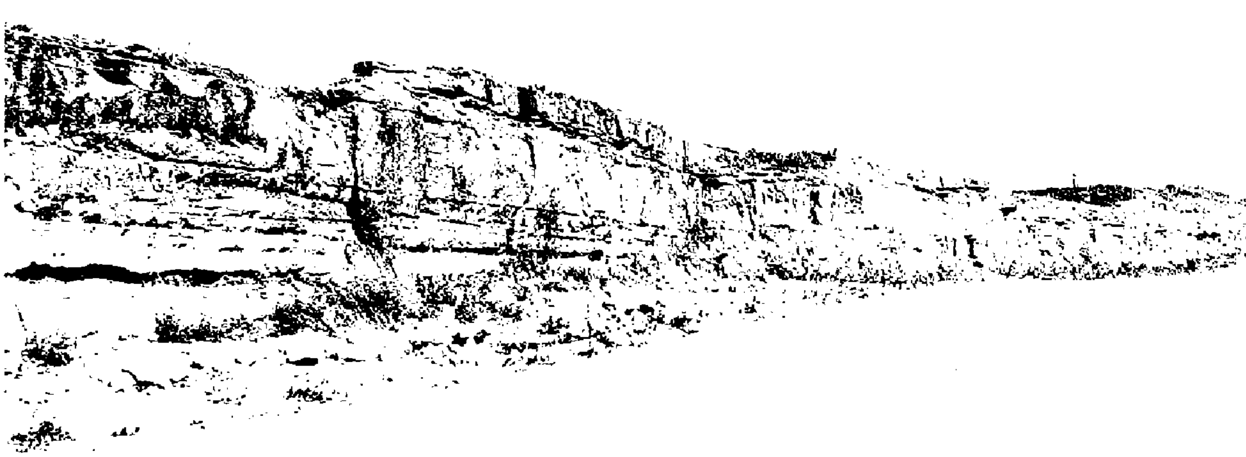
Oklahoma Geology Notes

OKLAHOMA GEOLOGICAL SURVEY / VOL. 44, NO. 3 — JUNE 1984



On the cover—

Limestone in Cuesta Country

The cover photo, view looking east on the north side of the road, in the SE SW sec. 24, T28N, R3E, shows the Fort Riley Member, the upper of two outstanding limestone members of the Barneston Formation that holds up the cuesta country immediately east of the Arkansas River in eastern Kay County, Oklahoma. The western part of this cuesta country has been deeply dissected and eroded by the Arkansas River, resulting in the formation of massive abrupt escarpments along both sides of its floodplain. The course of the Arkansas River is directed around Kaw City by this resistant escarpment of the Barneston Formation.

Quarries west of Kaw City and north and west of Uncas formerly made use of the massive, non-cherty, relatively pure Fort Riley Member for building purposes.

A geologic map in color showing Pennsylvanian-Permian surface outcrops in Kay County is in preparation, along with a county report. The scale of the map will be 1:63,360 (1 in. = 1 mi).

James Chaplin

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, $1.50; yearly subscription, $6. 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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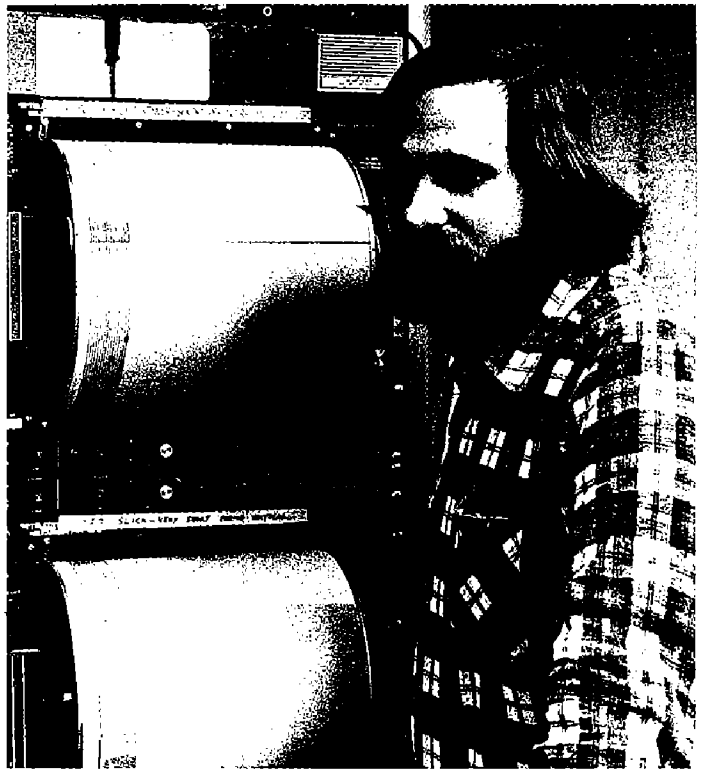
Contents

This publication, printed by The University of Oklahoma Printing Services, Norman, Oklahoma, is issued by the Oklahoma Geological Survey as authorized by Title 70, Oklahoma Statutes, 1981, Section 3310, and Title 74, Oklahoma Statutes, 1981, Sections 231-238. 1,800 copies have been prepared for distribution at a cost to the taxpayers of the State of Oklahoma of $2,357.



Richard L. Watkins

MODIFICATION OF SEISMOGRAPH NETWORK INCREASES RELIABILITY OF RECORDINGS

The Oklahoma Geological Survey's Oklahoma Geophysical Observatory (OGO) near Leonard, in southern Tulsa County, records ground motion on 11 heat-pen-writing seismographs and eight ink-pen-writing seismographs. Experience with both the ink and the heat pens demonstrated the greater reliability of the heat pens over extended periods of time.

In addition to the seismographs at OGO, seven volunteer-operated seismographs, located at various sites in Oklahoma, had been recording one ink seismogram each. In the past, as much as 10 percent of the recordings made at these stations was lost because of ink stoppages. Furthermore, ink pens, which must be replaced three times a year, have increased in price to almost $60 per pen.

Although it was desirable to convert the field stations' recording units from ink pens to heat pens, commercially available heat pens were not adaptable to our field equipment. Therefore, a new type of heat pen was developed and built by OGO electronics technician Richard L. Watkins. Because the new pen was innovative and had many potential uses (such as for electrocardiographs), The University of Oklahoma Patent Committee decided to file a patent application, which is now pending.

The new heat pens are operated by power supplies designed and built by

OGO electrical engineer Paul H. Foster. While building the power supplies, Foster developed the in-house capability to etch printed circuit boards.

In August of 1983, station BHO, near Bethel, in the Ouachita Mountains of southeastern Oklahoma, was converted from using ink pens to using heat pens. BHO has been operating seven months with the same heat pen without a loss of recording time resulting from pen problems. In February 1984, the conversion of all the field stations to the use of heat pens was completed at station ATO in Kingfisher County.

James E. Lawson, Jr.

SURVEY COMPILES MAP, DATA BASE ON STATE'S OIL AND GAS FIELDS

The Oklahoma Geological Survey is currently completing work on a new map of all officially named oil and gas fields in Oklahoma. The map, prepared at a scale of 1:500,000 (approximately 1 in. = 8 mi), follows closely the geographic descriptions of fields as determined by the Nomenclature Committee of the Oklahoma-Kansas division of the Mid-Continent Oil and Gas Association, the official group that names oil and gas fields in the State. The new map depicts the geographic boundaries of each field as enclosing only the areas where producing wells are present, thereby giving a more realistic shape to the fields than is presented on maps currently available.

The OGS oil- and gas-field map features a three-color format, indicating whether each field produces oil, gas, or a combination of oil and gas. Each field is assigned an index number that corresponds to an alphabetical listing of fields on the map sheet. The geographic location of each field is also included for reference, as well as a listing of smaller fields that have been combined into some of Oklahoma's major oil and gas "trends."

The map includes the 3,088 active fields and 32 abandoned fields named by the Nomenclature Committee as of April 1983. Oil and (or) gas fields are present in 73 of Oklahoma's 77 counties and represent more than 4 million acres in surface area.

A preliminary copy of the map is scheduled for presentation in a poster session at the annual meeting of the American Association of Petroleum Geologists, May 20–23, 1984, in San Antonio, Texas. The completed map will undergo cartographic preparation for publication later this year.

In addition to the oil- and gas-field map, the Oklahoma Geological Survey has designed and developed a computerized data base of oil and gas fields in the State. Information contained in the computerized data base includes field name, year of discovery, county name, county code, section, township, range, former name or consolidated history, product code (oil and/or gas), monthly production, formation name, and remarks. Current plans also call for the addition of the names of the producing formations. Monthly production figures now maintained in the data base cover January through December of 1983. OGS is in the process of evaluating the 1983 production figures. The Survey also plans to acquire past monthly production figures for the fields.

The information maintained in the computerized data base has been acquired from the Oklahoma Tax Commission, Gross Production Division, and the Nomenclature Committee of the Oklahoma-Kansas division of the Mid-Continent Oil and Gas Association.

The Survey also will generate a computerized listing of unassigned sections containing completed oil and gas wells. Until the unassigned-production figures for 1983 have been evaluated and put into the data base, this information will not be released. Thus, the field files will contain more complete information than is currently available on production figures and areas covered.

An important aspect of this project will be evaluations of the data by petroleum geologists on the OGS staff. If necessary, field checks will be made before the new information is added to the data base. Also important to the investigation will be reservoir evaluations of individual producing oil and gas fields, whereby decline curves will be constructed and projected.

Margaret R. Burchfield
Michelle J. Summers

SOIL CONSERVATION SOCIETY TO MEET IN OKC

The annual meeting of the Soil Conservation Society of America is scheduled for Oklahoma City July 29–August 1. Headquarters for the meeting will be the Sheraton–Century Center Hotel.

The society is celebrating its golden anniversary this year, an event that constitutes the theme of the meeting. A speech by U.S. Secretary of Agriculture John R. Block will highlight the keynote session. A high-level representative of the U.S. Environmental Protection Agency also will address the group.

During the meeting, about 100 papers will be presented in concurrent sessions. In addition, several poster sessions will be held.

The pre-registration fee for the meeting is $50 for members and $65 for nonmembers. Registrants signing up after July 1 will be charged $15 more.

For further information, contact Walter Peechatka, Soil Conservation Society of America, 7515 Northeast Ankeny Road, Ankeny, IA 50021 (phone, 515–289-2331).

Arthur J. Myers

ARTHUR J. MYERS RETIRES FROM OGS

He has been a significant part of the geological scene at The University of Oklahoma for 33 years. He is retiring at the end of this fiscal year.

Born in South Haven, Michigan, educated in Michigan (B.A. in chemistry, Kalamazoo College; B.S. and M.S. in geological engineering, Michigan Technological University, Houghton; Ph.D., geology, University of Michigan, Ann Arbor), Arthur J. Myers came to The University of Oklahoma as an assistant professor of geology in 1951. He was elevated in rank to associate professor in 1961 and was named professor of geology and geophysics in 1973. For many summers during these years he taught in the OU geology field camps, first at Lake Murray, then later in the camp in Colorado. During the summers not spent in field camp he worked as a geologist for the Oklahoma Geological Survey.

In 1978 Art Myers left the OU School of Geology and Geophysics to become a full-time geologist with the OGS. He has been with the Survey ever since, serving as geomorphologist and aerial-photo interpreter, although retaining a connection with the School in the position of adjunct professor of geomorphology.

Myers' first academic efforts were not focused toward geology at all but toward medicine, and at Kalamazoo College he enrolled in pre-med courses—first zoology, then switching to chemistry. World War II came, and he became a line officer in the U.S. Navy, serving in 1943 on the U.S.S. St. Mihiel in the Aleutian Islands and in 1944-45 on the U.S.S. Samaritan, a hospital ship that followed every Marine invasion in the South Pacific, including the

Marianas, Palau, Iwo Jima, and Okinawa. In 1946 the ship became part of the occupation force as the base hospital ship at Sasebo in Japan. Following the war, he remained in the Navy Reserves, retiring with the rank of Lieutenant Commander.

It was following his experiences in the Navy and his return home to Michigan that Myers transferred his major interest to geology, earning the two degrees in geological engineering at Houghton and receiving a scholarship to work on his Ph.D. at Ann Arbor. He served as a graduate assistant in geology while working on his master's at Michigan Tech. He worked as a field geologist for the Newfoundland Geological Survey in the summer of 1948.

He enrolled in vertebrate paleontology while pursuing his Ph.D., the only geologist to be accepted into the course: from his earlier studies in zoology, he was the only one with sufficient prerequisites in anatomy, comparative morphology, etc. It was really this work that sent him to Oklahoma; his major professor suggested that he come to western Oklahoma to investigate vertebrate fossils in the Cenozoic deposits. He requested and received employment from the Oklahoma Geological Survey in the summer of 1951 to aid in carrying out his investigations and ended up checking the Cenozoic for Hugh D. Miser's revision of the Oklahoma geologic map. This work continued during the months of June, July, and August.

Then, while he was on the scene, he was approached by Victor E. Monnett, chairman of OU's Department of Geology at the time, to teach geology at OU. He was virtually hired on the spot. The Ph.D. had to wait and was not awarded until 1957.

He went back to Newfoundland the next summer (1952) to work again as a field geologist, this time for American Zinc Co. of St. Louis, but he came back in the fall, and he has been on the University campus ever since.

Arthur Myers' specialty is geomorphology in reference to structure, types of rocks, paleoclimates, etc., as reflected in land forms, particularly in the Permian rocks and in the Pleistocene fluvial deposits of northwestern Oklahoma. He is an expert in photo interpretation as well. He has also taught undergraduate and graduate courses in physical geology, mineralogy, petrology, and field geology, and he earned a well-deserved reputation among knowledgeable people for being an outstanding teacher.

Myers has directed many masters' theses and has been on numerous committees for other masters' and Ph.D. theses and dissertations. He has also served on several Ph.D. committees in geography, education, and engineering. During the eight years (1966 through 1973) that the School of Geology and Geophysics was active in the Earth Science Teacher Training Institutes sponsored by the National Science Foundation, he directed 42 Master of Natural Science (MNS) theses.

He is chief author of OGS Bulletin 80 (a report on Harper County) and of OGS Guidebook 15, the recently revised guide to Alabaster Cavern and Woodward County. He has contributed many articles to *Oklahoma Geology Notes,* the most recent being an article on the boundaries of Oklahoma that appeared in the December 1983 issue. He is currently working on a report of Woodward County. He has written a description of Robbers Cave State Park and a section on the geology of the Robbers Cave area for a guidebook that will be issued shortly as a completely revised edition.

Others of his current and recent projects include assembling information on all mines, pits, quarries, and important mineral prospects in the State for storage in the MILS (Mineral Industry Location System), a data bank stored in the U.S. Bureau of Mines computers; an inventory to locate and evaluate all of the State's active and inactive surface mines for preparation of a map; and an inventory of the Survey's massive collection of aerial photos. Also, he reviews all OGS maps before publication.

It should be noted in connection with this list of his Survey projects that Art Myers has earned another justly deserved reputation—this for the meticulousness of his work.

As to professional affiliations: He holds membership in several scientific organizations, including the Geological Society of America, the American Association of Petroleum Geologists, the American Association for the Advancement of Science, the American Society of Photogrammetry, the International Oceanographic Foundation, Tau Beta Pi (honorary engineering fraternity), and Sigma Xi (an honorary research association).

Dr. Myers has accused me of writing his obituary in preparing this article, but nothing could be further from the truth. He remains quite active both in his professional and in his personal life. This is not even a farewell and Godspeed message. Art has most generously offered to contribute his knowledge and service to the Oklahoma Geological Survey following his official departure from the staff. So instead of retiring to his garden, the heirloom-quality rugs and needlepoint pillows he makes for friends, his bicycle riding, and his friends, he will remain on the scene for some time to come.

This is merely an appreciation of the many years he has put in at The University of Oklahoma, and most especially at the Oklahoma Geological Survey. It is merely a recognition of his official retirement on June 30, 1984.

Elizabeth A. Ham

A Review

U.S. ENERGY POLICY

U.S. Energy Policy—Crisis and Complacency, by Don E. Kash and Robert W. Rycroft, 1984, 334 p. University of Oklahoma Press, 1005 Asp Avenue, Norman, OK 73019. $19.95.

William D. Rose[1]

The authors, Don E. Kash and Robert W. Rycroft, track the events leading up to the oil embargo imposed by the Arab producing states in 1973, follow developments during 1973–80, and assess the Reagan administration's "radical" departure from the national consensus they identified to have developed by 1980 with respect to our nation's energy policy. Kash and Rycroft conclude that the United States has no coherent energy policy today and that the nation, therefore, is at risk.

Both authors are political scientists. Kash, in addition to his position as a George Lynn Cross professor of political science at The University of Oklahoma, is a research fellow in OU's Science and Public Policy Program. Rycroft is an assistant professor of public affairs and political science at George Washington University in Washington, DC. Each author has several books to his credit in the field of energy and public policy.

In the preface the authors explain their viewpoint when they began their study, saying that they had assumed that the United States policy process had failed to respond to the energy crisis which had begun in the early 1970's and exploded with the Arab oil embargo in 1973. The authors concluded, however, that this initial assumption essentially was incorrect—that between 1973 and 1980 a United States energy-policy system actually had been evolving. Though chaotic and fragmentary at first, this system by 1980 had been developing a national consensus on energy. Kash and Rycroft go on to say that in "moving the management of energy into the marketplace, the Reagan administration has rejected the fundamental tenet of the conservative: it has rejected both the procedures and the mechanisms that for over two hundred years have provided national stability" (p. xiv).

Whether or not the reader agrees with these basic perceptions, he or she surely will appreciate the thorough research, analysis, and documentation that have gone into the study. The writing is lucid, and the organization logical. There is an adequate bibliography and a good index. Perhaps one might

[1]Geologist/editor, Oklahoma Geological Survey, Norman.

feel that the authors are overly repetitious at many points, but evidently this was done for emphasis. One thing is sure: their points cannot be missed.

At the outset, four energy goals are identified as forming the focus of public attention at the beginning of the Arab embargo: abundance, cheapness, cleanness, and security. Through the exercise of traditional public-policy process, by 1980 three of these goals were held to be desirable: abundance, cleanness, and security; the fourth, cheapness, was no longer considered possible or desirable.

Kash and Rycroft state that before 1973 the nation's only energy policy was a loosely structured one centered around five principal fuels or energy forms—coal, crude oil, natural gas, electricity, and nuclear power—and that each was managed more or less independently from the others. The point is made that coal is the only one of the five that operated in an essentially free-market environment and that it was also the weakest in terms of its share in the growing energy market.

The evolving consensus on energy policy that had been developing after 1973 was beginning to recognize some 12 desirable forms or potential sources of energy, according to the authors: coal, crude oil, natural gas, electricity, nuclear power, hydroelectric power, oil shale, tar sands, geothermal power, organic waste, solar power, and conservation. Conservation? That's right; Kash and Rycroft emphasize conservation because of the striking improvement in energy efficiency resulting from steeply higher prices. By the end of 1980, conservation had provided more new energy to the nation than any other single source. In this categorization, wind power is included under solar power, since winds are the result of solar-radiation patterns.

The authors look at these 12 resource options with respect to what is currently available, potentially available, and theoretically possible. Under potentially available options the authors include liquefaction and gasification for coal, liquid-metal fast-breeder reactors for nuclear energy, surface and *in-situ* retorting for oil shale, *in-situ* processing for tar sands, and high-temperature concentrators and photovoltaic cells for solar power. Fusion is shown as a theoretically possible development for nuclear power. As for nuclear power in general, Kash and Rycroft view its future growth pessimistically, citing the public's increasing concern over nuclear safety, nuclear waste, and spent fuel.

The authors conclude that for the short and middle terms the principal sources of energy that will be developed and utilized in the United States are oil and gas, coal, conventional nuclear power, and synthetic fuels.

The effects of the Reagan administration's impact on the energy-policy consensus that had evolved by 1980 are seen by the authors as follows (p. 278):

> Primary responsibility for energy policy was handed over to the private sector, with policy management to be handled through marketplace decisions.
>
> With regard to national energy goals, the Reagan administration also committed itself to the marketplace process. It downgraded emphasis on environmental protection

and therefore the clean-energy goal. The administration's approach to the goal of energy abundance was to seek to make publicly owned resource lands more rapidly available for development by the private sector. Finally, the administration articulated the view that the goal of energy security was most effectively achieved by allowing the free working of the marketplace.

Thus the Reagan administration dismantled the energy policy community that had come together between 1973 and 1980.

In a final chapter Kash and Rycroft make 20 recommendations for reestablishing what they see as a dependable energy future for the United States. Some of these recommendations are summarized under the following four categories:

1. Short-term actions:
   - The Strategic Petroleum Reserve should be filled at an accelerated rate so that combined public and private stocks in the United States are 2 billion barrels or the equivalent of one year's imports.
   - If a crisis occurs, both public and private oil stocks should be handled as a single national reserve, with responsibility for implementing a government–industry allocation program resting with the oil industry.
2. Liquid-fuel options:
   - The government should act quickly to subsidize an alternative domestic liquid-fuel-production capability of 250,000 to 500,000 barrels per day.
   - This program should be carried out by the large energy companies.
3. Legislative-management actions:
   - The strength and viability of the U.S. Department of Energy and the U.S. Environmental Protection Agency should be reestablished.
   - The U.S. Department of the Interior should establish a single energy- and minerals-management bureau to manage the leasing and production of energy on public lands.
   - Congress should promote the development of a permanent storage system for nuclear waste.
4. Energy research and development actions:
   - The federal government should carry out a sustained program of research and development on solar photovoltaic technologies.
   - A substantial program of research and development in fast-breeder reactors should be undertaken.
   - The present program of fusion research and development should be sustained.
   - One focus of the present Department of Energy program of support for long-range research should be research on long-range energy demand.

In a concluding section the authors state: "The recommendations in this chapter share a central theme: a stable energy future for the United States requires a cooperative relationship among participants in government, the private sector, and the nonprofit research institutions" (p. 313). The authors emphasize that in order to have a secure energy future it is imperative that the nation restore this pattern as quickly as possible.

Most, if not all, readers would agree with the majority of the views that Kash and Rycroft espouse. Certainly some would disagree in part with their premises, conclusions, or recommendations. It seems to me, for instance, that the authors didn't give sufficient emphasis to the disruptive effect of environmental extremists on the orderly development of our nation's energy resources or the related subject of the necessity for sufficient access by energy companies to federal lands for carefully supervised exploration and development programs.

But why take my word? Buy a copy of this book and judge for yourself.

GEOLOGISTS THROUGHOUT WORLD TO CONVERGE ON MOSCOW

Moscow, the site of the 27th International Geological Congress (IGC), is expected to draw geologists from all over the world to its sessions, which are scheduled for August 4–14. Before and after the main meeting, a number of field trips will examine the geology of specific areas and regions. The International Union of Geological Sciences is serving as the official sponsor of the congress.

The U.S. National Committee on Geology held a detailed discussion on the IGC at its December meeting at the National Academy of Sciences in Washington, DC. At this meeting the committee adopted a position statement, which reads partly as follows:

> The U.S. National Committee on Geology is dedicated to the continuing and valuable functions of the international scientific programs embodied in the International Union of Geological Sciences (IUGS) and the International Geological Congress (IGC). Although recent troubling events have raised questions about participation in the 1984 IGC meeting to be held in Moscow, it is the position of the U.S. National Committee on Geology that participation in the activities of both the IGC and the IUGS is required for the continuing health and growth of important international science programs. . . .

At Moscow the U.S. National Committee on Geology will extend an invitation to hold the 28th IGC in the United States (in 1989). The chairman of the U.S. National Committee on Geology is Howard R. Gould, president of the American Geological Institute. Any inquiries concerning the congress can be addressed to the committee's secretary, Linn Hoover, at the U.S. Geological Survey, 917 National Center, Reston, VA 22092 (phone, 703-860-6418).

NOTES ON NEW PUBLICATIONS

Atlas of Major Texas Oil Reservoirs

This 139-page illustrated atlas, by W. E. Galloway, T. E. Ewing, C. M. Garrett, N. Tyler, and D. G. Bebout, gives geologic, engineering, and production data on approximately 450 oil reservoirs in Texas that have produced more than 10 million barrels of oil each. The atlas groups the reservoirs into 48 plays with similar characteristics. The volume includes 426 maps, as well as cross sections and logs, and five color plates.

Order from: Bureau of Economic Geology, University of Texas at Austin, University Station, Box X, Austin, TX 78712. The price is $40 plus a $3.25 handling charge (Texas residents add $2 sales tax).

Preliminary Log-Derived Maps of the Bakken Formation, North Dakota and Montana, Portions of Williston Basin

T. C. Hester and J. W. Schmoker's 27-page open-file report is available from: Open-File Services Section, Western Distribution Branch, U.S. Geological Survey, Box 25425, Federal Center, Denver, CO 80225. The price for OF 83-0717 is $3.50 microfiche, $3.75 paper copy.

Preliminary Map of the Resource Areas in the Basin and Range Province of Idaho

George Wong's 8-page report includes one oversized sheet at a scale of 1:500,000 (1 in. = about 8 mi). Order OF 83-0720 from: Open-File Services Section, Western Distribution Branch, U.S. Geological Survey, Box 25425, Federal Center, Denver, CO 80225. The price is $4 microfiche, $3.75 paper copy. The report supersedes open-file report 82-418.

Preliminary Map of the Resource Areas in the Basin and Range Province of Nevada

This report by George Wong contains 39 pages and one oversized sheet at a scale of 1:500,000. Order OF 83-0721 from: Open-File Services Section, Western Distribution Branch, U.S. Geological Survey, Box 25425, Federal Center, Denver, CO 80225. The price is $4 microfiche, $12.50 paper copy. This report supersedes open-file report 82-1100.

Petroleum and Mineral Resources of Antarctica

The available information on petroleum and mineral resources in Antarctica and the possibilities of future exploration there are discussed in this

75-page circular, edited by J. C. Behrendt. No economically recoverable resources occur at present, but if supergiant oil and gas fields were to be discovered in the future, petroleum resources could probably be exploited within 20–30 years. Mineral resources, by contrast, are unlikely to be economically recoverable in Antarctica for a number of decades.
Order C-0909 from: Eastern Distribution Branch, Text Products Section, U.S. Geological Survey, 604 South Pickett St., Alexandria, VA 22304. Circulars are free in limited quantities.

Map Showing Coal Deposits, Oil and Gas Wells and Seeps, and Tar Sandstone Occurrences in the Basin and Range Provinces

B. T. Brady's 100-page open-file report includes one oversized sheet. Order OF 83-0549 from: Open-File Services Section, Western Distribution Branch, U.S. Geological Survey, Box 25425, Federal Center, Denver, CO 80225. The price is $4 microfiche, $15.75 paper copy.

Preliminary Map of the Resource Area in the Basin and Range Province of Utah

George Wong's 21-page report includes one oversized sheet, scale 1:500,000. Order OF 83-0722 from: Open-File Services Section, Western Distribution Branch, U.S. Geological Survey, Box 25425, Federal Center, Denver, CO 80225. The price is $4 microfiche, $7.75 paper copy. This report supersedes open-file report 81-1305.

Mineral Resource Potential and Geologic Map of the Black Fork Mountain Roadless Area, Polk County, Arkansas, and Le Flore County, Oklahoma

M. H. Miller and M. C. Smith's 1983 map covers lat about 34°40′ to 34°45′, long 94°15′ to 94°37′30″. The scale is 1:50,000 (1 in. = about 4,200 ft). The map sheet measures 20 x 28 in. and is accompanied by a 4-page text.
Order MF-1599 from: Western Distribution Branch, U.S. Geological Survey, Box 25286, Federal Center, Denver, CO 80225. The price is $1.25.

Petroleum Potential of Wilderness Lands in the Western United States

B. M. Miller has edited this report, which provides the results of a systematic geological investigation of the conventional oil- and gas-resource potential of 74 million acres of designated and proposed Wilderness Lands in the 11 Western States of the United States. Geological and geophysical data and data from wells drilled in the vicinity of Wilderness Lands were compiled and interpreted to determine the geologic characteristics favorable or unfavorable for the occurrence of petroleum resources in each of the wilderness tracts.

The report presents papers on the geological, statistical, and digital cartographic procedures and methods used in the investigations, and formal reviews of the geology and known geological conditions in the 11 states relative to the locale of each of the wilderness tracts.

Order C 902-A-P from: Eastern Distribution Branch, Text Products Section, U.S. Geological Survey, 604 South Pickett St., Alexandria, VA 22304. Circulars are free in limited quantities.

Ground-Water Quality Data for Oklahoma, 1981

D. M. Ferree is the author of this 81-page open-file report, which is available for inspection at the USGS Water Resources Division office at 215 Dean A. McGee St., Room 621, Oklahoma City, OK 73102, or it may be ordered from: Eastern Distribution Branch, U.S. Geological Survey, 604 South Pickett St., Alexandria, VA 22304. The price is $3.50 for microfiche, $10.75 for a paper copy.

Oklahoma: Summary of Activities of the USGS, WRD, Oklahoma District, 1983

This open-file report by R. L. Hanson, J. C. Scott, and J. K. Kurklin consists of 104 pages and two oversized sheets. See OF 83-0767 at USGS, WRD, 215 Dean A. McGee St., Room 621, Oklahoma City, OK 73102, or order from: Open-File Services Section, Western Distribution Branch, U.S. Geological Survey, Box 25425, Federal Center, Denver, CO 80225. The price is $4.50 for microfiche, $2.75 for paper copy.

Land Use and Land Cover and Associated Maps for Enid, Oklahoma, Kansas

The four maps in this data set are keyed to the USGS topographic map of the Enid Quadrangle at a scale of 1:250,000 (1 in. = about 4 miles). These maps are coded for statistical data development. They depict land use and land cover, political units, hydrologic units, and county census subdivisions. Also included is one copy of the cultural base for Enid at 1:250,000.

For information on the availability and price of OF 83-0553, write: USGS, Mid-Continent Mapping Center (NCIC-M), 1400 Independence Rd., Rolla, MO 65401.

OKLAHOMA ABSTRACTS

GSA Annual Meeting, South-Central Section
College Station, Texas, March 3–4, 1983

The following abstracts are reprinted from *Abstracts with Programs* of the Geological Society of America, v. 15, no. 1. Page numbers are given in brackets below the abstracts. Permission of the authors and of the GSA to reproduce the abstracts is gratefully acknowledged.

The Meers Fault: Unusual Aspects and Possible Tectonic Consequences

M. CHARLES GILBERT, Department of Geological Sciences, Virginia Polytechnic Institute & State University, Blacksburg, VA 24061, and Oklahoma Geological Survey, Norman, OK 73019

The Meers Fault in southwestern Oklahoma has been considered a part of the Frontal Fault Zone separating the Wichita Mountains uplifted block from the deep Anadarko Basin. Its characteristics are important in limiting age of deformation and style of slip. Present surface geologic maps show 1) an outcrop trace of 26 km; 2) that net stratigraphic separation shows the fault is *down* to the north; and 3) that Hennessey-Post Oak age Permian is cut.

Inspection of the trace shows: 1) a distinct topographic lineament; 2) that topography is always *up* on the north; 3) that the fault plane is vertical; and 4) that lithofacies do not appear to be offset in a lateral sense.

The outcrop feature may be a fault-line scarp—fossil or present, or a fault scarp—fossil or present. Weight of evidence is against the fault-line scarp hypothesis and for a *present* (Quaternary ?) fault scarp. Therefore,

1) The existing trace is not compatible with the Early Pennsylvanian tectonic model suggested by the Brewer COCORP results. If the present surface Meers is a reactivated, older Pennsylvanian fault, then a very different tectonic regime is responsible for the present fault.

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.

2) The subsurface Meers Fault and the surface Meers Fault may not be equivalent.

3) Some crustal blocks of low short-term earthquake activity may have important episodic movements on a longer time interval. [1]

Age Relationships of Structures Along the Western Flank of the Broken Bow Uplift

JONATHAN MATTES and KENT C. NIELSEN, University of Texas at Dallas, Department of Geosciences, P.O. Box 688, Richardson, TX 75080

Early folding history along the western flank of the Broken Bow Uplift is more complex than previously thought. The dominant folds are overturned, southerly verging, and tight to isoclinal. The pronounced asymmetry of slaty cleavage and variation of unit thickness in these folds suggests flattening of early, more open folds as suggested by Feenstra and Wickham (1975). Local coaxial refolding of these early folds has been documented. These younger folds are inclined, tight, and verging towards the south. Younger northeast-trending kinks and locally developed crenulations are superimposed on this earlier sequence. Finally, high angle faults cut and reorient the early cleavage associated with these folds. It is suggested that part of the movement of these east–west trending faults of the Central Zone post-dates principal ductile deformation in the Broken Bow Uplift. [1]

Geologic Issues in Isolating Nuclear Waste in the Palo Duro Basin, Texas[1,2]

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Permian bedded salts in the Palo Duro Basin in the Texas Panhandle are being considered as a repository for high-level nuclear waste. Among the geologic issues being resolved are the extent and timing of salt dissolution within the basin, the extent and timing of faulting within the basin, the possibility that zones of intense fracturing provide pathways for accelerated groundwater movement towards the biosphere, and the future for hydrocarbon exploration in the basin.

Salt dissolution and subsidence of overburden are active processes along the western, northern, and eastern margins of the Palo Duro Basin (Southern High Plains). Dissolution of the uppermost salts also appears to have occurred during the late Quaternary beneath the Southern High Plains. Basement faulting offsets Permian strata and appears to have influenced both sediment distribution in younger strata and development of Quaternary physiographic features on the Southern High Plains. Fractures exposed along the eastern margin of the Southern High Plains occur in zones of high concentration with preferred orientations similar to major fault trends within the basin. Accelerated ground-water movement along concentrations of fractures has apparently resulted in increased dissolution of salt and the subsequent formation of collapse features oriented parallel to the preferred orientations of fractures. The Palo Duro Basin contains thermally mature hydrocarbon source rocks. Associated strata have stratigraphic and structural characteristics that could have provided trapping mechanisms. As a result, exploration for hydrocarbons is likely to continue in the basin.

[1]Publication authorized by the Director, Bureau of Economic Geology, University of Texas at Austin.

[2]Study supported by funding from DOE under contract DE-AC97-80ET46615. [3]

Hydrogeochemical Issues for High-Level Nuclear Waste Isolation in the Permian Evaporites of the Palo Duro Basin, Texas[1]

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Permian bedded salts of the Palo Duro Basin, Texas, are being considered by the U.S. Department of Energy as a repository for high-level nuclear wastes. The potential for breaching of the repository and for the release and transport of radionuclides to the biosphere is dependent on the hydrologic and geochemical characteristics of the basin. The basin can be subdivided into three hydrogeochemical units: the above-salt aquifers, the evaporite aquitard (the potential repository site), and the subsalt aquifers. Several major issues remain to be resolved for each hydrogeochemical unit.

The issues for the evaporite aquitard are the presence of permeable carbonates in the San Andres Formation, the history of fluid movement through the evaporites, the direction of potential fluid flow, and the geochemical stability of the evaporites and their potential for retarding radionuclide migration. The issues for the Dockum and Ogallala aquifers above the evaporite section are whether ground water is actively and rapidly dissolving salts at the top of the evaporite section, the general hydrogeochemical character of the aquifer, and the location of the discharge zones of the aquifers. The issues for the Wolfcamp and granite wash aquifers below the evaporite section are regional characterization of hydrology and geochemistry, the cause of the subhydrostatic pressures, the cause of ground-water flow toward the Amarillo Uplift (a granite high), and the possibility of discharge to the biosphere.

[1]Publication authorized by the Director, Bureau of Economic Geology, University of Texas at Austin. [3]

High-Level Waste in Bedded Salt: Licensing Issues in the Texas Panhandle

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Geologic investigations of Upper Permian salt deposits in the Texas Panhandle show that beds in the San Andres Formation may be suitable for a repository. The central Palo Duro basin is the area of interest; it contains major salt beds more than 70 feet thick at depths between 1000 and 2700 feet.

The licensing of a repository in the Palo Duro will require some degree of resolution of certain geologic and hydrogeologic issues. These include 1) Salt dissolution within the basin and its effect on siting, 2) Deep basin flow systems and flow velocities, 3) Permeability of the evaporite section above and below the San Andres salt beds, 4) Tectonic structures within sedimentary rocks of the central basin and 5) The effect of construction and operation of a repository on the Ogallala aquifer.

Studies under way in the Panhandle have been focused first on siting. However, these initial investigations have served to identify geologic questions which could be raised during licensing proceedings. For some of these issues, the data base is not presently sufficient to provide adequate resolution. The integrated system of geologic and geophysical investigations being carried out in the Palo Duro basin and those planned in the near future are geared to address the geologic issues in a stepwise fashion: First, to define the boundary conditions, second, to test hypotheses and model processes, and third, to provide a wider base of factual information for obtaining resolution by consensus. At any step, the issue may be resolved sufficiently to make further investigation unnecessary. [3]

Investigations of Salt Dissolution in the Permian Basin of the Texas Panhandle

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Bedded salt deposits within the Palo Duro and Dalhart basins of the Texas Panhandle are being investigated in a study by the Department of Energy

(DOE) for the storage of high-level radioactive waste. The feasibility of a permanent repository depends upon the existence of a stable geologic environment, and licensing of the disposal facility will require knowledge of the age and physical boundaries of salt dissolution in both the interior and periphery of the basin.

We redefine areas of peripheral salt dissolution through extensive detailed correlation of geophysical well logs throughout the area along with related studies. Primary areas of nondeposition are distinguishable from areas of deposition with active dissolution and from those of deposition with paleo dissolution. The structure of the basinal areas influenced both the salt deposition and the resultant dissolution patterns. Shallow wells drilled in peripheral areas have revealed stratigraphic information supporting our dissolution and nondeposition boundaries.

Core from wells drilled for the DOE study in Deaf Smith and Swisher Counties, in the basin's interior, shows weathering of the Alibates, Salado, and Yates formations which abruptly terminates at the uppermost salt bed within the Upper Seven Rivers formation, suggesting dissolution. However, the essentially featureless upper surface of the Alibates suggests that only small volumes of salt were dissolved in the inner basin. [3]

Joints and Joint Densities at Caprock Canyons State Park, Briscoe County, Texas Panhandle[1]

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Permian evaporite deposits of the Palo Duro Basin, Texas Panhandle, are under consideration as potential sites for nuclear waste storage. Studies of joints and joint densities are important for the evaluation of a potential repository site. Fracture density influences the ability of rock to transmit and hold fluids such as ground water and pollutants. Joints also influence the strength and slope stability of rock, two factors important for repository design.

Joint sets at Caprock Canyons State Park, Briscoe County, display a variety of orientations with an east-west trend being the most significant. In general, joint densities in sandstone and siltstone beds less than 1 m thick increase as the bed thickness decreases. Joint densities are almost constant for beds greater than 1 m thick. Joint density variations also occur in beds of uniform thickness as joint zones where the density of joints in the zone is greater than the predominant joint density for the unit. Joint zones extend vertically through Permian and Triassic beds, are as wide as 40 m, and extend for horizontal distances up to 0.75 km and possibly farther.

Deformation caused by dissolution-collapse processes has caused low-amplitude folds in the area. Systematic regional joints which predated dissolution-collapse could have been pathways for fluid migration and associated dissolution.

[1]Publication authorized by the Director, Bureau of Economic Geology, University of Texas at Austin. [3]

Permeability Variation in the Palo Duro Basin from Multiple Well Tests[1,2]

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The Bureau of Economic Geology at The University of Texas at Austin is conducting regional studies under contract to DOE to determine the suitability for high level nuclear waste storage in bedded Permian salts in the Palo Duro Basin. To date four deep hydrologic test wells have been drilled to investigate the brine flow system below the salt. The Deep Basin Brine Aquifer consists primarily of Permian Wolfcamp carbonates and Pennsylvanian carbonates and arkosic sandstones within interbedded shales and siltstones.

The test wells were drilled to total depth, cased, and then each permeable interval was in turn perforated and pumped with a walking beam pump in order to obtain a water sample and an estimate of formation pressure and permeability. A sodium thiocyanite tracer was added to the drilling mud to delineate drilling contamination. The test intervals were pumped from two to ten weeks until water was obtained with sufficiently low drilling mud contamination.

Because it was necessary for each test interval to be pumped for long periods of time, multiple pressure drawdowns with intervening recoveries were conducted giving several permeability estimates for each test interval. From these permeability estimates the variation inherent in a single permeability test, as a drill-stem test or a single flow pumping test, can be estimated. Ground-water flow velocities in the deep basin calculated from these permeability estimates are used to estimate travel times from a potential repository breach. The error in travel time resulting from error in permeability estimates can be significant to basin characterization for nuclear waste isolation.

[1]Publication authorized by the Director, Bureau of Economic Geology, University of Texas at Austin.
[2]Study supported by funding from DOE under contract DE-AC-97-80ET46615. [4]

Regional Ground-Water Flow in San Andres Formation, Texas Panhandle and Eastern New Mexico[1,2]

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Thick San Andres salt deposits in the Palo Duro Basin are being considered for use as a high-level nuclear-waste repository. Dolomite and limestone members of the San Andres Formation (Leonardian to Guadalupian) lie below potential repository horizons and may be capable of transmitting fluid. Most of the recharge to the karstic San Andres aquifer in eastern New Mexico is discharged to the Pecos River valley. Brine is discharged from the San Andres along its outcrop in North-Central Texas. The San Andres is a major oil reservoir across the northern shelf of the Midland Basin.

Transmissivity of the San Andres dolomite is low (less than 0.004 m^2/day) in the Palo Duro Basin where evaporite cement fills pore spaces. The low-transmissivity region changes the potential direction of ground-water flow from eastward in the recharge zone in New Mexico to southeastward through the Palo Duro Basin. Eastward flow takes place across the Midland Basin.

Around the periphery of the Palo Duro Basin, the San Andres contains percolating meteoric water. Its chemical composition evolved through solution of limestone and gypsum at shallow depth west of the Pecos River. As water moves through the salt solution zone between the Pecos River and the western Caprock Escarpment, total dissolved solids increase to more than 200 g/l and water approaches saturation with respect to halite. Total dissolved solids and apparent saturation index for halite decrease to the south away from the Palo Duro Basin. This change in water chemistry is coincident with the southward pinch-out of evaporite facies.

[1]Publication authorized by the Director, Bur. Econ. Geol., UT-Austin.

[2]Study supported by funding from DOE under contract DE-AC97-80ET46615. [4]

Depth-Controlled Community Succession in Pennsylvanian-Permian Mid-Continent Cyclothems

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Supposed depth-controlled sequences of communities described from Penn-Permian cyclothems are in disagreement, due to uncertainty on which part of the cyclothem was deposited under deepest water conditions. Using the phosphatic black shale unit as a marker of the deepest water phase makes it possible to reconcile these schemes into a unified model compatible with depth-controlled sequences of communities in western North America and Europe. The deepest communities contain ammonoids and nuculoid bivalves, intermediate depth communities contain stenotopic data, and shallowest depth communities contain common molluscs and/or calcareous algae.

Phosphatic black shales and adjacent dark gray-black shales contain a community with diverse ammonoids, conodonts and shark remains, and some bivalves and brachiopods. In many occurrences the specimens are immature, and in phosphatic black shales, the community composition is often distorted by lack of preservation of $CaCO_3$ shell material. Black shales are overlain by medium gray shales containing common ammonoids, nuculoid bivalves and other molluscs, and conodonts. This community has a higher diversity than the previous one. This is overlain by light gray shales and limestones containing a diverse assemblage of stenotopic taxa, including brachiopods, crinoids, bryozoa, corals, fusulinids, and molluscs, which occur in a complex of several communities. Depth control on these communities is poorly known. These are overlain by strata with molluscan-dominated or calcareous algae-dominated communities that lived in the shallowest marine waters, and often contain common ostracodes, or *Osagia.* Contrary to previous interpretation, brachiopods are rarely abundant in the shallow water communities. [4]

Toward Integration of Conodont Biostratigraphic Zones in the Middle and Upper Carboniferous

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Discovery that part of the type Desmoinesian contains fossils characteristically of "Atokan" age makes it no longer necessary to postulate unconformities due to some absences nor to consider that A→B→C and A′→B′→C′ represent heterochronous homotaxial homeomorphic [*phylogenies*] as has been done in the past; they represent the same taxa exactly as they appear to do. Absences and differing first appearances interpreted as of different ages are best explained by irregular distributions in space with time from either or both ecologic or provincial restrictions.

Middle Carboniferous conodont lineages across the systemic boundary, extending to about mid-Morrowan, include the *Gnathodus–Declinognathodus–Idiognathoides* lineage producing three or four widespread first occurrence zones. Contemporary with this phylogenetic lineage the cavusgnathoids were

undergoing a rare evolutionary burst that produced some morphologic variants with potential biostratigraphic usefulness. These forms are more restricted than the first group, but may constitute nearly the entire conodont fauna in some rocks. Finally, the extremely restricted *Rhachistognathus* lineage is useful where present. Mid-Morrowan to end Desmoinesian zonations are heavily weighted toward *Neognathodus* whose 11 species presently provide the tightest and most widespread zonation. In (mostly) Desmoinesian rocks 5 species of *Gondolella* and as many as 8 species of *Diplognathodus* form the bases of alternative zones. The best alternative, the *Streptognathodus-Idiognathodus* lineage, has not been fully exploited. Post-Desmoinesian beds are zoned primarily on this last group, although this work is still in a preliminary state and only 4 zones are recognized in the U.S. and a comparable number in the U.S.S.R. *Gondolella* promises to make an excellent genus for an alternative zonal scheme. [4]

Petrology and the Depositional Environment of the Stone Corral Formation (Lower Permian) Kansas

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The Stone Corral Formation is an important and widely used subsurface marker bed in the Permian redbed sequence of central and western Kansas. In Rice, Reno, and Kingman Counties the formation outcrops consist of dolomite and shale but in the subsurface is mostly anhydrite. In the subsurface it extends over about the western one-third of the state and ranges in thickness from about 6 to 100 feet. There are few cores but one complete core taken by the AEC in Sumner County is available for study.

Preliminary thin-section examination of surface samples of the dolomite has shown a fine matrix with sparry calcite filled vugs and a dark substance tentatively identified as manganese dioxide. Fragments of [recrystallized] brachiopods (?) are present locally. No dolomite rhombs as described previously have been identified. Cathodeluminescence has revealed some feldspar present as finely scattered particles. Insoluble residues are comprised of gypsum, manganese dioxide, and clay minerals. Texture is fine to granular with numerous vugs. The amount of shale increases to the south to where the unit is not recognizable at the Kansas–Oklahoma line. In the subsurface, the unit consists of nodular anhydrite and shale. The anhydrite has a chickenwire texture, and the shale is dolomitic.

Correlation of lithologies between the surface and subsurface is tenuous because of lack of cores (and detailed well logs) at shallow depths. However, it seems likely that the dolomite exposed on the surface may be equivalent to the dolomitic phase at the base of the anhydrite section in the subsurface. If that correlation is correct, then the anhydrite has been dissolved at the surface and in the shallow subsurface leaving only the dolomite. [6]

Normal Marine–Marine Marginal Sabkha Transition, Lower Permian, Palo Duro Basin, Texas Panhandle[1]

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Study of core from the northwestern (Oldham County) and northeastern (Donley County) Palo Duro Basin has led to recognition of depositional environments produced by the transition from open marine to continental evaporitic conditions.

Lower Wolfcampian shallow marine (coral and phylloid algae accumulations and dark crinoid and foram packstones) and interfingering coarse arkosic fan delta deposits were succeeded by high energy ooid and skeletal hash bars. Increasing restriction behind pisolitic supratidal flats to the northwest and behind subtidal shoals to the northeast initiated deposition of the Leonardian Wichita Group. Wichita environments include fine grainstone bars and interbar sediments composed of dark carbonate and terrigenous clastic mudstones and bedded nodular mosaic anhydrite. The presence of anhydrite beds, sparse burrows, and fauna of limited diversity (algal intraclasts, mollusks, ostracods, and forams) are indicative of hypersaline conditions.

Influx of terrigenous clastic mudstones of the Leonardian Red Cave Formation coincided with the establishment of supratidal conditions. In the northwest, near the Sierra Grande Uplift sediment source area, subtidal or intertidal ponds alternated with intermittent stream and caliche soil environments of the wadi plain. In the northeast, distant from a sediment source area, proximal wadi plain facies are absent. Terrigenous clastic pond environments alternated with ponds filled with carbonate grainstones and bedded anhydrite.

[1]Publication authorized by the Director, Bureau of Economic Geology, University of Texas at Austin. [6]

Permo–Pennsylvanian Cyclic Sediments in the Midcontinent

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The Permo–Pennsylvanian of the Midcontinent exhibits several types of cyclic sedimentary sequences (termed cyclothems). The simplest condition is a mostly clastic nonmarine–marine–nonmarine sequence interpreted as a shallow-water, single transgression–regression of the sea. With time, the sequences become more complex including other lithologies (which represent different environments) but also are interpreted as a single transgressive–

regressive event. Complex combinations of events are recognized as megacyclothems, hypercyclothems, and magnacyclothems.

Important in the interpretation of these events are criteria for determining: (1) configuration of the basin, (2) depth of water, and (3) the length of time involved in development of the basin. Basin-size criteria include type and lateral variation of the sediments, shape criteria are fossil content and sedimentary features, and time interpretations are based on sedimentary boundary conditions and thickness of units. Changes in basin conditions are reflected in the contained sedimentary sequences which form the basis of a time series of recorded events.

From the series of events through time, which in effect is a response model, an interpretation can be made as the mechanism responsible for the series. In general, the mechanisms can be grouped into (1) tectonic responses, (2) epeiric-sea changes, (3) environmental conditions, or (4) a combination of the first three. Any explanation on the origin of these sequences must take into consideration the lateral persistence of ultrathin beds, tremendous ratio of width to thickness of beds, extreme sharpness of stratigraphic boundaries, symmetrical arrangement (or lack of) of units, and cohesiveness of certain units in the cyclothem. [6]

Regional Lithostratigraphy of the Pitkin Formation (Chesterian), Northern Arkansas

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The Pitkin Formation crops out in an east-west trending belt from Batesville, Arkansas to Muskogee, Oklahoma, and dips slightly south due to structural influence of the Ozark Uplift. This dominantly carbonate unit forms the uppermost portion of a conformable Chesterian shale and carbonate sequence, and is overlain unconformably in most areas by lower Pennsylvanian strata.

Work undertaken for this study combined with that of previous workers suggests two distinct Pitkin depositional patterns. The western portion of the outcrop belt in Oklahoma and Northwest Arkansas is dominated by oolite grainstones, oncolite grainstones, bioclastic packstones and grainstones and mudstones, often with biohermal buildups. These shallow water facies are abruptly juxtaposed, do not show lateral persistence or a [discernible] pattern of facies, belts. This region is termed the Pitkin Shoal Facies Complex. Eastward, the character of the unit changes. Oolitic and bioclastic lithologies remain dominant, but dark, bedded, lime mudstone and black shale, regarded as deep shelf deposits, become major constituents. The facies are arranged in a sequence of upward-shoaling cycles, a cycle beginning with lime mudstone and shale, followed by packstone, and culminating with oolite. When correlated across the eastern outcrop belt, these cycles are believed to represent regional shoaling of the Pitkin sea that accompanied the repeated outbuilding and subsidence of a carbonate (oolite) sand platform. The random facies distribution of the Shoal Facies Complex appears to have resulted from storm activity on an adjacent, very shallow shelf. Persistent shoaling upward patterns are absent here due to lack of subsidence or poor preservation. [6–7]

Petrology of Lower Atoka Sandstone Units at the Northern Margin of the Arkoma Basin, Northwest Arkansas

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The Arkoma Basin of western Arkansas and eastern Oklahoma is a peripheral foreland basin that developed great structural relief during middle Atokan time. The early Atokan succession in the northern part of the basin is composed of multiple sandstone units ranging to 150 feet in thickness and separated by intervals of shale. The sandstone units accumulated in delta and delta-related environments as high destructive delta systems prograded southward across a stable shelf. Shale units were formed during transgressive episodes when open shelf conditions prevailed.

The lower Atoka sandstone and shale succession crops out in the Boston Mountains of northwest Arkansas along the northern margin of the basin. It is displaced into the subsurface of the Arkoma Basin by down to the south movement along the east-trending Cass fault system. Porous and permeable facies within the sandstone units serve as important natural gas reservoirs [throughout] the northern part of the basin.

Sandstone units within the lower Atoka succession are fine to very fine grained lithic quartzarenites and sublitharenites. Metamorphic rock fragments of phyllite and schist and minor quantities of feldspar are accessory constituents. Off channel sandstone facies tend to be [pervasively] cemented by quartz. Cementation in channel facies is less pervasive with porosities exceeding 8 percent. [7]

Development of DNAG Field-Guide Program for Oklahoma

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The geology of Oklahoma is varied and complex, and many areas in the State are worthy of inclusion in the DNAG Field Guide to the South-Central United States. A small ad hoc committee, knowledgeable about Oklahoma field geology, will select the best sites in the State where visitors can examine and understand major regional geologic features. Examples of such features include: the [Potato] Hills and Choctaw fault in the Ouachita Mountains; granite/gneiss relations and the Mill Creek Syncline in the Arbuckle Mountains; igneous rock relations and tectonic history of the Wichita Mountains; and Permian evaporite deposition/natural salt-water pollution in western Oklahoma. Field-guide study sites that are selected will be on readily accessible lands or roadcuts. The ad hoc committee will solicit recommendations for suitable sites in Oklahoma, and will identify one or several potential authors for each of the sites. [36]

Salt Dissolution and Resultant Salt-Water Pollution in Western Oklahoma: Description of a Field Trip Area for the DNAG Field-Guide Program

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Dissolution of Permian bedded rock salt in the shallow subsurface of western Oklahoma results in formation of natural high-salinity brines that migrate to the surface and cause contamination of several major [rivers]. The field area demonstrates the following features: collapse structures resulting from settling of outcropping strata into dissolution cavities; large and small salt plains, salt seeps, and brine springs where the brine emerges at the surface; commercial production of salt through solar evaporation of brines trapped on the surface; salt encrustations at, and downstream from the salt plains; environmental impact of brines upon the river systems; and possible remedial measures to reduce or eliminate pollution of the rivers. The field-trip area includes several public-access sites in northwestern Oklahoma. [36]

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Permian Sedimentation in the Meers Valley, Southwestern Oklahoma

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The Meers Valley was eroded in Permian times along the line of the Meers Fault which trends c. 320. Rocks to the south of the fault include the Tillman metasediments, Mt. Sheridan Gabbro, various granites and Carlton Rhyolite. The acidic rocks were the principal contributors of sediment to small alluvial fans debouching northward into the valley. Lower Paleozoic limestone and Carlton Rhyolite outcrops north of the fault were similarly sources for small fans debouching southwards. Along the axis of the valley fluvial transport to the southeast reworked materials from both sets of fans.

Most sediments in the valley are conglomerate; red, brown and buff sandstones and red shales increase upwards, recording the gradual choking and infill of the valley. Clasts in [conglomerates] vary greatly in appearance. Igneous clasts are well rounded pebbles, rounding being due *in situ* spheroidal weathering in the regolith rather than alluvial transport. Carbonate clasts are angular to rounded and vary enormously in size. Barn-size boulders are present. These boulders record scarp recession and collapse. Sandstones in the valley are arkosic; the limestones did not form sand-sized particles.

Pedogenic carbonates (calcretes) are found in all lithologies; they are particularly common in the upper shales and sandstones where they form profiles up to 10 ft thick and display tepee structures. Their presence suggests that an arid or semi-arid climate prevailed. Later carbonate cements are ubiquitous in the limestone conglomerates but are much less common in the siliclastic sediments. Poikilitic calcite cementation in some sandstones located along the axis of the valley is thought to record local ponding of carbonate-saturated ground waters. [79]

Seismic Reflection Evidence of a Late Proterozoic Basin in the Texas Panhandle

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A Proterozoic basin, postulated on the basis of COCORP surveys to have existed in southwestern Oklahoma, extends westward into the Texas Panhandle. Basement in the Panhandle consists of 1200 to 1400 mya bimodal volcanics and coeval granite, surrounded by older granites and gneisses. The essentially unmetamorphosed volcanics (the Panhandle [rhyolite] and Swisher [diabase] terranes) and interbedded dolomite and argillite cover about 20,000 mi^2 (50,000 km^2). Oil well data indicate that the rhyolites are greater than 3,700 ft (1,100 m) thick, whereas gravity and well data suggest that the mafic rocks occur as thin sills and flows within the rhyolite.

Seismic reflection profiles in the Panhandle reveal well-layered reflectors to a depth of 30,000 ft (9,000 m). Discrete reflectors (diabase?) are separated by up to 7,000 ft (2,100 m) of transparent material (rhyolite?). The reflectors are flat-lying to gently folded and are laterally continuous for over 30 mi (50 km). Precambrian-aged faults within the basin offset reflectors up to 4,000 ft (1,200 m). The reflectors terminate against faults or lap out onto transparent basement (granite?) and are truncated beneath Paleozoic strata at the basin margin.

Similar assemblages have been reported from southeastern Colorado (Las Animas Formation) and southeastern New Mexico (DeBaca terrane). Together, Proterozoic volcanic units cover nearly 50,000 mi^2 (130,000 km^2). They were probably deposited in a basin or basins formed as a result of rifting of an older crystalline basement.

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[1]Publication authorized by the Director, Bureau of Economic Geology, University of Texas at Austin, Austin, Texas.

[2]Study funded by the U.S. Department of Energy under contract no. DE-AC97-83WM46651. [79]

Studies of Upper Paleozoic (Devonian to Carboniferous) Radiolaria from the Ouachita Mountains, Oklahoma and Arkansas

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Until recently, little attempt has been made to utilize Paleozoic Radiolaria in biostratigraphic studies. Radiolaria have long been recognized to be *the* most abundant fossils within the Ouachita orogenic belt. However, there have been virtually no studies dealing with this group of microfossils. Extremely well-preserved and highly diversified faunal assemblages extracted from various Ouachita formational units have provided an opportunity to make detailed analyses of the most biostratigraphically important taxa.

A succession of characteristic radiolarian assemblages has been recognized through the Woodford and "Caney" in the Frontal Ouachitas and Stanley, Jackfork and Johns Valley in the Central Ouachitas. The majority of the stratigraphically diagnostic taxa are yet undescribed. A faunal assemblage is characterized by the *Holoeciscus,* simple, minute morphotypes of *Ceratoikiscum* and perforate shelled *Popofskyellum.* With dramatic faunal change, it is replaced by the overlying assemblage characterized by the [appearance] of

Cyrtisphaeractenium and a new genus-intermediate form between ceratoikisceids and albaillellids. Assemblage characterized by unique, very minute, primitive albaillellids associated with highly diversified ceratoikisceids and pylentonemids which can be distinguished from the two former assemblages and it also [predates] the younger assemblage with typical bi-winged, well-segmented albaillellids.

Three groups of faunal assemblages have been recognized among the Ouachita Radiolaria to be the most significant. These are: the Albaillellaria, the Pylentonemids and the "Spongodiscaceids." By [integrating] radiolarian biostratigraphic data with that of the conodonts, ammonoids, and other better known groups of fossils, it should be possible to formulate a detailed system of radiolarian zonation. [80]

Siderite at the Boundary Between the Cambrian Reagan Sandstone and Honey Creek Formation, Southwestern Oklahoma

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The boundary between the Reagan and Honey Creek Formations, as exposed in southwestern Oklahoma, is demarcated by the presence of a laterally persistent orange weathering sideritic zone up to 5 ft thick. A complex paragenetic sequence involving silica, carbonates and iron is recorded at this interface. The boundary between the two formations marks a transition from siliciclastic to calcium carbonate sedimentation.

The Reagan Formation is a peloidal glauconitic fine- to coarse-grained quartzitic sandstone with abundant phosphate shell fragments *(Lingula* sp.) and (Carlton) Rhyolite clasts. In contrast, the Honey Creek Formation is a bioclastic limestone consisting of numerous pelmatozoan trilobite and brachiopod fragments, with lesser amounts of peloidal glauconite, rhyolite clasts, phosphatic brachiopods and detrital quartz. The orange weathering zone, which lies between these lithologies, records the first incoming of carbonates and is an important diagenetic interface.

The diagenetic sequence began with syntaxial quartz overgrowths and the formation of glauconite. Necessary ions were available from devitrifying rhyolite. Subsequent corrosion of quartz, rhyolite, and glauconite by calcite released silica, iron, etc. into pore waters leading to the formation of siderite and chert. The formation of siderite required reducing alkaline waters, undersaturated with respect to iron and carbonate.

The distinctive weathering color of this zone means that it is a satisfactory lithostratigraphic marker in the field. [81]

Environmental Conditions During Deposition of the Upper Kindblade Limestone (Early Ordovician)—Arbuckle Mountains, South Central Oklahoma

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The Kindblade Limestone, a formation of Canadian Age within the Arbuckle Group of Oklahoma, represents an interval of Cambro-Ordovician sedimentation dominated by carbonate deposition. Like other formations of the Arbuckle Group, the Kindblade Formation represents shallow water deposition as evidenced by the intermittent presence of algal growth.

The upper Kindblade Formation on the south flank of the Arbuckle Anticline can be segregated into 10 distinct, recurring lithofacies recognizable at outcrop. These lithofacies suggest deposition in subenvironments within the shallow subtidal to supratidal zone of a tidal flat. As a general observation, the upper Kindblade is dominated by mudstone–wackestone with periodic occurrence of beds and scoured lenses of grainstone. This relationship implies that sedimentation was dominated by low energy conditions with episodic interruption by storm events. The climate during deposition of the upper Kindblade was probably humid (at least seasonally) as indicated by the rare occurrence of evaporites or evaporitic indicators.

In a broader sense the upper Kindblade can be divided into at least 5 units on the basis of abundance of a particular lithofacies (or combination of lithofacies) within specific intervals. Variation within these units exists and probably results from the vertical and lateral migration of subenvironments lying in close proximity to one another. [81]

Structure of the Wichita Frontal Fault Zone

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Recent mapping of the exposed part of the Wichita Frontal Fault Zone in the Slick Hills of southwestern Oklahoma has delineated two types of structural terrain developed in Lower Paleozoic limestones. Boundaries between these terrains are major high-angle faults trending 310–320 *viz.*, the Meers, Mountain View and Blue Creek Canyon faults. The last-named fault has a short distinctive segment oriented 350–360.

In the more complex terrains are found (1) left stepping en echelon fold arrays in which individual fold axes trend between 315 and 345. Fold attitudes vary from symmetrical to overturned (to the NE by as much as 45°). Geometry of some early folds is consistent with their axes having been rotated anticlockwise while their axial planes are rotated clockwise. Steeply dipping cleavage in such folds is also rotated; (2) local concentrations of reverse faults trending c. 330–350 and dipping SW. Individual fault planes show variations from vertical to horizontal; most are steeply dipping. Locally these faults have led to stratigraphic thickening by as much as 500%; (3) shear belts trending 310–330. In such belts bedding has been obliterated by brittle shearing which has produced phacoidal elements consistent with left-lateral movement.

In less complex terrains deformation of homoclinal sequences is mostly in the form of minor fracturing and minor normal faulting. The most common trends of such structures are 270, 330 and 030.

The larger scale features and trends noted above can be recognized in the adjacent subsurface. The entire pattern is consistent with genesis by long acting left-lateral transpression. In some areas compressional features are more strongly developed than strike slip and vice-versa. In general structural elements oriented c. 350 show compressional effects leading to eg. high-angle reverse faulting while elements trending c. 320 show left-lateral strike slip effects. [82]

The Anatomy of an Early Ordovician Shell Bank in the Honey Creek Formation, Southwestern Oklahoma

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In the Slick Hills of southwestern Oklahoma, strata of the Upper Cambrian Timbered Hills Group unconformably overlie the Carlton Rhyolite. In places the upper member of the Group, the Honey Creek Formation, overlaps the Reagan Formation to rest directly on the Rhyolite.

At one such site, a littoral shell bank composed of orthid brachiopods sits directly on the unconformity. The shells are not in their growth position, but have been sorted by waves into a variety of positions, the most distinctive of which are vertically packed, hemispheroidal groupings of valves similar to those encountered on modern beaches subject to moderate wave energy. Such groupings are remarkably stable and in this instance have acted as effective sediment baffles. As a result, a carbonate buildup consisting of brachiopod shells and trapped detritus (mostly lime mud) formed.

The infiltration of mud into the shell packs was not complete; as a result, a spectacular geometry of geopetals and early vadose fibrous cement fringes formed in the internal part of the buildup.

The buildup records a small pocket beach on a rocky shoreline. Elsewhere on the shoreline cross-bedded lime sands composed of pelmatozoan, trilobite and brachiopod sands were deposited. [82]

Late Paleozoic Structures of Texas[1]

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Subsurface structure mapping, compiled at 1:250,000 for the forthcoming Tectonic Map of Texas, provides a synoptic view of the principal elements of late Paleozoic tectonics. The frontal zone of the Ouachita deformed belt wraps south and west around the Llano Uplift; its thrust slices conceal highs such as the Waco Uplift and large pre-Desmoinesian normal faults. A chain of foredeeps formed along the Ouachita Front.

In front of the Ouachita orogen is a coeval belt of deformed basement, extending across the "Texas Craton" to New Mexico and Colorado. It is dominated by two axes of mixed reverse-slip and strike-slip deformation. The Wichita-Amarillo Uplift is bounded by NNE- and SSW-directed reverse faults but is cut by NW-trending strike-slip zones creating rhomb grabens and flower structures. The Central Basin disturbed belt includes W- and E-directed reverse faults, N-S folds, and NW- to WNW-trending strike-slip zones. Both axes of deformation are paralleled by deep (foredeep?) basins (Anadarko, Delaware). Two belts of en echelon structures occur between the axes (Matador Arch, Fort Chadbourne fault zone); to their east is an area of normal faults (Llano fault system).

The axes of deformation may have been localized along either Cambrian or older rift-related volcanosedimentary basins. These zones of weakness may have sheltered the Llano "eye" and guided tectonic stresses inland to New Mexico and Colorado.

[1]Publication authorized by the Director, Bureau of Economic Geology, University of Texas at Austin, Austin, TX 78712. [83]

Geochemical Investigation of Pre-Viola Limestone (Ordovician) Unconformity, South-Central Oklahoma

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The Middle to Late Ordovician Viola Limestone of the Arbuckle Mountains was deposited on a carbonate ramp within the tectonic framework of the Southern Oklahoma Aulacogen. Differential subsidence between the aulacogen axis and margin greatly affected sediment accumulation rates and facies variations during early Paleozoic time. In order to gain a more complete understanding of the depositional history of the lower Viola, it has been necessary to carefully examine the contact between the Viola and the underlying Bromide (Middle Ordovician) of the Simpson Group. This contact represents the first significant depositional break in the early Paleozoic stratigraphic section. Shallow marine carbonates of the upper Bromide are overlain abruptly by deeper marine limestones of the lower Viola. Although field and petrographic evidence [suggests] the presence of a hardground on the upper surface of the Bromide, the exact origin of that feature has been difficult to assess. Carbon and oxygen stable isotopes have been used to address the above problem.

Preliminary geochemical analyses suggest the uppermost Bromide surface was exposed to meteoric water. The isotope stratigraphy across the contact is marked by a strong $\delta^{13}C$ depletion and a slight $\delta^{18}O$ anomaly—a pattern suggestive of subaerial exposure.

The following scenario is tentatively proposed for the deposition of the lower Viola Limestone. The uppermost Bromide Limestone was exposed to diagenesis by meteoric water causing early lithification and centimeter-relief surface karstification. Rapid aulacogen subsidence and/or eustatic sea level rise drowned a southwestward dipping carbonate depositional ramp. Post-burial pressure solution and stylolitization has accentuated surface relief and insoluble concentration at the Bromide-Viola contact. [84]

Preliminary Characterization of the Mt. Scott Granite, Wichita Mountains, Oklahoma

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Mt. Scott Granite may be the oldest formation in the Wichita Granite Group (WGG) of Mid- to Lower Cambrian age. It has the most extensive outcrop (~140 km^2) of the WGG and is a sill. The original intrusive top has been eroded away but a reasonable thickness estimate is ~ ½ km. Stratigraphically, it overlies the Glen Mountains Layered Complex, Roosevelt Gabbros, and the Fort Sill section of the Carlton Rhyolite. It has the largest contact area against gabbro of any exposed granite. Near the contact, Mt. Scott commonly has a higher color index while substrate gabbros are modified. Also associated with this contact are irregularly distributed intermediate hybrid rocks.

The southern margin of the sill abuts Quanah Granite and is well preserved from French Lake westward. Quanah clearly intruded against and into Mt. Scott by stoping, structurally replacing the preexisting host wall rock, presumably Carlton Rhyolite.

Mt. Scott is hypersolvus with variable amounts of granophyre (0-70%), irregularly distributed miarolitic cavities, ubiquitous mafic inclusions and ovoid feldspars. Cores of feldspars (ovoid and others) are commonly unoxidized. This is the only WGG unit with unambiguous "primary" plagioclase. However, all feldspars now show only re-equilibrated compositions. Color index averages 5-7% (highest for any WGG unit) and is dominated by hornblende, pyroxene, and magnetite.

Mt. Scott is chemically homogeneous over an outcrop distance of 55 km. It is the most calcic (1.0–1.5 wt % CaO) of the WGG but still is A-type and represents one of the "primary" felsic liquids. Ultimate origin is as yet unknown but some evidence shows crustal residence at a depth of 12–15 km (4 kb) before eruption. [84]

Tectonic History of Part of the Central Stable Region of the Midcontinent Area

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Data from the Consortium for Continental Reflection Profiling (COCORP) in northeastern Kansas, coupled with other recent geophysical and petrological studies, indicate development of a rift system during Precambrian Y time from the Lake Superior area, through northeastern Kansas to south-central Kansas. Probable basaltic fissure flows along the rift are suggested by the Midcontinent Gravity High. COCORP data show post-extrusive block faulting on the flanks of the rift creating basins containing up to 5000 meters of late Precambrian sediments.

Post Cambrian warping of the crust deformed Cambrian sediments over most of Kansas. A different stress system acted during late Ordovician to Mississippian time to form the initial uplift in central Kansas and downwarp parts of northeastern Kansas. Mississippian movement adjacent and parallel to the Precambrian rift formed the Nemaha Ridge. Subdued arching and uplift over most the Midcontinent continued during Pennsylvanian penecontemporaneous with extensive deformation to the west in the uplift of the ancestral Rocky Mountains. Tertiary tilting and present-day earthquake activity indicate continued subtle tectonic activity. [85]

Structural Styles in the Lower Ordovician Rocks of the Broken Bow Uplift, Oklahoma

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Recent mapping in the lower Ordovician rocks of the Broken Bow Uplift of Oklahoma has revealed a deformation style characterized by strong, penetrative deformation and significant horizontal translation. A large scale (wavelength = .5 km), isoclinal, recumbent fold with an axis bearing 175° has been mapped for about 1 km along trend near Lukfata Creek. Slaty cleavage and boudinage are associated with this folding. Near Glover, Oklahoma the boudins in the Collier Limestone reveal a consistent northwest-southeast extension, while a more complex "chocolate tablet" flattening strain is recorded near Lukfata Creek. In addition, boudin axes show evidence of complex "crack-seal" crystal growth, with both anataxial and syntaxial crystals forming coevally. Associated with the ductile deformation is significant translation in which normal sections of Collier Limestone, Crystal Mountain Sandstone and Mazarn Shale are thrust over the Mazarn Shale. Additional deformation includes cross cutting, east-west trending rough cleavage and later broad warping along a northeast-southwest axis. Finally, along the northwest boundary of the area, truncated units and secondary faults suggest that the Glover Fault is a high angle reverse fault with the southeast side up, probably resulting from a later, brittle stage of deformation. [87]

Detailed Fault History in the East and Central Portions of the Arbuckle Mountains, Oklahoma

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Detailed mapping along the Reagan and Sulphur faults suggests a complex movement history within the Arbuckle Mountains. Near Wapanucka, Oklahoma the Sulphur fault trends 100°-120° and the associated fold (Wilson Syncline) trends east-west. The syncline is open, asymmetric, and slightly inclined towards the south. The trace of this fold is curved towards the southeast parallel to the trend of the associated anticline. Preliminary paleostress data from calcite twins in the Wapanucka Limestone (Morrowan) indicate a north-south compressional axis and a resolved oblique slip involving right lateral and reverse motion. By comparison the Reagan fault trace is characterized by [anastomosing] strands along a trend of 120°. In the northwest portion of the map area near the junction of the Washita Valley and Reagan faults, a triangular zone of reverse and strike-slip faults [cuts] the plunging Dougherty Anticline. To the southeast a family of faults trends 130°-150° and appear to dip to the southwest. Resolved motion on one of these faults indicates [predominantly] right-lateral strike slip with minor reverse slip and clockwise sense of rotation of the hanging wall. At the Arbuckle Reservoir a north-south trending thrust fault appears to reorient the major fold axial trace. Initial paleostress data from the Hunton Limestone (Devonian) reveal a northeast-southwest girdle of compression axes [compatible] with a general left lateral sense of offset on the Reagan fault. The difference between these two areas is believed to be related to the relative position in a faulted Precambrian basement block and to the timing of the offset. [87]

The Regional Geophysical and Tectonic Setting of the Ouachita System

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An analysis of regional geophysical data from areas along and adjacent to the Ouachita system has been undertaken. The primary emphasis has been on gravity data but all available geological and geophysical data have been employed as constraints. The prominent, linear gravity high which follows the interior zone of the Ouachita system appears to be the result of the combined effects of a major crustal boundary, metamorphism and basement features such as the Broken Bow uplift, Benton uplift, Waco uplift, and Devils River uplift. However, these uplifts display variations in width, structural relief, and relation to this crustal boundary. A major Eocambrian continental breakup created a structural framework which has dominated tectonic relations ever since. Linear gravity highs are associated with the Mississippi embayment, Wichita-Amarillo uplift, and Central basin platform, and major structure anomalies are required to explain the observed gravity values. Interpreting these features as Eocambrian failed rifts is attractive in that it provides a comprehensive mechanism for their formation. However, age relations are not well known, and there are many differences between these features. Gravity anomalies along the trend of the Ouachita system suggest that the Devils River uplift represents the most anomalous positive structural element and that the Arkoma basin is the major negative feature. Interpretations in the Gulf Coast region suggest that the crust has been variably attenuated by rifting. [88]

Gravity Anomalies in the Ouachita Mountains Area

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The deep structure of the earth in the Ouachita Mountains area has been investigated primarily via the integrated analysis of gravity and deep drilling data. A variety of filtered gravity maps and computer modeling were the main elements of this analysis, and the structural relations between several features have been clarified. For example, strike-reject filtering shows that the southern Oklahoma aulacogen structural trend does not extend beyond its intersection with the Ouachita orogenic belt. The Arkoma basin is also shown to have a northwest trend which may be the result of events before the late Paleozoic orogenic activity. Near-surface structures such as the Benton and

Broken Bow uplifts display complicated relations to deeper seated features. The crust appears to be attenuated between the Ouachita Mountains and the Sabine uplift and this uplift represents a block of relatively unattenuated continental crust. At least limited Mesozoic rifting can be seen to follow the Paleozoic continental margin. Gravity and magnetic anomalies delineate alignments of intrusions which can be inferred to follow older zones of weakness such as this margin. [105]

Rb–Sr and Sm–Nd Isotopic Study of the Glen Mountains Layered Complex, Wichita Mountains, Oklahoma

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The igneous rocks of the Wichita Mountains province in southwestern Oklahoma are a bimodal suite composed of older gabbroic and basaltic rocks and younger felsic rocks. Based on field evidence, the Glen Mountains Layered Complex (GMLC) is the oldest intrusion in the Wichita Mountains province. Previous attempts at dating the GMLC have resulted in conflicting data (509–1300 m.y.). In order to better constrain the igneous and tectonic history of the Southern Oklahoma Aulacogen, we report Rb–Sr and Sm–Nd data for rocks and minerals from the GMLC.

Rb–Sr isotopic data for three whole rocks (anorthosite, troctolite, and gabbro) and one plagioclase mineral separate yield an age of 564 $\pm$145 m.y. (2σ). The large uncertainty is due to the extremely low Rb/Sr ratios for these rocks (< 0.02). The initial $^{87}Sr/^{86}Sr$ was 0.70359 $\pm$2 (2σ) (ϵ_{Sr} at 564 m.y. = -3.2, calculated assuming bulk earth = 0.7045), which suggests a depleted mantle source region for the GMLC.

Preliminary Sm–Nd isotopic data for two whole rocks yield an initial $^{143}Nd/^{144}Nd$ of 0.512165 $\pm$41 (2σ) (ϵ_{Nd} at 564 m.y. = +5.0). This is also consistent with a depleted mantle source region. However, compared to oceanic basalt source regions, the initial Nd ratio is more depleted than the initial Sr ratio. The data may suggest that contamination by older Proterozoic continental crust may have influenced the isotopic systematics or may simply reflect a difference in Rb–Sr and Sm–Nd characteristics between sub-oceanic and sub-continental mantle source regions. [105]

Ammonoid Biostratigraphy of the Gene Autry Shale (Morrowan–Pennsylvanian), South-Central Oklahoma

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The Ardmore Basin, south-central Oklahoma, lies adjacent to the southern flank of the Arbuckle Mountains. Sedimentation during Morrowan and Atokan time was influenced by the Southern Oklahoma Aulacogen, resulting in deposition of the reddish-brown to maroon-weathering Gene Autry Shale Member of the Golf Course Formation in the deeper northern portion of the Ardmore Basin. Simultaneously, the Joliff Limestone Member was being deposited in the southern portion of the basin. A total of 1,515 complete or fragmental ammonoid conchs have been recovered from the Gene Autry Shale at 65 localities in south-central Oklahoma. The assemblage comprises 908 specimens of *Axinolobus,* consisting of 476 *A. modulus* and 158 *A. quinni* with the remaining fragments unidentifiable to species, 309 *Gastrioceras,* including *G. adaense* and *G. araium,* 137 *Wiedyoceras,* including *W. smithi* and *W.* n. sp., 93 *Verneuilites pygmaeus,* 30 *Diabloceras neumeieri,* 17 *Proshumardites morrowanus,* 14 *Syngastrioceras oblatum,* and 5 unidentifiable fragments. The occurrence of *Axinolobus modulus* in the Gene Autry assemblage supports correlation with the upper Wapanucka Formation in the northeast Arbuckle Mountains and the Dye Shale and Kessler Limestone Members of the upper Bloyd Formation, type Morrowan, northwest Arkansas. The Morrowan occurrence of *D. neumeieri* is of particular interest since it is a zonal name-bearer for a Lower Atokan assemblage in northwest Arkansas. [109]

SIR-A Analysis of the Anadarko Basin, Oklahoma

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The Anadarko Basin is a WNW-ESE elongated trough filled with 10 km+ of Paleozoic sediments. Most of the pertinent models call for tectonic activity to end in Pennsylvanian times. NASA Shuttle Imaging Radar (SIR-A) has revealed a distinctive and very straight lineament pair extending virtually the entire length of the Anadarko Basin. The character of this lineament is seen most obviously as a tonal variation. Between the lineaments there is a more poorly reflecting "gray" zone with better reflectors located south and particularly north of the lineaments. Analysis of stream drainage and topography suggests that the area between the lineaments is low in the west and positive in the east. Major streams, including the Washita and Little Washita rivers, appear to be controlled by the location of the lineaments. The lineaments cut across the relatively flat-lying Permian units exposed at the surface. Subsurface data indicate the lineaments may be the updip expression of a major fault system, the Mountain View Fault. This fault is characterized by Harlton (1963) as southerly dipping; recent COCORP data suggest a shallow dip (30-40°). Two principal conclusions arise from this analysis: (1) The Mountain View Fault appears to extend southeast to join either the Reagan, Sulphur, or Mill Creek Faults of the Arbuckle Mountains, and (2) This fault system has been active in post-Permian times. We infer that minor reactivation of the Pennsylvanian faults has resulted in a subdued surficial expression of buried structures which largely control the location of oil fields in the Anadarko Basin. These results indicate the SIR-A imagery may be useful in programs of regional petroleum exploration. [111]

The Origin of a Calcareous Sinter (Tufa) in South-Central Oklahoma

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The Lower Cretaceous Baum Limestone, located in south-central Oklahoma within the Arbuckle Mountains, has been interpreted as a brackish-water facies, deposited within a restricted basin. The deposit is surrounded by a calcareous sinter or tufa whose origin is problematic. The encrustations of calcareous sinter appear to have grown as coalescing mounds along the edges of the protected basin. The mounds range in size from 30 cm to 55 cm and have a rough, oxidized surface. Seasonal variations of water depth resulted in supersaturation with respect to calcium carbonate. The two primary sources of calcium carbonate were the erosion of older Paleozoic carbonate rocks of the Arbuckle Mountains and disintegration of Charophyte stems. Saturation and the oscillating water table resulted in the accumulation and growth of the sinter. The radial fanning nature of the sinter is compatible with both an inorganic and/or a biogenic origin. Photomicrographs of the sinter reveal filaments and fine tubules which suggest an algal origin. The deposit is closely similar to both modern and ancient deposits interpreted as inorganic sinter. [111]

Use of Gravity to Determine the Geometry and Location of the Octavia and Boktukola Faults in Oklahoma and Arkansas

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The central zone of the Ouachita Mountains in eastern Oklahoma consists of two large open, inclined, northerly verging synclines which are cut on the southern flanks by east-west trending faults. The Octavia fault to the north, and the Boktukola fault to the south are thought to be south-dipping, high angle reverse faults with vertical displacements on the order of several kilometers. The locations of the fault traces are well defined in Oklahoma where ridge-forming Atoka and Jackfork sandstones in the synclinal cores are in fault contact with the Stanley shales. The continuation of these faults into Arkansas is inferred because the fault contact is within similar shale units. Studies in other areas have revealed low density zones associated with major faults which produce narrow, low amplitude gravity minima. These minima can be used to delineate the fault position and possible orientation. Seven

parallel, north-south gravity profiles have been surveyed across the inferred trace of the central zone faults of eastern Oklahoma. These are 2–4 km in length with data spacing of 100–300 m. Negative residual anomalies with wavelengths of approximately 700 m, amplitudes of .5–1 mgal, gentle southern gradients and steeper northern gradients are observed in most of the profiles. Modelling has shown that these asymmetric anomalies could be related to a low density zone dipping steeply to the south. With additional detailed data it may be possible to map the faults into Arkansas and intersect the recent COCORP line. [112]

Silica in the Ordovician Cool Creek Formation As Seen in Southwestern Oklahoma

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Both primary and secondary silica are found in the Cool Creek Formation of southwestern Oklahoma.

The most common forms of primary silica are detrital quartz sand and silt. The grains range in size from fine silt to very coarse sand, are generally subrounded to rounded, and variably sorted. The quartz detritus is associated with lime mud, intraformational conglomerates and oolites. The associated sediments and sedimentary structures indicate that the quartz sands were deposited on a shallow marine shelf by sluggish streams; some of the grains may have undergone aeolian transport.

Secondary silica forms a significant part of the Formation (up to 10%), occurring as pore-filling cement (including syntaxial overgrowths) and as replacement products. The formation of the three major morphologies—equant megaquartz, fibrous chalcedony, and equant microquartz—was controlled by the concentration of silica in the ground water system which percolated through the sediments early in their diagenetic history.

The pH of the water and presence or absence of sulphates controlled the type of fibrous chalcedony that was formed. Slightly alkaline, sulphate-free water led to the formation of length fast chalcedonite. Length slow quartzine formed in highly alkaline environments usually in the presence of sulphates. Ghosts of evaporites and relict anhydrite laths are frequently found with quartzine fibers. Lutecite and zebraic chalcedony formed as the pH and sulphate content fluctuated. [112]

Geochemical Characteristics of Salt Springs and Shallow Subsurface Brines in the Rolling Plains of Texas and Southwest Oklahoma[1,2]

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Numerous salt-emission areas exist in the Rolling Plains of Texas and southwest Oklahoma. Sodium-chloride waters discharge from salt springs and seeps, and underlie the area at shallow depths. This study distinguishes discharge areas of different brine types, i.e., brine derived from dissolution of halite by local meteoric ground water in a shallow ground-water system versus brine derived from deep-basin aquifers. Halite-dissolution brines typically have molar Na/Cl ratios near to 1, and Br/Cl and I/Cl weight ratios less than 4×10^{-4} and 10×10^{-6}, respectively. Deep-basin brines, in contrast, exhibit ratios less than 1 and greater than 25×10^{-4} and 10×10^{-6} for these respective constituents.

According to these ratios, and supported by other chemical constituents and the geographic distribution of the samples, three groups of brines can be distinguished. (1) Halite-dissolution brines were found in most salt springs and testholes in the northern and western parts. (2) The presence of deep-basin brine is evident in testhole samples from the south. Ratios of chemical constituents plotted versus depth show that deep-basin brines approach land surface in the southeast. (3) Some spring and testhole samples exhibit characteristics between halite-dissolution and deep-basin brines, suggesting mixing.

Isotopic composition of the salt springs indicates a local meteoric origin for the brines. Testhole samples from the southeast plot on a line which includes deep-basin brine values and meteoric-water values as endpoints, suggesting mixing.

Comparison of potentiometric-surface maps of deep-basin aquifers with the water table supports conclusions drawn from the water chemistry: the potential of upward flow is highest in the southern part of the Rolling Plains.

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[1]Publication authorized by Director, Bur. Econ. Geol., UT-Austin.

[2]Funded by U.S. Dept. of Energy under contract no. DE-AC97-83WM46651. [112]

Paleoenvironments of the Main Street Limestone and Its Equivalents (Lower Cretaceous) of Central Texas

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The Main Street Limestone is a Lower Cretaceous (Upper Albian), dominantly carbonate unit that can be recognized along the Cretaceous outcrop belt from southern Oklahoma to Travis County, Texas. In a previous report, Scott, Fee, Magee, and Laali (1978) developed depositional models for the Upper Albian sequence in north-central Texas. This report involves a southward extension of their area of investigation and focuses attention on the uppermost part of the sequence as a test of their models.

Six distinct lithofacies are recognized on the basis of percentage of carbonate constituents, stratification features, and outcrop relationships. Recognized lithofacies include: 1) quartzitic mollusk–echinoid wackestone, 2) quartzitic mollusk–echinoid wackestone interbedded with shale, 3) quartzitic skeletal packstone, 4) mollusk–echinoid wackestone, 5) mollusk–echinoid wackestone interbedded with shale, and 6) shale and marl. Associated with these lithofacies are coincident fossil associations representing different paleoenvironments. *Neithea-Texigryphaea* and *Kingena* associations predominate in facies that record inner shallow shelf environments. A low diversity association of ostracodes, foraminifera and calcispheres is found in facies of deep outer shelf environments.

The distribution of facies in space and time supports the conclusions of Scott and others (1978), and indicates a southward transition of carbonate deposition in shallow shelf, to deep shelf, and back to shallow shelf environments. These environments primarily were controlled by low subsidence rates associated with low terrigenous influx. [114]

Morrowan Brachiopods in the Type "Derryan" Series (Pennsylvanian), New Mexico

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Thompson (1942) defined the Derry Series as including all pre-[Desmoinesian] Pennsylvanian strata in southern New Mexico. Lane, Sanderson and Verville (1972) recorded the lowest occurrence of *Eoschubertella* 2 feet above the base of the type Derryan section and the lowest occurrence of *Profusulinella* at 15 feet above the base. They equate Derryan with the Atokan Series in Oklahoma. A new roadcut exposure at the type Derryan on Interstate 25, east of Derry, New Mexico, exposes the Pennsylvanian unconformity with the Devonian Percha Shale and a 2.5 ft exposure of a previously covered shale lying below the described base of the type Derryan. This Pennsylvanian shale has produced a well preserved Morrowan brachiopod fauna that includes *Zia novamexicana* Sutherland and Harlow, *Neochonetes*? *platynotus* (White) and *Plicochonetes*? cf. *arkansanus* (Mather). This fauna occurs also in the La Pasada Formation in northern New Mexico (Sutherland and Harlow, 1975) and in part in the Kessler Limestone Member of the Bloyd Formation, in the type Morrowan of northwestern Arkansas. Thus, the lower type "Derryan" of New Mexico overlaps the type Morrowan of Arkansas and cannot be regarded as the precise equivalent of the Atokan Series. [115]

The Ketch Creek Fault, Wichita Frontal Fault Zone, Oklahoma

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The Ketch Creek Fault is located between the Blue Creek Canyon and

Mountain View Faults in the Wichita Frontal Fault Zone of southwestern Oklahoma.

The general trend of the Ketch Creek Fault trace is 150° with a steep easterly dip. Movement on the fault was high-angle reverse with a small component of left-lateral displacement. The fault has a maximum throw of 400 ft at its southernmost exposure, gradually decreasing to zero over a distance of approximately 5 mi to the north where the fault terminates.

The northern termination is characterized by numerous joints which show two predominant orientations at 320° and 090°. In addition, two major and several minor normal faults are present. These faults, which have a general east-west trend, all have a downthrow to the south. This fault pattern is [compatible] with that predicted for the termination of a high-angle reverse fault.

To the south, high-angle reverse movement on the main fault is suggested by both the relation of the fault to topography and the intense deformation seen in the footwall block. In addition, a left-lateral component of movement is suggested by the orientation of shear fractures, minor folds and the occurrence of several minor fault splays. These splays trend northwest from the main fault, and each terminates in a zone of highly jointed rock. The geometry of the splay faults conforms to that expected for left-lateral movement on the Ketch Creek Fault.

All observations on the Ketch Creek Fault are in accord with a left-lateral transpressional model for the pre-Permian deformation in the Wichita Frontal Fault Zone. [115]

Unroofing of the Arbuckle Mountains, Oklahoma, During the Time of Folding—An Update

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The general structural history of the Arbuckle Mountains, based on the stratigraphic placement and character of several Pennsylvanian limestone conglomerates, was established by William E. Ham (1954). More recent field data make possible modifications and additions to Ham's basic picture. He recorded the initial uplift as being in the northern Arbuckle area in early Desmoinesian time, based on an evaluation of the Franks Conglomerate. Significant new information concerns the time of initial uplift in this source area, termed the Hunton Arch, as follows:

1. The initial uplift, albeit subdued, began in Morrowan time, as indicated by a westward change in facies from shallow shelf limestones to nearshore mudstones in the Wapanucka Limestone.

2. Further uplift, in post-Wapanucka time, produced Wapanucka pebbles preserved locally as a 2-ft conglomerate at the base of the Atoka Fm. on the northeastern flank of the Arbuckles.

3. Higher in the Atoka Fm., both on the NE flank of the mountains and in the Mill Creek Syncline, several conglomerate layers were derived from the Devonian Woodford Chert, the next resistant formation to be exposed by further erosion on the Hunton Arch. These layers are interbedded with thin limestones that carry the late Atokan fusulinids *Fusulinella prolifica* and *Fusulinella* sp. aff. *F. leyi.*

Additional significant new information relates to the nature of the source area during deposition of the Ada Congl. in middle Virgilian time. According to Ham, the oldest clasts found in the Ada are rare Reagan Ss. (Upper Cambrian) pebbles. Recently, rare small Precambrian granite pebbles were recovered for the first time from the Ada Congl. at Ada. Thus, granite was exposed locally during Ada deposition, well before it became extensively exposed in late Virgilian time. [115]

Double Indentation Tectonic Model for Suturing of North and South America and Formation of the Ouachita Orogenic Belt

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The Ouachita orogenic belt formed as North and South America collided. Formation of this belt, consisting of a thrusted allochthonous subduction complex, volcanic arc and forearc basin, and its relation to the North American craton, with which it collided, can best be explained by utilizing a double indentation tectonic model.

As South America closed obliquely with the southern margin of North America with its Nashville and Texas salients and intervening Ouachita embayment, collision and suturing began at the Nashville salient with extrusion of the Ouachita belt laterally along right strike-slip faults into the Ouachita embayment. With continued closure, indentation of the rigid-plastic orogen by the Texas salient began, so that the belt was now extruded from two directions to fill the Ouachita embayment. Whereas right strike-slip had prevailed along the Nashville salient on the east side of the embayment, now left strike-slip occurred along the margin of the Texas salient on the west side. These opposing wrench movements into the embayment better explain the slicing and imbricate stacking of slices of shelf and cratonic margin crust onto the craton edge to form such positive features as the Central Mississippi, Waco, and Ouachita core uplifts.

Not only does this model explain the opposing tectonic transport, the origin of positive elements, but also the delay in suturing of the orogenic belt in the Marathon area. [116]

Middle Atoka Depositional Systems, Southwestern Arkoma Basin, Arkansas

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The Arkoma Basin of western Arkansas contains a sedimentary fill ranging from Cambrian to Pennsylvanian in age. The sedimentary fill is dominated by strata of the Atoka Formation. The formation ranges in thickness from a featheredge in the Boston Mountains immediately north of the basin to over 16,000 feet in the southern part of the basin adjacent to the frontal Ouachita Mountains.

The lower part of the Atoka Formation is composed of alternating sandstone and shale units that are continuous throughout the central and southern parts of the basin. The thickness of individual sandstone units, their continuity, and their characteristic coarsening upward grain size profile suggests deposition in prograding deltaic sand complexes on a stable shelf.

Middle Atoka successions in the northern and central part of the basin are composed of sandstone and shale units and range to 4000 feet in thickness. The sandstone units are continuous and appear to represent progradational sedimentation in shallow marine environments. In the southern part of the basin the interval assigned to the middle Atoka expands rapidly from 4000 to over 9000 feet in thickness. Shale is the dominant rock type with unbroken successions ranging to 5000 feet. Middle Atoka sandstone units are regionally discontinuous. They are usually thin-bedded, and characterized by numerous interbeds of shale. Massive sandstone units displaying both fining and coarsening upward profiles are locally observed. The stratigraphic pattern suggests that Middle Atoka sandstone units accumulated on numerous submarine fans in deep water settings. Sand supplied by middle Atoka deltas to the north were deposited in upper fan environments forming massive channelized successions, and in more distal positions where turbidity currents produced interbedded sandstone and shale. [117]

Succession of Biotic Assemblages in the Plattsmouth Limestone (Oread Formation, Virgilian, Upper Pennsylvanian) Algal Bank

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Marine algal banks are present in the Upper Pennsylvanian section of the Midcontinent. They are carbonate buildups on top of the normal or regular lithology of the unit in which they occur. Although they occur in several of the different units of the cyclothem (or megacyclothem), they are most prevalent in the wavy-bedded, mixed fauna regressive limestone which overlies the core (or pivotal) shale marking the change from transgression to regression. Banks are known in at least fifteen units of the Missourian and Virgilian aged units in southeastern Kansas and northeastern Oklahoma where they developed in the shallow, warm Pennsylvanian sea a few miles offshore. They range in size from a few miles across and several feet thick to several miles wide, tens of miles long, and about 150 feet thick and consist, for the most part, of phylloid algal fragments. The most abundant algae are [*Eugonophyllum*], [*Archaeolithophyllum*], *Epimastopora* and *Anchicodium*.

The algal bank in the Plattsmouth Limestone of the Oread Formation outcrops in southeastern Kansas in the vicinity of Sedan (Chautauqua County), Kansas. Although the eastern part of the bank has been eroded, the remainder of the bank is about 15 miles wide, 30 miles long, and at least 25 feet thick. It is in sharp contrast to the underlying and overlying "normal" Plattsmouth lithology. The bank is brownish gray, vuggy, thick-bedded limestone composed of phylloid algae. In the south, the basal part of the bank contains up to four *Caninia* coral beds separated by thin algal limestones. Fusulinids occur in thin beds near the crest of the bank and the very top is "coated" with what appears to be laminated algal biscuits which may represent a [subaerial] environment and termination of the bank development. [117]

Paragenesis and Characterization of the Redbed Copper Mineralizations, Flowerpot Formation (Mid-Permian), North Central Texas and Southwestern Oklahoma

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The copper mineralizations in the Flowerpot Formation are epigenetic in origin and are an integral part of the diagenetic history of the Flowerpot Formation. The copper mineralizations are mainly found in carbonaceous sandstones and shales as replacement of pyrite. The paragenetic sequence is pyritization and carbonate cementation, dolomitization, copper sulfide mineralization and finally weathering.

The first paragenetic stage involved pyritization of some organic matter and initiation of carbonate cementation by sulfate-reduction process. Carbonate cement, a sulfate-reduction byproduct sensitive to acidic conditions, usually formed around carbonaceous matter or in the gypsiferous layer that overlies the host rock. However, some wood fragments were totally replaced by carbonate.

The second paragenetic stage involved dolomitization of the carbonate cement. In the third stage, Cu-bearing fluids migrated through the pyrite-bearing formations, and pyrite was replaced by cuprous sulfides such as digenite and djurleite. Petrographic data indicate such reaction caused 130 to 150 percent net volume increase. Malachite is the major weathering product of cuprous sulfides. Azurite was derived from malachite.

The petrographic and geochemical data are [consistent] with Eh-pH diagram relationships. [118]

The San Angelo–Flowerpot Redbeds (Permian), North Central Texas and Southwestern Oklahoma; a Chemical Study of the Ferric Pigment

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The major lithofacies in the San Angelo–Flowerpot redbeds is dolomite-free blocky red mudstone containing ferric pigment. The ferric pigment is syngenetic in origin and probably was originally precipitated as "hydroxides." The exact mineralogy of the ferric pigment is unknown. When the sediments were deposited, the FeO/Al_2O_3 molar value (total Fe as FeO) was as high as 0.8; a maximum of one-half of the iron was in the form of ferric pigment with the remainder in the clay lattice. During diagenesis, reduction and removal of the ferric pigment was initiated by the consumption of organic matter and/or by migrating reducing fluids. Once the FeO/Al_2O_3 value dropped below approximately 0.47, the ferric pigment was "exhausted" and the host rock turned grey in color. Little additional iron was mobilized because the reducing process accompanying diagenesis had little effect on the removal of lattice Fe from clay minerals.

Because most mudstones are blocky, relatively impermeable, and organic-poor, they maintained their red color during diagenesis due to residual ferric pigment. In the relatively low permeable strata, the reducing fluids could only move along lithofacies boundaries and vertical tensional joints, which subsequently turned grey in color. The existence of grey colored vertical tensional joints in these redbeds indicates that the reducing fluids were able to migrate across the various lithofacies as well as along permeable strata. [118]