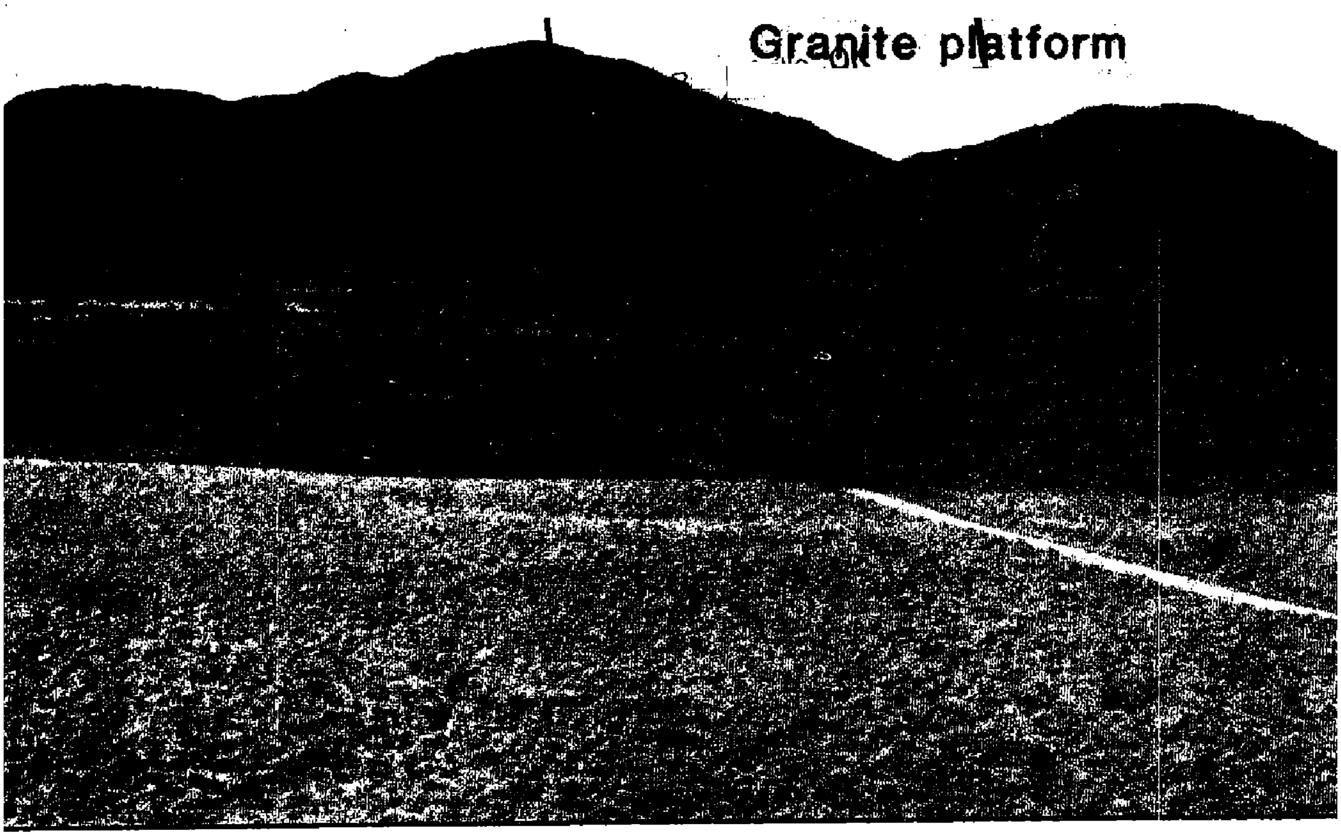
OKLAHOMA GEOLOGY



August, 1994

Vol. 54, No. 4

On The Cover —

King Mountain, Wichita Mountains, Oklahoma

King Mountain in the Lake Altus area of the western Wichita Mountains, Oklahoma (at center in the distance). Just below the summit of this granite hill is a pediment, which appears as a horizontal lineation, that was cut at the level of the Southern High Plains surface when it existed in the area during the Pliocene. This surface has since retreated 180 km westward where its remnants, the Llano Estacado, are now found in western Texas and easternmost New Mexico.

James A. Harrell
University of Toledo

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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 $847 to the taxpayers of the State of Oklahoma. Copies have been deposited with the Publications Clearinghouse of the Oklahoma Department of Libraries.

KLAHOMA GEOLOGY Notes

VOL. 54, NO. 4

Oklahoma's Petroleum Industry: A Modern-Day Phoenix?

Charles J. Mankin[1]

Oklahoma's petroleum industry has been in a malaise for the past several years. The departure of most of the major oil companies that have been operating in Oklahoma for many decades (some of whom owe their origin to early discoveries in the State) resulted in the loss of a substantial number of high-paying jobs and related supporting business activities. The collapse in world oil prices in 1986, and again in the fall of 1993, added to the industry's woes. These events have had both a real and a psychologically negative effect on the State's economy.

Although beset with a series of negative events, petroleum continues to be the State's major industrial activity (Fig. 1). While it is premature to declare an end to problems facing the State's largest industrial activity, positive signs are emerging. Crude-oil prices have rebounded on the basis of growing world demand, while natural-gas supply and demand are in balance for the first time in the past 20 years.

These positive signs must be tempered with the recognition that investment capital for the domestic petroleum industry is the lowest it has been in decades, and the departure of the major companies from the scene will further depress that flow of support. While the major companies obtain most of their capital from internal sources, a majority of smaller companies and independents must rely on external financing for exploration and development projects. The traditional capital-formation sources for the smaller companies and independents have experienced the wild fluctuations in prices for crude oil and natural gas, and are observing the growth in regulation and related liability with jaundiced eyes. Thus, the generation of capital needed to sustain the domestic petroleum industry will be a critical factor in forecasting its future.

Oklahoma's petroleum industry is dominated by smaller companies and independent operators. While the major companies were important in the development of the industry in the State, the domination by smaller operators has been evident for some time. Also, it should be noted that many of the major oil companies of today were small, aggressive companies during the early development of petroleum in Oklahoma. Their early success in our State and elsewhere led to their becoming the major companies of today. Figures 2 and 3 show the relationship of major companies to smaller entities in the production of oil and gas in Oklahoma. As noted, the share of oil production by the major companies has been relatively small in the recent past, ranging from 33% in 1980, down to 21% in 1993. The major companies' share of gas production has been smaller but somewhat more consistent, ranging from 22% in 1980, down to 19% in 1993.

The future of oil and gas production in Oklahoma is thus dependent upon the success of the smaller companies and independents. Because these operators do not have the vast internal re-

[1]Director, Oklahoma Geological Survey.

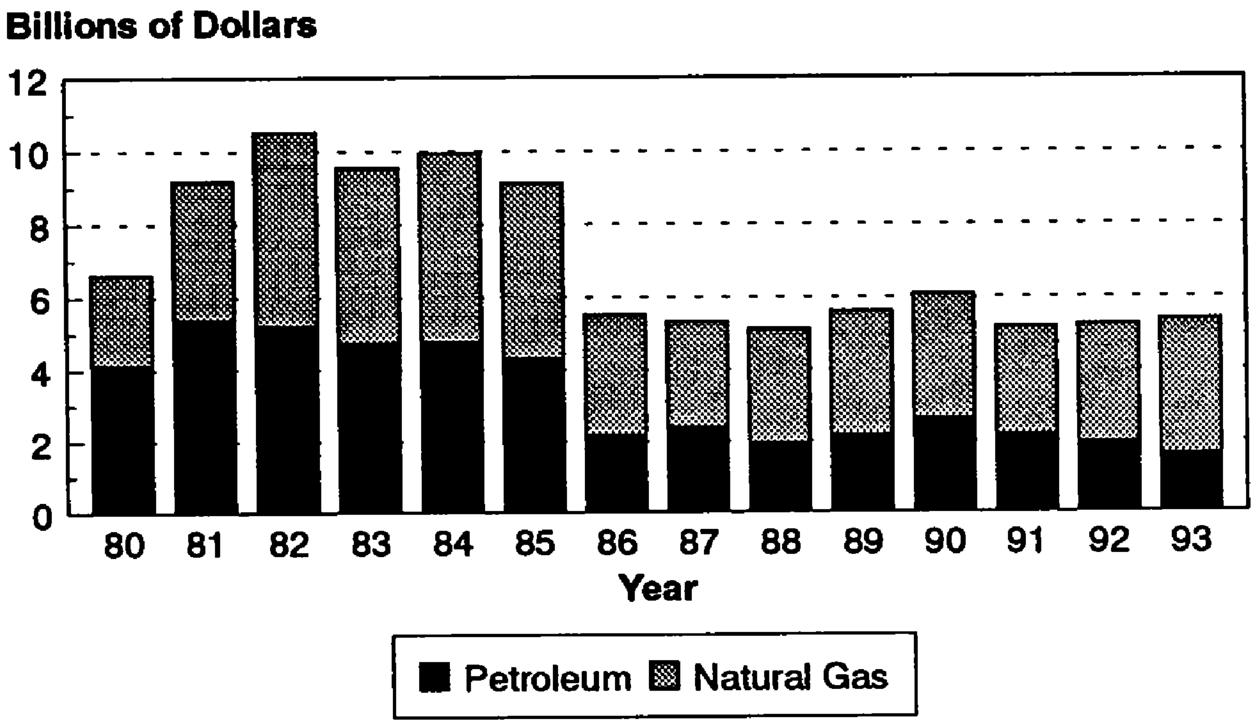

Figure 1. The value of petroleum and natural gas production in Oklahoma.

sources commonly found within major companies, it is important that the State address the financing and operating needs of these entities. Tax incentives that will assist in generating the needed external capital to fund exploration and development programs, and ready access to petroleum information and technical assistance are the two most critical needs.

It is important to remember that Oklahoma is not in competition with countries like Saudi Arabia or Venezuela for oil and gas production. We are, however, in competition with Texas, Kansas, Louisiana, and the other oil- and gas-producing states to attract and maintain the smaller companies and independent operators. Oil and gas businesses will explore opportunities in those states that do a better job in providing the incentives and technical information needed by these operators. In that sense, the petroleum industry is no different from any other business or industrial activity. In effect, we should consider every oil- and gas-producing lease in Oklahoma as the equivalent to a small business. Such leases generate revenue, create jobs, purchase services, and pay taxes. To the extent that these leases are operated by smaller companies and independent operators, the revenue generated from such operations tends to stay in Oklahoma, and, in many instances, in the locality where the production occurs.

To address some of the petroleum industry's needs, the Oklahoma Legislature passed in the last session an important tax-incentive bill that was signed by the Governor on June 7, 1994. That legislation contains the following provisions:

• *Inactive Wells*—Effective July 1, 1994, and extending until July 1, 1997, production from any oil or gas well that has not produced for a period of two or more years is eligible for a credit of all but 1% of the gross-production tax for a period of 28 months following the reactivation of the well.

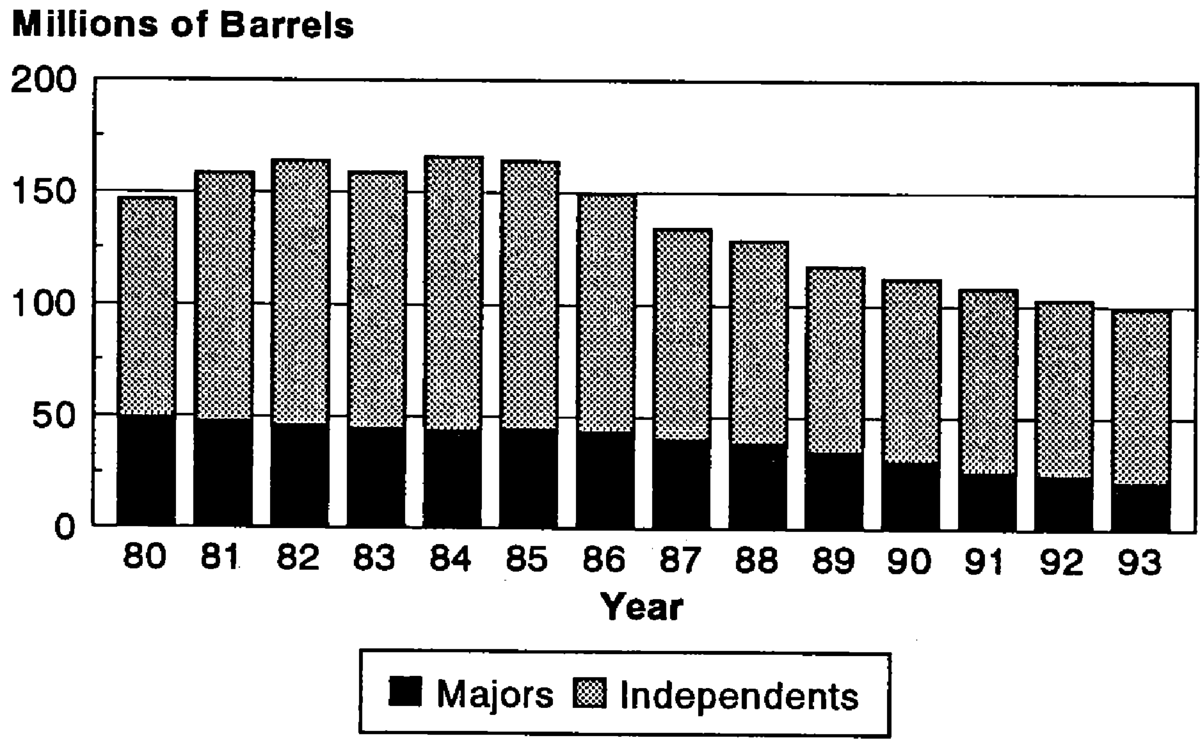

Figure 2. Production of petroleum by majors and all other operators.

• *Incremental Production*—Effective July 1, 1994, and extending until July 1, 1997, oil and gas production in excess of the average monthly production for the 12 months preceding June 7, 1994, that is the result of a "production-enhancement project" is eligible for a credit of all but 1% of the gross-production tax for a period of 28 months from the date of the completion of the production-enhancement project. A production-enhancement project is defined as any workover (including fracturing) and/or recompletion, but does not include routine maintenance.

• *Deep-Well Completions*—Oil and gas production from a well drilled to a depth of 15,000 feet or greater, and spudded between July 1, 1994, and July 1, 1997, is eligible for a credit of all but 1% of the gross-production tax for a period of 28 months from the date of first sale of production.

The tax-incentive provisions contained in this legislation are effective for oil as long as the weighted average price of Oklahoma oil does not exceed $20 per barrel, calculated on an annual calendar year, or for gas as long as the weighted average price in the State does not exceed $2.50 per million BTUs, also calculated on an annual calendar year. There are additional provisions for reinvestment and other issues contained in the legislation. Any operator considering participation should obtain a copy of Enrolled Senate Bill No. 841.

The State also has taken steps to improve access to technical information and assistance. The development of the Natural Resources Information System (NRIS) by the Oklahoma Geological Survey, in cooperation with Geological Information Systems (GIS), is one such example. The development of a computer laboratory at the Survey, where NRIS data and other information can be obtained by operators and others involved in the petroleum industry, will be available in the fall of this year. An information and technology-transfer program will be initiated in the fall by the Survey,

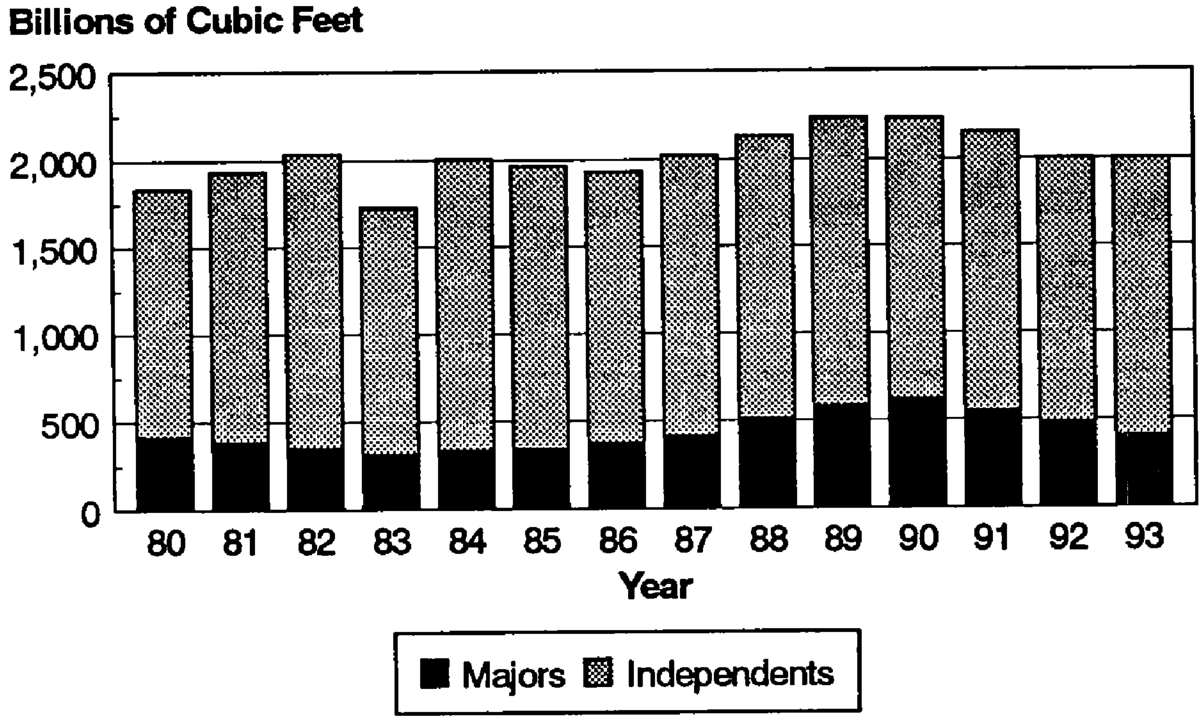

Figure 3. Natural gas production by major companies and all other operators.

with cooperation from GIS and the Oklahoma Commission on Marginally Producing Oil and Gas Wells. Finally, the Survey is engaged in discussions with GIS, the Oklahoma Corporation Commission, the Oklahoma Tax Commission, and the Commissioners of the School Lands to develop an improved production-reporting and management system for oil and gas for the State.

The petroleum industry in Oklahoma has been through much adversity during the past two decades, and it is too early to suggest that the worst may be over. However, the facts are that the U.S. supply and demand for natural gas are now in close balance and the world supply of crude oil is shrinking; this suggests that the industry can look forward to improved world oil prices and a corresponding increase in both price and demand for natural gas. Most experts agree that the present circumstances of low world oil prices will not prevail; the unanswered question is—when will prices rise? Oklahoma has taken an important step in providing incentives needed to aid in sustaining the State's largest industry. The ultimate reward to Oklahoma is the production of some portion of the 25 billion barrels of oil that remain in existing fields, the discovery of an estimated one billion barrels of oil yet to be found, and the recovery of an estimated 100 trillion cubic feet of natural gas remaining in the State. The major benefit to the nation will be reduced reliance upon imported petroleum through the preservation of the domestic petroleum industry. To the extent that the domestic petroleum industry is able to meet the nation's energy needs, the benefits that will accrue include a reduction in the growth of the merchandise trade deficit that now stands at an accumulated $1.3 trillion (from 1973 to present), the jobs that will be created and sustained, and the local, state, and national taxes that will be paid by such industrial activity.

Factors Related to Pesticide Occurrence in Ground Water in the Oklahoma City Urban Area[1]

Scott C. Christenson and Alan H. Rea[2]

Oklahoma City is the 29th largest city in the United States, based on population data from the 1990 census. Oklahoma City's population is 445,000, and 959,000 people live within the standard metropolitan statistical area. Oklahoma City is surrounded by numerous smaller municipalities with populations as large as 80,000, as well as a large dispersed residential population outside the boundaries of the municipalities. Although surface-water sources supply Oklahoma City's municipal water demands, the surrounding municipalities rely on ground water for all or part of their water supplies. Many residential areas within municipal boundaries are not served by public water supplies, and the residents rely on domestic wells. In addition, the dispersed residential population relies on ground water.

The source of the ground water is the Central Oklahoma aquifer, which underlies about 3,000 square miles in central Oklahoma and consists of bedrock (Permian sandstones and mudstones) and overlying Quaternary alluvium and terrace deposits. Most large-capacity wells completed in the Central Oklahoma aquifer are from 100 to 800 feet deep and are completed in the bedrock geologic units. Domestic wells are typically from 120 to 180 feet deep and may be completed in either the bedrock or the alluvium and terrace deposits.

As part of one of seven pilot studies of the U.S. Geological Survey's National Water-Quality Assessment Program, three ground-water sampling networks were designed to collect water-quality data and identify major factors that could affect water quality in the Central Oklahoma aquifer. All wells sampled were existing water-supply wells and were generally, but not exclusively, domestic wells. An urban network was designed to assess the effects of urbanization on ground-water quality. The urban network was established within the central part of Oklahoma City, and included the downtown business district, industrial areas, and older residential areas. Two networks were established to assess the water quality throughout the entire aquifer: a network of wells completed in the bedrock geologic units, and a network of wells completed in the alluvium and terrace deposits.

Pesticides and pesticide-related compounds (such as pesticide break-down products) were among the constituents analyzed from all networks. Pesticides that were analyzed included 3 carbamate insecticides, 12 organonitrogen herbicides, 17 organochlorine insecticides, 6 chlorinated acid herbicides, and 10 organophosphate insecticides. All analyses were performed at the U.S. Geological Survey's National Water Quality Laboratory using standard methods, either gas chromatography or high-performance liquid chromatography.

All pesticide detections were at small concentrations, generally at or just above the laboratory reporting level. More than one pesticide was detected in the water

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[1]Reprinted as published in Water Management of River Systems; 27th Annual AWRA Conference: American Water Resources Association Technical Publication Series, p. 343–344, 1991.

[2]Water Resources Division, U.S. Geological Survey, Oklahoma City.

samples from some wells. No carbamate insecticides were detected above the laboratory reporting level in any well in any network. The organochlorine insecticides aldrin, chlordane, and dieldrin were found in both the urban and bedrock networks. These pesticides generally are not expected to be found in ground water, because they tend to sorb to sediments and thus their presence is unusual in samples from wells. In the past, these insecticides were used extensively in the Oklahoma City urban area for termite control. The herbicides prometone and 2,4-D also were found in water samples from the urban network. Prometone generally is used for the total elimination of vegetation, and 2,4-D is used commonly for weed control. All pesticides that were found in water samples have been used both by commercial applicators and homeowners. The numbers of wells in each network with detectable pesticides are shown in the following table:

Compound	Network			Laboratory reporting level (μg/L)	Median detected concentration (μg/L)
	Urban	Bedrock	Alluvium/ terrace deposits		
Aldrin	1	0	0	0.01	0.01
Chlordane	5	1	0	0.1	0.2
Dieldrin	6	2	0	0.01	0.03
DDE	0	1	0	0.01	0.01
Heptachlor epoxide	0	1	0	0.01	0.01
2,4-D	2	3	0	0.01	0.01
2,4-DP	0	0	1	0.01	0.01
2,4,5-T	0	0	1	0.01	0.01
Picloram	0	1	1	0.01	0.01
Dicamba	0	1	1	0.01	0.01
Atrazine	0	1	2	0.1	0.1
Prometone	4	1	1	0.1	0.4
Wells with detections	11	8	6		
Wells in network	41	87	42		

A comparison of the proportions of wells in the urban network and the other networks shows that pesticides were detected in a greater proportion of wells in the urban network. Pesticides were detected in about 27 percent of wells in the urban network, but in only about 11 percent of wells in the other water-quality networks. Comparing the urban to the non-urban networks with a contingency table analysis using a chi-square statistic shows the proportion of wells with detectable pesticides is significantly different between the urban network and the other networks, with a p-value of 0.012.

The geologic unit in which wells were completed was expected to affect the proportion of wells with detectable pesticides, but this was not the case. Pesticides were detected in 14 percent of wells completed in alluvium or terrace deposits and in 9.2 percent of wells completed in bedrock. A contingency table analysis using a chi-squared statistic showed the proportion of wells with detectable pesticides was not significantly different among wells completed in different geologic units, with ap-value of 0.569. Wells in the urban network were excluded in this analysis, because the urban network represents only a small part of the bedrock aquifer.

Tritium concentration was found to be an effective indicator of ground-water vulnerability to pesticide contamination in the Central Oklahoma aquifer. Wells with tritium concentration larger than 0.3 picocuries per liter, the laboratory reporting level, are producing younger water than wells without detectable tritium. Wells were divided into two groups, wells with detectable tritium and wells with tritium concentrations below the reporting level. A contingency table analysis using a chi-squared statistic showed that the proportion of wells with detectable pesticides was significantly different between wells with detectable tritium and wells without detectable tritium (p-value of 0.007). Pesticides were found in only one well that did not have detectable tritium.

In summary, urbanization and tritium concentration were found to be factors related to the presence of particular pesticides in water samples from wells completed in the Central Oklahoma aquifer.

UPCOMING *Meetings*

American Geophysical Union Chapman Conference, "Aqueous Phase and Multiphase Transport in Fractured Rocks," September 12–15, 1994, Burlington, Vermont. Information: AGU, 2000 Florida Ave., N.W., Washington, DC 20009; (202) 462-6900, fax 202-328-0566.

CIM Geological Society Field Conference, "Exploration and Mining Geology of World Class Deposits: Strategies for Success," September 19–21, 1994, Sudbury, Ontario. Information: Ruth Debicki, MNDM, B6-933 Ramsey Lake Road, Sudbury, Ontario P3E 6B5, Canada; (705) 670-5627, fax 705-670-5622.

Dinosaur Diamond Safari, Field Trip, September 24–29, 1994, Grand Junction, Colorado, and Moab, Utah. Information: Dinamation International Society, Box 307, Fruita, CO 81521; (800) DIG-DINO.

Society of Petroleum Engineers Meeting, September 25–28, 1994, New Orleans, Louisiana. Information: Convention Dept., AAPG, Box 979, Tulsa, OK 74101; (918) 584-2555, fax 918-584-0469.

Society for Organic Petrology, 11th Annual Meeting, September 25–30, 1994, Jackson, Wyoming. Information: Ron Stanton, U.S. Geological Survey, 956 National Center, Reston, VA 22092; (703) 648-6462, fax 703-648-6419.

Oklahoma City Geological Society, Midcontinent Prospect and Acquisitions Expo, September 26–27, 1994, Oklahoma City, Oklahoma. Information: OCGS, 227 W. Park Ave., Oklahoma City, OK 73102; (405) 236-8086, fax 405-236-8085.

Geothermal Resources Council, Annual Meeting, October 2–5, 1994, Salt Lake City, Utah. Information: Geothermal Resources Council, P.O. Box 1350, Davis, CA 95617; (916) 758-2360, fax 916-758-2839.

Association of Engineering Geologists, Annual Meeting, October 2–7, 1994, Williamsburg, Virginia. Information: AEG, 323 Boston Post Road, Suite 2D, Sudbury, MA 01776; (508) 443-4639.

ISO 9000 . . . Moving Industrial Minerals into the 21st Century, October 5–7, 1994, Nashville, Tennessee. Information: Meetings Dept., Society for Mining, Metallurgy, and Exploration, P.O. Box 625002, Littleton, CO 80162; (303) 973-9550, fax 303-979-3461.

American Institute of Professional Geologists, Annual Meeting, October 12–15, 1994, Flagstaff, Arizona. Information: J. Dale Nations, Dept. of Geology, Northern Arizona University, Box 6030, Flagstaff, AZ 86011; (602) 532-7180.

Hydrogeology and Engineering Geology of Karst Terranes, 9th National Conference, October 16–18, 1994, Nashville, Tennessee. Information: James F. Quinlan, Box 110539, Nashville, TN 37222; (615) 833-4324.

SEPM International Workshop, "Applications of Sedimentary Geology and Paleontology into the 21st Century," October 16–20, 1994, Snowbird, Utah. Information: Myra Rogers, Society for Sedimentary Geology, P.O. Box 4756, Tulsa, OK 74159; 1-800-865-9765, fax 918-743-2498.

LIRA Workshop on the Ross Orogen: Crustal Structure and Tectonic Significance, October 21–23, 1994, Dallas, Texas. Information: John W. Goodge, Dept. of Geological Sciences, Southern Methodist University, Dallas, TX 75275; (214) 768-4140.

Society of Exploration Geophysicists, Annual Meeting, October 23–27, 1994, Los Angeles, California. Information: Robert H. Stolt, Box 702740, Tulsa, OK 74170; (918) 493-3516, fax 918-493-2074.

Petroleum Hydrocarbons Meeting, November 1–3, 1994, Houston, Texas. Information: National Ground Water Association, 6375 Riverside Dr., Dublin, OH 43017; (614) 761-1711, fax 614-761-3446.

American Water Resources Association Conference, November 6–11, 1994, Chicago, Illinois. Information: AWRA, 5410 Grosvenor Lane, Suite 220, Bethesda, MD 20814; (301) 493-8600, fax 301-493-5844.

Structural Geology of the Permian Basin, Big Bend to the Solitario, Field Seminar, November 11–13, 1994, sponsored by the West Texas Geological Society. Information: Rod Phares; (915) 683-4391.

American Petroleum Institute, Annual Meeting, November 13–14, 1994, Los Angeles, California. Information: API, 700 N. Pearl St., Suite 1840, Dallas, TX 75201; (214) 953-1101.

Aquifer Thermal Energy Storage, International Symposium, November 14–16, 1994, Tuscaloosa, Alabama. Information: Dan Thompson, University of Alabama, Box 870388, Tuscaloosa, AL 35487; (205) 348-3014, fax 205-348-6614.

Geology and Resources of the Eastern Frontal Belt, Ouachita Mountains, Oklahoma, Meeting and Field Trip, November 15–17, 1994, Poteau, Oklahoma. Information: Neil H. Suneson, Oklahoma Geological Survey, 100 E. Boyd, Room N-131, Norman, OK 73019; (405) 325-3031, fax 405-325-7069.

SEPM Research Conference, "Graphic Correlation/Composite Standard—The Method and Its Application," November 27–30, 1994, Houston, Texas. Information: Society for Sedimentary Geology, P.O. Box 4756, Tulsa, OK 74159; 1-800-865-9765 or (918) 743-9765, fax 918-743-2498.

Geostatistics for Geotechnical and Environmental Applications, Workshop and Symposium, January 26–27, 1995, Phoenix, Arizona. Information: R. Mohan Srivastava, FSS International, 800 Millbank, Vancouver, British Columbia V5Z 3Z4, Canada; (604) 875-1599.

Energy and Environmental Expo (sponsored by Energy-Sources Technology), January 29–February 1, 1995, Houston, Texas. Information: ASME Petroleum Division, 1950 Stemmons Freeway, Suite 5037c, Dallas, TX 75207; (214) 746-4901, fax 214-746-4902.

The Ames Structure and Similar Features, Workshop, March 28–29, 1995, Norman, Oklahoma. *Abstracts due November 1, 1994.* Information: Kenneth S. Johnson, Oklahoma Geological Survey, 100 E. Boyd, Room N-131, Norman, OK 73019; (405) 325-3031; fax 405-325-7069.

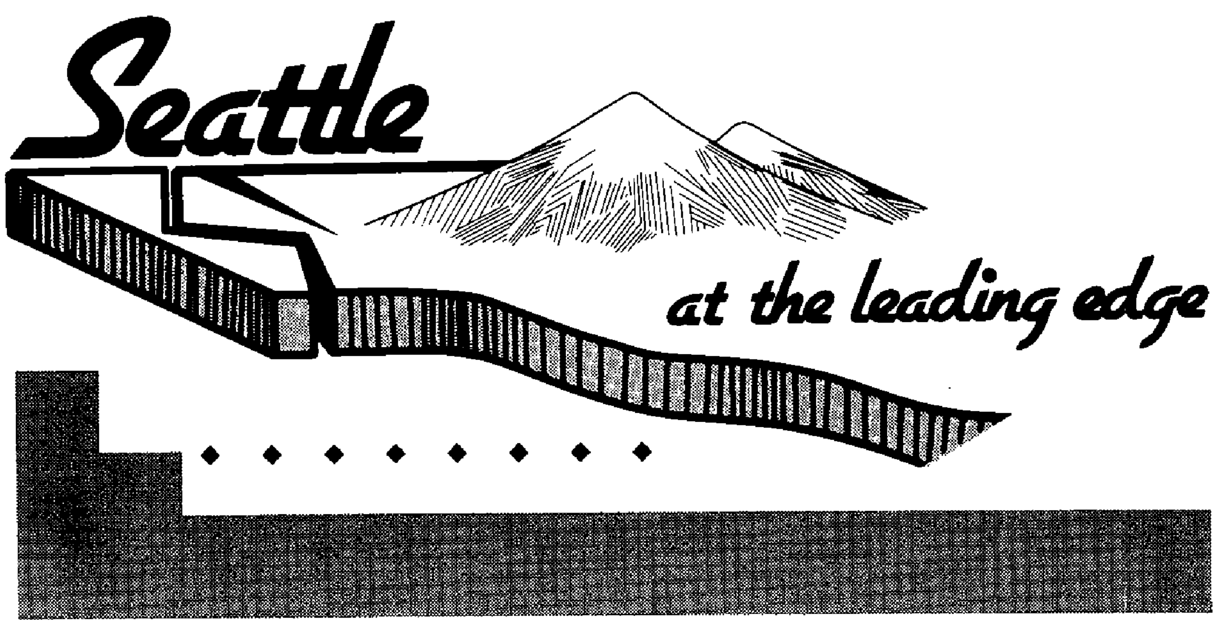
7th International Symposium on the Ordovician System, June 12–16, 1995, Las Vegas, Nevada. *Abstracts due December 1, 1994.* Information: Margaret Rees, Dept. of Geosciences, University of Nevada, Las Vegas, NV 89154; (702) 739-3890, fax 702-597-4064.

GSA ANNUAL MEETING
Seattle, Washington ◆ October 24–27, 1994

Geology AT THE LEADING EDGE *is the scientific theme of the Seattle meeting. The theme puts emphasis on both the geographical position of Seattle, situated on the leading edge of a convergent plate margin, and the application of "leading edge" theoretical approaches and technological advances to the elucidation of geological problems. Theme sessions and symposia will be offered not only on aspects of Pacific Rim and convergent margin geology, but also on a wide range of contemporary environmental and hydrogeological topics. An outstanding program of scientific sessions, field trips, continuing education courses, and exhibits is organized around this theme.*

Seattle: The Emerald City — *Seattle is a city of splendid views. No matter which direction you travel, there are mountains, forests, or stretches of salt and fresh water. Flanked by the Cascade Range to the east and the Olympic Mountains to the west, the city occupies an isthmus between Puget Sound, an 80-mile-long arm of the Pacific Ocean, and freshwater Lake Washington. Seattle is known these days for its rich and active cultural life, delicious foods and fresh-roasted coffees, and strong ties to the Pacific Rim. Seattle has changed a lot since the last time GSA was here, in 1977. Join us in the Northwest this October and experience the appeal of this unique destination. On behalf of the Annual Meeting Committee, we look forward to seeing you in Seattle.*

— DARREL S. COWAN
General Chairman



GSA Annual Meeting Agenda

Technical Program

Symposia

Keynote Symposium: Birth and Death of a Plate
Plate Motion and Displacement Partitioning in the Circum-Pacific Orogenic Belts
New Frontiers in Active Tectonics Science
Tectonic Geomorphology, Depositional Processes, and the Depositional Record
Geology and the Postindustrial Society
Meyer Symposium: Maintaining Compatibility of Mining and the Environment
Advances in Silica Geochemistry
Mineralogical Society of America 75th Anniversary Symposium
Frontiers of Mineral Surface Geochemistry: A Symposium in Memory of Andrew J. Gratz (1962–1993)
The Dreiss Symposium: Recent Trends in Studies of Coupled Hydrodynamic, Tectonic, and Thermal Processes
Hydrology and Active Volcanism: At the Leading Edge
Regional Economic Geology of the Northern Cordillera
Historical Investigations of Extraterrestrial Events and Causes in Earth History
Cataclysms and Catastrophes: The Planetary Perspective
Evolutionary Paleobiology
Military Geology in War and Peace
Pyrolysis Techniques for Source Rock Evaluation—Twenty Years Later
Origin of Compositional Characteristics in Tertiary Coals: Paleoecology, Paleobotany, and Palynology
The Late Cretaceous Marine and Continental Record of Global Climate Change
Use of Archaeology for Dating Geologic Events
Changing Gateways: The Impact of Technology on Geoscience Information Exchange
Recent Advances in Geosciences Education—The Leading Edge of Undergraduate Instruction and Research
Marine Trace-Element Biogeochemistry and the Sedimentary Record
The Geological Profession's Response to National Priorities in Science Education
Annual Environmental Forum: Crucial Environmental Issues—Fear and Loathing at the Leading Edge
Sigma Gamma Epsilon Student Research
Where Geology Matters: Past, Present, and Future

Theme Sessions

Liquefaction Hazard Mapping and Mitigation
Speciation, Mobility, and Bioavailability of Metals in Mining Wastes
The Role of Geology in Characterization, Contaminant Transport, and Remediation of Hazardous Waste Sites
Surprises for Society
The Geological Basis of Wild Salmon Ecology
Environmental Geology: The Voice of Warning
Environmental Geology: The Voice of Reason
Geochemistry of Contaminant Transport
Urban, Suburban, and Rural—Environmental Geology at the Leading Edge
The Management of Contaminated Sites in Near-Shore Marine and Estuary Environments

Stable Environmental Isotope Application in Ground-Water Systems
Hydrothermal Systems Evolution in the Cascade Range
Relation of Depositional Environments to Chemical and Physical Heterogeneity within Sedimentary Aquifers
Geologic Significance of Microbial Processes
Computational Hydrology and Data Visualization and Animation
Leading Edge Applications of Earth Science Modeling and Visualization
Integration of Hydraulic and Geochemical Approaches in Vadose Zone Transport Studies
Methods for Quantifying Unsaturated Permeability, Retardation, and Other Transport Properties in Rock, Soil, and Sediment
Description and Measurement of Constitutive Relations Governing Fluid Flow in Variably Saturated Media
Records of Glaciation and Climate Change Along the Leading Edge During the Last Glacial Maximum and the Pleistocene–Holocene Transition (20–8 ka).
The Last Interglacial: Timing and Environment
Paleoclimate Records from Arctic Lakes and Estuaries
Correlation of the Marine and Terrestrial Paleoclimatic Record of the Eastern North Pacific and Western United States
Tectonics and Landforms Around the Pacific Rim
The Juneau Icefield: A Half Century of Geoscience Education, Research, and Professional Training the Alpine and Glacial Environment
Quaternary Dating Methods
Late Quaternary Evolution of the Eastern Aleutian Arc: Volcanoes, Earthquakes, Glaciers, and Shorelines
Learning in Small Groups: Using Collaborative Activities to Teach Geology
Advances in the Geology and Metallogeny of Gold Deposits
Boron: Mineralogy, Petrology, and Geochemistry in Earth's Crust
Advances in Silica Geochemistry
Phase Transformations: Mechanisms and Kinetics of Mineral Reactions
Magmatic Evolution of Circum-Pacific Arc Systems
Volcanic Hazards and Disasters in Human History
Volatiles and Volcanoes
Geological Mapping of Terrestrial Planets: Use (and Abuse?) of Remotely Sensed Data
Impacts and Extinctions
New Perspectives on Faunal Stability in the Fossil Record
Tectonic and Climatic Influences on the Neogene Paleobiology of West-Central Nevada
Evolution of Reef Biotas Along Active Plate Margins
Teaching Paleontology
Educating Paleontologists for the Next Millennium: Evolution and Revolution
Pliocene Climates—Sea Levels and Ice Volumes
Scientific Results of the Continental Drilling Program: Creede Caldera, Newark Rift Basin, Manson Impact Structure
Teaching Structural Geology
Quantitative Analysis of Joints and Faults: New Approaches to Field, Laboratory, and Modeling Studies of Rock Fracture
Cascadia Subduction Zone
Cascadia Convergent Margin: Forearc Tectonics
Puget Sound–Georgia Strait Region: 140 Million Years of Tectonics
Tilt vs. Translation and the Late Cretaceous Tectonics of Western North America
Baja British Columbia: Evaluation of Large-Scale Northward Transport of the Northern Cordillera in Late Cretaceous to Early Tertiary Time
Convergent and Transform Processes at the Leading Edge of the Northern Pacific Rim
Geophysical Studies of the Continental Margin, Western North America

Late Mesozoic Basins in the North American Cordillera: Constraints on Terrane Accretion and Translation
Geology of the Coast Ranges of Oregon and Washington: New Discoveries
Birth and Life of an Island Arc at a Leading Edge—The Geologic Development of Japan
Active Arc-Continent Collision in Taiwan
Geologic Evolution of the Tian Shan Orogenic System, Central Asia
Rheological and Structural Evolution of Contractional Orogenic Belts
Dating Deformation
Precambrian and Phanerozoic Terrane Accretion: Contrasts and Similarities
Precambrian Orogens: Tectonic Setting and Crustal Architecture
Relations Between Diagenesis and Deformation
Perspectives on Desert Surface Processes
Cenozoic Sequences on Passive Margins: A Triad of Processes
West Coast Salt Marshes: Stratigraphy, Sea-Level Change, and Seismic Events
Evolution on the Atlantic Coastal Plain—Sedimentology, Stratigraphy, and Hydrogeology
Geologic Hazards Education for K–12 Students

Field Trips

Premeeting

Island and Coastal Hydrogeology of Hawaii, *Oct. 17–22*
Geomorphology and Stratigraphy of the Great Last-Glacial Missoula Floods in Central Washington and the Columbia River Gorge, *Oct. 18–23*
Late Cretaceous and Early Tertiary Orogeny in the North Cascade Range, *Oct. 19–23*
Gold Deposits of the Republic Graben, Washington, *Oct. 20–22*
Porphyry Ore Deposits of Southern British Columbia, *Oct. 20–22*
Volcanic, Sedimentary, and Structural Evolution of the Oregon-Idaho Graben, Southeast Oregon and Southwest Idaho, *Oct. 20–23*
Sedimentary, Volcanic, and Tectonic Framework of Tertiary Marine Forearc Basins and the Mist Gas Field, Northwest Oregon, *Oct. 20–23*
Quaternary Stratigraphy, Tectonic Geomorphology, and Fluvial Evolution of the Western Olympic Peninsula, Washington, *Oct. 21–23*
Pluton Emplacement During Mid-Cretaceous Contraction: Mount Stuart Batholith, North Cascades, *Oct. 21–23*
Vents and Basalt Flows of the Columbia River Basal Group, *Oct. 20–23*
Sequence Stratigraphy of the Eocene–Oligocene Transition: Examples from the Nonmarine, Volcanically Influenced John Day Basin, *Oct. 21–23*
Earth, Water, Trees, and Fish: Geomorphology and Land-Use Problems in the Forested Mountains of the Pacific Northwest, *Oct. 21–23*
Tectonostratigraphy of the Crescent Terrane and Related Rocks, Olympic Peninsula, Washington, *Oct. 21–23*
Mid-Tertiary Volcanism East of Mount Rainier: Fifes Peaks Volcano-Caldera and Bumping Lake Pluton–Mount Aix Caldera, *Oct. 22–23*
Mount Rainier, A Decade Volcano, *Oct. 22–23*
Holocene Tectonics in Western Washington, *Oct. 22–23*
Tertiary Coals of Western Washington, *Oct. 22–23*
Geoarcheology of Sites on San Juan Island, Washington, *Oct. 22*

Postmeeting

Geology and Tectonic Evolution of the Southern Coast Belt, B.C., *Oct. 27–29*
Fault-Zone Structures and Solution—Mass-Transfer Cleavage in Late Cretaceous Nappes, San Juan Islands, *Oct. 28–29*

The 1980 (Mostly) and Earlier Explosive Eruptions of Mount St. Helens Volcano, *Oct. 27–30*
Geologic Transect Across the Tertiary Cascade Volcanic Arc, Southern Washington, *Oct. 27–30*
Engineering Geology of Seattle and Vicinity, *Oct. 28–29*
Paleogene Cold Seeps and Macroinvertebrate Faunas in Forearc Sequences of Oregon and Washington, *Oct. 28–29*
Geohydrologic Setting of the Hanford Site, South-Central Washington, *Oct. 27–29*
Mineral Deposits of Vancouver Island, British Columbia, *Oct. 27–31*
Migmatites to Fault Gouge: Fault Rocks and the Structural and Tectonic Evolution of the Nason Terrane, North Cascade Mountains, *Oct. 28–29*
Cannon Epithermal Au-Ag Mine, Wenatchee, Washington, *Oct. 28–29*
Stratigraphy and Chronology of Early to Late Pleistocene Glacial and Interglacial Sedimentary Deposits in the Puget Lowland, *Oct. 28–30*
Character of Landslides in Western Washington and Oregon, *Oct. 28–30*
Chelan Migmatite Complex, North Cascades: Mafic Magmatism Spanning Crustal Anatexis and Protodiapiric Intrusion, *Oct. 28–30*

Short Courses/Workshops/Forums

Computer-Aided Plate Tectonic Modeling Techniques, *Oct. 22–23*
GPS Geodesy and Active Tectonics, *Oct. 22–23*
Phase I Environmental Site Assessments, *Oct. 22–23*
Quantitative Sedimentary Basin Modeling, *Oct. 22–23*
Soil and Ground-Water Remediation, *Oct. 22–23*
Applied Ground-Water Flow Modeling: Conceptualizing Hydrogeologic Systems and Calibrating Models, *Oct. 23*
Computer Applications in Undergraduate Geoscience Courses for the Macintosh, *Oct. 23*
Computer Mapping at Your Desk That Really Works, *Oct. 23*
GIS and the Geosciences, *Oct. 23*
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Geomorphic Applications of In-Situ–Produced Cosmogenic Isotopes, *Oct. 23*
Isotope Hydrology, *Oct. 23*
Recognition, Investigation, and Mitigation of Landslides, *Oct. 23*
Teaching Introductory Earth Systems for Non-Science Majors: An Interactive Approach, *Oct. 23*
Techniques for Analysis of Rock and Soil Slope Stability, *Oct. 23*
Silica: Physical Behavior, Geochemistry, and Materials Applications, *Oct. 21–23*
Geowriting: Guidelines for Writing and Referencing Technical Articles, *Oct. 22*
Joint Education Initiative (JEI) Workshop, *Oct. 22–23*
Solar Power Play, *Oct. 22*
Effective Teaching: A Workshop for Graduate Students, Assistant Professors, and Anyone Else Interested in Becoming a Better Teacher, *Oct. 22*
Fairly Simple Exercises in Geology Designed for Teachers with Little or No Geology Background, *Oct. 22*
Developing Good Multiple-Choice Test Questions, *Oct. 23*
Major Features of Vertebrate Evolution, *Oct. 23*
Job Hunting and Career Development Skills for Geoscientists, *Oct. 23*
Preparing Successful Grant Proposals to Fund Curriculum Innovation in the Geosciences, *Oct. 25*
Data Base Forum, *Oct. 23*

For further information about the annual meeting, contact GSA, Meetings Dept., P.O. Box 9140, Boulder, CO 80301; (303) 447-2020 or 1-800-472-1988. *The preregistration deadline is September 16.*

Notes ON NEW PUBLICATIONS

Distribution and Variability of Nitrogen and Phosphorus in the Alluvial, High Plains, Rush Springs, and Blaine Aquifers in Western Oklahoma

Prepared in cooperation with the Oklahoma Department of Agriculture, this USGS open-file report presents nutrient data from the National Water Information System data base for the alluvial aquifers west of longitude 98° W and from three bedrock aquifers, High Plains, Rush Springs, and Blaine. The 30-page report, written by Carol Johnson Becker, is intended to provide this information for future projects and for the facilitation of nutrient source management.

Order OF 94-41 from: U.S. Geological Survey, Water Resources Division, 202 N.W. 66th St., Bldg. 7, Oklahoma City, OK 73116; phone (405) 231-4256, fax 405-843-7712. A limited number of copies are available free of charge.

Annual Yield and Selected Hydrologic Data for the Arkansas River Basin Compact, Arkansas–Oklahoma, 1992 Water Year

Prepared in cooperation with the Arkansas River Compact Commission, Arkansas–Oklahoma, this 42-page USGS open-file report was written by C. S. Barks, R. L. Blazs, and S. T. Touschner.

Order OF 93-0171 from: U.S. Geological Survey, Books and Open-File Reports Section, Federal Center, Box 25425, Denver, CO 80225; phone (303) 236-7476. The price is $4 for microfiche and $6.75 for a paper copy; add 25% to the price for foreign shipment.

Regional Aquifers in Kansas, Nebraska, and Parts of Arkansas, Colorado, Missouri, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming—Geohydrologic Framework

Donald G. Jorgensen, John O. Helgesen, and Jeffrey L. Imes evaluate the resource potential of water in Cambrian through Lower Cretaceous rocks in part of the central United States. This 72-page USGS professional paper is one of five chapters reporting the findings of the Central Midwest Regional Aquifer-System Analysis (RASA) Program. The study area includes parts of the Interior Plains and the Ozark Plateaus physiographic divisions. In the Western Interior Plains, two regional water-yielding units are present—the Great Plains and the Western Interior Plains aquifer systems. In the Ozark area, the Ozark Plateaus aquifer system is present and consists of three aquifers—the Springfield Plateau aquifer, the Ozark aquifer, and the St. Francois aquifer. The volume contains 25 plates in a pocket.

Order P 1414-B from: U.S. Geological Survey, Books and Open-File Reports Section, Federal Center, Box 25425, Denver, CO 80225; phone (303) 236-7476. The price is $28; add 25% to the price for foreign shipment.

Oklahoma ABSTRACTS

The following are abstracts from theses and dissertations prepared by graduates of the University of Oklahoma, University of Kansas, Texas A&M University, University of Texas at Austin, Indiana University, University of Tulsa, University of Leicester, Baylor University, Stephen F. Austin State University, Texas Tech University, Kansas State University, University of Iowa, University of Texas at Arlington, University of Texas at Dallas, and University of Missouri at Rolla. Permission of the authors to reproduce the abstracts is gratefully achnowledged.

A Geochemical Study of Potential Source Rocks and Crude Oils in the Anadarko Basin, Oklahoma

HUAI DA WANG, University of Oklahoma, Norman, Ph.D. dissertation, 1993

Source rock and crude oil samples from the Anadarko Basin, Oklahoma have been characterized by a number of organic geochemical techniques. The source rocks investigated include the Late Ordovician Viola Limestone and Sylvan Shale, the Early Mississippian Lower Mississippian Limestone, and the Late Mississippian to Pennsylvanian Chester, Springer, and Morrow Formations. Since the Late Devonian Woodford Shale is an important source rock in the basin and has been investigated intensively in previous studies, the Woodford Shale was also analyzed and used as an "interval standard" or a reference formation to compare with other formations examined in this study. The crude oils examined in this study were obtained from various reservoir formations of different ages throughout the Basin.

Based on the results of screening analyses and geological information, a source rock evaluation model (PGI maps) has been built to evaluate the five source rock formations. Besides the Woodford Shale (which is proved by the model to be a very good source rock) the model indicates that the Lower and Middle sub-facies of the Viola Limestone are good source rocks, especially at the eastern Anadarko Basin. The Sylvan shale in the Anadarko area is probably not a good source rock. The black shales in the Springer and Morrow Formations are fairly good source rocks, especially for generation of natural gas. The results of this study support the proposal of multiple sources oil and gas generation in the Anadarko Basin.

Selected source rock and crude oil samples were processed for further organic geochemical analyses, which included stable carbon isotope (d13C), gas chromatography (GC), gas chromatography and mass spectrometry (GC/MS and GC/MS/MS) and pyrolysis gas chromatograph and mass spectrometry (PY–GC/MS). The distributions and concentrations (both relative and absolute concentrations were measured) of biomarkers in different source rocks and crude oils were investigated and compared and the variations of biomarker concentrations with maturity, migration, and weathering within each source rock were investigated. The biomarker characteristics were combined with other geochemical and geological information to interpret the sources, depositional environments, diagenesis and catagenesis processes, migration and weathering of the source rocks and crude oils. Apparent oil-source rock correlations were found between the Viola, Woodford, and Lower Mississippian source rocks and a number of crude oils using biomarker characterization, quantitation, and other geochemical data.

Petrographic descriptions and graptolite reflectance (or vitrinite reflectance) measurements were made to evaluate petrographic properties of source rocks and kerogens and to evaluate the maturity levels of the Viola and Lower Mississippian Limestones. There was a reasonable correlation between measured graptolite and calculated vitrinite reflectance values.

A Model for Assessing Surface Water and Soil Impacts of Oil Well Spills in Seminole County, Oklahoma

SALLY L. GROS, University of Oklahoma, Norman, Ph.D. dissertation, 1992

The environmental impacts of oil wells and pipelines are of concern to the oil industry, regulatory agencies, and the public. An evaluation of Oklahoma oil environmental regulations indicates that current evaluation techniques are reactive and address a site in response to a complaint. To administer proactive environmental policies which would predict environmental impacts and address concerns before damage occurs requires the development of environmental impact models which utilize terrain, land cover, hydrology, soils, and well/pipeline design feature data.

To increase understanding of the variables associated with surface environmental impacts of the oil industry, this study develops environmental models which indicate the impact potential of a well and pipeline. Oil activities in Seminole County, Oklahoma, provide a case study from which to develop the models. Model definition is based on the literature and professional judgement. Using the Delphi technique, relevant factors which govern the occurrence and severity of impacts are identified, weighted, and scaled through a sequence of questionnaires completed by knowledgeable individuals. Models assessing surface water and soil impacts from oil well spills are the major focus of this study. Models assessing surface water and soil impacts associated with pipeline leaks are developed, by were not implemented due to the unavailability of data.

Model implementation is performed using a geographic information system into which the weighted/scaled measures for each factor are coded. Individual map themes are then combined in an additive fashion to produce a composite map showing a numerical index which relates the impact potential of a well.

Results indicate that the surface water model represents a successful way to which to assess the surface water impact potential of an oil well. Success is evaluated on the basis of a statistical comparison of predicted and observed results. Results further indicate that the soil model could not be evaluated in terms of its success largely because of conflicting model factors and unreliable results from the independent site assessment survey.

Diagenetic Investigation of Pelitic Rocks across the Shale–Slate–Phyllite Transformation, Stanley Shale, Ouachita Mountains, Oklahoma and Arkansas

MATTHEW WAYNE TOTTEN, University of Oklahoma, Norman, Ph.D. dissertation, 1992

Considerable disagreement exists concerning whether shales behave as open or closed systems during diagenesis and low grade metamorphism. Because of their low abundances, trace elements and rare earth elements are particularly suitable for a test of element mobility.

Samples collected from the Stanley Shale (Mississippian) in the Ouachita Mountains of Oklahoma and Arkansas were analyzed using a variety of methods. The Stanley is part of a thick flysch sequence that grades from shale to slate to phyllite toward the core area of metamorphism. The data obtained were related to the areal distribution of maximum burial temperatures as determined using vitrinite reflectance data of Houseknecht and Matthews (1985).

Whole rock chemical abundances show no statistical correlation with thermal maturity across the wide range of reported reflectance values. Both major and trace element concentrations exhibit little variation.

Elements released during clay-mineral diagenesis precipitate as authigenic phases within the rock system. Silica precipitates as chert, the percentage of which increases at the expense of monocrystalline quartz. Released iron precipitates primarily as magnetite. Sodium appears to be involved in albitization of feldspars.

The grain size of the non-clay mineral fraction coarsens with increasing thermal maturity, supporting the actuality of diagenetic mineral growth involving elements released during clay-mineral transformations.

The results of this study indicate that shales are a closed system during diagenesis. Significant amounts of inorganic material are neither imported nor exported. The closed system behavior of trace and rare earth elements during diagenesis and low grade metamorphism contributes to their usefulness in discriminating provenance and tectonic environment in sedimentary rocks.

Comparison of average Stanley Shale trace element abundances to those from known tectonic environments (Floyd, 1991) suggests an active margin setting during deposition of the Stanley. Elemental trends are consistent with two-component mixing between a cratonic and a more mafic source. The association of higher than average percentages of chert in the Stanley with increased concentrations of elements unique to mafic minerals in anomalous samples supports an ocean-floor component to the Stanley Shale. It is possible that this material was derived from ophiolites obducted onto the continent during subduction of oceanic crust.

Facies Patterns in the Lower Deese Group (Desmoinesian) of the Ardmore Basin, Southern Oklahoma

PATRICIA C. BILLINGSLEY, University of Oklahoma, Norman, M.S. thesis, 1992

The clastic middle Pennsylvanian Lower Deese group was deposited in the Ardmore basin during a period of intermittent regional tectonic activity, with episodic influxes of distinctive chert pebble conglomerates into the basin, and cyclic worldwide sea level changes. Ten major facies have been defined in surface exposures from the study area: (A) fossiliferous sandstones and sandy limestones, (B) light and colored shales, (C) dark gray shales, (D) alternating thin bedded to laminated sandstone and shales, (E) unstructured sandstones and siltstones, thick to unbedded, (F) sandstones with large scale low angle crossbedding, (G) ripple cross-stratified sandstones, (H) large scale crossbedded sandstones, (I) upper flow regime plane beds, and (J) conglomeratic sandstones.

The facies combine to form seven distinctive facies assemblage patterns or sequences. These reflect deposition in changing water depths. Certain of these sequences are likely to occur in succession, creating three general assemblage packages which indicate deposition in similar and adjoining environments. The three assemblages are shallow marine, braidplain/alluvial, and delta/fluvial.

Most of the lower portion of the Lower Deese section was deposited in a shallow marine to delta front setting. Fining and coarsening upward repeating shallow marine and delta front sequences are commonly bundled in groups of approximately 5 cycles per set between thick dark-gray marine shales. This cyclic five-fold bundling pattern suggests deposition in changing water depths related to climatic changes with Milankovitch periodicity.

In the southern part of the basin, the middle part (Devil's Kitchen) of the Lower Deese section, and some sequences near the base, are composed of coarse cherty conglomeratic clastics probably deposited in response to episodes of tectonic activity in the Ouachita Mountain Thrust Belt. The upper portion of the Lower Deese section is composed mainly of deltaic and fluvial sediments.

The Effects of Confining Pressure on the Mechanical Behavior and Deformation Mechanisms for the Oil Creek Sandstone in Laboratory Tests

LOUIS ALFRED BOLDT, University of Oklahoma, Norman, M.S. thesis, 1992

Laboratory rock testing procedures are used to study the effect of confining pressure on the mechanical behavior and deformation mechanism for the Oil Creek Sandstone: a lightly cemented (quartz), high porosity (≈35%) quartz sandstone. [The samples are from U.S. Silica's Plant #39 just north of Mill Creek, Oklahoma.] Triaxial compression tests are run on room dry samples, at 25°C, and a constant strain rate of 1.34×10^{-5} sec^{-1}, at confining pressures of 5, 20, 40, 60, 80, 100, 120, and 135 MPa. Stress-strain curves for the sandstone are derived from triaxial test data. Indention tests are run on room dry samples, at 25°C, an approximate displacement rate of 1.76×10^{-4} mm $(sec)^{-1}$, and at confining pressure of 44.8 MPa (low) and 124.1 MPa (high). Indention test samples are utilized to study mechanisms by which this sandstone deforms.

Triaxial compression tests illustrate that: (1) the confining pressure at which the boundaries between brittle, transitional, and ductile behavior occurs is higher than for the lower porosity samples tested by Scott and Nielsen (1991), (2) the entire yield surface for Oil Creek Sandstone is delineated over confining pressures encountered in the shallow crust, and (3) porosity is a dominant factor controlling the yield strength of sandstones.

Microscopic observations of both triaxial and indention test samples reflect several types of grain fracturing. Brittle behavior is characterized by grain-contact microfractures that parallel the load axis. Slip along a shear fracture plane is required to produce an extreme reduction in grain size. Transitional behavior is divided into two categories. Category 1, associated with the lower boundary of transitional behavior, is similar to brittle behavior (an abundance of grain-contact microfractures parallel to the load axis with only a small percentage of fine particles). In category 2, associated with the upper boundary of transitional behavior, grain-contact microfractures parallel to the load axis are present, but fewer in number and there is a substantial increase in the percentage of fine particles. The increase in fine particles, however, is not a function of slip as is the case in the brittle domain. Ductile behavior is characterized by grain contact microfractures that do not show a preferred orientation.

Indention tests illustrate two modes of grain fracturing. Mode 1 is simply grain-contact microfractures. Mode 2, on the other hand, is another types of grain fracturing that polygonizes the grain into randomly oriented, small fragments. In low confining pressure tests, there is a spatial relationship between the indenter, the amount of indention, and growth and development of a zone of mode 2 grain fracturing.

Some of the textures developed, and genesis of the textures, in triaxial and indention tests are similar to natural deformation bands. The texture associated with the brittle domain, after visible slip along a shear fracture occurs, is somewhat similar to natural deformation bands. However, in natural deformation bands, this same texture is produced with only minuscule displacement. The texture of category 2 in transitional behavior is also similar to natural deformation bands and, like natural deformation bands, extreme granulation occurs without visible slip. In low pressure indention tests, the texture and development of mode 2 grain fracturing is also similar to natural deformation bands.

Paleomagnetic Investigation of Diagenetic Processes Affecting the Cambro–Ordovician Royer Dolomite, Arbuckle Mountains, Oklahoma

KELVIN DOUGLAS CATES, University of Oklahoma, Norman,
M.S. thesis, 1992

Specimens from the Cambro–Ordovician Royer Dolomite in southeastern Oklahoma display a streaked distribution of directions. Based on extensive sampling, two end members of the distribution were isolated. One end member is southerly and shallow and interpreted to be a Late Paleozoic chemical remanent magnetization (CRM) that resides in magnetite. Petrographic results suggest this magnetization resides in rocks that have been dolomitized by basinal fluids. The second end member, which resides in magnetite, is easterly and shallow, and is only partially preserved. It is interpreted to be an Early Paleozoic detrital remanent magnetization (DRM) or early CRM. This component is found in dolomite that is apparently early in origin. Rock magnetic analysis suggest that the magnetization process was more efficient for this component than for the Late Paleozoic CRM.

The streaked distribution of directions is interpreted to be the result of a vector addition of the Early and Late Paleozoic directions. The presence of specimens with both components and curved demagnetization paths support this interpretation. The process which caused the Late Paleozoic CRM was probably related to the dolomitizing or associated fluids.

Taxonomy and Evolution of Selected Species of *Neochonetes* and *Mesolobus* in the Early Middle Pennsylvanian (Late Atokan and Earliest Desmoinesian) of the Ardmore Basin, South-Central Oklahoma

CLIFFORD ANDREW CUFFEY, University of Oklahoma, Norman, M.S. thesis, 1992

Chonetid brachiopods from the Bostwick and Shale 3 Members of the Lake Murray Formation (Dornick Hills Group, upper Atokan and lowermost Desmoinesian) belong to *Neochonetes* cf. *N. henryi* (in the upper part of the Bostwick), *Mesolobus* cf. *M. obsoletus* (primitive) (in the lower part of Shale 3), *Mesolobus obsoletus* (in the middle part of Shale 3), and *Mesolobus striatus* (in the lower and middle parts of Shale 3).

A sequence of closely spaced samples of *Mesolobus* cf. *M. obsoletus* (primitive) and *Mesolobus obsoletus* was collected from the best bedrock exposure of the lower and middle parts of Shale 3 (measured section 363) in the Ardmore Basin of south-central Oklahoma. The specimens were measured, and these quantitative data were graphically plotted with summary statistics in order to detect morphologic changes through time.

Twelve characters were quantified, of which eleven were chosen for analysis, both

graphically and statistically. Of these, two exhibited consistent unidirectional trends and are interpreted to be the result of evolution. These characters are (1) the relative height of the mesial fold relative to the lateral surfaces at the commissure (CM) and (2) the relative height of the mesial fold relative to the lateral surfaces at the crest of the pedicle valve (PV). One character (LW—length/width ratio) exhibits unidirectional trend in all but the highest sample. Seven characters fluctuate in response to the diversity of the associated fauna and are interpreted as reflecting environmental control on the morphology of the chonetids. These characters are (1) shell width at the hinge (WD); (2) greatest length (LN); (3) greatest height (HT); (4) length/height ratio (LH); (5) relative strength of mesial fold (MF); (6) maximum width of mesial fold (MW); and (7) relative strength of sulcus (SU). One additional character (PM—distance from the beak to the beginning of the mesial fold) does not exhibit any consistent trend or fluctuation.

This new evidence from the Ardmore Basin strongly suggests that *Mesolobus obsoletus* evolved from *Neochonetes henryi* during the latest Atokan. Only the last phase of this transition is preserved in the sequence studied. The remainder of the transition probably was occurring during that part of the late Atokan that is missing at an underlying unconformity in the Ardmore Basin.

Detection of Bias in the Oklahoma Earthquake Catalog: Methods and Interpretation

JOHN EVANS DELAUGHTER, University of Oklahoma, Norman, M.S. thesis, 1993

Earthquake catalogs suffer at some magnitude level from missed events due to noise. In addition, some earthquake catalogs contain events in a given magnitude range that are due to sources other than earthquakes. Interpretations made from a catalog need to consider these forms of bias.

The Oklahoma earthquake catalog has not previously been analyzed to establish what types of bias, if any are present. This thesis investigates techniques for determining bias and attempts to establish possible relationships between observed biases and causes in the Oklahoma earthquake catalog for the years 1977 to 1991.

The strong bias exists in Oklahoma catalog for primary events with magnitudes lower than 2.0M. The bias cause is inferred to be masking by traffic noise and solar thermal noise, based on the timing and character of the bias. Another, weaker bias is seen for earthquakes with magnitudes greater than 2.23M. Timing of this bias suggests that it is not due to masking by traffic or solar thermal effects. Increased seismicity levels due to well completion activities and tidal forces are also eliminated as likely causes for this bias. The bias is, therefore, assumed to be due to statistical fluctuation in a limited data set; however, more data is needed before a conclusive analysis can be made.

The possibility of a correlation between earthquakes in Oklahoma and water injection has been suggested. While a slight correlation ($r = .29$) is found, the lack of character and quality of data suggest that there is no actual support for this relationship.

Coalbed Methane Potential of the Hartshorne Coals in Parts of Haskell, Latimer, Le Flore, McIntosh, and Pittsburg Counties, Oklahoma

JOHN MEHREN GOSSLING, University of Oklahoma, Norman, M.S. thesis, 1994

Previous investigations into the coalbed methane (CBM) resources in the Arkoma basin have been limited in aerial extent or have underestimated the resources by only using data associated with coal mining. Data from the oil and gas industry, coal mining industry, and recent CBM activity has been combined to better quantify the CBM resources in 65 townships in the Arkoma basin.

The Kim (1977) equation was used to estimate the CBM resources for the Hartshorne and upper Hartshorne coals on a by-depth and township basis. Variables used in the Kim equation were obtained from 842 geophysical well logs, 200 proximate analyses, 150 pressure gradients, 60 geothermal gradient values, 77 coal thickness measurements from coal mines and outcrops, and data from 163 coal test holes.

Hartshorne Formation CBM resources are controlled by several factors including coal thickness, total coal resources, reservoir pressure, and coal rank. Coals are thin or absent over major channel-fill sandstones of the Hartshorne and upper Hartshorne. The Hartshorne coal is ≤8 ft thick and the upper Hartshorne coal is ≤6 ft thick. Calculated coal resources of 8.01 billion tons of Hartshorne Formation coal exceed the previously calculated remaining coal resources for the entire state. The Hartshorne Formation reservoir pressure was calculated to be less than hydrostatic with an average pressure gradient of 0.306 psi/ft.

Calculated gas contents were found to be in agreement with the limited direct method measured data. Calculated gas contents are from 185.7 SCF/ton at 250–499 ft deep to 569 SCF/ton at >3,000 ft deep. The average gas content is 373 SCF/ton. CBM resources vary from 30–122 BCF/township. The townships with the largest CBM resources are in the eastern part of the study area where coals are of low-volatile bituminous rank and >1,000 ft deep. The majority (77%) of the Hartshorne Formation CBM resources are at reasonably shallow depths of <3,000 ft. The total CBM resources identified in this study range from 3.12 TCF to 3.54 TCF of gas.

Geochemistry of the Mississippian Volcaniclastics in the Stanley Group, Ouachita Mountains, Oklahoma and Arkansas: Implications for Tectonic Environment

JENNIFER LEE LOOMIS, University of Oklahoma, Norman, M.S. thesis, 1992

A total of 46 tuff samples from the Mississippian Stanley Group in outcrop and 8 rhyolite samples collected from cores near the Sabine Uplift in Sabine County, Texas, have been analyzed for major element, trace element and rare earth element abundances. The effects of differential settling of crystals during deposition, diagenesis and weathering on tuff geochemistry have been characterized. Despite post-eruptive alteration and modification of the Stanley tuffs, enough of the igneous geochemical signature remains so that tuff geochemistry can be used to determine what type of tectonic setting was present along the Paleozoic southern North American plate margin.

A study of young rhyolites and tuffs from known, present-day tectonic settings provides the framework by which to determine which geochemical characteris- tics can be used as tectonic discriminants. The presence of a Ta–Nb trough (and whether or not it is persistent throughout the samples of a volcanic suite), the variability and extent of Ba and Sr depletion, and the extent of mobile-element enrichment relative to mid-ocean ridge basalts are the geochemical features which can be collectively used to determine the tectonic setting of high-silica volcanics. Use of these geochemical features suggests that the Stanley tuffs and the Sabine rhyolite are associated with a continental island-arc system. In addition, plotting the tuffs and rhyolite samples on the granite tectonic discrimination diagrams developed by Pearce et al. (1984) implies that the Ouachita volcanics may have a back-arc basin component.

Factors Controlling Simpson Group Production in Central Oklahoma

PAUL WINSTON SMITH, University of Oklahoma, Norman, M.S. thesis, 1992

The area of study for this thesis includes Townships 7 through 9 North, Ranges 1 through 3 West, Cleveland and McClain Counties, Oklahoma. Sandstones of the five Simpson Group Formations have produced more than 65,000,000 barrels of oil from this 324 square mile area. Production is from structural traps, generally small faulted anticlines ranging in size from 80 to 750 acres. Cumulative oil production per field ranges from 36,000 to 11,760,000 barrels of oil.

The distribution of oil production from within the Simpson Group has been considered enigmatic because all of the sandstone members are present throughout the thesis area, but some fields have attained production from all of the sandstone members and others produce from only one horizon. The Simpson shales are not capable of generating hydrocarbons and the oil produced from the Simpson Group probably originated from the Devonian/Mississippian Woodford Shale. The McClain County fault juxtaposed the Woodford Shale with the Simpson Group which enabled lateral oil migration from the Woodford into the Simpson sandstones. Also, tortuous migration pathways allowed Woodford oil to ultimately accumulate in Simpson reservoirs which involve downthrown younger rocks adjacent to upthrown older rocks.

Slight structural movements occurred contemporaneously with the deposition of the Simpson Group creating semi-parallel northeast–southwest oriented thick and thin trends. Local structural movements were active during part or all of Simpson deposition. This created stratigraphic variations in the individual Simpson Group Formations which cause the apex of a field to migrate (or even vanish) with depth. Consequently, lower Simpson structures may not be reflected by upper Simpson structures, and conversely, upper Simpson structures may not continue with depth. Variations in Viola deposition enhanced the vertical discontinuity of structures within the study area so that mapped Viola structures may not reflect underlying Simpson structures. Furthermore, a dramatic change in the orientation of the structural grain began to appear in late Ordovician (Viola) time. Subsequent movements enhanced this later structural orientation producing two acute structural trends which control the entrapment of oil. This study demonstrates that the dual structural imprint is probably the single most important factor in controlling the distribution and accumulation of hydrocarbons within the thesis area. This study also identified stratigraphic conditions within the Simpson Group sandstones which may affect their productivity.

Lithology and Geochemistry of Shale Members within the Devonian–Mississippian Chattanooga (Woodford) Shale, Midcontinent, USA

MICHAEL WILLIAM LAMBERT, University of Kansas, Lawrence, Ph.D. dissertation, 1992

The Chattanooga (Woodford) Shale in a widespread marine mudrock, covering much of the central and eastern United States. In the Midcontinent, internal differences in radioactivity make it divisible into informally named lower, middle, and upper shale members. The present study investigates the distribution of these shale members in Oklahoma, Kansas, and southeastern Nebraska through detailed geophysical log correlation, and uses lithological and geochemical analysis of cored samples of the shale members to determine the depositional environments represented by each. Due to practical limitations on the number of geochemical analyses that could be conducted, a representative sample was chosen from each core of each shale member.

In addition to being the most radioactive part of the formation, the middle shale member is also the thickest and most areally widespread, covering most of the study area and becoming as much as 68.6 m (225 ft) thick in northeastern Kansas. The lower shale member is the thinnest and least areally widespread, and is about 45.7 m (150 ft) thick in southwestern Oklahoma. All three shale members are present in the southern part of the study area in Oklahoma, but to the north first the lower shale member and then the upper shale member pinch out.

Clay fabric analysis and redox facies determined from whole-rock elemental geochemistry suggest that the Chattanooga (Woodford) Shale was deposited in quiet, poorly oxygenated settings. Organic facies determined from kerogen geochemistry indicate that the middle shale member was deposited under the most anoxic conditions, and that the degree of anoxia for the formation lessened to the north.

The shale members within the Chattanooga (Woodford) Shale represent a third-order cycle of sea-level rise and fall. The lower shale member was deposited in the early stages of the Late Devonian–Early Mississippian transgression in the Midcontinent, while the middle shale member appears to have been deposited at the time of relative sea-level highstand. The upper shale member was deposited late in the cycle, when sea-level had already begun to fall. A regional unconformity is present at the base of the Chattanooga (Woodford) Shale, and a more subtle unconformity separates the formation from the overlying Mississippian carbonates. The shale members may therefore comprise a depositional sequence, but greater biostratigraphic control is needed to confirm that the shale members are time-stratigraphic units.

Diagenesis of Pennsylvanian Sandstones and Limestones, Cherokee Basin, Southeastern Kansas: Importance of Regional Fluid Flow (Fluid Flow)

KRZYSZTOF MIKOLAJ WOJCIK, University of Kansas, Lawrence, Ph.D. dissertation, 1992

The Cherokee basin in southeastern Kansas is a shallow, cratonic downwarp adjacent to the Arkoma foreland basin to the south and the Ozark Uplift to the east. Nearby pre-Pennsylvanian carbonates of the Ozarks host lead–zinc deposits that provide evidence of late Paleozoic fluid invasion. This study investigates diagenesis of Pennsylvanian sandstones and limestones to determine how this invasion event is recorded in the Cherokee basin.

Fluid inclusion homogenization temperatures in late carbonate cements are 20–60°C higher than temperatures calculated for peak burial of Pennsylvanian strata. Thermal maturation data (provided by C. E. Barker) show suppressed geothermal gradients and presence of small, anomalously hot areas. These observations are inconsistent with burial heating; it is thus proposed that the Cherokee basin experienced advective heat transfer related to the regional invasion of basinal fluids recorded in the Ozarks.

Paragenesis of Pennsylvanian rocks includes an early stage with pyrite, siderite, and calcite in sandstones, and calcite in limestones; an intermediate stage with quartz overgrowths in sandstones and iron-rich calcite in limestones; and a late stage in both lithologies characterized by a widespread dissolution event, baroque ankerite or Fe–dolomite, Ba–Sr sulfates, and kaolinite. This late-diagenetic assemblage resulted from invasion of hot basinal fluids that facilitated extensive diagenesis at shallow depths, providing heat to drive diagenetic reactions and fluid flux to transfer diagenetic components.

Paragenetic and spatial trends defined by the Ca–Mg–Fe, Mn, Sr, $\delta^{13}C$, and $\delta^{18}O$ composition of baroque cements indicate early replacement of preexisting carbonates followed by dissolution of framework grains and earlier replacive phases, followed in turn by precipitation of baroque cements. Compositional differences between late-diagenetic carbonates in sandstones and limestones resulted from a lithologic overprint, whereas paragenetic trends recorded by cements in both lithogies reflect evolution of the regional diagenetic system.

A significant part of the early stage of diagenesis took place in Na–Ca–brines with negative $\delta^{18}O$ and at temperatures below 50°C. During the late stage, hot basinal fluids (85 to 150°C) with positive $\delta^{18}O$ composition migrated from the Ouachita–Arkoma system, invading cratonic strata of the foreland; the first fluid mobilized was a Na–Ca–brine, and it was followed by a Na-rich brine.

A Shallow Seismic Reflection Study of the Meers Fault, Comanche County, Oklahoma

PAUL B. MYERS, University of Kansas, Lawrence, M.S. thesis, 1989

A high-resolution seismic survey in the vicinity of the Meers Fault Scarp in Comanche County Oklahoma was conducted to achieve a better understanding of the shallow structure associated with the fault zone. Three reflection profiles were acquired using a downhole 0.50-caliber rifle as the seismic energy source and two 100-Hz geophones connected in series at each receiving station. Two profiles (seismic lines 1 and 2) were oriented perpendicular to the scarp and one profile (seismic line 3) was oriented parallel to the scarp. Field parameters were set to optimize the recording of seismic reflections in the 40 to 150 ms range. Pre-analog-to-digital filters applied during recording helped increase the dominant reflection frequencies into the 100 to 250 Hz range. Reverse faulting is evident on the fault associated with the scarp as well as throughout a line extending 250 meters southwest to 200 meters northeast of the scarp. The high quality stacked CDP seismic data allows interpretation of an up-to-the-north vertical to high-angle reverse slip orientation on the Meers Fault. Quantification of most recent vertical displacement on the fault associated with the scarp requires drill-core data. Maximum vertical displacement does not exceed 10 meters on the remainder of the secondary interpreted faults. Normal faulting dominates the seismic data of line three acquired parallel to the scarp. A graben with maximum displacement of approximately 10 to 30 meters is the major feature on the stacked CDP section. Deformation is apparent throughout the line suggesting strike slip motion along the fault may have resulted in deformation along its entire length. The instantaneous phase and instantaneous frequency complex trace attributes of the seismic traverses support the interpreted fault structures. The evidence supporting strike slip motion in conjunction with high-angle up-to-the-north reverse faulting places the Meers Fault in a transpressive tectonic environment during Quaternary time.

The Northwest Extension of the Meers Fault in Southwestern Oklahoma

HASAN CETIN, Texas A&M University, College Station, M.S. thesis, 1991

The geology of southwestern Oklahoma is dominated by the Wichita Uplift. The uplift is bounded to the north–northeast by the Anadarko Basin and to the south by the Hollis–Hardeman Basin and is composed primarily of the Cambrian Wichita Granite

Complex and Precambrian Raggedy Mountain Gabbro Complex. The uplift is separated from the Anadarko Basin by the Frontal Fault Zone, which extends for 200 mi (330 km) in a northwest to southeast orientation. The zone, ranging from 7 to 10 mi (12 to 17 km) in width, has faults whose strike is roughly parallel to the dominant trend directions. There are three faults dominating the fault zone: the Meers (originally Thomas), the Blue Creek Canyon, and the Mountain View faults.

Detailed mapping of previously unmapped terrace deposits, a trench, and creek banks along an extended N60°W trending line in Kiowa County, Oklahoma, strongly suggests that the Meers Fault has an active northwest extension of about 30 km which bifurcates in the Sugar Creek area and continues with a new trend of N80°W. Substantial deflection of stream alignments, buried A-soil horizons, gravels coated by seeping oil from the fault zone, shale and A-soil horizon fragments (colluvium) eroded from the upthrown block, and displaced terrace deposits are the evidences for this activity. Bulk soil C-14 dates on two samples collected from an organic buried A-soil horizon and fragment gave ages of 1090 ±80 BP and 760 ±70 BP years, indicating that the Meers Fault must have moved in Late Holocene and may have caused a large earthquake that created a high scarp where well cemented Post Oak Conglomerate outcrops and a slope where flexible Hennessy Shale outcrops.

This suggests reevaluation of present building construction codes, careful assessment of seismic risk for critical facilities in the region, and implementation of precautionary safety and educational measures for the local population.

Geomorphic Evidence for Late Cenozoic Deformation, Wichita Mountains, Oklahoma

CHARLES BURTON SNELL, Texas A&M University, College Station, M.S. thesis, 1989

Holocene displacement on the Meers fault has prompted an investigation into Late Cenozoic tectonic activity in southwestern Oklahoma. The emphasis of this study was on geomorphic evidence in the Wichita Mountains which might document disturbances in landform development.

Map, aerial photograph, and field studies led to the identification of numerous pediments throughout the granite hills of the Wichita Mountains. These pediments may be divided into two groups based on physiographic and geomorphic relationships. The upper group, containing the previously recognized Lake Altus granite platforms (western Wichita Mountains) and similar surfaces to the east, formed following Ogallala deposition on the Southern High Plains in Late Pliocene time.

Pediments in the eastern Wichita Mountains were stripped of their in situ mantle by vigorous Early Pleistocene erosion. Subsequent lowering of the surrounding plains was accompanied by westward retreat of the Southern High Plains escarpment. By Middle Pleistocene (Yarmouth) time, the landscape east of the escarpment stabilized. Yarmouth age climatic stability resulted in the formation of a second pediment set within the valleys of the eastern Wichita Mountains.

Formed during the same period of climatic stability, all members of the upper pediment set would be expected to exhibit concordant elevations. However, this is not the case. Discordance among members of the upper pediment set document moderate post-Pliocene deformation along the Wichita Uplift. Tectonic activity along the Amarillo Uplift resulted in slight warping of the Southern High Plains surface. Modest upwarping is suggested by abnormal surface contours, lineament trends parallel to the Amarillo Uplift, apparent syndepositional deformation of Ogallala sediments, possible diversion of the Canadian River from the regional southeast gradient, and ongoing seismic activity along the western portion of the Amarillo Uplift.

Origin, Evolution, and Mixing of Saline and Dilute Groundwaters in Three Regional Flow Systems, Midcontinent, U.S.A.

MARYLYNN MUSGROVE, University of Texas, Austin, M.A. thesis, 1993

Lower Paleozoic strata in southeastern Kansas, southwestern Missouri and northern Oklahoma are predominantly marine carbonates that comprise portions of three regional flow systems. Groundwaters in these three adjacent systems exhibit extreme chemical and isotopic variations that delineate large-scale fluid mixing processes and two distinct mechanisms for the generation of saline fluids. Hydrodynamic and geochemical data closely correlate with geographic location and indicate that each system contains waters of markedly different origins. Results of elemental and isotopic mass balance modeling demonstrate that fluid mixing processes exert a fundamental control on groundwater compositions over the 40,000 km^2 study area. This quantification of groundwater mixing provides an important basis for determining endmember water compositions and evaluating hydrologic models for these flow systems. The three endmember groundwaters are as follows.

1) Dilute modern-day meteoric waters of the Ozark Plateaus aquifer system, recharged to southern Missouri. The evolution of this groundwater is dominated by interaction with host limestone and dolomite aquifer rocks.

2) Eastward migrating, saline Na–Ca–Cl groundwaters from the northern part of the Western Interior Plains aquifer system in central Kansas. These groundwaters are of meteoric origin with distant recharge areas. Salinity is acquired via the subsurface dissolution of Permian halite and subsequent water-rock interaction with silicate minerals. The chemical signature of these groundwaters, coupled with the presence of brines resulting from the dissolution of Permian halite in central Kansas, allow development of a model for the formation of saline Na–Ca–Cl fluids, a common component of many sedimentary basins. Additionally, the large-scale topographically driven flow of the northern part of this aquifer system is a modern analog for models for similar ancient systems.

3) Na–Ca–Cl brines in north-central Oklahoma. In contrast to the other saline endmember, the geochemical signature of endmember 3 groundwater, integrated with hydrogeologic data, indicate that this groundwater may represent a marine-derived brine from the deep Anadarko Basin.

Developmental and Sequence-Stratigraphic Analysis of Lower Cretaceous Sedimentary Systems in the Southern Part of the United States Western Interior: Interrelationships Between Eustacy, Local Tectonics, and Depositional Environments

JOHN MILLARD HOLBROOK, Indiana University, Bloomington, Ph.D. dissertation, 1993

Lower Cretaceous strata in northeastern New Mexico, southeastern Colorado, and the Oklahoma panhandle represent cycles, and are represented by the Lytle, Mesa Rica, Pajarit, and Muddy formations, and Plainview and Skull Creek equivalents. Photopanoramic cross sections of major canyon-wall exposures and bore-hole data were used to assess lithofacies distribution and morphology of arealy extensive lithofacies-bounding surfaces within these strata in order to formulate a regionally embracive model of Early Cretaceous deposition in the southern High Plains region.

Kiowa–Skull Creek transgression prompted filling of topographic lows in a regional erosional surface above Lytle and Jurassic Morris strata with valley-fill strata of the Plainview equivalent, and also produced a regionally correlative, transgressive surface of erosion/ravinement above these valley-fill strata. The marine Skull Creek equivalent was deposited during peak Kiowa–Skull Creek transgression and subsequent regression, and contains extensive marine marker beds that are critical to subsurface correlation of Lower Cretaceous units in the study area.

Incision of eastward and southeastward-directed valleys and formation of an extensive erosional surface above the Skull Creek equivalent accompanied maximum Kiowa–Skull Creek regression and regional exposure. Paleovalleys are absent in northeastern New Mexico, where development of stable base-level conditions promoted lateral migration and avulsion of fluvial channels and planation of the underlying Skull Creek equivalent. Greenhorn transgression followed maximum Kiowa–Skull Creek regression, resulting in aggradation of fluvial and coastal plain deposits recorded by Mesa Rica, Pajarito, and Muddy formations.

Early Cretaceous basement-cored uplifts affected thickness trends and lithofacies distribution in Lower Cretaceous strata of the study area and include the Las Animas, Turkey Creek, Rampart–Security, and Sierra Grande uplifts. Similar Early Cretaceous uplifts are prevalent throughout the United States Western Interior, suggesting presence of a widespread intraplate stress field that was in existence throughout the western United States, during Early Cretaceous time. This stress field is not explained by current tectonic models. The attendant tectonic features most likely reflect stresses that were introduced into the North American continent during Early Cretaceous subduction of the oceanic Farallon plate beneath the western North American margin.

Natural Gas Stability and Thermal History of the Arbuckle Reservoir, Western Arkoma Basin (Methane)

MAHMOUD TABIBIAN, University of Tulsa, Tulsa, Oklahoma, Ph.D. dissertation, 1993

In the Arkoma Basin the presence of dry gas (>90% methane) and high rank coals are not consistent with the present geothermal gradients. A variety of techniques was used to evaluate the thermal history and stability of natural gas in the Arbuckle Reservoir of the western Arkoma Basin. Dry gas, graphitic residues, and inclusion volatiles suggest a high paleotemperature for the Arbuckle Reservoir. Heating-stage fluid inclusion analyses show that the Arbuckle Reservoir has cooled from 173°C to 143°C (present reservoir temperature at the Wilburton Field) during Paleozoic basinal uplifting and unroofing. Burial history and thermal reconstructions reveal that the Arbuckle Reservoir should have experienced temperatures around 226°C, 278°C, and 343°C at the sites of the Wilburton, Red Oak and Bonanza Fields, respectively in order to provide consistency between organic maturity windows calculated using BasinMod program and the occurrence of dry gas and high rank coals.

Mass spectrometric analyses of fluid inclusions in fracture- and vug-filling cements reveal that volatile composition of fluid inclusions in the Arbuckle Reservoir is dominantly methane-rich at Wilburton Field and methane and carbon dioxide-rich at Bonanza Field. This compositional trend is coincident with the maturity trend in the basin and has been controlled by the paleotemperatures. Since carbon dioxide might have been derived from the thermal decomposition of carbonate minerals, as well as oxidation of methane, it appears that the compositions of volatiles in the fluid inclusions have been controlled by reservoir mineralogy and the initial hydrocarbon constituents.

Thermodynamic calculations indicate that natural gas stability in the Arbuckle Reservoir has been controlled by paleotemperature and reservoir mineralogy. With increasing depth, the concentration of methane decreases and carbon dioxide (or carbon monoxide) and hydrogen increase. Methane probably decreases because of dilution with carbon dioxide, oxidation with water, or by thermal destruction, and these conditions provide uneconomic gas in ultradeep reservoirs. Methane is stable in ultradeep horizons adjacent to the Wilburton Field, but its concentration decreases dramatically with depth. At the Bonanza Field, partly due to higher geothermal gradients and partly due to higher concentrations of carbon dioxide, methane is not stable in the deeper horizons.

A Reconnaissance Mapping of the Womble Formation Along the Glover River, McCurtain County, Oklahoma

STEVEN GARY ERICKSON, University of Tulsa, Tulsa, Oklahoma, M.S. thesis, 1990

A reconnaissance mapping project of the Womble Formation of Ordovician age was conducted along the Glover River in McCurtain County, Oklahoma. Seventy-five samples were collected and studied, and structural data was gathered.

The Womble sandstones have been metamorphosed to lowest greenschist grade rocks, still preserving most of the original textures. The Womble is usually found in beds 1 to 5 feet thick with interbedded shales. The psamites are usually brown, or blue-gray in color, are poorly sorted and have fine to coarse sized grains. The grains are mostly quartz and lithic fragments, and have a low percentage of feldspars. The cleavage in the Womble is the result of pressure solution of grains. Dissolved silica from the pressure solution in large part may be the cause of quartz veins. Carbonates mineral are seen as secondary replacement minerals in some samples.

The contact between the Womble and the overlaying Bigfork Chert Formation is a thrust fault. The fault zones frequently contain exotic blocks, including blocks of igneous rocks formerly called igneous intrusions. Folds of many sizes are common; most folds are tectonic in origin, not syndepositional.

The provenance of the Womble appears to be that of a recycled orogen. The Womble was deposited in an accretionary prism, probably near the "Llanorian" Plate.

Ostracoda (Arthropoda) from the Middle Ordovician Simpson Group, Oklahoma, U.S.A.

MARK WILLIAMS, University of Leicester, United Kingdom, Ph.D. dissertation, 1990

Middle Ordovician (Whiterockian–early Mohawkian) ostracodes are described from the Simpson Group of southern Oklahoma, U.S.A. These are referred to three orders (Beyrichiocopa, Platycopa, Podocopa), seven suborders (Palaeocopa, Leiocopa, Eridostraca, Binodicopa, Cytherelliformes, Metacopa, Cypridocopa), 23 families, 59 genera (17 new), two subgenera (one new) and 121 species and/or subspecies including eight new.

Both limestones and shales, from logged sections in the Simpson Group at six localities in the Arbuckle Mountains and Criner Hills of southern Oklahoma have yielded a prolific and well preserved calcareous ostracode fauna. The localities represent a shelf-basin transect across the Lower Palaeozoic Southern Oklahoma Aulacogen in which the Simpson Group was deposited. Very nearshore peritidal or tidal flat environments are dominated by abundant leperditicope and/or cytherel-liforme ostracodes, but have low species diversity. Ostracode faunas occupying more normal marine environments in water depths probably between 5 and 80 metres are taxonomically more diverse. Leperditicopes form a much reduced component of these faunas which are usually rich in palaeocope and leiocope taxa.

Simpson Group ostracodes include short ranging species and genera useful for local biostratigraphic resolution within each of the five formations. The fauna is also useful for inter-basinal correlation, at least 39 Simpson Group genera and 26 species are documented from elsewhere in N. America.

Palaeobiogeographic assessment of the Simpson Group ostracode fauna suggests faunal links existed between N. America (Laurentia) and the Baltic region (Baltica) by the late Whiterockian (Llandeilo–Caradoc). At least eight genera are common to the two areas. Ostracode faunal links with Britain (Avalonia) and southern and central Europe (Gondwana) are weaker during the same time period.

Middle Carboniferous Conodont Biostratigraphy: Frontal Ouachita Mountains, Pittsburg, Latimer, and Le Flore Counties, Oklahoma

JOSEPH ROY WHITESIDE, Baylor University, Waco, Texas, M.S. thesis, 1990

Carboniferous conodont faunas from the northwestern Ouachita Mountains, Oklahoma, represent six assemblages: two Mississippian (Meramecian?–Chesterian) and four Pennsylvanian (Morrowan–Atokan). The distribution of these assemblages suggests tentative modifications of previous biostratigraphic estimates for ages of stratigraphic units. Usage of the terms Caney and "Springer" Formations as equivalent to the chronostratigraphic subdivisions Mississippian and Pennsylvanian is unwarranted because the Caney is partly Pennsylvanian. The lower Johns Valley Formation is Pennsylvanian, but can now be shown to include rocks slightly older than previously estimated. Although observations are preliminary, Carboniferous stratigraphic units are demonstrably diachronous. Thus, the Mississippian/Pennsylvanian and Morrowan/Atokan boundaries cross lithostratigraphic boundaries. Future work should further refine the present work and more precisely locate chronostratigraphic boundaries.

Stratigraphy and Structural Styles of the Spiro Formation, Frontal Ouachita Mountains, Southeastern Oklahoma

LAWRENCE K. HINDE, Baylor University, Waco, Texas, M.S. thesis, 1992

The lower Atoka Spiro Formation is an excellent hydrocarbon host rock in the Arkoma Basin. The recent explosion in gas exploration from the Spiro is providing valuable new data for a comprehensive study of this formation.

The Spiro Formation consists of laterally interfingering sandstone, shale, and limestone that can be categorized into bar crest, bar flank, bar margin, interbar, and platform limestone facies. Sand bars deposited in a shallow marine shelf environment were derived from reworking of late Morrowan fluvio-deltaic Foster "channel sands."

Three sand bar fields are presently known within the Spiro in southeastern Oklahoma. The easternmost is the largest, with sand thickness in excess of 150 ft. Here,

sands exhibit primarily bar crest and bar flank facies. To the west, bar fields thin and become smaller in areal extent, exhibiting mostly bar margin and interbar facies. South of the present day Pine Mountain fault, slope and basinal sediments accumulated. To the east of the outcrop belt (along the frontal zone), the Spiro grades into a shale facies.

Field measurements of cross-bed orientations indicate a southwestward migration of sand bars. In addition, palinspastic restoration of thrust sheets confirms northeast–southwest paleodepositional trends and establish sand bar field geometries.

Late Pennsylvanian compressional tectonism has produced a narrow belt of thrust faults and repeated stratigraphic sequences, which crop out in the frontal Ouachita Mountains. Differences in thrusting styles are apparent from variations in the number of thrust imbrications in surface exposures. These variations are interpreted to be caused by upthrown block of deep seated normal faults acting as thrust ramps. Lithologic variations concordant with changes in structural styles indicate possible reactivation of syndepositional normal faulting.

Strain Distribution and Low Angle Faulting on the Eastern Flank of the Broken Bow Uplift, Oklahoma

RICKY LEE COLSON, Stephen F. Austin State University, Nacogdoches, Texas, M.S. thesis, 1992

Detachment between the core and flank sections of the Broken Bow Uplift, Ouachita Mountains, Oklahoma, has been debated since 1929. This issue is examined by field mapping and strain measurements.

The study area contains a low angle, southerly directed fault which separates a horizontally stacked shale-sandstone sequence that is characteristic of the core zone and an asymmetric, southerly verging fold involving cherts, sands and shales that is associated with the flank sections.

Synthetic modeling of the Fry technique for strain measurements as applied to sandstones demonstrates samples must be arenites for meaningful results. Measurements made from the flank section are reproduced through forward modeling with a generalized deformation scheme based on field observations.

The modeled orientations are compatible with average fold axes from the core section as reported in previous works and substantiated here by beta diagrams.

Elemental Geochemistry of Shales in Pennsylvanian Cyclothems, Midcontinent North America

WEE SENG TEO, Texas Tech University, Lubbock, Ph.D. dissertation, 1991

Pennsylvanian cyclothemic marine shales present a wide range of depositional environments that allow the study of depositional controls on distribution of certain elements in shales. Samples were collected from upper Desmoinesian to lower Virgilian units in north-central Texas, Kansas, and Oklahoma. The samples were analyzed for Si, Ti, Al, Fe, Mn, Mg, Ca, Na, K, P, Sc, V, Cr, Co, Ni, Cu, Zn, Be, Sr, Ba, Zr, Y, Rb, S, and total organic carbon (TOC). X-ray diffraction showed that illite, kaolinite, and quartz were the predominant minerals. The weathering index and the chemical index of alteration both indicate that the source minerals of the shales were highly weathered. Thin sections reveal the presence of red brown aggregates of clay, organics, and oxides, gray clay aggre-

gates, and quartz grains. Abundances of Mn and Fe are quite variable (except of Mn in calcareous shales, and Fe in pyritic shales).

Core shales, deposited during maximum transgression, may be high or low TOC shales depending on the original sedimentary redox conditions. In high TOC core shales (TOC/Al ratio above 1.2), abundances of V, Zn, and Cr correlate strongly with TOC. Sulfur correlates strongly with Fe. In low TOC core shales (TOC/Al ration below 1.2), abundances of V, Zn, and Cr do not correlate with TOC. In some low TOC core shales, Zn, Cr, Ni, and Cu increase in maximum transgressive intervals and decrease stratigraphically upwards due to dilution by deltaic clays. Outside shales, deposited during regression, are normal to marginal marine shales with low TOC. Carbonate-related elements (Ca, Sr, Zn, Mn, P, Y, Ni) are more abundant where the shale contains more calcareous skeletal material. Marginal marine shales show widely variable TOC and elemental composition.

This study indicates that the main factors controlling the distribution of elements in cyclothemic shales are (1) the degree of weathering before deposition, (2) redox condition in the depositional environment, (3) settling time of the clay and organic matter through the water column, (4) conditions conducive to the formation and deposition of carbonates, (5) the composition of the organic matter, and (6) dilution by fine-grained terrestrial sediments.

Regional Stratigraphic Analysis of the Blackjack Creek Limestone (Desmoinesian, Middle Pennsylvanian) in Southeast Kansas and Northeast Oklahoma

STEVEN M. ROTH, Kansas State University, Manhattan, M.S. thesis, 1991

Detailed regional stratigraphic analysis of the "lower Fort Scott cyclothem," Middle Pennsylvanian (Desmoinesian) was carried out in southeast Kansas and northeast Oklahoma, utilizing a hierarchal genetic stratigraphic approach (Busch et al., 1989). In this approach, lithostratigraphic, biostratigraphic, and sedimentologic data are used to define and correlate Punctuated Aggradational Cycles (PACs). Lithofacies and isopach maps, based on these correlated PACs, illustrate the development of the "lower Fort Scott cyclothem."

The "lower Fort Scott cyclothem," which is composed of the Blackjack Creek limestone (Fort Scott Formation, Marmaton Group) and the underlying Excello shale (upper most unit within the Cherokee Group), contains three PACs and is bounded above by the Little Osage shale (basal unit of the "upper Fort Scott cyclothem"), which constitutes a fourth PAC.

The lower boundary of PAC 3, which occurs in the middle part of the Blackjack Creek limestone, represents the most marine (or driest) phase within the interval studied, followed by a period of stasis, shallowing, or wetter climate.

The Excello and Little Osage (black) shales are recognized as shallow, marginal marine units, possibly deposited during inundation of peat swamps.

Chaetetids, which are common in the Blackjack Creek limestone, were found throughout the study area in the regressive (or drying) parts of PAC 2 and PAC 3. Laminar chaetetids represent turbid, shallow, marine environments with moderate water energy. Low-domical chaetetids represent slightly less turbid, possibly deeper marine water with slightly less energy.

Climate-change curves based on changing lithologies within the study interval were constructed and seemingly correlate, one-to-one, with relative water depth curves. Also,

large-scale climate effects were suggested as the cause for the change from the coal-dominated Cherokee Group (Desmoinesian Stage) to the limestone-dominated section of the Missourian Stage. Furthermore, these large-scale changes were recorded in the Midcontinent before they occurred in the eastern United States.

The Petrology and Depositional Environments of the Upper Pennsylvanian (Missourian) Ladore Shale in Southeastern Kansas and Adjacent Oklahoma

PETER L. NIMMER, University of Iowa, Iowa City, M.S. thesis, 1992

The Missourian Ladore Shale (Middle Pennsylvanian) overlies the Bethany Falls Limestone and is bounded above by the Mound Valley Limestone on the Cherokee shelf in southeastern Kansas. The Mound Valley pinches out southward, and the Ladore Shale and overlying Galesburg Shale are recognized as portions of the Coffeyville Formation in Oklahoma.

Three Ladore lithofacies are recognized on the Cherokee shelf of southeastern Kansas and northern Oklahoma. The fine-grained, silty-shale lithofacies, present across southeastern Kansas, is dominated by black or grey shale containing fine siltstone interlaminations with abundant plant fragments, and represents rapid deposition of sediments in a low-energy prodeltaic facies. The siltstone-shale lithofacies is predominantly composed of lenticular, wavy and flaser-laminated siltstone interbedded with shale. This lithofacies, which is increasingly thick and more widespread southward in southern Kansas and northern Oklahoma, is extensively bioturbated and contains abundant plant fragments. It represents deposition along a seaward-sloping delta front within a distal bar and distributary mouth bar facies. Shoaling conditions seaward of the river discharge allowed fluvially deposited sediments to be reworked by tidal activity. The sandstone lithofacies, present only in northern Oklahoma, is composed of very fine-grained massive and laminated sandstone beds that were deposited as distributary channel sand in a lower delta plain setting. Southward increases in grain size and sandstone thickness indicate that Ladore sediments were most likely derived from the Ouachita Mountains and deposited as a northward prograding fluvial-deltaic complex.

Formation of siderite nodules began before significant compaction. Alteration of potassium feldspars to kaolinite by meteoric waters liberated silica that was precipitated as quartz overgrowths on detrital grains. Poikilitopic calcite cement and pyrite formation occurred as saline waters moved through these units during the deposition of the overlying Mound Valley Limestone. As burial continued, increasing temperatures allowed smectite to be converted to illite. This coupled with maturation of organic matter produced a shale-water solvent which produced framework grain alteration and dissolution in sandstone units. Modern weathering of siltstones and sandstones resulted in increased secondary porosity and production of "box-work" iron-oxide structures due to dissolution of iron-rich carbonate cements.

Depositional Environments and Diagenesis of Sandstones in the Galesburg Shale, Southeastern Kansas and Northeastern Oklahoma

EDWARD G. STERMER, University of Iowa, Iowa City, M.S. thesis, 1992

The Upper Pennsylvanian (Missourian) Galesburg Shale of southeastern Kansas and northeastern Oklahoma consists of siliciclastics deposited in a fluvial-dominated deltaic complex during a marine lowstand. Based on outcrop sections, well cores, and geophysical well logs analysis, seven lithofacies were recognized: (1) fine- to medium-grained, cross-stratified sandstone; (2) very fine- to fine-grained, calcite-cemented sandstone; (3) interstratified convoluted shale, siltstone and sandstone; (4) bioturbated siltstone and carbonaceous shale; (5) a blocky mudstone sometimes overlain by a thin coal; (6) thinly laminated clay shale; and (7) fossiliferous shale. Internal characteristics and lateral and vertical relationships with other lithologies, suggest that these lithofacies respectively represent: (1) fluvial/distributary channel sands; (2) distributary mouth bar/delta front sands; (3) natural levee and crevasse splay; (4) interdistributary bay fill; (5) marsh or swamp deposits; (6) prodeltaic muds, and (7) distal prodeltaic muds at the base and transgressive deposits at the top of the formation.

Isopach maps and cross sections show that the Galesburg Shale thickens southward toward the Oklahoma border where it has been recognized as an interval in the upper portion of the Coffeyville Formation. The fine-grained prodeltaic shales are more common to the north whereas coarser-grained siltstone and sandstone lithofacies thicken toward the south. Sandstone isolith maps and cross sections show that the thickest sands were deposited in narrow, north-south oriented elongate bodies that thin northward. These characteristics suggest that the Galesburg sediments were mostly derived from a southern source area and that the deltaic deposits prograded northward as an extension of Coffeyville deposition.

The sandstone units are fine-grained to very fine-grained sublitharenites with significant amounts of muscovite and feldspar grains. Lithic fragments consist primarily of muscovite schists, suggesting that they were derived from a metamorphic source, probably the Ouachita Fold–Thrust Belt in southern Oklahoma.

The composition and texture of the Galesburg sandstones were substantially altered by the effects of meteoric and compactional regime diagenesis during burial. Soon after deposition, the dissolution of carbonate shell fragments initiated an early, localized stage of calcite cementation. Decaying organic matter increased the acidity of meteoric waters promoting the alteration of feldspars to kaolinite and illite. Subsequent compaction of the Galesburg sediments provided a flush of compactional waters, and more significantly, allowed ions liberated from clay diagenesis in adjacent shales to be transported through permeable Galesburg sandstones. Silica released during the alteration of feldspars and the formation of authigenic clays promoted overgrowths on quartz grains. The conversion of smectite to illite liberated Fe and Mg ions promoting the formation of chlorite. Late-stage ferroan calcite cement precipitated from compactional waters enriched in $CaCO_3$ and Fe released from clay diagenesis and the dissolution of underlying carbonate units. Recent subaerial exposure of Galesburg sandstones has resulted in the weathering of ferroan carbonates and the formation of secondary porosity and iron oxide precipitates.

Facies Analysis of the Lower Cretaceous (Albian) Goodland and Lower Kiamichi Formations of Southeast Oklahoma

RICHARD ALAN NEELEY, University of Texas, Arlington, M.S. thesis, 1991

The contact between the Goodland and overlying Kiamichi Formation represents a sharp lithologic change and is important to Lower Cretaceous stratigraphy because it separates the Fredericksburg and Washita divisions. The purpose of this study was to resolve the nature of this contact in the study area (conformable or unconformable) and to determine the depositional environment of the Goodland and lower Kiamichi formations. Detailed lateral and vertical facies relationships indicated that the Goodland Formation represents a shoaling upward sequence of a westward prograding carbonate ramp which suggests that the depositional strike was roughly north–south. The formation of a ramp may be related to the Paleozoic Broken Bow uplift or to an actively subsiding North Texas–Tyler basin. The Goodland–Kiamichi contact appears to be a submarine disconformity surface in the off ramp areas and a weathered, subaerial disconformity surface in the ramp area. Deposition of the lower Kiamichi Formation was probably in response to a return of deeper water conditions as regional subsidence deepened the North Texas–Tyler basin.

Deformation of Broken Bow Uplift, Ouachita Mountains, Southeastern Oklahoma

QINGMING YANG, University of Texas, Dallas, Ph.D. dissertation, 1993

The Broken Bow uplift in southeastern Oklahoma contains the oldest rocks exposed in the Ouachita orogenic belt and has experienced four phases of deformation. First generation folds are tight, overturned, southerly verging, and have a well developed slaty cleavage. Second generation folds are coaxial with first generation structures, are open to tight, are inclined, and reveal southerly vergence. Northerly dipping faults truncate second generation fold limbs. Third phase structures, including recumbent folds and pencil structures, are interpreted to be contemporaneous with southerly directed thrusting. The hinges of earlier folds documented in the area least affected by thrusting are horizontal and trend east-west. The hinges of folds of the same generation within fault zones are plunge 30°–50° toward the north or northwest. It is concluded that the earlier folds as well as the contemporaneous folds and pencil structures have been passively rotated during southerly directed thrusting. Unlike passive rotation of folds reported from many other orogenic belts, deformation in the Broken Bow uplift is believed to have occurred in the upper crust. A simple shear model associated with southerly directed thrusting is proposed to explain these geometrical relations. The rotated fold hinges provide quantifiable shear strain gauges which can be used to quantify shear strain in the Broken Bow uplift as well as in other orogenic belts. The slaty cleavage is penetrative in outcrops and characterized by zones of pressure solution residuals (PSR) consisting of mica, iron oxides, and other insoluble opaque materials at a microscopic scale. Whether the cleavage formation by pressure solution involves large column loss is still under intensive debate. Estimates of volume loss across these PSRs using several independent approaches, including deformed stylolites, dissolved microfolds, and quartz grains, indicates significant volume loss of 30%–40% in the Broken Bow uplift. Evaluation of the PSR has revealed two distinct morphologies: one high frequency spacing of narrow PSR and one low frequency spacing of broader PSR. The low frequency spacing of broader PSR is believed to be younger and represents the coalescence of earlier narrower PSR as a result of progressive deformation. Using SEM, weakly developed fabrics can be seen in the pencil fragments: the original bedding and modified slaty cleavage. As a result, field observations of cleavage orientation reveal an upper limit to the southerly dipping slaty cleavage of 50°–60°. Subsequently, slaty cleavage in the silt stone is intensified by progressive deformation and regional flattening and has attitude approaching that of a locally developed rough cleavage. It is the intersection of progressive deformed and intensified slaty cleavage and bedding that have resulted in pencil structures. Although a variety of models have been proposed for doubly verging structures in Ouachita Mountains, the model proposed by Miser and Purdue (1929) and

Nielsen (1985) can best account for the present data. The southerly verging structures exposed in the Broken Bow uplift can be explained by reactivation of earlier listric normal faults developed on the stretched passive continental margin.

Three-Dimensional Seismic Interpretation, Frontal Zone of Ouachita Mountains, Hartshorne, Oklahoma

MARIO VALDERRAMA, University of Texas, Dallas, M.S. thesis, 1993

The boundary between the frontal Ouachitas fold and thrustbelt and the foreland Arkoma basin has been interpreted as a triangle zone. 3-D seismic reflection data from this triangle zone show details not recognized in conventional 2-D seismic data. The data indicates that the frontal Kiowa syncline in the Arkoma basin has been passively uplifted by blind thrusting at deeper levels. Blind thrusting takes place at two levels: the Morrowan Wapanucka Formation and the Silurian Hunton Formation. Detachments for the thrusting in the Wapanucka Formation are in the Springer Shale and the Woodford Formation. The thrusts offsetting the Hunton Formation have detachments in the Simpson Group and possibly in the Arbuckle Group or even deeper. Horizontal shortening in the Wapanucka Formation ranges from tens of meters to a few kilometers, and in the Hunton Formation from tens of meters to a few hundred of meters.

Four reflectors were interpreted: a reflector in the lower Atoka Formation, two repeated Wapanucka limestone sections and the Hunton Formation. All of the surfaces exhibit the same geometry with their fold axis plunging to the southwest. The surface geometry and fold axis data suggest that the first thrusting was in the Wapanucka Formation and later in the Hunton Formation. Faulting in the Hunton Formation has been traditionally interpreted as normal, although basement-involved reverse faults, such as the Carbon fault, have been mapped. The interpretation of some individual inlines or crosslines may also show normal faults, but the interpretation of the whole 3-D survey support the proposed compression in the older sequence.

Ore Microscopy of the Paoli Ag–Cu Deposit, Paoli, Oklahoma

CRAIG ANTHONY THOMAS, University of Missouri, Rolla, M.S. thesis, 1990

The Paoli silver–copper deposit is located in south-central Oklahoma, about 85 kilometers south–southeast from Oklahoma City, centered around section 7, T4N, R1E. The ore is contained in zones of the Permian Wellington Formation, also known as part of the Wichita Formation. The Wellington Formation is relatively flat-lying with a regional dip of ½° to the northwest. The formation is characterized by red mudstone and siltstone.

The most abundant copper-bearing sulfide at Paoli has been found to be a mixture of anilite ($Cu_{1.75}S$) and djurleite ($Cu_{1.934}S$), but lesser amounts of bornite (Cu_5FeS_4), chalcopyrite ($CuFeS_2$), and native copper (Cu) also are present. Secondary copper minerals consist primarily of covellite (CuS) and malachite ($Cu_2CO_3(OH)_2$). The copper sulfides have two primary modes of occurrence. In sandstone-hosted ores, the copper sulfides replace carbonate cement. In mudstone-hosted ores, the copper sulfides occur in a wide variety of geometric shapes; these shapes suggest that they replace diagenetic pyrite that occurs as remnants within the copper sulfide grains.

Silver occurs only as native silver. Native silver replaces copper sulfides, with all stages of replacement observed. Locally native silver contains high mercury concentrations of up to 7 weight percent (wt%).

Gangue minerals found at the Paoli deposit consist primarily of igneous clastics and carbonate cement. The igneous clastics include grains of rutilated quartz, zircon, anatase, ilmenite, feldspar, and sphene.