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On The Cover —

Wister State Park, Le Flore County, Oklahoma

View (taken looking southward) of the upper part of the Atoka Formation (Pennsylvanian) exposed in the Wister Lake Spillway, Wister State Park, Le Flore County (SW¼NW¼NE¼SW¼ sec. 6, T. 5 N., R. 25 E., Wister quadrangle). The entire exposed section in the spillway is ~886 ft thick. Units 6–8 (133–158-ft interval), located stratigraphically ~1,150 ft below the Atoka/Hartshorne contact, have an abundance of diverse ripple-bed forms on the 26° northward-dipping bedding-plane surfaces. Stratigraphic up is to the right on the photo. The diverse ripple-bed forms represent a range of flow velocities and directions, which suggests the combined influence of waves and currents. Wave-generated features consist of symmetrical and asymmetrical ripple-bed forms. Current-ripple bed forms include straight-crested, weakly undulatory, strongly undulatory, lunate, and linguoid types.

The beds exposed in the photo are interpreted as part of one of the isolated shallowing-upward (coarsening-upward) regressive sandstone lithofacies. These isolated sandstone lithofacies were deposited on a storm-influenced, mud-dominated shelf during a relative sea-level fall within an overall deepening-upward transgression (flooding event). The isolated sandstone lithofacies are encased in thick marine-shale lithofacies that record deposition from suspension in a relatively low-energy, moderate-to-deep marine setting.

Distinguishing differences among turbidite-sandstone facies, deltaic-sandstone facies, and storm-influenced shelf sandstones is one of the keys to effective exploration and to production and ultimate recovery of hydrocarbons from sandstone reservoirs in the Arkoma basin/Ouachita Mountains frontal belt.

James R. Chaplin

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OKLAHOMA GEOLOGY Notes

CONTENTS

Clay Mineralogy of the Paleozoic Shales around the Western Plunge of the Benton Uplift, Arkansas

Abdolali Babaei[1] *and Chao-min Hsueh*[2]

Abstract

Samples of the Paleozoic shales from the western plunge of the Benton uplift in Arkansas and from the easternmost part of the Broken Bow uplift in Oklahoma were collected and analyzed to identify their mineral content, illite crystallinity and polytype, and to estimate the degree of metamorphism using illite crystallinity. X-ray powder diffraction analyses of oriented, glycolated specimens showed illite to be the main constituent in all samples studied. Other clay minerals include chlorite and kaolinite. All of the samples also contain very small quantities of the nonclay mineral quartz. An average of 75% of clay minerals in these samples is illite. Both 2M and 1Md illite polytypes are found. The crystallinity of illite indicates that these rocks have undergone a very low degree of metamorphism. Illite crystallinity values for samples collected near the regional thrust faults are higher than crystallinity values of samples collected away from the faults. This difference could be due to shearing of rocks along these thrust faults.

Purpose and Methodology

Samples of Paleozoic shales were collected around the western plunge of the Benton uplift in Arkansas and eastern plunge of the Broken Bow uplift in Oklahoma (Fig. 1). Mineralogy and illite crystallinity and polytype of these samples were studied and the degree of metamorphism estimated (using illite crystallinity) in order to assess the structural deformation and metamorphism of the region. The clay (diameter $<2\mu$) was separated from bulk shale samples and analyzed by X-ray powder diffraction (XRD), using CuKα radiation and a graphite crystal monochromator. Two types of specimens were prepared: (1) preferentially oriented clay mounts, to identify the clay species; and (2) randomly oriented clay mounts, to identify the polytypes of illite. Both air-dried and glycolated, preferentially oriented clay mounts were used. Glycolated samples were used to detect expandable clays. All identifications were based on intensity of first-order (001) basal reflections: 10 Å for illite and 7 Å for chlorite and kaolinite.

Geologic Setting

The Ouachita Mountains of Arkansas and Oklahoma are a large exposure of a Paleozoic orogenic belt that lies mostly buried beneath Mesozoic and Cenozoic strata of the Gulf coastal plain. The eastern end of the tectonic belt is in eastern Mississippi, where it meets the Appalachian orogenic belt. The western part is exposed in the Marathon Mountains of West Texas and extends southwest into Sonora, Mexico.

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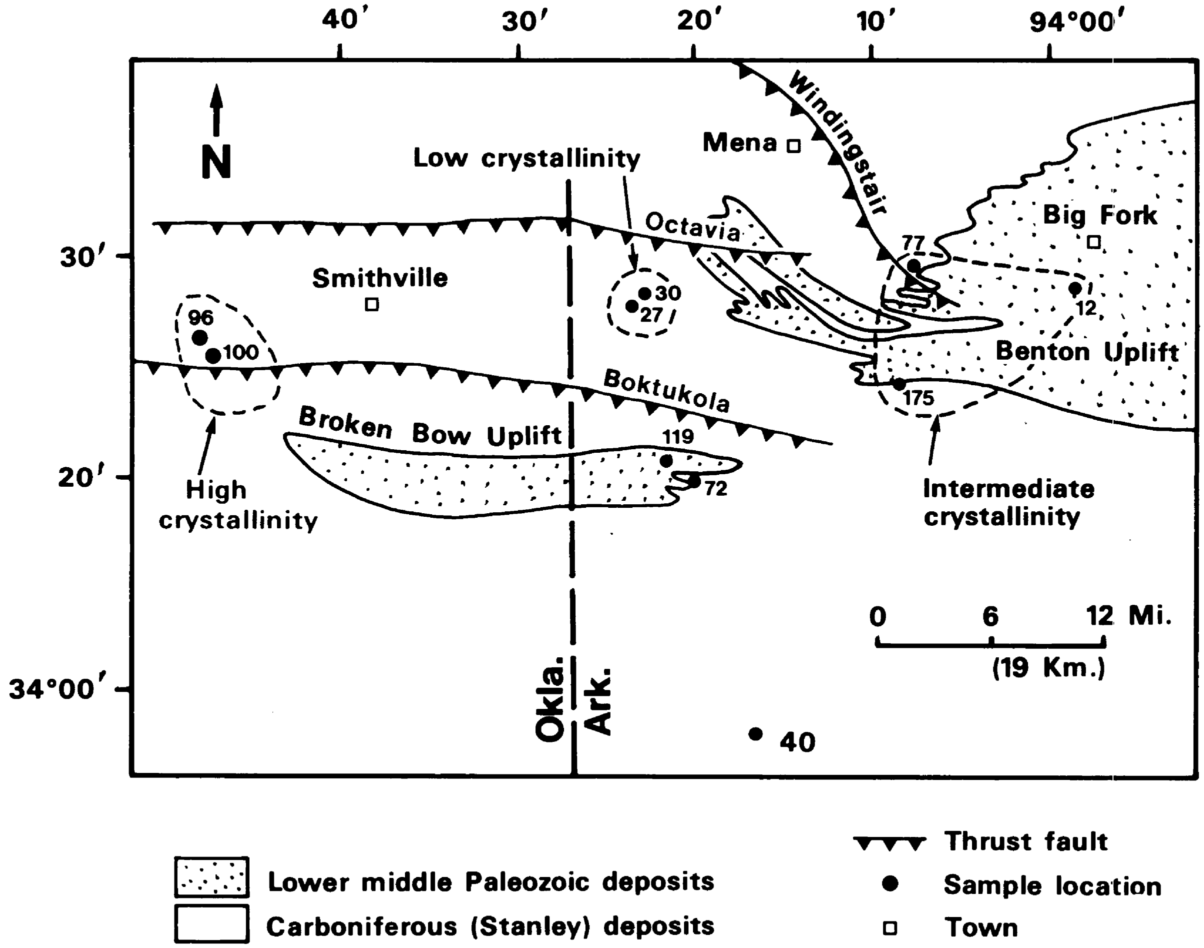

Figure 1. Map of the study area showing the variation of illite crystallinity values in the western plunge of the Benton uplift in Arkansas and eastern plunge of the Broken Bow uplift in Oklahoma.

The surface geology consists of a thick (>10 km) Carboniferous flysch sequence (Stanley, Jackfork, Johns Valley, and Atoka Formations) overlying a thin (~3.7 km) early to middle Paleozoic deep-water sequence (Collier Shale through Arkansas Novaculite). The entire sequence has been complexly thrust-faulted and folded; anastomosing faults, isoclinal folds, and recumbent folds are important locally. The deformation is commonly interpreted to have occurred over a south-dipping subduction zone.

Mineral Constituents

Figure 2 shows XRD patterns of representative samples from the study area. Illite is the main constituent in all samples studied. Other clay minerals include chlorite and kaolinite. Illite content is 50–94% in these samples and averages 75%. This variation in mineral content may be explained by provenance and the weathering history of different parent rocks (Graham and others, 1975; Morris, 1974; Niem, 1976).

When the diffractograms of the glycolated and unglycolated samples are normalized using quartz as the standard, the intensity of the 10 Å reflection of illite is

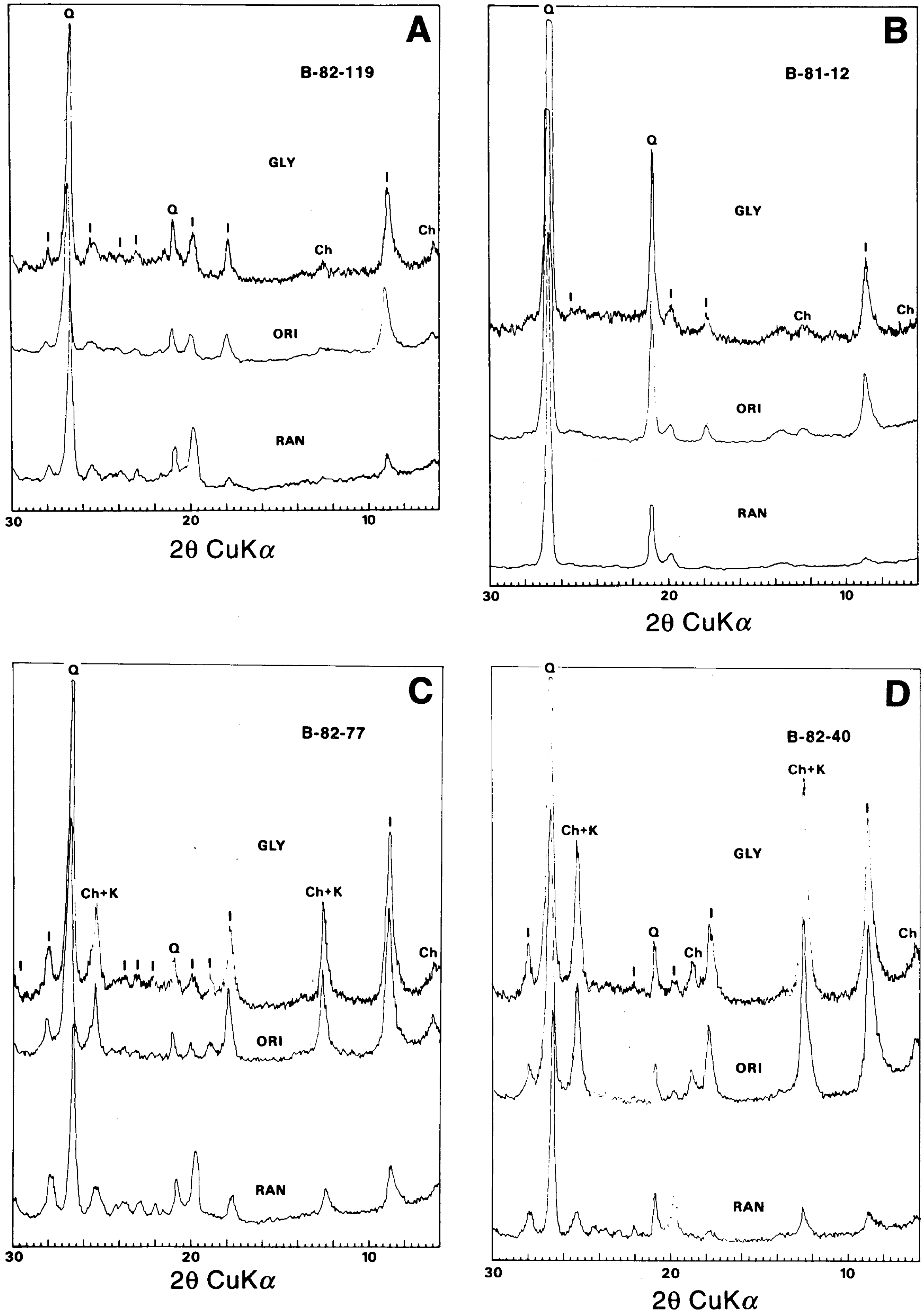

Figure 2. X-ray diffractograms (CuKα radiation) of glycolated preferentially oriented (GLY), air dried preferentially oriented (ORI), and randomly oriented (RAN) clay mounts of Stanley Shales from the study area. I, illite; Ch, chlorite; K, kaolinite; Q, quartz; θ = Bragg reflection angle.

reduced in some glycolated samples (Fig. 2, samples B-12 and B-119, for example). Such a decrease could be interpreted as a mixed layer of illite and smectite or as partial weathering of detrital illite. In smectite, spacing tends to expand on glycolation, thereby reducing the 10 Å intensity. Chlorite is identified at 14 Å ($2\theta = 6.2°$) in all the samples and as strong peaks at 7 Å ($2\theta = 12.6°$) and 3.5 Å ($2\theta = 25.3°$) in samples B-40 and B-77. These strong reflections are formed by overlapping of second-order (002) and fourth-order (004) peaks of chlorite with first-order (001) and third-order (003) peaks of kaolinite, respectively. A nonclay constituent, quartz, occurs in all the samples and has peaks at $2\theta = 20.85°$ and $2\theta = 26.68°$, which overlap with illite peaks.

Illite Polytypes

Polytypes of muscovites and illites can be described as 1Md, 1M, 2M, and 3T. The 3T polytype is very rare among the illites. The 1Md polytype structure is most stable at low temperatures. The order of stability of polytype structure with respect to increasing temperature is 1Md, 1M, 2M (Yoder and Eugster, 1955; Velde, 1965). The polytypes change through diagenesis from 1Md (most common in sedimentary rocks and authigenic processes) to 1M (less common in sedimentary rocks) to 2M (the most stable polytype, which occurs as the end product of diagenesis or metamorphism) (Dunoyer De Segonzac, 1970).

Illite polytypes 2M and 1Md are found in the samples in this study. Of the three illite peaks (at 10 Å, 5.0 Å and 3.33 Å), the one at 10 Å ($2\theta = 8.4°$) is the strongest (Fig. 2), which probably means that these illites have a high iron content (Brown, 1955). The percentage of 2M illite relative to total illite in study samples was determined by calculating the ratio of the intensity of a unique 2M peak to the intensity of a peak representing all the illite polymorphs in the samples [2M/(2M + 1Md)] (Maxwell and Hower, 1967). The lower intensity 2M peak, at 2.8 Å, was chosen as the numerator of the ratio. The 2.58 Å peak was used as the denominator. This ratio for study samples was compared to the 2.80 Å peak/2.58 Å peak intensity ratio of illite established by Yoder and Eugster (1955), and 1Md was found to be the most abundant illite polytype (30%) in study samples. Illite 1Md polymorphs commonly form at early stages of diagenesis and represent shallow depths of burial (Maxwell and Hower, 1967).

Illite Crystallinity and Metamorphism

Illite crystallinity has been used by many workers to assess the relative degree of diagenesis and metamorphism in fold belts (Weaver, 1960; Kubler, 1964,1968; Maxwell and Hower, 1967; Weber, 1972; Frey and Niggli, 1971; van Moort, 1971). The degree of illite crystallinity is indicated by values of the "sharpness ratio," defined by Weaver (1960) as the width (or relative sharpness) of the 10.0 Å X-ray diffractogram peak of illite. The sharpness ratio is calculated as the ratio of the height of the illite peak at 10.0 Å to its height at 10.5 Å (Weaver, 1960).

In regionally deformed orogenic belts, the degree of crystallinity and the polytypes of illite change from place to place (Dunoyer De Segonzac and others, 1966). Such regional variation of the sharpness ratio of illite could indicate diagenesis and/or degree of metamorphism. The sharpness ratio of samples in this study is 2–6 (Fig. 3; Table 1). On Weaver's (1960) scale, such values correspond to incipient to very weak metamorphism.

The sharpness ratio data on Figure 3 show change in metamorphic grade parallel and perpendicular to the trend of the uplifts (see Fig. 1 for sample locations) as has been recorded in other folded belts (Dunoyer De Segonzac and others, 1966; Siddans, 1977; Pique, 1982). High crystallinity values are found for samples collected near the eastern plunge of the Broken Bow uplift in Oklahoma (Fig. 1, B-96 and B-100), while samples from the younger Mississippian Stanley Shale (B-27 and B-30) in the lowlands around the Benton and Broken Bow uplifts have the lowest values. Such a pattern of illite crystallinity is consistent with tectonic deformation and sedimentary burial. Recent studies of vitrinite reflectance values and tectonic

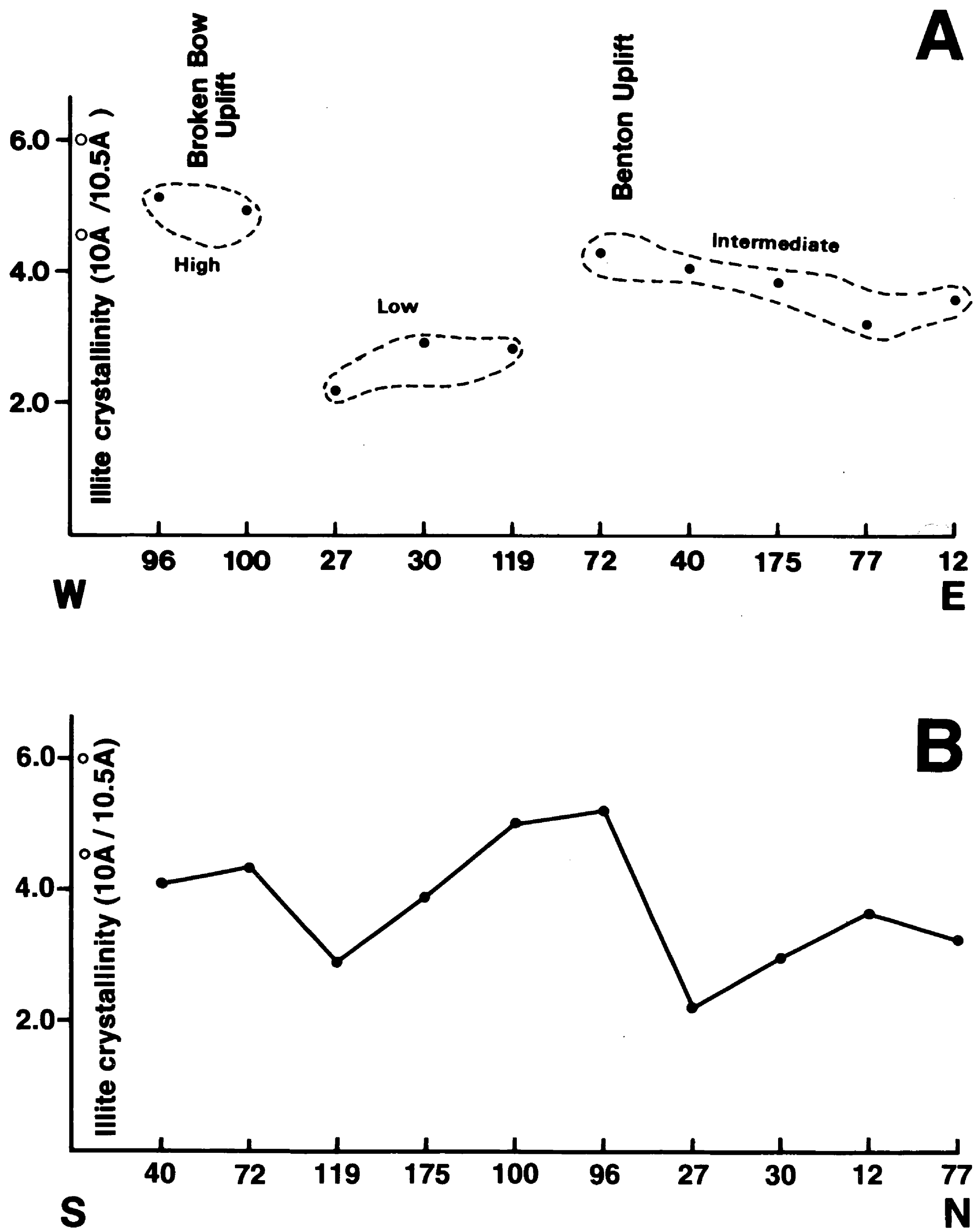

Figure 3. (A) Variation of illite crystallinity parallel to the trends of the Benton and Broken Bow uplifts. (B) Variation of illite crystallinity perpendicular to the trends of the Benton and Broken Bow uplifts.

deformation of the Carboniferous strata of the Ouachita Mountains by Houseknecht and Mathews (1985) and Guthrie and others (1986) show (1) that the vitrinite reflectance values increase with increasing age of strata and (2) that older strata on upthrown sides of thrust faults are more mature thermally than younger strata on downthrown sides.

TABLE 1.—ILLITE SHARPNESS RATIOS FOR SAMPLES OF PALEOZOIC SHALES IN THE STUDY AREA

Sample no.*	Sharpness ratio 10.0 Å/10.5 Å	
	Glycolated	*Untreated*
B-96	5.17	4.81
B-100	5.03	6.39
B-27	2.25	1.67
B-30	2.97	2.43
B-119	2.83	3.36
B-72	4.38	4.07
B-40	4.13	3.24
B-175	3.86	2.73
B-77	3.20	3.18
B-12	3.59	3.54
Mean	3.74	3.54
Standard deviation	0.96	1.32

*For locations, see Figure 1.

Regional geological maps (Feenstra and Wickham, 1975; Nielsen and others, 1989) indicate a series of east–west trending thrust faults (Octavia and Boktukola, for example) that cut through the Stanley Shale near sample locations B-96 and B-100 and disappear in Arkansas (Fig. 1). It is probable that the high crystallinity values in this locality represent higher thermal maturation due to overprinting effects of these faults. The lowest crystallinity values for samples at locations B-27 and B-30 (Fig. 1) in the same stratigraphic unit (Stanley Shale) probably reflect lower thermal maturity. In other words, rocks at locations B-27 and B-30 may have been unaffected by these regional faults or areas of intense deformation. Intermediate crystallinity values were calculated from samples from pre-Carboniferous strata in the Benton uplift (sample locations B-12, B-77, B-175, Figs. 1 and 3). Compared with samples B-27 and B-30 from the Mississippian Stanley Shale, these pre-Carboniferous rocks record higher degrees of thermal maturation, due either to depth of burial or to thrusting.

Summary

Diffractograms of glycolated and oriented samples were used to measure the peak intensities of the constituents 7 Å (chlorite and kaolinite) and 10 Å (illite) in order to estimate the relative abundance of clay particles and their polytypes in Paleozoic shales from the western plunge of the Benton uplift in Arkansas and from the easternmost part of the Broken Bow uplift in Oklahoma. The degree of metamorphism of the shales also was estimated through analysis of the samples. Illite was found to be the most abundant clay constituent; chlorite and kaolinite also were identified in the samples. The nonclay mineral quartz was found in all samples. Illite polytypes 2M and 1Md were found in the samples.

Field observation and laboratory analysis show that (1) the rocks at the western plunge of the Benton uplift have undergone a very low degree of metamorphism compared to rocks in the eastern part of the Benton uplift; (2) high crystallinity values of illite are found in rocks that are bounded by major thrust faults; (3) low crystallinity values are found in rocks that either are far from the regional thrust faults or have not been buried deeply.

Acknowledgments

We would like to express our appreciation to all of the people who gave their support and guidance for the completion of this paper. Special thanks go to Drs. George W. Viele and William D. Johns for their constructive criticism and comments. We also would like to thank H. A. Babaie, Charles Mankin, and Neil Suneson for critical review of the earlier version of this manuscript. Partial funding for this study was provided (to A. Babaei) by Shell Oil Co. and Tenneco Oil Co.

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OGS Holds First Workshop on State's Fluvial-Dominated Deltaic Reservoirs

The first in a series of one-day workshops designed to help oil and gas producers identify and exploit resources in fluvial-dominated deltaic reservoirs drew a crowd of more than 200 operators, geologists, and engineers June 1 and 2. The workshop featured the Morrow play in northwestern Oklahoma.

"So many participants signed up for the Morrow workshop that we had to present it twice," said Michelle Summers, Oklahoma Geological Survey technical project coordinator.

The series of workshops is a major component of the Fluvial-Dominated Deltaic (FDD) Reservoir Project, a five-year cooperative effort between the Oklahoma Geological Survey (OGS), the University of Oklahoma's Geo Information Systems (GeoSystems) unit, and the OU School of Petroleum and Geological Engineering.

"These workshops are part of the technology and information-transfer phase of the FDD project," said Charles J. Mankin, OGS director and overall FDD project coordinator. "This project is directed at the several thousand smaller companies and independent operators in Oklahoma who do not have easy access to the information we are compiling.

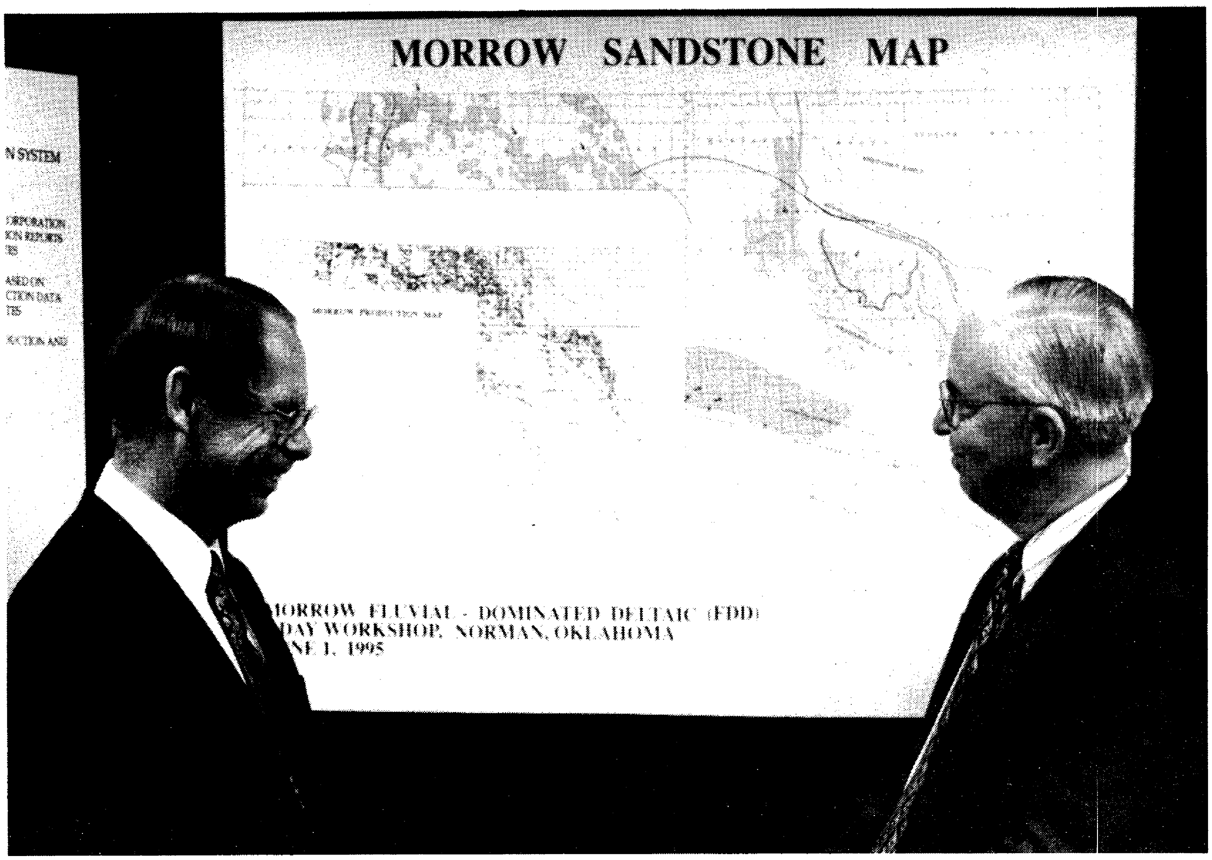
"The workshops are focused on fluvial-dominated deltaic reservoirs because in Oklahoma, as well as nationally, such reservoirs are a major source of crude oil production that is at high risk of abandonment. Their architecture contributes to low primary recovery factors through internal barriers to fluid flow. Thus, large quantities of bypassed mobile oil remaining in these reservoirs are targets for improved oil recovery using currently available technologies."

The OGS and GeoSystems proposed the FDD project with the goals of identifying all FDD reservoirs in the State; grouping them into plays with similar exploration and development characteristics; collecting, organizing, and analyzing all available data on the reservoirs; conducting characterization and simulation studies on selected reservoirs in each play; and implementing a technology-transfer program targeted to the operators of FDD reservoirs to sustain the life expectancy of existing wells and increase oil recovery.

The project is funded partially through a grant from the Department of Energy's Project Office in Bartlesville, Oklahoma, under a program to improve oil recovery from reservoirs at high risk of abandonment. Funds were matched by the State of Oklahoma.

Light-oil production from Oklahoma's FDD reservoirs makes up a large portion of its total crude oil output, an estimated 15%. Because production from these reservoirs commonly is low (one to three barrels per day), and recovery costs are high, without positive intervention to help provide operators with practical means of improving production, reservoirs are likely to be abandoned.

"The reason I think it's important for the State to be involved is that the oil industry brought Oklahoma to the dance at statehood, and it has remained the State's No. 1 industry since that time. Its gross value is more than $5 billion a year," Mankin said in his opening remarks to workshop participants.



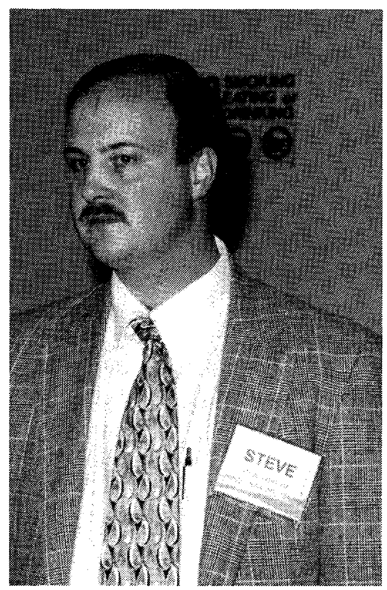
Richard D. Andrews (left), lead geologist for the Morrow play workshop, and Charles J. Mankin, FDD project director.

Richard D. Andrews, an exploration and development geologist with Geo-Systems, served as lead geologist on the Morrow play and the main speaker at the Morrow workshop. He said the Morrow play was chosen as the subject of the first workshop because of its size and the importance of its FDD reservoirs. "The Morrow is one of the most active plays for gas and oil, and it also has excellent potential for secondary recovery through waterflooding. The areal distribution of the Morrow is more limited than some of the other plays, but the FDD portion is certainly one of the most aggressively pursued by industry."

In the first session of the workshop Andrews gave participants a general overview of fluvial and FDD depositional environments, including different types of fluvial deposits, and related the depositional environments to their well log responses, type and quality of hydrocarbon production, sandstone trends, and reservoir characteristics.

Following the general overview, Andrews described Morrow FDD areas in Oklahoma. For the study, the Morrow was subdivided into two units, upper and lower Morrow sandstones. In Oklahoma, the upper Morrow produces in the Panhandle and the lower Morrow produces over the western portion of the State.

The results of studies in three areas, the Canton area, South Balko field, and Rice NE field, were presented next, with discussion of stratigraphy and structure, isopach mapping, oil and gas production, detailed cross sections, and other topics pertinent for each location. Participants were able to follow the dis-



Guest speaker Steve Harpham (right), geological engineer and log analyst for Ensign Operating Company, presented a case history of an ongoing waterflood project for workshop participants (above).

cussion in a play workbook that provided more detailed information and included maps, type log figures, and references.

Two workshop sessions dealt with waterflooding in the Rice NE field in the Oklahoma Panhandle. Roy Knapp, petroleum engineer for the FDD project and a professor in the OU School of Petroleum and Geological Engineering, described a case study of reservoir characterization and computer simulation, including a simulated waterflood project. The simulation used data provided by Ensign Operating Company. Knapp said, "A reservoir simulation has at least two uses: to modify future operating policies by checking predictions against what the reservoir actually does, and to test alternative schemes for exploiting the resource base contained in the reservoir."

The computer simulation session, along with a case history of an ongoing waterflood project, generated a number of comments and questions from participants. The case history was presented by Steve Harpham, geological engineer and log analyst for Ensign Operating Company. "I want to share the reality checks we received when we put the waterflooding into operation," he said. Harpham retraced the steps and problems involved in the process, from unitization to the installation of the floods in October 1994; he said it is still too early to know how much the project will increase production.

"I'm very pleased to see this type of industry/government/academic cooperation. This is the exact type of practical workshop that we need to see more of," Harpham said.

In the final phase of the workshop, Rob Moody, GeoSystems information technology manager, demonstrated the capabilities of the Natural Resources Information System (NRIS), a group of data bases containing records on well history and oil and gas production in Oklahoma. NRIS, as well as all data files for the plays featured in the workshops, can be accessed by operators and other interested members of the public through the OGS NRIS Facility, a resource facility equipped with PCs, a plotter, a laser printer, CD-ROM drives, and scanning and digitizing equipment.

Carlyle Hinshaw, petroleum geologist with GeoSystems, told participants about the software available for use in the resource facility, including geology-related mapping programs, as well as word processing, spreadsheet, data-base, and CAD programs. Staff members provide assistance with the computers and are available for technical consultation for specific projects. Training sessions also are offered to familiarize people at all levels of computer knowledge with the NRIS program and computer software.

Overall, attendee comments about the Morrow workshop and the FDD project were favorable, and a number of participants said they wanted to attend some of the future workshops.

"I'll probably attend any other workshops offered that cover the Anadarko basin," said John Buckthal, an independent geologist working out of Amarillo, Texas.

Interest in workshop sessions dealing with waterflooding was especially

Next FDD Workshop Spotlights Booch Play

The next FDD workshop will focus on the Booch play and will be held at Green Country Vocational Technical School in Okmulgee, Oklahoma, on August 31, 1995.

Registration fee for all FDD workshops is $15 for operators in the featured play, $25 for all others. The cost includes lunch, coffee breaks, and a copy of the play workbook. (See page 101 of this issue for information on the Morrow play workbook, which can be purchased from the OGS Publication Sales Office.)

For more details on the play workshops, or to receive registration forms, contact:

Michelle Summers
Oklahoma Geological Survey
100 E. Boyd, Room N-131
Norman, OK 73019
(405) 325-3031 *or* (800) 330-3996
FAX 405-325-7069

The OGS NRIS Facility is open from 8:30 a.m. to 4:30 p.m., Monday through Friday, except on holidays recognized by the University of Oklahoma. Both computer usage and technical consultations are by appointment only. For appointments or further information, contact Jane Weber, facility manager, at the address and phone number above.

high. Arthur Bushman, an Oklahoma City geologist with Samedan Oil Corp., was impressed with the waterflood computer simulation. "It was amazing what they could do with that program," he said.

Keith Rasmussen, a geologist with Ward Petroleum Corporation in Enid, Oklahoma, referring to the waterflood case study, said, "It was interesting to review the sequence of events that you go through."

Rasmussen also had a suggestion for case studies presented in future workshops. "It would have been nice to see some cores if they had been available," he said.

"Keith's suggestion that having cores from some of the FDD reservoirs available for examination will be given serious consideration for future workshops. We are soliciting such suggestions from all workshop participants," said Charles Mankin.

Rhonda Lindsey, project manager for applied research with the DOE Project Office in Bartlesville, thought the workshop struck a chord with participants. "I was impressed with the response of the independents. These were the people we had hoped to reach. The questions that were generated and the discussions were pretty good. It was apparent that the audience was involved and picking up information."

Although the NRIS Facility did not officially open until the day of the first workshop, it already has attracted interest and users. "Those members of the petroleum industry who have visited the NRIS Facility seem pleasantly surprised with the amount and type of information available and the ease with which they will be able to access it," said Jane Weber, facility manager.

The OGS will hold an additional seven workshops focusing on the following plays or groups of plays (tentative dates in parentheses):

- ▲ Booch play—August 31, 1995
- ▲ Layton/Osage-Layton play—(November 1995)
- ▲ Prue/Skinner play—(February 1996)
- ▲ Cleveland and Peru plays—(May 1996)
- ▲ Red Fork play—(August 1996)
- ▲ Bartlesville play—(November 1996)
- ▲ Tonkawa play—(February 1997)

All workshops are open to the public as space permits, with priority given to operators in the featured play.

— *Tracy Peeters*

NEW OGS *Publication*

SPECIAL PUBLICATION 95-1. ***Fluvial-Dominated Deltaic (FDD) Oil Reservoirs in Oklahoma: The Morrow Play,***
by Richard D. Andrews and others. 67 pages, 6 plates. Price: $6.

The first in a series of publications to be released addressing fluvial-dominated deltaic (FDD) light-oil reservoirs in Oklahoma, this volume presents the material covered in the Morrow play workshop held in June 1995. (See page 96 of this issue for more information about the FDD project and workshop.)

In Part I of this publication, Richard D. Andrews, lead geologist for the Morrow play, explains the scope of the FDD project and describes the significant features of the depositional setting of an FDD reservoir system to provide an understanding of the properties of the individual FDD reservoirs identified in the project. Jock A. Campbell and Robert A. Northcutt also contributed to this part of the book.

Part II, also by Andrews, contains an overview of Morrow FDD areas in Oklahoma. Morrow fluvial systems are found principally in three regions within the State: the Dewey–Blaine Counties embayment, the Woodward "trench," and the Panhandle region. This section of the book also presents studies of three areas within these regions of the Morrow: the Canton area, South Balko field, and Rice NE field, including stratigraphy, structure, isopach mapping, reservoir characteristics, and oil and gas production.

The results of a reservoir simulation of the upper Morrow reservoirs in Rice NE field, Texas County, Oklahoma, are presented in Part III, by R. M. Knapp and Zahid Bhatti. The simulation included a forecast of expected waterflood performance, and used data provided by Ensign Operating Co.

The book also includes a list of selected references and a glossary of terms. Plates included with the publication are a map of Morrow sandstone play areas, stratigraphic cross sections of study areas, a production map of Morrow FDD areas, a map of Morrow oil and gas fields, and an index to selected Morrow references used for Morrow sandstone mapping.

Author Richard D. Andrews is an exploration and development geologist with the University of Oklahoma's Geo Information Systems (GeoSystems) unit. R. M. Knapp is the petroleum engineer for the FDD project and a professor in the OU School of Petroleum and Geological Engineering. Zahid Bhatti is a graduate student in the OU School of Petroleum and Geological Engineering. OGS geologist Jock A. Campbell and consulting geologist Robert A. Northcutt, Oklahoma City, are the other two lead geologists on the FDD project team. The next publication to be released in this series will be on the Booch play.

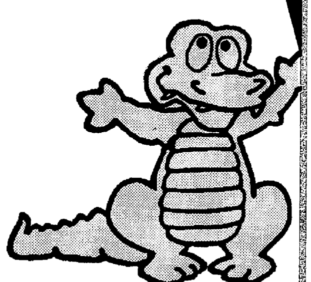
SP 95-1 can be purchased over the counter or by mail from the Survey at 100 E. Boyd, Room N-131, Norman, OK 73019; phone (405) 325-3031 *or* (800) 330-3996; fax 405-325-7069. Add 10% to the cost of publication(s) for mail orders, with a minimum of 50¢ per order.

GSA ANNUAL MEETING

New Orleans, Louisiana □ November 6–9, 1995

The theme for the 1995 Annual Meeting is BRIDGING THE GULF. *This theme has several meanings. In particular, we will draw attention to the Gulf of Mexico–Caribbean, and the surrounding American continents, bridging the knowledge gap that exists across a region divided by political boundaries and language but sharing a common geologic framework.* BRIDGING THE GULF *also addresses the need to develop a closer link between technology and the science of geology and to educate the public on issues critical to the development of intelligent policies on the environment and geologic hazards. We also hope to bridge the gulf between the past and the future with both a retrospection on the past 25 years of plate tectonics and a look at the future as geologists respond to society's needs. Finally, we view the city of New Orleans, the Mississippi River and its delta, and the Gulf Coast as a laboratory where the long-term effects of humans on the environment can be examined.*

—Bill Craig
General Chairman

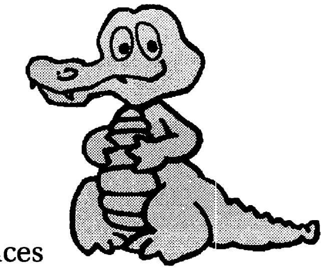


WHILE YOU ARE AT THE GSA MEETING, BE SURE TO STOP BY THE OKLAHOMA GEOLOGICAL SURVEY BOOTH (NO. 914). REGISTER TO WIN $25.00 IN OGS PUBLICATIONS!

NEW ORLEANS

BRIDGING THE GULF

GSA Annual Meeting Agenda



Technical Program

Symposia

Keynote Symposium: The Mississippi River—Control and Consequences
Building Bridges Over Troubled Waters: Identifying, Educating, Recruiting, and Retaining the Stakeholders in Earth Science–Environmental Justice Issues
25+ Years of Plate Tectonics: Where Do We Go from Here?
Geology and Tectonics of the Caribbean Region
Products and Processes of Continental Extension
Third International Symposium on the Cenozoic Tectonics and Volcanism of Mexico
Quaternary Geologic Framework and Processes of Coastal Land Loss in Louisiana
The Mississippi River as a Sedimentary System
Hydrology of Wetlands
Bredehoeft Symposium on Hydrogeology and Geologic Processes
Coastal Settings of Peat Formation and Their Stratigraphic Record: Ecosystems, Allocycles, and Sequences
Environmental Lessons from Planetary Exploration
Duration of Hydrothermal Events
Frontiers in Geochemistry
Weathering Rates of Silicate Minerals
The Dana Legacy, a Century Later
Recovery from Mass Extinctions
Variability of Isotope Compositions in Modern and Fossil Organic Matter
Taphonomy of Microfossils: Paleoenvironmental Reconstruction and Environmental Assessment
Gulf and Atlantic Coast Vertebrate Paleontology, Including Multidisciplinary Approaches to Vertebrate Localities
High-Resolution Geophysics in Cultural Resource Management
Annual Environmental Forum: Politics and Economics—Geological Research Bridging the Gulf
Crossing the Bridge to the Future—Managing Geoscience Information in the Next Decade: Archiving, Access, and Outreach
Scholarship in the Geosciences—Beyond Academia
Assessing Teaching and Learning
Dynamics of Aqueous and Hydrocarbon Fluids in Sedimentary Basins

Theme Sessions

Plate Tectonics: The Next Generation
Geology and Tectonics of the Caribbean Region
Tectonic Geomorphology and Paleoseismology in Intraplate Tectonic Settings
Proterozoic Terranes of the Americas: Bridging the Gulf and Caribbean
Before the Gulf—Paleozoic Tectonics of the Southern Margin of Laurentia
Advances in the Geology of Mexico
Paleoceanographic and Paleoclimatic Results from ODP Legs 151 and 152 to the North Atlantic
Subaqueous Sediment Gravity Flow Deposition: Scaling, Processes, and Applications
Recognizing the Impact of Subtle Structures on the Stratigraphic Record
Recent Progress in Shale Research
Tectonic and Paleoclimatic Records from Rift Basin Sediments of East Africa and Siberia
Back to the Moon

Coastal Wetland Dynamics in Response to Sea-Level Rise: Erosion, Accretion, and Ultimately Transgression
Quaternary Geologic Framework and Processes of Coastal Land Loss
Processes Defining the Dynamics, Evolution, and Stratigraphy of Coastal Swamp and Marsh Environments
Effects of Geologic Framework on Shoreface Evolution
Geologic Hazards in Mexico
Environmental Geology: The Voice of Warning
Environmental Geology: The Voice of Reason
Wetlands: Past, Present, and Future
Incorporating Research Results into Ground-Water Contamination Investigations and Remediation
The Watershed Approach to Water Resource Management
Geochemistry, Hydrology, and Environmental Impacts of Brines and Saline Waters
Innovative Characterization of DNAPL Impacted Aquifers
The Role of Geosciences in Ecosystem Analysis
Environmental Justice
Hydrochemical Interaction Between Shallow Ground Water and Surface Water in Karst Terrane
Multidisciplinary Approaches to Hydrogeologic Research on Carbonate Islands
Hybrid Carbonate-Siliciclastic Sedimentary Environments
Research Results from the 1994–95 Louisiana Applied Oil Spill Research and Development Program Projects
Halogen Hydrology
Weathering Silicate Minerals
Biological Microinclusions of Aqueous Minerals
Experimental Taphonomy: Deep Sea to Terrestrial Realms
Impact in the Gulf: Chicxulub
Global Catastrophes: P-E and K-T Events Compared
Applications of Coal Geology to Mining and Environmental Problems
Andes to the Amazon: Geology and Mineral Wealth of a Continent
Mineral Deposits and Geology of the Caribbean Rim
Appalachian Mineral Deposits
Airborne and Spaceborne Radar Studies of the Geologic Environment
Advances in Pegmatite Genesis
Simulation, Animation, and Data Visualization in Hydrology
Environmental Issues Across the Geoscience Curriculum
Making Connections: Ties Between K–12 and University Education
Undergraduate End-of-Program Assessment in Geoscience Departments

Field Trips

Premeeting

Explosive Volcanism and Pyroclastic Deposits in East-Central Mexico: Implications for Future Hazards, *Oct. 31–Nov. 5*
Island and Karst Hydrogeology of Andros, Bahamas, *Nov. 1–5*
Wisconsinan to Holocene Sedimentation, Soil Formation, and Evolution of the Mississippi River Flood-Plain, Southern Lower Mississippi Valley, *Nov. 3–5*
Sulfur and Sulfide Mineralization in Gulf Coast Salt Domes, *Nov. 4–5*

Gulf Coast from New Orleans, Louisiana, to Pensacola Beach, Northwest Florida, *Nov. 4–5*
Hydrogeology and Depositional Setting of Coastal Louisiana Floating Marshes, *Nov. 5*

Half Day—Concurrent with the Meeting

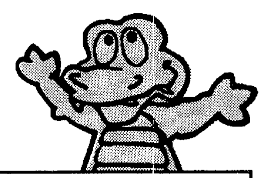
Engineering Geology of the New Orleans Area: Water, Water Everywhere, *Nov. 7* or *Nov. 8*

Postmeeting

Geology and Cultural Excursion from Jackson, Mississippi, to St. Francisville, Louisiana, *Nov. 9–11*
Gold Deposits of the Carolina Slate Belt, *Nov. 9–11*
Paleogene Molluscan Biostratigraphy of the Eastern Gulf Coastal Plain, *Nov. 9–12*
The Appalachian Thrust Belt in Alabama: Influences on Structural Geometry, *Nov. 9–11*
Cultural Adaptation to Landforms in the Mississippi Delta Plain, *Nov. 10*
Site Characterization and Application of Horizontal Wells for Ground-Water Remediation, *Nov. 10*
Internal Structure of the Five Island Salt Dome with a Visit to Côté Blanche Salt Dome, *Nov. 10*
Sand and Gravel Mining in the Amite River Flood Plain, Southeastern Louisiana, *Nov. 10*

Short Courses/Workshops/Forums

Fractals and Nonlinear Dynamics: New Numerical Techniques for Sedimentary Data, *Nov. 3–4*
Contaminant Organic Geochemistry, *Nov. 4*
Effective Teaching: A Workshop for Graduate Students, Assistant Professors, and Anyone Else Interested in Becoming a Better Teacher, *Nov. 4*
Exploring the Solar System in the Classroom: A Hands-On Approach, *Nov. 4*
Fundamentals of Project Management for Environmental Professionals, *Nov. 4–5*
Introduction to Experimental Modeling of Tectonic Processes, *Nov. 4–5*
Introduction to Soil and Ground-Water Remediation Techniques, *Nov. 4–5*
Multidimensional Computer Visualization in the Geosciences, *Nov. 4–5*
Phase I Environmental Site Assessments, *Nov. 4–5*
Chemical Weathering Rates of Silicate Minerals, *Nov. 4–5*
Coastal Land Loss, *Nov. 5*
Essentials of Subsurface Mapping, *Nov. 5*
GIS and the Geosciences, *Nov. 5*
Geomorphic Applications of In Situ-Produced Cosmogenic Isotopes, *Nov. 5*
Hydrogeology and Geochemistry of Wetlands, *Nov. 5*
Preparing Successful Grant Proposals to Fund Curriculum Innovation in the Geosciences, *Nov. 5*
Project Atmosphere, *Nov. 5*
Siliceous Microfossils, *Nov. 5*
Job Hunting and Career Development Strategies and Skills for Geoscientists, *Nov. 5*
Geoscience DataBase Forum, *Nov. 5*
Celebrating the Founding of Modern Geology: The 200th Anniversary of James Hutton's "Theory of the Earth," *Nov. 5*
Fairly Simple Exercises in Geology Designed for Teachers with Little or No Geology Background, *Nov. 6*
Seismic Sleuths: An Earthquake Curriculum for Grades 7–12, *Nov. 6*
Earth Scientists on Capitol Hill, *Nov. 8*
Geology and Public Policy Forum, *Nov. 8*



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, fax 303-447-0648; E-mail: meetings@geosociety.org. The preregistration deadline is September 29.

UPCOMING *Meetings*

3rd International Field Conference and Symposium on Intraplate Magmatism: Petrology and Metallogeny of Volcanic and Intrusive Rocks of the Midcontinent Rift System, August 22–September 1, 1995, Duluth, Minnesota. Information: Penny Morton, Dept. of Geology, University of Minnesota, Duluth, MN 55812; (218) 726-7962, fax 218-726-8275.

Early/Middle Precambrian Orogenic Belts, International Meeting, August 28–September 1, 1995, Montréal, Québec. Information: J. A. Percival, Geological Survey of Canada, 601 Booth St., Ottawa, Ontario K1A 0E8, Canada; (613) 995-4723, fax 613-995-9273.

3rd Hutton Symposium, "Origin of Granites," August 28–September 2, 1995, College Park, Maryland. Information: Michael Brown, Dept. of Geology, University of Maryland, College Park, MD 20742; (301) 405-4082, fax 301-314-9661.

GSA Penrose Conference, "Fine-Grained Fault Rocks," August 31–September 4, 1995, Leavenworth, Washington. Information: Jerry F. Magloughlin, Dept. of Geological Sciences, 1006 C.C. Little Bldg., University of Michigan, Ann Arbor, MI 48109; (313) 747-0664, fax 313-763-4690.

Geographic Names Conference, September 6–9, 1995, Wagoner, Oklahoma. Information: T. Wayne Furr, Oklahoma Geological Survey, 100 E. Boyd, Room N-131, Norman, OK 73019; (405) 325-3031 *or* (800) 330-3996, fax 405-325-7069.

American Institute of Professional Geologists, Annual Meeting, October 1–5, 1995, Denver, Colorado. Information: William V. Knight, AIPG National Headquarters, 7828 Vance Dr., Suite 103, Arvada, CO 80003; (303) 431-0831, fax 303-431-1332.

Association of Engineering Geologists, Annual Meeting, October 1–7, 1995, Sacramento, California. Information: Jim Borchers, U.S. Geological Survey; (916) 278-3005, fax 916-278-3013; E-mail: jborcher@usgs.gov.

26th Binghamton Geomorphology Symposium, "Biogeomorphology—Terrestrial and Freshwater Aquatic Systems," October 6–8, 1995, Charlottesville, Virginia. Information: Cliff R. Hupp, U.S. Geological Survey, 430 National Center, Reston, VA; (703) 648-5207, fax 703-648-5484; E-mail: crhupp@wrdmail.er.usgs.gov.

American Association of Petroleum Geologists, Mid-Continent Section Meeting, October 8–10, 1995, Tulsa, Oklahoma. Information: Jean R. Lemmon, 1524 S. Cheyenne, Tulsa, OK 74119; (918) 582-8904.

Rockhounds Workshop, October 28–29, 1995, Oklahoma City, Oklahoma. Information: Kenneth S. Johnson or Neil H. Suneson, Oklahoma Geological Survey, 100 E. Boyd, Room N-131, Norman, OK 73019; (405) 325-3031 *or* (800) 330-3996, fax 405-325-7069.

North American Rock Mechanics Symposium, June 19–21, 1996, Montréal, Québec. *Abstracts due August 1, 1995.* Information: Michel Aubertin, Conference Chair, École Polytechnique, Dept. of Mineral Engineering, CP 6079, Succ. Centre-ville, Montréal, Québec, Canada; (514) 340-4046, fax 514-340-4477.

Notes ON NEW PUBLICATIONS

United States Geological Survey Programs in Oklahoma Fact Sheet

Programs conducted by the U.S. Geological Survey are outlined in this newly released, four-page pamphlet. The pamphlet gives an overview of the various functions of the USGS in Oklahoma, which include: providing assistance in developing and managing energy resources; furnishing flood-related information; managing surface- and ground-water resources; monitoring water contamination; producing topographic maps, distributing aerial photographs and satellite images of the State; and providing information to the public.

Order "USGS Programs in Oklahoma Fact Sheet" from: U.S. Geological Survey, Water Resources Division, 202 N.W. 66th St., Bldg. 7, Oklahoma City, OK 73116; phone (405) 843-7570, fax 405-843-7712. The pamphlet is available free of charge.

Energy and the Environment; Application of Geosciences to Decision-Making

Edited by L. M. H. Carter, this 134-page volume contains 67 extended abstracts that summarize some of the oral and poster presentations of the 10th annual V. E. McKelvey forum on mineral energy resources, held in Washington, D.C., Feb. 13–17, 1995. The publication focuses on U.S. energy resources and the environment, new resource techniques, and cooperative efforts between the USGS and industry, state and federal agencies, universities, and other countries.

Order C 1108 from: U.S. Geological Survey, Information Services, Box 25286, Federal Center, Denver, CO 80225. The circular is available free of charge.

Annual Yield and Selected Hydrologic Data for the Arkansas River Basin Compact, Arkansas–Oklahoma, 1993 Water Year

Written by J. E. Porter and C. S. Barks, this USGS open-file report contains 61pages. It was prepared in cooperation with the Arkansas River Compact Commission, Arkansas–Oklahoma.

Order OF 94-0364 from: U.S. Geological Survey, Information Services, Box 25286, Federal Center, Denver, CO 80225. The price is $4 for microfiche and $9.75 for a paper copy; add 25% to the price for foreign shipment.

Total-Field Aeromagnetic and Derivative Maps of the Lawton Area, Southwestern Oklahoma

These USGS geophysical investigations maps, on two color sheets, were prepared by Meridee Jones-Cecil. Sheet 1 measures 37 × 33 in. and shows latitude 34°30′ to 35°05′, longitude 98° to 99°. Sheet 2 measures 34 × 58 in. and shows latitude 34°30′ to 35°05′, longitude 98°22′30″ to 99°15′. The scale on Sheet 2 is 1:100,000 (1 in. = ~1.6 mi).

Order GP-0998-A from: U.S. Geological Survey, Information Services, Box 25286, Federal Center, Denver, CO 80225. The price is $6.75, plus $1 for postage and handling; add 25% to the price for foreign shipment.

The Oklahoma Geological Survey thanks the American Association of Petroleum Geologists, the Geological Society of America, the Association of Engineering Geologists, and the Society of Professional Well Log Analysts for permission to reprint the following abstracts of interest to Oklahoma geologists.

Reservoir Distribution and Exploration Potential of the Spiro Sandstone in the Choctaw Trend, Arkoma Basin, Oklahoma and Arkansas

JONATHAN S. GROSS, SHEREE A. THOMPSON, and *BRENDA L. CLAXTON,* Amoco Production Co., P.O. Box 3092, Houston, TX 77253; and *MATTHEW B. CARR,* Dept. of Geological Sciences, University of South Carolina, Columbia, SC 29208

A multidisciplinary study of the Spiro Sandstone shows that in Pittsburg and Latimer Counties, Oklahoma, along the Choctaw fault trend, the thrusted Spiro is predominantly a barrier island deposit consisting of reservoir-quality progradational and aggradational sandstones; however, to the east from Le Flore County, Oklahoma, through Yell County, Arkansas, along the structural trend, the Spiro is composed predominantly of tight, nonproductive, retrogradational sandstones. Petrographic observations of the progradational Spiro show that sands in the west are medium to fine grained, and in the east they are very fine grained. Chlorite coatings that inhibit quartz cementation are present only in the west. Vitrinite reflectance data indicate that the Spiro in the west is within the gas window (~1.5% R_o), but in the east it is overmature (>2.5% R_o). The term "overmature" applies to reservoirs that have insufficient porosity for commercial production due to destructive diagenesis caused by thermal stress. The simultaneous multidisciplinary approach is economically significant because exploration analysis time for this study was decreased, and decisions were made with more reliability.

Reprinted as published in the American Association of Petroleum Geologists *Bulletin,* v. 79, p. 159, February 1995.

Sedimentology of the Upper Part of the Atoka Formation (Pennsylvanian), Southeastern Arkoma Basin, Oklahoma

JAMES R. CHAPLIN, Oklahoma Geological Survey, 100 E. Boyd, Room N-131, Norman, OK 73019

This is the first published lithofacies study, of either a local or regional nature, on the upper part of the Atoka Formation, a stratigraphic interval rarely exposed. Approximately 886 ft (270 m) of the upper part of the Atoka Formation is exposed in the Wister Lake Spillway, Le Flore County, Oklahoma. The lower 207 ft (63 m) of the succession (less distal shelf) is mud-dominated, but is more sand-rich, has higher sand/shale ratios, and shows more frequent indications of oscillatory flow and of sedimentary features recording deposition by less distal processes than the upper part. The upper 679 ft (207 m) of the succession (more distal shelf) is mud-dominated, but has lower sand/shale ratios, and shows less frequent evidence of oscillatory flow than the lower part. The upper part records deposition by more distal processes as evidenced by the dominance of finer-

grained sediments and paucity of shallow-water features. The upper part contains rare isolated sand lithofacies, that suggests only localized transportation of sand.

The textures, vertical succession of facies, and sedimentary features suggest conditions ranging from suspension fallout and, possibly, weak density flows below storm wave base through the progressively higher energy and greater sediment supply of storm-wave influence. All of the vertical stratigraphic trends of the succession, considered together, suggest that the upper part of the Atoka Formation, at least at this stratigraphic level and geographic setting, was deposited as part of an overall thick, fining-upward transgressive shale sequence containing thin, coarsening-upward regressive sandstone sequences deposited on a storm influenced, mud-dominated shelf.

The key to effective exploration and to production and ultimate recovery of hydrocarbons from sandstone reservoirs in the Arkoma Basin is the ability to identify the differences among turbidite-sandstone facies, deltaic-sandstone facies, and storm-influenced shelf sandstone facies, and to successfully predict the occurrence and trend of those sandstones that have hydrocarbon-production potential.

Reprinted as published in the Geological Society of America *1995 Abstracts with Programs*, v. 27, no. 3, p. 42–43.

Stratigraphic Geometry of Cavern Collapse and Seismic Modeling—A Predictive Tool for Exploration

C. ROBERTSON HANDFORD, 621 Twilight Trail, Richardson, TX

The exploration importance of carbonate paleokarst/cave reservoirs is underscored by large fields, such as Puckett and Brown-Bassett Fields in West Texas, Wilburton Field in Oklahoma, and Casablanca Field of offshore Spain. In light of these, there has been some important facies analysis work done comparing modern cave facies with paleocave reservoirs, but there has not been any effort to determine how cave geometries may be imaged by seismic reflection data.

In an effort to fill this gap, modern caves have been examined in order to construct models illustrating the stratigraphic geometry of cavern collapse. As cave chambers in bedded limestones are excavated and enlarged by vadose and phreatic waters, shear stress and tension loads on unsupported ceiling beds increase resulting in ceiling collapse and the deposition of ceiling-derived breakdown. This leads to interbedded breakdown, fluvial elastics, and speleothem deposits. Subsequently, an arch-shaped ceiling geometry forms in an effort to attain a more stable configuration. If the cave chamber is not destroyed from the surface by fluvial entrenchment and karst denudation, it passes into the subsurface during subsidence. However, with increasing burial, stress loads increase, and cause total collapse of cave chambers. Thus, chambers tend to be filled with early breakdown and fluvial deposits followed by burial-related breakdown. Continued loading leads to readjustment and refracturing of the breakdown and the propagation of fractures from the central chamber outward into the country rock. This forms a halo of crackled and mosaic breccia surrounding a chaotically brecciated zone of breakdown and cave-fluvial sediment. The geometry of the buried and collapsed cave chamber depends upon the size of the excavated cave chamber, depth of burial, and the bulk physical properties of the encasing limestone.

Seismic modeling was conducted in order to determine if the cavern collapse geometry could be resolved seismically in a subsurface setting. A geologic model, consisting of layers of differing densities and P-wave velocities, was constructed and convolved with a zero-phase Ricker wavelet at various frequencies. Assuming preservation of significant breccia porosity within the collapsed chamber, the models show a passage from continuous reflections in the undisturbed country rock to discontinuous reflections inclined towards the cavern core. Reflection character in the collapsed cave chamber was variable depending upon model parameters. Pullups and pulldowns are significant where velocity and density contrasts between the country rock and collapsed chamber are important. Similar reflection character may be visible in high-resolution 2-D and 3-D data and could help delineate paleocave reservoirs.

Reprinted as published in the American Association of Petroleum Geologists *1995 Annual Convention Official Program*, v. 4, p. 38A.

Geometry of Thrust System In Wilburton Gas Field and Surrounding Areas, Arkoma Basin, Oklahoma

SALEEM AKHTAR, IBRAHIM CEMEN, and *ZUHAIR AL-SHAIEB*, School of Geology, Oklahoma State University, Stillwater, OK 74078

The Arkoma basin is an arcuate structural feature, located in southeastern Oklahoma and southwestern Arkansas. It is one of the important gas producing basins in North America. The Wilburton gas field is located in the central part of the basin and produces mostly from the Pennsylvanian Spiro sandstone.

We have constructed eight balanced structural cross-sections in the Wilburton gas field and and surrounding areas to determine the detailed geometry and structural history of the thrusting in the area. They are based on updated surface geology, wire-line well log data and interpretation of the seismic profiles donated by the EXXON oil company. We have restored these cross-sections to ensure the balancing, and estimate the shortening. We have also plotted the original distribution of the depositional facies of the Spiro sandstone on these cross sections to determine the extent of the facies distribution especially reservoir gas facies in the Spiro sandstone.

Within the Wilburton area we have recognized the presence of a shallow triangle zone floored by the Lower Atokan detachment. The flanks are delimited by the south-dipping Choctaw thrust to the south and north-dipping Carbon fault to the north. The Choctaw is recognized as the leading-edge thrust of the Ouachita frontal belt. There are several thrust faults in the hanging wall of the Choctaw. These thrusts can be classified as the leading imbricate fans dipping with a high angle, approximately 70–80 degrees, southward. One of these shows substantial reverse separation and is recognized as the Ti Valley fault. The foot wall of the Choctaw contains duplexes that are located between Springer detachment (the lower detachment) and the Lower Atokan Detachment (the upper detachment). These duplexes contain overpressured sandstone gas reservoirs.

Reprinted as published in the Geological Society of America *1995 Abstracts with Programs*, v. 27, no. 3, p. 33.

Depositional Environment of the Spiro Sandstone in the Wilburton, Red Oak, and Kinta Fields, Arkoma Basin, Oklahoma

FORREST B. HESS and *ARTHUR W. CLEAVES*, School of Geology, Oklahoma State University, Stillwater, OK 74078

The Basal Atokan sandstone commonly referred to as the Spiro was deposited in a shallow marine to fluvial setting on an Atlantic type shelf. In the area of study, the Spiro is predominately a fine to medium grained, well sorted sandstone. Porosity is variable and depends on the presence of chamosite grain coatings which helped preserve primary porosity.

The Basal Atokan sandstone was originally deposited as a lowstand incised valley fill commonly referred to as the Foster trends. The channels cut into the underlying sub-Spiro shale and the Wapanucka limestone. Isopach mapping of the channels indicates a northwest to southeast trend. A possible source for the Foster trends is from the northeast, possibly the Ozark Dome. Following deposition of the channel fill, a northward marine transgression resulted in the subsequent reworking of the channel sands and formation of a predominately wave dominated embayed coastline. Continued clastic influx created bay-head deltas, tidal flats and the formation of a barrier island–shoreface complex. Storm wave energy transported sediments offshore where they were reworked to form strike fed submarine bars.

Reprinted as published in the Geological Society of America *1995 Abstracts with Programs*, v. 27, no. 3, p. 58.

Characteristics of Overpressured Gas Compartments and Potential Sealing Mechanisms in the Spiro Sandstone, Arkoma Basin, Oklahoma

RODNEY B. FELLER, School of Geology, Oklahoma State University, Stillwater, OK 74078

This investigation provides some plausible explanations for the generation of abnormal pressures of Spiro sandstone reservoirs in the Arkoma Basin. These reservoirs are thrusted and completely sealed compartments. A better understanding of the geometry and sizes of these compartments may provide a more precise estimate of the basin's natural gas reserves. In addition, the findings may also lead to significant decreases in the risk involved in exploring for natural gas in such a tectonic setting.

Compartmentation processes and sealing mechanisms were studied by integrating various geological and geophysical data and information. These include: structural and tectonic framework of the basin, depositional setting, diagenetic patterns, and pressure regimes. A significant finding was the reconstruction of the Wilburton Embayment prior to the Ouachita orogeny. Chamosite bearing facies were identified as providing the best reservoir quality in the Spiro sandstone. These facies were mapped on restored cross sections and post thrust distribution delineated.

Diagenetic patterns observed were greatly influenced by mechanical as well as chemical processes involved in the basin evolution. These patterns were very useful in evaluating diagenesis and genesis of seals and porosities.

Reprinted as published in the Geological Society of America *1995 Abstracts with Programs*, v. 27, no. 3, p. 49.

Relations of Ouachita Fold-Thrust Belt to Its Appalachian Counterpart and to Initial Late Triassic Opening of a "*Closed*" Gulf of Mexico

DEWITT C. VAN SICLEN, Consulting Geologist, Bellaire, TX

The southern Appalachian subduction system continued southwest off the North American craton into the Late Proterozoic oceanic embayment that occupied the area of the present western Gulf Coastal Plain. These dissimilar crustal types (and altitudes) were separated by the convergent right-lateral Phillips basement-fault zone along the northern northeast side of the present Mississippi salt basin. On gravity and magnetic maps this faulting truncates the Appalachian structures and supports the continuation of the Phillips faulting into the eastern "core" of the Ouachita Mountains.

The narrow Wiggins arch along the southern side of this basin was part of the volcanic arc assigned to the oceanic embayment. Of four described wells drilled into Wig-

gins basement, two bottomed in granite and two in phyllite, all "age-dated between 275 and 300 million years (Early Permian–Late Pennsylvanian)," consistent with cooling ages for the mainly Pennsylvanian Ouachita deformation. Earlier, however, the eastern end of the Wiggins arch had collided with the craton near the present Wilcox embayment, where it slowly pivoted about 60° clockwise into its present orientation.

In Late Triassic, during the first stage in opening of the Gulf of Mexico, the Wiggins arch was left behind when the adjoining lithosphere north and east of it moved northward with the rest of North America. This rifting created the Mississippi basin and north-trending Jackson faults across the Wiggins' east end. The Monroe arch north of the west end of the Wiggins may be its former continuation that remained with North America, in which case these arches should be linked by a mirror image of the Jackson faulting.

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Proterozoic Lithospheric Mantle Source for the Prairie Creek Lamproites: Re-Os and Sm-Nd Isotopic Evidence

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Geochemical and isotopic studies of the Cretaceous (106 Ma) Prairie Creek olivine lamproites in southwestern Arkansas indicate that these diamond-bearing ultrapotassic magmas were derived from metasomatized Proterozoic subcontinental lithospheric mantle. Re-Os isotopic data yield a nonradiogenic initial γ_{Os} = –3.2 to –3.6 (percent deviation in $^{187}OS/^{188}OS$ from chondritic mantle) and mantle model ages (T_{MA}) of 0.9 to 1.2 Ga. Sm-Nd isotopic data yield a nonradiogenic initial ε_{Nd} = –10 and a depleted mantle model age (T_{DM}) of 1.2 Ga. These data are consistent with initial stabilization of low-density lithospheric mantle at ~1.2 Ga, followed closely in time by reenrichment in incompatible trace elements. This Middle Proterozoic lithospheric mantle source is younger than overlying Early Proterozoic crust of the southern U.S. midcontinent. Pre-Grenville subduction of oceanic lithosphere may have juxtaposed 1.2 Ga mantle beneath 1.6 to 2.0 Ga crust and imparted the necessary slab-derived chemical components for the growth of diamonds.

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Detection of Natural Weathering of Upper McAlester Coal and Woodford Shale, Oklahoma, U.S.A.

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Natural weathering refers to the natural oxidation of organic and inorganic matter in rocks at the surface and in the shallow subsurface. The objective of this study is to apply routine geochemical analyses (including organic petrography) to coal and shale samples, extending from the weathered to unaltered zones, to illustrate the effects of weathering on organic matter in coal and shale. Some significant observations from the Up-

per McAlester coal and the Woodford Shale are: (1) a sulfate index (SI), using sulfur-form analysis data that reveals the transformation of pyrite to sulfate minerals, is a very sensitive weathering indicator; it increased in weathered samples; (2) Rock-Eval pyrolysis data, such as hydrogen index (HI) and oxygen index (OI), are very sensitive to weathering; OI/HI increased in weathered samples; (3) vitrinite reflectance decreased in weathered samples; and (4) petrographic signs of weathering include microfractures, pitted surface, dark reaction rims, and high relief. Sulfate index and petrographic signs of weathering should be used on surface and shallow subsurface rock samples as an indication of the extent of weathering; the validity of other analyses can then be evaluated accordingly.

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Development of the DOE GASIS National Oil and Gas Reservoir Database

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The Department of Energy's Morgantown Energy Technology Center (METC) is supporting the development of a national database of geological, engineering, and summary production and ultimate recovery data for U.S. oil and gas reservoirs. The reservoir database will be the primary component of the DOE Gas Information System ("GASIS"), and will combine previously compiled public domain data, newly acquired and interpreted data, and newly released data into a single database with over 18,000 reservoir records. Each reservoir record is expected to contain approximately 180 individual data items. The GASIS database will be made available to industry on CD-ROM for personal computer applications.

The database is being developed both for DOE and the oil and gas industry. DOE will use GASIS data as input for a micro-computer based national supply and demand model. For industry and the research community, GASIS will be the first large-scale national public domain compilation of reservoir data.

In addition to database development, the GASIS project includes a major geological research effort designed to improve the coverage and quality of reservoir information in selected regions and plays. This work includes regional and field-level log correlation, log analysis, data collection, and geological interpretation. Reservoir studies are planned for the Mid-Continent region, Texas, and the Central and Eastern Gulf Coast region. These studies will result in a dramatic improvement in the quality and coverage of reservoir level information in the studied areas. In the Mid-Continent region, reservoir studies are concentrating on the assignment of completion level gas production to individual reservoirs.

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Elastic Wave Scaling Studies at the Gypsy Project in Integrated Reservoir Characterization

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The "Gypsy Project" was undertaken by BP Exploration to provoke confrontation between reservoir description and performance prediction at a very highly characterized site. The implementation of "Gypsy" consists of coupled outcrop and subsurface sites supported by extensive laboratory and field measurements.

The Gypsy Project provided the opportunity to examine the dispersion of elastic wave velocity over a wide frequency range. The handling of this scale problem is an important element in the seismic characterization of reservoir flow units.

This paper reports the findings of the first year of a two year project on these two issues of scaling and characterization. The project, carried out largely by New England Research, is a joint venture of BPX and the Gas Research Institute. In this first year, two new classes of velocity data have been established at Gypsy.

NER developed a new method for the laboratory measurement of sonic velocity and attenuation. The method "waveform inversion" provides data in a range from 100 kHz down to 10 kHz.

BPX, implementing a field experiment designed by NER, gathered in-situ (borehole) full waveform sonic logging data at a nominal frequency of 1 kHz, using BPX's Cross-Well field system in a single well mode.

When the new data are incorporated into the existing Gypsy data set the result covers five decades of sonic frequencies from ultrasonic (1,000 kHz) to VSP (0.1 kHz).

The borehole measurements show consistent dispersion, up to 6%, between the 10 kHz and 1 kHz measurements. The dispersion appears to be higher in the faster sands units than in the shaley units.

In 1992 the Gypsy Project and attendant data sets were ceded to the University of Oklahoma, by BPX, where it now serves as a cornerstone of the Center for Reservoir Characterization of the Oklahoma Energy Center.

This paper discusses each class of data and characterizes the sources of error associated with the measurements. It begins with a review of the Gypsy Project stressing elements which support logging studies.

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A Critical Review of Theories on the Origin of Mississippi Valley-Type Lead-Zinc Deposits in the North American Midcontinent

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We review the most widely discussed hypotheses proposed to explain the origin and migration of Mississippi Valley-type (MVT) brines: flow driven by water released from compaction or metamorphism following overthrusting, and topographically driven flow.

Although sediment compaction and fluid expulsion by overthrusting is intuitively appealing, numerical simulations have shown fluid flow rates (~cm/yr) are inadequate by at least an order of magnitude to efficiently transport heat to the sites of ore deposition unless flow is spatially or temporally focused. However, field studies have shown that abnormally high paleotemperatures were not confined to the ore deposits themselves.

While additional fluid released by metamorphic reactions has not been examined quantitatively, the amount of fluid available is still limited and would probably have to be temporally focused.

Topographically driven flow is a physical process that is observed in several sedimentary basins today. Flow velocities can be comparatively high (~1–10 m/yr) if aquifers of sufficient permeability are present. High flow velocities imply that heat can be efficiently transported over hundreds of kilometers. In the North American midcontinent, the Cambrian Lamotte sandstone may have functioned to channel flow to sites of NWT ore deposition on the craton. However, there are several observations that the topographically driven flow hypothesis cannot by itself satisfactorily explain. The very high homogenization temperatures (~80–120°C) associated with fluid inclusions at shallow depths (500–1500 m) in the southeast Missouri ore district cannot be duplicated by any model of topographically driven flow known to us, including models with thermal transients, which has realistic values of permeability and background heat flow. Other problems include the apparent presence of multiple fluids during ore deposition, a severe mass balance problem, and periodicity in ore deposition as revealed by banding.

Although considerable progress has been made in understanding the physical limitations of different hypotheses for formation of MVT deposits, the mechanism which created these ores is still an open question.

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Midcontinent Pennsylvanian Deposition in the Context of Global Patterns

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Depositional patterns are produced by changes in sedimentation, tectonism, eustatic sea level, and plate migration relative to climatic zones. Sedimentation and tectonism are generally basinal in scale, while eustasy and plate migration are global or continental in scope. Recognition of the latter can clarify the former.

The Pennsylvanian is noted for its eustatic signal, expressed as cyclothems. These are fourth-order sequences in the sense of Vail; fifth-order sequences are often recognizable within them. A broad second-order signal is also evident in the Pennsylvanian worldwide. The Mississippian closed with low sea levels and restricted deposition, followed by a rise in the Morrowan. The early Atokan was a period of renewed restriction, marked by basinal siliciclastic influx and a poor fossil record. Sea level rose during the Atokan and the Desmoinesian, with no clear boundary between them. The latest Desmoinesian, Missourian, and early Virgilian was a time of high sea levels, gradually declining in the later Virgilian. Third-order punctuation is problematic. Some episodes, correlatable worldwide, such as the Desmoinesian/Missourian boundary, are marked by a series of lowstands and extinction events. Lesser boundaries are present, such as the major lowstand marked by the Galesburg/Marchand complex and followed by the first *Triticites*. Other third-order divisions should be present, but are not now recognized.

Polar ice migrated across the southern cone of South America in the Early Pennsylvanian, crossed Africa and left Australia in the Early Permian. This Pangaean migration is also expressed by changing climates in the Midcontinent. A correlative of a migrating pole model is that polar ice at any one time may have been less extensive and more subject to topography, affecting the amplitude of the glacio-eustatic signal.

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Stratigraphic Units and Features Formed During Sea-Level Drop (Forced Regression) in Pennsylvanian Glacial-Eustatic Cyclothems from Midcontinent to Appalachian Basin

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Pennsylvanian glacial-eustatic cyclothems can be properly characterized by sequence stratigraphic terminology only when the thick regressive upper limestones that dominate the marine units of the shelf sequence along the Midcontinent outcrop are recognized as the major component of a forced-regressive systems tract deposited mainly during drops in sea level. Conodont correlation of the Appalachian succession of 6 Conemaugh marine units, from Brush Creek through Ames, with 6 major cyclothems in the coeval Midcontinent succession that contains at least 22 eustatic T-R cycles (the remaining 16 of lesser lateral extent and water depth), indicates that the Appalachian basin during early Late Pennsylvanian time lay high on the shelf and was therefore inundated only by the margins of the greatest marine transgressions. Thus, unlike the Midcontinent forced-regressive upper limestone, most of the thickness of Appalachian marine units forms true highstand deposits, along with the lower parts of the overlying paralic/deltaic detrital units. Sea-level drop (forced regression) in the Appalachian basin resulted mainly in fluvial incision of the weakly consolidated detrital units, valley formation, and paleosol development, with local detrital deposition as fluvial channel and paleovalley fillings, including slumping of riverbanks and general colluvial reduction of the landscape. These processes ultimately produced a complex detrital succession containing a number of "type 1" unconformities. Features include large stacked sandstone-filled paleovalleys, a buried hilltop containing a marine outlier, and an even larger possible paleovalley filled with several thin coals and associated marine units, representing the margins of later, lesser marine incursions only into the valley. These features provide evidence for major eustatic sea level drops in the Appalachian basin followed by lowstands, which often were punctuated by lesser eustatic fluctuations that produced marine deposits across the Midcontinent, but only in paleovalleys in higher shelf areas, such as the Appalachian region.

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Sequence Hierarchy and Early Absaroka Onlap in North American Midcontinent

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Permo-Pennsylvanian strata in the Midcontinent of North America are characterized by widespread but comparatively thin successions of repetitive lithologies that record cycles of cratonic deposition and subaerial exposure. These stratal successions, bounded by hiatal surfaces, have long been referred to as cyclothems. Here they are treated as depositional sequences, and incorporate the entire range of associated lithologies. Variation of the genetic units comprising these sequences are ascribed to dynamic interactions of parameters such as sediment supply, shelf elevation, and relative sea-level history. Field studies and experiments using stratigraphic simulation models demonstrate that contrasting shelf settings exhibit considerable change in expression and a lack of strict temporal correlation for genetic units. Thus, relative "completeness" of a sequence in terms of idealized lithologic successions is a function of location and changing parameters along a depositional profile. Interbasin correlations among contrasting shelf settings has been problematical, dependent on cycle counting or inferred stacking geometries; exclusively lithological correlations can be difficult or impossible. Increasing biostratigraphic resolution permits independent confirmation and refinement of physical correlations down to the scale of individual sequences.

Examples from Late Atokan–Early Desmoinesian successions show that in mid-shelf positions sequences contain the greatest preservational fidelity. This reflects modern sediment accommodation and sedimentation rates, and longer residence time under shallow-marine conditions. Those same sequences thin basinward into lithologically

simplified condensed sections due to reduced sedimentation and longer episodes of deeper water. Sequences thin shoreward into peritidal settings dominated by amalgamated paleosols that represent prolonged periods of subaerial weathering, or they may thicken into nearshore clastic wedges where sediment supply was significant. Stacking patterns of the Late Atokan–Early Desmoinesian sequences suggest that composite sequences were similarly controlled by longer-term changes in relative sea level. These sequences onlap the heavily dissected pre-Absaroka surface and reduce its original erosional and structural relief.

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Variations in Oil Composition During Production and Water Flooding: A Case Study in the Prairie Gem Field, Central Oklahoma

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Reservoir geochemistry is a relatively new application of geochemistry to the solution of production and reservoir characterization problems. Oil production decreases often are related to reservoir heterogeneities caused by compositional changes of the oils and their interactions with the mineral matrix. The aim of present study is to evaluate compositional changes occurring in oils during production before and after water flooding and the influence of these changes on reservoir performance.

The Prairie Gem Field, located in Lincoln Co. of central Oklahoma, where the water flooding had started in 1993 was selected for this study. The oils were collected from well-heads at different stages of production before and after the water flooding and analyzed by gas-chromatography, high temperature gas chromatography and gas chromatography–mass spectrometry. Detailed geochemical studies of the oils collected prior to water flooding enabled various oil families related to different production zones to be differentiated and to determine the extent of reservoir continuity. The changes in relative abundances of alkanes, asphaltenes and waxes content during different stages of production will be further discussed in relation to the vertical and horizontal heterogeneity of the reservoirs and the fractionation effects on the mobile oils.

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Image Analysis Characterization of Small-Scale Heterogeneities in Fluvial Reservoirs: A Case Study from the Gypsy Sandstone of Central Oklahoma

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To test the ability of the Formation MicroScanner (FMS mark of Schlumberger) tool to discriminate small-scale heterogeneity in fluvial reservoirs, six wells were logged with the FMS in a well characterized reservoir—the Gypsy sandstone of central Oklahoma. The reservoir was examined in outcrop, shallow borings and "normal" reservoir environments. The reservoir was purposely chosen to contain only water, so that the effects of lithofacies on log response could be isolated.

The outcrop site includes 22 shallow borings, each between 70 and 120 feet deep, drilled immediately north of the highway roadcut. One of these boreholes was reamed out and logged with a suite of tools that included the FMS. A detailed description of lithofacies, large-scale erosional surfaces and the distribution of porosity and permeability was made on the outcrop face and in the cores. To further characterize reservoir properties 1194 core plugs were obtained. Measurements of porosity, permeability, grain size and sorting were made across the outcrop face.

In the 5 acre subsurface study site, the Gypsy sandstone observed at a depth of 890 to 1000 feet was completely cored and logged with a full suite of wireline tools. In all wells, core plug porosity and permeability measurements were made every foot. Lithofacies were described from core. Framework mineralogy and cements were described by point counting samples from two of the wells.

A comparison of the surface and subsurface sites revealed that the Gypsy sandstone has similar sedimentary structures, grain size and framework mineralogy in both settings. In each location, sedimentary structures (i.e., fluid escape structures, cross-bedding and planar laminations) are commonly defined by thin clay-rich laminations. These laminations are composed of sand-sized mudstone clasts. Between surface and subsurface there are, however, differences in the abundance and mineralogy of cements. These differences result from weathering of the ferroan dolomite, an important cement phase in the subsurface.

Given these data, it was possible to characterize reservoir heterogeneity in the Gypsy sandstone in great detail. The tool was able to image sedimentary structures that were defined by thin clay-rich laminations such as dewatering structures and some foreset laminations.

The interpretations from FMS data are being incorporated into the studies of sonic scaling and attenuation reported in the accompanying paper by D. Burns et al.

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Three-Dimensional Distribution of Lithofacies, Bounding Surfaces, Porosity, and Permeability in a Fluvial Sandstone, Gypsy Sandstone of Northern Oklahoma

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Where it was studied at two sites in north-central Oklahoma, the Gypsy sandstone of the Pennsylvanian Vamoosa Formation provides significant insights into the controls on reservoir quality in a meandering river deposit. At an outcrop site west of Tulsa, a three-dimensional architectural framework, based on erosional surfaces, allowed the recognition of a channel-fill sequence consisting of six channel sand bodies and representing at least three channel belts. Belts are vertically stacked and are incompletely separated by low-permeability flood-plain deposits, which are locally eroded. Porosity and permeability are primarily related to depositional facies. Within channel belts, mudclast lags associated with erosion surfaces at the base of channels have the potential to act as vertical permeability baffles between channel sand bodies, as do mud-draped lateral accretion surfaces within channel sand bodies.

At a subsurface site 31 km (19 mi) to the west of the outcrop site, nine wells were drilled and cored through the Gypsy interval. At this site, it was possible to identify and correlate three channel belts comprising amalgamated channel sand bodies. Although lower level architectural elements could be recognized in cores, they could not be correlated with confidence given a 100-m (330-ft) well spacing.

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Integrating Landsat TM, Airborne Video, and Hand-Held Spectral Data for Lake Water Quality Assessment

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Washita-94, a collaborative effort involving NASA, USDA-ARS, and faculty from several universities, assessed hydrologic aspects of the Little Washita River basin in Oklahoma. Narrow band reflectance spectra were acquired from lakes using a SE-590 radiometer and coincident water samples were obtained. Eleven lakes were sampled in April and eight lakes were sampled in August.

Landsat TM data were acquired for both April and August. Digital airborne video data was acquired using three narrow bandwidths during the August sampling period. Comparison of the remote sensing data sets indicates that narrow band spectral measurements are needed to assess variations in chlorophyll a concentration.

Comparison of spectral data with water quality data indicates significant relationships between reflectance and several measures of water quality. Increases in suspended particulates are related to increases in overall brightness in the reflectance data. Organic activity is best expressed in the narrow chlorophyll absorption band at 680 nanometers.

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Characterization of Fluvial-Dominated Deltaic Reservoirs in a Mature Oil Field: Glenn Pool Field, Northeastern Oklahoma

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Glenn Pool Field, located on the Northeastern Oklahoma Platform, has produced for 90 years from the Glenn Sand, a fluvial-dominated deltaic system equivalent to the Pennsylvanian Bartlesville Sandstone. About 70 percent of OOIP remains as a result of the complex reservoir architecture. This study has focused on a 160 acre block (82 wells drilled to date) in the southern part of the field.

Detailed reservoir architecture is critical for improving production performance. Through detailed well log correlation, the 120–140 ft thick Bartlesville Sandstone is subdivided into six discrete genetic intervals (DGI) descending from A to F. Core and log facies studies show that DGI A through E are likely to be delta plain fluvial channel-fill and crevasse splay deposits, and F channel-mouth bar deposits. Channel-fill facies is characterized by upward-fining texture and reduction in scale of physical sedimentary structures, and it is subdivided into: lower channel-fill subfacies, well to moderately sorted medium-grained sandstone with medium-scale cross stratification, middle channel-fill subfacies, moderately sorted, lower medium-grained to poorly sorted, silty fine-grained sandstone with low-angle parallel stratification and ripple lamination or ripple lamination superimposed on cross stratification; and upper channel-fill subfacies, mudstone to silty claystone. Splay facies is characterized by fine- to medium-grained sandstone with ripple lamination and upward-coarsening texture. Channel-

mouth bar facies is characterized by well sorted, generally massive, upper medium- to lower coarse-grained sandstone. Lab core measurements have shown that the porosity and permeability are strongly DGI-related. Descending from DGI A to F, porosity increases from about 8 percent to about 22 percent, permeability increases from less than 0.1 md to more than 300 md. Initial results suggest that within a given DGI, petrophysical properties are facies/subfacies related.

Analysis of a microresistivity image log, which was acquired in a project cooperative well—Uplands Resources Self No. 82, permitted a detailed architecture reconstruction. At location of Self No. 82, DGI C is made up of lateral accretion bar deposits. Comparison of azimuthal orientations for cross strata and lateral accretion surfaces indicates a downstream location. From spatial orientation of lateral accretion surfaces, it is predicted that 19 lateral accretion mud drapes are present between Self No. 82 and Self No. 81 (270 ft apart). Based on orientation patterns, in the vicinity of Self No. 82, DGI D is divided into 4 splay units and DGI E is divided into 2 splay units. Image color proportion analysis indicates that of 22 ft DGI D splay deposits, only a 4 ft interval has been contacted by water flooding.

The facies architecture model is being incorporated with results of crosswell tomography and reservoir simulation for the development and implementation of a reservoir management plan.

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Interdisciplinary Analysis of Fluvial Dominated Deltaic Reservoirs: Glenn Pool Field, Creek County, Oklahoma

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Glenn Pool Field, located on the Northeastern Oklahoma Platform, has been under production since 1905. However, it still contains 80% of the original oil in place, due to the high reservoir complexity. The field study is focused on a 160-acre block (Self Unit) which was under primary production, then was gas pressurized and has been under water flood ever since. At present, a 99% water cut makes it necessary to develop a better management plan. A detailed multi-disciplinary (Geology, Geophysics, Petroleum Engineering) reservoir study with state-of-the-art technology was undertaken in this mature, marginal oil field.

Self Unit was studied with conventional methods prior to drilling a cooperative project well (Uplands Self #82). Stratigraphic framework of the Glenn Sand reservoir has been established through a series of northeast to southwest stratigraphic cross sections. Six discrete genetic intervals (DGI) for the 120–140 ft thick reservoir were delineated from well log correlations. Channel-fill, splay, channel mouth bar, levee and interdistributary mudstone facies were recognized from well log profiles and core analysis. Attempts were made in simulating geology using sequential indicator simulation methods; results were not entirely satisfactory.

Self #82 was drilled in late December, 1993. The project objectives for drilling the well were: (1) evaluate reservoir predictions; (2) collect data using conventional and advanced technologies. Pre-drilling facies architectural characterization was reasonably successful. In addition to the conventional well log suites and core, advanced technologies including microresistivity imaging log and crosswell tomography were applied. Simulation of the DGI distribution was undertaken using truncated Gaussian simulation method. Simulation results strongly agree when comparing probability input distributions with the output distributions. Porosity distribution was simulated using the simulated annealing method. For a selected well location (Self #82) the comparison between simulated and core porosity is very good although core data were not used as conditioning data. The permeability distribution was transformed from porosity using a conditional distribution approach and was validated using well test data. Crosswell transmission and migrated reflection tomography images between Self #82 and three offset wells constrained lateral reservoir continuity.

A reservoir management plan, which is to be implemented in the last quarter of 1994, was developed from reservoir performance simulation, well test data, facies architecture and crosswell tomography.

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Preliminary Comparison of Rare-Earth Element Variation in Pennsylvanian Phosphate Nodules from Kansas/Oklahoma with Those in Indiana/Illinois

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Three rare earth element (REE) patterns characterize Desmoinesian and Missourian phosphate nodules in marine black and gray shales in eastern Kansas and northeastern Oklahoma. Flat, shale-normalized REE patterns and patterns enriched in middle REE (MREE) are common, whereas patterns preserving a minor Cerium depletion are rare. Flat patterns probably reflect terrigenous detrital influence. MREE-enriched patterns may record a fecal component. Ce-depleted patterns are most likely the result of a seawater component that has only been preserved in special cases.

Preliminary REE data from phosphate nodules from the Mecca Quarry Shale in Indiana and Illinois (Shaffer et al., 1988) display REE patterns that are similar to those in Kansas and Oklahoma phosphates. However, the shale-normalized abundance in the Indiana and Illinois samples is lower than in many of the Kansas and Oklahoma phosphates. This could reflect the preliminary nature of the sampling in Indiana and Illinois. If the lower abundance reflects a difference in the phosphate genesis, it conflicts with the REE patterns, which suggest a more similar origin for the Indiana/Illinois and Kansas/Oklahoma phosphates.

Similarities between flat REE patterns from the two regions are probably meaningless. Comparable MREE-enrichments may be useful for depositional comparisons.

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Sedimentological Analyses of Rhythmic Bedding in the Labette Formation, Northeastern Oklahoma

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The Labette Formation (Marmaton Group, upper Desmoinesian), located in northeastern Oklahoma, contains many interesting depositional features, including cyclic patterns of laminae, a variety of sedimentary structures, and abundant trace fossils. The presence of these features provides an excellent opportunity to reconstruct the original depositional environment of the formation.

The Labette Formation is composed primarily of fine grained sandstone layers separated by thin, impersistent mud drapes. The sandstone itself is light to medium gray in color, well sorted, and displays lenticular bedding and herringbone cross stratification. The layers separate easily along the silt partings to reveal well preserved current ripples and other sedimentary structures such as current shadows and other various toolmarks. Also preserved within the laminae are a variety of trace fossils, particularly arthropod trackways, formed by epifaunal grazers and scavengers, resulting in few vertical burrows and little or no bioturbation of the bedding planes.

The cyclic patterns of the Labette Formation occur at two different scales, one involving the individual laminae themselves, and the other involving groups of laminae, called cycles. Lamination thickness ranges from 2 to 45 mm and it can be seen that the laminae are grouped into regular bundles. The groups of laminae, or cycles, range in thickness from 2 to 37 cm, and contain between 12 and 22 laminae, with an average of 18 laminae each.

The periodicities recorded within the outcrop show a remarkable similarity to those of lunar orbital parameters. This evidence, when combined with the sedimentary structures and trace fossils, provides strong evidence of deposition within a tidally controlled environment.

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Geohydrology of Alluvium and Terrace Deposits Associated with the Cimarron River in Northwest Oklahoma

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Ground water in Quaternary alluvium and terrace deposits associated with the Cimarron River in northwest Oklahoma, an area of approximately 1,305 square miles, is used extensively for irrigation, municipal, stock, and domestic supplies. It is the major source of water for the City of Enid, the largest single user of ground water in Oklahoma. These deposits are composed of varying proportions of clay, silt, sand, and gravel with a maximum thickness of 120 feet. The underlying geologic units are Permian shales, sandstones, siltstones, dolomite, gypsum, and salt beds. The aquifer is unconfined and has an average saturated thickness of 28 feet with an estimated 4.47 million acre-feet of water in storage.

The Maximum Contaminant Levels were exceeded for 31 of 63 of the wells sampled for nitrate and for 3 of 61 of the wells sampled for cadmium.

A finite-difference ground-water flow model was developed to provide state water managers with quantitative knowledge necessary to manage the ground-water resource effectively. The model was calibrated to observed ground-water heads and aquifer discharge assuming time-averaged steady-state conditions. The model depicted an average annual recharge to the saturated zone of 203.38 cubic feet per second (ft^3/s) (2.24 inches per year) from downward percolation of precipitation, 0.70 ft^3/s from leakage of surface water through stream channels, and 0.22 ft^3/s by subsurface inflow. Simulated average annual discharges consisted of 174.98 ft^3/s to the Cimarron River and its perennial tributaries by seepage and evapotranspiration of the saturated zone, 24.06 ft^3/s from withdrawals from wells, 5.86 ft^3/s by leakage to Permian geologic units, and 0.07 ft^3/s from subsurface outflow from alluvium. The calibrated hydraulic conductivity is 104.5 feet per day for the alluvium and 47.5 feet per day for the terrace deposits.

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Source and Distribution of Eolian Surficial Material, Central Southern High Plains

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In the past, the surficial geology of the central and southern High Plains of Kansas, Oklahoma and northern Texas has received only cursory attention. Thorp and Smith (1952) produced the last comprehensive map that included this region. As part of a larger ongoing study, we are examining High Plains surficial units on a reconnaissance basis from the Arkansas River in Kansas to the Canadian River in the panhandle of Texas.

Seasonal wind maps for the southern High Plains show a shift in primary winds from the northwest to the southwest immediately south of the Cimarron River. This zone of convergence is reflected in the distribution of eolian features.

An attempt was made to relate the distribution of the uppermost surficial units to source areas in this region. The particle size distribution of the <2 mm fraction (clay-free basis) for the upper strata of several sites between the Arkansas and Cimarron Rivers were examined. For these upper units, the Arkansas River appears to be the most likely source. R^2 values for size versus distance from source are generally >0.80. R^2 values for a Cimarron source in this area were <0.60. This suggests that the Cimarron is a more local source for eolian material. Field studies show textures of the upper strata coarsen northward toward large dune fields on the south side of the Arkansas River.

Both the Beaver and Cimarron Rivers were tested as possible sediment sources for sites located between these rivers. Based on preliminary data, no significant relation of particle size with distance was found. This reinforces the chaotic nature of many of the eolian features delineated in this region.

The southernmost sites are from the Beaver to the North Canadian Rivers. Preliminary interpretations of particle size suggest that sources for material at these sites may include major tributaries to the Beaver and Canadian.

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Jurassic San Rafael Group Stratigraphy in NE New Mexico, SE Colorado, and NW Oklahoma Panhandle

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A new stratigraphic model that uses existing nomenclature is proposed for the Jurassic San Rafael Group in the Dry Cimarron Valley of NE New Mexico, SE Colorado, and NW Oklahoma Panhandle. The San Rafael lithostratigraphic sequence from top to bottom is Summerville F, Sheep Pen Ss, Todilto F, and Entrada Ss. San Rafael thickness is 0–41 m. The Morrison F overlies the San Rafael.

The Summerville consists of the Bell Ranch Mbr ("brown-silt") and the Exeter Ss Mbr. Thickness is 0–30 m. The top of the Bell Ranch agate bed is the top of the Summerville. The Bell Ranch conformably overlies the Exeter. The base of the Summerville is a major disconformity exhibiting at least 41 m of paleotopographic relief. The Sheep Pen traditionally has been considered to be the uppermost Triassic unit in the area. It is reassigned to the San Rafael. Thickness is 0–40 m. The base is locally scoured and channeled. The Todilto is composed of sandstone, siltstone, shale, and dolomite. Thickness is 0–3 m. Molds and casts of halite, gypsum, and glauberite are locally abundant. The Todilto conformably overlies the Entrada. Entrada thickness is 0–9 m.

The San Rafael overlies various Upper Triassic units with angular unconformity and marked disconformity. At least 27 m of post-Triassic paleotopographic relief is indicated. The Entrada occurs only in the lowest portions of this paleotopography.

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