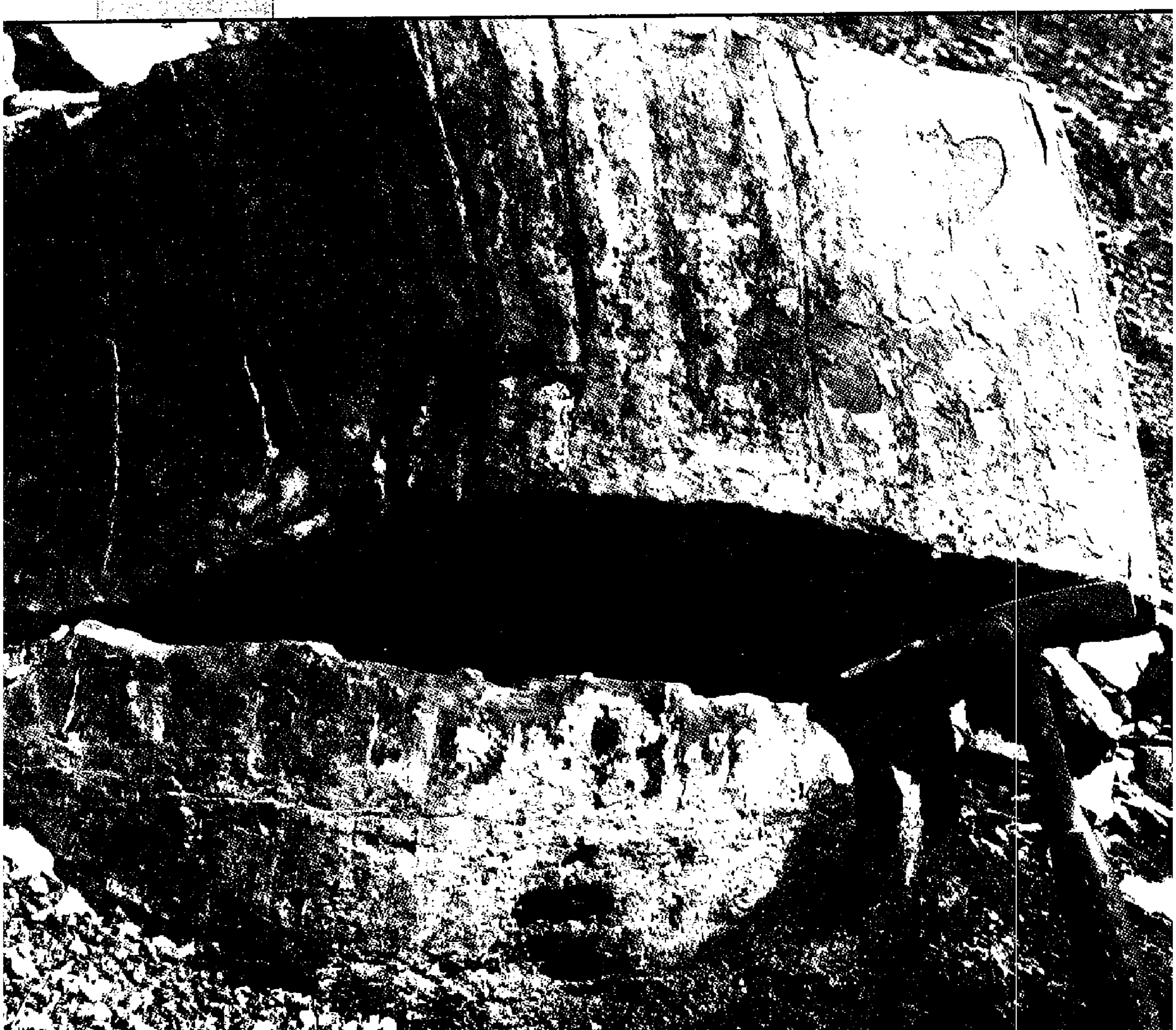
OKLAHOMA GEOLOGY



Vol. 56, No. 2
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Oklahoma Geological Survey

On The Cover —

Calamites Stump, Hartshorne Formation (Pennsylvanian)

Calamites was a large, treelike plant that made up a significant part of the Pennsylvanian forests of North America. The genus *Calamites* is a type of Sphenophyta, or joint-grass. A modern Sphenophyta is called *Equisetum*; its popular name is common horsetail rush or scouring rush. It is relatively common in swamps and along streams in many parts of Oklahoma.

The *Calamites* stump pictured on the cover is not petrified wood; rather, it is the internal cast of a large trunk that was more than 3 ft in diameter. Like modern Sphenophyta, the trunk of *Calamites* was filled with pith, a spongy tissue. Casts like these formed when a living *Calamites* trunk broke and its interior filled with sand and silt. Eventually, sand and silt lithified and the woody cylinder that comprised the *Calamites* trunk disintegrated. The sandstone cast perfectly preserves the internal features of the woody, but formerly pith-filled, trunk.

The inset photograph below shows geologists from the Oklahoma Geological

(continued on p. 48)

OKLAHOMA GEOLOGICAL SURVEY

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OKLAHOMA GEOLOGY

Notes

C O N T E N T S

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COGEOMAP: Cooperative Geologic Mapping Program in Oklahoma, 1984–1993

Kenneth S. Johnson[1] *and Neil H. Suneson*[1]

Introduction

In 1984, the U.S. Geological Survey (USGS) issued a request for proposals to state geological surveys to carry out geologic mapping under the new Federal/State Cooperative Geologic Mapping (COGEOMAP) Program. The Oklahoma Geological Survey (OGS) saw this as an opportunity to pool its resources and capabilities with those of the USGS and the Arkansas Geological Commission (AGC) in a cooperative mapping program in the Ouachita Mountains of southeastern Oklahoma and southwestern Arkansas. The two-state cooperative program (Oklahoma and Arkansas) was unique among COGEOMAP proposals from the various state geological surveys.

The national COGEOMAP Program was designed through discussions and planning by USGS geologists and many of the state geologists, working through the Association of American State Geologists Liaison Committee (Reinhardt and Miller, 1987). It was designed to "promote new geologic mapping that meets high-priority Federal and State objectives" (Reinhardt and Miller, 1987, p. 1). Cooperative funding was to provide support for any or all of the following: (1) detailed geologic mapping; (2) preparing state geologic maps; (3) acquiring geologic and geophysical data to enhance understanding geologic-map relations; and (4) preparing a state digital geophysical-map series (Reinhardt and Miller, 1987). The first year of the program was Federal Fiscal Year (FY) 1985 (starting October 1, 1984); the national program began with Federal appropriations of $1.0 million in FY-85, which rose to levels of $1.3 million to $1.5 million for each of the remaining seven years of the program. For the most part, COGEOMAP projects were funded on the basis of 50:50 matching (Federal-to-State); the Federal portion was not to exceed 50% of the total funding for any project (Reinhardt and Miller, 1987).

First-Year Activities

The first year was critical in defining a comprehensive, long-range program of joint research that would be responsive to State and Federal needs. A proposal needed to be prepared and staff for the project had to be identified. Kenneth S. Johnson, OGS associate director, assumed the role of principal investigator and coordinator for OGS activities; new staff would be hired for field mapping.

A program for mapping and study of the Ouachita Mountains of Oklahoma was identified by OGS as its highest priority, which fit in with AGC plans to complete mapping of the Arkansas part of the Ouachita Mountains. The two states, therefore, prepared a joint proposal to the USGS, which included cooperation by OGS, AGC, and USGS to pool the in-house expertise of each agency.

A planning meeting, held in Norman, Oklahoma, on January 21–22, 1985, brought together 21 people with experience and/or interest in Ouachita Moun-

[1]Oklahoma Geological Survey.

tain geology (Fig. 1). The USGS group was led by Juergen Reinhardt and Harry A. Tourtelot; the OGS was led by Charles J. Mankin and Kenneth S. Johnson; the AGC was led by Norman F. ("Bill") Williams and Charles G. Stone; three other specialists that attended were Boyd R. Haley, Kaspar Arbenz, and Rodger E. ("Tim") Denison, each with many years of Ouachita Mountain mapping experience. From this meeting and follow-up discussions and activities, the combined OGS–AGC–USGS program was developed.

Throughout the life of the program, the major OGS goal was preparation of a series of new 1:24,000-scale geologic maps (plotted on 7.5-minute topographic-quadrangle maps) of the Ouachita Mountains and adjacent parts of the Arkoma basin, and their release as black-and-white open-file maps. In addition, companion OGS studies would involve: (1) preparing maps and cross sections depicting subsurface geology of the Ouachita Mountains and Arkoma basin, and (2) assessing the potential for petroleum and other mineral resources in the Ouachita Mountains and Arkoma basin provinces.

The original first-year proposal from OGS requested $250,000 for the Oklahoma part of the program: $125,000 each from OGS and USGS. However, there was only $1 million available for the the USGS to match proposals from all of the various states in the first year. A revised budget of $150,000 for

Figure 1. Personnel who attended the meeting in Norman, Oklahoma, on January 21–22, 1985, to plan the combined OGS–AGC–USGS COGEOMAP program. Top photo shows OGS staff (from left): Brian J. Cardott, Robert O. Fay, Thomas W. Amsden, Michelle J. Summers, Patrick K. Sutherland, Kenneth V. Luza, James R. Chaplin, Margaret R. Burchfield, Kenneth S. Johnson, and Charles J. Mankin. Middle photo shows USGS staff (from left): Lindrith Cordell, Juergen Reinhardt, Dudley D. Rice, Harry A. Tourtelot, John Grow, and Joseph R. Hatch. Bottom photo shows AGC staff and invited specialists (from left): Charles G. Stone, Norman F. ("Bill") Williams, Boyd R. Haley, Kaspar Arbenz, and Rodger E. ("Tim") Denison.

TABLE 1.— FUNDING FOR OKLAHOMA COGEOMAP PROJECT, FY 85–92

Contract Year	Federal Fiscal Year	Contract Period	USGS Funds		OGS Funds	Total Funds
			Cash	In-Kind		
1	FY-85	10/1/84–9/30/85	$35,000	$40,000	$75,000	$150,000
2	FY-86	10/1/85–9/30/86	69,915	50,085	120,000	240,000
3	FY-87	6/29/87–1/31/88	75,000	25,000	100,000	200,000
4	FY-88	2/1/88–1/31/89	71,000	30,400	101,400	202,800
5	FY-89	2/1/89–1/31/90	71,000	25,000	96,000	192,000
6	FY-90	2/1/90–1/31/91	65,000	20,000	85,000	170,000
7	FY-91	7/1/91–6/30/92	40,000	20,000	60,000	120,000
8	FY-92	7/1/92–6/30/93	40,000	20,000	60,000	120,000
			$466,915	$230,485	$697,400	$1,394,800

the first year was submitted and approved (Table 1). In the first year of the COGEOMAP Program, USGS received proposals from 35 states; because of the $1 million limit, it was able to make awards for only 17 geologic-mapping projects (including the combined Oklahoma–Arkansas program).

The first year's activities for the approved OGS COGEOMAP project involved: (1) hiring an experienced field-mapping geologist to set up, direct, and carry out the field program; and (2) assembling the data needed to support the program. Neil H. Suneson was hired in January 1986 to head the field-mapping program (which would start in the second year), and OGS staff members began assembling the necessary support data. During the first year (and subsequent years, in some cases), the OGS part of the project required many support tasks, listed here with the OGS staff who carried out the work:

1. Preparation of an annotated bibliography (Robert O. Fay);
2. Preparation of an index to geologic mapping and field studies (Kenneth V. Luza);
3. Preparation of a catalog of oil and gas wells (Margaret R. Burchfield);
4. Assessment of data on chronostratigraphy (Robert O. Fay and James R. Chaplin);
5. Computer-data processing (Michelle J. Summers); and
6. Project coordination (Kenneth S. Johnson).

USGS in-kind services in the first year centered on providing personnel and services for digital processing and interpretation of geophysical data for the Ouachita Mountains of Oklahoma and Arkansas.

Years Two Through Eight

Following his arrival at OGS, Suneson reviewed all existing geologic maps of the Oklahoma part of the Ouachita Mountains and decided to focus OGS efforts on the frontal belt (Fig. 2). He had two principal reasons: (1) some parts of the frontal belt had not been mapped since the 1920s; and (2) because the frontal belt is adjacent to known major producing gas fields, it would be a likely site for future petroleum exploration. Charles A. Ferguson was hired later in 1986 to assist Suneson, and field work began in the Higgins 7.5-minute quadrangle in October (Table 2).

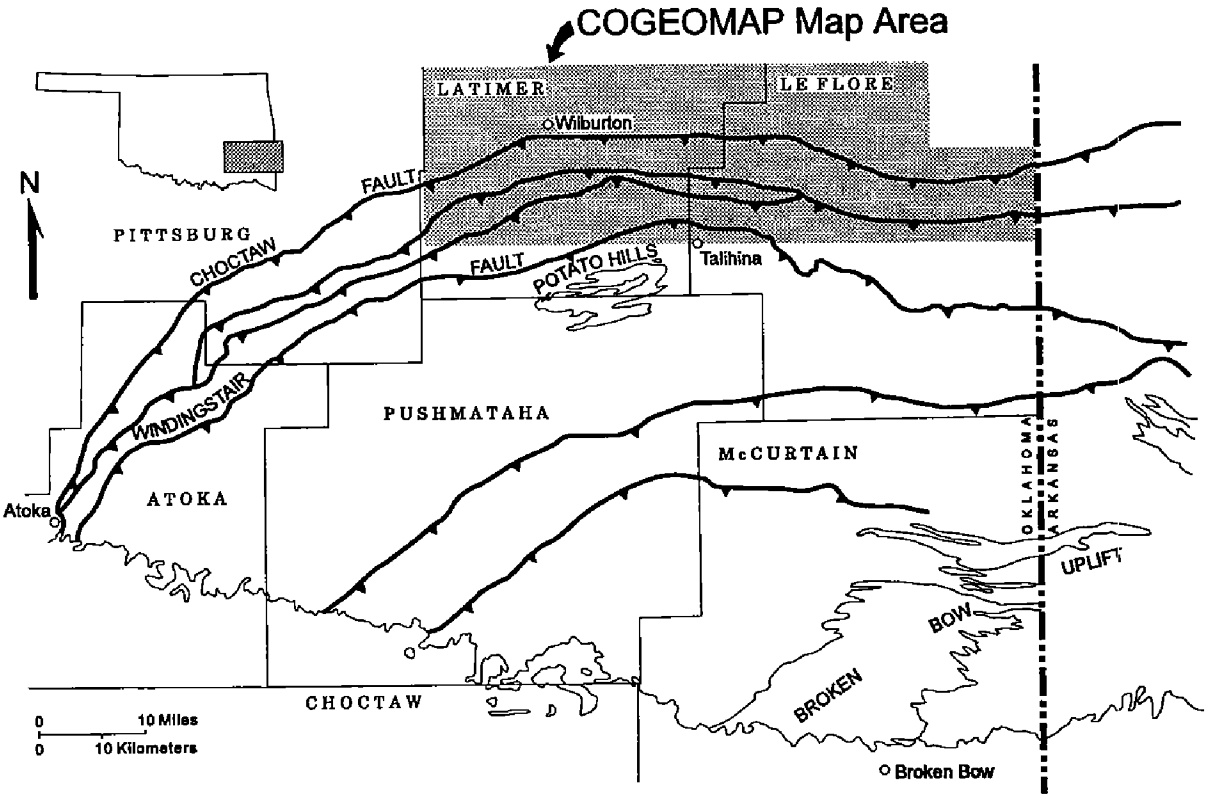

Figure 2. Map of Oklahoma Ouachita Mountains showing principal thrust faults and COGEOMAP area. The frontal belt is located between the traces of the Choctaw and Windingstair faults. To the south, strata of the Ouachita Mountains are unconformably overlain by Gulf Coastal Plain strata (Cretaceous).

After the first field season (fall 1986 through spring 1987), Suneson, Ferguson, and Johnson agreed that the mapping effort should include the southern part of the Arkoma basin immediately north of the Choctaw fault in order to provide a more complete understanding of the structural and stratigraphic development of the Ouachitas. This addition also would allow whole quadrangles to be completed, and it would permit as well an investigation of coal resources in that area. OGS geologist LeRoy A. Hemish, who had mapped extensively in the northern part of the Oklahoma coal field, joined the COGEOMAP project in the fall of 1987 with the responsibility of mapping areas north of the Choctaw fault.

The first of two major COGEOMAP meetings designed to review the results of the Oklahoma and Arkansas efforts was held on April 1, 1987, in Norman. Those present on behalf of the OGS were Johnson, Suneson, Ferguson, Fay, Burchfield, Summers, Chaplin, Brian J. Cardott (organic petrologist), Jane L. Weber (organic geochemist), Jock A. Campbell (petroleum geologist), Dorothy J. Smith (petroleum geologist), and David L. Brown (student assistant). Attending for the AGC were Stone, Haley, and William V. Bush (assistant state geologist), and for the USGS, Tourtelot, David M. Miller, Jon C. Matti, John E. Repetski, Robert M. Kosanke, and William J. Perry, Jr. John C. Nichols, geologist with the U.S. Forest Service, also attended the meeting. A two-day field trip to the Higgins and Damon 7.5-minute quadrangles followed the meeting.

A second COGEOMAP meeting and field trip were held about a year later (April 7–9, 1988). The meeting was held in Norman; the field trip that followed be-

TABLE 2. — DATES OF BEGINNING AND COMPLETION OF COGEOMAP QUADRANGLE MAPPING AND RELEASE OF GEOLOGIC MAPS

Name of 7.5′ Quadrangle	Mapping Started	Mapping Completed	Map Released
Higgins	10/86	12/86	First Half 1989
Damon	2/87	4/87	First Half 1989
Wilburton	2/87	12/87	First Half 1990
Baker Mountain	10/87	12/87	First Half 1989
Panola	10/87	6/88	First Half 1990
Talihina	4/88	3/89	Second Half 1990
Red Oak	4/88	12/88	Second Half 1990
Blackjack Ridge	3/89	10/90	First Half 1991
Leflore	12/88	12/89	First Half 1991
Leflore SE	3/89	10/90	First Half 1991
Hodgen	10/90	12/90	First Half 1993
Gowen	3/91	6/91	First Half 1992
Hontubby and part of Loving	9/91	12/91	First Half 1993
Summerfield	3/92	5/92	Second Half 1992
Wister	4/92	11/92	First Half 1993

gan in Mena, Arkansas, and ended near Talihina, Oklahoma. Attendees for the 1988 meeting included Hemish, Joe R. Whiteside (student, Baylor University), and Wayne L. Newell (USGS COGEOMAP coordinator), as wells as many of those who had attended the 1987 meeting.

Ferguson left the OGS in the summer of 1988 to begin work on his doctoral degree at the University of Calgary in Alberta, Canada. During his two years with the OGS, he coauthored six geologic maps, two abstracts, and one paper, and also wrote the text for two stops in a field-trip guidebook. He has continued to be active in thrust-belt studies in Canada and in mapping in Arizona and New Mexico.

A major field trip to the Oklahoma part of Arkoma basin and Ouachita Mountains was held on October 1, 1988, following the 25th annual national meeting of the American Institute of Professional Geologists in Tulsa. It was well attended (about 30 geologists). Three of the stops were within the COGEOMAP project area and one was immediately to the west. Ferguson, Hemish, Johnson, and Suneson contributed papers and/or stop descriptions to the guidebook that was published in conjunction with the trip (*Shelf-to-Basin Geology and Resources of Pennsylvanian Strata in the Arkoma Basin and Frontal Ouachita Mountains of Oklahoma,* OGS Guidebook 25).

Following Ferguson's departure, mapping by Suneson and Hemish continued at a steady, albeit slightly slower, pace. Hemish extended his efforts to include areas south of the Choctaw fault, beginning with field work on the Leflore 7.5-minute quadrangle in December 1988.

Serendipitously, as Suneson and Hemish mapped farther east, gas-exploration activity in the western part of the COGEOMAP project area increased. This activity may have been sparked by minor discoveries in 1987 in the frontal belt in northern Atoka County or a deep Arbuckle test spudded in February 1987, immediately west of Wilburton. Regardless, Amoco spudded the No. 1 Garrett A in December 1987, just west of the COGEOMAP project area and the No. 1 Zipperer in March 1988, in the Higgins quadrangle. In December 1988, Amoco announced that the Zipperer was a major gas discovery. Suddenly and quite unexpectedly, the OGS COGEOMAP program came to the attention of the oil and gas industry.

A second major field trip to the Ouachita Mountains of Oklahoma was held September 27–28, 1989, following the Mid-Continent Section Meeting of the American Association of Petroleum Geologists (AAPG). The field trip was well attended (about 60 geologists), perhaps as a result of the high level of industry interest. It originated in Oklahoma City and started with three stops in the COGEOMAP project area (and two just outside). The trip focused on the petroleum geology of the Ouachita Mountains and concentrated on the western part of the frontal belt, west of the COGEOMAP area. The field-trip guidebook, OGS Special Publication 90-1, *Geology and Resources of the Frontal Belt of the Western Ouachita Mountains, Oklahoma,* by Suneson, Campbell, and Maxwell J. Tilford (Tide West Oil Co., Edmond, Oklahoma), sold out quickly and had to be reprinted. By request, the field trip was repeated April 11–12, 1991, following the AAPG Annual Convention in Dallas. About 45 geologists attended that trip.

In the spring of 1991, Hemish temporarily stopped his eastward progression of mapping and started work on the Gowen 7.5-minute quadrangle, located just north of the Higgins quadrangle, where mapping for the COGEOMAP project had started. The purpose was to complete a block of eight 7.5-minute quadrangles (Nos. 1–8 on Fig. 3) that could be compiled at a scale of 1:50,000.

Suneson left the COGEOMAP project in the summer of 1991 to spend one year as a visiting scientist with the New Zealand Department of Scientific and Industrial Research (DSIR), now the Institute of Geological and Nuclear Sciences, in Lower Hutt. He was replaced by Colin Mazengarb, an experienced field geologist from DSIR. Hemish and Mazengarb continued COGEOMAP mapping, working on the Hontubby and Loving 7.5-minute quadrangles in the fall of 1991 and on the Summerfield 7.5-minute quadrangle in the spring of 1992 (Fig. 3).

In the summer of 1992, Suneson returned to the U.S. and Mazengarb returned to New Zealand. Suneson extended his work area to include the Arkoma basin north of the Choctaw fault. In the fall of 1992, he assisted Hemish in mapping the Wister 7.5-minute quadrangle. This effort and the release of the Wister geologic quadrangle map (Fig. 3) highlighted the final year of the COGEOMAP project (FY-92, contract period July 1, 1992 through June 30, 1993) (Tables 1, 2).

The Heavener and part of the Bates 7.5-minute quadrangles then were mapped by Suneson and Hemish as part of the new USGS STATEMAP program (Fig. 3). The Bates quadrangle straddles the border between Oklahoma and Arkansas at the eastern end of the geographic area originally proposed for COGEOMAP mapping. With publication of those geologic maps, the geology of 16 (and parts of two more) contiguous quadrangles, covering much of the Ouachita Mountains frontal belt and the southern part of the Arkoma basin, had been published by the OGS (Appendix A).

A third major field trip to the Arkoma basin and Ouachita Mountains was sponsored by the OGS and held at the Robert S. Kerr Conference Center near Poteau,

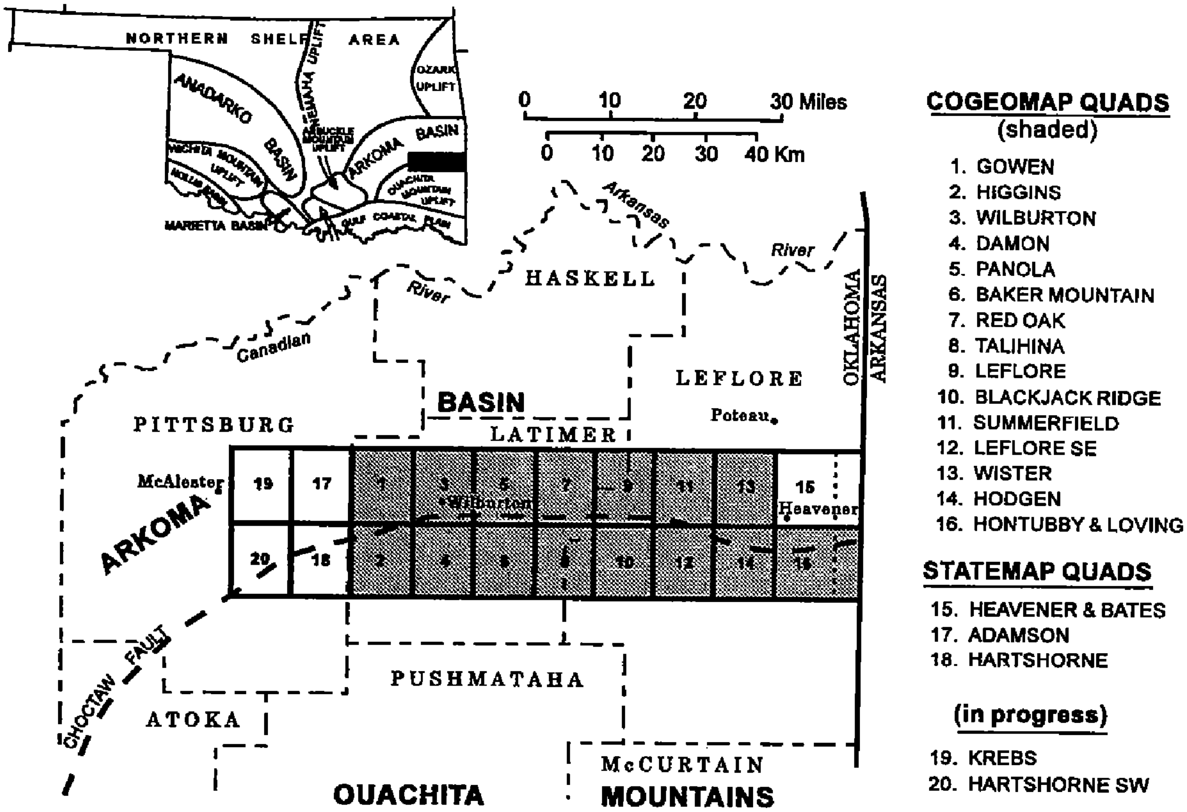

Figure 3. Index map of geologic maps published by the OGS as part of the COGEOMAP project. Also shown are maps that are part of the STATEMAP project (published and in progress).

Figure 4. OGS conference participants at Stop 9 of the field trip conducted November 16–17, 1994. This outcrop of turbidites in the Pennsylvanian Atoka Formation is complexly deformed by out-of-the-syncline faults and flexure slip folds.

TABLE 3.— FUNDING (IN MILLIONS OF DOLLARS) AUTHORIZED BY CONGRESS IN THE NATIONAL GEOLOGIC MAPPING ACT (NGMA) OF 1992, AND ACTUAL APPROPRIATIONS AS ALLOCATED BY THE USGS

NGMA Component	FY-93		FY-94		FY-95		FY-96	
	Auth.[a]	App.[b]	Auth.[a]	App.[b]	Auth.[a]	App.[b]	Auth.[a]	App.[b]
FEDMAP	$12.0	$20.54[c]	$14.0	$21.00[c]	$16.0	$20.59[c]	$18.0	?
SUPPORTMAP	9.5		10.0		10.5		11.0	?
STATEMAP	15.0	1.44[d]	18.0	1.98[d]	21.0	1.29[d]	25.0	?
EDMAP	0.5	0	0.75	0	1.0	0	1.5	?
	$37.0	$21.98	$42.75	$22.98	$48.5	$21.88	$55.5	?

[a]Auth. = Authorized funds, as outlined in NGMA of 1992.
[b]App. = Appropriated funds, as allocated by the USGS.
[c]Separate allocations to FEDMAP and SUPPORTMAP are not available; only the combined figure is available.
[d]With removal of 18% of this amount for USGS overhead, funds available to all state surveys under STATEMAP are $1.18 (FY-93), $1.62 (FY-94), and $1.06 (FY-95).

Oklahoma, on November 16–17, 1994 (Fig. 4). It was preceded by a one-day workshop. OGS Guidebook 29, *Geology and Resources of the Eastern Ouachita Mountains Frontal Belt and Southeastern Arkoma Basin, Oklahoma*, by Suneson and Hemish, includes descriptions of 23 stops (19 of which are in the COGEOMAP project area) and 13 papers by industry, university, and government geologists. As stated in its preface, the guidebook is largely a result of mapping completed under the COGEOMAP project.

In addition to the geologic maps produced as a result of the COGEOMAP mapping, many derivative studies and resultant publications were completed (Appendix B). These range from student theses (Baylor University, University of Texas at El Paso, Oklahoma State University) to, for example, studies of the petroleum geology of the area by professional geologists. Many informal field trips were organized and led by OGS personnel for visiting geologists from abroad (Australia, Great Britain, People's Republic of China); for geologists from U.S. companies (Dolese Brothers, CGG American Services, Farrell-Cooper Mining, ARCO, Amoco, Conoco, Anadarko); and for students (Eastern Oklahoma State College, Oklahoma State University, University of South Dakota). In summary, the COGEOMAP project was the source of many exceptionally fruitful exchanges of knowledge about the complex geology of southeastern Oklahoma.

STATEMAP—The Next Generation of Geologic Mapping

In 1992, President George Bush signed Public Law 102–285 (PL 102–285), the National Geologic Mapping Act (NGMA), which is intended to support a program of detailed geologic mapping by the USGS and state geologic surveys, and to train

TABLE 4.—MEMBERSHIP OF THE OKLAHOMA GEOLOGIC MAPPING ADVISORY COMMITTEE

James R. Chaplin	Oklahoma Geological Survey
Bob Faubian	Oklahoma Water Resources Board
Curt Hayes	Oklahoma Department of Transportation
Mike Houts	Department of Environmental Quality
Kenneth S. Johnson	Oklahoma Geological Survey, Chair
Claude V. McNully	Oklahoma Corporation Commission
Pary Shofner	Commissioners of Land Office
Bob Springer	Oklahoma Conservation Commission
Neil H. Suneson	Oklahoma Geological Survey

students in field-geology procedures and the making of geologic maps. The Association of American State Geologists (AASG), in cooperation with the USGS, designed and proposed the NGMA. Charles J. Mankin (OGS) chaired AASG's NGMA committee and was instrumental in designing and proposing the NGMA, as well as in working (along with all the other state geologists) to get the legislation through Congress. The four components of NGMA are:

1. Federal geologic-mapping component (FEDMAP).—USGS prepares detailed geologic maps and publishes the results in a national geologic-map data base at a scale of 1:100,000;
2. State geologic-mapping component (STATEMAP).—State geological surveys prepare detailed geologic maps and publish the results as part of the national geologic-map data base at a scale of 1:100,000;
3. Geologic-mapping-support component (SUPPORTMAP).—USGS provides interdisciplinary support for the FEDMAP and STATEMAP components; and
4. Geologic-mapping-education component (EDMAP).—USGS awards grants to universities to develop or enhance programs that teach geologic mapping and field analysis to students.

The authorized level of Federal funding for the NGMA, as outlined in PL 102–285, was to range from $37 million in FY-93 to $55.5 million in FY-96 (Table 3). Unfortunately, Congress funded the program with appropriations of only $22 million in FY-93, $23 million in FY-94, and $22 million in FY-95, and the USGS then allocated those funds as shown in Table 3. The level of funding for FY-96 is not yet established by Congress.

The STATEMAP program replaces COGEOMAP, and OGS continues to vie for support in its geologic-mapping activities (funded on a basis of 50:50, Federal-to-State, matching). OGS submitted a successful STATEMAP proposal for FY-93 to map the Heavener and part of the Bates 7.5-minute quadrangles (OGS providing $20,000; USGS providing $20,000). The Heavener/Bates STATEMAP geologic quadrangle map was released in 1994.

Beginning in FY-94, Suneson became principal investigator and coordinator of the new program, and Johnson now chairs the Oklahoma Geologic Mapping Advisory Committee (OGMAC), which was set up to establish geologic-mapping priorities for the State (Table 4). The OGMAC identified Pittsburg County (which embraces parts of the frontal Ouachitas, Choctaw fault, and Arkoma basin) as the number-one priority for geologic mapping in Oklahoma (Fig. 3). OGS submitted successful STATEMAP proposals for FY-94 to map the Adamson (map released in 1995) and Hartshorne (map released in 1996, see p. 64 of this issue) 7.5-minute quadrangles (OGS $50,000; USGS $50,000), and for FY-95 to map the Hartshorne SW and Krebs 7.5-minute quadrangles (OGS $80,000; USGS $30,000) (Fig. 3). Mapping is being carried out by Suneson and Hemish. Thus, the geologic mapping begun with COGEOMAP continues under the new STATEMAP program.

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— Appendix A —

Geologic Maps Published as Part of COGEOMAP Ouachitas Work

(Listed in order of publication)

Suneson, N. H.; and Ferguson, C. A., 1989, Geologic map of the Higgins quadrangle, Latimer County, Oklahoma: Oklahoma Geological Survey COGEOMAP Geologic Quadrangle Map, 1 sheet, scale 1:24,000.

Suneson, N. H.; and Ferguson, C. A., 1989, Geologic map of the Damon quadrangle, Latimer County, Oklahoma: Oklahoma Geological Survey COGEOMAP Geologic Quadrangle Map, 1 sheet, scale 1:24,000.

Suneson, N. H.; and Ferguson, C. A., 1989, Geologic map of the Baker Mountain quadrangle, Latimer County, Oklahoma: Oklahoma Geological Survey COGEOMAP Geologic Quadrangle Map, 1 sheet, scale 1:24,000.

Hemish, L. A.; Suneson, N. H.; and Ferguson, C. A., 1990, Geologic map of the Wilburton quadrangle, Latimer County, Oklahoma: Oklahoma Geological Survey COGEOMAP Geologic Quadrangle Map, 1 sheet, scale 1:24,000.

Hemish, L. A.; Suneson, N. H.; and Ferguson, C. A., 1990, Geologic map of the Panola quadrangle, Latimer County, Oklahoma: Oklahoma Geological Survey COGEOMAP Geologic Quadrangle Map, 1 sheet, scale 1:24,000.

Hemish, L. A.; Suneson, N. H.; and Ferguson, C. A., 1990, Geologic map of the Red Oak quadrangle, Latimer County, Oklahoma: Oklahoma Geological Survey COGEOMAP Geologic Quadrangle Map, 1 sheet, scale 1:24,000.

Suneson, N. H.; and Ferguson, C. A., 1990, Geologic map of the Talihina quadrangle, Latimer and Le Flore Counties, Oklahoma: Oklahoma Geological Survey COGEOMAP Geologic Quadrangle Map, 1 sheet, scale 1:24,000.

Hemish, L. A., 1991, Geologic map of the Leflore quadrangle, Le Flore and Latimer Counties, Oklahoma: Oklahoma Geological Survey COGEOMAP Geologic Quadrangle Map, 1 sheet, scale 1:24,000.

Hemish, L. A.; and Suneson, N. H., 1991, Geologic map of the Leflore SE quadrangle, Le Flore County, Oklahoma: Oklahoma Geological Survey COGEOMAP Geologic Quadrangle Map, 1 sheet, scale 1:24,000.

Suneson, N. H., 1991, Geologic map of the Blackjack Ridge quadrangle, Le Flore County, Oklahoma: Oklahoma Geological Survey COGEOMAP Geologic Quadrangle Map, 1 sheet, scale 1:24,000.

Hemish, L. A., 1992, Geologic map of the Gowen quadrangle, Latimer County, Oklahoma: Oklahoma Geological Survey COGEOMAP Geologic Quadrangle Map, 1 sheet, scale 1:24,000.

Hemish, L. A.; and Mazengarb, Colin, 1992, Geologic map of the Summerfield quadrangle, Le Flore County, Oklahoma: Oklahoma Geological Survey COGEOMAP Geologic Quadrangle Map, 1 sheet, scale 1:24,000.

Hemish, L. A.; and Suneson, N. H., 1993, Geologic map of the Wister quadrangle, Le Flore County, Oklahoma: Oklahoma Geological Survey COGEOMAP Geologic Quadrangle Map, 1 sheet, scale 1:24,000.

Mazengarb, Colin; and Hemish, L. A., 1993, Geologic map of the Hontubby and Loving quadrangles, Le Flore County, Oklahoma: Oklahoma Geological Survey COGEOMAP Geologic Quadrangle Map, 2 sheets, scale 1:24,000.

Suneson, N. H.; and Hemish, L. A., 1993, Geologic map of the Hodgen quadrangle, Le Flore County, Oklahoma: Oklahoma Geological Survey COGEOMAP Geologic Quadrangle Map, 1 sheet, scale 1:24,000.

— Appendix B —

Papers and Abstracts Published as Part of COGEOMAP Ouachitas Work

(Listed in order of publication)

1986

Suneson, N. H., 1986, Ouachita guidebooks indexed: Oklahoma Geology Notes, v. 46, p. 140–145.

1987

Suneson, N. H., 1987, Measured sections, Oklahoma Ouachita Mountains: Oklahoma Geology Notes, v. 47, p. 48–61.

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***Calamites* Stump** *(continued from p. 34)*

Survey, Anadarko Petroleum Company, and the Chengdu Huauchuan Petroleum and Natural Gas Exploration and Development Corporation (People's Republic of China) examining the Hartshorne Formation in the U.S. Highway 59 road cut about 2 mi south of Heavener, Oklahoma. Here, the formation consists mostly of sandstone and shale. The 2-ft-thick Lower Hartshorne coal is the dark unit being examined by the geologist highest on the outcrop. The *Calamites* stump pictured on the cover can be seen in the inset photo just above the coal in the middle of the photograph (arrow).

Fossil casts of Pennsylvanian plants are relatively common in eastern Oklahoma, particularly in association with those formations that contain coal. The most common are of *Calamites* and the lycopods *Lepidodendron* and *Sigillaria.* Another common plant fossil is *Stigmaria,* which is the rootlike part of the lycopods.

The Farrell-Cooper Mining Company currently is strip-mining the Lower Hartshorne coal at the Pine Mountain Mine just southwest of Heavener. Casts of large *Calamites* in growth position frequently are found directly above the coal bed; Farrell-Cooper has been storing many of the larger casts.

Neil H. Suneson

Photographs by John W. Hook
Salem, Oregon

OKLAHOMA EARTHQUAKES, 1995

James E. Lawson, Jr.,[1] and Kenneth V. Luza[2]

Introduction

More than 930,000 earthquakes occur throughout the world each year (Tarbuck and Lutgens, 1990). Approximately 95% of these earthquakes have a magnitude of <2.5 and are usually not felt by humans (Table 1). Only 20 earthquakes, on average, exceed a magnitude 7.0 each year. An earthquake that exceeds a magnitude 7.0 is considered to be a major earthquake and serious damage could result.

Earthquakes tend to occur in belts or zones. For example, narrow belts of earthquake epicenters coincide with oceanic ridges where plates separate, such as in the mid-Atlantic and east Pacific Oceans. Earthquakes also occur where plates collide and/or slide past each other. Although most earthquakes originate at plate boundaries, a small percentage occur within plates. The New Madrid earthquakes of 1811–12 are examples of large and destructive intraplate earthquakes in the United States.

The New Madrid earthquakes of 1811 and 1812 are probably the earliest historical earthquake tremors felt in Oklahoma (Arkansas Territory) by residents in southeastern Oklahoma settlements. Before Oklahoma became a state, the earliest

TABLE 1. — ESTIMATED NUMBER OF WORLDWIDE EARTHQUAKES PER YEAR BY MAGNITUDE
(Modified from Tarbuck and Lutgens, 1990)

Magnitude	Estimated number per year	Earthquake effects
<2.5	>900,000	Generally not felt, but recorded
2.5–5.4	30,000	*Minor to moderate earthquakes* Often felt, but only minor damage detected
5.5–6.0	500	*Moderate earthquakes* Slight damage to structures
6.1–6.9	100	*Moderate to major earthquakes* Can be destructive in populous regions
7.0–7.9	20	*Major earthquakes* Inflict serious damage if in populous regions
≥8.0	1–2	*Great earthquakes* Produce total destruction to nearby communities

[1]Oklahoma Geological Survey Observatory, Leonard.
[2]Oklahoma Geological Survey.

documented earthquake occurred October 22, 1882, probably near Fort Gibson, Indian Territory, although it cannot be located precisely (Ross, 1882; Indian Pioneer Papers, date unknown). The *Cherokee Advocate* newspaper reported that at Fort Gibson "the trembling and vibrating were so severe as to cause doors and window shutters to open and shut, hogs in pens to fall and squeal, poultry to run and hide, the tops of weeds to dip, [and] cattle to lowe" (Ross, 1882, p. 1). These observations indicate MM-VIII intensity effects. The next documented earthquake in Oklahoma occurred near Jefferson, Grant County, on December 2, 1897 (Stover and others, 1981). The next known Oklahoma earthquake happened near Cushing, Payne County, in December 1900. This event was followed by two additional earthquakes in the same area in April 1901 (Wells, 1975).

The largest known Oklahoma earthquake (with the possible exception of the 1882 earthquake) occurred near El Reno, Canadian County, on April 9, 1952. This magnitude-5.5 (mb, Gutenberg-Richter) earthquake was felt in Austin, Texas, as well as Des Moines, Iowa, and covered a felt area of ~362,000 km^2 (Docekal, 1970; Kalb, 1964; von Hake, 1976). From 1897 through 1995, 1,297 earthquakes have been located in Oklahoma.

Instrumentation

A statewide network of 11 seismograph stations was used to locate 167 earthquakes in Oklahoma for 1995 (Fig. 1). The Oklahoma Geological Survey Observatory station, TUL, located near Leonard, Oklahoma, in southern Tulsa County, records 15 continuous seismic signals from sensors located at four stations. The data are recorded, analyzed, and archived on a GSE digital seismic system provided by the Defense Advanced Research Projects Agency/Nuclear Monitoring Research Office.

Signals are digitized by one Geotech RDAS (Remote Data Acquisition System) unit at either 36,000 or 1,200 24-bit samples per second. The RDAS then applies digital anti-alias filtering to eliminate frequencies too high for the final sampling rate. After one to three digital filter and resampling stages, the RDAS produces 60, 40, 20, or 10 24-bit samples per second. The samples are time-tagged by RDAS clocks locked to low-frequency time signals from National Institute of Standards and Technology station WWVB. The signals are passed by RS422 serial links to an AST 386/25 RTDS (Real Time Data Server) computer, which has a Lynx™ real-time Unix-like operating system. The partially processed signals are passed by ethernet to a Sun Sparc 2+ Unix workstation with 64 megabytes of memory, two 660-megabyte disks, two 2.1-gigabyte disks, and two 2.5 gigabyte Exabyte™ tape drives. All of the data from the most recent two weeks are retained on disk. Each day, data from the preceding day (167 million bytes) are automatically archived onto Exabyte™ tape. All Oklahoma earthquakes, and other selected events, are placed in named de-archive directories on disk. An Oracle™ data base on the Sun Sparc 2+ keeps track of every second of data on the permanent archive tapes, the last 14 days' data on disk, and data in the de-archive directories. Data analysis is done by Teledyne-Geotech and Science Applications International Corp. software on the Sparc 2+ workstation.

The digital system signals are from three sensors in the Observatory vault (international station abbreviation TUL); from a three-component broadband sensor in a 120-m borehole; and from single sensors located at Rose Lookout (RLO) in Mayes County, at the Bald Hill Ranch near Vivian (VVO) in McIntosh County, and at the

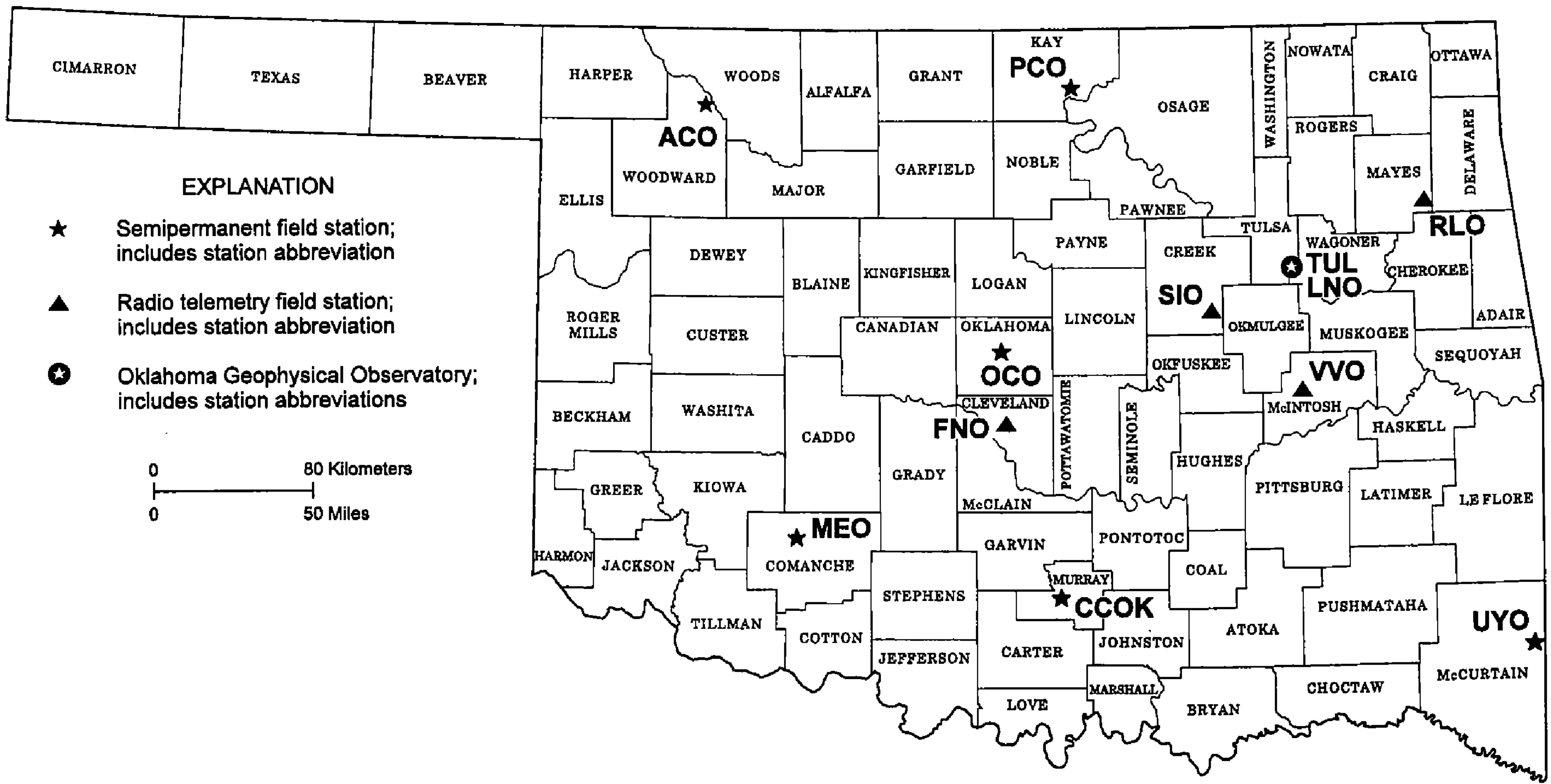

Figure 1. Active seismographs in Oklahoma.

Jackson Ranch near Slick (SIO) in Creek County.

TUL has three (vertical, north–south, east–west) Geotech GS-13 seismometers which produce 40-sample-per-second short-period signals. A three-component broadband Geotech KS54000-0103 seismometer in a 120-m-deep borehole produces seven digital data channels. Three are broadband signals from seismic signals in vertical, north–south, and east–west directions. From the broadband signals the Sparc 2+ workstation derives three long-period signals. A seventh signal, the vertical earth tides, is recorded from the vertical mass displacement signal from the KS54000-0103. The broadband signals are archived at 10 samples per second, and the long-period and vertical-earth-tide signals are recorded at one sample per second. On November 10, 1994, the broadband sample rate was increased from 10 samples per second to 20 samples per second. This increase was for two purposes. One was to allow the broadband borehole seismometer to record higher frequencies characteristic of Oklahoma earthquakes. The other was to make the signals compatible for the GSETT-3 (Group of Scientific Experts Technical Test-3), which began in 1995. GSETT-3 is a prototype international seismic-monitoring system to detect underground nuclear tests. Data segments will be copied automatically and sent to the International Data Center by Internet without affecting the recording and analysis of Oklahoma earthquakes.

An Internet gopher server running on a Sun Sparc SLC allows anyone on the Internet to copy digital data on disk, as well as several documents such as the Oklahoma Earthquake Catalog in one single list, or a series of two-year lists. The gopher can be contacted with "gopher [space] wealaka.okgeosurvey1.gov" or by WWW clients with "gopher://wealaka.okgeosurvey1.gov/" (see sidebar, this page). The broadband signals are sel-

How to Obtain the Oklahoma Earthquake Catalog and Maps Over the Internet

With a gopher client program, go directly to the top-level menu of the OGS gopher by typing:

gopher wealaka.okgeosurvey1.gov

From the top-level menu, select submenus, including "Oklahoma Earthquake Catalog" and "Oklahoma Earthquake Maps."

To go to the top-level menu with a Web browser (such as Xmosaic or Netscape), use this URL:

gopher://wealaka.okgeosurvey1.gov/

To go directly to the Oklahoma earthquake catalog or to Oklahoma PostScript earthquake maps, use one of these URLs:

gopher://wealaka.okgeosurvey1/11/okeqcat/
gopher://wealaka.okgeosurvey1/11/okmap/

The catalog can be accessed quickly with the "finger" command:

finger okquake@wealaka.okgeosurvey1.gov
(for the entire catalog, current year not included)
finger okq95@wealaka.okgeosurvey1.gov
(for 1995 earthquakes)
finger okq96@wealaka.okgeosurvey1.gov
(for 1996 earthquakes)

If your site is not a live internet node, the finger command may not work. In that case, you could use a WWW-finger gateway, but it would be quicker to access the catalog directly through:

http://wealaka.okgeosurvey1.gov/11/okequcat/

Digital seismograms for about 90% of all Oklahoma earthquakes since late 1991 can be accessed on the OGS gopher. They are in U.S. Department of Defense (DOD) CSS3.0 format. They can be analyzed and displayed by the DOD public-domain geotool package. At present, geotool is available only in Sparc binaries. Some users have displayed these seismograms with simple XY-plotting software, although XY-plotting programs will not show time, date, or station labels. For information on the digital seismogram files or for information on obtaining seismograms use:

gopher://wealaka.okgeosurvey1.gov/11/waveforms/

and read all *READ*NOW* files.

dom used in the study of Oklahoma earthquakes; the long-period signals are never used. The short-period signals are particularly useful in calculating the direction of arrival of waves by digital calculation of polarization.

RLO, VVO, and SIO have Geotech S-13 seismometers in shallow tank vaults. The seismic signals are amplified and used to frequency modulate an audio tone that is transmitted to Leonard with 500-mW FM transmitters at various frequencies in the 216–220-mHz band. The signals are received by antennas on a 40-m-high tower at Leonard, the tones are discriminated to produce a voltage which is proportional to the remote seismometer voltage, and the voltages are digitized at 40 samples per second by the vault RDAS.

A fourth radio-telemetry station, FNO, was installed in central Oklahoma on April 28, 1992. The seismometer, Geotech S-13, is located on a concrete pad, ~7 km northeast of the Oklahoma Geological Survey's (OGS) building. A discriminator converts the audio-signal frequency fluctuations to a voltage output. The voltage-output is amplified and recorded by a Sprengnether MEQ-800 seismograph recorder (located in an OGS display case) at 60 mm/min trace speed.

In the Leonard vault, seven additional seismometers produce analog (wiggly-line) recordings on paper-drum recorders. Eleven such recordings are produced, five of which are the proper frequencies to record some aspect of nearby earthquakes. One paper recording is produced from each of RLO, VVO, and SIO. The paper records are used as a digital system backup, and to scan for earthquakes faster than is possible on computer screens.

In addition to the digital and analog seismograms recorded at the OGS Observatory, seismograms are recorded by six volunteer-operated seismographs. Each consists of a Geotech S-13 short-period vertical-motion-sensing seismometer in a shallow tank vault, or in an abandoned mine shaft (station MEO) or large-diameter, hand-dug, shallow water well (station UYO). A new station, CCOK, opened on August 10, 1994, at Camp Classen (YMCA Camp) in Murray County. This station is operated by Jim Parry and his staff. (Red Rock Canyon station, RRO, has been closed.) The seismometer signal runs through 200–1,800 ft of cable in surface PVC conduit to the volunteer's house or other building. The volunteer has a Sprengnether MEQ-800B timing system amplifier-filter-drum recorder, which records 24 hours of seismic trace at 1 mm/min in a spiral path around the paper on the drum. The times are set by a time signal radio receiver tuned to the National Institute of Standards and Technology and high-frequency radio station WWV. The volunteers mail in the seismograms weekly (or more often, if requested).

Data Reduction and Archiving

Paper-recorded seismograms from short-period vertical records (SPZ) from TUL, RLO, VVO, and SIO, as well as short-period north–south (SPN), and short-period east–west (SPE) from TUL, are scanned initially for Oklahoma earthquakes. At this stage, >95% of Oklahoma earthquakes are seen.

When an Oklahoma earthquake is found on paper records, the digital system is used to analyze the SPZ, SPN, and SPE digital records from TUL, and the SPZ digital records from RLO, VVO, and SIO. This gives a preliminary location that is immediately posted on the earthquake catalog on the OGS gopher. This initial posting usually takes place within 24 hours of the earthquake's occurrence.

All digital traces are examined later in a systematic way for mainly distant earthquakes. At this stage, Oklahoma earthquakes are seen again, but few new Oklahoma earthquakes are spotted.

Near the beginning of each month, all paper records for the previous month from all stations in Oklahoma are examined. An occasional additional Oklahoma earthquake is found. All readings from the digital and paper records are then used to determine a final location. These final locations then replace the preliminary locations in the gopher catalog.

Earthquake Distribution

All Oklahoma earthquakes recorded on seismograms from three or more stations are located. In 1995, 167 Oklahoma earthquakes were located (Fig. 2; Table 2). Six earthquakes were reported felt (Table 3). The felt and observed effects of earthquakes generally are given values according to the Modified Mercalli intensity scale, which assigns a Roman numeral to each of 12 levels described by effects on humans, man-made constructions, or natural features (Table 4).

The first Oklahoma earthquake reported felt in 1995 was a magnitude 4.2 (mbLg) earthquake that occurred on January 18 in northwestern Garvin County. This earthquake, the fourth largest to have occurred in Oklahoma this century, produced MM VI effects near the epicenter. The earthquake was felt in Tuttle, Maysville, Elmore City, and as far away as Slick, Oklahoma. Very minor damage resulted from this earthquake.

The felt areas for four earthquakes listed in Table 3—Harper, Marshall, and the two events in Grady County—are probably restricted to a few tens of square kilometers away from the epicentral location. No damage was reported from these events.

At 7:31 p.m., September 14 (local time and date), a magnitude 3.8 (mbLg) was reported felt in Alva, Cherokee, Enid, and several places in southern Kansas (Fig. 3). This earthquake, which produced MM VI effects near the epicenter, had a felt area that exceeded 24,600 km^2. Very minor damage resulted from this earthquake.

Earthquake-magnitude values range from a low of 1.3 (m3Hz) in Atoka County to a high of 4.2 (mbLg) in Garvin County. Three earthquake swarms, April 20–21, August 21–22, and December 14–15, produced an unusually high number of earthquakes in southeastern Grady County. Grady, Garvin, and McClain Counties contained more than half of the earthquakes located in 1995. Cotton and Cherokee Counties experienced their first locatable earthquakes.

Catalog

A desktop computer system, including linked HP-9825T and HP-9835A computers, hard and flexible disks, and printers, is used to calculate and catalog local earthquake epicenters. Any earthquake within Oklahoma or within about 100–200 km of Oklahoma's borders is considered a local earthquake. A catalog containing date, origin time, county, intensity, magnitude, location, focal depth, and references is printed in page-sized format. This catalog is maintained in addition to the gopher catalog of earthquakes only in Oklahoma. Table 2 contains 1995 Oklahoma earthquake data displayed in a modified version of the regional earthquake catalog. Each event is sequentially numbered and arranged according to date and origin time. The numbering system is compatible with the system used by Lawson and Luza (1980–90, 1993–95a), Lawson and others (1991,1992), and for the *Earthquake Map of Oklahoma* (Lawson and Luza, 1995b).

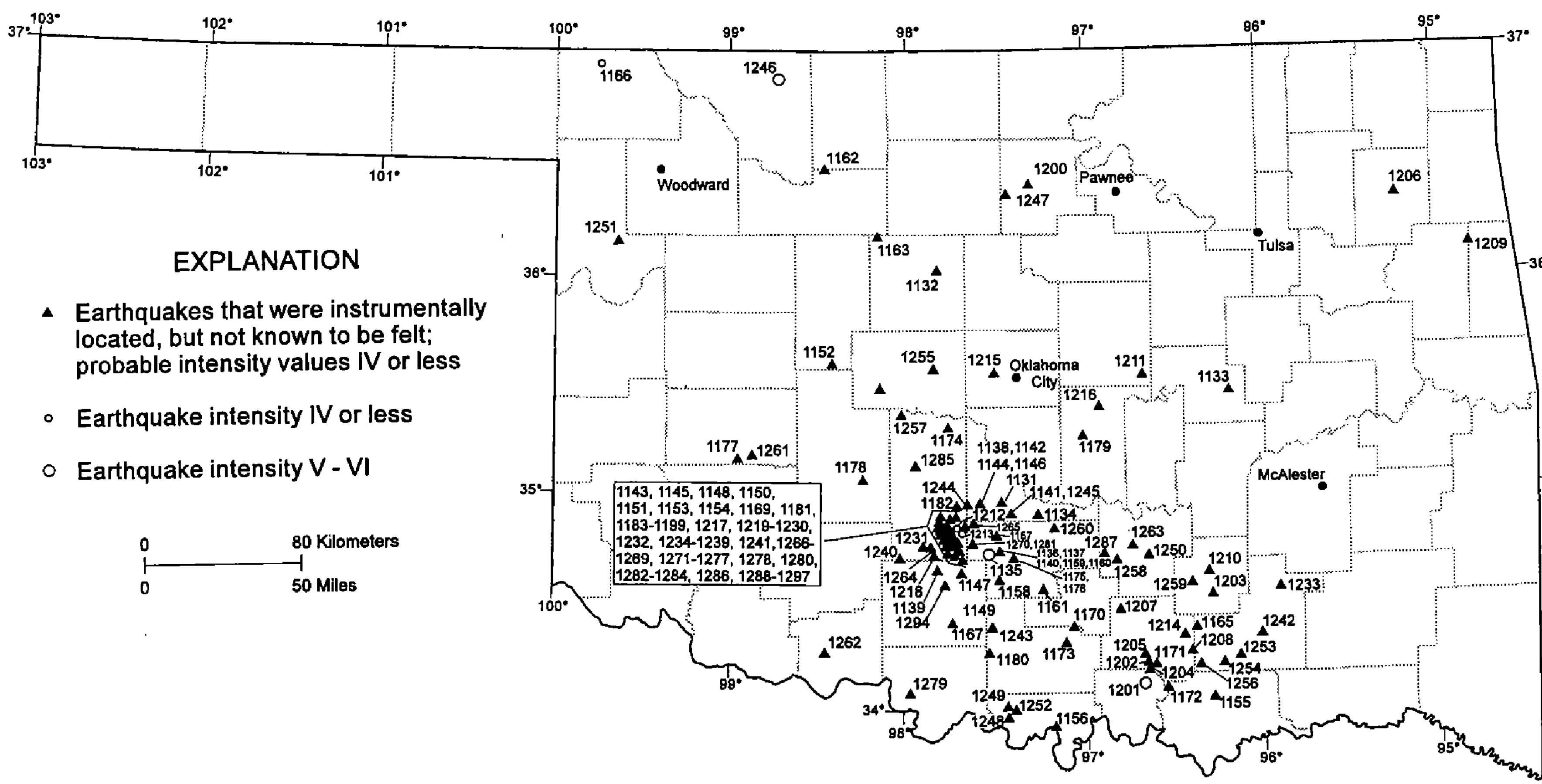

Figure 2. Distribution of Oklahoma earthquakes for 1995. Numbers correspond to event numbers in Table 2.

TABLE 2. — OKLAHOMA EARTHQUAKE CATALOG FOR 1995

Event no.	Date and origin time (UTC)[a]	County	Intensity MM[b]	Magnitudes 3Hz	bLg	DUR	Latitude deg N	Longitude deg W	Depth (km)[c]
1131	JAN 02 08 35 57.61	McClain	—	1.4		1.6	34.945	97.459	5.0R
1132	JAN 04 00 39 35.15	Kingfisher	—	1.8	1.9	2.0	35.999	97.838	5.0R
1133	JAN 06 21 02 15.58	Okfuskee		2.6		2.4	35.451	96.184	5.0R
1134	JAN 14 13 30 45.40	McClain		2.5	2.0	2.2	34.882	97.270	5.0R
1135	JAN 18 15 51 39.90	Garvin	6	4.1	4.2		34.712	97.542	5.0R
1136	JAN 18 15 54 30.45	Garvin	—	2.7	2.9	2.4	34.676	97.413	5.0R
1137	FEB 13 18 10 47.71	Garvin	—	1.9		1.6	34.739	97.499	5.0R
1138	FEB 14 17 17 25.21	McClain	—	1.8	1.6	2.2	34.923	97.553	5.0R
1139	FEB 14 17 28 45.78	Stephens	—	1.6		2.0	34.639	97.835	5.0R
1140	FEB 14 17 30 33.94	Garvin	—	2.1	2.2	2.0	34.730	97.502	5.0R
1141	FEB 14 17 53 03.94	McClain	—	1.6		1.8	34.886	97.440	5.0R
1142	FEB 14 18 12 14.74	McClain	—			2.1	34.934	97.583	5.0R
1143	FEB 14 18 18 01.87	Grady	—	1.8		2.2	34.825	97.761	5.0R
1144	FEB 14 19 37 36.22	McClain	—	2.1	1.8	1.8	34.946	97.597	5.0R
1145	FEB 14 19 54 35.04	Grady	—			2.0	34.692	97.694	5.0R
1146	FEB 14 20 27 43.64	McClain	—	1.9		2.0	34.917	97.569	5.0R
1147	FEB 14 21 24 34.98	Stephens	—	1.6		2.1	34.623	97.698	5.0R
1148	FEB 14 21 55 20.33	Grady	—	1.7		2.3	34.776	97.772	5.0R
1149	FEB 14 22 33 45.88	Stephens	—			1.6	34.493	97.714	5.0R
1150	FEB 14 23 23 00.76	Grady	—	1.9		1.8	34.790	97.753	5.0R
1151	FEB 15 00 44 11.44	Grady	—			1.8	34.791	97.714	5.0R
1152	FEB 15 03 07 46.05	Blaine	—	2.2	2.1	1.8	35.574	98.423	5.0R
1153	FEB 15 07 41 04.49	Grady	—			1.7	34.735	97.749	5.0R
1154	FEB 15 08 00 36.27	Grady	—			1.9	34.760	97.768	5.0R
1155	FEB 15 15 25 44.92	Bryan	—	1.9	1.8	1.8	34.067	96.296	5.0R
1156	FEB 16 16 00 08.06	Love	—	1.8	1.9	1.6	33.911	97.171	5.0R
1157	FEB 23 14 23 07.77	Garvin	—	1.6		1.7	34.800	97.488	5.0R
1158	FEB 23 14 25 18.24	Garvin	—	1.8	1.7	1.8	34.618	97.488	5.0R
1159	FEB 23 14 31 44.72	Garvin	—	2.8	2.5	2.3	34.739	97.517	5.0R
1160	FEB 23 16 11 02.33	Garvin	—	1.8		1.7	34.723	97.499	5.0R
1161	FEB 23 17 29 06.48	Garvin	—	1.7	1.8	1.7	34.551	97.257	5.0R
1162	FEB 24 17 58 13.92	Major	—			1.9	36.460	98.466	5.0R
1163	MAR 01 09 20 21.80	Kingfisher	—	1.5		1.9	36.150	98.168	5.0R
1164	MAR 02 16 55 38.09	Grady	—	2.2	1.9	2.0	34.835	97.682	5.0R
1165	MAR 22 13 24 43.90	Atoka	—	2.2		1.6	34.364	96.406	5.0R
1166	MAR 23 11 10 12.46	Harper	4	2.3	2.2	2.4	36.949	99.740	5.0R
1167	MAR 28 06 45 34.76	Stephens	—	1.4		1.7	34.395	97.726	5.0R
1168	MAR 30 16 59 38.30	Grady	—	2.4	2.2	2.2	34.835	97.678	5.0R
1169	MAR 30 18 58 34.95	Grady	—	2.6	2.6	2.4	34.820	97.729	5.0R
1170	MAR 31 22 31 21.45	Murray	—			1.9	34.380	97.077	5.0R
1171	APR 02 06 53 55.75	Johnston	—	2.8	2.6	2.0	34.210	96.619	5.0R
1172	APR 02 14 02 29.84	Bryan	—	2.7	2.2	2.1	34.099	96.559	5.0R
1173	APR 04 18 33 12.47	Carter	—			1.9	34.312	97.124	5.0R
1174	APR 04 18 43 01.35	Grady	—			1.8	35.279	97.776	5.0R
1175	APR 04 19 14 39.84	Garvin	—	2.0		1.8	34.704	97.468	5.0R
1176	APR 04 19 30 18.81	Garvin	—			1.7	34.708	97.460	5.0R
1177	APR 05 05 31 17.90	Washita	—	2.9	2.8	2.5	35.152	98.936	5.0R
1178	APR 05 05 34 10.36	Caddo	—	1.8	1.9		35.050	98.233	5.0R
1179	APR 08 03 00 59.95	Pottawatomie	—	2.1	1.8	2.3	35.261	97.026	5.0R
1180	APR 12 16 42 06.21	Carter	—	1.8		1.8	34.255	97.546	5.0R
1181	APR 20 14 00 57.50	Grady	—	2.1		1.6	34.770	97.765	5.0R
1182	APR 20 14 09 14.31	Grady	—			1.7	34.926	97.718	5.0R
1183	APR 20 15 06 29.24	Grady	—			1.5	34.862	97.732	5.0R
1184	APR 20 15 22 27.99	Grady	—			1.7	34.751	97.765	5.0R
1185	APR 20 15 32 15.00	Grady	—	1.7		2.0	34.876	97.718	5.0R
1186	APR 20 15 57 14.43	Grady	—	2.2	1.9	1.9	34.783	97.760	5.0R
1187	APR 20 16 42 39.25	Grady	—			1.9	34.762	97.769	5.0R

Event no.	Date and origin time (UTC)[a]	County	Intensity MM[b]	Magnitudes 3Hz	bLg	DUR	Latitude deg N	Longitude deg W	Depth (km)[c]
1188	APR 20 18 18 18.75	Grady	—	1.9		1.8	34.742	97.760	5.0R
1189	APR 20 22 32 35.13	Grady	—	1.8	1.9	1.9	34.784	97.760	5.0R
1190	APR 20 23 15 35.82	Grady	—	2.5	2.3	2.0	34.759	97.779	5.0R
1191	APR 21 01 12 29.93	Grady	—	1.7		1.6	34.883	97.765	5.0R
1192	APR 21 04 37 29.65	Grady	—	1.5		1.9	34.739	97.777	5.0R
1193	APR 21 05 38 37.59	Grady	—	1.9		1.7	34.755	97.749	5.0R
1194	APR 21 06 33 08.40	Grady	—	1.6		1.8	34.831	97.760	5.0R
1195	APR 21 07 07 24.14	Grady	—	1.9	1.7	1.9	34.794	97.752	5.0R
1196	APR 21 09 24 59.96	Grady	—	1.5		1.7	34.761	97.761	5.0R
1197	APR 21 10 33 25.34	Grady	—	1.8	1.6	1.7	34.806	97.751	5.0R
1198	APR 21 20 43 54.39	Grady	—	2.0	1.7	1.7	34.727	97.765	5.0R
1199	APR 22 03 33 17.78	Grady	—	2.0	1.8	1.8	34.792	97.756	5.0R
1200	MAY 06 11 42 16.98	Noble	—	1.9	1.6	1.8	36.404	97.318	5.0R
1201	JUN 01 04 49 27.70	Marshall	5	3.3	3.0	2.7	34.134	96.683	5.0R
1202	JUN 03 04 16 46.01	Johnston	—	1.6	1.4	1.4	34.216	96.663	5.0R
1203	JUN 04 22 58 59.95	Coal	—	1.8		1.5	34.530	96.294	5.0R
1204	JUN 07 00 24 45.45	Johnston	—	2.7	2.2	1.9	34.180	96.659	5.0R
1205	JUN 07 05 19 25.79	Johnston	—	1.5		1.3	34.239	96.683	5.0R
1206	JUN 11 19 02 46.55	Mayes	—	1.2		1.6	36.335	95.217	5.0R
1207	JUN 21 02 23 09.07	Johnston	—	1.5	1.8	1.5	34.450	96.812	5.0R
1208	JUN 27 21 19 43.50	Atoka	—	2.2	2.8	1.5	34.270	96.406	5.0R
1209	JUL 04 01 00 48.80	Cherokee	—			1.1	36.100	94.800	5.0R
1210	JUL 05 00 54 25.59	Coal	—			1.3	34.627	96.320	5.0R
1211	JUL 10 12 06 12.56	Lincoln	—	1.6	1.5	1.9	35.531	96.670	5.0R
1212	JUL 19 00 04 04.93	Grady	2	2.4	2.2	2.0	34.839	97.709	5.0R
1213	JUL 20 04 29 57.06	Grady	2	2.5	2.5	2.4	34.835	97.682	5.0R
1214	JUL 25 21 53 07.50	Johnston	—	1.9		1.7	34.350	96.450	5.0R
1215	JUL 27 07 50 00.85	Oklahoma	—	1.4		1.6	35.538	97.526	5.0R
1216	AUG 06 19 14 26.98	Pottawatomie	—	1.6	1.4	1.6	35.387	96.915	5.0R
1217	AUG 11 13 46 48.44	Grady	—		1.9	2.2	34.815	97.772	5.0R
1218	AUG 21 13 25 39.38	Grady	—		1.8	2.1	34.703	97.833	5.0R
1219	AUG 21 14 01 58.63	Grady	—	2.0	2.0	2.2	34.841	97.796	5.0R
1220	AUG 21 14 48 24.81	Grady	—	2.3	2.1	2.0	34.813	97.792	5.0R
1221	AUG 21 15 46 02.86	Grady	—			2.1	34.803	97.799	5.0R
1222	AUG 21 16 27 09.21	Grady	—	2.0	2.4	2.1	34.786	97.788	5.0R
1223	AUG 21 17 22 55.81	Grady	—	2.1	2.1	1.9	34.778	97.790	5.0R
1224	AUG 21 17 56 23.48	Grady	—	1.9	2.1	2.0	34.784	97.796	5.0R
1225	AUG 21 19 19 02.93	Grady	—			1.7	34.862	97.803	5.0R
1226	AUG 21 19 58 37.22	Grady	—	1.9	1.8	2.2	34.826	97.792	5.0R
1227	AUG 21 20 44 52.46	Grady	—	2.1	2.3	2.0	34.856	97.796	5.0R
1228	AUG 21 22 32 32.96	Grady	—	2.4	2.2	2.0	34.796	97.773	5.0R
1229	AUG 22 00 17 13.25	Grady	—	1.7	1.7	2.1	34.815	97.772	5.0R
1230	AUG 22 00 45 35.31	Grady	—	1.3		1.8	34.815	97.788	5.0R
1231	AUG 22 00 51 05.63	Grady	—	1.9	1.8		34.741	97.874	5.0R
1232	AUG 22 02 06 03.29	Grady	—	2.1	2.2	2.0	34.825	97.804	5.0R
1233	AUG 22 02 44 12.29	Atoka	—	1.4	1.4	1.6	34.556	95.909	5.0R
1234	AUG 22 02 58 11.03	Grady	—	1.9		2.1	34.819	97.772	5.0R
1235	AUG 22 04 06 21.07	Grady	—	1.9	1.7	1.7	34.776	97.773	5.0R
1236	AUG 22 04 58 51.39	Grady	—	1.7	1.6	1.7	34.744	97.772	5.0R
1237	AUG 22 06 10 10.12	Grady	—	1.5		1.6	34.885	97.819	5.0R
1238	AUG 22 06 22 20.42	Grady	—	2.3	2.1	2.3	34.829	97.781	5.0R
1239	AUG 22 11 10 41.88	Grady	—	2.0	1.8	1.9	34.789	97.815	5.0R
1240	AUG 22 14 36 21.47	Grady	—	2.3	2.2	2.1	34.692	98.031	5.0R
1241	AUG 22 20 46 57.11	Grady	—	1.9	2.0	1.8	34.833	97.798	5.0R
1242	AUG 27 08 08 29.84	Atoka	—	1.5		1.7	34.337	96.015	5.0R
1243	AUG 30 02 00 52.06	Carter	—			1.6	34.374	97.533	5.0R
1244	AUG 30 11 51 58.29	McClain	—			1.5	34.916	97.663	5.0R
1245	SEP 04 09 04 12.15	McClain	—	2.0	1.8	1.7	34.898	97.434	5.0R
1246	SEP 15 00 31 33.05	Woods	6	3.7	3.8	3.0	36.870	98.726	5.0R

Event no.	Date and origin time (UTC)[a]	County	Intensity MM[b]	Magnitudes 3Hz	bLg	DUR	Latitude deg N	Longitude deg W	Depth (km)[c]
1247	SEP 19 06 50 26.13	Noble	—	1.8	1.4	1.9	36.351	97.451	5.0R
1248	SEP 25 12 16 54.46	Love	—			2.1	33.962	97.443	5.0R
1249	SEP 25 14 39 05.13	Love	—			2.0	34.020	97.445	5.0R
1250	SEP 26 16 10 37.19	Pontotoc	—	1.6		1.8	34.712	6.648	5.0R
1251	OCT 01 16 43 16.21	Ellis	—			2.2	36.146	99.629	5.0R
1252	OCT 02 21 56 29.98	Love	—			1.7	33.989	97.409	5.0R
1253	OCT 05 04 59 36.84	Atoka	—	1.3		1.6	34.237	96.159	5.0R
1254	OCT 05 22 06 41.53	Atoka	—	2.1	2.1	1.6	34.208	96.243	5.0R
1255	NOV 03 17 52 56.94	Canadian	—	2.0	1.9	1.9	35.554	97.865	5.0R
1256	NOV 04 17 51 19.15	Atoka	—	1.8		1.5	34.200	96.363	5.0R
1257	NOV 21 13 00 48.26	Grady	—	1.7		1.4	35.349	98.026	5.0R
1258	NOV 21 19 31 39.85	Pontotoc	—	1.8		1.6	34.680	96.866	5.0R
1259	NOV 23 11 47 37.11	Coal	—	1.6	1.4	1.8	34.576	96.410	5.0R
1260	NOV 27 22 39 12.24	Garvin	—	1.7	1.7	1.6	34.829	97.175	5.0R
1261	DEC 01 14 37 43.00	Washita	—	2.9	3.0	2.6	35.155	98.897	5.0R
1262	DEC 04 21 34 25.27	Cotton	—			1.8	34.268	98.460	5.0R
1263	DEC 12 21 30 56.01	Pontotoc	—			1.5	34.755	96.749	5.0R
1264	DEC 14 17 05 59.75	Grady	—	1.9		1.5	34.723	97.833	5.0R
1265	DEC 14 17 14 29.91	Garvin	—	2.1	2.1	1.7	34.846	97.626	5.0R
1266	DEC 14 17 15 46.96	Grady	—	1.7		1.5	34.825	97.687	5.0R
1267	DEC 14 17 24 01.05	Grady	—	2.0	2.1	2.1	34.762	97.736	5.0R
1268	DEC 14 17 30 32.11	Grady	—	2.2	2.1	2.1	34.759	97.749	5.0R
1269	DEC 14 17 38 15.80	Grady	—	2.3	2.1	2.1	34.688	97.706	5.0R
1270	DEC 14 17 45 33.36	Garvin	—	1.9	1.8	1.8	34.770	97.652	5.0R
1271	DEC 14 17 48 56.61	Grady	—	2.5	2.4	2.3	34.723	97.741	5.0R
1272	DEC 14 18 02 22.20	Grady	—	2.2	2.1	2.1	34.700	97.718	5.0R
1273	DEC 14 18 10 19.80	Grady	—	2.1	1.9	1.9	34.737	97.699	5.0R
1274	DEC 14 18 30 00.00	Grady	—	1.9		1.8	34.739	97.734	5.0R
1275	DEC 14 18 38 07.65	Grady	—	2.4	2.4	2.0	34.719	97.765	5.0R
1276	DEC 14 18 44 07.71	Grady	—			1.9	34.778	97.743	5.0R
1277	DEC 14 19 01 39.76	Stephens	—	2.4	2.2	2.2	34.676	97.687	5.0R
1278	DEC 14 19 20 23.11	Grady				1.8	34.748	97.753	5.0R
1279	DEC 14 19 23 21.25	Jefferson	—	2.0		2.3	34.088	97.983	5.0R
1280	DEC 14 19 35 26.99	Grady	—	2.1	2.0	1.8	34.792	97.734	5.0R
1281	DEC 14 19 53 07.74	Garvin	—	2.3	2.1	2.0	34.778	97.648	5.0R
1282	DEC 14 20 32 48.46	Grady	—	2.0		1.6	34.708	97.718	5.0R
1283	DEC 14 20 42 05.37	Grady	—	1.9		1.6	34.755	97.726	5.0R
1284	DEC 14 20 56 52.83	Grady	—	2.2	2.1	1.9	34.723	97.718	5.0R
1285	DEC 14 21 08 12.96	Grady	—			2.1	35.114	97.960	5.0R
1286	DEC 14 22 31 54.69	Grady	—			1.2	34.877	97.796	5.0R
1287	DEC 14 22 34 04.25	Pontotoc	—	1.8		1.8	34.708	96.890	5.0R
1288	DEC 14 22 37 42.92	Grady	—			1.9	34.745	97.710	5.0R
1289	DEC 14 23 09 39.58	Grady	—	1.9		1.8	34.751	97.718	5.0R
1290	DEC 14 23 15 43.89	Grady	—	1.8		1.8	34.747	97.702	5.0R
1291	DEC 14 23 38 23.68	Grady	—	2.1		2.0	34.741	97.740	5.0R
1292	DEC 14 23 48 02.00	Grady	—			2.1	34.757	97.747	5.0R
1293	DEC 15 02 47 18.95	Grady	—	2.2	2.0	2.1	34.692	97.749	5.0R
1294	DEC 15 03 57 04.70	Stephens	—			1.7	34.573	97.788	5.0R
1295	DEC 15 09 33 57.95	Grady	—	2.7	2.5	2.5	34.770	97.734	5.0R
1296	DEC 15 09 56 27.72	Grady	—			1.7	34.731	97.733	5.0R
1297	DEC 15 21 09 00.52	Grady	—	1.8		1.8	34.739	97.749	5.0R

[a]UTC refers to Coordinated Universal Time, formerly Greenwich Mean Time. The first two digits refer to the hour on a 24-hour clock. The next two digits refer to the minute, and the remaining digits are the second. To convert to local Central Standard Time, subtract 6 hours.

[b]Modified Mercalli (MM) earthquake-intensity scale (see Table 4).

[c]The hypocenter is restrained (R) at an arbitrary depth of 5.0 km, except where indicated, for purposes of computing latitude, longitude, and origin time.

TABLE 3. — EARTHQUAKES THAT WERE REPORTED FELT IN OKLAHOMA, 1995

Event no.	Date and origin time (UTC)[a]	Nearest city	County	Intensity MM[b]
1135	JAN 18 15 51 39.90	5 km E of Purdy	Garvin	6
1166	MAR 23 11 10 12.46	16 km NW of Buffalo	Harper	4
1201	JUN 01 04 49 27.70	10 km NE of Madill	Marshall	5
1212	JUL 19 00 04 04.93	10 km E of Lindsay	Grady	2
1213	JUL 20 04 29 57.06	5 km SE of Lindsay	Grady	2
1246	SEP 15 00 31 33.05	10 km NW of Alva	Woods	6

[a]UTC refers to Coordinated Universal Time, formerly Greenwich Mean Time. The first two digits refer to the hour on a 24-hour clock. The next two digits refer to the minute, and the remaining digits are the second. To convert to local Central Standard Time, subtract 6 hours.

[b]Modified Mercalli (MM) earthquake-intensity scale (see Table 4).

The date and time are given in UTC. UTC refers to Coordinated Universal Time, formerly Greenwich Mean Time. The first two digits refer to the hour on a 24-hour clock. The next two digits refer to the minute, and the remaining digits are the seconds. To convert to local Central Standard Time, subtract 6 hours.

Earthquake magnitude is a measurement of energy and is based on data from seismograph records. The magnitude of a local earthquake is determined by taking the logarithm (base 10) of the largest ground motion recorded during the arrival of a seismic-wave type and applying a standard correction for distance to the epicenter. When the magnitude value is increased one unit, the amplitude of the earthquake waves increases 10 times. There are several different scales used to report magnitude. Table 2 has three magnitude scales, which are mbLg (Nuttli), m3Hz (Nuttli), and MDUR (Lawson). Each magnitude scale was established to accommodate specific criteria, such as the distance from the epicenter, as well as the availability of certain seismic data.

For earthquake epicenters located 11–222 km from a seismograph station, Otto Nuttli developed the m3Hz magnitude scale (Zollweg, 1974). This magnitude is derived from the following expression:

$$\mathrm{m3Hz} = \log(A/T) - 1.63 + 0.87 \log(\Delta),$$

where A is the maximum center-to-peak vertical-ground-motion amplitude sustained for three or more cycles of Lg waves, near 3 Hz in frequency, measured in nanometers; T is the period of the Lg waves measured in seconds; and Δ is the great-circle distance from epicenter to station measured in kilometers.

In 1979, St. Louis University (Stauder and others, 1979) modified the formulas for m3Hz. This modification was used by the OGS Observatory beginning January 1, 1982. The modified formulas had the advantage of extending the distance range for measurement of m3Hz out to 400 km, but also had the disadvantage of increasing m3Hz by about 0.12 units compared to the previous formula. Their formulas were given in terms of $\log(A)$ but were restricted to wave periods of 0.2–0.5 sec. In

TABLE 4. — MODIFIED MERCALLI (MM) EARTHQUAKE-INTENSITY SCALE
(Abridged) (Modified from Wood and Neumann, 1931)

I	Not felt except by a very few under especially favorable circumstances.
II	Felt only by a few persons at rest, especially on upper floors of buildings. Suspended objects may swing.
III	Felt quite noticeably indoors, especially on upper floors of buildings. Automobiles may rock slightly.
IV	During the day felt indoors by many, outdoors by few. At night some awakened. Dishes, doors, windows disturbed. Automobiles rocked noticeably.
V	Felt by nearly everyone, many awakened. Some dishes, windows, etc., broken; unstable objects overturned. Pendulum clocks may stop.
VI	Felt by all; many frightened and run outdoors.
VII	Everybody runs outdoors. Damage negligible in buildings of good design and construction. Shock noticed by persons driving automobiles.
VIII	Damage slight in specially designed structures; considerable in ordinary substantial buildings; great in poorly built structures. Fall of chimneys, stacks, columns. Persons driving automobiles disturbed.
IX	Damaged considerable even in specially designed structures; well-designed frame structures thrown out of plumb. Buildings shifted off foundations. Ground cracked conspicuously.
X	Some well-built wooden structures destroyed; ground badly cracked, rails bent. Landslides and shifting of sand and mud.
XI	Few if any (masonry) structures remain standing. Broad fissures in ground.
XII	Damage total. Waves seen on ground surfaces.

order to use $\log(A/T)$, we assumed a period of 0.35 sec in converting the formulas for our use. The resulting equations are:

(epicenter 10–100 km from a seismograph)

$$\mathrm{m3Hz} = \log(A/T) - 1.46 + 0.88\log(\Delta)$$

(epicenter 100–200 km from a seismograph)

$$\mathrm{m3Hz} = \log(A/T) - 1.82 + 1.06\log(\Delta)$$

(epicenter 200–400 km from a seismograph)

$$\mathrm{m3Hz} = \log(A/T) - 2.35 + 1.29\log(\Delta).$$

Otto Nuttli's (1973) earthquake magnitude, mbLg, for seismograph stations located between 55.6 and 445 km from the epicenter, is derived from the following equation:

$$\mathrm{mbLg} = \log(A/T) - 1.09 + 0.90\log(\Delta).$$

Where seismograph stations are located between 445 and 3,360 km from the epicenter, mbLg is defined as:

$$\mathrm{mbLg} = \log(A/T) - 3.10 + 1.66\log(\Delta),$$

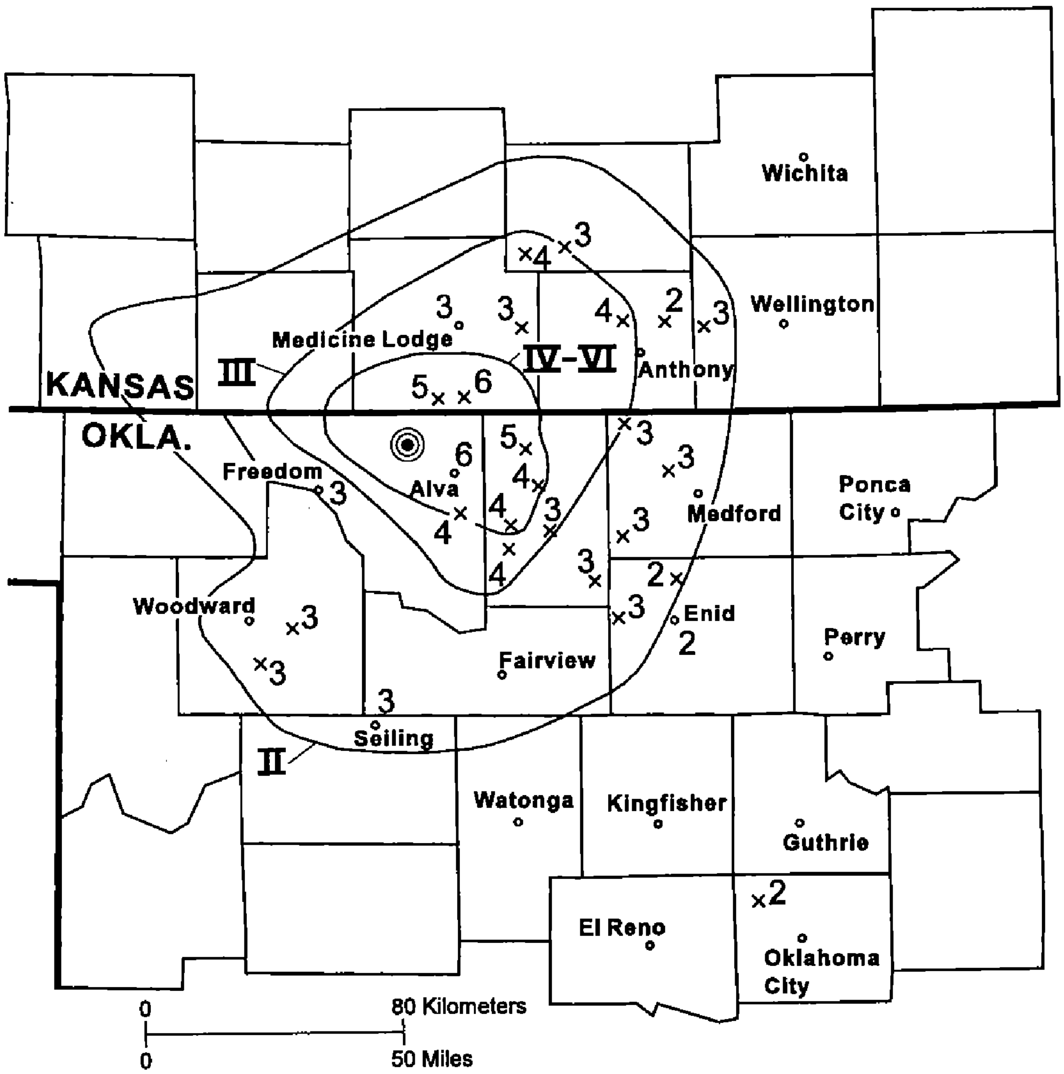

Figure 3. Modified Mercalli (MM) intensity values for the Alva earthquake, September 14, 1995, 7:31 p.m. (local time), Woods County, Oklahoma.

where A is the maximum center-to-peak vertical-ground-motion amplitude sustained for three or more cycles of Lg waves, near 1 Hz in frequency, measured in nanometers; T is the period of Lg waves measured in seconds; and Δ is the great-circle distance from epicenter to station measured in kilometers.

The MDUR magnitude scale was developed by Lawson (1978) for earthquakes in Oklahoma and adjacent areas. It is defined as:

$$\text{MDUR} = 1.86 \log(\text{DUR}) - 1.49,$$

where DUR is the duration or difference, in seconds, between the Pg-wave arrival time and the time the final coda amplitude decreases to twice the background-noise amplitude. Before 1981, if the Pn wave was the first arrival, the interval between the earthquake-origin time and the decrease of the coda to twice the background-noise amplitude was measured instead. Beginning January 1, 1982, the interval from the beginning of the P wave (whether it was Pg, P*, or Pn) to the decrease of the coda to twice the background-noise amplitude was used.

The depth to the earthquake hypocenter is measured in kilometers. For most Oklahoma earthquakes the focal depth is unknown. In almost all Oklahoma events, the stations are several times farther from the epicenter than the likely depth of the event. This makes the locations indeterminate at depth, which usually requires that the hypocenter depth be restrained to an arbitrary 5 km for purposes of computing latitude, longitude, and origin time. All available evidence indicates that no Oklahoma hypocenters have been deeper than 15–20 km.

Earthquake detection and location accuracy have been greatly improved since the installation of the statewide network of seismograph stations. The frequency of earthquake events and the possible correlation of earthquakes to specific tectonic elements in Oklahoma are being studied. It is hoped that this information will provide a more complete data base that can be used to develop numerical estimates of earthquake risk, giving the approximate frequency of the earthquakes of any given size for various regions of Oklahoma. Numerical risk estimates could be used for better design of large-scale structures, such as dams, high-rise buildings, and power plants, as well as to provide the necessary information to evaluate insurance rates.

Acknowledgments

Shirley Jackson, Ruth King, and Todd McCormick maintained the OGS Observatory at Leonard. Volunteer seismograph-station operators and landowners at various locations in Oklahoma make possible the operation of a statewide seismic network.

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SPECIAL PUBLICATION 96-1. ***Fluvial-Dominated Deltaic (FDD) Oil Reservoirs in Oklahoma: The Layton and Osage-Layton Play,*** by Jock A. Campbell and others. 78 pages, 14 plates. Price: $6.

The third 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 Layton and Osage-Layton play workshop held in April 1996.

In Part I of this publication, Richard D. Andrews and others explain the scope of the FDD project and describe 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.

In Part II, Jock A. Campbell presents the regional geology of Layton and Osage-Layton fluvial systems in the Cherokee platform in northeastern Oklahoma.

Part III of the book presents reservoir studies of two areas, one each in the Layton and Osage-Layton sands: the South Coyle field, by Dennis L. Shannon, and the East Lake Blackwell field area, by Jock A. Campbell. Included are stratigraphy, structural and isopach mapping, reservoir characteristics, and oil and gas production.

The reservoir study of the Osage-Layton sand interval in the East Lake Blackwell oil field area, Payne County, Oklahoma, is developed into a reservoir simulation study in Part IV by R. M. Knapp and X. H. Yang. The simulation includes a forecast of ultimate recovery based on infill drilling and abandonment of some structurally low wells.

The book also includes a list of selected references and a glossary of terms. Plates included with the publication are a map of Layton and Osage-Layton oil fields, production maps of the Layton and Osage-Layton sands and the Cottage Grove sandstone, stratigraphic cross sections of study areas, and an index to selected references used for Layton and Osage-Layton sand mapping.

Author Jock A. Campbell is a petroleum geologist with the Oklahoma Geological Survey. Richard D. Andrews, exploration and development geologist with the University of Oklahoma's Geo Information Systems (GeoSystems) unit, and Robert A. Northcutt, consulting geologist, Oklahoma City, are the other two lead geologists on the FDD project team. R. M. Knapp is the petroleum engineer for the FDD project and a professor in the OU School of Petroleum and Geological Engineering. X. H. Yang is a graduate student in the OU School of Petroleum and Geological Engineering. The next publication in this series is scheduled for release in June 1996; it will be on the Skinner and Prue plays.

GEOLOGIC MAP OF THE HARTSHORNE QUADRANGLE, PITTSBURG AND LATIMER COUNTIES, OKLAHOMA. One sheet, scale 1:24,000. Xerox copy. Price: $6, rolled in tube.

The Ouachita STATEMAP project, which began in 1993, is a joint effort of the Oklahoma Geological Survey and the U.S. Geological Survey to prepare new 1:24,000 geologic maps of the Ouachita Mountains and Arkoma basin in Oklahoma. STATEMAP is part of the National Cooperative Geologic Mapping Program and replaces the successful COGEOMAP program, which began in 1984. Under COGEOMAP, the OGS completed and published 15 7.5′ geologic quadrangle maps along the northern part of the Ouachita Mountains frontal belt and southern part of the Arkoma basin (see article on p. 36 of this issue for more information about the COGEOMAP program).

During the first year of STATEMAP, in early 1994, the Oklahoma Geologic Mapping Advisory Committee, chaired by OGS associate director Kenneth S. Johnson, was established to recommend mapping priorities for the State. The committee recommended Pittsburg County, especially near McAlester, as an important area for OGS efforts. The committee chose the McAlester area for several reasons: (1) Coal has been a major resource in the area, and substantial reserves still are present. (2) A number of natural-gas fields have been discovered recently and others are being developed in this part of the Arkoma basin, and the giant Wilburton deep gas field was discovered in 1987 immediately east of the area. (3) Environmental problems resulting from open mine shafts, undocumented underground mines, and poor reclamation practices in the past may impact urban development near McAlester, as well as rural development throughout the region. (4) Several type localities of Arkoma basin formations are in the area, but are unmeasured or otherwise poorly documented.

The Hartshorne Quadrangle, by Neil H. Suneson, is the second in a series of STATEMAP geologic maps of Pittsburg County. It is now available as a black-and-white, author-prepared xerox copy, comprising geologic map, cross sections, description and correlation of units, and a list of gas wells. This map is an important addition to the series of previously mapped quadrangles because of its proximity to the expanding urban area of McAlester. Planners for new highway construction, building construction, and abandoned coal-mine reclamation will find the map useful in addressing environmental concerns. Further economic assets of the area include gas reservoirs and documented coal reserves in several of Oklahoma's principal coal beds.

COGEOMAP and STATEMAP maps also are available for the Higgins, Damon, Baker Mountain, Panola, Wilburton, Red Oak, Leflore, Talihina, Leflore Southeast, Blackjack Ridge, Gowen, Summerfield, Hodgen, Hontubby/Loving, Wister, Heavener/Bates, and Adamson Quadrangles.

List of Available OGS Publications, 1996/1997.
24-page catalog. Available free of charge.

SP 96-1 and COGEOMAP/STATEMAP geologic quadrangle maps 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. For SP 96-1, add 20% to the cost for mail orders, with a minimum of $1 per order. For mail orders of 1–10 maps, add $2; for 11–25 maps, add $3.

A new OGS Publications Sales Office will open May 13, 1996.
(See back cover of this issue for information.)

PTTC Holds First Focused Technology Workshop

Despite predictions of bad weather and the noontime appearance of a snowstorm, 45 participants from Arkansas, New Mexico, Texas, and Oklahoma attended the Petroleum Technology Transfer Council (PTTC) South Midcontinent Region's first Focused Technology Workshop in Oklahoma City. The focus of this February 1 meeting was on information and technical assistance—and where and how to find it. Of the 45 attendees, 21 identified themselves as small operators, while the rest were consultants, independents, employees of medium and large companies, and representatives of university and government groups.

Using responses from two PTTC problem-identification workshops held last year, the Producers Advisory Group that is the PTTC regional steering body determined that one of the most fundamental needs of producers is access to information and technology already available but not known to all. This workshop was planned and researched carefully to provide an overview of industry sources and programs and to give producers a chance to meet and share both their questions and their knowledge.

"This workshop was a success because we took the time, through two problem-identification workshops, to find out what issues are most important to the producers," said Charles J. Mankin, director of the Oklahoma Geological Survey, which is the South Midcontinent's Regional Lead Organization (RLO). "The background established from those initial working sessions has allowed us to hit the ground running, so to speak, with a program for which there is a need."

Each person at the meeting received a thick book containing material provided by the speakers about additional reading, programs, services, workshops, information, and technology that is available to them.

After Mankin called the meeting to order, Steve Jones of the Oklahoma Independent Petroleum Association (OIPA) talked to the group about his organization, which was established in 1955 to represent independent producers in the political, regulatory, and technical arenas and inform them of developments. Although OIPA has been in existence for 46 years, there was much new information about activities, programs, and short courses. OIPA's World Wide Web site on the Internet can be accessed at "http://www.oipa.com".

OIPA and the Gas Research Institute (GRI) are involved in a technology transfer program in Oklahoma that is offering local workshops at a cost of \$20–\$50. The program is approaching three years old, and has 85 documented technology-information transfers at this point. Jones said significant economic benefits had resulted among the client list of 1,100 people and 570 companies. GRI also has information centers in Houston and Denver, and has produced gas atlases of the Midcontinent (Oklahoma, Kansas, Arkansas), Texas, Gulf Coast, Rocky Mountains, and low-permeability reservoirs in 24 tight gas sands in 13 basins.

Jack Shadle, Jr., executive director of the Oklahoma Commission on Marginally Producing Oil and Gas Wells (MWC), then told the group about MWC, which formed in 1992 to help prevent the premature plugging and abandonment of Oklahoma's more than 70,000 marginal wells. These units account for approximately three-fourths of all the oil produced in Oklahoma. The Commission has undertaken a number of studies to examine marginal well issues, develop an economic profile of stripper wells, look at operational costs for marginal wells, and analyze the economic impact of reducing taxes and costs.

The MWC also has a technology transfer program designed to provide real-world information and solutions to some of the problems faced by operators of marginal wells. The Commission held 14 workshops in 10 different locations in 1995, with approximately 475 people attending. In 1996, 19 workshops are scheduled for the first six months. The meetings typically run from 9 a.m. to 5 p.m., and the $45 registration fee covers the workshop, lunch, workshop manual, a certificate, and a video tape of the workshop. Current workshops include "Chemical Use in the Oil Field," "Natural Gas Metering," "Environmental Compliance," "Surface Equipment Operations," "Downhole/Beam Pump and Sucker Rod Optimization," and "Plunger Lift." Workshops are being planned on "Produced-Water Diversion and Disposal," "Low-Cost Well Stimulation," and "Water-Flooding Feasibility." For more information about the MWC workshops, contact Michael Earls, Technology Transfer Coordinator, Oklahoma Commission on Marginally Producing Oil and Gas Wells, 1218-B W. Rock Creek Road, Norman, OK 73069; phone (405) 366-8688, fax 405-366-2882.

Another important part of MWC is their petroleum technology lending library. The library has videos, CD-ROM, and printed material that can be checked out on a no-cost basis by operators, public libraries, the media, and other agencies. The library currently has more than 300 items, and more will be added with the acquisition of new space.

Mankin then talked about the wide variety of commercial services and companies, professional organizations, and state and federal agencies that are sources of information and assistance for the industry. The workbook contained information about each group mentioned, so that those at the meeting had a complete set of names, addresses, phone numbers, and order forms to take home with them.

After this presentation, Nancy Richardson, oil technology coordinator for OIPA/BDM in Oklahoma City, told the group about ongoing projects at OIPA/BDM, and the efforts to meet the needs of producers in Oklahoma. She discussed problems with paraffin deposits in wells and the uses of mechanical, thermal, chemical, and microbial solutions to this problem. Information also was given to the audience about the development of improved alkaline flooding methods. BDM Oklahoma, Inc., and the National Institute for Petroleum and Energy Research (NIPER) are involved in a program to aid independent oil producers with urgent production problems. These projects are aimed at small companies with no more than 50 full-time employees or contractors, and incorporate innovative field technologies to increase production, reduce operating costs, reduce environmental concerns, or any combination of these problems. Examples of recent projects were included in the book attendees received.

The PTTC South Midcontinent Region Resource Center that is now open at OGS was explained to the group by Mankin. The Center consists of a log library, core and sample library, open-file reports, the Youngblood Energy Library, the OGS Natural Resources Information System (NRIS) Facility, and the technical staff of the Oklahoma Geological Survey and Geo Information Systems. These facilities allow operators access to one of the nation's finest collections of oil and gas information and provide assistance from experienced geologists, computer experts, and librarians that can help them find the answers to their questions. A fax-on-demand system (put into operation since the meeting) allows anyone with a fax machine to have specific documents faxed to them 24 hours a day. Users can call 405-325-7113 from their fax machines and follow the voice prompts to retrieve documents on subjects such as events and workshops, OGS publications, and providers of petroleum information and technology. Future plans for the resource center include a World Wide Web page and satellite centers in Oklahoma and Arkansas.

Winding up the day, Mary Banken, director of the University of Oklahoma's Geo Information Systems, discussed the Oklahoma Geological Survey's NRIS program. NRIS is a collection of digital data files concerned with Oklahoma's natural resources. Detailed information on Oklahoma's oil and gas production and well history records are available on computer, and can be accessed through the OGS NRIS Facility computer lab that is a part of the PTTC Resource Center at the Oklahoma Geological Survey. For those not familiar with computers, help is available through the lab.

This first Focused Technology Workshop of the PTTC South Midcontinent Section proved successful, judging from favorable comments received on questionnaires returned by the group. "I simply wasn't aware of a lot of this," commented one participant, while another wrote, "In my opinion, most producers are not aware of the extent of information available—particularly from OGS."

Additional problem-identification and focused technology workshops will be held during this calendar year, the exact times and places yet to be determined. For more information, contact Michelle Summers at the Oklahoma Geological Survey, 100 E. Boyd, Room N-131, Norman, OK 73019; phone (405) 325-3031 *or* (800) 330-3996. For faxed documents, dial 405-325-7113 from a fax machine.

—Connie Smith

ELIZABETH A. "BETTY" HAM

Retired OGS Associate Editor

Betty Ham
(1915–1995)

Elizabeth Awbrey Ham, known to all her many friends as "Betty," died of a hematoma in Norman on December 23, 1995, at the age of 80. During her very productive and purposeful life, she had devoted a great deal of energy to sharing knowledge, and compiling information, about the geology of Oklahoma. She will be sorely missed by her colleagues and friends, who are legion throughout Oklahoma and the U.S., and include many throughout the world.

Betty was born in El Paso, Texas, on June 14, 1915, to S. C. and Ethyl (Powell) Awbrey. The family moved to Fort Smith, Arkansas, when she was 5, and then on to Kansas City, Missouri, where she graduated from Westport High School in 1933. She earned a B.S. degree in geology from the University of Missouri, Kansas City, in 1937, and then moved to Norman that year to do graduate studies at the University of Oklahoma. While studying at OU she met William E. Ham, who at that time was an instructor in geology; this meeting, and their subsequent marriage on June 1, 1940, helped establish her permanent relationship with OU and the Oklahoma Geological Survey. Betty received her M.S. degree from OU in 1939. Her thesis, "A comparative study of species of the ostracode genus *Cythereis* of the Washita Group in north Texas," was directed by the well-known and respected Drs. Reginald W. Harris, Charles E. Decker, and Victor E. Monnett.

Betty filled a number of roles and responsibilities during her life. She was a collaborator and co-worker to her husband, a loving and caring family member, and a professional in her own right. She accompanied and assisted Bill during much of his field studies in the Arbuckle Mountains, where he did work for his Ph.D., and also accompanied him on many of his trips throughout the world. Bill was an eminent geologist and professor who worked 29 years for the OGS, until his untimely death in 1970. Betty knew, and was loved by, all of her husband's professional colleagues, and graciously hosted them at parties, meals, and for overnight stays: She often spoke proudly of operating the "Ham Hotel" for visiting geologists and friends.

Family was most important to Betty. She and Bill raised three sons, of whom Betty spoke often and proudly. She always talked with her friends and colleagues about the activities and achievements of their sons and their families: William Ham and his wife, Patricia, of Andover, Massachusetts; Robert Ham and his wife, Anne, of Norman; and Donald Ham of Chicago, Illinois. Through her loving words and descriptions we were able to follow the growth and development of her family members, whether they were here in Norman or far away.

She was an accomplished and gifted professional. With a master's degree in geology, Betty rejoined the work force in 1970 by working as a library assistant in OU's Geology and Geophysics Library. She then took the job of editorial assistant at the Oklahoma Geological Survey in 1971, and was promoted to associate editor in 1977. At the Oklahoma Geological Survey she was perfectly suited to integrate her geology background with her love of writing and editing. She compiled an excellent and comprehensive series of bibliographies of Oklahoma geology (OGS Special Publications 81-5, 82-2, and 90-4); a catalog of OGS publications (SP 85-3) and a catalog of OU geology theses and dissertations (SP 79-2); and wrote a warm and insightful book, *A History of the Oklahoma Geological Survey, 1908–1983* (SP 83-2). She expanded her duties to become the Survey's first public information officer in 1980. During her career, she was an active member of the OU Geology Wives and the Association of Earth Science Editors. Betty retired from her professional career in 1989, but she continued her interest in and contact with geology and geologists in Oklahoma and throughout the world.

Betty's life extended beyond her family and her profession. She volunteered for many activities in her church and her community. She was an active member of St. John's Episcopal Church in Norman and of the Daughters of the King. Betty was unique in that she never met a person that she didn't like—and she genuinely liked people. In speaking of any and all her friends and acquaintances, she always said: "He (or she) is *so* nice—I really do *like* him (or her)." And she really meant it! Betty *always* extended a helping hand to those with any kind of a need. She never turned anyone away. A number of students and struggling co-workers found a place to stay at her house, and they also received wise counsel from Betty as an extra benefit.

And so, all of us—her family, friends, and colleagues—will miss her greatly.

—Kenneth S. Johnson

Former Associates Remember Betty Ham

"I knew Betty Awbrey Ham from 1933 through 1936 at the University of Kansas City, Missouri (now University of Missouri at Kansas City). She was always the academic leader of her fellow students. Her charming personality was well known to all of the university students. It was a great pleasure to know that she and Dr. William Ham had three sons as their family. Betty's work at the Oklahoma Geological Survey was nationally recognized. The loss of her activity at the Survey will be felt by the whole geological community."

—Samuel P. Ellison, Jr.
Geologist, Austin, Texas

"Bill Ham, Al Loeblich, and I were graduate students in geology at OU when Betty Awbrey first came to Norman, nearly 60 years ago. In fact, Al introduced Betty and Bill, and the four of us became close friends as well as students in many courses together. As we successively moved to all four borders of the country, we frequently returned to Norman to visit the Hams; they were on their way to the West Coast to return our visit to them when Bill died. We kept in touch with Betty and continued to visit her, the Geology Department, and the Survey whenever our path crossed Oklahoma. We even spent a couple of nights at the "Ham Hotel" while attending our 50th class reunion at OU a few years ago. Norman, the Survey, and the University all share the great loss now felt by Betty's many friends and co-geologists, just as over the years all have shared the gifts of her numerous talents and her boundless friendship. We miss her."

—Helen Tappan Loeblich
Professor Emeritus
University of California–Los Angeles

"Betty was a dedicated member of the Survey, perhaps my most loyal and loving critic. While her contributions to the Survey were many, her history of the organization stands as a landmark contribution. While many will follow in her footsteps, there will be only one Betty Ham."

—Charles J. Mankin
OGS Director

"Betty Ham was a great observer of people and life, and always looked for the best in everyone. She saw things in people that many of us failed to see, and brought out the best in those around her. Betty loved to write and was a compelling author. Even the most mundane news releases benefited from her unique perspective. She was a witty and funny person—someone I loved to sit and talk to, and share a laugh with. Going to her home was a treat because she always made you feel comfortable and special—one of the many things that made *her* so special. Her home was a haven for many, and a place where ideas and philosophies were exchanged and nourished.

I will *always* think of Betty when I see a room decorated predominantly in blue, Blue Willow china, a blue coat or dress, the sea, or a sparkling blue October day. The color blue was her favorite—to the exclusion of any other second-rate colors! Betty and blue will always be linked in my mind."

—Connie Smith
OGS Promotion and Information Specialist

"With the passing of Betty, I lost a very dear friend. She was caring, hospitable, and always ready to reach out to others. When I came to the Oklahoma Geological Survey, Betty immediately made me feel welcome and lost no time in introducing me to different places and people of Norman, one of which was the Episcopal Church.

I soon learned that Betty had the ability to sense when I was discouraged and would usually find ways to encourage me. When we visited on the telephone she always ended our conversation with 'Come see me.' I felt free to drop by at any time unannounced and she always had time for me. I, however, had to beg her not to try to 'feed me' since my main purpose for coming was to visit.

I thank Betty for the pleasant memories she has left me and the positive role model she was for me."

—Patronalia Hanley
OGS Chemist

"What I remember most about Betty Ham is that she was a caring person. She cared deeply about her family and her friends, and also about her colleagues in the Oklahoma Geological Survey and the University. She cared about our whole society, especially those whom she viewed as less fortunate.

Betty gave of herself to help those in her neighborhood and community. She contributed financially to help others; I'm certain she also helped them through her prayers.

The qualities Betty Ham expressed will continue to bless those of us who were privileged to have known her."

—William D. Rose
Former OGS Geologist/Editor

"Betty Ham had a goodness, a kindness about her that was completely transparent. You couldn't meet her without noticing. This was coupled with a sly wit and a well-developed sense of humor. She was a wonderful editor as well—careful and meticulous. She could edit something you wrote and it always ended up sounding just like you wrote it—only better."

—Rodger E. "Tim" Denison
Research Scientist
The University of Texas at Dallas

OGS Senior Coal Geologist Samuel A. Friedman Retires

Sam Friedman, senior coal geologist, retired in December 1995 after 24 years of service to the OGS.

Samuel A. Friedman came to the Oklahoma Geological Survey in 1971, at a time when energy was on everyone's mind. The United States was approaching the time of the oil crisis, and world events were driving the country to examine and evaluate its coal resources. Before Friedman joined the Survey, large reserves of bituminous coal were known to exist in Oklahoma, but no comprehensive quadrangle-by-quadrangle study of thickness, quality, mined areas, and resources had been undertaken for 20 years in the State's 19 coal-bearing counties.

Sam was hired by the OGS to conduct a statewide investigation and assessment of Oklahoma's coal reserves and resources. The first major project was a detailed report for the Ozarks Regional Commission (ORC) on the bituminous-coal resources and recoverable reserves in Oklahoma and potential uses for the coal. The OGS published Sam's final report to the ORC in 1974 as Special Publication 74-2, *Investigation of the Coal Reserves in the Ozarks Section of Oklahoma and Their Potential Uses*; it was reprinted four times.

When Sam began work at the OGS, he had a solid geological background in education and 19 years of experience in coal geology. He received a B.S. from Brooklyn College, CUNY, in 1950, and an M.S. in geology from Ohio State University in 1952. He did additional graduate work at Indiana University and the University of Tennessee. From 1952 to 1967 Sam worked as a coal geologist for the Indiana Geological Survey, where he mapped coal beds and prepared coal quadrangle maps and county coal resource maps. From 1967 to 1971 he served as a coal project leader for the U.S. Bureau of Mines in Knoxville, Tennessee, and Pittsburgh, Pennsylvania, documenting low-sulfur coal reserves in the Appalachian Coal Region.

Sam became interested in geology late in his grade-school years when he started to think about the little red pebbles he noticed in the sand around his neighborhood in Brooklyn (which, he will tell you, is situated on an outwash plain). Where did they come from? And which came first, the sand or the pebbles? About this same time, he began to wonder whether dinosaurs really had existed or were just a fantasy in a cartoon in the Sunday paper. Hearing tales of a volcano that sprouted from a cornfield, Sam also wanted to know if this really happened. With his natural curiosity and active imagination, these topics took root and later grew into a love of the earth sciences. The interest resurfaced in college when Sam suspended his French major after two years and began to take other classes. His first science class was in physical geology, a section still taught at Brooklyn College, and, as he says, "THAT was IT!" Soon, he was president of the geology club and was exploring industry to see where the jobs were and what was required to get them.

During his college years he considered teaching geology, and while at the OGS he also served as an instructor for the Oklahoma Center for Continuing Education, as an adjunct professor of geology and member of the graduate faculty at OU's School of Geology and Geophysics, and as a visiting professor of geological engineering in OU's College of Engineering.

In college Sam took one year each of courses in chemistry, physics, and biology, which allowed him to become one of Brooklyn College's first geology graduates to earn the Bachelor of Science degree. Because this variety gave him a sound background for many aspects of geology, it was, as he says, "Coal by chance." Before graduating from Ohio State—at a time when no courses were offered specifically in coal geology—he interviewed with an oil company, but he graduated two months too late to take the job they offered. When a job opened at the Indiana Geological Survey for a coal geologist, his interest was piqued. He had found a field that suited him and presented a lifetime of opportunities for further study and learning.

At both the Indiana and Oklahoma Geological Surveys Sam's fields of interest in research included stratigraphy, sedimentology, channel-fill sandstones, fossil river systems, cyclic sequences, and depositional environments of the Middle Pennsylvanian. In the past 16 years, two other related research topics have attracted his interest: fractures in coal in relation to coal-bed methane resources, and coal reserves environmentally acceptable for electric-power generation in the 21st century.

Sam belongs to several professional organizations and often serves as officer, editor, or committee chair for these groups. Currently he is a fellow of the Geological Society of America (GSA) and is a past chairman of its Coal Geology Division; he belongs to the Society for Sedimentary Geology (SEPM); he is a member of the American Association of Petroleum Geologists (AAPG) and is a past president of its Energy Minerals Division (EMD); and he is a member of the American Institute of Professional Geologists. He has received a number of professional awards, including the Distinguished Service Award, Coal Geology Division, GSA, 1992; Past President's Award, EMD, AAPG, 1992; Distinguished Founders Award, AAPG, 1993; Gordon Wood, Jr., Memorial Award, Eastern Section, AAPG, 1994; and Distinguished Service Award, AAPG, 1995. On June 1, 1995, Brooklyn College, CUNY, presented him with its Distinguished Alumnus Award (see *Oklahoma Geology Notes*, v. 55, p. 246).

Sam's life in retirement will be more a reshuffling of his schedule than a major break with his routine. He will continue to attend professional geological meetings and to work at the OGS, donating his time on special projects. He will remain active in the Norman Lions Club, for whom he has served on the board of directors for 20 years. He is a member of Emanuel Synagogue and Temple B'nai Israel in Oklahoma City. He also is a member of B'nai Brith International and has filled many volunteer posts in that organization.

In addition to attending family gatherings and constructing a family tree, Sam hopes that he and his wife, Evelyn, a Norman school librarian, will be able to find more time to enjoy the home they built four years ago. They also want to build their library of classical music recordings, attend concerts, and travel to geologically interesting locations.

Even though he will be in the office on a sporadic basis, Sam will be missed day-to-day by his colleagues and friends at the OGS. He has provided the State of Oklahoma with a tremendous knowledge of its coal resources and given those who follow a sound basis for future study. To him we extend our thanks and our good wishes.

—*Connie Smith*

Geoscience and Remote Sensing, International Symposium, May 27–31, 1996, Lincoln, Nebraska. Information: IEEE Geoscience and Remote Sensing Society, 2610 Lakeway Drive, Seabrook, TX 77586; (713) 291-9222, fax 713-291-9224; E-mail: stein@harc.edu.

Acoustic Emission/Microseismic Activity in Geologic Structures Conference, June 11–13, 1996, University Park, Pennsylvania. Information: H. Reginald Hardy, Jr., Pennsylvania Mining and Mineral Resources Research Institute, Pennsylvania State University, 110 Hosler Bldg., University Park, PA 16802; (814) 863-1620; fax 814-865-3248.

Karst Hydrology Workshop, June 16–22, 1996, Bowling Green, Kentucky. Information: Nicholas Crawford, Director, Center for Cave and Karst Studies, Western Kentucky University, Bowling Green, KY 42101; (502) 745-4555.

Incorporated Research Institutions for Seismology, Annual Workshop, June 19–22, 1996, Blaine, Washington. Information: IRIS, 1616 N. Fort Myer Drive, Suite 1050, Arlington, VA 22209.

National Minerals Education Conference, June 19–22, 1996, Scottsdale, Arizona. Information: Larry McBiles, Chairman, Minerals Ed. '96 Conference, 2702 N. Third St., Suite 2015, Phoenix, AZ 85004; (602) 266-4416.

International Organization of Paleobotany Conference (sponsored by the Botanical Society of America), June 30–July 5, 1996, Santa Barbara, California. Information: Bruce H. Tiffney, Dept. of Geological Sciences, University of California, Santa Barbara, CA 93106; fax 805-893-2314; E-mail: tiffney@magic.ucsb.edu.

Watershed Restoration Management Annual Meeting (sponsored by the American Water Resources Association), July 14–17, 1996, Syracuse, New York. Information: Peter E. Black, SUNY College of Environmental Science and Forestry, Syracuse, NY 13210; (315) 470-6571, fax 315-470-6956.

History of Oil and Gas Exploration in North America Symposium, July 18–21, 1996, Titusville, Pennsylvania. Information: W. R. Brice, Dept. of Geology, University of Pittsburgh, Johnstown, PA 15904; (814) 269-2901.

Geomorphology: Understanding Landforms and Landscapes Seminar, July 21–27, 1996, Steuben, Maine. Information: Eagle Hill Field Research Station, P.O. Box 9, Steuben, ME 04680; (207) 546-2821, fax 207-546-3042.

AAPG Rocky Mountain Section, Annual Meeting, July 28–31, 1996, Billings, Montana. Information: Betsy Campen, 7314 Charolais St., Billings, MT 59106; (406) 652-1760.

30th International Geological Congress, August 4–14, 1996, Beijing, China. Information: Secretariat Bureau, 30th International Geological Congress, P.O. Box 823, Beijing 100037, P.R. China; telephone 86-1-8327772, fax 86-1-8328928.

Society for Organic Petrology (TSOP), Annual Meeting, September 15–19, 1996, Carbondale, Illinois. *Abstracts due May 17, 1996.* Information: John Crelling, Dept. of Geology, Southern Illinois University, Carbondale, IL 62901; (618) 453-7361, fax 618-453-7393; E-mail: jcrelling@geo.siu.edu.

Prue and Skinner Plays Featured in Upcoming OGS Workshop

The Oklahoma Geological Survey will present a one-day workshop, "Fluvial-Dominated Deltaic (FDD) Oil Reservoirs in Oklahoma: The Prue and Skinner Plays," on June 19 and 20, 1996, at the Francis Tuttle Vo-Tech Center in Oklahoma City and on June 26, 1996, at the Phillips Petroleum Company Research and Development Center in Bartlesville.

The registration fee for operators in these plays is $15; for other attendees it is $25. (Note: The $15 fee is for only one representative from each company; additional registrants will need to pay $25.) The cost includes lunch and a copy of the play folio, *Fluvial-Dominated Deltaic (FDD) Oil Reservoirs in Oklahoma: The Skinner and Prue Plays* (OGS Special Publication 96-2). Prue and Skinner operators have priority status to attend if registered by June 7; the registration deadline for other attendees is June 14.

The workshop is the fourth in a series of eight workshops to be presented as part of the Fluvial-Dominated Deltaic Oil Reservoirs project, which involves participation from the OGS, the University of Oklahoma's Geo Information Systems, and the OU School of Petroleum and Geological Engineering.

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

Fossil Collecting at Well-Known Ada Site to End

The "Brick Plant Fossil Pit" (originally Superior Clay Products, Inc. shale pit) in Ada, Oklahoma, a significant paleontological site, soon will be unavailable for collection and research. The property was purchased by a private group for a housing development and work already has begun on a 17-acre tract immediately south of the fossil location. The pit has long been famous for its wide variety of material and its easy access, and has been the subject of several research studies.

The pit is located in the NE¼SE¼ sec. 4, T. 6 E., R. 3 N., Pontotoc County, Oklahoma, and is in the Francis Formation of Upper Pennsylvanian (Missourian) age. The paleontology and sedimentology of the Francis Formation at the pit were described by A. E. Giles (University of Oklahoma M.S. thesis, "Physical paleoecology of the Francis Formation [Pennsylvanian] near Ada, Oklahoma," 1963, 127 p.), who divided the formation in the Ada area into 16 units, A (oldest) through P (youngest). The brick pit exposes the upper part of unit F (fossiliferous shale) and unit G (sandstone and chert conglomerate).

The upper part of unit F contains a wide variety of invertebrate fossils. Starfish, complete crinoids, and a nearly complete chiton have been collected from the pit, but are rare (Giles, 1963). Brachiopods, pelecypods, gastropods, cephalopods, and fragments of crinoids and echinoids are common and easily collected. In addition, shark teeth and septarian concretions with vugs containing calcite crystals are present in the upper part of unit F.

Persons wanting to collect or do research should contact Dr. Robert Neman, Chair, Dept. of Chemistry, East Central University, Ada, OK 74820; phone (405) 332-8000, or E-mail: bneman@mailclerk.ecok.edu.

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

Nd Isotopic Constraints on Sediment Sources of the Ouachita–Marathon Fold Belt

JAMES D. GLEASON, P. JONATHAN PATCHETT, WILLIAM R. DICKINSON, and *JOAQUIN RUIZ,* Dept. of Geosciences, University of Arizona, Tucson, AZ 85721

Nd isotopes for the overthrust deep-marine Ouachita–Marathon sedimentary assemblage of Arkansas–Oklahoma and west Texas, and associated Paleozoic shelf and foreland deposits, resolve into three distinct populations: (1) Lower to Middle Ordovician, $\varepsilon_{Nd} = -13$ to -16 (average $T_{DM} = 2.0$ Ga); (2) Upper Ordovician to Pennsylvanian, $\varepsilon_{Nd} = -6$ to -10 (average $T_{DM} = 1.6$ Ga); and (3) Mississippian tuffs, $\varepsilon_{Nd} = -1$ to -3 (average $T_{DM} = 1.1$ Ga). A rapid shift in ε_{Nd} from −15 (passive margin shales) to −7 (orogenic turbidites) in the Ouachita assemblage at ca. 450 Ma implies termination of craton-dominated sources and the emergence of the Appalachian orogen as the primary source of sediment for sea floor lying south of North America. This connection is reinforced by Nd isotopes in Ordovician–Silurian turbidites from both the Ouachita assemblage and the southern Appalachian Sevier–Martinsburg (Taconic) foredeep, which are identical ($\varepsilon_{Nd} = -7$ to -9). The post-450 Ma Ouachita assemblage falls along a single Nd isotopic trend that, significantly, is not deflected by onset of Carboniferous flysch ($\varepsilon_{Nd} = -7$ to -10) sedimentation nor by associated regional volcanism. The less negative ε_{Nd} (−2) of Mississippian ash-flow tuffs that erupted from arc(s) to the south probably resulted from isotopic mixing of old (Precambrian) crust with young, mantle-derived components within a continental margin arc. There is little isotopic, trace element, or petrographic evidence for any significant volcaniclastic detritus in the Carboniferous turbidites, indicating that volcanic arc sources were minimal.

Nd isotopes in fluvio-deltaic strata of the Ouachita–Appalachian foreland and continental interior, that is, Arkoma, Illinois, and Black Warrior basins ($\varepsilon_{Nd} = -7$ to -10), imply that continental margin pathways and interior basins received the same detritus as the Ouachita trough by Pennsylvanian time. These data are consistent with a composite Carboniferous Ouachita submarine fan complex built down the axis of a remnant ocean basin from varied mature/immature delivery systems tapping dominantly Appalachian fold-thrust belt sources to the east (Graham et al., 1975). Carboniferous turbidites from the Marathon fold belt (west Texas), which are isotopically similar ($\varepsilon_{Nd} = -8$ to -11) to Ouachita turbidites, may have been ultimately derived from similar sources; however, they probably do not represent merely distal turbidites of a Ouachita fan complex. It is suggested that dominantly Appalachian-derived detritus, augmented by uplifted plutonic and fold-thrust belt sources south of the Marathon basin, was swept up into subduction complexes on the north side of the approaching arc and recycled along the collision zone.

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Reinterpretation of Depositional Processes in a Classic Flysch Sequence (Pennsylvanian Jackfork Group), Ouachita Mountains, Arkansas and Oklahoma

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The Pennsylvanian Jackfork Group in the Ouachita Mountains of Arkansas and Oklahoma has conventionally been interpreted by many workers, including us, as a classic flysch sequence dominated by turbidites in a submarine fan setting; however, normal size grading and Bouma sequences, indicative of turbidite deposition, are essentially absent in these sandstone beds. They appear massive (i.e., structureless) in outcrop, but when slabbed reveal diagnostic internal features. These beds exhibit sharp and irregular upper bedding contacts, inverse size grading, floating mudstone clasts, a planar clast fabric, lateral pinch-out geometries, moderate to high detrital matrix (up to 25%), sigmoidal deformation (duplex) structures, and contorted layers. All these features indicate sand emplacement by debris flows (mass flows) and slumps. Mud matrix in these sandstones was sufficient to provide cohesive strength to the flow. Discrete units of current ripples and horizontal laminae have been interpreted to represent traction processes associated with bottom-current reworking.

The dominance of sandy debris-flow and slump deposits (nearly 70% at DeGray Spillway section) and bottom-current reworked deposits (40% at Kiamichi Mountain section), and the lack of turbidites in the Jackfork Group have led us to propose a slope setting. Our rejection of a submarine fan setting has important implications for predicting sand-body geometry and continuity because deposits of fluidal turbidity currents in fans are laterally more continuous than those of plastic debris flows and slumps on slopes. A turbidite-dominated fan model would predict an outer fan environment with laterally continuous, sheetlike sandstones for the Jackfork Group in southern Oklahoma and western Arkansas, whereas a debris-flow/slump model would predict predominantly a slope environment with disconnected sandstone bodies for the same area.

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Opening the Ouachita Ocean

GEORGE W. VIELE, Dept. of Geological Sciences, University of Missouri, Columbia, MO 65211

Opening of the Ouachita ocean began with late Precambrian–Cambrian rifting of the southeastern and southern margins of the Laurentian continent. An ocean opened with northwest-trending transform faults separating northeast-trending segments of a mid-ocean ridge (Thomas, 1991), and Ouachita sediments were deposited at the base and offshore of the Laurentian trailing margin. The oldest Ouachita strata are shales interstratified with clastic limestones containing Upper Cambrian trilobites that were transported from the Laurentian shelf to the Laurentian continental slope and rise. Debris flows containing clasts of limestone and chert are also present. Succeeding formations comprise shales, micrites, bedded cherts, and sandstones containing clasts of granite, probably from the Precambrian rhyolite/granite terranes of the Midcontinent. A thick sequence of black shale follows interstratified with micrite and bedded chert. The ocean continued to widen and deepen over a span of 100 m.y., and middle Paleozoic siliceous shale, chert, and manganese-bearing radiolarian cherts were deposited at abyssal depths. Nd isotopes indicate a Laurentian provenance for all these preorogenic strata (Gleason and others, 1995). The Ouachita stratigraphic section mimics the succession of sediments deposited in the Atlantic as it opened, and the Ouachita subsidence curve roughly mimics that of spreading oceans. Moreover, seismic reflection-refraction and gravity surveys indicate a transition from early Paleozoic continental crust to oceanic crust along the trace of the Ouachita orogenic belt. The pre-orogenic Ouachita strata were deposited in large part on this oceanic crust and were later thrust onto the edge of the Laurentian continent.

What was left behind on the Laurentian craton as the Ouachita ocean opened? Little is known about an early Paleozoic passive margin shelf facies in the subsurface of east Texas, because it is buried beneath Ouachita thrust sheets. The interior metamorphic belt in this region is mostly marble, quartzite, and phyllite unlike the black shale, chert, and micrite of the Ouachita belt. Possibly, the interior metamorphic belt is a rind of shelfal sediment left behind on the Laurentian craton as the Ouachita ocean opened, but it seems more probable that it is an exotic terrane accreted during the Carboniferous orogeny.

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Tectonically Dismembered Greywacke and Shale in the Broken Bow Uplift, Ouachita Allochthon, Oklahoma: Evidence for a Young-Over-Old Backthrust Above a Passive-Roof Duplex

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The Ordovician through Mississippian, deep-marine strata of the Broken Bow uplift show complex polyphase deformation dominated by early-formed, S- to SE-vergent folds and faults. These structures are in direct opposition to the well-documented N to NW tectonic transport of the Ouachita allochthon as a whole. In addition, the structural disharmony between recumbently folded and imbricated strata in the core of the uplift (Collier Formation through Mazarn Shale), and the tightly folded but only moderately faulted flank sequence (Bigfork Chert through Arkansas Novaculite), led to the controversial proposal of a young-over-old detachment fault (Miser, 1929). There is still no consensus among Ouachita workers as to the origin and significance of the S- to SE-vergent structures, or as to the existence of the detachment known as the Glover fault.

We have addressed both of these problems with detailed mapping of the greywacke and shale sequence we informally call the "Mountain Fork sandstone" (equivalent to the Middle Ordovician Womble Shale). A discontinuous belt of faulted and dismembered strata has been identified at the base of this unit, and closely follows the proposed trace of the Glover fault. Internally, bodies of dismembered formation show a classic "fragment-in-matrix" aspect, and are characterized by a moderately to very well-developed L-S tectonite fabric. Linear (L_2) elements display a strong, subhorizontal, NW–SE orientation and are represented by: (1) striations on cleavage surfaces, (2) quartz slickenfibers on cleavage surfaces, (3) alignment of elongate, dismembered greywacke fragments, and (4) alignment of rare, remnant F_2 fold hinges. Anastomosing, subhorizontal cleavage in the shale matrix defines the main planar (S_2) element. The tectonite fabric has been slightly overprinted by later D_3 (NW-trending F_3 folds) and D_4 (NE-trending, NW-vergent F_4 folds and reverse faults) structures.

Zones and slices of dismembered strata are interpreted as remnants of ductile shear zones which evolved into a network of anastomosing, SE-directed backthrusts. The main backthrust corresponds to the Glover fault, shows a young-over-old sense of displacement, and accommodated large-scale disharmonic deformation by detaching the flank sequence of the Broken Bow uplift from the underlying core sequence. The overall structural geometry suggests that the Broken Bow uplift evolved as an early formed, multi-story, passive-roof duplex. Strata above the Glover fault represent the strongly folded but relatively intact roof of the duplex. Imbricated sheets of the core sequence (Hubert, 1984) represent a lower structural level that must be floored in the subsurface by at least one more major backthrust. Duplex formation was synchronous with N to NW tectonic transport of the allochthon as a whole.

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Kinematic Problems in Palinspastic Restorations at Bends in Thrust Belts: The Example of the Ouachita Salient

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Arcuate bends of orogenic belts pose kinematic problems in balancing restorable cross sections. Standard balanced cross sections along lines perpendicular to regional strike of compressive structures may be palinspastically restored; however, restorations of an array of cross sections around a bend in regional strike result in apparent space problems in map view. At recesses, palinspastic restorations result in an apparent deficit of rocks ("gaps"); at salients, restorations result in an apparent surplus of rocks. For example, arc length of a curved fault in a salient is significantly reduced in palinspastically restored map view; and in the extreme, the entire length of a curved thrust fault restores to a single point. Alternatively, the arc length of a curved fault in a salient may encompass tangential extension to account for the shorter arc length in palinspastic restoration.

Palinspastic restoration in three dimensions can be kinematically balanced for cross sections drawn parallel to the direction of translation, not necessarily perpendicular to thrust strike. Where the translation direction is perpendicular to strike of compressive structures, shear strain is zero. Where the translation direction is oblique to strike of thrust faults, shear strain results in significant along-strike movement of rocks and, possibly, in an en echelon pattern of folds. Restorations of standard cross sections perpendicular to regional strike result in underestimation of total displacement, because only the compressive component is measured. Determining the amount and direction of strike-slip motion is difficult; however, orientations of folds internal to the allochthon may be a useful guide to proper orientation of cross sections.

Regional en echelon patterns of folds mapped around the large-scale bend in thrust-belt strike in the Ouachita Mountains of southeastern Oklahoma and western Arkansas suggest a component of shear strain during late Paleozoic thrusting. Palinspastic restoration of three evenly spaced cross sections perpendicular to thrust-fault strike illustrate problems of kinematic balancing in map view. A regional volume-balancing approach, using isopach maps of allochthonous rocks, depth to basement, configuration of the basal detachment, and critical-taper theory suggests a restoration that is kinematically balanced.

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A Regional Perspective on the Ouachita Trend and Related Foreland Structures

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The Ouachita trend represents a major Paleozoic orogenic belt which is only exposed in the Ouachita Mountains and the Marathon region of West Texas. Despite its location in what is commonly viewed as "oil country," the structure, evolution, and petroleum potential of this significant geologic feature is poorly known. Because of the scarcity of detailed studies and deep drilling, some insight can be gained from the analysis of regional geophysical data such as gravity, magnetic, and refraction surveys. The UTEP geophysics group has been engaged in studies of the Ouachita trend for many years, and we continue to enlarge our database in the area. The integration of seismic refraction data with gravity and drilling data has led to a surprising picture of the early Paleozoic passive continental margin which developed prior to the Ouachita orogeny. This margin appears to be largely intact beneath thrust sheets that are indicative of thin-skinned tectonics. It is thus a very viable deep exploration target. The Ouachita thrust sheets appear to overlap this margin to varying degrees along the trend. About half of the Arkoma basin is overthrusted whereas an entire basin may be overthrusted near San Antonio. A deep wildcat presently being drilled west of San Antonio appears to be testing this hypothesis. Most of the structural framework of the adjacent foreland areas is due either to the early Paleozoic rifting which formed the Ouachita margin or the late Paleozoic Ouachita orogeny. The sub-Ellenberger units which resulted have yet to be adequately tested in many areas.

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Stratigraphic Sequences and Reservoir Facies of the Wapanucka and Spiro Formations

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An understanding of the stratigraphic boundaries and lithofacies of the Spiro, middle shale (sub-Spiro shale in the subsurface), and the Wapanucka, will lead to a better prediction of the location of petroleum reservoirs in southeastern Oklahoma. Although the Spiro rests unconformably on the Wapanucka in some parts of the Arkoma basin; the base of the Spiro and the top of the Wapanucka are conformable surfaces throughout the frontal Ouachita outcrops. Small, discontinuous deposits of cross-bedded sandy calcarenites and bioclastic sandstones commonly occur within the middle shale sequence. These are commonly referred to as the "sub-Spiro sand" in the subsurface, and can make it difficult to distinguish the base of the Spiro and top of the Wapanucka sequences.

At the Wapanucka shelf margin, subtidal cycles are capped by shoaling carbonate sand bodies (bioclastic and oolitic grainstones). In areas of paleotopographic highs, these shoal deposits can build up above sea level and form island beaches. Subaerial exposure is evidenced by the abundance of trees that grew on these islands.

Sponge boundstones and phylloid algal bioherms grew adjacent to the shelf margin, while tubular algal (*Donezella*) boundstones occasionally formed small banks in slightly deeper water. The Spiro contains identical lithofacies to the Wapanucka; however, in certain areas, significant amounts of sand were transported to form shallow marine bars.

In addition to the sandstones of the Spiro, several limestone facies of the Wapanucka and Spiro are potential hydrocarbon reservoir rocks. Fracture styles, related to certain lithofacies in outcrop, can aid in predicting fractured reservoirs in the subsurface.

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Were the Taconian and Famatinian Orogens Once Connected?: Significance of the Middle Ordovician "Mountain Fork" Clastic Wedge, Ouachita Allochthon, Oklahoma

MICHAEL C. DIX, DOUGLAS R. REID, and *JOHN F. CASEY,* Dept. of Geosciences, University of Houston, Houston, TX 77204

A consensus appears to be emerging among geologists that the Paleozoic Occidentalia terrane, largely exposed in the Argentine Precordillera of western South America, is a continental block that originally rifted away from the Cambrian Ouachita embayment of Laurentia (ancient North America). This inference is based on the remarkable lithologic and faunal similarity of Cambrian to Early Ordovician carbonate sequences of both the Precordillera and the southern Appalachians. There is still uncertainty, however, as to how far this terrane drifted from the Ouachita embayment by the Middle Ordovician, when it collided with Gondwana (ancient South America) during the Famatinian orogeny. Paleontologic data (Astini et al., 1995) strongly suggest that Occidentalia may have drifted over 3000 km by this time, and that the Famatinian orogen is completely unrelated to the Middle Ordovician Taconian orogen along eastern Laurentia. Alternatively, Dalla Salda et al. (1992) and Dalziel et al. (1994) have noted striking similarities in the geology of both the Taconian and Famatinian belts, and to the fact that each is abruptly truncated in their present-day configurations. Similarities include tectonic polarity (oceanic arc and/or active margin to the east; passive margin to the west), structural vergence (predominantly west), timing of peak metamorphism and plutonism (460–480 Ma), and timing and style of foreland basin and clastic wedge development (Middle Ordovician). They have suggested that the two orogens were continuous along strike, actually comprising a single Middle Ordovician collisional belt between eastern Laurentia and western Gondwana. Following the collision, Occidentalia was rifted away from Laurentia in the Late Ordovician as a part of Gondwana. This second model requires that Cambro–Ordovician Occidentalia did not drift a significant distance out of the Ouachita embayment (<1000 km?), and must have bordered the deep, relatively narrow Ouachita basin along its southeastern margin.

In the Broken Bow uplift of the Ouachita allochthon, Oklahoma, the Middle Ordovician "Mountain Fork sandstone" (Womble Shale equivalent) is a deep-marine, southeasterly derived, Taconian clastic wedge. If tectonic reconstructions based on the Taconian–Famatinian connection are accurate, the "Mountain Fork" clastic wedge should show stratigraphic, sedimentologic, and petrologic affinities with the coeval Yerba Loca clastic wedge and related units along the western margin of Occidentalia. Sparse paleocurrent data (Spalletti et al., 1989; Dix et al., 1994) suggest that both sediment packages were derived from the same general direction. Additional data on detrital framework modes, whole rock geochemistry, Nd isotopes, and U-Pb (zircon) geochronology will be needed to establish a possible intercontinental linkage between these two clastic wedges.

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Asymmetric Conjugate Rift Margins of the Ouachita Rift and the Argentine Precordillera

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Stratigraphic and faunal data indicate that the Argentine Precordillera was rifted from the Ouachita embayment of the southern (present coordinates) margin of Laurentia during Cambrian time. The Ouachita rift on the northwest and the Alabama–Oklahoma transform fault on the northeast bound the Ouachita embayment. Plate reconstructions suggest that the Ouachita rift (margin of the Ouachita embayment and Texas promontory of Laurentia) and the western (present coordinates) margin of the Precordillera are a conjugate rift pair. In the context of low-angle detachment models for crustal extension, the Ouachita rift and the western Precordillera represent the upper plate and lower plate, respectively.

The Ouachita rift margin of Laurentia is interpreted to have an upper-plate configuration because of a general lack of synrift rocks and a steep eastward descent of the top of continental basement rocks, as documented by seismic reflection profiles and a few deep wells. An Upper Cambrian–Lower Ordovician passive-margin carbonate succession is relatively thin and rests on Precambrian basement rocks.

If it is part of a conjugate rift pair with the Ouachita rift, the Precordillera must be the lower plate. Cambrian–Ordovician passive-margin carbonate rocks are exposed in thrust sheets in the Precordillera; structure of the originally underlying basement is unknown (basement rocks are known from xenoliths). Red fine-grained clastic rocks and evaporites of late Early Cambrian age (exposed in the northeastern Precordillera) are similar to temporally equivalent, graben-filling successions north of the Alabama–Oklahoma transform fault on southern Laurentia, suggesting an extensional tectonic setting on the Precordillera. West-facing slope deposits in the Los Sombreros Formation mark the western edge of the Precordilleran passive-margin shelf. Carbonate olistoliths within the slope deposits represent the passive-margin-shelf stratigraphy, and a block of subfeldspathic to quartzose conglomerate containing quartz and lithic clasts suggests synrift deposition in lower-plate listric-fault-bounded extensional basins.

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Rifting of the Argentine Precordillera from the Ouachita Embayment of the Laurentian Margin

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Cambrian faunas and stratigraphy indicate that the Argentine Precordillera originally was part of Laurentia, and rifting history suggests that the Precordillera was rifted from the Ouachita embayment of the Laurentian margin. The Ouachita embayment between the Texas and Alabama promontories was outlined by a ridge shift at ~577 Ma from the Blue Ridge rift to the Ouachita rift and the consequent initiation of the Alabama–Oklahoma transform fault. A block of Laurentian continental crust, which was similar in size to the Precordillera, was rifted from the Ouachita embayment. Seismic velocity modeling illustrates the boundary of Laurentian crust at the Alabama–Okla-

homa transform fault. Ages of synrift and post-rift rocks and structures document the rifting history of the Ouachita embayment. Ages of a transgressive post-rift succession and underlying synrift rocks and basement along the Blue Ridge rift indicate establishment of a passive margin in earliest Cambrian time. Early to Early Late (Dresbachian) Cambrian synrift fine clastic sediments and minor evaporates filled intracratonic grabens on Laurentian crust, indicating extension parallel to the Alabama–Oklahoma transform fault. Synrift igneous rocks along the Southern Oklahoma transform system range in age from ~577 to ~525 Ma. As the Ouachita Ocean opened, the end of the Ouachita ridge migrated past Laurentian crust along the Alabama–Oklahoma transform fault; a passive margin was established entirely around the Ouachita embayment when the ridge end migrated past the corner of Laurentian crust on the Alabama promontory. Ages of carbonate-shelf facies indicate initiation of passive-margin deposition along part of the Ouachita margin during Middle Cambrian time; an extensive carbonate-shelf succession, extending entirely around the Ouachita embayment, covered the synrift rocks and structures by Middle Late (Franconian) Cambrian time. The oldest beds in an off-shelf passive-margin succession in the Ouachita embayment are of Late Cambrian age (equivalent to the base of the extensive passive-margin carbonate-shelf succession). Faunal successions and migration patterns indicate that open ocean separated the Precordillera from Laurentia by the end of Cambrian time. Stratigraphic data indicate collision of the Precordillera with Gondwana in Middle Ordovician time.

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Jackfork Sandstones, Shallow Water Sequence Stratigraphy and Sedimentology, U.S. 259, Le Flore County, Oklahoma

RODERICK W. TILLMAN, Consulting Sedimentologist/Stratigrapher, Tulsa, Oklahoma

The Morrowan Jackfork Group, where it crops out in the Ouachitas, has long been regarded as a deep-water, primarily turbidite, deposit. Recent work in southeastern Oklahoma indicates that at least two or more periods of significant shallowing occurred during the deposition of the Jackfork. Upper Jackfork outcrops along U.S. Highway 259, originally described by Lewis Cline and Frank Moretti in 1956, are herein interpreted as shelf, slope, and deltaic deposits.

These interpretations suggest that new and varied exploration plays exist in the Jackfork. The relatively shallow water deposits occur in the uppermost part of the Jackfork Group.

Several significant sequence-stratigraphic surfaces occur in the Jackfork Group. Relatively abrupt shallowing is evident at what are interpreted to be sequence boundaries at the base of the Prairie Mountain Formation and at the base of the shelf and deltaic deposits that form the lower part of the Markham Mill Formation. Significant flooding surfaces are observed between the slope and overlying shelf deposits in the upper Prairie Mountain Formation and either in the upper part of the Markham Mill Formation or at the base of the Wesley Formation. A third flooding surface may occur at or near the base of the Game Refuge Formation.

Slope, shelf, and deltaic deposits in the Jackfork Group are characterized by features distinctly different from those of the turbidites in the Wildhorse Mountain Formation, which forms the lower two-thirds of Jackfork along U.S. 259.

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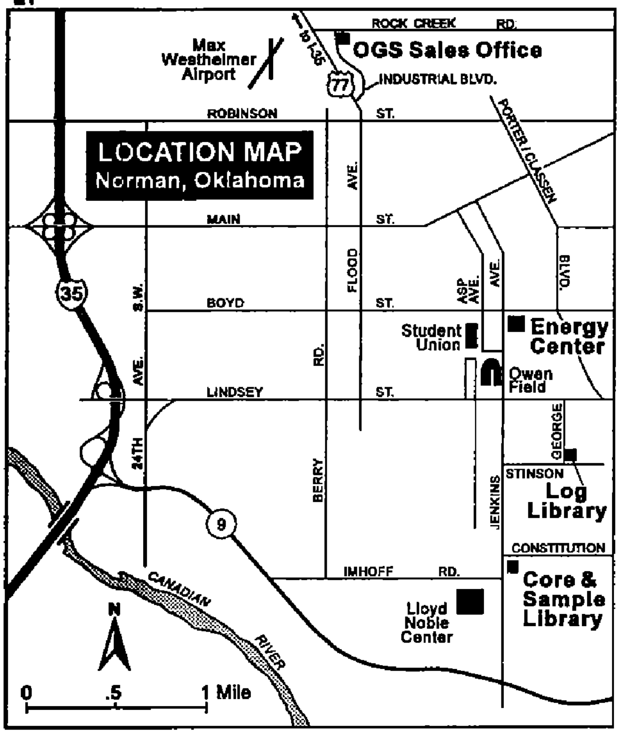

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