OKLAHOMA GEOLOGY

Vol. 56, No. 6
December 1996

Oklahoma Geological Survey

On The Cover —

Oklahoma's Ice Age

"Oklahoma's Ice Age" is the topic of the Oklahoma Geological Survey's 1997 Geocalendar. The scene on the cover portrays Paleoindian hunters attempting to bring down one of Oklahoma's most majestic residents during the Great Ice Age—the Columbian mammoth.

The Great Ice Age occurred during the Pleistocene Epoch, which lasted from about 1.65 million years ago until about 10,000 years ago. Cycles in which great ice sheets covered as much as a third of the Earth's surface characterized this episode in geologic history. In North America, the last great ice sheet covered virtually all of Canada and much of the northern United States, beginning to wane only about 11,000 to 12,000 years ago.

Although the ice sheets did not reach as far south as the area we now know as Oklahoma, the climate, vegetation, and animal life of the region would have been quite different. Average summer temperatures were 5°–10° Fahrenheit cooler, and the climate was more moist. In the western and central part of the state, lush prairie grasslands intermingled with woodlands, while forests grew in the east. Roaming the land were mammoths, as well as other large mammals such as cheetahs, lions, saber-tooth cats, horses, camels, llamas, and mastodons.

As the last great continental ice sheet was melting, the first human inhabitants of North America entered what is now Oklahoma. Clues recovered from ancient sediments at sites in Oklahoma such as Domebo, in Caddo County, and Cooperton, in Kiowa County, indicate that these early inhabitants hunted mammoths here.

For more details on Oklahoma Geocalendar 1997, see p. 247, this issue.

Painting by Karen Carr
Natural History Artist
North Manchester, Indiana

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, abstracts, notices of new publications, and announcements of general pertinence to Oklahoma geology. Single copies, $1.50; yearly subscription, $6. Send subscription orders to the Survey at 100 E. Boyd, Room N-131, Norman, OK 73019. Short articles on aspects of Oklahoma geology are welcome from contributors; general guidelines will be sent on request.

This publication, printed by the Oklahoma Geological Survey, 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. 1,500 copies have been prepared for distribution at a cost of $1,030 to the taxpayers of the State of Oklahoma. Copies have been deposited with the Publications Clearinghouse of the Oklahoma Department of Libraries.

OKLAHOMA GEOLOGY

Notes

C O N T E N T S

VOL. 56, NO. 6
DECEMBER 1996

Oklahoma Natural Gas: The Need for More Effective Marketing of a Valuable State Resource

Charles J. Mankin[1]

In the search for expanded industrial and commercial business, Oklahoma proudly portrays its assets: quality labor force, lower cost of living, low tax rate, high quality of life, and good tax incentives. Commonly overlooked in this process, agricultural raw materials and natural gas are two assets that could give our State a competitive advantage in the quest for additional industrial and commercial business. For the most part, these two important components of Oklahoma's economy are exported to other states, where these resources are used in the creation of products. For example, wheat and natural gas are shipped to Michigan, where cereal is produced. Thus, Oklahoma's resources, obtained at minimal value, generate employment and value-added income for Michigan's economy. While the production of cereal in Oklahoma may not be the answer, the question of how to use Oklahoma's resources within the State should be given priority consideration.

It has been said that agriculture and the petroleum industry "brought Oklahoma to the dance" at statehood, a time when the petroleum industry was the largest segment of Oklahoma's economy. Today, the petroleum industry, with annual gross revenues in excess of $5 billion, continues to be a major segment of the State's economy.

In recent years, natural gas has become the major source of Oklahoma's petroleum income, overtaking crude oil, which was the primary revenue generator throughout much of the State's history. Natural gas is expected to remain the larger source of petroleum activity and revenue in Oklahoma for the near future. Nevertheless, crude oil will continue to be a significant segment of the State's economy, and its importance will increase with the projected recovery of world crude oil prices.

Today, natural gas is one of our nation's most important natural resources. Its development has been an important factor in the State's economy for many years, as well as a major contributor to the tax base. From 1947 (when statewide collection of natural gas production data was initiated) through 1995, more than 69 trillion cubic feet of natural gas was marketed (Fig. 1). Annual production increased from 420 billion cubic feet in 1947 to 2.26 trillion cubic feet in 1990 (Fig. 2). Since 1990, production has declined because market prices for natural gas have been below replacement cost, and exploratory drilling has been virtually nonexistent for the past several years. Natural gas production for 1995 was 1.77 trillion cubic feet, and it is expected to be about 1.6 trillion cubic feet in 1996.

The contribution of natural gas to Oklahoma's economy is shown in Figure 3. Production peaked in value in 1982 at $5.34 billion. While both production and value have declined for the past few years, the value of natural gas produced in 1995 was more than $2.55 billion; the estimated value for 1996 is $3.35 billion, even though production is expected to decline by about 100 billion cubic feet.

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[1]Director, Oklahoma Geological Survey.

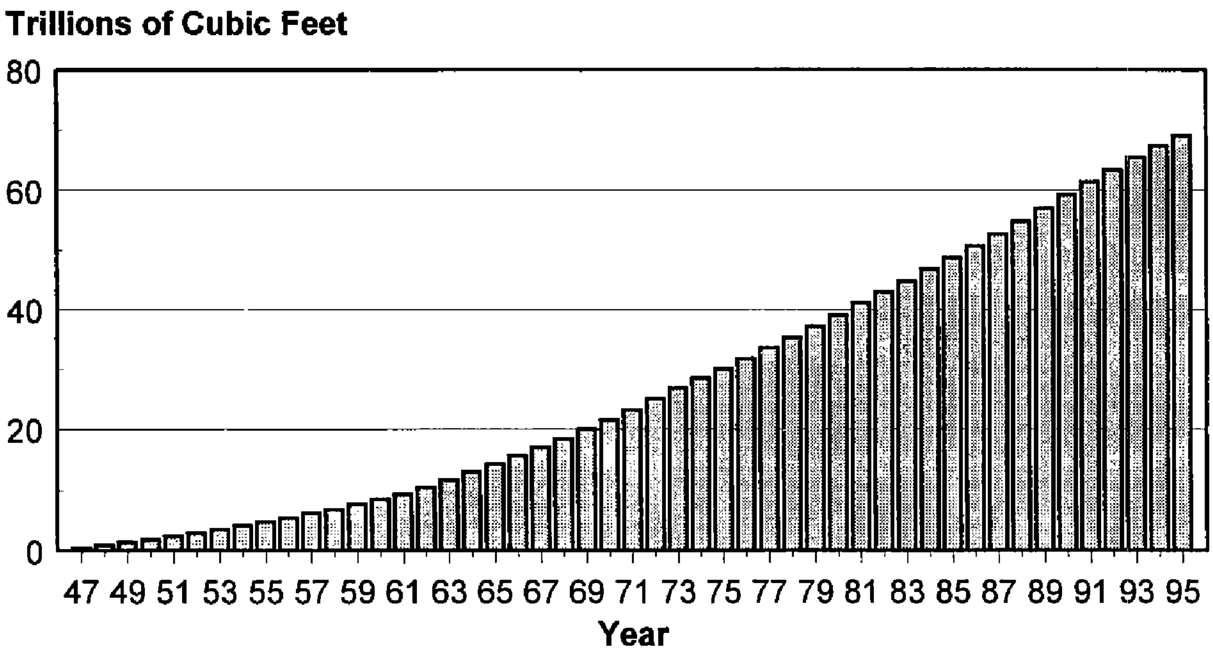

Figure 1. Cumulative natural gas production in Oklahoma from 1947 through 1995. (Unpublished data from the Oklahoma Tax Commission.)

Oklahoma's production compares favorably with that of other natural gas producing states. In fact, when the Federal Outer Continental Shelf gas is removed from the totals for Texas and Louisiana, Oklahoma's production ranks second among natural gas producing states (Fig. 4). However, unless the current production decline is reversed soon, Oklahoma will fall to third or fourth place because both Louisiana and New Mexico are increasing in-state production.

Oklahoma's decline in production is reflected in the graph depicting the State's share of the U.S. market (Fig. 5). From 1958 to 1990, Oklahoma's market share of U.S. natural gas sales increased from 6.5% to more than 12%. During the past few years, Oklahoma's market share has declined rapidly, because of the State's declining production as well as increased imports of natural gas from Canada.

In most areas of natural gas activities, Oklahoma compares favorably with other states. That is not the case, however, in the intrastate consumption of natural gas. While Louisiana consumes 112% of its in-state production and Texas uses 77%, Oklahoma consumes only 30% of the natural gas produced in the State (Fig. 6). In fact, although Texas produces more than twice as much natural gas as does Oklahoma, the volume of gas each state sends to the interstate market is virtually identical. Figure 6 shows that Oklahoma is more comparable to New Mexico and Wyoming in its in-state natural gas market than it is to the other major producing states. It should be noted that New Mexico and Wyoming, Public-Land states, have small populations, whereas the other major producing states have population densities comparable to that of Oklahoma.

Unfortunately, in-state consumption of natural gas in Oklahoma is decreasing. Figure 7 depicts the percentage of in-state consumption with respect to total production. Note that the in-state consumption ranges from a high of 45% in 1979 to a low of 26% in 1991. The apparent increase after 1991 is in fact a reflection of declining production rather than an actual increase in in-state consumption.

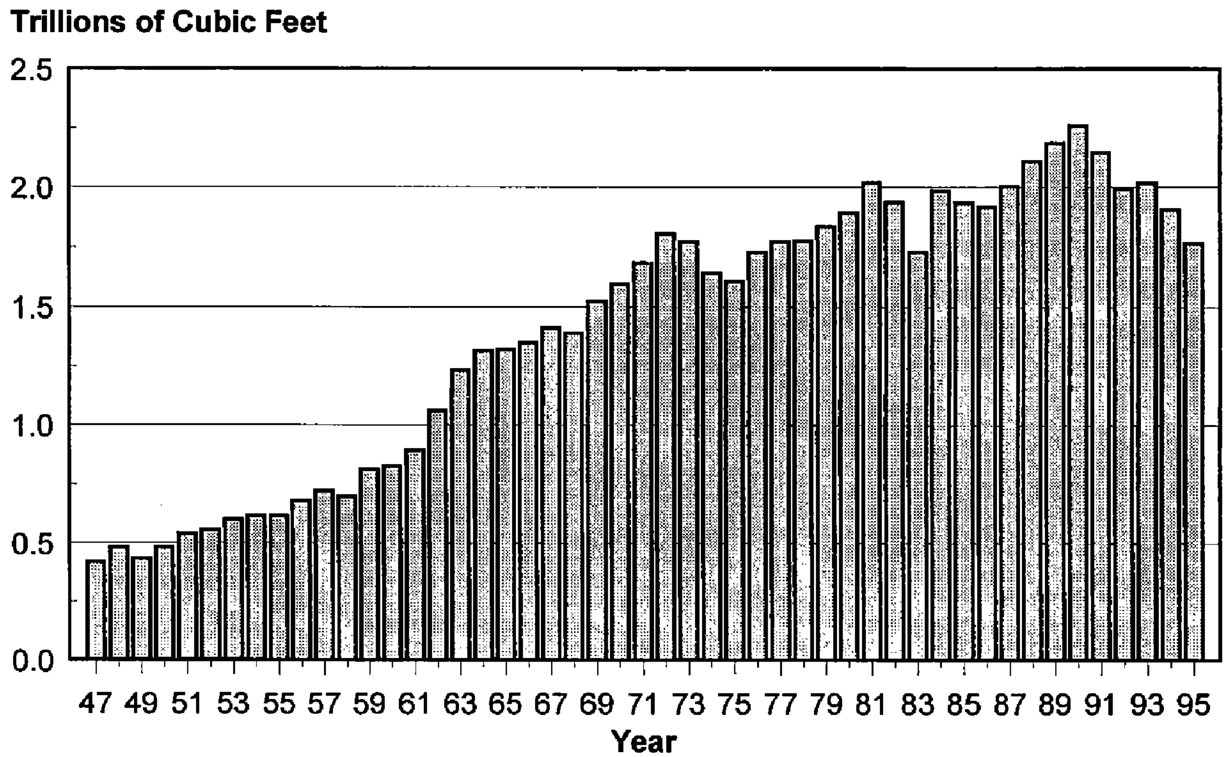

Figure 2. Annual production of natural gas in Oklahoma. (Unpublished data from the Oklahoma Tax Commission.)

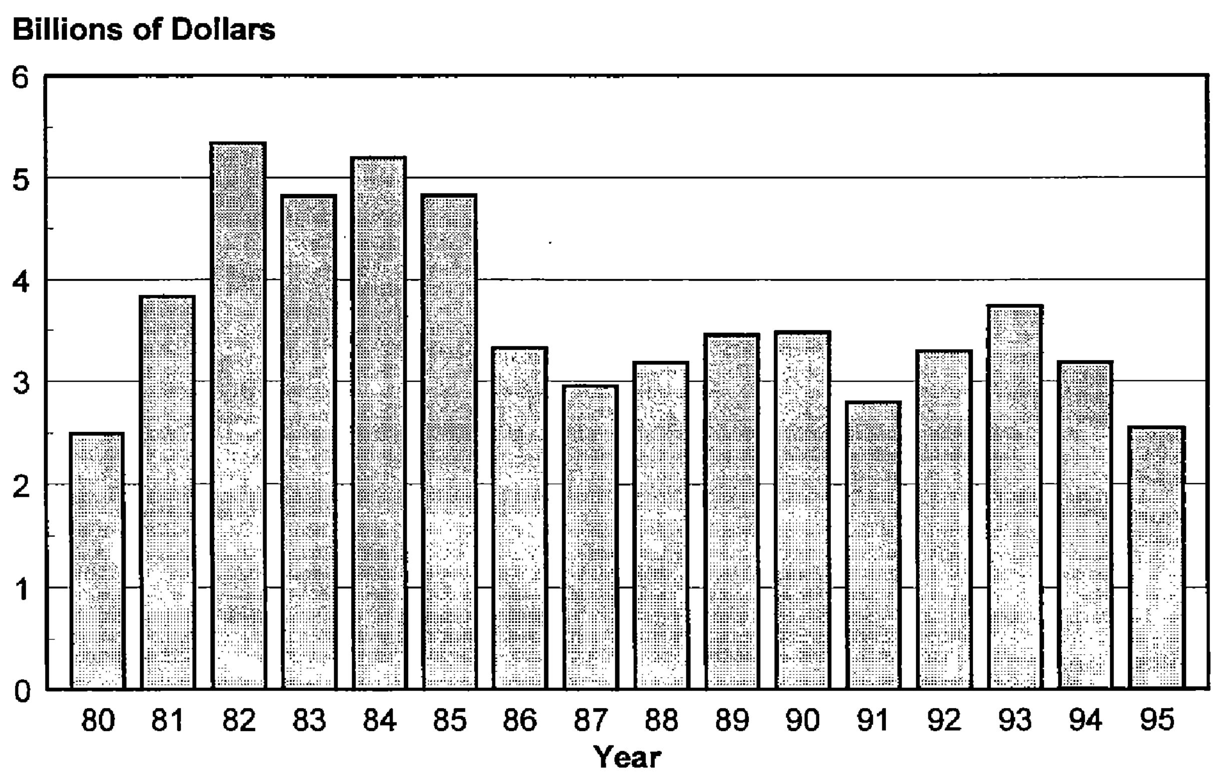

Figure 3. Annual value of natural gas produced in Oklahoma from 1980 through 1995. (Unpublished data from the Oklahoma Tax Commission.)

An examination of where natural gas is used in Oklahoma will help to focus on both the problem and the opportunity. Figure 8 shows the usage of natural gas in Oklahoma from 1980 through 1994. Data on consumption for 1995 are not yet available, but are expected to be comparable to those of 1994. The usage is separated into four categories: residential, commercial, industrial, and electric utilities. Note that for the 15-year period, usage in the residential, commercial, and industrial categories has remained relatively constant. The decline has been in electric utilities. The relatively constant usage in the industrial sector (primarily in the production of chemical fertilizer) indicates that either little has been done to attract industries that use natural gas, or such efforts have been unsuccessful. Nevertheless, the opportunity to use natural gas as an asset in recruiting new industries to the State, or in creating such industries internally, still exists and should be pursued.

The issue of in-state consumption of natural gas is more important to Oklahoma than to perhaps any other major natural gas producing state for a number of reasons:

- One-fourth of Oklahoma's natural gas production is from the 10 largest operators.
- An additional one-fourth is from the next 30 largest operators.
- The remaining one-half of the production is from more than 3,000 smaller operators.
- One-half of Oklahoma's natural gas production is from leases that produce less than 600,000 cubic feet per day.
- 25% of the production is from leases that produce less than 300,000 cubic feet per day.

Thus, Oklahoma's natural gas industry can be characterized as two groups: (1) a few larger operators who produce about one-half of the State's natural gas; (2)

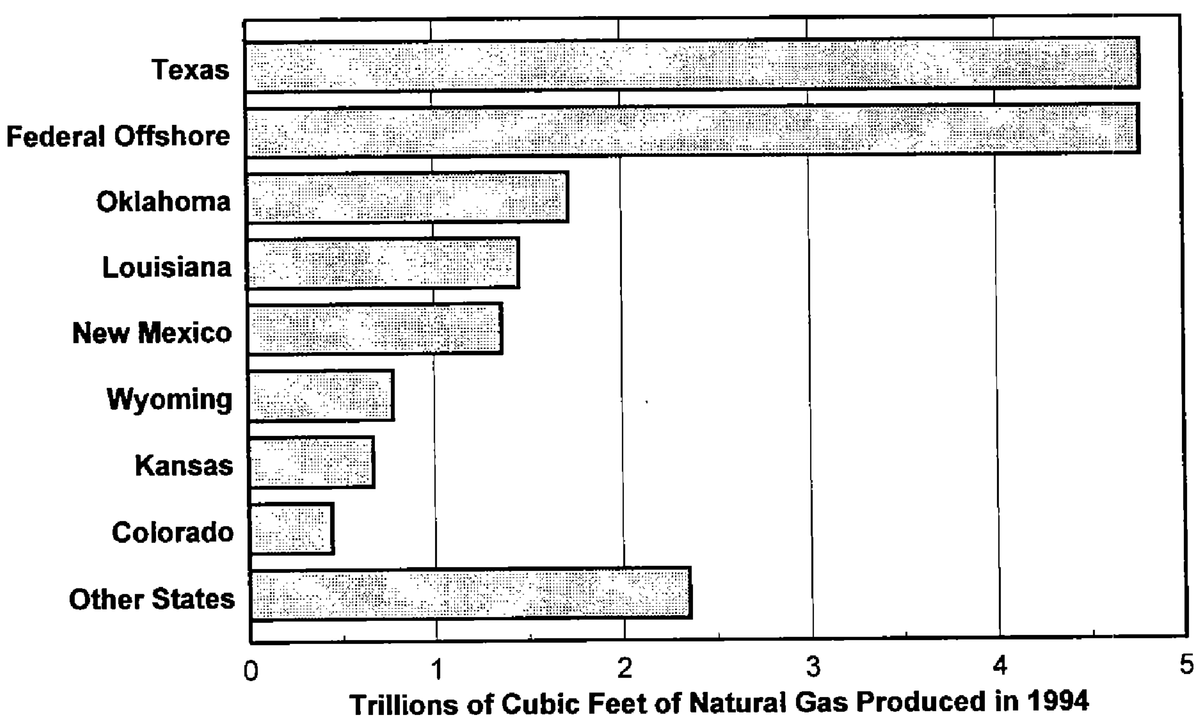

Figure 4. Production of natural gas by state and the Federal Outer Continental Shelf for 1994. (Data from the U.S. Department of Energy, 1995a, compiled by the Oklahoma Geological Survey.)

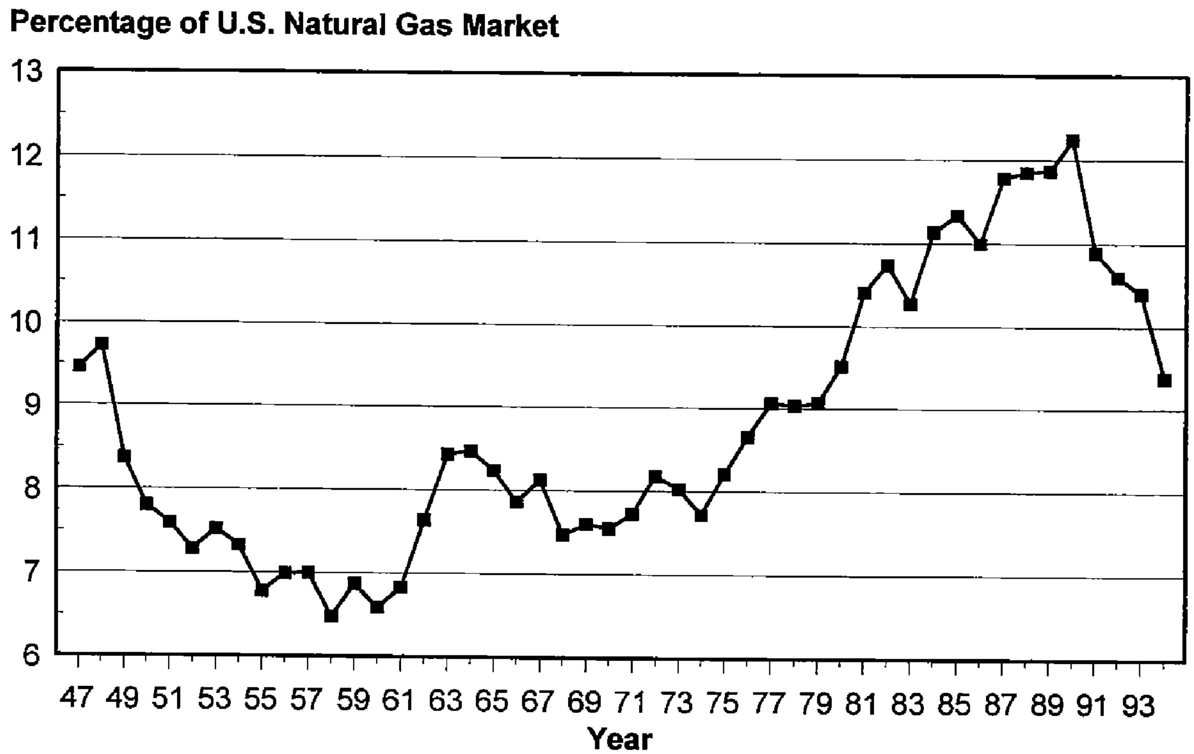

Figure 5. Oklahoma's percentage of the U.S. natural gas market by year from 1947 through 1994. (Data from the U.S. Department of Energy, 1995b, compiled by the Oklahoma Geological Survey.)

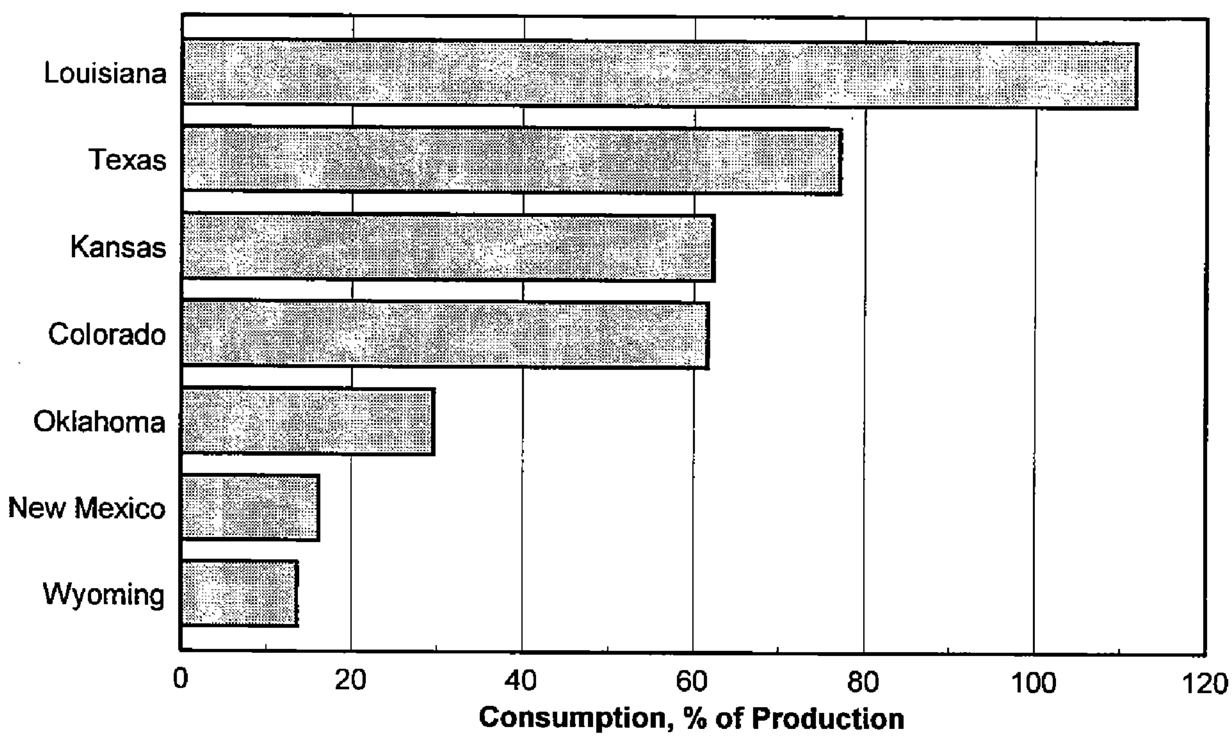

Figure 6. In-state consumption as a percentage of production of natural gas for the major producing states for 1994. (Data from the U.S. Department of Energy, 1995a,b, compiled by the Oklahoma Geological Survey.)

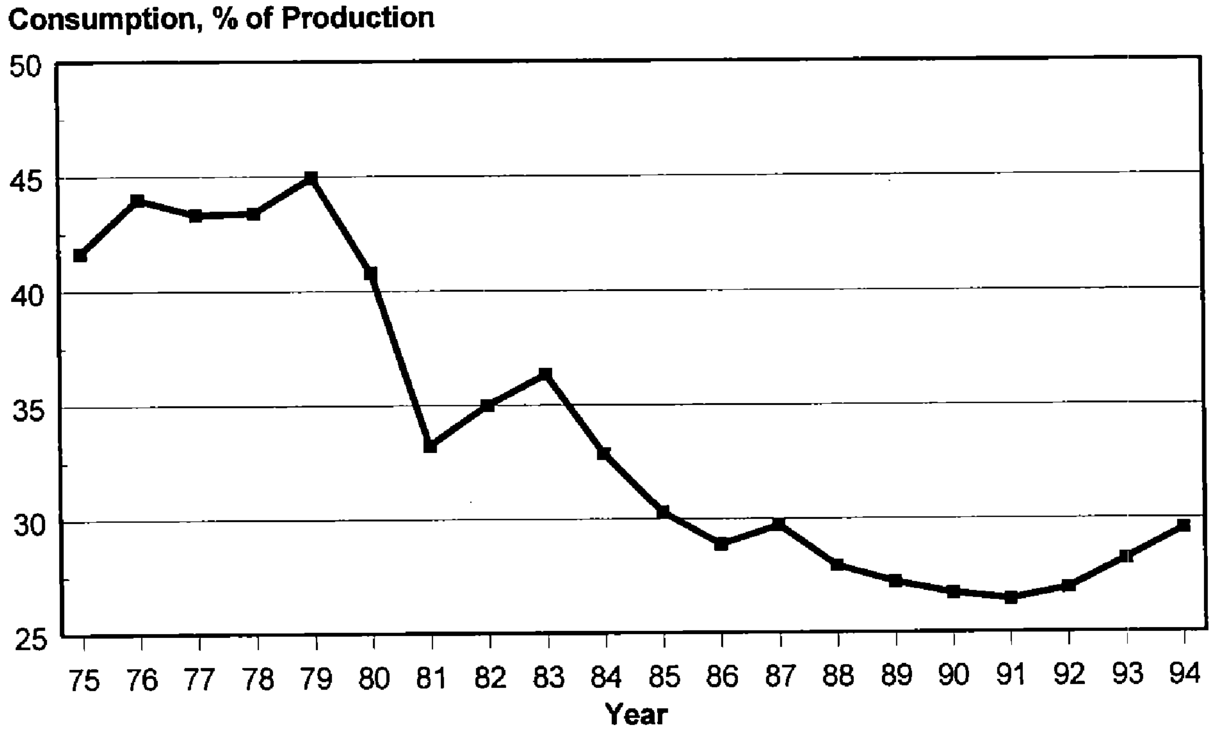

Figure 7. In-state consumption as a percentage of production of natural gas for Oklahoma by year from 1975 through 1994. The apparent increase after 1991 is in fact a reflection of declining production. (Data from the U.S. Department of Energy, 1995b, compiled by the Oklahoma Geological Survey.)

many smaller operators who produce small volumes of natural gas that make up the remaining one-half of the State's production.

Most of the small operators have neither the volume of natural gas nor the marketing staff to compete for large contracts that have relatively constant demands throughout the year and, commonly, also have higher prices to justify the committed supply. Because most of Oklahoma's gas is sold in the interstate market, these small operators have to compete with larger producers that have larger supplies. Many of these larger producers are located offshore in the Gulf of Mexico and thus serve the same markets as Oklahoma operators. Canadian natural gas producers also serve much of the same upper Midwest market as Oklahoma natural gas producers. The limited marketing capability and small production volumes of smaller operators leads to a disproportionate use of their natural gas to fill local storage in the summer (when prices commonly are lower) and to make-up gas in larger operators' contracts during the remainder of the year. In both instances, smaller operators with their smaller volumes of natural gas are at a competitive disadvantage in the interstate market.

Thus, it is in the smaller operators' interest to increase the usage of Oklahoma's natural gas within the State. For several reasons, they would have a competitive advantage over out-of-state suppliers:

- The in-state operator knows, or has the ability to know, the local market better. The same issue that works against small operators in out-of-state sales works to their advantage in state.

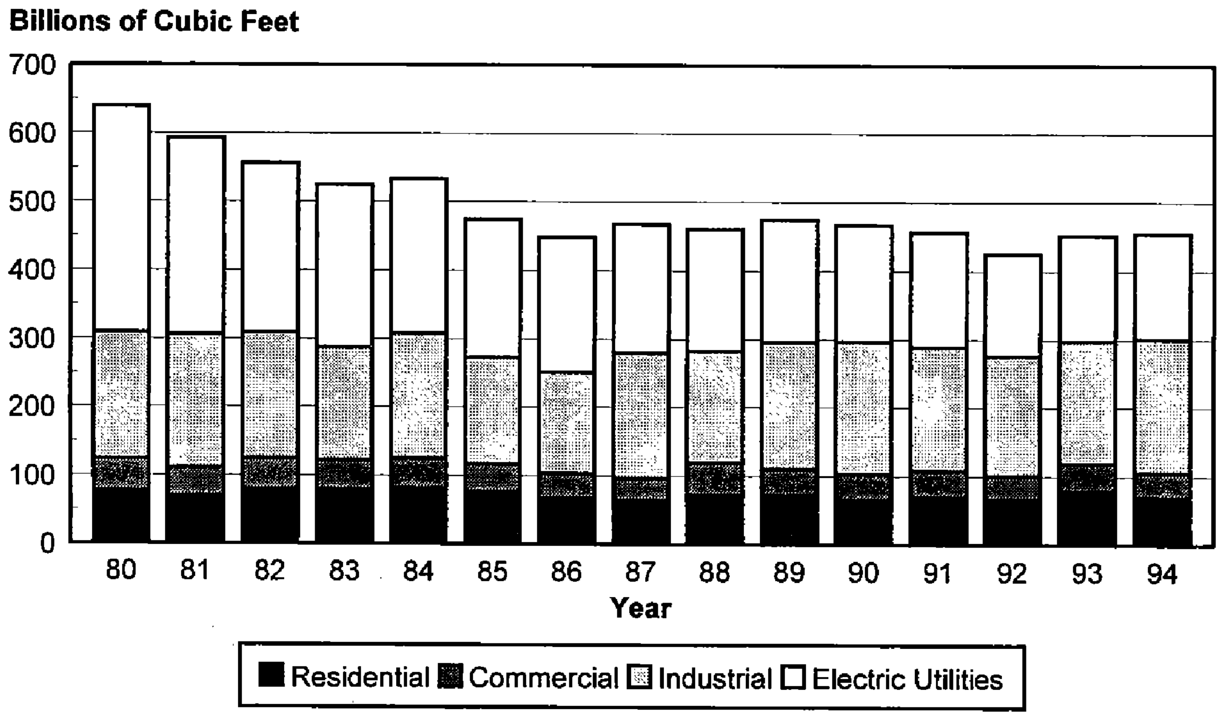

Figure 8. In-state usage of Oklahoma natural gas by category and year from 1980 through 1994. (Data from the U.S. Department of Energy, 1995b.)

- In-state operators can make the argument that they are in a position to dedicate their gas to that market, whereas a larger out-of-state producer will sell to the best market nationwide. The smaller operator does not have that option.
- Transportation costs should be less because distances are shorter.

Increased in-state usage of Oklahoma natural gas also would benefit the State, because industrial employment would increase and revenue from gross-production taxes would increase. Revenue from gross-production taxes would be higher because the net price after deducting the transportation cost is less, thus making the sale price for the gas effectively higher. (The gross production tax is based upon the first-sale price.) Therefore, increased usage of Oklahoma's natural gas within the State would be a winning situation for all concerned.

References Cited

U.S. Department of Energy, 1991, Natural gas annual 1990, volume 1: Energy Information Administration, Washington, D.C., 253 p.

______ 1995a, U.S. crude oil, natural gas, and natural gas liquids reserves; 1994 annual report: Energy Information Administration, Washington, D.C., 153 p.

______ 1995b, Natural gas annual 1994: Energy Information Administration, Washington, D.C., 249 p.

NEW OGS *Publication*

OKLAHOMA GEOCALENDAR 1997. ***Oklahoma's Ice Age.***
Price: $4 for calendar and 8-page booklet, rolled in tube.

Two tusks were recovered at the Allison-Menifee mammoth excavation site, northwestern Oklahoma City, in 1984. *Photo from booklet accompanying Oklahoma Geocalendar 1997; courtesy Oklahoma Archeological Survey.*

The second in the Geocalendar series, this 1997 poster-style calendar features Karen Carr's dramatic painting of an encounter between prehistoric hunters and a Columbian mammoth *(Mammuthus columbi)* during the Pleistocene Epoch, often called the "Great Ice Age" (see front cover, this issue). Two sites in Oklahoma, the Domebo site in Caddo County and the Cooperton site in Kiowa County, provide evidence that mammoths were hunted by Paleoindians, who were the earliest people known to have occupied North America. The calendar measures 20″ × 30″ and is accompanied by a full-color 8-page booklet that contains information on mammoths and the Great Ice Age and its effect on the area we now know as Oklahoma. (Booklets also can be purchased separately for $1 each.) Authors are Nicholas J. Czaplewski, staff curator at the Oklahoma Museum of Natural History; Don G. Wyckoff, associate curator of archeology at the Oklahoma Museum of Natural History; and Kenneth S. Johnson, OGS associate director.

SPECIAL NOTE: Now available at a discounted price of $2 are copies of the popular "Oklahoma Dinosaur Days—*Acrocanthosaurus atokensis*" (1996 Geocalendar and booklet), spotlighting an enormous carnivorous dinosaur that terrorized the Oklahoma area during the Early Cretaceous (140 million to 100 million years ago). OGS Geocalendars are designed to make great posters at year's end.

Geocalendar 1997 and Geocalendar 1996 can be purchased by mail from the Survey at 100 E. Boyd, Room N-131, Norman, OK 73019; fax 405-325-7069. Add 20% to the cost for mail orders. A special 20% volume discount applies for orders of 25 or more calendars or booklets.

All OGS publications can be purchased over the counter at the OGS Publication Sales Office's new location at 1218-B W. Rock Creek Road, Norman; phone (405) 360-2886; fax 405-366-2882. Parking is free and readily available.

Marine Clastics — A Workshop
Norman, Oklahoma, March 25–26, 1997

"Marine Clastics in the Southern Midcontinent" is the theme of a two-day workshop cosponsored by the Oklahoma Geological Survey and the Bartlesville Project Office of the U.S. Department of Energy. The workshop will be held at the Postal Service Technical Training Center (PSTTC) in the southeastern part of Norman.

This is the 10th annual workshop designed to transfer technical information that will aid in the search for, and production of, our oil and gas resources. Marine clastics include those units deposited in shallow or deep sea water: environments include delta front, barrier island, offshore bar, continental shelf and slope, submarine fan, and transgressive sands. Such clastics are major reservoirs that already have yielded large volumes of oil and gas, and they have great potential for yielding additional hydrocarbons through the use of improved exploration and development techniques.

The preliminary program for talks and posters is listed below:

Oral Presentations

Petroleum Production from Marine Clastics in Oklahoma, by Kenneth S. Johnson, Robert A. Northcutt, and G. Carlyle Hinshaw

Depositional Environments of Marine Sands in Oklahoma, by Richard D. Fritz

Marine Facies in the Upper Cambrian Reagan Sandstone in the Slick Hills, Southwestern Oklahoma, by R. Nowell Donovan

Facies, Petrography, and Reservoir Properties of McKee Sands of the Simpson Group, Ware-McKee Field, Texas, by Jim Mazzullo and Michael Bosco

McLish Formation: Influence of "Ames Crater" on Reservoir Lithofacies and Petrophysical Characteristics?, by Michael D. Kuykendall

Reservoir Development and Production from the Clifty-Sylamore Interval (Devonian), Shallow Gas Province, Northwestern Arkansas, by Walter L. Manger and Phillip Shelby

Sequence Stratigraphy of the Jackfork Sandstone in the Ouachita Mountains and Applications to Petroleum Exploration, by Richard D. Fritz and Michael D. Kuykendall

Turbidite Elements in the Jackfork Formation of South-Central Arkansas, with Applications to Jackfork Exploration and Development in Eastern Oklahoma, by Roger M. Slatt and Charles G. Stone

Upper Jackfork Slope, Shelf, and Deltaic Deposits, Highway US-259, Southeastern Oklahoma, by Rodrick W. Tillman

Effects of Depth on Reservoir Characteristics in Morrow and Springer Well Completions in the Anadarko Basin, by Paul W. Smith, Walter J. Hendrickson, Craig M. Williams, and Ronald J. Woods

Effects of Depth on Gas Well Recovery in Marine Sandstones in the Anadarko Basin, by Tom Woods and Paul W. Smith

Submarine Fan Complexes: Red Fork Sandstone, Anadarko Basin, by Zuhair Al-Shaieb, J. Puckette, and Eric Anderson

Palinspastic Restoration of the Choctaw, Pine Mountain, and Ti Valley Overthrust Plates with Constraints on Spiro Paleogeography and Sequence Analysis, by Mark R. Longden, Daniel J. Patterson, and Steven S. Demecs

Evidence for a Spiro-Equivalent Lowstand Fan in the Ouachita Overthrust Belt—A New Exploratory Target in Southeast Oklahoma, by Mark R. Longden, Daniel J. Patterson, and Steven S. Demecs

Sequence Stratigraphy Systems Tracts in the Spiro Sandstone of Eastern Oklahoma, by Arthur W. Cleaves

Diagenesis and Porosity Evolution of the Spiro Sandstone in the South Haleyville and South Hartshorne Fields, Pittsburg County, Oklahoma, by James M. Forgotson, Jr., Huaibo Liu, Harvey Blatt, and W. Phillip Schreiner

Chamosite: A Key Mineral for Interpretation of the Depositional Environment of the Spiro Sandstone, by Zuhair Al-Shaieb

Depositional Systems and Diagenetic History of the Middle Atoka Succession in the Arkoma Basin, by T. A. (Mac) McGilvery and D. W. Houseknecht

Facies and Reservoir Petrophysics of the Hartshorne Sandstone, by Jim Mazzullo

Geochemical Trends in Midcontinent Pennsylvanian Shales: Cyclothem Models Revisited, by Anna M. Cruse and Timothy W. Lyons

Poster Presentations

Production Characteristics of Marine Morrow Clastics as Measures of Reservoir Characteristics, by Ted Dyman, James Schmoker, and John Quinn

Outcrop Analogs of Turbidite Petroleum Reservoirs for Assessing Volumetric, Development-Drilling, and Simulation Scenarios, Jackfork Formation, South-Central Arkansas, by Roger M. Slatt, P. Weimer, H. Al-Siyabi, and E. Williams

Diagenesis and Porosity Evolution of the Spiro Sandstone in the South Haleyville and South Hartshorne Fields, Pittsburg County, Oklahoma, by James M. Forgotson, Jr., Huaibo Liu, Harvey Blatt, and W. Phillip Schreiner

Trends in Production, Reservoir Characteristics, and Stratigraphic and Depositional Boundaries of the Clastic Facies of the Springer Group Within a Portion of the Anadarko Basin of Oklahoma, by Walter J. Hendrickson, Paul W. Smith, Craig M. Williams, and Ronald J. Woods

Microbial Reservoir Characterization of Mature Bartlesville Sandstone Reservoir, Washington County, Oklahoma, by Daniel Hitzman, James D. Tucker, and Brooks A. Rountree

Petroleum Production from Marine Clastics in Oklahoma, by Kenneth S. Johnson, Robert A. Northcutt, and G. Carlyle Hinshaw

Interpreting Formation Microscanner Log Images of Gulf of Mexico Pliocene Turbidites by Comparison with Pennsylvanian Turbidite Outcrops, Arkansas, by Roger M. Slatt, Douglas W. Jordan, and Robert J. Davis

Marine Facies Transitions in the Upper Cambrian Timbered Hills Group, Slick Hills, Southwestern Oklahoma, by Danielle Ayan, Andrea Bucheit, and R. Nowell Donovan

Depositional Environments of the Permian Childress Sandstone/Gypsum, Eastern Flank Permian Basin, Texas, by James O. Jones

An Expandable Alpha-Numeric Stratigraphic Classification System Indexed to Base-Level Depositional Time, by Ron Young

Clastics as Seismic Markers: Images and Imagings from the Mountain Front, Southwest Oklahoma: 1979–1996, by Roger A. Young, David Thomas, and Zhi-Ming Liu

Geology of the Brentwood Shallow Gas Field, Washington County, Arkansas, by Walter L. Manger and Phillip Shelby

Origin and Distribution of Porosity in a Carbonate-Cemented Reservoir, Hale Formation (Morrowan), Arkoma Basin of Arkansas, by Doy Zachry

Comparative Sedimentology of the Dutcher and Cromwell Sandstones—Implications for Exploration and Development, by Dorothy L. Swindler and J. Glenn Cole

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Registration Information

The fee for advance registration (prior to March 7) is $50, and includes two lunches and a copy of the proceedings. Late and on-site registration will be $70 per person. Lodging will be available at the PSTTC and local hotels/motels.

For more information, contact Kenneth S. Johnson, General Chair, Oklahoma Geological Survey, University of Oklahoma, 100 E. Boyd, Room N-131, Norman, OK 73019; phone (405) 325-3031 *or* (800) 330-3996; fax 405-325-7069. To request registration forms, contact Tammie Creel or Jan Coleman at the same location and numbers.

UPCOMING *Meetings*

Petroleum Technology-Transfer Council (PTTC), Problem-Identification Workshop, February 15, 1997, Smackover, Arkansas. Information: Michelle Summers, Oklahoma Geological Survey, 100 E. Boyd, Room N-131, Norman, OK 73019; (405) 325-3031 *or* (800) 330-3996, fax 405-325-7069.

Marine Clastics in the Southern Midcontinent Conference, March 25–26, 1997, Norman, Oklahoma. Information: Kenneth S. Johnson, Oklahoma Geological Survey, 100 E. Boyd, Room N-131, Norman, OK 73019; (405) 325-3031 *or* (800) 330-3996, fax 405-325-7069. (See p. 248, this issue, for further information.)

American Institute of Professional Geologists, Annual Meeting, April 18–19, 1997, Norman, Oklahoma. Information: Michelle Summers, Oklahoma Geological Survey, 100 E. Boyd, Room N-131, Norman, OK 73019; (405) 325-30311 *or* (800) 330-3996, fax 405-325-7069.

Extinctions in the Fossil Record, National Fossil Forum, April 18–20, 1997, Macomb, Illinois. Sponsored by Mid-America Paleontology Society and Western Illinois University, Dept. of Geology. Information: Tom Witherspoon, 6611 Miller Road, Dearborn, MI 48126; (313) 582-3139.

Geological Society of America Presidential Conference: "Ethics in the Geosciences," July 16–21, 1997, Welches, Oregon. *Must apply to participate; deadline is February 15, 1997.* Information: Richard Graunch, U.S. Geological Survey, M.S. 973, Denver Federal Center, P.O. Box 25046, Denver, CO 80225; (303) 236-5551, fax 303-236-3200; e-mail: rgraunch@helios.cr.usgs.gov.

Next FDD Workshop Features Red Fork Play

The Oklahoma Geological Survey will present a one-day workshop, "Fluvial-Dominated Deltaic (FDD) Oil Reservoirs in Oklahoma: The Red Fork Play," on March 5, 1997, at the U.S. Postal Service Technical Training Center in Norman, and on March 12 at the Phillips Petroleum Company Research and Development Center in Bartlesville.

The registration fee for operators in these plays is $15; for other attendees it is $25. (Note: The $15 fee is for only one representative from each company; additional registrants must pay $25.) The cost includes lunch and a copy of the play workbook, *Fluvial-Dominated Deltaic (FDD) Oil Reservoirs in Oklahoma: The Red Fork Play* (OGS Special Publication 97-1). Red Fork operators have priority status to attend if registered by February 20; after February 20, registration will be on an as-received basis for all attendees.

The workshop is the sixth in a series of eight to be presented as part of the Fluvial-Dominated Deltaic Oil Reservoirs project. The FDD project is sponsored by the Oklahoma Geological Survey, in cooperation with the University of Oklahoma's Geo Information Systems and the OU School of Petroleum and Geological Engineering.

For more details or for registration forms, contact Michelle Summers, Oklahoma Geological Survey, 100 E. Boyd, Room N-131, Norman, OK 73019; (405) 325-3031 or (800) 330-3996; fax 405-325-7069.

GSA SOUTH-CENTRAL AND ROCKY MOUNTAIN SECTIONS JOINT ANNUAL MEETING

El Paso, Texas March 20–21, 1997

The Department of Geological Sciences at the University of Texas at El Paso will host the annual meeting of the South-Central and Rocky Mountain Sections of the Geological Society of America. The meeting will be held on campus during spring break week.

The following agenda is planned:

Symposia

Pander Society Conodont Symposium
Precambrian Geology of the Western United States
Mesozoic Redbeds of Mexico
Rio Grande Rift: Its Geology and Geophysics
Environmental Geology and Hydrogeology of Intermontane Basins
Mesozoic Geologic History of the Southern United States and Mexico
Recent Advances in the Economic Geology of Mexico and Adjacent Areas
Using Multimedia in the Classroom
Geology and Public Policy: The Political Education of a Scientist
New Refinements of the Geochronology of Events in the Western U.S. and Mexico
Nuclear Waste Disposal in the Southwest
Cenozoic Paleontology of the American West

Short Course

Industrial Minerals and Their Markets

Field Trips

Lower Mississippian Waulsortian Mounds, Sacramento Mountains, New Mexico
Facies Architecture and Stratigraphic Evolution of the Great American Bank: The Lower Ordovician El Paso Group, Franklin Mountains, El Paso, Texas
Geochronology and Geochemistry of the Potrillo Volcanic Field, New Mexico
Stratal Architecture of Forestepping and Backstepping Shallow Marine Sequences: The Upper Cretaceous Gallup and Hosta Sandstones, San Juan Basin, New Mexico
Quaternary Landscape Evolution and Geoarchaeology of the El Paso–Las Cruces Region
Beginning of the Age of Dinosaurs

For further information about the meeting, contact Elizabeth Anthony, Dept. of Geological Sciences, University of Texas, El Paso, TX 79968; (915) 747-5483; fax 915-747-5073; e-mail: anthony@geo.utep.edu. *The preregistration deadline is February 7.*

THE GEOLOGICAL SOCIETY OF AMERICA 1888

Water Resources Data for Oklahoma, Water Year 1995

Records on both surface water and ground water in Oklahoma are contained in this two-volume annual report by R. L. Blazs, D. M. Walters, T. E. Coffey, D. K. White, D. L. Boyle, and J. F. Kerestes. The report consists of discharge records for 114 gaging stations; stage and contents for nine lakes or reservoirs and two gage-height stations; water quality for 47 gaging stations; 17 partial-record or miscellaneous streamflow stations and 28 ground-water sites. Also included are lists of discontinued surface-water discharge and water-quality sites. Data for the Arkansas River basin are given in volume 1 (424 pages), and data for the Red River basin are given in volume 2 (242 pages). The data in this report represent the part of the National Water Data System collected by the U.S. Geological Survey and cooperating State and federal agencies in Oklahoma.

Order Water-Data Report OK-95-1 from: U.S. Geological Survey, Water Resources Division, 202 N.W. 66th St., Bldg. 7, Oklahoma City, OK 73116; phone (405) 843-7570, fax 405-843-7712. A limited number of copies are available free of charge.

Estimated Flood Peak Discharges on Twin, Brock, and Lightning Creeks, Southwest Oklahoma City, Oklahoma, May 8, 1993

A flash flood that occurred in Oklahoma City on May 8, 1993, is considered one of the greatest flood disasters in the city's history. Southwestern Oklahoma City was hit hardest, especially along Twin, Brock, and Lightning Creeks, where four people were killed and more than 1,900 structures were damaged. The study described in this USGS water resources investigations report, by Robert L. Tortorelli, was conducted to determine the magnitude of the flood peak discharge in the three creeks and compare these peaks with published flood estimates. The 127-page report presents data that will provide city officials and consultants with a technical basis to make flood-plain management decisions and assist them in deciding future courses of action on the flood-prone areas.

Order WRI 96-4185 from: U.S. Geological Survey, Water Resources Division, 202 N.W. 66th St., Bldg. 7, Oklahoma City, OK 73116; phone (405) 843-7570, fax 405-843-7712. A limited number of copies are available free of charge.

USGS Miscellaneous Field Studies Map: Anadarko Basin

Prepared by M. E. Henry and T. C. Hester on three sheets, this map shows petroleum exploration intensity and production in major Cambrian to Ordovician reservoir rocks in the Anadarko basin. Area shown is latitude 35°–39°, longitude 98°–103°, and extends through Colorado, Kansas, Oklahoma, and Texas. Scale 1:1,713,400. Sheet 1 measures 57 × 41 in., sheet 2 is 57 × 38½ in., and sheet 3 is 49½ × 38½ in.

Order MF-2313 from: U.S. Geological Survey, Information Services, Box 25286, Denver Federal Center, Denver, CO 80225; for information, call 1-800-HELP-MAP. Cost is $4, plus $3.50 per order for handling.

The Oklahoma Geological Survey thanks the American Association of Petroleum Geologists and the Geological Society of America for permission to reprint the following abstracts of interest to Oklahoma geologists.

Application of Petroleum Exploration/Development Methods to an Environmental Remediation Project, Tinker Air Force Base, Oklahoma

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The North Tank Area (NTA) was designated as an operable unit of the Building 3001 NPL Site at Tinker AFB. A perched layer of the uppermost regulatory aquifer is contaminated with #2 fuel oil as free product.

An approach to remediation of the NTA has been conducted in a manner similar to that used follwing the initial discovery and ensuing development of a typical sandstone petroleum reservoir. The methods include exploration drilling, 3D geophysical modeling and interpretation, production/development drilling, and formation fracturing.

After drilling several monitoring (exploration) wells around the NTA, the extent of free product contamination could not be sufficiently defined to determine the placement of extraction (development) wells for removal of the free product. In order to further define the areal extent of the free product, a geophysical method using electromagnetic induction tomography was applied to generate three dimensional views (models) of high resistivity anomalies such as hydrocarbon.

Following geophysical data interpretation, three sets of wells were drilled in areas of the free product layer where optimum production could be anticipated. Each set of wells contained a fracture inducement well and a fluids recovery well. After drilling the fracture/recovery well sets, pneumatic fracturing techniques were employed to enhance the product yield of the aquifer. Air was injected into the formation at pressures of approximately 400 psi. Preliminary results of the project indicate enhanced yield of the aquifer.

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Investigation of Underpressurization Caused by Erosional Unloading at the Guymon Site, Oklahoma

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Deep-well injection of hazardous liquid wastes into underpressured reservoirs has been mentioned as a potentially safe means for waste disposal because of their tendency to contain fluids for a practically permanent time frame (Bradley, 1985). The Guymon reservoir in Texas County, Oklahoma, is underpressured and has been considered as a potential site for liquid waste disposal (Jiao and Zheng, 1995). The understanding of the mechanisms for the underpressurization phenomenon at the site is critical if this site is actually to be used as a safe repository for wastes. One of the possible mechanisms is the delayed adjustment of subsurface pore pressures to erosional modifica-

tions of the topographic relief (e.g., Neuzil and Pollock, 1983). This paper presents the preliminary findings of numerical investigation of the subnormal pressure due to uplift and erosion in the Guymon area.

The geological evidence shows that the Guymon area has been uplifted and eroded. The history and timing of the uplift and erosion are examined to estimate the approximate rate of erosion based on the regional stratigraphical and sedimentologic information. A finite-difference model is developed to simulate the change in fluid pressure in response to erosional unloading. The erosion rate and other hydrogeologic parameters are calibrated against the current distribution of subnormal pressure. The sensitivity of the subpressures to the erosion rate, formation hydraulic properities, and boundary conditions is analyzed to gain physical insight into the critical factors controlling the underpressurization caused by uplift and erosion. The findings presented in this paper provide valuable information for the feasibility study of using the Guymon reservoir for waste disposal and are instructive in understanding the mechanisms of the underpressurization in many similar reservoirs in the regional Hugoton-Panhandle field.

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Use of Artificial Neural Nets to Predict Permeability in Hugoton Field

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One of the most difficult tasks in petrophysics is establishing a quantitative relationship between core permeability and wireline logs. This is a tough problem in Hugoton Field, where a complicated mix of carbonates and clastics further obscure the correlation.

One can successfully model complex relationships such as permeability-to-logs using artificial neural networks. Mind and Vision, Inc.'s neural net software was used because of its orientation toward depth-related data (such as logs) and its ability to run on a variety of log analysis platforms. This type of neural net program allows the expert geologist to select a few (10–100) points of control to train the "brainstate" using logs as predicters and core permeability as "truth."

In Hugoton Field, the brainstate provides an estimate of permeability at each depth in 474 logged wells. These neural net-derived permeabilities are being used in reservoir characterization models for fluid saturations.

Other applications of this artificial neural network technique include deterministic relationships of logs to: core lithology, core porosity, pore type, and other wireline logs (e.g., predicting a sonic log from a density log).

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Incorporating Geologic and Data Uncertainties into Hugoton Field Pore Volume Estimates

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Estimating volumetric original gas in place (OGIP) for a large gas field is a process involving several uncertainties. In Hugoton Field, chief among these are uncertainties inherent in estimating porosity from well logs and in the spatial distribution of porosity. This paper will discuss the results of a reservoir characterization study to estimate a plausible range of pore volumes for Hugoton reflecting these uncertainties.

Hugoton Field is a mixed-lithology reservoir (limestones/dolomites and sandstones/siltstones) consisting of 5 main reservoir intervals with intervening non-reservoir zones. As a first step in the study, a 3-D geological framework was established using data from 420 wells in the field with modern wireline logs. Artificial neural networks (ANN) were used to estimate transform functions to calculate porosity from well logs. These functions were based on 15 wells in the field with core porosity data. Due to problems with log data such as thin beds, residual gas, etc., the log-derived vs. core porosity correlation was only about 70%, even with the ANN method.

Estimates of spatial continuity of porosity showed significant differences in spatial variation within the reservoir formations, whereas the non-reservoir formations showed no systematic variation. The Sequential Gaussian Co-simulation method was used to estimate the porosities in each formation by including both log-derived and core porosity values and specifying a 70% certainty factor for the log-derived porosity values.

The OGIP results from geostatistics were more realistic both in terms of the spatial distribution of gas volumes as well as the range of total OGIP. In addition, the geostatistical approach resulted in a range of pore volumes, thus quantifying the uncertainty in the calculations, unlike the deterministic approach which produced a single number.

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Surface Water Paleotemperatures and Chemical Compositions from Fluid Inclusions in Permian Nippewalla Group Halite

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Quantitative climatic data for the Permian have been determined from Nippewalla Group halite. The middle Permian Nippewalla Group of Kansas and Oklahoma consists of several hundred feet of bedded halite, anhydrite, and red beds. Study of core and surface samples suggest that this halite was deposited by ephemeral lakes. Fluid inclusions provide evidence for the geochemistry of these Permian saline lake waters, including temperatures, salinities, and chemical compositions.

Primary fluid inclusions are well-preserved in the Nippewalla halite. They are 5–30 μm cubic inclusions situated along chevron and cornet growth bands. Most are one phase aqueous inclusions, but some also contain anhydrite "accidental" crystals. Rare two phase liquid-vapor inclusions may have formed by subaqueous outgassing or trapping of air at the water surface.

Fluid inclusion freezing-melting behavior and leachate analyses suggest that Nippewalla halite precipitated from Na-Cl–rich waters with lesser quantities of SO_4, Mg, K, Al, and Si. This composition may be a product of long-term weathering.

Surface water paleotemperatures were determined from one phase aqueous fluid inclusions. Homogenization temperatures range from 32° to 46°C in primary fluid inclusions and are consistent (within 3°C) along individual chevrons and cornets. These homogenization temperatures are interpreted to represent maximum surface water temperatures.

These fluid inclusion data are significant in addressing global change problems. Temperatures and chemistries in these Permian lake waters agree with some modern shallow saline lake waters and with Permian climate models. This study suggests that this Permian environment was relatively similar to its modern counterparts.

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Driving Mechanisms for Karst Development in Gypsum-Bearing Aquifers

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Gypsum ($CaSO_4 \cdot 2H_2O$) is highly soluble and can rapidly equilibrate with aqueous solutions. Traditional laboratory-based gypsum dissolution studies predict that dissolution rates are transport controlled (rate-limited by diffusion through a hydrodynamic boundary layer) and are so fast that gypsum should quickly dissolve when in contact with undersaturated surface water, but dissolution should end very quickly along a flow path as groundwater approaches gypsum saturation. The geomorphologic consequence, then, should be fractures or other hydrologic pathways which open rapidly at the point of first entry of water in gypsum-bearing aquifers, but are not dissolved down hydrologic gradient. Numerous examples of natural gypsum karst conduits, however, suggest this analysis must be incomplete in some way.

Recent experiments in rotating-disc/mixed flow reactors show that dissolution rates of gypsum in aqueous solutions of low ionic strengths at 25°C and over a wide range in saturation conditions exhibit a "mixed" kinetic control, i.e., influenced by both hydrodynamic regime and reaction rate at gypsum-water interfaces. This has the effect that rates, which decrease approximately linearly with decreasing solution saturation far from equilibrium, slow dramatically close to equilibrium. Results from gypsum dissolution experiments conducted in situ in the Permian Blaine Formation of southwestern Oklahoma agree well with laboratory-derived rates in this close-to-equilibrium range. Such a rate retardation is analogous to a proposed "kinetic trigger" allowing conduit development in carbonate karst. We develop a rate law for mixed kinetic control governing gypsum-water reaction under varying transport and saturation conditions that reproduces our experiments very well.

A mathematical model coupling gypsum wall rock reaction with fluid flow along a conduit, parameterized with our proposed rate law, is used to show a transition between end member behaviors of surface denudation and subsurface conduit development. We discuss geometric and hydrologic factors influencing this transition.

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Dedolomitization in Gypsum-Bearing Aquifers as a Driving Force for Karst Development

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The occurrence of cyclic deposits of shales, dolomites, and gypsum-bearing layers in the Permian Blaine Formation in southwestern Oklahoma has set the stage for geochemical enhancement of porosity and karst development. Gypsum and dolomite interactions with groundwater, when occurring in close spatial proximity, can result in a process termed dedolomitization, whereby coupled gypsum and dolomite dissolution proceed with calcite precipitation. The net loss of mass accompanying this process can be manifest in secondary porosity development, while the coupled nature of the set of reactions results in the retention of undersaturated conditions of groundwater with respect to gypsum, a system which should otherwise rapidly equilibrate. The overall reaction increases the effective solubility of gypsum roughly 1.5 times over gypsum solubility in water alone.

Geochemical modeling of historical water-well chemical data from southwestern Oklahoma from the present back to the 1950s shows that dedolomitization is actively occurring or has occurred in the Blaine aquifer in Harmon County, southwestern Oklahoma. Recent data from karst-bearing intervals show that the process is presently occurring in cave systems. Examination of core from one such gypsum- and dolomite-bearing interval displays authigenic calcite. Data from single locations over time show that dedolomitization in the Blaine aquifer has been discontinuous in time; samples from the same cavern system taken only hours apart show that its operation is also spatially discontinuous. Due to its distinct chemical signature, chemical groundwater mapping can identify areas likely undergoing active karstification by dedolomitization.

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Origin of Iodine in the Anadarko Basin, Oklahoma: An ^{129}I Study

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Iodine comes almost exclusively from organic matter in sedimentary basins and, therefore, can be used as a source indicator for hydrocarbons. The long-lived (half-life 15.7 m.y.) cosmogenic and fissiogenic isotope ^{129}I has been applied to tracing brine migration in the Anadarko basin, Oklahoma. Because all of the likely source formations for I are Paleozoic, the cosmogenic ^{129}I component has decayed to undetectable levels and all of the measured ^{129}I is of fissiogenic origin. Comparison of $^{129}I/^{127}I$ ratios measured in 12 brines from the platform area of the Anadarko basin with ratios determined for potential source rocks reveals that the Woodford Shale is the probable source formation for the extremely high I concentrations observed in these brines. If the Woodford Shale is the exclusive source for I, the time of expulsion can be constrained to between 2 and 90 Ma. Although this date is much later than most estimates of expulsion time derived from conventional methods, a case is presented for more recent expulsion in the northern part of the basin, which was the sample area.

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Origin of Iodine in the Anadarko Basin, Oklahoma: A ^{129}Iodine Study

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Properties of the long-lived cosmogenic and fissiogenic isotope of iodine, ^{129}I (half-life 15.7 Ma), and the biophilic behavior of iodine, make this isotope useful in the study of sources and migration patterns of brines and hydrocarbons in sedimentary basins. In the Anadarko basin, Oklahoma, where iodine concentrations in oilfield brines are among the highest in the world, potential source rocks for iodine and associated hydrocarbons are all Paleozoic. The cosmogenic component of ^{129}I in the brines has therefore decayed away completely, and the fissiogenic component has reached secular equilibrium.

$^{129}I/I$ ratios, measured by accelerator mass spectrometry, in twelve brine samples from the platform area of the basin fall in the range $95–348 \times 10^{-15}$. While some of these ratios are close to the lowest $^{129}I/I$ ratios ever measured, there is significant variation, and a few ratios are significantly higher than the "blank." By comparing ratios measured

in the brines with those calculated for some potential source rocks, the fissiogenic component can be traced to a formation with relatively high uranium concentrations. The Woodford Shale is thus identified as the main source for iodine and associated hydrocarbons. When information from $^{36}Cl/Cl$ ratios is also considered, the time of expulsion is constrained to be between 2 and 90 Ma. These conclusions corroborate results from organic geochemical and hydrogeological approaches.

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Orbital Forcing Timescale for the Late Devonian–Early Carboniferous (Frasnian–Tournaisian)

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Magnetic susceptibility is used to document microrhythmic patterns of sedimentation in the Late Devonian–Early Carboniferous (late Frasnian–early Tournaisian) Woodford Shale of southern Oklahoma. The rhythmicity of the magnetic susceptibility signature for the Woodford defines three cycles with average periodicities of 50, 100, and 400 ka; values close to calculated Milankovitch orbital frequencies for the Late Devonian of 40, 123 and 414 ka. The most prominent minimum peaks (lowest magnitude) in the magnetic susceptibility record used to establish the orbital forcing timescale correspond to the known global Devonian events Kellwasser, Nehden, *Annulata*, and Hangenberg; all thought to be the result of deepening conditions. Precessional and obliquity cycles (19–23 & 41 ka) have not been resolved. Together with the existing conodont zonation, these cycles are used to establish a cyclostratigraphy for the Woodford Shale. The problem of missing portions of cycles in different sections is solved by building a Woodford composite reference section. Preliminary studies indicate that microrhythms contained within the magnetic susceptibility record can provide intra- and interbasin correlations of higher resolution than associated biozones used for temporal control. While cycles greater than 1 Ma within the magnetic susceptibility record can be used to establish correlations at interregional scales, data from regions other than southern Oklahoma presently do not exist at intervals sufficient to test interregional correlations at higher resolutions.

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Fluid Inclusion Evidence for the Migration of Anomalously Hot Fluids in the Silurian/Devonian Hunton Group Below the Pre-Mississippian Unconformity Surface, Anadarko Basin, Oklahoma

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Fluid inclusion assemblages in vug- and fracture-filling diagenetic minerals in the carbonates of the Hunton Group record anomalously high homogenization temperatures and salinities. Temperature profiles of single wells display maxima directly below or close to the unconformity with the overlying Woodford Shale, and decrease gradually or abruptly downward. In a few wells, suitable diagenetic minerals directly above the unconformity in the Woodford Shale contain fluid inclusions with homogenization temperatures comparable to those below the anomaly. Highest temperatures coincide with a high-permeability zone developed towards the top of the Hunton carbonates.

The thickness and permeability of this zone depends on the development of a paleokarst after Hunton deposition and are controlled by the paleogeographical position within the basin. Depending on the location within the basin, fluids evolve generally from meteoric or moderately saline (up to ~10 weight% NaCl equivalent) with temperatures of 80° to 120°C to highly saline (up to ~26 weight% NaCl equivalent) with temperatures up to 260°C, followed by a decrease in temperature with either increasing or decreasing salinities. Associated petroleum inclusions suggest that the hottest temperatures coincide with peak petroleum migration. Temperature anomalies are highest in the north near the Hunton subcrop on the basin shelf where the total Hunton thickness is generally <100 feet, and the strongly karsted carbonates are sandwiched in between the Woodford and Sylvan Shales resulting in a highly focused flow.

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Regional Correlations and Gas Well Recovery-vs-Depth Studies in the Anadarko Basin Area of Western Oklahoma

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To investigate the industry assumption that individual well recovery is merely a function of depth (increased pressure), a cooperative study between the Gas Research Institute and Dwight's Energydata Inc. was conducted. The Anadarko Basin was selected as the site of these investigations because of the wide distribution of producing depths observed in the basin and because of favorable data availability throughout the basin. Furthermore, several formations are amenable to evaluation through a wide range of depths. However, the nomenclature used within the Anadarko Basin and encompassing shelf areas is typically erratic. An estimated 35% of the wells with an operator-defined producing reservoir were incorrect. Therefore, detailed log cross-sections were constructed to ensure a proper reservoir production allocation for each well. All the producing gas wells within a study area from T9–29N, R10–26W (12,852 square miles) were examined—about half the Anadarko Basin.

This study evaluates the relationships existing between gas well recovery and depth. The results of this investigation indicate that reservoir characteristics have a more pronounced effect on formation productivity than does depth (pressure). Also, components of the study identified discrepancies in the recovery/depth relationships based upon formation lithology and by various formations which have similar lithologies. The statistical results of the studies and the regional log cross-sections generated are presented.

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AVO Analysis of High-Impedance Sandstone Reservoirs

CAROLYN P. PEDDY, Geotechnology Research Institute, Houston Advanced Research Center, The Woodlands, TX; and *MRINAL K. SENGUPTA*, Consultant, Houston, TX

We present case studies of high-impedance gas sands in order to investigate the possibility of using AVO analysis in areas such as the Mid-Continent. The case studies illustrate some of the differences in approach that must be used in order for AVO analysis to be used effectively in high-impedance reservoirs. Sands in the Morrow Formation of the

Anadarko basin vary in local properties, significantly affecting the AVO response observable on seismic data. The reflection from the top of a gas-charged Woodbine sandstone shows a strong gas effect that is consistent at four well locations along a seismic line. Aspects of rock properties as they relate to AVO analysis in high-impedance reservoirs indicate that AVO may be a powerful lithology discriminator in higher velocity rocks.

Several issues need to be understood by the explorationist using AVO for high-impedance gas sand exploration. For example, the A*B plot used in AVO interpretation in the Gulf Coast does not provide useful information in the AVO analysis of high-impedance sandstone reservoirs. Normal-incidence reflection coefficients are not direct hydrocarbon indicators as in the Gulf Coast. A limitation of AVO analysis for gas detection in high-impedance sands is that there is often very little difference between the wet sand Poisson's ratio and the gas sand Poisson's ratio. As the Vp of a pure sand increases, the Poisson's ratio of the sand decreased. However, in many Mid-Continent trends, sand channels are fully charged, and the exploration problem is finding the location of the sand channel. In these cases, AVO is an excellent exploration tool, as the difference in Poisson's ratio between rocks of varying lithologies tends to increase as Vp increases.

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The Role of Diagenesis in the Formation of Compartments: A Fully Coupled 3D Reaction-Transport-Mechanical (RTM) Modeling Approach

CHANGXING QIN, FAICAL TOUNSI, KHAIREDDINE SAKRANI, WALID SIBO, JUDY LUNARDINI, MILES J. MAXWELL, and *PETER J. ORTOLEVA*, Indiana University, Bloomington, IN

Compartments and related abnormal pressures in sedimentary basins widely exist and are of great significance for hydrocarbon exploration and production. It is widely recognized that the interplay of many processes taking place in a basin determines the formation of a compartment. However, it is generally considered that the original sedimentary features and faults are the dominant factors, while the role of diagenesis is underestimated.

We used the fully coupled three dimensional RTM simulator, CIRF.B, to model the development of compartments and overpressuring in the Anadarko and Piceance basins and to assess the relative importance of pressure solution, mechanical compaction, fracturing and tectonic, thermal, and sedimentation history. Simulation results show that the timing and location of the formation of a compartment are determined by the overall influence of those parameters. The contribution of a specific factor can change from basin to basin because of the differences in the tectonic and sedimentation history, etc. Seals are likely to form in finer grain beds due to rapid diagenetic reduction of permeability there. It can also form in roughly uniform strata due to the formation of diagenetic bedding. The latter is a challenge for conventional prediction of compartment based on lithology and geological structure.

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Heat Flow in Oklahoma

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Oklahoma is one area in which terrestrial heat flow data are sparse. The thermal state of the southern mid-continent, however, is a key to understanding several important geologic problems. These include thermal anomalies associated with Paleozoic fluid migrations and the formation of Mississippi Valley-type lead-zinc deposits, the thermal evolution of the Arkoma and Anadarko sedimentary basins, and the history of hydrocarbon generation and overpressuring in the Anadarko Basin.

In the late 1920s, the American Petroleum Institute made a set of equilibrium temperature logs in idle oil wells. These temperature data are generally regarded as being high quality, accurate estimates of rock temperature and they cover the entire central part of Oklahoma. Average thermal gradients in the API survey range from 14° to 43°C/km (average 31.2°C/km) over depth intervals that extend from the surface to an average depth of 961 m. Geothermal gradients decrease from NNE to SSW. The observed change in thermal gradients could be due to a number of factors. The change in thermal gradients could simply reflect changes in lithology and thermal conductivity. Alternatively, the variation in thermal gradients could be indicative of a change in heat flow related perhaps to variations in the concentration of radioactive heat-producing elements in the crust or heat transport by one or more regional groundwater flow systems. We are proceeding to reduce ambiguity in interpretation by estimating heat flow from thermal conductivity measurements on drill cuttings and heat production from available gamma-ray logs which penetrate basement rocks.

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Comparison of Resource Assessment Methods and Geologic Controls—Deep Natural Gas Plays and Zones, United States and Russia

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Deep (greater than 4.5 km [15,000 ft]) conventional natural gas resources will play an important role in the future energy needs of the United States and Russia. Deep sedimentary basins are widespread in these countries and have formed in a variety of depositional and tectonic settings. Significant volumes of undiscovered deep natural gas are in the Gulf Coast, Anadarko, Permian, and Rocky Mountain basins of the U.S., and in the Timan-Pechora, West Siberia, East Siberia, and North and South Caspian basins of the former Soviet Union.

Deep natural gas resources are regularly assessed by the All-Russia Petroleum Research Exploration Institute (VNIGRI) and the U.S. Geological Survey (USGS) as part of their normal research activities. Both VNIGRI and the USGS employ similar assessment methods involving play (or zone) analysis using geological data and based on an analysis of confirmed and hypothetical plays using field-size distributions, discovery-process models, and statistical estimation procedures that yield probabilistic estimates of undiscovered accumulations. Resource estimates for the deep structural and stratigraphic plays of the Anadarko basin and deep Paleozoic zones in the Timan-Pechora basin are compared and contrasted using both methods.

Differences in results of assessments between VNIGRI and USGS arise due to (1) the way in which plays/zones are defined; (2) different geochemical models for hydrocarbon generation as applied to hypothetical plays; (3) variations in the ways in which statistical estimation procedures are applied to plays and regions; and (4) differences in economic and technologic assumptions, reserve growth calculation, and accumulation size limits and ranges.

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