VOL. 42, NO. 4 AUGUST 1982

OKLAHOMA GEOLOGY NOTES

OKLAHOMA GEOLOGICAL SURVEY / THE UNIVERSITY OF OKLAHOMA

On the cover—

Hicks Mountain on Lake Altus in Quartz Mountain State Park

On the cover is a view of Hicks Mountain, a granite knob that rises about 325 ft above the level of Lake Altus. Hicks Mountain is a mass of the Cambrian Lugert Granite that makes up a large part of the western Wichita Mountains.

In the foreground is Lake Altus, which backs up behind Altus Dam, built by the U.S. Bureau of Reclamation in 1948. The purpose of the dam is to provide water for irrigation and municipal supply and to aid in flood control on the North Fork of the Red River.

Lake Altus, along with Hicks Mountain, and a number of other granite mountains in the area have been embraced into Quartz Mountain State Park, which is located in Greer and Kiowa Counties of southwestern Oklahoma.

The view in the photograph is looking north from State Highway 44 at the base of King Mountain.

Kenneth S. Johnson

Oklahoma Geology Notes

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

Oklahoma Geology Notes, ISSN 0030-1736, is published bimonthly by the Oklahoma Geological Survey. It contains short technical articles, mineral-industry and petroleum news and statistics, reviews, and announcements of general pertinence to Oklahoma geology. Single copies, $1; yearly subscription, $4. All subscription orders should be sent to the Survey at 830 Van Vleet Oval, Room 163, Norman, Oklahoma 73019.

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

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This publication, printed by the Transcript Press, Norman, Oklahoma, is issued by the Oklahoma Geological Survey as authorized by Title 70, Oklahoma Statutes, 1971, Section 3310, and Title 74, Oklahoma Statutes, 1971, Sections 231–238. 1,800 copies have been prepared for distribution at a cost to the taxpayers of the State of Oklahoma of $1,969.

FLUVIAL PROCESSES AND GEOLOGY IN WASHITA RIVER AREA SOUTH-CENTRAL OKLAHOMA

John M. Harlin[1]

Abstract—The friable nature of the Rush Springs Sandstone and the fine sandy soils associated with this formation promote relatively high drainage density and well-defined channel incision in south-central Oklahoma. Hypsometric curves for watersheds developing upon the Rush Springs demonstrate lower integrals and increased headward development relative to drainage basins forming over the more shaly Marlow and Dog Creek formations. Intensive tributary development on the Rush Springs is an example of positive feedback in a geomorphic system. High hydraulic conductivity and high hydraulic gradients near streams promote increased channel flow, which, in turn, promotes channel degradation and still higher hydraulic gradients. Owing to the strong constraints placed on the geomorphology of the Southern Plains region by Permian lithologies, it is suggested that hydrophysical models, like the synthetic unit hydrograph, consider the influence of geology upon watershed geometry.

Introduction

The purpose of this paper is to describe the geomorphology of a few third- and fourth-order basins selected in south-central Oklahoma, and to offer possible explanations for what appear to be morphologic-geologic relationships. This research area encompasses 1,500 mi^2 along the Washita River and is centered just west of Chickasha, Oklahoma.

It has been more than 100 million years since the floor of a great Cretaceous sea began to rise, ultimately exposing this region to subaerial erosion. This Late Cretaceous surge of tectonic activity occurred in tandem with the building of the Rocky Mountains and today provides Oklahoma with a general west-to-east tilt toward the Mississippi River. Oklahoma's present east-southeast drainage pattern was probably established about 60 million years before the present (Johnson, 1971). Late Tertiary paleohydrology indicates, according to Evans (1955) and Johnson (1971), fluvial sedimentation episodes when major river systems carried large volumes of coarse sediments from the High Plains, which in turn received clastics from the Rocky Mountains. The general positions of the Red and Arkansas Rivers—as well as their tributaries, the Washita, the Canadian, the North Canadian, and the Cimarron Rivers—probably became fixed during the Pleistocene Epoch. With each interglacial stage, Rocky Mountain meltwaters were able to remove large volumes of material from stream beds

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and banks. Today, the wide, sandy channels of these larger rivers generally occur 300 ft below Pleistocene terraces (Johnson, 1971).

The channels of Oklahoma's larger rivers are aggrading today. Periodic flooding sweeps segments of channels only to bring additional fill from upstream and from numerous upland tributaries. Stumps buried in as much as 100 ft of canyon fill at the mouth of a Washita tributary in Caddo County, Oklahoma, have been dated (Hall, 1982) at 3,200 years before the present and attest to the degree of adjustment since the last glacial melt. However, enough relief remains from the Cretaceous uplift so that upland surfaces are now undergoing channel initiation and development much as they have for perhaps 100 million years.

To gain a better understanding of present-day geomorphology in this area, one must look into the past beyond the Cretaceous seas and beyond the building of the Rocky Mountains. Owing to events that took place almost 150 million years before the disappearance of the Cretaceous seas, the research area offers an excellent opportunity to examine fluvial development upon varying lithologies.

Events of the Mesozoic have been erased from the research region. The Washita River is flowing across sediments that once were pouring into a shallow Permian sea. The Washita is somewhat distinct from the other major waterways in Oklahoma. With headwaters arising in the Texas Panhandle, near Miami, the Washita begins farther east than the Canadian, the North Canadian, the Cimarron, the Arkansas, or the Red River. Pleistocene outpourings of water and sediment were therefore somewhat less extensive in the Washita than in the other drainage systems. According to Evans (1955), the channel of the Washita is probably deeper and more narrow because it entered the post-Pleistocene aggradation phase more recently than the other large rivers in Oklahoma.

The Washita begins at an elevation of just over 3,030 ft and enters Lake Texoma above the Red River at just under 620 ft. The gradient is approximately 3 ft per mile in the research area, although the main streams of smaller third- and fourth-order basins within the sytem have gradients approaching 200 ft per mile. These smaller tributaries, recognizable in the field and on 7.5-minute topographic maps, are presently developing on Permian sandstones and shales of the Anadarko Basin. It is here as soils and new channels arise simultaneously on the Permian uplands that geological controls can be appraised.

Permian Red Beds of Research Area

Permian sedimentation in Oklahoma was relatively moderate in comparison to that of the Pennsylvanian Period, which was characterized by extensive mountain building. For example, the Wichita Mountains, just southeast of the research area, were uplifted 10,000 to 15,000 ft during Pennsylvanian time. To the north and east of the Redbed Plains, the Nemaha Ridge was uplifted and rivers were flowing toward the Anadarko Basin axis from both the northeast and southwest. Numerous pulses of folding and uplift followed until the region was invaded by an early Permian sea

(Johnson, 1971). The Little Washita, a tributary of the Washita, flows from the southwest downdip toward the axis of the Anadarko Basin and away from the Wichita-Criner Arch (fig. 1). Crossing the axis of the Anadarko Basin, it flows against the direction of dip and finally joins the Washita just south of Chickasha. This area is of particular interest, since the Little Washita basin (246 mi^2) is oriented almost perpendicular to the Anadarko Basin axis, dissecting rocks of the El Reno and Whitehorse Groups. In this area, soils and low-order upland tributaries are developing primarily upon three formations within the El Reno and Whitehorse Groups. The area from the eastern section of the Little Washita basin northward to the area surrounding Chickasha is represented by the uppermost El Reno formation, the Dog Creek Shale.

The Dog Creek is a reddish-brown shale with thin beds of siltstone and dolomite and attains a thickness of about 220 ft. The shale grades eastward into the older Chickasha Formation (Carr and Bergman, 1976). The Dog Creek Shale was first named by Cragin (1896), and it is generally agreed that the shale is conformable with the underlying Chickasha Formation but possibly unconformable with the overlying Marlow Formation of the Whitehorse Group. The sand-silt ratio increases substantially from the Dog Creek to the Marlow. Hydraulic conductivities also increase. The Marlow, however, is not considered a good ground-water source. Davis (1955) indi-

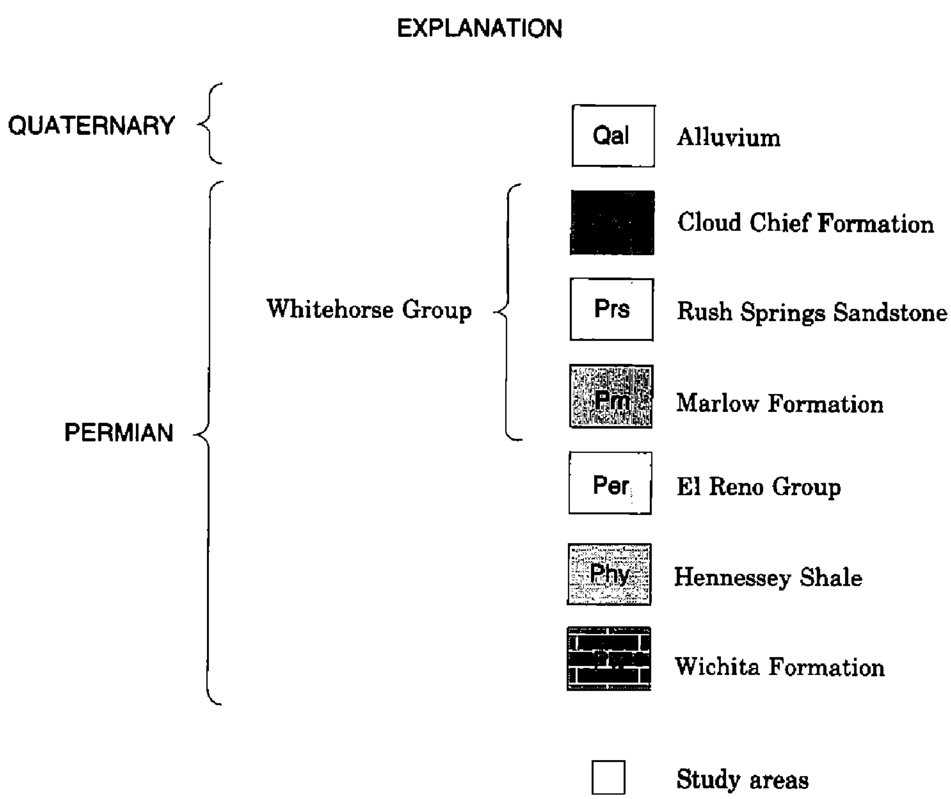
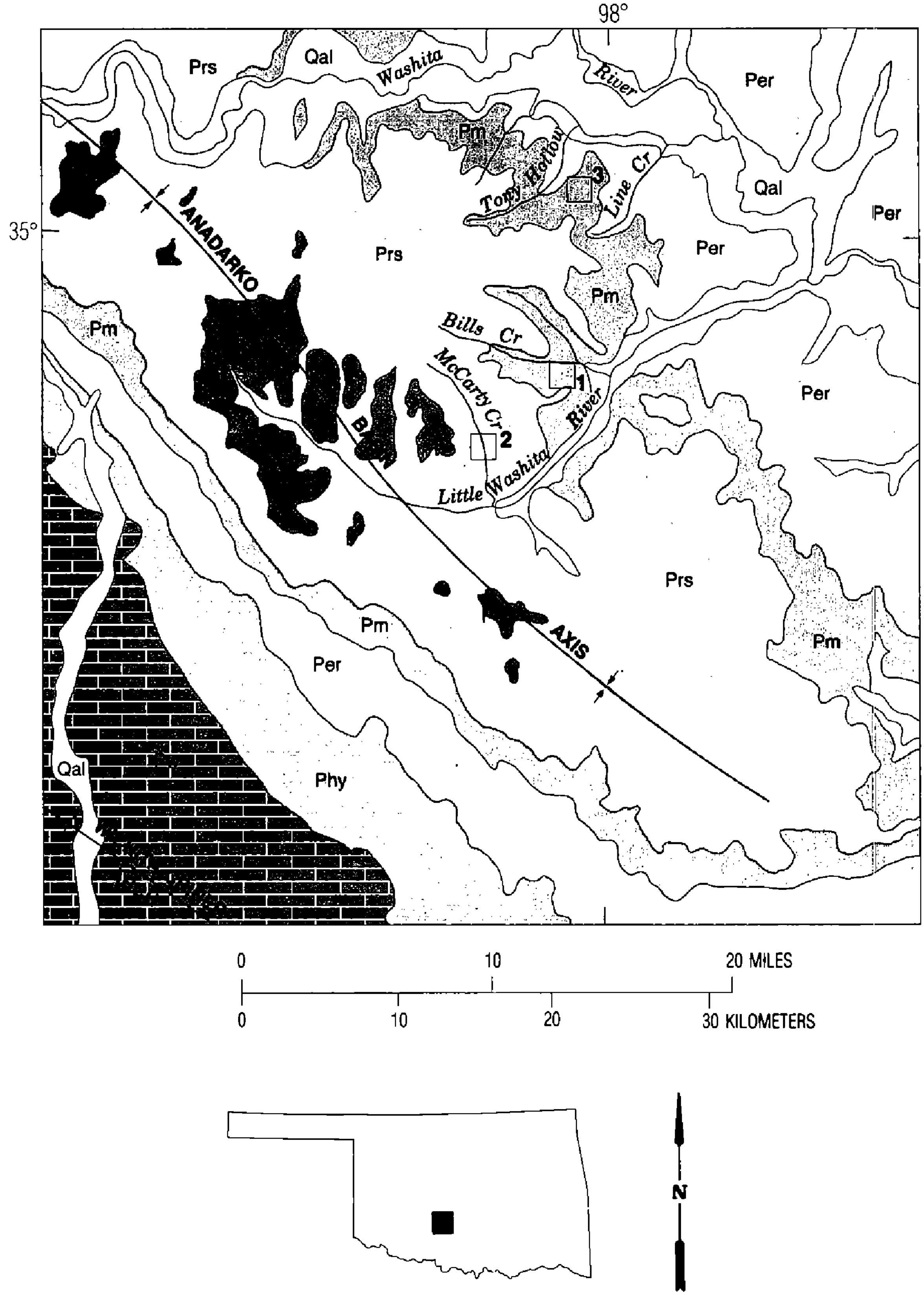


Figure 1. Geologic map, *opposite*, with explanation, *above*, of study area. Geology adapted from Hart (1974), Bingham and Moore (1975), Carr and Bergman (1976), and Havens (1977).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35°
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Tony Hollow
Line Cr
1
2
3
ANADARKO
AXIS
Bills Cr
McCarty Cr
Little Washita River
Phy
0
10
20 MILES
0
10
20
30 KILOMETERS
N

cated that the Marlow is composed mostly of gypsiferous silty shale but also includes shales, sandstones, and dolomites. Early literature implies a marine origin for the Marlow. Bass (1939), for example, attributed a sand member within the Marlow to spit deposits across the mouth of a shallow marine bay. Sandstones are cross-bedded within the Verden Member and dip northward, suggesting a source from the Wichita-Criner Arch, uplifted in Pennsylvanian times.

Moffatt (1973) indicates that the Marlow underlies only a 1–2 mi belt around the southeastern end of the Anadarko Basin, and that it consists of 120 ft of "watermelon-pink" sandstone. Havens (1977) mapped the Marlow within most of the Little Washita Basin and reported a thickness of 90 to 130 ft. The most extensive formation in this area, both in thickness and at the surface, is the Rush Springs Sandstone, which conformably overlies the Marlow.

The Rush Springs Formation was named by Sawyer (1929) and was first described as being almost entirely red, cross-bedded sandstone with little or no shale or gypsum. Havens (1977) stated that the Rush Springs is a very fine-grained, cross-bedded sandstone, 136–300 ft thick with gypsum and dolomite in the upper 60 ft. Little agreement exists as to the origin of the Rush Springs. Davis (1955) suggested a shallow-marine origin. He also attributed the high degree of sorting to a distant source. The direction of foreset dip generally shows a northwestern origin, although Reeves (1921) noted an irregular type of dip in at least a part of the Rush Springs. The irregular cross-bed dip, a complete absence of marine fossils, sections of cross-beds 20–40 ft thick, frosted grains in some locations, and spectacular sorting suggest to me a possible eolian origin. Perhaps the Rush Springs is this region's version of the Navajo Sandstone or, perhaps, a combination of marine deltaic and eolian processes. This issue is not a prime consideration for the study at hand, but the Rush Springs' "remarkable homogeneity" was noted by Davis (1955), and its water-yielding capacity, by Johnson (1971). Also, the sandstone is friable.

Geomorphology

This region undoubtedly has seen several stages of geomorphic development since the end of the Mesozoic Era. Equilibrium and near equilibrium phases were surely approached and subsequently interrupted by changing lithologies and climates as the stream network settled down to its present position. The main course of the Washita is controlled by the underlying Pennsylvanian and Permian rocks, which dip southwestward toward the Anadarko Basin. The Washita follows the strike, crossing at north-south facies changes (Oklahoma Water Resources Board, 1968). Lower order tributaries, however, are somewhat independent of strike-dip relationships and join the Washita at varying angles, providing a dendritic stream pattern. The Little Washita, for example, joins the Washita from the southwest, flowing almost perpendicular to strike. The Little Washita basin is a geomorphically mature sixth-order basin with 1,056 first-order tributaries. The average bifurcation ratio is 4.34, and figure 2 demonstrates a good (R^2 = 0.99) negative exponential relationship between stream order and stream number. The hypsometric curve for the Little Washita is shown in figure 3, and projects advanced headward development. That is, the curve approaches the ordinate at a gentle slope because much material has been removed, even in the upper reaches of the basin. Low-order tributaries extend nearly to the watershed perimeter. The region in and around the Little Washita watershed is not geomorphically homogeneous, however. Dendritic drainage characterizes the area, but hypsometric curves and stream networks vary considerably between study areas 1, 2, and 3 (fig. 1).

Each study area represents a different lithology, and three basins were drawn from each study area. Geomorphic information is obtained from four 7.5-minute topographic maps: Chickasha, Verden, Laverty, and Rocky Ford Quadrangles. There are a limited number of sample basins; however, the land area associated with both the Marlow and Dog Creek formations restricts the sample size. The sample does contain 336 first-order channels. Basins were chosen so that each empties into a stream of the next higher order. This type of order-ratio requirement ensures that no basin directly joins the Washita, in which case alluvial influence would create a problem ultimately leading to statistical "noise."

The three basins of study area 1 join Bills Creek, with one draining southward and the remaining two draining northward. Bills Creek is developing on sandstone of the Marlow Formation. Uplands of the three third-order sample basins reach slightly into the Rush Springs Sandstone; however, this is unavoidable if the Marlow is to be examined at all. Three

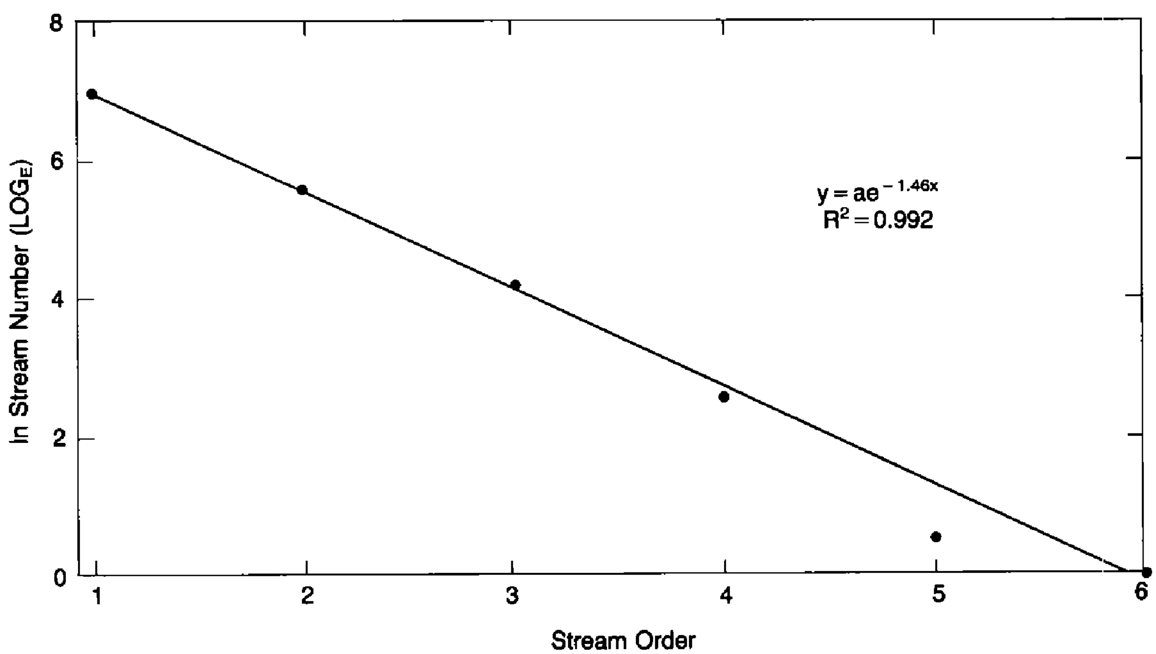

Figure 2. Graph showing negative exponential relationship between stream order and stream number.

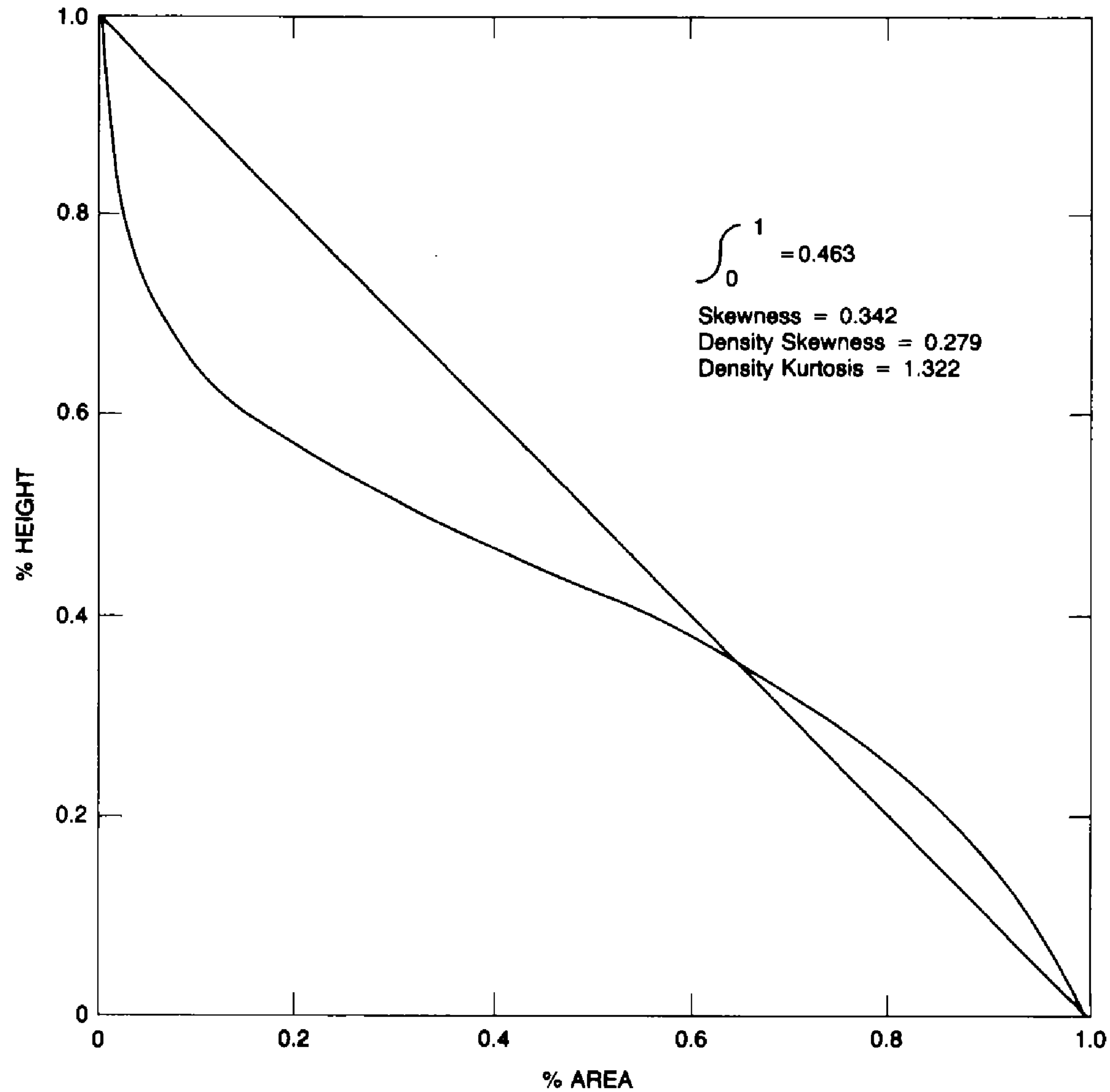

Figure 3. Hypsometric curve for Little Washita watershed.

more basins were drawn from area 2 along McCarty Creek, the first major tributary upstream on the Little Washita from Bills Creek. McCarty Creek and the three sample tributaries, two joining from the west and one joining from the northeast, are developing on the Rush Springs Sandstone. The last three basins belong to the Tony Hollow and Line Creek study area, and are developing on the Dog Creek Shale. Geologic information comes from geologic maps prepared for Hydrologic Atlas 3 (Hart, 1974), Hydrologic Atlas 4 (Bingham and Moore, 1975), Hydrologic Atlas 5 (Carr and Bergman, 1976), and Hydrologic Atlas 6 (Havens, 1977). The scale of these maps is 1:250,000, and they were published by the Oklahoma Geological Survey in cooperation with the U.S. Geological Survey.

Average relief is similar for basins in the Rush Springs, Marlow, and Dog Creek formations; that is, 163.33, 157.33, and 141.66 ft respectively.

Basin characteristics begin to diverge, however, when stream networks and basin geometry are examined. Basins developing in the Marlow and Dog Creek formations show much less channel dissection than channels in the Rush Springs. Channels within the Rush Springs are shorter, deeper, and more narrow than those of the Marlow and Dog Creek. Field checks of this region and perusal of 7.5-minute topographic maps indicate much higher drainage densities in the Rush Springs Sandstone than in the more shaly Marlow Formation. The first-order-channel density for the three basins in the Rush Springs is 92/mi^2 as compared to 29/mi^2 in the Marlow. Overall basin geometry, as monitored through the hypsometric curve, also indicates more advanced development for basins along McCarty Creek in the Rush Springs. The average hypsometric integrals for the Rush Springs, the Marlow, and the Dog Creek basins are 0.512, 0.565, and 0.563 respectively.

The hypsometric integral has been shown to be somewhat insensitive as a basin descriptor. Schumm (1956) found that a "strong" linear relationship exists between the integral and both relief ratio and stream gradient, but he also noted that the relationship begins to fail when the integral approaches about 0.500. Carson and Kirkby (1972) indicated that when a basin attains maturity, the integral converges to a value of about 50 percent and thereafter changes little. It has been shown that a multitude of hypsometric-curve forms can exist for any given hypsometric integral, and that employing the skewness of the hypsometric curve considerably increases the descriptive power of the technique (Harlin, 1978, 1980). For example, increasing headward erosion of the main channel and its tributaries results in increasing values for skewness of the hypsometric curve. This "skewness-headward erosion" relationship was found when I (Harlin, 1980) used the technique to describe basins developing on Peorian loess in Illinois, Iowa, and Nebraska. The present study differs from the loess study because of the difference in geology, and it appears that the skewness-headward-development relationship becomes region-specific with the change in lithologies, soils, and vegetation.

A strong negative relationship was expected in this study between the hypsometric integral and hypsometric skewness. A strong positive relationship was expected between first-order tributary density and hypsometric skewness. Neither of these relationships was forthcoming. For example, the regression coefficient for the skewness-first-order-density relationship is −207.03, the coefficient of determination (R^2) 0.101, and the F-value only 1.02. Not only are these findings highly nonsignificant, but the direction of the relationship is just the opposite from that expected. The answer for the failure of the linear model seems to come from the variation of lithology.

As the basins within the Rush Springs Sandstone develop, first-order channel density and headward development (as described by hypsometric skewness) increase. This is not true for basins in the Marlow and the Dog Creek Shale. Lithology and resulting clayey soils in the Dog Creek and Marlow areas reverse the development characteristics that were found in the Rush Springs. The form of the hypsometric curves in the Rush Springs area is relatively independent of the next higher order (master) stream to which they respond. In other words, the reduction of the area under the curve is a function of the stream channels within the basin perimeter, and as headward erosion dominates in the sandstone, hypsometric skewness increases as first-order channel density increases. This is not the case in the Marlow, where channel incision is less pronounced. Bills Creek, in the Marlow area, has developed a wider flood plain that encroaches upon the mouths of the sample basins. The hypsometric curves in the Marlow thus join the abscissa at a much lower angle than in the Rush Springs. This situation results in less material (and possibly stream abstraction) in the lower reaches of the basin, with weight along the abscissa shifting toward the origin, and finally with relatively high values for hypsometric skewness even with low first-order drainage densities. Another analysis between skewness and first-order channel density was performed, but in this second model geology was entered as a criteria (discrete) variable in an analysis of covariance. The form of the model is:

$$FD = a + \beta_1 Hs + \beta_2 w_1 + \beta_3 w_1 Hs + \epsilon;\ \text{where}$$

$$FD = \text{first-order density (mi}^2\text{)},$$

$$Hs = \text{hypsometric skewness},$$

$$w_1 = 0 \text{ if Dog Creek or Marlow, and}$$

$$w_1 = 1 \text{ if Rush Springs.}$$

The coefficient of determination (R^2) improves from 0.101 in the simple two-variable model to 0.964 when geology is allowed to interact with the independent variable. The F-value increases from 1.02 to 62.29 when geology is included in the model.

The interrelationship among geology, soils, vegetation, and the precipitation regime in south-central Oklahoma seems largely to explain the basin morphometry described in this paper. The soil surveys of Caddo County (Moffatt, 1973) and Grady County (Bogard, and others, 1978) cover the basins sampled in this research. The maps contained in these publications are drawn at a scale of 1:20,000. Soils along McCarty Creek and on the Rush Springs uplands exhibit minimum infiltration rates of 2–6 in. per hour and maximum infiltration rates of 6–20 in. per hour. These soils are moderately acid, coexisting with oak-forest vegetation. As discussed previously, the Rush Springs Sandstone is friable and the associated soils are especially weak when wet. During storms, much of the rainfall is quickly channeled and little overland flow results. The high level of permeability allows banks to yield water long after rainfall ceases or accumulated snowfall melts. A January 1982 field examination of first-order channels verified flow one week after a 1-in. melt. The first order channels on the Dog Creek and Marlow were dry that same day. High acid-water levels present in the bedrock and soil mantle, and more continuous low-order channel flow, allow the fine sands of the Rush Springs to be carried downslope, and severe erosion to occur especially in the Konawa and Stephenville soil complexes. High hydraulic conductivity and high hydraulic gradients promote increased channel flow, which, in turn, promotes channel degradation and even higher hydraulic gradients. It is also possible that a falling water table in this area is aggravating the development of gullies.

The Grant Silt Loam occupies most of the basins developing in the Dog Creek Shale, study area 3. The Grant complex is a silty clay loam, mildly alkaline, developing over a red siltstone bedrock. Infiltration rates fall from a high of 20 in. per hour in the Konawa to 0.6–2 in. per hour in the Grant Silt Loam. These soils seal rapidly and with a bimodal peak in annual precipitation, this equates to excessive overland flow (Nicks, 1966). Each basin in the Dog Creek Shale terminates in the Port Silt Loam at Tony Hollow and Line Creeks. The Port Silt Loam is a deep alkaline soil with an infiltration rate of 0.6–2 in. per hour. Sealing of the upper soil layer results in a slick, gleic surface, reduced infiltration, and less pronounced channel incision characteristic of the Rush Springs. The basins in the study area 1, along Bills Creek, are developing over the Marlow. This shaly bedrock breaks down into low-permeable, low-acid soils similar to the Dog Creek Shale area. Infiltration rates for the Lucien–Nash and Minco Silt Loam soils in this area are 0.6–2 in. per hour. Channels developing on the gleic surfaces overlying the Dog Creek and Marlow Formations are less dense, shallower, and wider than those of the Rush Springs area. First-order tributaries tend to be longer over the shale. Entry of these basins into Bills Creek, Line Creek, and Tony Hollow Creek is at a low angle, with flow across a part of the master stream's flood plain before termination in the master channel. The influence from this type of development is immediately noted in the form of the hypsometric curve and stream-network topology.

Conclusions

That basin geometry and channel development seem to arise from the interaction among geology, soil, and climate in the research area is not surprising. However, the manner in which development occurs in this region is somewhat different than originally expected. Sandstone areas are much more susceptible to erosion and soil-loss problems than shale-dominated areas. Remote-sensing techniques of stream-network topologies could be employed to identify facies changes in this area and possibly elsewhere. It is also worthy of note that consideration of lumped hydrologic models, like the synthetic unit hydrograph, which depend on coarse geomorphic parameters such as basin area or main channel length, should take into account the fact that many of these parameters are region-specific. Thus, developing hydrophysical models without consideration of the influence of geology upon watershed geometry would greatly restrict the transferability of these models.

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SOUR-GAS-TREATING PLANT DONATED TO UNIVERSITY

Jay Morris has spent the past year working on a labyrinth of pipes, valves, and pumps to complete his master's thesis in chemical engineering and modify a pilot plant for treating sour gas. The plant was donated to OU's Chemical Engineering Department by Perry Gas Processors, Inc., of Odessa, Texas.

"It has been like putting a jigsaw puzzle together with some of the pieces missing and no picture to use as a model. I've had to reuse as many of the parts as I could, but I've had to rearrange much of the system to meet our needs. It's been a challenge right from the start," Morris said.

"I originally visited Perry Gas Processors to explore opportunities to acquire equipment for our unit operations lab," explained Dr. John M. Radovich, chemical engineering professor and Morris' advisor. "Perry Gas Processors offered to rent the plant to OU for $1 a year, and after four years the unit will be donated to the University."

The sour-gas-treating plant was built about 1979 by Perry Gas Processors to run unattended in the field for one of its clients. After collecting the needed data, the portable plant was removed to a storage yard, where it sat unused for about a year. Morris cleaned and replaced some components and altered the network of pipes and tanks to form a closed-loop system to be used in undergraduate studies and research.

Natural gas containing acid gases, such as H_2S and CO_2, passes through an absorber tower. A solution enters the tower and absorbs the acid gases, then the purified natural gas leaves the tower. The solution containing the acid gases is pumped to a stripper tower and heated. The acid gases are driven off by the heat, regenerating the solution for reuse, Radovich explained.

Normally the acid gases would be released into the air, and the purified gas would be piped off to be sold. To keep the cost of running the plant to a minimum, the acid gases are remixed with the purified natural gas to form a steady supply of sour gas, he said.

"Recent finds of natural gas like those in the Overthrust Belt of Wyoming and Montana are under great pressure and contain high volumes of CO_2. Computer models are available which suggest changes that will have to be made to the current gas-treating systems to eliminate higher concentrations of CO_2 from the natural gas, but no commercial process has actually been developed from these models," Radovich explained.

"No one knows for sure which solutions are best for absorbing acid gases under higher pressure and temperature conditions. The plant will be used to develop performance data to test the validity of the computer models currently available," Radovich said.

"As far as I know, no other university has a research facility of this type. We are extremely grateful to the people who have helped make this a reality," Radovich concluded.

COAL-MAPPING PROJECTS CONTINUE IN NORTHEASTERN OKLAHOMA

Field reconnaissance and mapping of the coal-bearing region of northeastern Oklahoma was begun in 1978 in Craig County by the Oklahoma Geological Survey. The mapping is being done on 7.5-minute quadrangles at a scale of 1:24,000 and will be published at a scale of 1:63,360 (1 inch to the mile). The projects involve county areas, exclusive of those parts of counties that are not within the coal belt. Figure 1 shows the mapping projects and their current status.

The first project includes Craig County and a small part of Nowata County; the second project includes Rogers County and the western part of Mayes County; the third project includes parts of Creek, Tulsa, Wagoner,

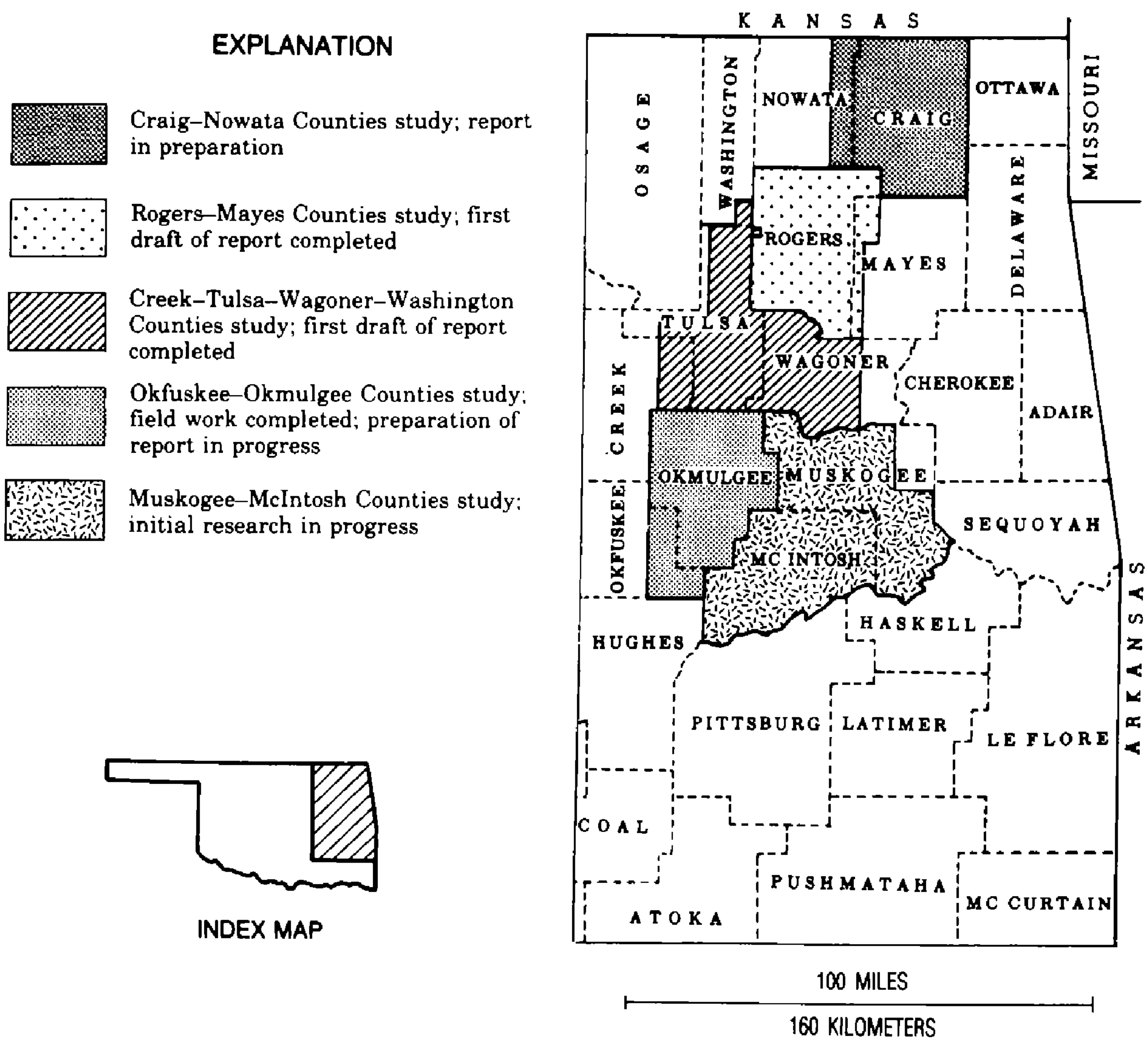


Figure 1. Map of northeastern Oklahoma showing status of Oklahoma Geological Survey 7.5-minute quadrangle coal-mapping projects.

and Washington Counties; the fourth project includes Okmulgee County and part of Okfuskee County; and the current project includes most of Muskogee County and all of McIntosh County.

In addition to providing coal maps (which show outcrop boundaries of each coal bed, coal thickness, depth of overburden, and mined-out areas), the reports include geologic information such as stratigraphy and structure, data concerning quality of the coals, and tables of coal resources and reserves on both a township and a county basis. All of the maps, charts, tables, and records of calculations for each study are kept on open file at the office of the Oklahoma Geological Survey and are available for public examination.

LeRoy A. Hemish

FUELS FROM COAL BEING STUDIED

The improved production of synthetic fuels from coal is being scrutinized by University of Oklahoma chemist David Marten. Specifically, Marten is studying the effects of selected catalysts in the Fischer–Tropsch process of converting coal to gasoline, diesel, and other fuels and providing feedstocks for the petrochemical industry.

Marten's work is being sponsored by OU's Energy Resources Center, which was established in 1978 to fund faculty explorations into new areas of research.

"We have at least 200 years of proven coal reserves available in the United States and a dwindling supply of oil. It makes sense for the U.S. to have the best process technologically possible for coal conversion to liquid fuels," Marten said.

"In the Fischer–Tropsch process, coal is converted to carbon monoxide and hydrogen, which is then converted to hydrocarbon fuels and water," Marten explained. "A catalyst is added to the process to speed up the chemical reaction. The most common catalysts contain the elements iron and cobalt."

Currently the Fischer–Tropsch process is not competitive in the energy market because of high energy consumption in the process and because catalysts now being used produce such a wide range of products, many of which have limited marketability, Marten said.

"We really don't understand how each of the steps in the process occurs. By discovering what intermediate compounds are formed during the conversion process, we can select catalysts which will promote the specific type of hydrocarbon fuel we want. For instance, current processes are yielding 60 percent gasoline-type fuels. If 90 percent of the coal could be converted to gasoline-type fuels the process could be economically feasible," Marten said.

Marten is currently studying the use of several model iron compounds as catalysts and has identified an intermediate compound formed when using one of the iron-based catalysts in the Fischer–Tropsch process.

By identifying the intermediate compounds, catalysts composition and conditions in the process can be changed to enhance their production. These changes can better produce the desired hydrocarbon fuels at lower energy levels and higher selectivity, he said.

The Fischer–Tropsch process is not new—Germany used it in World War II. Despite prohibitive costs, South Africa is currently using the Fischer–Tropsch process because they are rich in coal and do not want to depend on imported oil for political reasons, Marten said.

"Right now, the cost of producing gasoline from coal, using the Fischer–Tropsch process, is approximately twice the current price of an equivalent amount of energy derived from oil. We are working to make the Fischer–Tropsch process an economically feasible alternative to current sources of energy as well as a viable source of feedstock for the petrochemical industry," Marten concluded.

BIBLIOGRAPHY FOR 1980 RELEASED

A *Bibliography and Index of Oklahoma Geology, 1980* has been released by the Oklahoma Geological Survey as Special Publication 82-2.

Compiled by Elizabeth A. Ham, OGS associate editor, the bibliography contains 300 entries that include journal articles, books and book chapters, theses and dissertations, maps, abstracts, and open-file reports on Oklahoma geology. Most of the items listed were issued in 1980, although a few entries have been retrieved from previous years.

The entries are indexed in detail under such categories as localities covered, geologic time periods, geologic provinces, and subdisciplines such as structural geology, geophysics, hydrology, stratigraphy, sedimentology, paleontology, and environmental geology.

Since 1955 a bibliography of Oklahoma geology has been issued annually by the Survey. Previous versions have appeared in *Oklahoma Geology Notes*. The recently published bibliography represents the first appearance of the set as a separate publication.

These indexed bibliographies have proved useful to those seeking information on the geology of Oklahoma and Oklahoma's earth resources. Listings covering the period 1955 through 1979 were combined late last year and are available as a two-volume set issued as OGS Special Publication 81-5.

Bibliography and Index of Oklahoma Geology, 1980 can be obtained from the Oklahoma Geological Survey at the address given inside the front cover. The price is $2.

OGS ISSUES COAL-ACTIVITY MAP

A new map released by the Oklahoma Geological Survey provides information on coal-mining activity during the period 1977-79 in 14 counties of eastern Oklahoma. The publication, *Map of Eastern Oklahoma Showing Locations of Active Coal Mines, 1977-79,* which has been issued as Oklahoma Geological Survey Map GM-24, was compiled by Samuel A. Friedman, senior coal geologist for the Survey. Friedman was assisted by K. C. Sawyer.

The map locates coal mines, preparation plants, two loading docks, two port facilities, and a tailings-recovery operation in the coal fields of the eastern part of the State. Counties covered include Craig, Nowata, Rogers, Mayes, Tulsa, Wagoner, Okmulgee, Muskogee, McIntosh, Sequoyah, Haskell, Le Flore, Latimer, and Pittsburg. The map is on one sheet and is at a scale of 1:500,000, or approximately 1 inch = 8 miles. The area of known coal resources is delineated in color.

Data included on the map sheet offer information for 196 localities on the producers, names of the coal beds mined, thicknesses of coals and of overburden, sulfur content, Btu values, uses to which the coal from each mine was put, and annual production ranges.

Map GM-24 can be obtained from the Oklahoma Geological Survey at the address given inside the front cover. The price is $3.

ISP AWARDED DOE CONTRACT

The University of Oklahoma was recently awarded a contract by the U.S. Department of Energy to build a computerized master file containing approximately 800,000 hydrological and stream-sediment analyses collected through the National Uranium Resource Evaluation (NURE) program. The contract will be administered through Information Systems Programs, a division of OU's Energy Resources Center.

The contract extends from April 1, 1982, through March 31, 1983, and is funded for a total of $88,834.

Work on this contract will begin by combining into a standard form 30 different data forms now being used. ISP staff will then build a master file from the 400 to 500 data tapes containing these data, using the GIPSY storage and retrieval software system, which was developed and patented at OU. User manuals and complete systems documentation also will be developed.

At the conclusion of the project, ISP will consider the feasibility of maintaining this data file in the computer network of energy data bases it currently offers for public use.

WEBER ADDED TO OGS STAFF

Jane L. Weber

Jane L. Weber, a chemist and computer programmer, is the latest addition to the staff of the Oklahoma Geological Survey. Weber, who was most recently a chemist and laboratory safety officer for Shaklee Corp., of Norman, is working under the direction of OGS geologist William E. Harrison to complete laboratory analyses for a number of projects. Among these are samples from both tar-sands and petroleum-source-rock investigations.

Weber previously worked as a chemist for the U.S. Army Corps of Engineers Waterways Experiment Station in Vicksburg, Mississippi; the M.D. Anderson Hospital and Tumor Institute in Houston, Texas; PPG Industries–Chemical Division in Corpus Christi, Texas; and the National Institutes of Health in Bethesda, Maryland.

She also spent 3 years as an instructor of science and mathematics at the American College for Girls in Istanbul, Turkey, where she chaired the Preparatory School Science Department and introduced a new science curriculum. During her stay in Turkey, she was able to travel extensively in Europe and other countries surrounding Turkey, and even rode the famous Orient Express from Vienna back to Istanbul.

"It was quite an experience," she said. "Sometimes you would wait for hours to show your papers at the borders. You could see that the train had been plush at one time, but it was a little dirty by then."

While in Turkey, she was housed along with some of the other instructors in one of the old summer palaces of the sultans. Although the building was not as luxurious as it once had been, some of the rooms still contained such trappings as velvet ceilings with hand-painted gold stars.

Along with Weber's background in chemistry and teaching, she has recently completed a number of hours in computer programming at The University of Oklahoma. She has already put this experience to good use and has initiated a number of programs for the Survey's Hewlett–Packard 85 and 9835A computers and is working with graphics on the 7225B plotter.

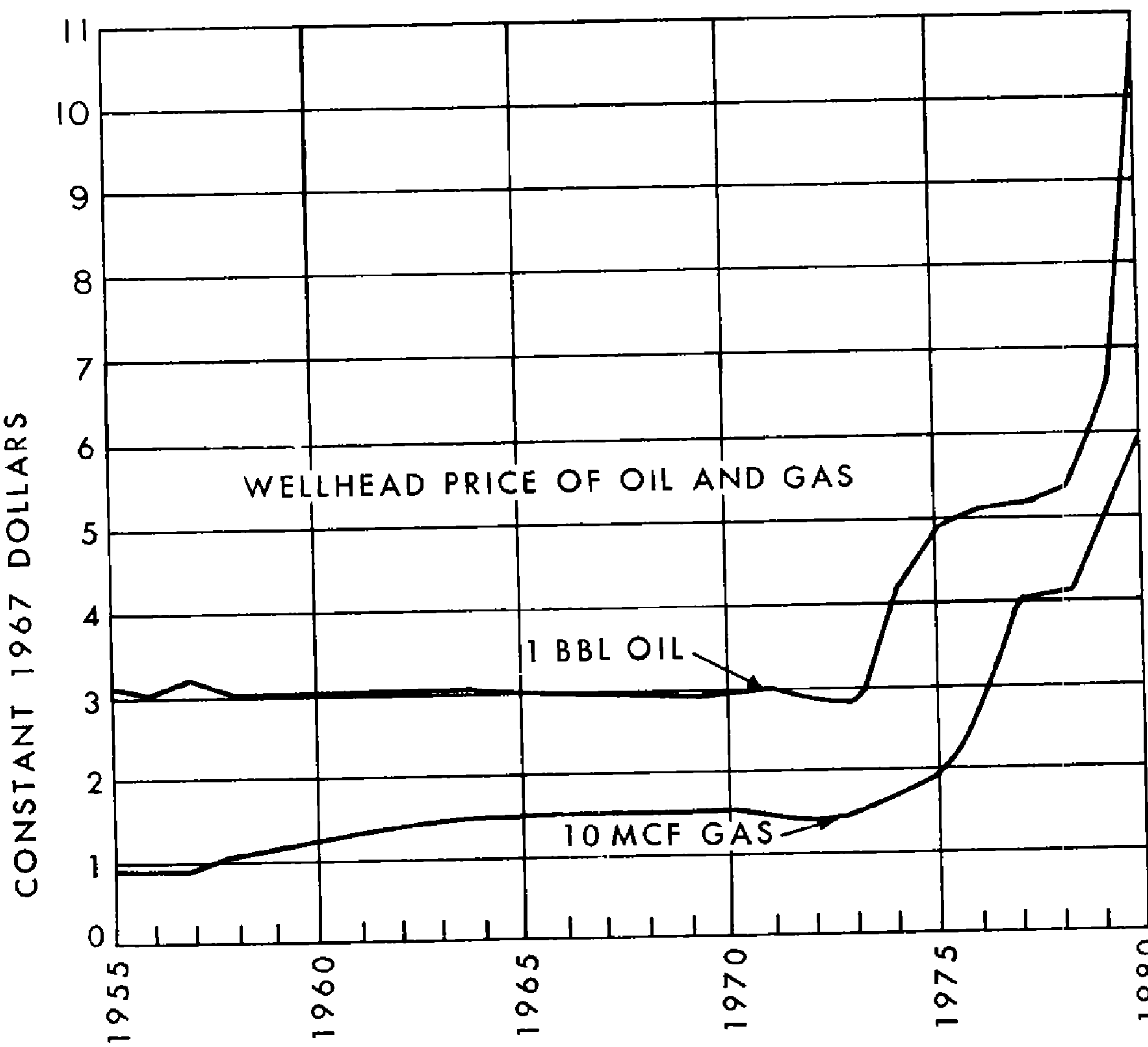
She is married to OGS chemist Steve Weber and they have two children, Mark, 13, and Tracy, 9. The Webers live in Moore.

GAS-PRICE FIGURES CORRECTED

An extra "0" in a graph appearing in the December 1981 issue of *Oklahoma Geology Notes* caused the apparent wellhead price of natural gas to appear much lower than it actually has been for the years since 1955.

The corrected version of this graph, below, shows the prices for 10 MCF of gas rather than for the 100 MCF erroneously quoted before.

The graph was graph 2 in an illustration that originally appeared in the *Notes* (v. 41, no. 6, p. 203) in an article entitled "Statistics in Oklahoma's Petroleum Industry, 1980." The price per barrel of oil is correct as was originally published.



Graph of hydrocarbon prices in Oklahoma, 1955–80, in constant 1967 dollars.

NOTES ON NEW PUBLICATIONS

Sedimentary Petrology

Examining each rock group in turn, M. E. Tucker emphasizes composition, petrography, sedimentary structures, and diagenesis of sedimentary rocks in his new 252-page book, *Sedimentary Petrology*. Depositional environments and facies are only briefly considered.

Order from: Wiley Professional Books-By-Mail, John Wiley & Sons, Inc., Dept. 0328, P.O. Box 063, Somerset, NJ 08873. Price: $12.95, paperback.

Applied Geophysics, 2d Edition

The new second edition of Gerhard Dohr's *Applied Geophysics* gives priority to techniques that play an important part in petroleum and natural-gas exploration, with emphasis on modern seismic methods.

This 256-page book has been reorganized. Rewritten chapters on digital processing of seismic data to reflect new developments are included, and more space is devoted to magneto-telluric methods.

Order from: Wiley Professional Books-By-Mail, John Wiley & Sons, Inc., Dept. 0328, P.O. Box 063, Somerset, NJ 08873. Price: $21.95, paperback.

Economic Mineral Deposits, Revised 3d Edition

The revised third edition of *Economic Mineral Deposits* contains an updated examination of world mineral deposits, as well as statistical data on production, reserves, and mineral resources. The authors, Mead L. Jensen and Alan M. Bateman, have added chapters on mineral economics and exploration, and the newly recognized bacteriogenic and exhalative volcanogenic processes.

Order this 593-page volume from: Wiley Professional Books-By-Mail, John Wiley & Sons, Inc., Dept. 0328, P.O. Box 063, Somerset, NJ 08873. Price: $26.95.

Modern Igneous Petrology

Mohan K. Sood, in his recent 244-page publication, *Modern Igneous Petrology*, discusses the application of phase equilibrium data in silicate systems to explain magmatic crystallization. Components representing the major rock-forming mineral groups conforming to the bulk chemistry of the igneous rocks are included in the systems described.

Also, new data are given on magma generation, volatile solubility, and petrological implications of plate tectonics. Significant features of major systems are summarized for easy reference and are illustrated with polythermal diagrams.

Order from: Wiley Professional Books-By-Mail, John Wiley & Sons, Inc., Dept. 0328, P.O. Box 063, Somerset, NJ 08873. Price: $27.50.

Composition and Properties of Petroleum

The composition and characteristics of various types of petroleum, natural gas, and oil-field waters are reviewed in a new 208-page volume by H. J. Neumann, B. Paczynska–Lahme, and D. Severin. Also described through the use of phase diagrams are the physical properties of petroleums, condensates, and natural gases.

Order from: Wiley Professional Books-By-Mail, John Wiley & Sons, Inc., Dept. 0328, P.O. Box 063, Somerset, NJ 08873. Price: $16.95.

Paleoecology, Concepts and Applications

In a new 544-page book that stresses application as well as theory, J. Robert Dodd and Robert J. Stanton have reconstructed ancient depositional environments using paleontologic techniques.

Discussion includes taxonomic uniformitarianism, biogeochemistry, skeletal structure, adaptive functional morphology, and populations, ecosystems, and communities.

Order from: Wiley Professional Books-By-Mail, John Wiley & Sons, Inc., Dept. 0328, P.O. Box 063, Somerset, NJ 08873. Price: $39.95.

Scientific Basis for Nuclear Waste Management, Volume 3

Compiled from the Proceedings of the Third International Symposium on the Scientific Basis for Nuclear Waste Management, which met in Boston, Massachusetts, this 650-page volume contains information on repository characterization, high-level-waste forms, non-high-level waste, natural analogues, leach studies, radiation effects, radionuclide migration, engineered barriers, and performance assessment.

Order from: Plenum Publishing Corp., 233 Spring St., New York, NY 10013. Price: $49.50.

Computer Applications in the Earth Sciences—An Update of the 70's

The papers in this 400-page volume, from the Proceedings of the 8th Geochautauqua held at Syracuse University, explore the usefulness of the computer in geological fields ranging from petroleum exploration to paleoecology.

Order from: Plenum Publishing Corp., 233 Spring Street, New York, NY 10013. Price $45.

Illustrated Petroleum Reference Dictionary, 2d Edition

This new, 592-page edition contains 3,000 entries that cover areas from lease acquisitions, exploration, production, and transportation to refining, petrochemicals, and marketing. The dictionary also includes 246 conversion tables and 4,000 oil- and gas-industry abbreviations.

Order from: PennWell Books, P.O. Box 21288, Tulsa, OK 73121. Price: $37.50.

Synfuels: Hydrocarbons of the Future

The important chemical advances made in the synfuels industry and the opportunities available for artificially producing new fuels today are discussed in this 386-page book.

Some of the topics covered are: types of synthetic fuels, raw materials needed for synfuels production, various gasification processes, coal liquefaction and related processes, and economic analyses of the developing processes.

Order from: PennWell Books, P.O. Box 21288, Tulsa, OK 74121. Price: $30.

ALABASTER CAVERNS GUIDEBOOK REVISED

Oklahoma Geological Survey Guidebook 15, a guide to the Alabaster Caverns area of Woodward County in northwestern Oklahoma, has been issued in a new, revised edition.

The guidebook was first published in 1969, and the original version has been reprinted three times because of popular demand. Revisions in the new edition are, for the most part, minor: some statistical data have been corrected; information on facilities available has been updated; a note has been added on the 1973 collapse of Chimney Rock, a famous monolithic landmark that stood near the park; and a short description of the formation of alabaster (a variety of gypsum) has been corrected.

Guidebook 15 contains four sections. A discussion of the "Geology of the Alabaster Cavern Area" was written by Arthur J. Myers, geologist with the Oklahoma Geological Survey. Myers and Carol R. Patrick, former OGS associate editor, prepared a "Description of Recreation Areas" in the park and at Boiling Springs State Park and Fort Supply Reservoir. Arrell M. Gibson, George Lynn Cross Research Professor of History at The University of Oklahoma, is the author of an article on the "History of Woodward County," and Bryan P. Glass, professor of zoology and director of the museum at Oklahoma State University, contributed an article on the bats that inhabit the caverns.

The 38-page volume contains 41 illustrations, including maps, cross sections, and numerous outstanding photographs showing geologic and geomorphic features, history, and wildlife of the area.

Guidebook 15 can be obtained from the Oklahoma Geological Survey office at the address given inside the front cover. The price is $1.

DRILLING BREAKS RECORD IN 1981

Oklahoma continued to rank second among all states in 1981 in the total number of wells drilled in the search for oil and gas, Robert C. Moore, president of the Oklahoma–Kansas Oil and Gas Association, said recently. Only Texas was ahead of the Sooner State in drilling activity, Moore noted.

Moore also indicated that industry reports show that a total of 58.6 percent more money was spent on oil and gas drilling in the state in 1981 than in 1980. The amount was $1.7 billion more than the $2.9 billion expenditures in the previous year.

While a total of 11,299 wells were drilled and completed in Oklahoma in 1981, a marked slowdown has caused drilling to slacken during the first half of 1982.

Oklahoma wells drilled in 1981 included 6,453 oil wells, 2,299 gas wells, and 2,947 dry holes, according to the Petroleum Information Corp. of Denver. This represented a success rate of 74.8 percent.

The 1981 total footage of Oklahoma wells was 54,796,899, a total of 10,378 miles drilled into the earth, Moore said. The average well drilled in the state was 4,683 ft deep, slightly more than the national average of 4,620 ft.

Moore noted that throughout the nation 78,884 wells for oil and gas were drilled in 1981, surpassing the previous record set in 1980. The prior record was in 1956.

In 1981 Oklahoma's Osage County regained its place as the second most actively drilled county in the United States, outranked only by Kern County, California. The county, which had 897 completions in 1981, had dropped to third place in 1980.

New-field wildcat wells in the state numbered 450, as compared with 338 for 1980, and the Anadarko Basin was the fifth-ranked geologic province in the country again in 1981, according to Moore. PI reported 5,456 wells drilled there—2,112 oil wells, 1,665 gas wells, and 1,679 dry holes. The total footage was 40,819,466 for an average of 7,481 ft per well.

The cost of drilling a well increases substantially on a footage basis as the well goes deeper, Moore said. A 1980 Joint Association Survey of Drilling Costs, sponsored by three national industry associations, reveals that this is especially true of wells drilled below 15,000 ft. Wells drilled to a depth of less than 2,500 ft in Oklahoma cost an average of $36.92 per ft during 1980, while those between 7,500 and 10,000 ft cost $62.61 per ft. From then on the costs rose rapidly.

Wells sunk to depths of between 17,500 and 20,000 ft cost the companies an average of $257.85 per ft to drill in the State, while the average cost per ft on wells drilled to 20,000 ft or deeper ran to $386.53, the report indicated.

OKLAHOMA ABSTRACTS

GSA Annual Meeting, North-Central Section West Lafayette, Indiana, April 29–30, 1982

The following abstract is reprinted from *Abstracts with Programs* of the Geological Society of America, v. 14, no. 5. The page number is given in brackets below the abstract. Permission of the authors and of John C. Frye, executive director of GSA, to reproduce the abstract is gratefully acknowledged.

Pennsylvanian Polyplacophora from Oklahoma and Texas

R. D. HOARE, Department of Geology, Bowling Green State University, Bowling Green, OH 43403; R. H. MAPES, Department of Geology, Ohio University, Athens, OH 45701; and D. E. ATWATER, MAPCO, Tulsa, OK 74105

The new subfamily Acutichitoninae of the Lepidopleuridae Pilsbry is erected to embrace polyplacophorans with tail valves having a terminal mucro and with lateral and posterior underturned margins (hypotyche). Asethete canals opening on the hypotyche appear to have been functional and probably served a sensory function.

A fauna from the Gene Autry Formation (Morrowan) contains *Pterochiton carbonarius* (Stevens), *Pterochiton* n. sp. and *Acutichiton* n. sp. *P. carbonarius* is also reported from the Smithwick Formation (Upper Atokan) in Texas. [262]

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.

AAPG Annual Meeting
Calgary, Alberta, Canada, June 27–30, 1982

The following abstracts are reprinted from the *AAPG Bulletin* of the American Association of Petroleum Geologists, v. 66, no. 5. Page numbers are given in brackets below the abstracts. Permission of the authors and of Myron K. Horn, editor, to reproduce the abstracts is gratefully acknowledged.

Geochemistry and Isotopic Composition of Hydrocarbon-Induced Diagenetic Aureole (HIDA), Southwestern Oklahoma

ZUHAIR AL-SHAIEB, Oklahoma State University, Stillwater, OK; and R. A. LILBURN, Union Oil Co. of California, Oklahoma City, OK

The Permian red beds at Cement and Chickasha oil fields in southwestern Oklahoma have undergone extensive and intensive alteration. This diagenetic mineralization is a direct expression of hydrocarbon migration along unconformity surfaces and fault zones. The oxidation of seeping hydrocarbons to carbon dioxide is the major source of carbon in diagenetic carbonates, which occur as cement and as replacement of gypsum and detrital grains. Calcite cement with δC^{13} values up to −39 ppt PDB reflect this hydrocarbon source. However, a few calcite samples analyzed show δC^{13} values of approximately −6 ppt PDB which indicates a freshwater origin. In addition, isotopically hybrid carbonate cement with a bimodal carbon source also is found throughout the stratigraphic section.

Bleaching of red beds and formation of pyrite are explained as reduction of iron oxides by hydrogen sulfide associated with hydrocarbons. Sulfur isotope ratios of pyrite are similar to those of crude oil. The δS^{34} values of pyrite samples collected from the surface and shallow subsurface tend to be slightly enriched in S^{32}. The enrichment of pyrite with the light isotope S^{32} may be due either to increases in biological activity or to increases of oxygen fugacity. Authigenic kaolinite and mixed-layered illite-smectite are formed as by-products of hydrocarbon migration, which has significant effect on formation-water chemistry. The relationship between hydrocarbon migration and diagenetic minerals may be used as a pathfinder for hydrocarbon accumulation at depth. [542–543]

Stability of Natural Gas at High Temperatures, Deep Subsurface

COLIN BARKER and MARWIN K. KEMP, University of Tulsa, Tulsa, OK

The components of natural gas are reactive in the deep subsurface and may not survive under all conditions. The stability of natural gas in reservoirs of various lithologies is studied using a combined theoretical and experimental approach.

A computer program uses real gas data to calculate equilibrium in multicomponent (up to 50), multiphase (up to 30) systems simulating subsurface conditions to 12 km (40,000 ft). This program predicts the stability of hydrocarbons in sandstone reservoirs by first considering clean sands and then sequentially adding feldspars and clays, carbonate cements, and iron oxides. In all examples, equilibrium compositions have been computed for low, average, and high geothermal gradients; hydrostatic and lithostatic pressures; and with and without graphite. Graphite is present when deep gases are generated by the cracking of oil but is absent in reservoirs originally filled with dry gas. Similar calculations have also been made for limestone and dolomite reservoirs with various combinations of clays, iron minerals, anhydrite, and sulfur, again with and without graphite. Natural gas shows considerable stability in sandstone reservoirs under most conditions, but its concentration in deep carbonates is more variable and tends to a hydrogen sulfide-carbon dioxide (H_2S–CO_2) mixture except when an appreciable concentration of iron is present. Hydrogen is present at the 1 to 2% level for most lithologies.

A multicolumn gas chromatograph is used to analyze inorganic and organic gases released by crushing rock samples in a Teflon ball-mill. Gas samples from deep wells in the Anadarko basin and southern Louisiana have been analyzed and the compositions compared with those predicted from the computer program. [545]

Origin for Uraniferous Organic Nodules, Hennessey Group (Permian), Oklahoma

JOSEPH A. CURIALE and SALMAN BLOCH, Oklahoma Geological Survey, Norman, OK; JANINA RAFELSKA-BLOCH, The University of Oklahoma, Norman, OK; and WILLIAM E. HARRISON, Oklahoma Geological Survey, Norman, OK

Geologic field relations may be used to infer a coal- or petroleum-related origin for uraniferous organic nodules of the Hennessey Group (Permian), in Kiowa County, Oklahoma. The local presence of crude oil in the shallow subsurface and the local absence of commercial coal deposits suggest a petroleum-related origin for these nodules. This conclusion is compatible with the subsurface structure near the nodule site, which is dominated by several major near-vertical reverse faults, below the Permian unconformity. These faults may provide vertical conduits for petroleum sources below.

Geochemical analyses of the uraniferous nodules, including infrared spectra and elemental analyses, reveal characteristics of both coal and petroleum. However, carbon isotopic analyses favor a petroleum-related origin. A model can be proposed whereby petroleum, migrating from depth, is initially altered near the surface to a more viscous material. Concurrently migrating, uranium-rich ground water is then stripped of its uranium by the degraded petroleum. Subsequent radiation damage in the uranium-rich nodules has resulted in unusual chemical characteristics. Such a model suggests that associated petroleums may geochemically correlate to the organic matter of the nodules. This is confirmed by carbon isotope ratios, which are very similar for both the petroleum and the uraniferous nodules. [560–561]

Comparative Organic Geochemistry of Shales and Coals from Cherokee Group and Lower Part of Marmaton Group of Middle Pennsylvanian Age, Oklahoma, Kansas, Missouri, and Iowa

JOSEPH R. HATCH and JOEL S. LEVENTHAL, U.S. Geological Survey, Denver, CO

Mid-Continent middle Pennsylvanian rocks are a complex assemblage of coal-cyclothem lithologies. Organic-matter-rich rocks in the section include coals (33 to 76% organic carbon—org. C), marine, dark-gray to gray-black shales (1 to 8% org. C), and laminated, phosphatic black shales (4 to 28% org. C). Organic matter in these rocks came mostly from peat swamps, as shown by similarities between coal and shales in organic petrography, hydrogen (H) and oxygen (O) indices (Rock-Eval pyrolysis), pyrolysis-gas chromatographic analyses, and gas chromatographic analyses of saturated hydrocarbon fractions of $CHCl_3$ extracts. A halocline, resulting from the river waters that transported the dissolved and fine particulate organic matter from the extensive swamps, may have been the principal mechanism for restricting circulation in the shale-depositing environments.

Some organic geochemical properties vary significantly within and between the coal and shale lithologies, reflecting inferred differences in intensity of depositional and diagenetic anoxic conditions and degree of thermal maturation. For shales with comparable thermal maturities, deposition and diagenesis under more intense anoxic conditions result in higher org. C, P, U, Se, Mo, V, Ni, Ag, and Cr contents, H indices, saturate/aromatic and NSO/asphaltene ratios in $CHCl_3$ extracts and lower O indices, pristane/phytane ratios, and organic carbon $\delta^{13}C$ values (more negative by 1 to 2 per mil). H and O indices in coals resemble those of shales deposited under the most intense anoxic conditions. In contrast, saturate/aromatic, NSO/asphaltene, and pristane/phytane ratios in coal extracts, trace- and minor-element contents, and organic carbon $\delta^{13}C$ of coals resemble shales deposited under relatively oxic conditions. A few coals are overlain by black phosphatic shales and have been subjected to more intense anoxic diagenesis. These coals have higher U, Se, Mo, V, Ni, and Cr contents, lower pristane/phytane ratios, and more negative (~ 1 per mil) organic carbon $\delta^{13}C$ values. When normalized in n-C_{18}, most pristane/phytane variability in all rock types appears to be related to variation in amounts of pristane, phytane content remaining relatively constant. With increased degree of thermal maturity, (1) H and O indices decrease in both coals and shales; (2) total bitumen/org. C and pristane/phytane ratios increase in shales but decrease in coals; and (3) saturate/aromatic ratios increase significantly only in shales that were subject to high levels of anoxic diagenesis. The black phosphatic shales contain extractable organic matter that is most similar to Cherokee crude oils from northeast Oklahoma and southeast Kansas. [579]

Mesozoic Paleo-Oceanography of Atlantic and Western Interior Seaway

WILLIAM W. HAY, University of Miami, Coral Gables, FL

Mesozoic oceans were filled with warm, salty water formed in marginal seas in the arid zones, rather than by cold water from polar sources as is the modern ocean. The early Atlantic and Gulf of Mexico were sites of significant salt extraction, serving as evaporative basins refluxing dense brine to the world ocean. As connection with the world ocean became better established, salt deposition in these basins ceased but sea level rose in response to growth of the mid-ocean ridge system, resulting in extensive flooding of the continents. Marginal seas and that part of the seaway through the Western Interior of North America lying in the arid zone then became sites of formation of plumes of dense, warm, salty, oxygen-poor water. These dominated the structure of the adjacent oceans. Periodic filling of individual basins by especially dense warm salty bottom water caused partial overturning and high productivity, followed by temporary stagnation and oxygen depletion, with the result that organic carbon-rich sediments were preserved. Because such "anoxic events" were dependent on local climatologic factors they were not necessarily synchronous in different basins. [579]

Diagenetic Model for Carbonate Rocks in Mid-Continent Pennsylvanian Eustatic Cyclothems

PHILIP H. HECKEL, University of Iowa, Iowa City, IA

Diagenetic patterns in cyclic Mid-Continent Pennsylvanian carbonates are readily explained in terms of a predictive diagenetic model derived logically from the eustatic depositional model for widespread Pennsylvanian cyclothems. Transgressive shoal-water calcarenites are characterized by overpacking of grains, discernible neomorphism (with excellent preservation of structure) of originally aragonitic grains (ooids, green algae, mollusks), and ferroan calcite and dolomite cement, which indicate movement from the marine phreatic environment of deposition and diagenesis into the low-oxygen deeper burial connate zone, with substantial compaction before any cementation. Offshore invertebrate calcarenites associated with offshore

("core") shales also are characterized by overpacking of grains and ferroan carbonate cements, which indicate a similar diagenetic history. Regressive shoal-water calcarenites show a much greater variety of diagenetic features, including early marine cement rims and large-scale leaching of originally aragonitic grains, commonly with subsequent collapse of micrite envelopes, grain fragments, and overlying material in samples insufficiently stabilized by early cement rims. This was followed by pervasive cementation by blocky calcite before much further compaction, then by ferroan calcite, and finally ferroan dolomite in remaining voids. This pattern indicates replacement of depositional marine phreatic water by meteoric water, which dissolved unstable carbonate grains and then deposited stable carbonate cements in environments that eventually became increasingly oxygen-depleted and otherwise chemically changed, probably as mixing-zone and deeper connate water moved back into the rock and replaced the meteoric water during and after the succeeding transgression. Trends in calcilutites are essentially similar to those in calcarenites of equivalent phase of deposition, with evidence of subaerial exposure and meteoric vadose soil formation in strata at the top of many regressive limestones. It is apparent that with the regression of the sea and emergence that terminated deposition of a cyclothem, meteoric water penetrated the permeable parts of the regressive carbonate and left its distinctive diagenetic patterns of early leaching and cementation before much compaction occurred, but rarely did meteoric water penetrate the impermeable offshore shale, which acted as a seal and allowed associated deep-water and underlying transgressive carbonates to become more deeply buried and substantially compacted before cementation, with unstable grains undergoing slow neomorphism in the absence of leaching. [580]