Oklahoma Geology Notes

OKLAHOMA GEOLOGICAL SURVEY / VOL. 43, NO. 3 - JUNE 1983

On the cover—

Mine Structure a Reminder of State, Survey History

A photograph of the weathered outer structure of a zinc mine in existence many years ago near Miami, Oklahoma, serves as a reminder of the diversity and importance of the State's geology. The mine was worked in the Tri-State Mining District, which extends from northeastern Oklahoma into southeastern Kansas and southwestern Missouri. In the first quarter of this century, the district was a world-leader in the production of lead and zinc.

In recent years the mines have again been the focus of much public attention. But this time the interest is centered on subsidence problems associated with the abandoned mine shafts rather than the rich ore produced in earlier days. A study of the problem by Oklahoma Geological Survey engineering geologist Kenneth V. Luza was outlined on the April 1983 issue of *Oklahoma Geology Notes* (v. 43, no. 2, p. 36). In this month's issue (p. 61), Congressman Mike Synar comments on the importance of that study, and indicates that states will work along with the federal government to being solving such problems.

During this 75th Anniversary year of the Oklahoma Geological Survey, OGS associate editor Elizabeth A. Ham is taking a look back at the history of the Survey and its involvement through the years in such issues. The history is quite extensive, and will be published later this year in a special commemorative edition that will include a number of other historic and geology-related photographs.

Also to celebrate this Anniversary, the Survey will host a special symposium in Norman late in November. For more information on this event, please turn to page 64 of this issue.

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

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PROJECTED PRODUCTION AND VALUE OF CRUDE OIL AND NATURAL GAS IN OKLAHOMA

Charles J. Mankin[1]

Introduction

In response to a request by the Fiscal Office of the Oklahoma Legislature, I have formulated projections on the production and value of crude oil and natural gas for the State of Oklahoma for the next 3 years. These projections are presented here, at the request of the editors, in the hope that they will be of interest in providing background and insight into current market conditions and trends that might affect Oklahoma.

The projections in production and value for crude oil and natural gas in Oklahoma for the years 1983, 1984, and 1985 have been made primarily on the basis of professional judgment and differ in point of view from some others that have been made recently. In arriving at these projections, all available information was taken into consideration with respect to historical production and recent drilling activity that resulted in new field discoveries and extensions to existing fields. Projections in demand were given special consideration with respect to natural gas.

Crude-Oil Projections

Crude-oil production in Oklahoma is expected to begin a slow decline this year (table 1). Drilling activity has declined markedly, although shallow oil drilling is continuing at a moderate pace. The principal reason for projecting a 1-million barrel decline in production in 1983 is the expectation that discoveries will not keep pace with production. In addition, the current excess supply of natural gas is causing some casinghead production to be shut in, resulting in some loss of related crude-oil production. In succeeding years it is expected that production will continue to decline at a relatively slow rate, with the range in uncertainty skewed toward the low end of the production. The 160-million-barrel figure for the range of uncer-

[1]Director, Oklahoma Geological Survey.

TABLE 1. — PROJECTED PRODUCTION AND VALUE OF CRUDE OIL IN OKLAHOMA THROUGH 1985

Year	Production (millions of barrels)	Range
1982	158.7	—
1983	157.0	150–160
1984	155.0	145–160
1985	152.0	140–160
	Price ($ per barrel)	**Range**
1982	32.74	—
1983	29.00	27–31
1984	30.00	28–35
1985	32.00	30–40
	Value (million $)	**Range**
1982	5,196.	—
1983	4,553.	4,050–4,960
1984	4,650.	4,060–5,600
1985	4,864.	4,200–6,400

tainty is believed to be a reasonable upper expected limit for future crude-oil production in Oklahoma.

The projected price per barrel is based upon the expectation that the world price of crude oil will not decline in 1983 from its present value. It should be noted that some energy analysts are predicting further major declines in the world price of crude oil, but that projection has been considered unlikely in this analysis. The small increases in crude-oil price for 1984 and 1985 are based upon the expectation that world demand will not grow substantially and therefore that supply will continue to exceed demand by many millions of barrels per day. Obviously, those projections become much less certain by 1985, and the range of uncertainty in price is skewed in the upward direction, reflecting the probability that crude-oil prices are more likely to increase than to decrease in the future.

The value of crude-oil production in Oklahoma was obtained by multiplying the price per barrel by the expected production for each of those years. The range in value simply reflects the minimum and maximum possibilities by using the minimum range in price together with the minimum range in production for the lower figures and the corresponding figures for the higher values. Obviously, this results in unrealistically larger ranges in numbers, but the range projections in production and value did not seem to warrant a more sophisticated treatment.

Natural-Gas Projections

The projection in production of natural gas for the years 1983, 1984, and 1985 is an exceedingly difficult task and is based upon a substantial level of uncertainty (table 2). An examination of the information will show that the State of Oklahoma is capable of producing substantially more than 2 trillion cubic feet of natural gas on an annual basis. Thus, the figures reflected in this projection are based upon expected constraints in demand during the

TABLE 2. — PROJECTED PRODUCTION AND VALUE OF NATURAL GAS IN OKLAHOMA THROUGH 1985

Year	Production (trillions of cubic feet)	Range
1982	1.924	—
1983	1.650	1.5–2.0
1984	1.700	1.4–2.0
1985	1.900	1.2–2.2
	Price ($/millions of cubic feet)	**Range**
1982	2.77	—
1983	2.70	2.60–3.00
1984	3.10	2.80–3.50
1985	3.50	3.00–4.00
	Value (million $)	**Range**
1982	5,336	—
1983	4,455	3,900–6,000
1984	5,270	3,920–7,000
1985	6,650	3,600–8,800

next several years. Obviously, such projections are tenuous at best, even when hard data are readily available. In the present situation, the decline in production is based for the most part on anecdotal information with some supporting systematically collected data. Some analysts believe the present decline in natural-gas demand is based predominantly upon an unusually mild winter. Still others believe that the effect of the recession is finally catching up with the industrial sector, resulting in a decline in demand.

An examination of the use of natural gas in the residential and commercial sector for the last quarter of 1982 and the first quarter of 1983 does not support the view that natural-gas demand has declined because of an unusually mild winter. In fact, the residential and commercial sector used slightly more gas during these two quarters than they did for the comparable period last year. Much of that decline seems to be coming from those industries that are either switching permanently to coal or have taken advantage of lowered crude-oil prices to switch to fuel oil in some parts of the country. Where crude oil is replacing natural gas, that phenomenon is probably only temporary, and natural gas will be able to recapture that market as crude-oil prices rise. However, where the industrial sector has switched to coal, that part of the gas market represents a permanent loss and must be factored into future demand.

First-quarter natural-gas production figures for Oklahoma in 1983 indicate that production for this calendar year could decline by as much as 300 billion cubic feet. The projections for 1984 suggest that demand may continue to remain low because of continuing soft prices in the world crude-oil market as well as continuing shifts in the industrial sector to coal. The range of uncertainty for these years reflects the view that there is a greater probability that the gas market will continue to decline rather than to increase. In the absence of Congressional action with respect to incremental pricing and the Fuel Use Act, the use of natural gas in the industrial sector could decline even more precipitously, and production could approach the lower limits as indicated by the range of uncertainty.

The projected pricing of natural gas is difficult and is further complicated by uncertainty with regard to Congressional action on the Natural Gas Policy Act of 1978. The values that have been projected are based upon the belief that there is a greater probability for a more rapid escalation than for a steady-state condition. Thus, the range in uncertainty is skewed toward larger numbers.

It should be noted that the average price projected for 1983 is less than the average price for 1982. This projection is based upon the belief that most of the higher priced contracts for new, deep natural gas either have been or will be renegotiated downward. Also, smaller quantities of that gas will be produced in 1983 because of related changes in take-or-pay provisions in those contracts.

CHEMIST JOINS OGS STAFF

Keith A. Catto, Jr., is the newest member of the staff of the Oklahoma Geological Survey. Catto joined the Survey recently to fill a vacancy created in the OGS analytical-chemistry laboratory and is working currently on an extensive program of testing water samples for trace elements, some of which may be toxic. He expects also to be conducting analyses of rock samples, particularly carbonates, and samples of Oklahoma coals.

Catto is a native of Plainview, Texas, but received his academic education in Arkansas; he graduated from Jonesboro High School and earned a B.S. degree in chemistry and an M.S. degree in analytical chemistry, both from the University of Arkansas in Fayetteville. His master's thesis was on "Spectrophotometric Determination of Calcium with Eriochrome-Black T."

While at Fayetteville, he was employed as an analytical chemist on confidential research projects for the Institute of Science and Technology of the University of Arkansas, doing analyses of pyrotechnic and explosive materials. He continued this work on a half-time basis while pursuing his master's degree.

Catto comes to the Survey from 28 years of employment as an analytical chemist with Halliburton Services, a division of Halliburton Co., in Duncan, Oklahoma, where, he says, all his work was in the field of inorganic chemistry. Among other things, he developed procedures for the use of atomic-absorption spectrophotometers in analysis of industrial cleaning materials and a procedure for detecting metal particles in lubricating oils from diesel engines. He also devised methods for determining sodium and potassium in oil-field brines and ran calcium and magnesium tests, which yielded information usable in identifying geologic formations in wells. He organized a computer file of oil-well-brine analyses and developed and presented in-house instructive courses in spectrophotometry, flame emission, and atomic absorption. He is co-author of several papers on this work.

Catto is a member of the American Chemical Society, the Royal Society of Chemistry (London), the Society of Applied Spectroscopy, and the American Petroleum Institute.

CONGRESSMAN COMMENDS REPORT

Congressman Mike Synar, of Oklahoma's Second Congressional District, said recently that a study completed by the Oklahoma Geological Survey will give officials a place to start in solving problems associated with abandoned mines in the Picher area in northeastern Oklahoma.

The study, conducted by OGS geologist Kenneth V. Luza, listed mining-shaft locations in the area and suggested ways to make them safer. An article outlining this report was published on page 36 of the April 1983 issue of *Oklahoma Geology Notes* (v. 43, no. 2). Similar studies are being conducted by Kansas and Missouri.

"I want to commend the Oklahoma Geological Survey for the tremendous work they have done in studying the subsidence problems in the Tri-State Mining District," Synar said. "Three years ago, Congressmen Bob Whittaker (of Kansas), Gene Taylor (of Missouri), and I worked to get this much-needed study under way. With this study and the critical mapping information contained in it, we are in a good position to help the State follow up on the Survey's recommendations," Synar said.

"The residents of the Tri-State area can be proud of the difficult task performed by the Survey and can be confident that Congressmen Whittaker, Taylor, and I will work closely with our states, the surveys, and the federal government to move ahead in whatever ways are necessary to begin to correct the serious subsidence problems which citizens in that area continue to face."

"The Geological Survey's study also fits right into place with the work now being done by the Tar Creek task force, which is looking at potential water-contamination problems in the area," Synar added.

All of the findings have been issued as an "open-file" report by the U.S. Bureau of Mines and can be inspected at the Survey office in Norman. The report, "A Study of Stability Problems and Hazard Evaluation of the Oklahoma Portion of the Tri-State Mining Area," also can be seen at the Miami, Oklahoma, public library.

The report will be issued later as a serial publication of the Oklahoma Geological Survey.

Among the report's contents are three maps that show mine and shaft locations; open mine shafts, pits, and collapse features; and accumulations of mine and mill waste. Also in the report are several tables, including one that lists and describes more than 80 subsidences in the area and another that describes waste piles and tailings ponds.

MOST HIGH-PLAINS-AQUIFER WATER SUITABLE FOR CROPS, DRINKING

Aquifer water from about 80 percent of the eight-state area underlain by the High Plains aquifer is of low enough salinity to permit general use of the water, barring other problems, to irrigate most crops, according to a report published by the U.S. Geological Survey.

Water from this 80 percent of the aquifer area also meets U.S. Environmental Protection Agency drinking-water standards for dissolved-solids concentrations. Amounts of dissolved solids in water also are used to measure salinity levels.

Although higher in salinity as measured by dissolved solids, water from most of the remainder of the aquifer can be used for irrigation of most crops if soils are permeable enough and if farmers take special precautions to prevent salt buildup in soils, says the report.

Generally, salinity levels increase from north to south in the 174,000 square mi underlain by the aquifer in parts of South Dakota, Nebraska, Wyoming, Kansas, Colorado, Oklahoma, Texas, and New Mexico. The High Plains aquifer, which consists of the Ogallala Formation and associated rocks, is the principal source of water over most of its area for municipal and domestic use as well as for irrigation. Ground-water levels in most parts of the aquifer have been falling since World War II, mainly because of extensive irrigation.

The dissolved-solids map and text that accompany the report and a companion map and text on sodium concentrations in the High Plains aquifer are part of a USGS study of the aquifer begun in 1977. The study should provide a better understanding of the aquifer so that its water resources can be more wisely used and conserved. Computer models will be developed to predict aquifer response to possible future changes in ground-water development and use.

Noel C. Krothe, a USGS hydrologist in Denver, and principal author of the report, said that most crops can tolerate water containing as much as 500 milligrams per liter (mg/L) of dissolved solids without adverse effect. Solids include calcium, sodium, sulfate, chloride, and other minerals that, in the main, are dissolved from surrounding rocks. Dissolved-solids concentrations of 500 to 1,500 mg/L in irrigation water are not likely to be harmful if leaching or drainage is adequate, he said.

Krothe added that 19 percent of the High Plains aquifer area (in parts of Nebraska, Wyoming, Colorado, and Kansas) contains water with less than 250 mg/L of dissolved solids. Barring other problems, this water can be used for irrigating virtually all types of crops and also meets EPA drinking standards.

Another 62 percent of the aquifer area (in regions of all eight states) contains water with 250 to 500 mg/L of dissolved solids, providing good irrigation water for most crops and meeting EPA standards for drinking water, if there are not other problems.

Krothe said that the remaining 19 percent of the aquifer area (in scattered regions throughout the High Plains) contains water exceeding 500 mg/L dissolved solids. In most cases, this water can be used for irrigation if leaching or drainage is adequate, but unless treated to remove some of the solids, it does not meet EPA standards for drinking water. In about 3 percent of the aquifer area, including parts of Beaver County in Oklahoma, water contains more than 1,000 mg/L dissolved solids.

The text portion of the report dealing with dissolved solids includes a table showing chemical analyses of water samples from 15 sites in the High Plains aquifer.

The sodium-concentration map and text show areas of the High Plains aquifer that contain water with various concentrations of sodium, in milligrams per liter. This, however, is not a direct indication of suitability of water for irrigation purposes or for drinking.

An accompanying table shows, among other things, specific-conductance values for water samples from 28 sites in the High Plains aquifer region. Specific conductance reflects the electrical conductivity of water, which increases with higher concentrations of dissolved solids and therefore is an indirect measure of dissolved solids and salinity.

The report was published as USGS Hydrologic Investigations Atlas HA-658, entitled *Dissolved Solids and Sodium in Water from the High Plains Aquifer in Parts of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming.*

Copies of the atlas can be purchased for $6 each from the Western Distribution Branch, U.S. Geological Survey, Box 25286, Federal Center, Denver, CO 80225. Orders must include the identification number HA-658 and checks or money orders payable to the U.S. Geological Survey.

Copies can be purchased over the counter at USGS Public Inquiries Offices in Denver, CO, and Dallas, TX.

SURVEY MARKS 75th ANNIVERSARY WITH AUTUMN SYMPOSIUM

The Oklahoma Geological Survey, the only state survey mandated in a state's constitution, is celebrating its 75th Anniversary this year. The Survey was written into Oklahoma's Constitution in 1907, then the enabling act passed by the first legislature was signed by the governor on May 19, 1908. The Oklahoma Geological Survey began operation on July 25 of that year.

The highlight of the Survey's anniversary activities will be a 75th Anniversary Symposium to be held on The University of Oklahoma campus November 30 and December 1 of this year. The theme of the symposim is "Mineral, Energy, and Water Resources Development: National and Oklahoma Perspectives." The symposium will deal with national, regional, and Oklahoma perspectives of resource development and with public attitudes and political and governmental actions that impinge upon this development. Anyone working in these resource fields should find this symposium to be of exceptional interest. The two-day meeting will feature a group of nationally recognized speakers and will focus on both national and State issues. The formal program will be supported with luncheon and dinner speakers, cultural perspectives, and a number of other activities and exhibits.

An announcement giving the final program, speakers, housing information, registration forms, and banquet/luncheon plans will be mailed in late September. For more information or for copies of the program, contact: 75th Anniversary Symposium Committee, Oklahoma Geological Survey, 830 Van Vleet Oval, Room 163, Norman, OK 73019. The telephone number is 405-325-3031.

NEW THESIS ADDED TO OU GEOLOGY LIBRARY

The following M.S. thesis has been added to the University of Oklahoma Geology and Geophysics Library:

Constructive and Destructive Paleosoils Capping Regressive Carbonate Cycles, Cochise County, Arizona, by Robert K. Goldhammer. 65 p., 30 figs., 1982.

NOTES ON NEW PUBLICATIONS

Machine-Processed Magnetic-Anomaly Contour Maps and Profiles

The U.S. Department of Energy is placing on open file the following quadrangle magnetic-anomaly contour maps and profiles: GJM-049 (82) Enid, OK; GJM-323 (83) Fort Smith, AR/OK; GJM-139 (82) McAlester, OK/AR; GJM-143 (82) Tulsa, OK/AR/MO; GJM-144 (82) Texarkana, TX/OK/AR; GJM-329 (83) Oklahoma City, OK; GJM-331 (83) Sherman, TX/OK; GJM-342 (83) Woodward, OK; GJM-343 (83) Clinton, OK; GJM-356 (83) Perryton, OK/TX; GJM-344 (83) Lawton, OK/TX; GJM-368 (83) Dalhart, TX/NM/OK.

Order from: Bendix Field Engineering Corp., Technical Library, P.O. Box 1569, Grand Junction, CO 81502. The microfiche price is $4 per quadrangle, prepaid. For orders outside the U.S. and Canada, add $3.

Carbonate Depositional Environments

AAPG Memoir 33 has been specifically designed to help the explorationist recognize the ancient environments in which carbonates were deposited. The 700-page book focuses on visual examination of rocks and touches on log, geophysical, and thin-section interpretation. Geologists in academic fields as well as petroleum exploration and development should find the publication useful. The volume includes 1,300 color pictures, most enhanced by laser and computer technology.

Order catalog number 656 from: AAPG, P.O. Box 979, Tulsa, OK 74101. Price: $48, AAPG-SEPM members; $58, nonmembers.

Deconvolution of Seismic Data

This 336-page collection of 17 papers, edited by V. K. Arya and J. K. Aggarwal, discusses the processing of seismic data. The book describes the major techniques currently used in the oil and gas industries, including complex applications of modern digital-signal-processing techniques.

Order from: Scientific and Academic Editions, 135 West 50th St., New York, NY 10020. Price: $45 hardbound.

Computer Applications In Petroleum Geology

Volume I, a new 288-page book, was designed for petroleum geologists, geographers, and geophysicists as well as geology professors. This text, by Joseph E. Robinson, provides an up-to-date description of computer techniques currently used in exploration geology. Some of the topics discussed are: geological data, data files, information contents of files, construction of computer maps, computer contouring, multivariate analysis of geologic data, and computer analysis of well logs.

Order from: Scientific and Academic Editions, 135 West 50th St., New York, NY 10020. Price: $16.95 paperbound; $26.95 hardbound.

Basic Well Log Analysis for Geologists

Published in the fall of 1982 by AAPG, this book is written for the geologist who, while relying heavily on well-log analysis, may lack a basic understanding of how it works. Author George Asquith says that he wrote the book in lay terms, glossing over complicating exceptions. The material was taken from the information Asquith used to teach an AAPG well-log-analysis course beginning in 1979. He is also author of *Log Analysis by Microcomputer* and *Subsurface Carbonate Depositional Models.*

For more information, contact: AAPG, P.O. Box 979, Tulsa, OK 74101.

National Uranium Resource Evaluation, Sherman Quadrangle, Texas and Oklahoma

Consisting of 35 pages, 28 oversize illustrations, and 28 fiche, this report is by D. K. Hobday and F. G. Rose, Jr.

To order, contact: U.S. Department of Energy, Grand Junction Area Office, P.O. Box 2567, Grand Junction, CO 81502. Price: $9 fiche, $10 paper.

National Uranium Resource Evaluation, Oklahoma City Quadrangle, Oklahoma

Consisting of 27 pages, 16 oversize illustrations, and two fiche, this report is by J. R. Derby and others.

To order, contact: U.S. Department of Energy, Grand Junction Area Office, P.O. Box 2567, Grand Junction, CO 81502. Price: $7 fiche, $10 paper.

Dissolved Solids and Sodium in Water from the High Plains Aquifer in Parts of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming

This atlas, by N. C. Krothe, J. W. Oliver, and J. B. Weeks, consists of two sheets, scale 1:2,500,000. The sheets measure 29 × 41 in.

Order from: Western Distribution Branch, U.S. Geological Survey, Box 25286, Federal Center, Denver, CO 80225. Price: $6 per set.

Statistical Abstract of Oklahoma, 1982

Included are tables and information that make this a unique reference and research tool for individuals involved in commerce, industry, education, government, communication, business, and finance in the State of Oklahoma.

Order from: Center for Economic and Management Research, University of Oklahoma, 307 West Brooks, Room 4, Norman, OK 73019. Price: $15.

A NEW STRATIGRAPHIC CODE FOR NORTH AMERICA

Publication of a new North American Stratigraphic Code in the May 1983 *Bulletin* of the American Association of Petroleum Geologists (v. 67, no. 5, p. 841-875) heralds the first major revision of a North American code since 1961. In that year a comprehensive Code of Stratigraphic Nomenclature was published, also in the AAPG *Bulletin* (May 1961, v. 45, no. 5, p. 645-665). In 1970 a slightly revised version was published by AAPG that incorporated some minor amendments.

This new version of the code was prepared over a four-year period under the aegis of the North American Commission on Stratigraphic Nomenclature. Serving as principal editor for the commission's work was Steven S. Oriel, of the U.S. Geological Survey. Malcolm P. Weiss, of Northern Illinois University, chaired the commission from 1978 to 1982. Scientists on the North American Commission represented the following groups: AAPG, Association of American State Geologists, Geological Society of America, U.S. Geological Survey, Geological Survey of Canada, Canadian Society of Petroleum Geologists, Geological Association of Canada, Asociación Mexicana de Geólogos Petróleros, Sociedad Geólogica Mexicana, and Instituto de Geologia de la Universidad Nacional Autónoma de Mexico. Thus the commission's efforts were continent-wide in scope.

Readers will note with interest several new concepts, which reflect advances in the earth sciences over the past 20 years. In the foreword to the new code, the commission writes: "Publication of the International Stratigraphic Guide in 1976 [John Wiley and Sons, New York, 200 p.] made evident some insufficiencies of the American Stratigraphic Codes of 1961 and 1970. The Commission considered whether to discard our codes, patch them over, or rewrite them fully, and chose the last."

Many of the sections in the previous codes are little changed, such as those covering aspects of lithostratigraphy, biostratigraphy, and chronostratigraphy. New terms have been introduced, however, to characterize units that fall under recent concepts.

Examples of such units in the category of content or physical limits are (1) *lithodemic unit,* a defined body of predominantly intrusive, highly deformed, and/or highly metamorphosed rock, distinguished and delineated on the basis of rock characteristics; (2) *magnetopolarity unit,* a body of rock unified by its remanent magnetic polarity and distinguished from adjacent rock that has different polarity; and (3) *allostratigraphic unit,* a mappable stratiform body of sedimentary rock that is defined and identified on the basis of its boundary discontinuities.

Several new units have been introduced in categories related to geologic age: (1) *polarity-chronostratigraphic unit,* a body of rock that contains the primary magnetic-polarity record imposed when the rock was deposited, or crystallized, during a specific interval of geologic time; (2) *polarity-chronologic unit,* a division of geologic time distinguished on the basis of the record of magnetopolarity as embodied in polarity-chronostratigraphic units; (3) *diachronic unit*, a unit that comprises the unequal spans of time represented either by a specific lithostratigraphic, allostratigraphic, biostratigraphic, or pedostratigraphic unit, or by an assemblage of such units; and (4) *geochronometric unit*, a unit established through the direct division of geologic time, expressed in years.

The presentation of the new code is well organized. In addition to the main body of the code — the articles — a preamble gives the background and an overview of the project, and an addenda section includes references and appendixes. Several line drawings illustrate the overall categories of the code as well as enhance various concepts of its terminology.

The North American Commission on Stratigraphic Nomenclature welcomes comments and suggestions, and also welcomes reports of formal adoption or endorsement of the code. Remarks can be sent to the chairman of the commission, c/o American Association of Petroleum Geologists, P.O. Box 979, Tulsa, OK 74101. Copies of the code are available for $1.00 each, postpaid, from the same address.

This new code is a major achievement. It deserves the careful scrutiny of geological scientists practicing in North America.

William D. Rose

EDITORS TO MEET IN HOUSTON

The Association of Earth Science Editors (AESE) will hold its annual meeting in Houston, Texas, October 9–12 of this year. The group's current president is William D. Rose, geologist/editor at the Oklahoma Geological Survey.

Sessions are scheduled to include such topics as graphics and illustrations, editing techniques, new technology, and the editor and public-information duties. A panel discussion will be held on Wednesday morning to give members an opportunity to discuss the group's future and let officers and program-committee members know what topics they would most like to explore in future meetings.

The group will take a geology-oriented field trip along the Galveston beaches on Tuesday afternoon, and conclude at the Strand in time for the annual banquet, which will be held on the deck of the restored ship Elissa. Headquarters for the meeting will be the Nassau Bay Hilton in Houston.

For more information, contact Pam Jones at the Lunar and Planetary Institute, 3303 NASA Road 1, Houston, TX 77058. The telephone number is 713–486-2150.

OKLAHOMA ABSTRACTS

AAPG Annual Meeting
Dallas, Texas, April 17-20, 1983

The following abstracts are reprinted from the *Bulletin* of the American Association of Petroleum Geologists, v. 67, no. 3. Page numbers are given in brackets below the abstracts. Permission of the authors and of AAPG to reproduce the abstracts is gratefully acknowledged.

Origin and Genesis of Fracture Porosity in Viola Limestone (Ordovician)

GEORGE DORROH ALLEN, Baylor University, Waco, TX

Analysis of surface exposures of the Viola Limestone is important to understanding Viola oil and gas production trends in the Marietta basin of southern Oklahoma. Surface exposures of the Viola Limestone in the Arbuckle Mountains and Criner Hills of Oklahoma indicate a critical dependence of fracture development on structural position and lithology. Maximum fracturing occurs in tensional zones along fold crests, rather than in areas characterized by intense compressional stress. Fracturing also appears to be related to lithology. The basal, cherty unit has a fracture density approximately two to four times greater than that of the upper, more calcareous units. These relationships could be important to understanding oil and gas occurrence in the Viola Limestone, because the same controls may dictate distribution of fracture porosity in the subsurface. [411]

Role of CO_2 in Evolution of Secondary Porosity in Pennsylvanian Morrow Sandstones, Anadarko Basin, Oklahoma

ZUHAIR AL-SHAIEB, Oklahoma State University, Stillwater, OK

The Anadarko basin is one of the most outstanding hydrocarbon producers in the North American continent. Examination of more than 50 cores

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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.

from the Pennsylvanian Morrow sandstones reveals a complex diagenetic history. Although quartzarenite is the major lithology, shell fragments, glauconites, and clayey matrix occur in considerable amounts throughout the section. This diagenetic complexity is a function of depositional environment and burial and thermal history of the basin.

Most porosity in the Morrowan sandstones throughout the Anadarko basin is chiefly secondary. Such porosity results from the dissolution of clayey matrix, carbonate fragments and cement, glauconite, and quartz grains and their overgrowth.

Evolution of secondary porosity is related directly to the generation of hydrocarbons. CO_2 gas, with concentrations ranging from 0.3 to 4.7% by volume, was detected in more than 150 natural gas wells examined in the basin. Based on geothermal and geopressure gradients, and on experimental investigations of the solubility-potential of CO_2 in formation fluids under elevated temperatures and pressures, a good estimate of solubility of CO_2 in the Morrow Formation water may be attained. Because the concentration of CO_2 appears to increase with depth in the basin, secondary porosity should not be restricted to a particular zone or to particular depths, but definitely would persist with depth. Organic acids at shallow depths and H_2S in deeper zones may be important in enhancement of secondary porosity.

Amounts of porosity and the geometry of pore space are directly related to the original lithology. A better understanding of lithofacies is very critical in evaluating a reservoir quality. [412]

Lacustrine and Paludine Facies: Cretaceous Baum Linestone, South-Central Oklahoma

E'LESHA D. BALKAN, KELLY CLINTON-RACE, and R. DOUGLAS ELMORE, The University of Oklahoma, Norman, OK

The Lower Cretaceous Baum Limestone in the Arbuckle Mountains of south-central Oklahoma was deposited in lacustrine and paludine settings near the Cretaceous shoreline. The unit rests unconformably on folded Pennsylvanian rocks and is overlain by and grades into the Paluxy Formation, a sandstone deposit with numerous *Ophiomorpha* burrows. The lacustrine lithofacies include the following: (1) massive micrite containing charophyte fragments and ostracodes; (2) intraformational conglomerate composed of rounded micrite clasts in a micritic matrix; (3) rounded peloids and coated peloids; (4) laminated micrite; and (5) conglomerate composed of clasts derived from Paleozoic rocks within a micritic matrix. Disintegration of charophytes that grew in the littoral zone of the lake produced the massive micrite. Intraformational conglomerates and peloids represent reworking of massive micrite whereas the other conglomerates represent fluvial influx. The coated peloids and laminated micrite probably formed as a result of algal activity in the shallow margins of the lake.

Features found within the paludine facies include: (1) brecciated micritic limestone that probably formed as a result of shrinking and swelling due to an oscillating phreatic water table; (2) subspherical nodules of micrite (peds) separated by red shale (plasma) that represent pedogenic alteration of exposed lacustrine mud; and (3) subcylindrical columns composed of micritic limestone representing root-casts. These paludine features formed as a result of pedogenic processes in a marsh that rimmed the shallow lake where the lacustrine facies accumulated.

The lacustrine and paludine facies are not grouped into sequences similar to those reported from some modern and ancient lacustrine carbonate deposits, but alternate in an apparently random pattern. Comparison with modern carbonate-dominated lacustrine systems indicates that the facies in the Baum Limestone have no precise counterparts, although they are most similar to facies in temperate-region marl lakes. [417]

History of Development and Depositional Environment [of] Upper Cherokee Prue Sand, Custer and Roger Mills Counties, Oklahoma

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In western Oklahoma the uppermost sand member of the Cherokee Group, the [Prue] sand, was first drilled and found productive in two discoveries, completed in 1980, in west-central Custer County and in central Roger Mills County, Oklahoma. For 1½ to 2 years these two discoveries, some 18 mi (29 km) apart, were thought to be stratigraphic equivalents of two separate sand bodies occurring parallel to the classic northwest-southeast-trending systems of the Anadarko basin. Energy Services has drilled eight productive Prue sand wells in this area and has been instrumental in establishing that the 1980 Prue discoveries are actually part of a predominantly east-west-trending system that extends come 40 mi (64 km) across the west-central part of western Oklahoma.

At present, some 40 productive wells will ultimately produce more than 100 bcf of gas and 3 million bbl of condensate from an average depth of 11,500 ft (3,500 m). Sand porosities range from 3 to 18% with most producing wells having porosities in the 12 to 15% range. Because Prue sand is slightly overpressured (a pressure gradient of .53 psi/foot), the reserves are generally better than normal-pressured wells at this depth.

Log and sample data from the 40 producing Prue wells and numerous surrounding nonproductive tests, along with the one core of the sand, give a fairly good picture of the sand geometry and depositional history.

The sand body is over 40 mi (64 km) in length, 1 to 1.5 mi (1.6 to 2.4 km) wide, and 60 ft (18 m) thick. The east-west trend of the sand is parallel to the present-day structure at the top of the Cherokee Group as well as to the interval isopach of the Cherokee Group. The majority of the open-hole logs and samples show a fining-upward sequence, where most of the clean productive interval is at the basal to middle part of the sand. Study of the core shows the interval to grade from a medium to fine-grained sand, highly laminated and cross-bedded with black shale, to a slightly coarser grained nonstructured interval and back into a highly laminated cross-bedded sandy black shale interval. The interval is topped by a 10-ft (3-m)-thick black shale layer that is a predominant bed throughout the whole area. We interpret the sand morphology as that of a submarine offshore bar sand that was deposited in shallow water but never emerged above sea level to form a barrier island of beach-type environment.

The existence of a shaly limey interval for 500 ft (152 m) above the Prue sand along with the excellent preservation and consistency of the Prue sand geometry indicate that the Prue was never reworked and was likely deposited in a transgressive or at least a subsiding basin environment.

These conclusions have implications that may assist in the exploration of other Pennsylvanian sands in this area. [420]

Importance of Shelf to Trough Black Phosphatic Shales in Mid-Continent

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Pennsylvanian black shales containing radiolarian-rich phosphatic nodules, such as are now accumulating on outer shelves and upper slopes of modern tropical seas, are widespread throughout much of Kansas, Oklahoma, and other Mid-continent states.

Conodonts, inarticulate brachiopods, conularids, fish teeth, and radiolarians constitute the main biota of these black shales. Such shales characterize about half the 60 or more known Pennsylvanian cyclothems of Oklahoma and Kansas. These shales, individually approximating about 1 m (3 ft) in thickness in the extensively mined limestone and coal sequences of eastern Kansas and northeastern Oklahoma, have been described by Moore, Branson, Heckel, and others. However, much thicker, up to 8 m (26 ft), coeval zones in the deep Arkoma and Anadarko basins are surprisingly under-reported considering that such highly organic shales may have been the prime source of commercial oil and gas. Furthermore, those coeval black shale wedges that interfinger southward from the Arkoma trough into the red bed- and conglomerate-dominated sequences flanking the southern tectonic borderlands are virtually unreported.

These are the "core shales" of Heckel, the deep stillstand or maximum transgressive facies. Representative black phosphatic shales crossing two or more tectonic provinces include the Desmoinesian sub-Verdigris, Anna, and Nuyaka Creek beds, and the Missourian Mound City and Stark beds.

Dysaerobic (low oxygen) and supposedly slightly shallower water, dark gray concretionary shales adjoin these black phosphatic shales. In many cyclothems the dysaerobic facies represent the deep stillstand facies where the latter is missing. Typically, it features a middle to outer shelf diverse molluscan community, including rapidly evolving goniatites useful for correlations.

These deep-water stillstand indicators are more useful for regional correlations than those for the low water stillstand that include coals, coaly shales, red beds, and paleosols. Carboniferous sea level fluctuations at times probably exceeded 200 m (656 ft), arising from interacting tectonic pulses and glacial-eustatic changes. Recent findings indicating that Carboniferous glacial maxima in southern Pangea exceeded Pleistocene maxima may account for the numerous regressive events on a global scale at that time. [422]

A New Model of Succession of Middle and Late Pennsylvanian Fossil Communities in North Texas, Mid-Continent, and Appalachians with Implications on Black Shale Controversy

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A new model for the succession of Pennsylvanian fossil communities, preserved in cyclothems, is proposed on the basis of more than 200 fossil localities in the Mid-Continent, Appalachians, and north Texas.

Early models for Mid-Continent cyclothems placed the black shales in shallow water, with maximum transgression at the fusulinid-bearing zone in the overlying limestone. The most recent model proposed that the black phosphatic shales, which commonly occur between two subtidal carbonates, are widespread and laterally continuous over great distances and represent maximum transgression.

The black phosphatic shales contain: ammonoids; inarticulate brachiopods; radiolarians; conularids; shark material and abundant and diverse conodonts. This assemblage represents a pelagic or epipelagic community developed in a stratified water column over an anoxic bottom.

The black shales grade vertically and laterally into dark gray-black shales which contain many of the same pelagic and epipelagic forms found in the phosphatic black shales, plus the following: low diversity of articulate brachiopods; large numbers and diversity of ammonoids together with other cephalopods; hyolithids; blastoids; trilobites; corals; and moderate diversity and numbers of bivalves and gastropods. This facies contains the deepest water benthic community. Most of these forms are immature, pyritized, and generally are preserved as molds. The ammonoids include both nepionic and late juvenile–early mature forms with the body chambers. These ammonoids, along with the other immature invertebrates, suggest mass mortality due to fluctuating low bottom oxygen as the deeper water stratification was breaking up.

The dark gray-black facies grades into a medium gray shale facies which contains a mature molluscan fauna. This assemblage contains many of the same benthics as the dark gray facies, but with greater diversity. The pelagics and epipelagics, including plants, are rare to absent, except for the conodonts, which are diverse and abundant.

The medium gray shale grades into a lighter gray facies, which is dominated by brachiopods, crinoids, and corals, with occasional bivalves and gastropods. Fusulinid and coral communities may also occur in the slightly shallower depths. (These facies are interpreted as being a moderate to shallow depth shelf community.)

The brachiopod-crinoid community is succeeded by shallow water communities which may have occupied shoreline, lagoonal, bay, interdeltaic, or shallow prodeltaic environments. These communities are low to high diversity molluscan assemblages, generally lacking ammonoids, and have a very low diversity conodont assemblage. These shallow water assemblages are discontinuous and occur commonly interbedded with sandstone, in the regressive and early transgressive portions of each cycle. In addition, coals are sometimes present that grade vertically into black carbonaceous shales that are non-phosphatic, lack benthic and pelagic forms, and contain plant compressions. These black shales are interpreted as being marsh deposits.

This model is consistent with the findings of Yancey and Stevens with the Lower Permian fossil communities in the western United States. In addition, this model agrees with Calver's work on the succession of communities associated with the cyclothems in the Westphalian of England. [426]

Recurrent Motion on Precambrian-Age Basement Faults, Palo Duro Basin, Texas Panhandle

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The distribution of Late Precambrian(?) through Quaternary strata in the Palo Duro basin and surrounding uplifts documents recurrent motion on Precambrian-age basement faults. Basement blocks have been uplifted with little tilting or folding of overlying strata along a system of northwest-southeast oriented faults, part of a regional trend extending from central Colorado to southwestern Oklahoma. The orientation of basement terranes in Colorado and that of a 50-mi (80-km) long mylonite zone in east-central New Mexico suggest a Precambrian age for the faults.

An Arkosic sandstone overlies basement and underlies a Cambrian(?) quartzose sandstone in a few Palo Duro basin wells. It may represent debris shed from active fault blocks during the opening of the southern Oklahoma [aulacogen] in the Late Precambrian or Early Cambrian. Ordovician carbonates thin or are missing beneath Mississippian carbonates on some fault blocks, indicating a post-Ordovician–pre-Mississippian period of faulting.

The greatest amount of deformation occurred during the Pennsylvanian. Thickness, distribution, and facies of sediments were controlled by the location of active faults. Lower Pennsylvanian strata thin by up to 50% across some structures. Fault blocks provided sources of arkosic debris and loci for carbonate buildups throughout the Pennsylvanian and Early Permian. Around the periphery of the basin, Late Pennsylvanian or Early Permian faulting caused a wedging out of older units beneath the Wolfcamp.

Permian, Triassic, and Neogene units, along with present topography, all have been subtly affected by basement structures. The entire section thins over basement highs. Middle and Upper Permian evaporites are thicker in structural lows. The overlying Dockum Group (Triassic) and Ogallala Formation (Neogene), both nonmarine clastic units, become finer grained over basement highs. Present topographic highs coincide with some basement highs. Also, in some places remarkably straight stream segments parallel basement faults. Low-level seismic activity, primarily north and west of the Palo Duro basin, suggests continuing motion on at least some of the faults. [433]

A Sedimentological Analysis of Some Coarse-Grained Clastic Units in the Ouachita Mountains, Arkansas[1]

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A sedimentological analysis of three coarse-grained clastic intervals (from the Missouri Mountain Shale, the Arkansas Novaculite, and the basal Stanley Shale) in the Ouachita Mountains, Arkansas, reveals that these units are representative of submarine gravity-flow deposits. Gravity-flow deposits dominantly reflect the debris flow regime; however, debris flow–grain flow, fluidal flow, and high-density turbidity deposits also were observed. Flow types are determined from thickness, geometry, bedding, grading, imbrication, stratification, fabric, and matrix percent. The effects of sediment loading by larger gravel-size clasts, which increases the vertical pressure gradient (i.e., competence and buoyancy), also must be strongly evaluated.

Allogenic clastic materials were derived from a sedimentary—metasedimentary source and reflect some older Paleozoic lithotypes. Most units are very poorly sorted and contain gravel-size sedimentary-rock fragments (chert and shale), sand-size well-rounded to rounded quartz grains and SRF, and finer grained matrix material.

Initiation of flow occurred along the tectonically active basinal margin (shelf-slope break), and sediments were transported and deposited in the deeper Ouachita trough. A coarsening-upward sequence, where thick-bedded sandstone units are overlain and channeled by matrix-supported conglomeratic units, reflects a regressive sequence, indicative of a proximal basin-slope environment.

[1]The following abstract is being substituted, at the request of the author, for the abstract that originally appeared on page 452 of the AAPG *Bulletin*—Ed.

Deep-To-Shallow Carbonate Ramp Transition in Viola Limestone (Ordovician), Southwest Arbuckle Mountains, Oklahoma

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The Viola Limestone (Middle and Upper Ordovician) of the southwest Arbuckle Mountains was deposited on a carbonate ramp within the south-

ern Oklahoma Aulacogen. Depositional environments include (1) anaerobic, deep-ramp setting represented by microfacies RL, CH, CGL, and A, (2) dysaerobic, mid-ramp setting represented by microfacies B, and (3) aerobic, shallow-ramp setting represented by microfacies C and D.

Deposition in the deep- and mid-ramp environments was dominated by bottom-hugging currents produced by off-platform flow of denser waters. These currents moved down a broad slope that was locally incised by gullies. Deposits of the broad slope, microfacies A and B, originated from a line-source and are found throughout much of southern Oklahoma. Primary sedimentary structures include millimeter-size laminations, starved ripples, and concave-up and inclined erosional surfaces. Shelly benthic fauna are rare in A and B; trace fossils are common only in B. Deposits associated with the line-source gully, microfacies RL, CH, and CGL, are laterally confined; they have been observed only in the southwest Arbuckle Mountains. Primary sedimentary structures present in RL include wavy and ripple-cross laminae. Microfacies CH, contained with RL and interpreted as a submarine channel deposit, is present only at one locality. Primary sedimentary structures present in CH include an erosional base and several internal erosional surfaces, lateral accretionary sets, and imbricated, locally derived intraclasts.

Deposition in the aerobic, shallow-ramp setting (microfacies C and D) was dominated by storm processes and intervening periods of bioturbation. An increase in both size and abundance of [pelmatozoan] fragments is the characteristic feature of these microfacies.

High total organic carbon (TOC) values have been reported for the lower Viola. TOC values of 1% have been reported from microfacies A, and TOC values of 5% have been reported from microfacies RL. These high values suggest that A and RL may act as hydrocarbon source rocks. Recognition of these microfacies in the subsurface will contribute to our knowledge of the Viola Limestone as an exploration target. [466–467]

Stratigraphy and Environmental Significance of Continental Triassic Rock of Texas

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The continental Triassic rocks of Texas are represented by four distinct but similar rock groups that exist both in outcrop and in the subsurface and include the Eagle Mills Formation (south-central and northeast Texas), Sycamore Formation (central Texas), Dockum Group (west Texas), and Bissett Formation (southwest Texas). They are clearly terrigenous in nature derived principally from older Paleozoic sedimentary rocks. The rock groups are composed in part or entirely of mudstone, siltstone, medium to coarse-grained sandstone, and pebble to boulder conglomerate (intrabasinal and extrabasinal). The sediments were deposited in alluvial fans, braided and meandering streams, lobate deltas, fan deltas, and lakes. The coarse sandstone and conglomerate are the products of high-energy, shortduration depositional events. Sedimentation was greatly affected by alternating climatic conditions that produced changes in base level, water depth, and lake area as well as the type of streams that flowed into the depositional basins. The character of the rock groups strongly suggests semi-arid to arid deposition typical of the low latitude desert regions of today. Thus, the rocks comprising the Eagle Mills, Sycamore, Dockum, and Bissett Formations appear to be products of continental clastic deposition during a major semi-arid to arid climatic episode, such as that of late Triassic time. [469]

Storm Deposits (Tempestites) in Ordovician Cratonic Carbonates (Arbuckle Group, South-Central Oklahoma)

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The Early Ordovician Kindblade Formation (Arbuckle Group), exposed in the Arbuckle Mountains of south-central Oklahoma, is a shallow marine epicontinental carbonate sequence that contains numerous storm deposits. Similar deposits also occur in other [Arbuckle] Group units, although not as abundantly as in the Kindblade Formation. The storm deposits (tempestites) are of two types, proximal and distal; the latter dominates in terms of both number and aggregate thickness. Distal tempestites consist of a fining upward sequence, 5 to 50 cm (2 to 20 in.) thick, that overlies an eroded hardground or firmground. The sequence consists of a lag lithoclastic grainstone that grades up into a laminated peloidal grainstone and then into mudstone. Firmgrounds are characterized by hummocky, sharp, and erosional contacts (relief 2 to 7 cm, 0.75 to 2.75 in.) with grainstone-filled erosive pockets. Hardgrounds are characterized by sharp hummocky-to-convolute surfaces (relief < 4 cm, 1.5 in.), which are mineralized and bored. Primary sedimentary features such as laminations, burrows, and allochems are truncated at the surfaces, and borings are filled with unsorted lithoclasts. The lithoclasts at the base of the sequence are bored, generally well rounded, discoid in shape, and consist of mudstone, peloidal packstone, and oolitic grainstone. Infiltration fabrics within the lithoclastic grainstone include cement-filled shelter voids beneath large clasts and internal sediment perched on the upper surfaces of lithoclasts. The overlying peloidal grainstones contain ripple cross-laminations, plane-laminations, and hummocky cross-stratification as well as rare escape burrows. The overlying mudstone is sparsely fossiliferous and bioturbated with burrows either selectively dolomitized or infilled with lithoclastic grainstone. Although there are many examples of the ideal sequence described above, complex composite or amalgamated beds are also common.

Proximal tempestites consist of coarse lithoclastic flat pebble conglomerate beds approximately 1 m (3.25 ft) thick that are interbedded with ooid grainstone and overlie mudstone. The contact between the units is sharp and erosional. The lithoclasts are of variable composition and may be up to 20 cm (7.75 in.) in diameter.

The two types of tempestites occur in crude cycles, which consist of distal deposits overlain by proximal tempestites and ooid grainstones. The cycles are interpreted as shallowing-upward progradational sequences. The abundance of the storm deposits in the section, approximately one every 20 cm (7.75 in.), indicates that hundreds of storm-induced events are recorded in the Kindblade Formation. The tempestites represent rare catastrophic events, while the hardgrounds-firmgrounds are discontinuity surfaces that represent gaps in the sequence. [471]

Diagenesis of Viola Limestone (Middle and Upper Ordovician), Southeastern Arbuckle Mountains, Oklahoma

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The Viola Limestone in the Arbuckle Monuntains was deposited on a carbonate ramp within the southern Oklahoma aulacogen. Depositional environments within the Viola ranged from anaerobic deep-ramp, through dysaerobic mid-ramp, to fully oxygenated shallow-ramp conditions. Corresponding microfacies in the southeastern Arbuckles include, respectively, nonbioturbated, spiculitic pelletal packstones; thoroughly bioturbated fossiliferous wackestones and packstones; and pelmatozoan packstones and grainstones.

A complex diagenetic history has occluded virtually all primary porosity within the Viola. Petrographic evidence suggests that the following approximate sequence of diagenetic events has occurred; (1) microboring and subsequent micritization of bioclasts to form micrite envelopes; (2) very early submarine cementation that bound the loosely sorted allochems and partly occluded porosity, characterized by drusy overgrowths on trilobite and brachiopod fragments, bladed, void-filling cement, and turbid, inclusion-rich syntaxial overgrowths on pelmatozoan fragments; (3) initial compaction evidenced by local fracturing of elongate bioclasts; (4) neomorphism, including the inversion of aragonitic allochems to calcite and the recrystallization of micrite to microspar and pseudospar in the presence of low-salinity pore fluids; (5) freshwater cementation dominated by clear [syntaxial] overgrowths on pelmatozoan fragments and pore-filling mosaic calcite that filled virtually all remaining pore space; (6) selective dolomitization; (7) silicification, including the formation of chert nodules and the replacement of bioclasts and calcite cements by microgranular quartz and/or lutecite; (8) compaction and pressure solution, probably due to deep burial, characterized by nonsutured seam stylolites, sutured seam stylolites oriented subparallel to bedding, and sutured grain boundaries; and (9) tectonically imposed pressure solution indicated by sutured seam stylolites oriented at high angles to bedding that developed during the late Paleozoic deformation of the Arbuckle Mountains.

The Viola Limestone is known as a reservoir rock and possible source unit for hydrocarbons throughout much of south-central Oklahoma. Thorough understanding of the nature and timing of diagenetic events is important for the further economic development of the Viola Limestone and other similar carbonate ramp deposits. [473–474]

Correlation of Wireline Logs with a Shaly Sandstone Sequence, Red Fork Sandstone, Payne County, Oklahoma

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The optimal use of well logs is to measure properties of rocks in a manner that permits valid and reliable inferences about rock type, porosity, permeability, fluid content, and related characteristics. The success of such an endeavor must be evaluated in terms of the known or fully determinable properties of the rocks that have been logged. Reservoir rocks whose actual physical properties differ significantly from those inferred from wireline logs are common.

At some localities in north-central Oklahoma, logs of Red Fork Sandstone (Desmoinesian, Middle Pennsylvanian) show suppressed [spontaneous]-potential curves, incomplete bed definition, misleadingly low resistivity, and no consistent, direct quantitative correlation between porosity and permeability. Foot-by-foot evaluation of an enigmatical core of the Red Fork by thin-section analysis, scanning-electron microscopy, and X-ray diffraction explained peculiarities in the gamma-ray and spontaneous-potential curves, and contributed to explanation of uncommonly low resistivity. Diagenetic effects and primary and authigenic clay seem to have had strong effects on log signatures. A large proportion of porosity is secondary. [498]

Thermal Maturity of Carboniferous Strata, Ouachita Thrust Fault Belt

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The Ouachita thrust fault belt, a large, relatively untested hydrocarbon province, contains more than 30,000 ft (9,100 m) of Carboniferous flysch rich in potential source and reservoir rocks. To estimate the thermal maturity of these strata, vitrinite reflectance (in oil) was measured from more than 90 bulk samples of the Carboniferous-age Stanley, Jackfork, Johns Valley, and Atoka Formations. Inasmuch as no subsurface samples were available, the freshest possible outcrop samples were used for the analysis, de-

spite the possible deleterious effects of oxidation on the accuracy of measured reflectance values.

Iso-reflectance contours generally trend parallel to structural grain in the western two-thirds of the Ouachitas. The "core" areas where pre-Carboniferous strata are exposed, as well as areas immediately adjacent to the core, are well defined by reflectance values greater than 2.0%. Outward from the core areas toward the north and south, reflectance values tend to decrease, although some minor variations owing to complex structure are present. In Arkansas, samples from the thrust-fault belts both north and south of the Benton uplift yield reflectance values between 1.0 and 2.0%. In Oklahoma, samples from the area north of the Broken Bow uplift yield reflectance values between 0.5 and 1.0%.

In the eastern third of the Ouachitas, iso-reflectance contours obliquely cut structural grain, and reflectance values are significantly higher. Samples from the Benton uplift give reflectance values higher than 3.0%, and measured values approach 5.0% from samples in and near the core. Although there is a general decrease outward from the core area to both the north and south, reflectance values greater than 2.0% characterize the entire width of the Ouachitas in this eastern area.

Reflectance values obtained from samples collected from both sides of major thrust faults in the western Ouachitas reveal that older, upthrown strata are more thermally mature than younger, downthrown strata. In contrast, samples collected from analogous structural positions in the eastern Ouachitas display identical thermal maturities on both upthrown and downthrown sides of thrust faults.

In the western two-thirds of the Ouachitas, stratigraphic depth of burial appears to have been the primary factor that controlled thermal maturity. The Carboniferous strata at the surface in this area are well within the window of oil and gas generation and preservation. The anomalously high thermal maturity of Carboniferous strata in the eastern third of the Ouachitas is probably the result of heat dissipated from Mesozoic rifting and intrusive events. This thermal overprint places the maturity of these strata beyond the limits of oil preservation and locally beyond the limits of wet gas preservation. [509]

Tectonic History and Influence on Sedimentation of Rhomb Horsts and Grabens Associated with Amarillo Uplift, Texas Panhandle

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The Amarillo uplift consists of an en echelon series of fault blocks separating the Anadarko basin from the Palo Duro basin. The uplift is part of a northwest-southeast zone of basement weakness that extends from the Wichita Mountains in Oklahoma to southeastern Colorado.

Initial faulting, related to the opening of the southern Oklahoma aulacogen, took place from late Precambrian through Middle Cambrian time. Renewed movement in the Late Mississippian or Early Pennsylvanian, probably of a left-lateral transcurrent nature, broke the Amarillo uplift into a series of rhomb grabens and rhomb horsts. The Lefors basin, for example, in Gray County is a small rhomb graben 4 mi (6.4 km) by 8 mi (12.8 km) that contains in excess of 4,000 ft (1,200 m) of Pennsylvanian and Wolfcampian arkose ("granite wash"). The Amarillo uplift continued to subtly affect depositional patterns following its burial in Wolfcampian time.

Salt beds in the Clear Fork Formation (Leonardian) are purer and thicker in grabens where salt deposition proceeded at at faster rate relative to horsts. Recurrent motion on the Potter County fault in northern Potter and northeastern Oldham County produced cumulative displacements of 1,600 ft (488 m) on top of the Pennsylvanian, 800 ft (244 m) on Wolfcampian strata, 600 ft (183 m) on top of the Clear Fork Formation, and 450 ft (137 m) on the Dockum Group (Triassic). Post-Permian displacements are the result of both salt dissolution and minor structural movement. There is no direct evidence for Quaternary faulting, although the uplift is seismically active. [511]

Fault Analysis in Wichita Mountains

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Analysis of a large population, but small displacement, fault array in the Wichita Mountains of southern Oklahoma strongly supports the hypothesis of left-lateral wrench faulting as a major tectonic control for the region. Middle Cambrian granites make up most of the exposed core of the Wichita uplift. Because these granites were emplaced prior to the development of the Anadarko basin structures, they should reflect Anadarko tectonics. In addition, the granites would have behaved in a brittle manner so that abundant faulting is practically the only mechanism of deformation within them; this permits uncomplicated structural analysis. Offset and trend measurements were made both in the field and from aerial photographs, and the collective data show statistically significant groupings with respect to trend and sense of shear. The fault fabric is consistent with a left-lateral wrench system that trends N70°–80°W, but also contains strong elements of the entire Riedel system (R, R′, and P shears). In addition to the wrench motions indicated by the analysis of small displacement faults, there is also a large component of vertical displacement in the region. A fault system known as the Wichita front, separates the Wichita uplift from the Anadarko basin and has 9 km (5.5 mi) of differential vertical relief across a zone 10 to 20 km (6 to 12 mi) wide. The relationship between the lateral and vertical motion is essential in understanding the types and distribution of structural traps in the Anadarko basin, and perhaps, even in neighboring basins. [511–512]

Progradational Sequences in Springer Formation, Ardmore Basin, Oklahoma

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The transitional Mississippian-Pennsylvanian Springer Formation, exposed in the Ardmore basin of southern Oklahoma, consists of coarsening-upward progradational sequences that were deposited in the southern Oklahoma aulacogen. The unit is divided into three sandy members: the Rod Club, Overbrook and Lake Ardmore, which are separated by shale intervals. Each of the sandy members consists of one or more of the coarsening-upward sequences. A typical sequence includes from the base upward, dark gray shale with abundant siderite concretions, rhythmically interbedded siltstones and shales, interbedded burrowed sandstones and shales, and abundantly burrowed sandstones. The latter contain wood impressions, ripple cross-laminations, and occasional festoon cross-stratification. In addition, one of the sequences contains a thin, discontinuous marine limestone. These sequences represent the transition from an offshore/prodelta setting to a distributary mouth bar/lower shoreface setting.

One of the sequences in the Rod Club contains an additional lithofacies at its base which consists of interbedded shales and green-gray sandstones. Sedimentary features of the sandstones include: massive nongraded bedding, large lutite casts, ripple and dish laminations, flute casts, and numerous soft sediment microfaults. The general characteristics of the sandstones suggest deposition by sediment gravity flows. This lithofacies represents deposition in a slope setting, with the sandstones derived from the proximal delta/shoreface.

Offsets on microfaults in the lower Rod Club occur on two different scales. Small scale microfaults have displacements of a few millimeters. Offset on the larger microfaults (up to 5 cm, 2 in.) is expressed on both the upper and lower surfaces of a sandstone bed. There are no fault zones within the beds which suggest the faults are synsedimentary and represent deposition on an unstable slope. The microfaults are consistently oriented approximately 90° to the flute casts, and most are downthrown in the direction of transport. Paleoslope data from the flute casts and microfaults indicate the sandstones were transported southeastward along the axis of the Ardmore-Anadarko basin during deposition of the Springer. [512]

Submarine Fan Sedimentation, Ouachita Mountains, Arkansas and Oklahoma

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More than 10,000 m (33,000 ft) of interbedded sandstones and shales comprise the Upper Mississippian and Lower Pennsylvanian flysch succession (Stanley, [Jackfork], Johns Valley, Atoka) in the Ouachita Mountains of Arkansas and Oklahoma. Deposited primarily by turbidity current and hemipelagic processes in bathyal and abyssal water depths, these strata form major submarine fan complexes that prograded in a westerly direction along the axis of an elongate remnant ocean basin that was associated with the collision and suturing of the North American and African plates.

A longitudinal fan system is visualized as the depositional framework for these strata which were deposited in a setting [analogous] to the modern Bengal fan of the Indian Ocean. Facies analysis of the Jackfork Sandstone indicates that inner fan deposits are present in the vicinity of Little Rock, Arkansas; middle fan distributary channel and crevasse splay deposits occur at DeGray Dam, Arkansas; and outer fan depositional lobe deposits are present in southeastern Oklahoma. Basin plain equivalents are postulated to exist as far away as the Marathon region in west Texas.

Boulder-bearing units (olistostromes) with exotic clasts were shed laterally into the Ouachita basin, primarily from its northern margin. These olistostromes occur throughout the fan succession in all facies (i.e., inner, middle, and outer fan). This relationship may serve as a useful criterion for recognizing similar fan systems in the rock record. [517]

Paleoenvironments of Lower Cretaceous DeQueen Formation of Southwestern Arkansas

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The Lower Cretaceous DeQueen Formation crops out in a narrow sinuous band extending east-west from Pike County, Arkansas, to near Broken Bow, Oklahoma. Natural exposures are poor, but quarrying has exposed excellent vertical sections of the formation about 75 ft (23 m) thick at several localities. The DeQueen is composed of a lower sulfate facies and an upper sandstone-limestone-shale facies. The lower facies which is correlated with the subsurface Ferry Lake Anhydrite, is about 40 ft (12 m) thick. It is 60% gypsum and 40% dark shale, with minor interbedded mudstones. The upper facies, which is also about 40 ft (12 m) thick, is unconformably overlain by Upper Cretaceous clastic sediments. The upper facies is predominantly shale, with interbedded thin beds of sandstone, sandy limestone, and celestite. This facies is equivalent to the lowermost beds of the Mooringsport Formation of the subsurface.

The environments of deposition of units within the lower sulfate facies have been interpreted from a sparse faunal assemblage, sedimentary structures, and trace fossils. However, the most intensive study has been concerned with the more richly fossiliferous beds of the upper facies of the DeQueen. Present in this unit are well-preserved pseudomorphs of displacive halite hoppers, calcite pseudomorphs after gypsum, and preserved intrastratal gypsum nodules. Oscillation ripples, current ripples, and a variety of trace fossils are very common in these beds also. Body fossil assemblages range from a less diverse restricted pelecypod-ostracod assemblage to a more diverse gastropod-pelecypod-ostracod-serpulid worm assemblage. Marine and terrestrial vertebrates are also common in these upper beds.

All of the above information has been incorporated with subsurface data in order to reconstruct the local and regional depositional framework of the DeQueen and its subsurface equivalents. A better understanding of the depositional environment of these rocks will promote interest in, and may lead to the development of, undiscovered hydrocarbon reserves within less-well-known downdip areas. [535]

Flexure of Anadarko Basin

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The Anadarko basin in Oklahoma has long been a major oil and gas producing region and contains the deepest wells drilled in North America. The region has had a long sedimentary-tectonic history reaching back to the Proterozoic and was the site of an early Paleozoic basin. The present shape of the Anadarko basin, however, was developed in late Paleozoic times as a result of the uplift of the Wichita Mountains. COCORP seismic reflection profiles show at least 8 to 9 km (5 to 5.6 mi) of overthrusting northward, and the Anadarko basin was developed as a result of flexural bending of the lithosphere due to this shortening. Downwarping of the basin can be observed to extend for over 300 km (185 mi) northward, indicating a high flexural rigidity (Te> 40 km [25 mi]). However, nearer the Wichita front, the basin steepens rapidly as the post-Mississippian sediments thicken to over 20,000 ft (6,100 m). The shape of the bending is such that it cannot be explained by the use of a constant rigidity elastic plate model. We have modeled the post-Mississippian development of the Anadarko basin as the result of flexure of an elastic-plastic plate due to vertical and horizontal loading caused by the Wichita Mountains. Implications of these results for the development of the Anadarko basin and the mechanical properties of continental lithosphere will be discussed. [552]

Carbonate-Dominated Shelf Cycles in Late Pennsylvanian of Mid-Continent: Intrabasinal and Extrabasinal Controls on Sedimentation and Early Diagenesis

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The Upper Pennsylvanian (Missourian) Lansing–Kansas City Groups in the subsurface of western Kansas consist of a dozen cyclothems of carbonate and terrigenous clastics deposited on a platform that was gently tilted southward toward the more rapidly subsiding Anadarko basin. Maps of the study area covering western Kansas, derived from several thousand well logs and over 30 cores, describe four cyclothems in the Kansas City Group. Regressive carbonates developed in each of these cyclothems are major petroleum reservoirs in this region and are the focus of this examination.

The regressive carbonates thicken southward (basinward) at rates controlled by the tilt of the platform. Local and subregional variations in thickness and facies distribution are affected by local differential subsidence on the shelf, particularly along broad positive areas that closely correspond with previously active uplifts. Relatively thin carbonates having restricted shallow-marine facies are abundant over these positive areas. Subtle flexures along the shelf, especially where the slope increased basinward, were loci for ooid shoal development caused by wave and current action during shallow-water deposition.

Facies patterns interpreted from core and log-derived mapping demonstrate that neither the flexures nor the broader positive areas of the shelf were consistently active throughout the deposition of all four cycles studied. Hence, despite remarkable similarities, there are distinct variations between the cycles. Furthermore, not all cycles cover the study area to the same extent because (1) in some cycles, regressive carbonates pinch out along the northern (landward) shelf; (2) shallow restricted marine facies can be displaced southward; (3) the marine black shale, the deepest water phase of the cycle, can be missing or only poorly developed; and (4) intense local variations can occur in the early meteoric freshwater diagenesis that affects all cycles over much of the shelf.

Terrigenous clastics in the cycles are composed of thin layers of silty shale and claystone that prograded southward over much of the northern half of Kansas during the regressive phase of each cycle. Clastics from the Ouachitas, important components in cycles in eastern Oklahoma and southeast Kansas, never reached western Kansas until the Virgilian because these sediments were trapped by a relatively deep basin in western and central Oklahoma.

Extensive and prolonged subaerial weathering and associated freshwater diagenesis, marked and sharp vertical changes in the lithofacies, and broad repetitive facies patterns in relatively thin carbonates and shales can be explained by glacial eustatic changes in sea level. The Gondwana glacially influenced eustatic sea level changes had a periodicity and magnitude comparable to those of the Pleistocene. Variations in thickness, carbonate facies patterns, and diagenesis were also strongly influenced by second-order intrabasinal processes, including differential subsidence over positive areas and along breaks in slope. [567]

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Early and Middle Paleozoic History of the Anadarko Basin

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The Anadarko Basin is a sedimentary–structural basin with sediments dipping and thickening southward to the Wichita Uplift. The Wichita Fault Zone has a stratigraphic throw of some 6 miles, and no post–Early Ordovician to pre–Late Pennsylvanian sediments are presently known from the uplift although such strata are present in the Wichita Fault Zone north of the Meers Fault. Blocks of Hunton–Woodford strata within the fault zone show evidence of late Paleozoic erosion, suggesting that the Wichita Fault System was quiescent during early and middle Paleozoic time, with movement starting after Woodford deposition, probably in Late Mississippian–Early Pennsylvanian time. The lithofacies–lithostratigraphic characteristics of Ordovician through Devonian strata in the basin are similar to those in the Arbuckle Mountains except for an increase in thickness, indicating that the environment of deposition was reasonably constant over the entire region. The paleoenvironmental pattern and regional distribution of these strata point to deposition in a widespread, generally shallow seaway which inundated the present Wichita Uplift. The depocenter of the basin during this time is inferred to have been in the position of the present Wichita Uplift. Hunton and older strata were affected by at least two major periods of erosion, one in the Early Devonian (pre-Frisco, pre-Sallisaw) and a second in the Middle and Late Devonian (pre-Woodford). Both uplifts were concentrated on the margins of the basin, and both represent broad upwarpings accompanied by little or no faulting or lateral compression. The structural grain of the Anadarko complex probably developed in Precambrian time and is apparent in these middle Paleozoic periods of uplift.