Fayetteville Shale; samples from the lower shale unit of the Fayetteville Shale were collected at all other locations.

thick units that were deposited between these two shale units. The similarities imply that the source and (or) the environment of deposition (at least with respect to most of the elements) were similar for the Fayetteville and Chattanooga Shales. The Chattanooga Shale may contain more potassium (table 2) and apparently contains less strontium (table 1) than the Fayetteville Shale (however, it should be noted that the potassium data is from the analysis of only 2 Fayetteville Shale samples and only 1 Chattanooga Shale sample).

Compared with Turekian's (1972) computations for average shale composition, the Fayetteville Shale is lower in iron; higher in nickel, zinc, and rubidium; slightly higher in yttrium and zinc (tables 1 and 2). Zirconium, which is indicative of detrital contribution, is occasionally present in anomalously high amounts, probably reflecting local concentrations of heavy minerals. There are old zinc prospects in Washington County, and the higher zinc values may reflect light mineralization. The lower iron value suggests leaching, but the higher rubidium value tends to argue against this possibility, because rubidium normally is easily removed by leaching.

Iron, chromium, and nickel contents usually correlate positively with the detrital fraction of shale; however, iron sometimes correlates with the organic carbon fraction (Vine and Tourtelot, 1970). Both chromium and nickel yield general positive correlations with iron for the Fayetteville Shale (fig. 3), which indicates that a significant part of the iron is detrital;

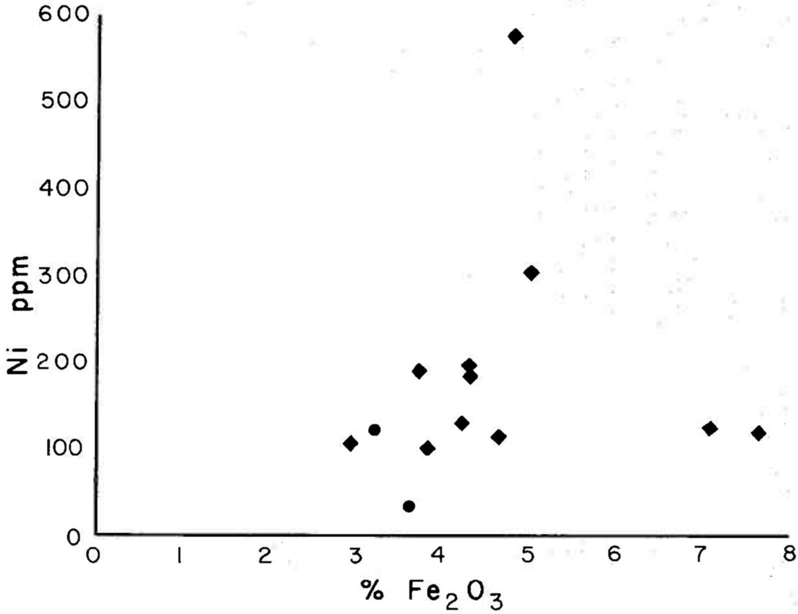

Figure 3. Plot showing nickel versus iron content. Circles represent Chattanooga Shale samples; diamonds represent Fayetteville Shale samples.

TABLE 1. ATOMIC-ABSORPTION DATA[1] FOR THE FAYETTEVILLE AND CHATTANOOGA SHALES COMPARED WITH "AVERAGE SHALE"[2]

SAMPLE NO.	FE	MG	CA	NA	K	MN	CD	CO	CU	CR	NI	PB	ZN
3	7.41	2.18	8.38	0.21	1.87	0.108	0.39	<1	37	447	133	48	221
4	1.40	0.42	—	0.04	2.60	—	0.25	7	37	328	82	39	89
Chattanooga	2.06	1.01	—	0.10	3.40	0.013	0.24	9	18	123	45	38	45
Average shale	4.72	1.50	2.21	0.96	2.66	0.085	0.3	19	45	90	68	20	95

[1]Iron, Mg, Ca, Na, K, and Mn are in weight percent; other elements are in ppm.
[2]Turekian, 1972.

TABLE 2. COMPARISON OF FAYETTEVILLE SHALE CHEMISTRY (DETERMINED BY X-RAY FLUORESCENCE) WITH OTHER SHALES
(Iron Content Is Given in Weight Percent; Other Elements Are Shown by PPM)

	FE	CR	NI	ZN	RB	SR	Y	ZR
Fayetteville								
Range	3-7	50-200	100-600	100-1300	250-450	140-500	20-100	120-820
Average	2.7	100	160	280	360	270	50	280
Chattanooga								
Literature range[1]	1-2	50-100	50-100	0-200	—	100-200	20-50	50-100
Average (this study)	3.3	80	80	120	—	70	45	360
Upper Paleozoic[2] Arkansas Shale	3.3	110	45	—	—	110	23	79
Lower Paleozoic[3] Arkansas Shale	1.9	60	30	120	—	35	16	80
Other Carboniferous Shales								
Tacket (Kansas)[3]	2.4	350	120	290	—	210	18	33
Missouri-Kansas-Oklahoma[4]	4.0		38			200		110
Cherokee Group[2]	3.6	260	100	500	—	330	28	51
Woodford[1]	0.2-10	10-1000	50-500	<70-500	—	50-500	20-100	50-100
SE Kansas-NE Oklahoma[5]	1.6	290	110	2200	—	220	31	51
Average Shale[6]	4.72	90	68	95	140	300	26-35	160-200

[1]Landis, 1962
[2]Vine and others, 1969
[3]Vine and Tourtelot, 1969
[4]Connor and Ebens, 1972
[5]Vine, 1969
[6]Turkekian, 1972

yet the lack of a zirconium-iron trend (not shown) indicates that part of the iron content is nondetrital. Strontium would be expected to be associated with carbonate minerals; therefore, it is somewhat surprising to note that it has a positive correlation with iron (fig. 4). However, the strontium concentration may be related to organic activity, and the decaying organic matter could have caused iron precipitation by production of hydrogen sulfide. Because zirconium is indicative of detritus, the correlation of yttrium and rubidium with zirconium (fig. 5) suggests that the major source of these elements is also detrital material.

The Fayetteville Shale is higher in nickel, zinc, strontium, yttrium, and zirconium than the Paleozoic shales of the Arkansas Ouachita region (table 2). These shales, no doubt, had different source areas and possibly different depositional environments than the Fayetteville Shale, and therefore differences in composition would be expected. Compared with other carboniferous shales in the region (table 2), the Fayetteville is slightly lower in chromium content and higher in zirconium and perhaps in yttrium. Thus, although the Fayetteville Shale has its own characteristic composition, it is not atypical in composition.

The manganese-iron and rubidium-potassium ratios are in agreement with those reported for marine shales. Degens and others (1958) report a manganese-iron value of 0.014 for nonmarine shale and 0.025 for marine shale. Most of the Fayetteville Shale samples had manganese concentrations below detection, and the highest value for the three samples with detectable manganese yielded a 0.019 manganese-iron ratio. Campbell and Williams (1965) found a rubidium-potassium ratio of 0.004-0.006, indica-

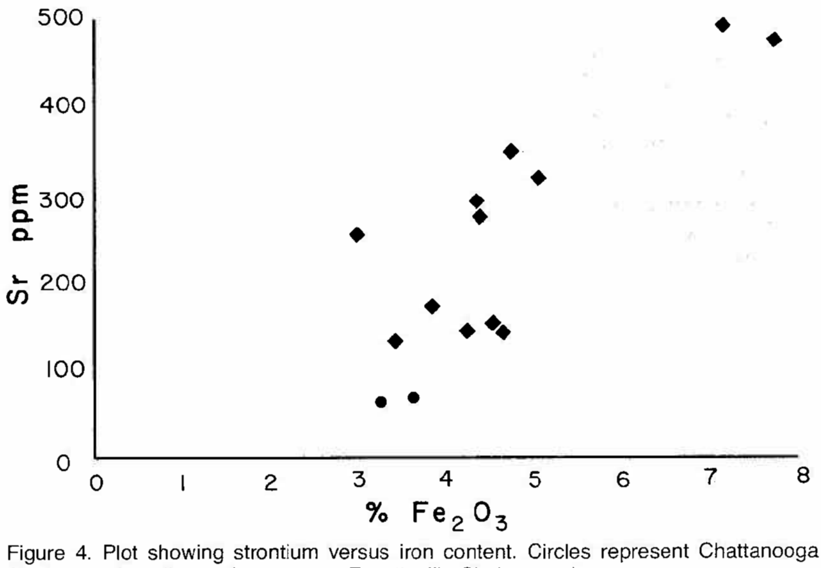

Figure 4. Plot showing strontium versus iron content. Circles represent Chattanooga Shale samples; diamonds represent Fayetteville Shale samples.

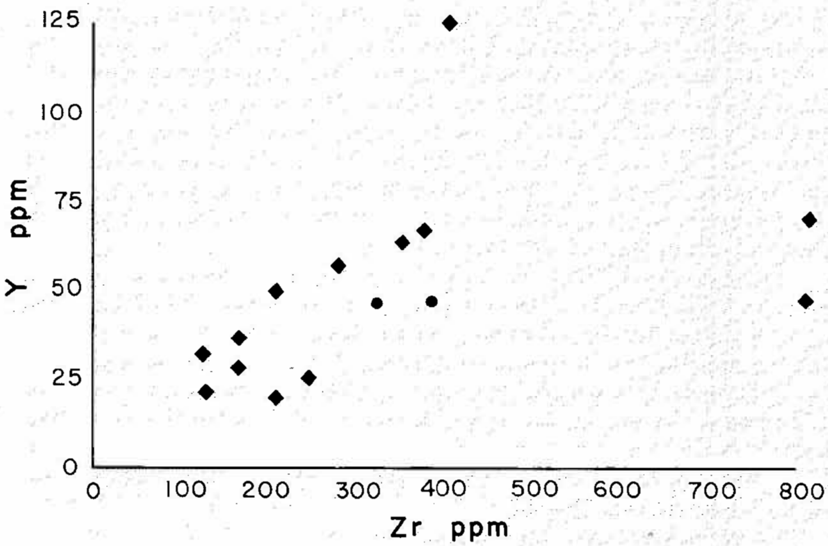

Figure 5. Plot showing yttrium versus zirconium content. Circles represent Chattanooga Shale samples; diamonds represent Fayetteville Shale samples.

tive of a brackish regime, and greater values indicative of a marine origin. Using the two potassium analyses available, the Fayetteville Shale's rubidium-potassium ratio is about 0.013.

Conclusions

It should be noted that data on the Fayetteville Shale are limited; however, it appears that the upper and lower shale units are similar in composition to the Chattanooga Shale, which suggests a similar source and depositional environment for them. As expected, no systematic chemical variations for the Fayetteville Shale samples were evident, because the samples were collected parallel to shoreline. The shale is not an anomalously metal-rich shale. Zirconium, yttrium, and tubidium contents are primarily associated with detrital material. Chromium and nickel correlate positively with iron, which may be partly detrital and partly chemically deposited. Strontium is apparently controlled by organic material.

References Cited

Campbell, F. A., and **Williams, G. D.,** 1965, Chemical composition of shales of Mannville Group (Lower Cretaceous) of central Alberta, Canada: American Association of Petroleum Geologists Bulletin, v. 49, p. 81-87.

Cate, P. D., 1962, The geology of the Fayetteville quadrangle, Washington County, Arkansas: University of Arkansas unpublished M.S. thesis, 111 p.

Connor, J. J., and **Ebens, R. J.,** 1972, Geochemical variation in Pennsylvanian shale: Geological Society of America North-Central Section Program, v. 4, no. 5, p. 314-315.

Croneis, C. G., 1930, Geology of the Arkansas Paleozoic area, with special reference to oil and gas possibilities: Arkansas Geological Survey Bulletin 3, 457 p.

Degens, E. T., Williams, E. G., and **Keith, M. L.**, 1958, Environmental studies of carboniferous sediments, Part II; Application of geochemical criteria: American Association of Petroleum Geologists Bulletin, v. 42, p. 981-997.

Landis, E. R., 1962, Uranium and other trace elements in Devonian and Mississippian black shales in the central midcontinent area: U.S. Geological Survey Bulletin 1107-E, p. 289-336.

Turekian, K. K., 1972, Chemistry of the Earth: New York, Holt, Rinehart and Winston, Inc., 131 p.

Vine, James D., 1969, Element distribution in some Paleozoic black shales and associated rocks: U.S. Geological Survey Bulletin 1214-G, 32 p.

Vine, J. D., and **Tourtelot, E. B.**, 1969, Geochemical investigations of some black shales and associated rocks: U.S. Geological Survey Bulletin 1314-A, 43 p.

———1970, Geochemistry of black shale deposits—Summary report: Economic Geology, v. 65, p. 253-272.

Vine, J. D., Tourtelot, E. B., and **Keith, J. R.**, 1969, Element distribution in some trough and platform types of black shale and associated rocks: U.S. Geological Survey Bulletin 1214-H, 38 p.

Zachry, D. L., Jr., 1964, The lithology of the Fayetteville black shale: University of Arkansas unpublished M.S. thesis, 81 p.

Zangerl, Rainer, Woodland, B. G., Richardson, E. S., and **Zachry, D. L., Jr.**, 1969, Early diagenetic phenomena in the Fayetteville black shale (Mississippian) of Arkansas: Sedimentary Geology, v. 3, p. 87-119.

USGS Film Shows OCS Inspections

An independent survey made of people living near the East Coast, West Coast, and the Gulf of Mexico indicated that few people know anything specific about safety-inspection programs for oil and gas operations on the Outer Continental Shelf (OCS). "Consensus of Concern," a color and sound motion-picture film has been produced for the U.S. Geological Survey by Jerry Warner and Associates, Westlake Village, California, to acquaint the public with USGS procedures.

The 28-minute film focuses on the USGS petroleum-engineering technicians who make daily helicopter flights over OCS areas to insure that oil and gas production is accomplished safely and without damage to the environment, in compliance with federal regulations and orders that govern OCS operations.

The opening scenes of the film show a USGS petroleum technician surveying the Santa Barbara, California, coastline and inspecting the platform and well that brought national attention to offshore oil drilling. Most of the film, however, concentrates on procedures conducted by the teams of drilling and production inspectors in the Gulf of Mexico.

Educational, institutional, industrial, and other groups with special interests in environmental and natural-resource activities are invited to view the film by contacting the U.S. Geological Survey's Branch of Visual Services, 303 National Center, Reston, Virginia 22092.

GSA Annual Meeting, North-Central Section Carbondale, Illinois, April 28-29, 1977

The following abstracts are reprinted from the *Abstracts with Programs* of The Geological Society of America, v. 9, no. 5. Page numbers are given in brackets below the abstracts. Permission of the authors and of Jo Fogelberg, managing editor of GSA, to reproduce the abstracts is gratefully acknowledged.

Ctenostome Bryozoans and Burrowing Barnacles of the Wreford Megacyclothem (Lower Permian; Kansas-Oklahoma-Nebraska)

ROGER J. CUFFEY, Department of Geosciences (Deike Bldg.), Pennsylvania State University, University Park, Pennsylvania

At some Wreford localities, a few shells bear encrusting thread-like networks, the inconspicuous traces of ctenostome bryozoans. Although nowhere abundant, these fossils are intriguing because they represent a major bryozoan group which today is distributed rather differently from surviving tubular bryozoans, more like those dominating Permian suites.

Wreford ctenostome colonies consist of thread-like, uniform-width, branching stolons, in places encrusting up on the shell's surface but elsewhere descending down into narrow grooves or tunnels boring into the shell. The stolons lack zooecial attachment scars and flanking bulbous vesicles. Two species are recognizable; *Condranema magna* has moderately thin stolons 0.10-0.18 mm wide, and the much rarer *Condranema parvula* has extremely thin stolons only 0.02 mm across.

Found usually on brachiopod and pelecypod shells (especially derbyids, productids, and pectinids), *Condranema* occurs mostly in Wreford calcareous shales but also sparsely in brachiopod-molluscan and molluscan limestones. At some horizons, these ctenostomes show more southern distribution, but in others they scatter across central and northern Kansas as well. They thus preferred deeper, normal-marine offshore paleoenvironments but also tolerated somewhat more brackish and near-shore settings (unlike some distinctly estuarine living ctenostomes).

Wreford strata also contain shells marked by deep narrow slit- or dent-like depressions, often connected by thin stolons. This fossil is *Bascomella gigantea*, originally described as a ctenostome species but instead clusters of borings made by acrothoracic barnacles which by coincidence sometimes settled among *Condranema* networks. [587-588]

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.

Coal Deposits of the Senora Formation (Middle Pennsylvanian) in Part of Northeastern Oklahoma

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Preliminary maps and cross sections show the stratigraphic and geographic distribution of the Weir-Pittsburg, Mineral, Croweburg, and Iron Post coals in Craig, Mayes, Nowata, and Rogers Counties, northeastern Oklahoma. As members of the 280-foot-thick Senora Formation (Cabaniss Group, Desmoinesian Series), these coals contains 257 million short tons of identified, remaining strippable resources. Although this represents only 4% of the State's remaining total coal resources of 7,200 million short tons, 69% of Oklahoma's 1975 coal production came from 11 strip mines in these coals. The coals contain sparse, thin bands of vitrain and moderately bright attritus. The average thickness of the coals is 1.5 feet, and the average sulfur content, 3.7%. Gray shale, light-brown sandstone, or dark- or medium-gray limestone and shale overlie the coals.

Three minor coals, of which only the Fleming contains identifiable resources, and an unnamed 2-inch-thick coal below the Verdigris Limestone also occur in the Senora Formation.

Neither the major nor the minor coals persist southward into the Arkoma basin. The Weir-Pittsburg, Mineral, and Croweburg coals are present northeastward in Kansas and Missouri, where they are lower in rank and are separated by thinner stratigraphic intervals.

The maps (1 inch = 5,280 feet) and cross sections prepared so far, plus increased exploration interest, point to the desirability of mapping all coal beds on 7.5-minute topographic quadrangles (1 inch = 2,000 feet). [596-597]

Correlation of Late Morrowan and Early Atokan (Early Pennsylvanian) Conodont Faunas from the Frontal Ouachita Mountains and the Ardmore Basin (Oklahoma)

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Correlation of strata of latest Morrowan and earliest Atokan age and placement of the Morrowan-Atokan boundary have not been consistent. This results primarily from the poorly fossiliferous nature of the lower part of the Atoka Formation in the region of the type Atokan and type Morrowan Series in Oklahoma and Arkansas as compared to the well known Morrowan faunas that occur in both areas. Nearby sequences in Oklahoma that include continuous fossiliferous strata of both ages are: (1) the Wapanucka Formation in the Frontal Ouachitas, and (2) the Jolliff through Bostwick Members of the Golf Course and lower Lake Murray Formations of the Ardmore Basin. New information concerning the ranges and evolutionary history of several biostratigraphically important conodont elements have been obtained from these sequences. Preliminary study suggests that a more precise understanding of Morrowan-Atokan time relationships will be possible due to the detailed and continuous conodont faunas recovered from these units. A preliminary evaluation of these faunas supports the contention that there is not a time overlap between highest type Morrowan units and units in the Atokan containing the lowest occurring fusiform fusulinids.

The succession of conodont faunas in Oklahoma demonstrates the distinctive nature of Lower Pennsylvanian conodont form-species in their degree of regional and local variability, phyletic evolution, and homeomorphy. [600]

Some Major Lineaments in the Central United States

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Many large lineaments form a complex intersecting network in the central United States. This network is bounded by the Appalachian fold and thrust belt to the east, the Gulf Coastal Plain and Ouachita Mountains to the south, and the Rocky Mountains to the west.

Major structures of repeated uplift lie between and are crossed by the lineaments. Examples of uplifts are (1) the Cincinnati arch, (2) the Ozark dome, (3) the Wisconsin dome and arch, (4) the Llano uplift, and (5) the Black Hills uplift. Large structures of repeated subsidence are (1) the Mississippi River Embayment, and (2) the Michigan, (3) Illinois, (4) Forest City, (5) Salina, (6) Anadarko, (7) Arkansas, (8) Denver, and (9) Williston basins.

Nearly all of the lineaments follow Precambrian zones of weakness in the basement and are segments of these older zones along which some renewed movement has taken place since Precambrian time. Many show evidence of strike-slip components of movement. This is particularly true of the 38th-parallel lineament; the similar 34th-parallel lineament that follows the Matador-Red River uplifts; the east-trending faults east of Roswell, N. Mex.; the left-lateral Republican River lineament, Neb.; and the Washita River-Meers Valley-Mountain View fault system of southern Oklahoma. These lineaments may represent the continental equivalents of the Mendocino and Kelvin fracture zones. Other lineaments, which also exhibit complex interacting fault zones, alkalic intrusions, and marked tensional features such as grabens, may be incipient rift valleys. Examples are the New Madrid fault system of the Mississippi River Embayment, the Ottawa River graben systems of Quebec and Ontario, and the Rio Grande trough farther west. Some other lineaments that seem to be slight wrench faults or hinge lines between blocks are the Nemaha uplift, the Thurman-Wilson fault, and the La Salle anticline. [605]

Brachiopoda from the Cape Limestone (Upper Ordovician) of Southeastern Missouri

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As part of an extensive study of Upper Ordovician brachiopods in the mid-continent, samples totaling approximately 400 pounds were collected from the Cape Limestone at the Glen Park Quarry, section 5, T. 41 N., R. 6 E., Jefferson County, Missouri. More than 2000 silicified specimens were recovered by etching with hydrochloric acid. Representatives of *Thaerodonta* and *Lepidocyclus* dominate all samples. Other diagnostic genera include in descending order of abundance: *Plaesiomys, Hesperorthis, Strophomena, Austinella, Diceromyonia, Megamyonia,* and *Paucicrura.* Based on genera in common and closeness in species, the fauna is especially allied to unit 3 of the Viola Formation (as defined by Alberstadt) and the Maquoketa Formation of Iowa and partly allied to the Fernvale fauna of Tennessee and the Aleman and Cutter faunas of west Texas. Key species include *Lepidocyclus cooperi, L. capax, L. laddi, Thaerodonta saxea, Plaesiomys bellistriatus, P. proavita, Austinella multicostella, Platystrophia equiconvexa, Strophomena neglecta,* and *Paucicrura oklahomensis.* [607]

Trans-Cratonic Correlation of Early Ordovician Conodont Faunas B and C between Northwest Greenland and Western United States

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Samples collected from Early Ordovician strata at 87°07′ N Latitude and 63°40′ W Longitude in southern Washington Land contain conodont faunas that indicate precise biostratigraphic ties between Northwest Greenland and western United States.

The upper 50 meters of the Cass Fiord Formation contains Fauna B, including *Cordylodus lindstromi, Cordylodus* n. sp. aff *C. rotundatus, Cordylodus,* in. sp. aff. *C. prion, Oneotodus nakamurai, Paltodus bassleri* and *Acodus* aff. *A. sevierensis.* Fauna B is restricted to a relatively thin stratigraphic interval of less than 50 meters at localities in Texas, Oklahoma, Utah, Wyoming and Montana.

The overlying Cape Clay formation (50-60 meters thick) contains early Fauna C species including *Cordylodus rotundatus, Acontiodus iowensis, Scolopodus oneotensis* and *Drepanodus* aff. *D. conulatus.*

The succeeding 200+ meters of strata also contain taxa characteristics of Fauna C including *Paltodus variabilis, P. bassleri, P. spurius, Oneotodus simplex,* together with drepanodids and scolopodids.

Fauna C occupies a thicker stratigraphic interval than does Fauna B, up to several hundred meters thick in western United States. [618]

Biostratigraphy of the Mississippian-Pennsylvanian Boundary, Southern Midcontinent and Southwestern United States

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Fossiliferous marine successions in the southern Midcontinent and southwestern United States provide the best opportunity for definition of the Mississippian-Pennsylvanian boundary. Both the Grove Church Shale, latest type Mississippian of southern Illinois, and the Imo Formation, northern Arkansas, contain Mamet Zone 19 foraminifers and *Adetognathus unicornis* Zone conodonts. In addition, the Imo Formation yields a rich ammonoid assemblage equivalent to E_{2b-c} of the European Namurian Series. The base of the type Morrowan Hale Formation in northern Arkansas contains Mamet Zone 20 foraminifers and *Rachistognathus primus* Zone conodonts, with ammonoids equivalent to Namurian zone R_{1a}. However, this fauna occurs 7.9m above the base of the formation, which leaves the correlation of the lowest strata uncertain.

The Bird Spring Formation, southern Nevada, appears to represent uninterrupted deposition across the Mississippian-Pennsylvanian boundary. Here, highest Mississippian strata contain Zone 19 foraminifers in association with *Adetognathus unicornis* and succeeding *Rachistognathus muricatus* Zone conodonts. Zone 20 foraminifers and *R. primus* Zone conodonts mark the base of the Pennsylvanian System. No ammonoids have been found in proximity to the boundary in these sections.

Recently described conodont assemblages from Britain suggest that the Mississippian-Pennsylvanian boundary in North America corresponds to the base of the *Homoceras* Zone of the European Series. [625]

Observations on Cibolocrinus **Weller, A Late Paleozoic flexible Crinoid from the North American Midcontinent**

ROGER K. PABIAN, Conservation and Survey Division, University of Nebraska, Lincoln, Nebraska, and HARRELL L. STRIMPLE, Department of Geology, University of Iowa, Iowa City, Iowa

Although the late Paleozoic Leacanocrinacea are represented by 10 genera, only 2, *Cibolocrinus* and *Calycocrinus* are important or even known in North America; all others are restricted to the upper Permian of Timor. Of the above two genera, *Cibolocrinus* is far more important in numbers, geographic distribution, and range. *Cibolocrinus* makes some unusual "disappearances" and "reappearances" during its range. Important populations of *Cibolocrinus* are known from the Morrowan Brentwood Limestone of Arkansas and Oklahoma. *Cibolocrinus* is absent from large crinoid faunas of Atokan and Desmoinesian age from Missouri, Oklahoma, Texas and New Mexico, and from lower Missourian faunas of Oklahoma, Missouri, Kansas, Nebraska, Iowa and Illinois. By upper Missourian time, however, *Cibolocrinus* seems to "reappear" and undergo a "population explosion" as evidenced by several large populations from the Wann Formation near Bartlesville and Ochelata, Oklahoma; the Plattsburg-Bonner Springs interval near Altoona, Kansas; and the Captain Creek and south Bend Limestones near Wayside, Kansas. A small population of *Cibolocrinus* is present in the Eudora Shale at Louisville, Nebraska. *Cibolocrinus* again "disappears" in the Virgilian only to "reappear" in the lower Permian of Texas and New Mexico. Samples of *Cibolocrinus* studied show rectilinear growth trends and variation in position of the small plate in the infrabasal circlet. Immature specimens show an auxillary second primibrachial followed by three secundibrachials; mature individuals may show up to seven secundibrachials. [638-639]

Fenestrate and Pinnate Bryozoans in the Wreford Megacyclothem (Lower Permian; Kansas, Oklahoma, and Nebraska)

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Fenestrate and pinnate bryozoans heavily dominate the important bryozoan assemblages under detailed investigation in the Mid-continent Wreford Limestone.

Eleven species represent the bryozoan order Fenestrata in Wreford strata. Delicate fenestrate colonies (fenestellids — *Fenestella spinulosa, F. tenax, Minilya binodata;* and septoporids — *Septopora spinulosa*) and robust pinnate ones (some acanthocladiids; *Acanthocladia guadalupenis*) are more dominant, abundant, and widely distributed. In contrast, robust fenestrate zoaria (polyporids; *Polypora aestacella, P. nodolinearis, Protoretepora elliptica*) and delicate pinnate forms (other acanthocladiids; *Penniretepora auernigiana, P. curvula, P. flexistriata*) are subordinate, sparser, and less ubiquitous.

Wreford Fenestrata are concentrated in calcareous shales, some limited thereto, all others reaching maximum development therein. Consequently, optimum paleoenvironment for these animals was deeper (perhaps 50 feet), quieter, normal-marine, mixed-mud bottoms off-shore. Within individual horizons, most species seem more abundant and ubiquitous in northern and central Kansas; however, no rocks encountered were entirely fenestrate coquinas. Some species also occur sparingly in brachiopod-molluscan, cherty, and chalky limestones (in these last, fenestellids helped trap and stabilize carbonate mud on and around mudbank mounds); a few forms range very rarely into other limestone and clastic rock types. Such distribution indicates that those species could occasionally tolerate other muddy or sandy bottoms, some very shallow or even along-shore, some brackish, and a few moderately agitated. [652]

A Plate Tectonic Model, Ouachita Folded Belt

GEORGE W. VIELE, Department of Geology, University of Missouri, Columbia, Missouri

The plate tectonic history of the Ouachita folded belt comprises two phases. First, in late Precambrian-early Paleozoic, the southern part of North America rifted, and an ocean opened between North America and a southern continental plate, Llanoria. The Ouachita folded belt roughly mimics the American margin, which was indented by three aulocogens: the Reelfoot, Anadarko, and Toboso. The basal formations of the Ouachitas were deposited on a continental rise downslope from an abrupt platform margin. Continued spreading and subsidence formed abyssal depths in which subsequent Ordovician through Devonian shales, cherts, and novaculites slowly accumulated.

In the second phase, the ocean closed via south-directed subduction beneath the returning Llanorian plate. As much as 10 kilometers of Carboniferous flysch, derived from northern, eastern and southern sources, engulfed the trench and closing ocean. A few tuffs lie in the basal part of the flysch. Subduction caused northward overthrusting of an accretionary wedge composed of off-scraped Ordovician-Devonian strata that form the present-day Benton uplift. Final plate-plate collision backfolded this wedge southward. Scattered serpentinite blocks, broken formations, and negative gravity mark the trace of the suture along the north side of the Benton uplift. Southward, the deformation decreases; wells on the Texarkana platform penetrate Desmoinesian shallow-water carbonates resting unconformably on broadly-folded strata. The basement of the Gulf Coast may be Precambrian, a part of the Llanorian plate, later fragmented by Mesozoic opening of the Gulf of Mexico. [661-662]

Structural Geology of the Southern Part of the Paron Quadrangle, Arkansas

RICHARD WAUGH and ALAN ZICK, Department of Geology, University of Missouri, Columbia Missouri

The Paron Quadrangle, west of Little Rock, Arkansas, includes two tectonic zones: a northern and western of Carboniferous shale and sandstone flysch and a southern of Ordovician-Devonian shale, quartzite, and chert, forming the north margin of the Benton-Broken Bow uplift. The Ordovician and Devonian rocks constitute a large nappe both underlying and overlying nappes of Carboniferous strata. Bounding thrust faults dip north but are backfolded by later south-verging folds. Windows and klippen shown on earlier maps are reinterpreted as fold interference patterns. Metamorphic grade is low, probably upper zeolite facies. Clinozoisite and serpentine were observed in thin section.

An axial plane cleavage formed with the last folding. Although most fold hinges rake northeast, they define a girdle in the cleavage plane—probably due to stretching and rotation of fold hinges. Bedding-cleavage lineations exhibit a similar pattern, and scattered boudins indicate elongation parallel to fold hinges. Locally a fracture cleavage parallels the slaty cleavage; continued deformation folded quartz veins filling the fracture cleavage planes.

The tectonic history comprises three phases: initial emplacement of a nappe accompanied by progressive gravitational flattening, a strong backfolding phase associated with the formation of the predominant cleavage, and a broad gentle warping of the entire area. The northern margin of the Benton-Broken Bow uplift may mark an ancient plate boundary, reflecting southward subduction of North America beneath a southern continent. [663-664]

GSA Annual Meeting, Rocky Mountain Section
Missoula, Montana, May 12-13, 1977

The following abstract is reprinted from the *Abstracts with Programs* of The Geological Society of America, v. 9, no. 6. The page number is given in brackets below the abstract. Permission of the author and of Jo Fogelberg, managing editor of GSA, to reproduce the abstract is gratefully acknowledged.

Anomalous Uranium Concentrations Related to Paleo-Drainage System in the Pliocene Ogallala Formation in Southwestern Kansas

PIETER BERENDSEN, Kansas Geological Survey University of Kansas, Lawrence, Kansas

Rocks of the Ogallala Formation of Pliocene age are widespread from central west Texas northward into South Dakota. They are exposed in an arc-shaped pattern in Meade and Clark counties, southwestern Kansas, and consist of a heterogeneous mixture of clastic fluviatile material attaining a thickness of several hundred feet. To the west and north of the outcropping Ogallalla occur younger volcanic ash units ranging in thickness from a few inches up to fifteen feet.

A narrow band of Ogallala, stretching in an east-west direction for about 12 miles, is quite different in character and has anomalous uranium concentrations.

Near or at the surface, the rocks have been completely replaced by a mixture of calcite, quartz, and alpha-cristobalite, giving rise to a well-indurated unit having a crystalline texture. The unit reaches a maximum thickness of approximately 10 feet in the center and tapers off toward the edges. The width of it varies considerably but can be as much as one-half mile. Field observations suggest that the unit was formed by replacement of pre-existing sediment in possibly a braided channel flowing at or near the surface in an easterly direction.

Uranium concentrations of this unit range up to 125 ppm U_3O_8 and are apparently related to the amount of cristobalite present. The source of the uranium is believed to be the volcanic ash. Analyses of the ash show concentrations in the range of 10 ppm U_3O_8.

Volcanic ash deposits as well as altered Ogallala are reported from other places. The potential for other accumulations must therefore be considered. [708]

New Theses Added to OU Geology Library

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

Depositional History of the Devil's Kitchen Sandstones and Conglomerates in the Ardmore Basin, Southern Oklahoma, by Ola M. Saether.

Metamorphic History of the Older Granites, Central Rhode Island, by Vernon Max Brown.

OKLAHOMA GEOLOGY NOTES

Volume 37 April 1977 Number 2

Page

Basinward Facies Changes in the Wapanucka Formation (Lower Pennsylvanian), Indian Nation Turnpike, Ouachita Mountains, Oklahoma
PATRICK K. SUTHERLAND and ROBERT C. GRAYSON, JR. 39

Geochemistry of the Fayetteville Shale, Northwestern Arkansas
KENNETH F. STEELE and GARLAND C. LAMB 47

Homoclinal Dip on South Flank of Arbuckle Mountains 38
AAPG Sponsors Field Seminars 44
OGS Issues Trilobite Bulletin 45
OU Plans Energy Center 45
Colorado Coal Resources Summarized 46
Colorado Survey Sponsors Coal Symposium 46
USGS Film Shows OGS Operations 55
Oklahoma Abstracts 56
GSA Annual Meeting, North-Central Section 56
GSA Annual Meeting, Rocky Mountain Section 63
New Theses Added to OU Geology Library 64