OKLAHOMA GEOLOGY

Oklahoma Geological Survey Vol. 53, No. 2 April 1993

On the cover—

A Unique Sandstone Monolith in Eastern Oklahoma

A unique exposure of resistant sandstone of the Atoka Formation (Pennsylvanian), located in the NE¼SW¼NE¼SW¼ sec. 7, T. 5 N., R. 24 E., Le Flore County, Oklahoma, is shown in the cover photo. The outcrop is ~200 ft long, 12 ft wide, and 15 ft high. The sandstone is grayish-orange to moderate reddish-brown in color, very fine-grained, silica-cemented, massive, and thick-bedded.

The bed strikes N 78° E and dips SE at 35–40°. The west end is truncated by the channel of the Fourche Maline, whereas the east end disappears under terrace deposits.

The wall-like piece of bedrock can rightfully be called a monolith, which, by definition, is a large upstanding mass of rock produced by differential erosion, usually more than a few meters across, and generally composed of one kind of rock. The cemented sand grains that compose the rock were deposited in a shallow marine environment ~300 million years ago. The monolith is unique because it presently stands alone, surrounded by thousands of acres of nearly featureless flood plains and low terraces of the Fourche Maline and Poteau Rivers, now the mudflats and backwaters of man-made Wister Lake. It has withstood the ravages of nature through the millenia, resisting the erosive power of the Fourche Maline, and in fact, deflecting the course of the river.

Trunks of bleached, lifeless trees, drowned when Wister Dam was constructed, stand vigil around the monolith. They rear up out of the mud and shallow stagnant pools of water, giving the landscape a starkly haunted appearance, much as if the area had been devastated by a nuclear disaster (Fig. 1).

Adding to the catastrophic appearance of the scene is the debris and driftwood

(continued on page 65)

OKLAHOMA GEOLOGY NOTES

Editor
Christie Cooper

Publications Assistant
Jo Lynn Pierce

Cartography
T. Wayne Furr, *Manager*
James H. Anderson
Charlotte Lloyd

Oklahoma Geology Notes, ISSN 0030-1736, is published bimonthly by the Oklahoma Geological Survey. It contains short technical articles, mineral-industry and petroleum news and statistics, abstracts, notices of new publications, and announcements of general pertinence to Oklahoma geology. Single copies, $1.50; yearly subscription, $6. Send subscription orders to the Survey at 100 E. Boyd, Room N-131, Norman, OK 73019. Short articles on aspects of Oklahoma geology are welcome from contributors; general guidelines will be sent on request.

This publication, printed by the Oklahoma Geological Survey, Norman, Oklahoma, is issued by the Oklahoma Geological Survey as authorized by Title 70, Oklahoma Statutes 1981, Section 3310, and Title 74, Oklahoma Statutes 1981, Sections 231–238. 1,500 copies have been prepared for distribution at a cost of $1,115 to the taxpayers of the State of Oklahoma. Copies have been deposited with the Publications Clearinghouse of the Oklahoma Department of Libraries.

OKLAHOMA GEOLOGY

C O N T E N T S

OKLAHOMA GEOLOGICAL SURVEY

VOL. 53, NO. 2

APRIL 1993

THE OKLAHOMA BOARD ON GEOGRAPHIC NAMES: A HISTORICAL SKETCH

T. Wayne Furr[1]

Abstract

In 1983, when Elizabeth A. Ham wrote *A History of the Oklahoma Geological Survey, 1908–1983* (OGS Special Publication 83-2), a little known but important objective and duty of the Survey was omitted inadvertently. The 30th Legislative Session, State of Oklahoma, 1965, bestowed upon the Oklahoma Geological Survey the responsibility to "act as the Oklahoma Board on Geographic Names" [HB 810, sec. 310 (b), (4)].

This paper explores the history of the Survey's involvement with "official names," from Territorial Geologist A. H. Van Vleet to the present Board on Geographic Names. It has been revised since it was originally presented at the Western States Geographic Conference, Astoria, Oregon, May 7, 1992, as part of the workshop entitled "The Structure and Status of State Boards within States."

Introduction

In our daily activities, we use geographic place names to form mental maps of our local area, state, nation, and even the world. These names provide us with a geographic reference system that is becoming increasingly important in today's complex technical society. Geographic names provide a key to the history and settlement patterns of cultural groups. They help us form the mental signposts we need in search and rescue operations. Delivery and transportation industries are heavily dependent on geographic names for accurately locating places.

When referring to a geographic feature, we most often use the name in common or local use. But, herein lies a problem. Many times the name we use may not be recognized by everyone. Why? Often, the common name is spelled or pronounced differently from the official name. The generic part of a name may be changed through daily use. For example, a reservoir is often called a lake, and a stream may be called a creek when, officially, the generic part of the name is "River." Often, the specific part of a name contains two words, which become compounded in daily use. Stone Bluff, for example, became Stonebluff. When such changes happen, confusion is created on all levels of communication—from casual conversation to legal documents.

A Geographic Quiz

Test your knowledge with the following examples of a few Oklahoma names. These names were selected because different forms of each can be found in daily use and in print. (If you find this exercise fun and interesting and would like to see more examples, please let us know.)

---

[1]Oklahoma Geological Survey.

Which do you consider to be the correct or official name?

1) Windingstair or Winding Stair Mountain?
2) Canadian or South Canadian River?
3) Grand Lake, or Lake O' the Cherokees, or Grand Lake O' The Cherokees, or Lake of the Cherokees?
4) Leflore or Le Flore (the town)?
5) Oklahoma, or Oklahoma State, or State of Oklahoma?

(Answers appear at the end of this article.)

These examples should stir a few more names from your memory. Many more have created confusion for both layman and professional. But, where can we turn when confusion and conflicts about our geographic names occur?

Information on geographic names, or clarification about a name, may be obtained from the United States Board on Geographic Names. Oklahoma has a board of geographic names (as do many other states) to assist with name problems within the State.

The United States Board on Geographic Names*

The United States Board on Geographic Names is a federal body created in 1890. It was established in its present form in 1947 by Public Law 80-242. Comprised of representatives of several federal agencies and appointed for a two-year term the Board is authorized to establish and maintain uniform geographic name usage throughout the federal government. Sharing its responsibilities with the Secretary of the Interior, the Board has developed principles, policies, and procedures governing the use of both domestic and foreign geographic names as well as undersea and extraterrestrial feature names. Although established to serve the federal government as a central authority to which all name problems, name inquiries, and new name proposals can be directed, the Board also plays a similar role for the general public.

With respect to domestic names, it is the policy of the Board to recognize present-day local usage or preferences when possible. To implement this policy, the Board cooperates closely with state geographic boards, state and local governments, and with the general public. When there is confusing duplication of local names or when a local name is derogatory to a particular person, race, or religion, the Board may disapprove such names and seek alternate local names for the features. In cases where local usage is conflicting or weak, well-established documented names and names with historical significance are given strong consideration. The Board also has a policy of not approving new domestic geographic names that commemorate, or may be construed to commemorate, living persons.

Any person or organization, public or private, may make inquiries or request that the U.S. Board on Geographic Names render formal decisions on proposed new names, proposed name changes, or names that are in conflict. Communications concerning domestic geographic names should be addresed to Roger L. Payne, Executive Secretary, Domestic Geographic Names, U.S. Board on Geographic Names, National Center, Stop 523, Reston, Virginia 22092.

---

*Information from *Decisions on Geographic Names in the United States:* United States Board on Geographic Names, United States Department of the Interior, 1990.

The Oklahoma Board on Geographic Names

The Oklahoma Geological Survey has the responsibility to act as the Oklahoma Board on Geographic Names. This long-standing responsibility can be traced back to the topographic mapping program of the U.S. Geological Survey prior to statehood. In 1902, Dr. A. H. Van Vleet, the Oklahoma Territorial geologist, wrote about the benefits of topographical maps for people in all walks of life (Second Biennial Report). In this report, he presented a case for the "immediate need for a Topographical Survey of . . . the Oklahoma Territory," a case that clearly highlighted "official names." His arguments have been echoed by each of the State geologists to follow, starting with Dr. Charles N. Gould in 1908. The State geologists that followed Gould—Daniel W. Ohern and Charles W. Shannon—continued the work for an "accurate topographic" mapping program for the State. Each man was successful in his term as State geologist in securing appropriations from the State legislature for the program (Ham, 1983).

It was not until 1926 that the first State Geographic Name Board was appointed. On October 19, 1926, Governor Martin E. Trapp duly commissioned the first Geographic Board. His actions were the result of encouragement from Frank Bond, the chairman of the United States Geographic Board. Three well-qualified professionals, who were already in the service of the State were appointed to the Board. Adjutant General of the State, General Charles F. Barrett, was named chairman; Joseph B. Thoburn, curator of the Oklahoma Historical Society, was named secretary; and Dr. Charles N. Gould, then serving his second term as director of the Oklahoma Geological Survey and State geologist, became the third member. There were no statutory provisions for the creation of this early Board; therefore, its function was purely advisory. No appropriations were available for necessities such as postage or stationery. Since each member was already in the service of the State, no extra expenses were expected to be incurred in the operation of the Board.

The primary function of the Board was "to cooperate with the National Board of Geographic Names, in the determination of the proper spelling and pronunciation of geographic names and in the adjustments of disputes concerning such names in cases where two or more names for the same object are in more or less common use." The Board did not propose to initiate any reforms in regard to such matters. They were to appeal to the citizens of the State interested in geographic names, encouraging them to respond with recommendations that would lead to adjustments of the "disputes, misunderstandings, misspellings or mispronunciations" (Barrett and others, 1927).

Each of these men published extensively in his own profession; however, only two publications written by Board members concerning geographic names could be found: *Oklahoma Place Names* by Gould (1933) and "The Naming of the Canadian River" by Thoburn (1928). No information regarding their activities as a Board could be uncovered. This early Board of Geographic Names had been unknown, even by members of the Oklahoma Board on Geographic Names.

Officially, the Oklahoma Board on Geographic Names was created by the State of Oklahoma Legislature in 1965; HB 810, sec. 310 (b), (4). House Bill 810 established a Higher Education Code dealing with the governments of universities and colleges. Section 310 of the code places the Oklahoma Geological Survey "under the direction and supervision of the Board of Regents of the University of Oklahoma." Sub-paragraphs (b) and (4) list one of the Survey's objectives and duties as, to "act as the Oklahoma Board on Geographic Names and make recommendations to the United States Board on Geographic Names." Actually, the Survey was placed under the Board of Regents years earlier; the significance of HB 810 is the addition of the Board on Geographic Names to the objectives, duties, and responsibilities of the agency.

Dr. Carl C. Branson, OGS director from 1954 to 1967, actively pursued the topographic mapping program of the U.S. Geological Survey. Through it and his concern for geologic names taken from geographic place features, an involvement with geographic names and name problems developed. From the time he assumed the directorship of the Survey, several inquires about naming and requests for name clarification were made to the U.S. Board on Geographic Names. The U.S. Board, which prefers to recognize present-day local usage, encourages the formation of a board within a state; such was the case for Oklahoma.

In January 1965, Dr. Branson wrote to Dr. George L. Cross, president of the University of Oklahoma, requesting permission to establish the "Oklahoma Board of Geographic Names." He wrote, "the U.S. Board on Geographic Names has requested assistance from states and it is clear that persons familiar with local customs should be consulted." He continued by outlining individuals and departments from which the representatives for the "State Board" should be invited. Branson saw no need for additional budget or a staff, indicating that the Survey could handle "the rather slight amount of paper work and correspondence." But of most importance, he stated that it would be "desirable that the State Board receive recognition as an official agency of the State." Dr. Cross's response must have been verbal, as no official correspondence could be found at the Survey or in the University archives. Nevertheless, the word got through, culminating in the passage of House Bill 810, which made the Oklahoma Geological Survey the State's authority on geographic names.

In August 1965, Dr. Branson wrote to Mr. J. O. Kilmartin, executive secretary of the Domestic Geographic Names Committee, U.S. Board on Geographic Names, announcing "the Oklahoma Geological Survey as the Oklahoma Board on Geographic Names." In response, Mr. Kilmartin congratulated and welcomed the Survey and announced that Mr. Donald Orth of the U.S. Board would be visiting in late September "to discuss name problems in general, and specifically methods of State/Federal cooperation." Mr. Orth became executive secretary of the U.S. Board in 1974. Dr. Branson also wrote to Dr. Cross with an outline of the "proposed form and function" for the State Board. In the letter, he requested "authorization from the OU Board of Regents." He then appointed four individuals, well versed in the history and geography of Oklahoma, to the Board: (1) Dr. Arrell M. Gibson, noted professor of history and curator of the Phillips Collection, University of Oklahoma's Western History Collection; (2) Dr. John W. Morris, historical geographer and chairman of the OU geography department; (3) Dr. John J. Hidore from the department of geography at Oklahoma State University; and (4) Miss Muriel H. Wright of the Oklahoma Historical Society, granddaughter of Allen Wright, the "Chief of the Choctaws, who in 1866, suggested the name Oklahoma" (Gould, 1933). Dr. Branson assumed the chairmanship of the Board, and his secretary, Jane Howe, was appointed as recording secretary.

The Board intended to proceed with caution. Their plan was to submit "only controversial names" and to prevent errors in names on maps that were produced under the U.S. Geological Survey's topographical mapping program. The Board also wanted to prevent name errors in Oklahoma Geological Survey reports. But, most importantly, the Board recognized the need to make intelligent decisions that would be accepted by the citizens of Oklahoma.

The first year of operation appears to have been very busy for the Board. Mapping activities in the Stillwater area and several disputed names kept the Board members active in research. Ms. Howe proved to be a valuable asset in this area. She found several name problems and brought them to the attention of the Board. As the months passed, the case load diminished. Correspondence waned; Board members became less active in Board affairs and returned to their own areas of interest.

In 1967, Dr. Branson gave up directorship of the Survey, turning over the reins to Dr. Charles J. Mankin. He remained on staff, however, as a research geologist and chairman of the Board on Geographic Names. In May 1967, Dr. Branson started the search to replace Dr. Hidore, who had resigned and left the State. Branson wanted to replace Hidore with someone from the Stillwater area, and, as he had in 1965, he solicited the help of Dr. V. Brown Monnett at Oklahoma State University. Dr. Monnett recommended Dr. Ralph E. Birchard, who was appointed to the Board in September 1967.

In August 1967, Dr. Branson received a letter from University of Oklahoma President Cross regarding the Oklahoma Board on Geographic Names. President Cross had conferred with David Swank, University of Oklahoma Law School professor. The president's letter clearly confirmed that, by law, the Oklahoma Geological Survey was indeed the State's Board on Geographic Names. This opinion changed the tenor of the Board somewhat from Dr. Branson's original conception. Dr. Cross wrote that he saw "no reason why the Survey should not have an advisory body . . ., but as the law is written, it appears that the Survey itself must accept the responsibility for such decisions and reports as are made on Geographic Names." The Board continued to operate as Dr. Branson had organized it until he suffered a disabling stroke in 1969, forcing his retirement in 1972.

Dr. Mankin named Mr. William D. Rose, publications editor of the Survey, to replace Dr. Branson as chairman of the Board. According to Mr. Rose, he fell into the chairmanship of the Board by default. From about 1970, the Board had "become more or less inactive," and he had "handled the job of checking geographic names in Oklahoma on a rather spasmodic basis." His active workload as editor for the Survey did not allow him the time to be as active on geographic name matters as Dr. Branson had been; therefore, he would respond "to Oklahoma proposals from the U.S. Board" (W. D. Rose, personal communication, January 29, 1992).

In July 1978, Professor Jim Rogers from the department of geography, Central State University in Edmond, joined Mr. Rose. Mr. Rogers continued to assist with name questions until the Board was reorganized in 1985. His continued interest in Oklahoma names makes him a valuable advisor. During this period of Board activities, Mr. Rose and Professor Rogers worked independently in attempting to resolve name problems and in the evaluation of new name proposals for the State (J. Rogers, personal communication, April 28, 1992).

August 1985 was a time of change for the Board. Mr. Rose left the Survey for a new position. Mr. James R. Chaplin, an OGS research geologist who had served on the Kentucky Board of Geographic Names, was the logical choice to become Board chairman and was so named by Dr. Mankin. The Board was resurrected from its "more or less inactive" condition and reorganized. A number of considerations influenced the reorganization: (1) recognition that a geographically widespread group is difficult to convene on short notice and that correspondence tends to be slow, and (2) the legal opinion from Dr. Cross and Professor Swank. Therefore, the new Board members were selected from the Survey staff. Dr. Mankin assumed the ex officio position and takes an active part in each name issue. Dr. Kenneth S. Johnson, associate director, Dr. Kenneth V. Luza, engineering geologist, and Mr. T. Wayne Furr, manager of cartography, were appointed as members to the Board.

Some of the philosophy from the first Board, and that of Dr. Branson, continues in the current structure. The Board continues to proceed with caution, not looking for "dragons to slay." Each inquiry, whether from the U.S. Board or from a citizen simply asking a question about a name, is handled promptly by the Board. We continue the belief that each decision must be carefully researched and thoughtfully evaluated. The Oklahoma Board relies on the principles, policies, and procedures of the U.S. Board to govern its operation. By adopting these guidelines, the Oklahoma Board is able to provide recommendations to the U.S. Board that help them make the best decisions regarding geographic names in Oklahoma.

In *Oklahoma Place Names* (1933), Charles N. Gould wrote, "Unfortunately, the origin of many Oklahoma names has already passed out of the memory of men." He continued by stating that in "regard to linguistic origins, there are four general kinds of place names in Oklahoma; namely, Indian, English, Spanish, and French." When we consider that Oklahoma has more Native American tribes represented than any other state, we realize that the linguistic origins for Oklahoma place names number many times greater than four. This in itself makes research and decisions about geographic names even more challenging. In its endeavor to make intelligent decisions, the Board researches historical records and maps. State agencies, county commissioners, city planning departments, and concerned citizens are consulted for their views and opinions before the Board renders findings. The Oklahoma Board on Geographic Names' opinion is then forwarded to the U.S. Board for their decision.

If you have a question about a name in Oklahoma, contact one of the Oklahoma Board members: Mr. James R. Chaplin, Mr. T. Wayne Furr, Dr. Kenneth S. Johnson, Dr. Kenneth V. Luza, or Dr. Charles J. Mankin at:

Oklahoma Geological Survey
100 East Boyd St. Room N-131
Norman, Oklahoma 73019-0628
Phone: (405) 325-3031

Information may also be obtained from the U.S. Board on Geographic Names at the address listed on page 45.

Answers to the Geographic Names Quiz

1) Winding Stair Mountain is the correct name for the mountain. However, the geologic community uses the form Windingstair to describe a fault in the Ouachita Mountains (Geographic Names Information System, Alphabetical Listing of Oklahoma, U.S. Board on Geographic Names, 1990).

2) Canadian River is the official name recognized by both the U.S. and Oklahoma Boards on Geographic Names. The river has also been called the Rio

Colorado, Red River, Little Red River, Upper Canadian River, and, commonly, South Canadian River (*Decisions on Geographic Names in the United States,* Decision List, Number 6501, p. 52. United States Board on Geographic Names, January through March 1965). Gould (1933) wrote that "the Osage name for this stream was *Ne-sout-che-bra-ra.*"

3) Although Grand Lake is the most commonly used name, the official name is Lake O' the Cherokees (*Decisions on Geographic Names in the United States,* Decision List 6504, p. 17. United States Board on Geographic Names, October through December 1965).

4) Leflore is the official name for the town, located in Le Flore County (*Decisions on Geographic Names in the United States.* Decision List 6604, p. 19. United States Board on Geographic Names, October through December 1966). The post office, established August 26, 1887, was named for the Le Flore family of Choctaw/French descent (Gould, 1933, p. 75–76; Shirk, 1965, p. 123). The town name was officially changed in 1966 to Leflore; however, the county retains the original form, Le Flore, as named at statehood.

5) Believe it or not, State of Oklahoma is the official name (*Decisions on Geographic Names in the United States,* Decision List 5401, p. 48. United States Board on Geographic Names, July 1950 to May 1954).

References

Barrett, C. F.; Thoburn, J. B.; and Gould, C. N., 1927, Oklahoma Geographic Name Board; circular letter no. 1: Chronicles of Oklahoma, v. 5, p. 95–96.

Gould, C. N., 1933, Oklahoma place names: University of Oklahoma Press, Norman, 146 p.

Ham, Elizabeth A., 1983, A history of the Oklahoma Geological Survey, 1908–1983: Oklahoma Geological Survey Special Publication 83-2, 60 p.

Oklahoma Board on Geographic Names records files: Oklahoma Geological Survey.

Rose, W. D., 1974, "Donald Orth named leader of Geographic Names Committee: Oklahoma Geology Notes, v. 34, p. 28.

Shirk, G. H., 1965, Oklahoma place names: University of Oklahoma Press, Norman, 233 p.

Thoburn, J. B., 1928, "The naming of the Canadian River: Chronicles of Oklahoma, v. 6, p. 181–185.

State of Oklahoma, 1965, Oklahoma Session Laws 1965: 30th Legislature, Regular Session; convened January 5, 1965, adjourned July 22, 1965.

Van Vleet, A. H., 1902, Introductory, *in* Second Biennial Report (1901–1902): Territory of Oklahoma Department of Geology and Natural History, p. 1–6.

OKLAHOMA EARTHQUAKES, 1992

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. The earliest documented earthquake in Oklahoma occurred near Jefferson, Grant County, on December 2, 1897 (Stover and others, 1981). The next oldest known Oklahoma earthquake happened near Cushing 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 occurred near El Reno on April 9, 1952. This magnitude-5.5 (mb) 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 1992, more than 943 earthquakes have been located in Oklahoma.

Instrumentation

A statewide network of 12 seismograph stations was used to locate 45 earthquakes in Oklahoma for 1992 (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 five 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 two Geotech RDAS (Remote Data Acquisition System) units 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 40, 60, or 10 24-bit

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

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

samples per second. The samples are time-tagged by RDAS clocks locked to very low-frequency Omega Navigation/Time signal receivers. 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 1+ Unix workstation with 40 megabytes of memory, two 660-megabyte disks, and two 2.3-gigabyte Exabyte™ tape drives. All of the data from the most recent two to three days 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 dearchive directories on a 900-megabyte disk attached to a Sun 3/50 computer belonging to Lawrence Livermore National Laboratories. The dearchive directories are remote mounted, by way of the ethernet, by the Sun Sparc 1+ workstation. An Oracle™ data base on the Sun Sparc 1+ keeps track of every second of data on the permanent archive tapes, the last two or three days' data on disk, and data in the dearchive directories.

Data analysis is done by Teledyne-Geotech and Science Applications International Corp. software on the Sparc 1+ workstation.

The digital system signals are from six sensors in the Observatory vault (international station abbreviation TUL); from three sensors in a borehole on the Observatory property (station LNO); 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 Jackson Ranch near Slick (SIO) in Creek County.

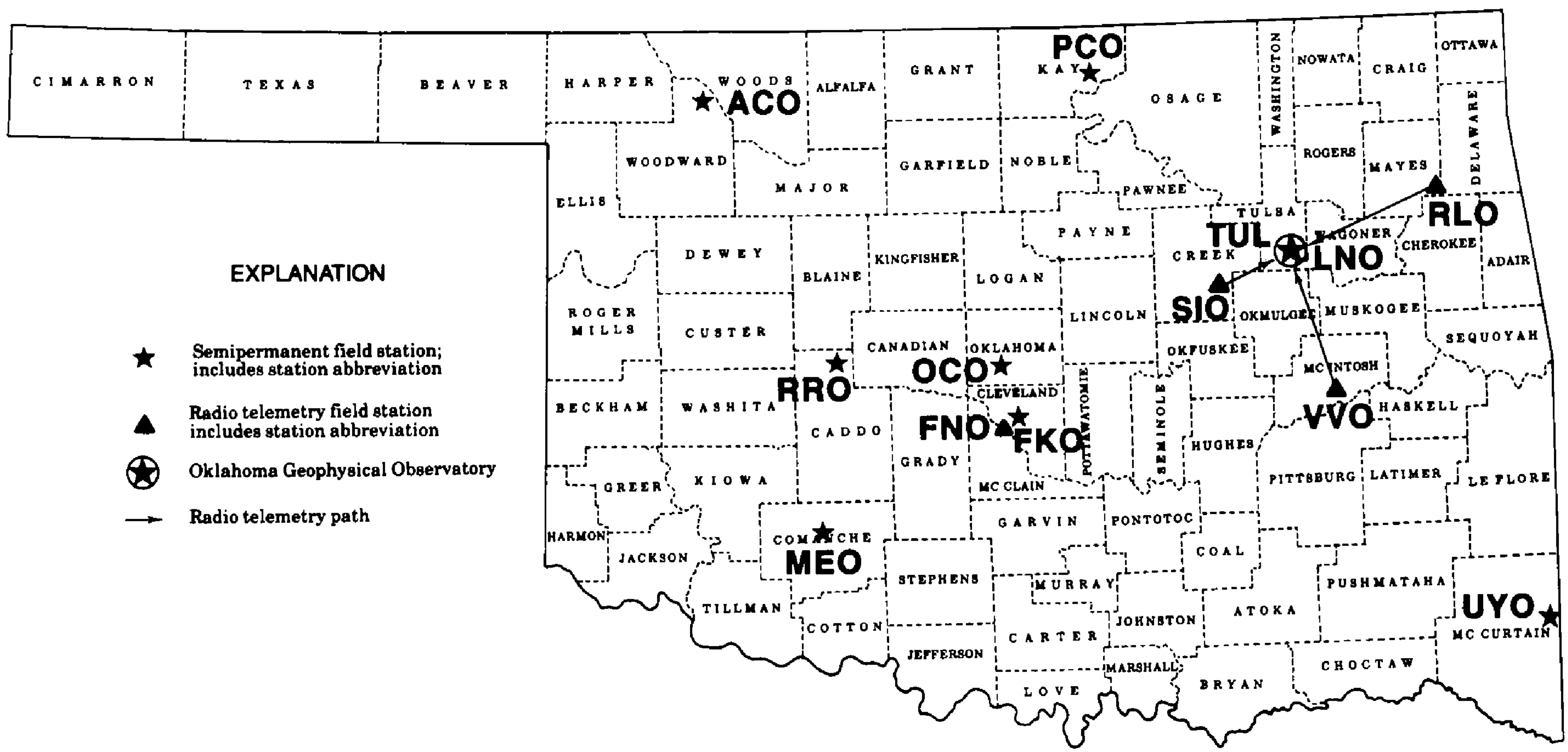

Figure 1. Active seismographs in Oklahoma.

TUL has three (vertical, north–south, east–west) Geotech GS-13 seismometers which produce 40-sample-per-second short-period channels. Three Geotech BB-13 seismometers produce 10-sample-per-second broadband channels; three one-sample-per-second long-period channels are derived by the workstation from the broadband channels. The broadband channels are seldom used in the study of Oklahoma earthquakes; the long-period channels are never used. The short-period signals are particularly useful in calculating the direction of arrival of waves by digital calculation of polarization.

The LNO station has a Geotech 20171A seismometer in a 4.5-m-deep borehole and two Geotech 23900 (a deep-hole version of the 20171A) seismometers at 432- and 748-m depth in a borehole that is 1 m away from the 4.5-m-deep hole. The LNO equipment is provided and partially supported by Lawrence Livermore National Laboratories. The three LNO channels are digitized by a second RDAS near the borehole and recorded and archived at 60 samples per second. This allows recording of higher frequency waves than is possible with the 40-sample-per-second data. The higher frequencies are particularly prominent in nearby (Oklahoma and adjacent areas) earthquakes. At frequencies above 10 Hz, the high-frequency background noise produced by wind and cultural activity is almost absent at the 748-m-deep sensor. It is particularly important for recording signals from smaller Oklahoma earthquakes, which are very difficult to see on seismograms from near-surface seismometers.

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. The operation of RLO, VVO, and SIO are partially supported by the Nuclear Regulatory Commission.

A fourth radio-telemetry station, FNO, was installed in central Oklahoma on April 28, 1992. The seismometer, Teledyne Geotech S-500, is located at the bottom of a 30-m-deep borehole, ~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. There are no LNO paper records. 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 at the OGS Observatory, there are seven volunteer-operated seismographs. Each consists at a Sprengnether 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). 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, upon request.

Data Reduction and Archiving

Seismic traces from the TUL vault vertical seismometer (TUL sz), the deepest borehole short-period vertical seismometer of station LNO (LNO/sz1) and one radiotelemetry site (usually VVO) are displayed on a 19-in. monitor on the Sun Sparc 1+. The traces are band passed through 0.4–4.0-Hz digital filters and are displayed in 90-min segments. A fourth, long-period vertical trace is displayed, but it records only waves from distant earthquakes. The 90-min traces are fuzzy lines with spikes showing signals above the noise. Distant earthquakes of magnitude ≥5.0 are usually identifiable by the shape of the spike and the following long-period surface waves. Other spikes represent local or regional earthquakes or surface-mine blasts. There are from 10 to 30 recordable surface-mine blasts each weekday, two to five on Saturday, and one or two on Sunday.

The monitor display is zoomed on a 60-sec segment surrounding each spike, and the event is identified by its appearance. If it is a P-wave from a distant earthquake, the display is zoomed to 15 sec and the arrival time, frequency, amplitude, and polarization (direction) are measured, calculated, and recorded for transmission to international data centers.

If a spike is identified as a possible near or regional earthquake, nine traces are displayed on the monitor (TUL sz, sn, se; LNO sz1, sz2, sz3; RLO sz; VVO sz; SIO sz). They are then filtered and unfiltered repeatedly to enhance and identify the phases. One set of filters, developed at NORESS (Norwegian Experimental Seismic System) is described by Mykkeltveit and others (1990). Using the time interval between phases, the distance can be determined; the direction is determined from polarization (using the TUL vault vertical, north–south, and east–west signals). The distance and direction give an approximate location, which is then improved by incorporating arrival times from remote sites RLO, VVO, and SIO. At this point, a short press release is issued from the OGS offices at Norman. Paper seismograms are also searched for regional and local earthquakes. At times, a small earthquake may initially be spotted on only the digital system or only on paper seismograms.

The next stage is dearchiving digital data from the nine short-period signals (listed in the preceding paragraph). These are put in a permanent named disk file and indexed in the on-line Oracle™ data base.

Each quarter, paper seismograms from all volunteer stations and from Observatory seismograms are carefully searched for local earthquakes. Arrival times are measured and added to those already determined from the digital system. As many as two or three additional earthquakes may be found. These are dearchived from Exabyte™ tapes for digital system analysis.

Arrival times, signal durations, and various signal amplitudes are entered into a location program running on a Hewlett-Packard 9825T computer. After each location is finalized, it is entered into an Oklahoma earthquake catalog maintained by Hewlett-Packard 9825T and linked 9835A computers. This catalog is used to produce lists (by date, by county, by latitude–longitude rectangle, and several other choices), and to produce maps with a six-color Hewlett-Packard 7975A plotter.

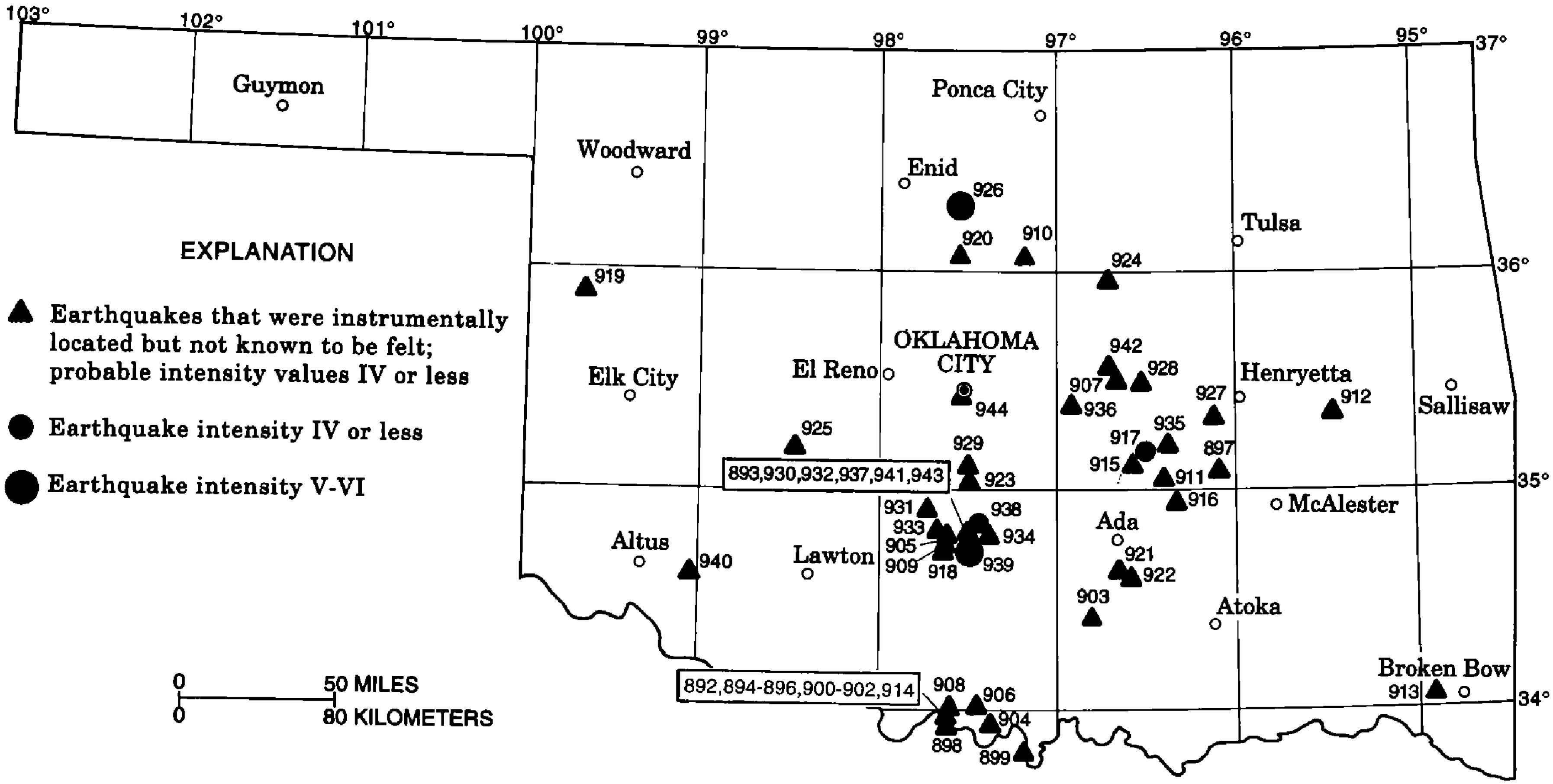

Figure 2. Distribution of Oklahoma earthquakes for 1992. Numbers correspond to event numbers in Table 2.

TABLE 2. — OKLAHOMA EARTHQUAKE CATALOG FOR 1992

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]
892	JAN 8	131053.46	Jefferson	—	1.9	1.7	2.2	33.994	97.585	5.0R
893	JAN 13	171522.56	Garvin	—	2.2	1.8	2.0	34.824	97.589	5.0R
894	JAN 22	024122.34	Jefferson	—	—	2.2	2.3	34.026	97.585	5.0R
895	JAN 25	123453.76	Jefferson	—	1.7	—	2.1	33.987	97.591	5.0R
896	JAN 27	154829.85	Jefferson	—	2.0	—	2.2	34.014	97.585	5.0R
897	JAN 29	094622.66	Hughes	—	0.9	1.2	1.8	35.127	96.071	5.0R
898	FEB 16	023018.52	Jefferson	—	1.7	1.7	2.1	33.967	97.589	5.0R
899	FEB 17	145432.88	Love	—	2.3	2.2	2.1	33.811	97.173	5.0R
900	FEB 26	225115.86	Jefferson	—	2.3	2.4	2.2	34.039	97.577	5.0R
901	MAR 1	055014.59	Jefferson	—	1.7	1.8	2.0	34.002	97.569	5.0R
902	MAR 2	050827.47	Jefferson	—	1.5	—	1.9	34.033	97.569	5.0R
903	MAR 10	224807.74	Johnston		2.0	2.0	1.8	34.415	96.843	5.0R
904	MAR 20	111525.78	Love	—	1.7	1.8	2.0	33.955	97.413	5.0R
905	MAR 20	123935.02	Garvin	—	2.3	2.0	2.2	34.808	97.663	5.0R
906	MAR 23	103305.51	Love	—	1.7	1.7	1.9	34.018	97.522	5.0R
907	MAR 24	023856.13	Lincoln	—	—	—	1.6	35.500	96.624	5.0R
908	MAR 24	130123.99	Jefferson	—	—	—	2.2	34.049	97.569	5.0R
909	APR 27	174147.84	Garvin	—	—	1.9	2.3	34.800	97.656	5.0R
910	APR 28	092245.95	Payne	—	—	1.5	1.9	36.076	97.170	5.0R
911	MAY 20	032512.05	Hughes	—	1.7	—	1.8	35.016	96.394	5.0R
912	MAY 26	010044.31	McIntosh	—	—	—	1.6	35.321	95.456	5.0R
913	MAY 30	072828.19	McCurtain	—	—	2.4	2.1	34.038	94.892	5.0R
914	MAY 30	091536.10	Jefferson	—	—	2.7	2.4	33.994	97.581	5.0R
915	JUN 7	034631.51	Seminole	—	1.5	1.0	1.6	35.136	96.542	5.0R
916	JUN 19	175237.85	Hughes	—	2.0	1.9	1.9	34.946	96.339	5.0R
917	JUN 30	012548.25	Seminole	2	2.9	2.3	2.5	35.277	96.495	5.0R
918	JUL 7	061115.75	Garvin	—	2.1	—	1.7	34.757	97.651	5.0R
919	JUL 10	123200.98	Ellis	—	—	2.1	2.5	35.869	99.702	5.0R
920	JUL 17	162326.58	Logan	—	—	—	1.8	36.099	96.723	5.0R
921	AUG 9	210546.71	Pontotoc	—	—	—	1.9	34.618	96.623	5.0R
922	AUG 10	112122.63	Pontotoc	—	2.4	1.9	1.9	34.601	96.588	5.0R
923	AUG 10	200303.86	McClain	—	2.8	2.8	2.6	35.038	97.510	5.0R
924	OCT 3	235848.28	Payne	—	—	—	2.2	35.974	96.723	5.0R
925	OCT 4	212513.61	Caddo	—	2.5	2.0	2.4	35.199	98.440	5.0R
926	OCT 5	044408.56	Garfield	5	2.9	2.6	2.8	36.357	97.506	5.0R
927	OCT 5	053147.68	Okfuskee	—	—	—	1.9	35.321	96.112	5.0R
928	OCT 27	064632.65	Okfuskee	—	—	—	1.4	35.502	96.512	5.0R
929	NOV 18	214048.08	McClain	—	2.0	2.0	2.1	35.117	97.518	5.0R
930	NOV 19	182230.62	Garvin	—	2.0	1.6	1.8	34.808	97.573	5.0R
931	NOV 21	022143.59	Grady	—	2.2	2.2	2.3	34.921	97.717	5.0R
932	NOV 21	185826.86	Garvin	—	1.9	2.0	2.0	34.802	97.633	5.0R
933	NOV 23	115609.06	Garvin	—	2.4	2.3	2.3	34.837	97.676	5.0R
934	DEC 2	081456.74	Garvin	—	1.7	1.8	1.8	34.808	97.502	5.0R
935	DEC 2	101722.07	Hughes	—	—	—	1.4	35.235	96.401	5.0R
936	DEC 13	060903.44	Pottawatomie	—	1.6	—	1.8	35.382	96.904	5.0R
937	DEC 17	033524.90	Garvin	—	—	—	1.7	34.773	97.557	5.0R
938	DEC 17	040119.28	Garvin	2	2.5	2.6	2.6	34.843	97.580	5.0R
939	DEC 17	071805.65	Garvin	5	3.8	3.5	3.1	34.730	97.541	5.0R
940	DEC 18	214245.58	Kiowa	—	—	—	2.0	34.657	99.063	5.0R
941	DEC 20	123520.79	Garvin	—	2.3	1.9	2.2	34.752	97.520	5.0R
942	DEC 22	043151.35	Lincoln	—	—	—	1.1	35.569	96.664	5.0R
943	DEC 29	035141.53	Garvin	—	1.7	1.7	2.0	34.796	97.572	5.0R
944	DEC 30	045454.38	Oklahoma	—	1.4	—	1.1	35.461	97.568	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.

Earthquake Distribution

All Oklahoma earthquakes recorded on seismograms from three or more stations are located. In 1992, 53 Oklahoma earthquakes were located (Fig. 2; Table 2). Four earthquakes were reported felt (Table 3). The felt and observed effects of earthquakes are generally 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 felt areas for two of the earthquakes listed in Table 3, Seminole County earthquake (event no. 917) and Garvin County earthquake (event no. 938), are probably restricted to a few tens of square kilometers away from the epicentral location. Each earthquake produced intensity-MM II effects. However, no damage was reported.

At 11:44 p.m. (local time) on October 5, 1992, a magnitude 2.9 (m3Hz) earthquake (event no. 926) occurred 33 km east of Enid. Intensity-MM V effects were reported in Stillwater, Payne County; Perry, Noble County; and Covington and Garber, Garfield County. No damage was reported.

On December 17, 1:18 a.m. (local time), a magnitude 3.8 (m3Hz) earthquake (event no. 939) occurred 14 km southeast of Lindsay. Intensity-MM V effects were reported in Lindsay, Erin Springs, and Purdy, Garvin County. The felt area probably did not exceed 500 km^2. No damage was reported.

Earthquake-magnitude values range from a low of 0.9 (m3Hz) in Hughes County to a high of 3.8 (m3Hz) in Garvin County. Between January 1 and May 30, 10 earthquakes occurred in eastern Jefferson County, an area that has experienced few earthquakes in the past. Fifteen earthquakes occurred in Garvin, McClain, and Grady Counties, one of the most active areas in the State since 1979. Three earthquakes were located in Love County; Lincoln, Payne, Seminole, Pontotoc, and Okfuskee Counties experienced two 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. Table 2 contains 1992 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 for the *Earthquake Map of Oklahoma* (Lawson and others, 1979) and subsequent additions (Lawson and Luza, 1980–90; Lawson and others, 1991,1992).

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. There are several different scales used to report magnitude. Table 2 has three magnitude scales, which are mbLg (Nuttli), m3Hz (Nuttli), and MDUR (Law-

Table 3. — Earthquakes that were Reported Felt in Oklahoma, 1992

Event no.	Date and origin time (UTC)[a]		Nearest city	County	Intensity MM[b]
917	JUN 30	012548.25	E Seminole	Seminole	II
926	OCT 5	044408.56	33 km E Enid	Garfield	V
938	DEC 17	040119.28	Lindsay	Garvin	II
939	DEC 17	071805.65	14 km SE Lindsay	Garvin	V

[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).

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.

son). 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:

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

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 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)

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

(epicenter 100–200 km from a seismograph)

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

(epicenter 200–400 km from a seismograph)

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

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:

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

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

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

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.

This work was funded directly by the Oklahoma Geological Survey, with partial funding by the Nuclear Regulatory Commission. The GSE digital seismic system, provided by the Defense Advanced Research Projects Agency/Nuclear Monitoring Research Office, considerably enhanced the OGS's ability to analyze Oklahoma earthquakes. A borehole seismic system, a joint project with the Lawrence Livermore National Laboratories, was useful in recording Oklahoma earthquakes. The Observatory exists because of building and land-purchase gifts from Jersey Production Research Co. (now merged into Exxon) and the Sarkeys Foundation.

References Cited

Docekal, Jerry, 1970, Earthquakes of the stable interior, with emphasis on the Midcontinent: University of Nebraska, Lincoln, unpublished Ph.D. dissertation, v. 1, 169 p.; v. 2, 332 p.

Kalb, Bill, 1964, Earthquakes that shook Oklahoma: Orbit Magazine—The Sunday Oklahoman, Oklahoma City, September 27, p. 4–7.

Lawson, J. E., Jr., 1978, A preliminary duration magnitude scale for local and regional earthquakes recorded at Oklahoma seismograph stations: Oklahoma Geological Survey Observatory open-file report, 14 p.

_____ 1980, Geophysical observatory establishes continuous time synchronization: Oklahoma Geology Notes, v. 40, p. 214.

Lawson, J. E., Jr.; and Luza, K. V., 1980, Oklahoma earthquakes, 1979: Oklahoma Geology Notes, v. 40, p. 95–105.

_____1981, Oklahoma earthquakes, 1980: Oklahoma Geology Notes, v. 41, p. 140–149.
_____1982, Oklahoma earthquakes, 1981: Oklahoma Geology Notes, v. 42, p. 126–137.
_____1983, Oklahoma earthquakes, 1982: Oklahoma Geology Notes, v. 43, p. 24–35.
_____1984, Oklahoma earthquakes, 1983: Oklahoma Geology Notes, v. 44, p. 32–42.
_____1985, Oklahoma earthquakes, 1984: Oklahoma Geology Notes, v. 45, p. 52–61.
_____1986, Oklahoma earthquakes, 1985: Oklahoma Geology Notes, v. 46, p. 44–52.
_____1987, Oklahoma earthquakes, 1986: Oklahoma Geology Notes, v. 47, p. 65–72.
_____1988, Oklahoma earthquakes, 1987: Oklahoma Geology Notes, v. 48, p. 54–63.
_____1989, Oklahoma earthquakes, 1988: Oklahoma Geology Notes, v. 49, p. 40–48.
_____1990, Oklahoma earthquakes, 1989: Oklahoma Geology Notes, v. 50, p. 68–76.

Lawson, J. E., Jr.; DuBois, R. L.; Foster, P. H.; and Luza, K. V., 1979, Earthquake map of Oklahoma (earthquakes shown through 1978): Oklahoma Geological Survey Map GM-19, scale 1:750,000.

Lawson, J. E., Jr.; Luza, K. V.; and Moss, Dan, 1991, Oklahoma earthquakes, 1990: Oklahoma Geology Notes, v. 51, p. 50–61.

Lawson, J. E., Jr.; Luza, K. V.; Brown, R. L.; and Moss, Dan, 1992, Oklahoma earthquakes, 1991: Oklahoma Geology Notes, v. 52, p. 48–59.

Luza, K. V., 1978, Regional seismic and geologic evaluations of Nemaha uplift, Oklahoma, Kansas, and Nebraska: Oklahoma Geology Notes, v. 38, p. 49–58.

Mykkeltveit, Svein; Ringdal, Frode; Kvaerna, Tormad; and Alewine, R. W., 1990, Application of regional arrays in seismic verification: Seismological Society of America Bulletin, v. 80, p. 1777–1801.

Nuttli, O. W., 1973, Seismic wave attenuation and magnitude relations for eastern North America: Journal of Geophysical Research, v. 78, p. 876–885.

Stauder, W.; Hermann, R.; Singh, S.; Reidy, D.; Perry, R.; and Morrissey, Sean-Thomas, 1979, Central Mississippi Valley Earthquake Bulletin: First Quarter 1979, no. 19, 50 p.

Stover, C. W.; Reagor, B. G.; Algermissen, S. T.; and Lawson, J. E., Jr., 1981, Seismicity map of the State of Oklahoma: U.S. Geological Survey Miscellaneous Field Studies Map MF-1352, scale 1:1,000,000.

Tarbuck, E. J.; and Lutgens, F. K., 1990, The earth—an introduction to physical geology: Merrill Publishing Co., Columbus, Ohio, 651 p.

von Hake, C. A., 1976, Earthquake history of Oklahoma: Earthquake Information Bulletin, v. 8, p. 28–30.

Wells, L. L., 1975, Young Cushing in Oklahoma Territory: Frontier Printers, Stillwater, Oklahoma, 221 p.

Wood, H. O.; and Neumann, Frank, 1931, Modified Mercalli intensity scale of 1931: Seismological Society of America Bulletin, v. 21, p. 227–283.

Zollweg, James, 1974, A preliminary study of the seismicity of the central United States, 1974: St. Louis University unpublished undergraduate report, 15 p.

UPCOMING MEETINGS

Case Histories in Geotechnical Engineering, 3rd International Conference, June 1–6, 1993, St. Louis, Missouri. Information: Shamsher Prakash, University of Missouri–Rolla, Rolla, MO 65401; (314) 341-4489, fax 314-341-4729.

11th Rapid Excavation and Tunneling Conference, June 13–17, 1993, Boston, Massachusetts. Information: Meetings Dept., Society for Mining, Metallurgy, and Exploration, P.O. Box 625002, Littleton, CO 80162; (303) 973-9500, fax 303-979-3461.

34th U.S. Symposium on Rock Mechanics, June 27–30, 1993, Madison, Wisconsin. Information: Bezalel C. Haimson, Dept. of Materials Science and Engineering, 1509 University Ave., Madison, WI 53706; (608) 265-3021, fax 608-262-8353.

Petroleum Computer Conference, July 11–14, 1993, New Orleans, Louisiana. Information: Society of Petroleum Engineers, 222 Palisades Creek Dr., Richardson, TX 75083; (214) 952-9393, fax 214-952-9435.

International Symposium on Hydrometallurgy, August 1–5, 1993, Salt Lake City, Utah. Information: Meetings Dept., Society for Mining, Metallurgy, and Exploration, P.O. Box 625002, Littleton, CO 80162; (303) 973-9500, fax 303-979-3461.

Society for Organic Petrology, 10th Annual Meeting, October 9–13, 1993, Norman, Oklahoma. *Abstracts due June 30.* Information: Brian Cardott, Oklahoma Geological Survey, 100 E. Boyd, Room N-131, Norman, OK 73019; (405) 325-3031, fax 405-325-7069.

Geological Society of America, Annual Meeting, October 25–28, 1993, Boston, Massachusetts. *Abstracts due July 7.* Information: Vanessa George, GSA Meetings Dept., Box 9140, Boulder, CO 80301; 1-800-472-1988 or (303) 447-2020, fax 303-447-1133.

SEPM ELECTS NEW OFFICERS

Officers of the Society for Sedimentary Geology for the 1993–94 term are:

President: SHERWOOD W. WISE, JR., Florida State University
President-Elect: NOEL P. JAMES, Queen's University, Kingston, Ontario
Paleontology Councilor: CARLTON E. BRETT, University of Rochester
Sedimentology Councilor: ROBERT E. GARRISON, University of California, Santa Cruz
Secretary-Treasurer: EMILY L. STOUDT, Texaco Exploration and Production Research Dept., Houston
Councilor for Research Activities: S. J. MAZZULLO, Wichita State University
Editor, *Journal of Sedimentary Petrology:* JOHN B. SOUTHARD, Massachusetts Institute of Technology
Editor, *PALAIOS:* DAVID J. BOTTJER, University of Southern California
Editor, Special Publications: PETER H. SCHOLLE, Southern Methodist University

NEW OGS PUBLICATIONS

GUIDEBOOK 28. *GEOLOGY OF THE WISTER STATE PARK AREA, LE FLORE COUNTY, OKLAHOMA,* by LeRoy A. Hemish.
28 pages, 32 figures, 1 plate. Price: $5.

This guidebook will acquaint the user with the diverse geology of Wister State Park. For those readers who have only an elementary knowledge of geology, a glossary has been included to explain the technical or unfamiliar geologic terms. Therefore, the guidebook should be of interest to amateurs and professionals alike. It is presented in a well-illustrated, easy-to-follow format.

The text contains an overview of the geologic setting, structural geology, and stratigraphy of the area. A detailed geologic map and a road log for a self-guided field trip are included. Eight stops, complete with measured sections, graphic columnar sections, and photographs give the reader the opportunity to examine most rock units present in the area, from oldest to youngest.

The guidebook and accompanying map were produced from new, detailed field mapping by the author at a scale of 1:24,000 in the Summerfield and Wister 7.5′ Quadrangles. The work was undertaken as part of the Oklahoma Geological Survey's ongoing cooperative geologic mapping project (COGEOMAP).

GEOLOGIC MAPS OF THE HODGEN, HONTUBBY/LOVING, AND WISTER QUADRANGLES, LE FLORE COUNTY. Scale 1:24,000.
Xerox copies. Price: $6 each, rolled in tube.

The Ouachita COGEOMAP Project is a joint effort of the U.S. Geological Survey, Oklahoma Geological Survey, and Arkansas Geological Commission to prepare a series of new geologic maps of the Ouachita Mountains in Oklahoma and Arkansas. The project includes review and compilation of existing information and maps on the Ouachita Mountains, and new geologic mapping at a scale of 1:24,000 (7.5′ topographic base). The purpose of the mapping is threefold: The new maps should provide a basis for (1) resource exploration and development, (2) land-use planning such as highway construction, and (3) university field trips and future theses.

Based on existing geologic maps and resource interest and potential, the Oklahoma Geological Survey elected to focus its mapping effort on a west-to-east strip of 7.5′ quadrangles starting immediately southeast of Hartshorne, Oklahoma, and ending at the Arkansas state line. The mapping effort was designed to begin where the geologic map by Hendricks and others (1947) ended, and to include all the area within the quadrangles south of the Choctaw fault. Later, it was decided to map those parts of the Arkoma basin affected by Ouachita tectonics and included in quadrangles that contain the Choctaw fault.

Mapping began in 1986 and is continuing. The first three maps (Higgins, Damon, and Baker Mountain) were released in 1989; the Panola, Wilburton, Red Oak, Leflore, and Talihina Quadrangles were released in 1990; the Leflore Southeast and

Blackjack Ridge Quadrangles were released in 1991; and the Gowen and Summerfield Quadrangles were released in 1992.

The Hodgen Quadrangle (by Neil H. Suneson and LeRoy A. Hemish), the Hontubby/Loving Quadrangle (by Colin Mazengarb and LeRoy A. Hemish), and the Wister Quadrangle (by LeRoy A. Hemish and Neil H. Suneson) are now available as black-and-white, author-prepared xerox copies, comprising geologic map, cross sections, description and correlation of units, and a list of wells.

Guidebook 28 and COGEOMAP geologic quadrangle maps of the Ouachita Mountains 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, fax 405-325-7069. Add 10% to the cost of publication(s) for mail orders, with a minimum of 50¢ per order. For mail orders of 1–10 maps, add $1.50 to the cost for postage and handling.

Sandstone Monolith *(continued from p. 42)*

draped across the top and sides of the monolith (Fig. 2), remnants of the flood caused by torrential rains in the spring of 1990. The level of Wister Lake rose from its normal pool elevation of ~472 ft to ~500 ft. A strandline composed of debris and driftwood completely surrounds Lake Wister, marking the maximum flood water level.

However, it will not be battering by catastrophic natural disasters such as floods that will eventually bring ruin to the sandstone bulwark. Rather it will be the inexorable action of chemical and physical processes slowly attacking the rock, dissolving the cement and causing crumbling by frost action or the invasion of plant roots into fractures. Since the retreat of the flood waters, which deposited silt and organic material on the outcrop and in its fractures, brambles have established a foothold, and their roots are already accelerating the process of erosion.

Figure 2. Driftwood and other debris draped on the monolith, nearly concealing it from view. Back waters of Wister Lake visible in upper left of photo.

Figure 1. Mudflats and dead trees surrounding the sandstone outcrop. Beds dip to the right (SE) in the photo.

Perhaps, before its destruction, the monolith will be covered by muds washed into Wister Lake and thus protected by new sediments as the lake basin fills. If so, it will survive until another time when it may once again be exhumed by the forces of nature.

LeRoy A. Hemish

NOTES ON NEW PUBLICATIONS

Simulation of Ground-Water Flow in the Antlers Aquifer in Southeastern Oklahoma and Northeastern Texas

Author Robert B. Morton presents the results of a study to determine the hydrologic effects of increased pumpage to the year 2040 on the potentiometric surface, saturated thickness, drawdown, and potential well yield for the Antlers aquifer. Prepared in cooperation with the U.S. Army Corps of Engineers, this 22-page USGS water-resources investigations report also includes maps on seven plates.

Order WRI 88-4208 from: U.S. Geological Survey, Water Resources Division, 202 N.W. 66th Street, Bldg. 7, Oklahoma City, OK 73116; phone (405) 231-4256. A limited number of copies are available free of charge.

Ground-Water-Quality Assessment of the Central Oklahoma Aquifer, Oklahoma: Hydrologic, Water-Quality, and Quality-Assurance Data 1987–90

In this USGS open-file report, Dale M. Ferree, Scott Christenson, Alan H. Rea, and Benard A. Mesander present data collected between 1987 and 1990 from 202 wells in four sampling networks. Maps are provided showing the locations of wells sampled in each sampling network. The 193-page report includes a discussion of the design of the sampling networks and sampling procedures and a description of the data tables. The data tables include well information, constituents analyzed, minimum reporting levels for each sampling network, and results of the analyses of the ground-water and the quality-assurance samples. Interpretation of the data is beyond the scope of this report and will be included in subsequent reports.

Order OF 92-641 from: U.S. Geological Survey, Water Resources Division, 202 N.W. 66th Street, Bldg. 7, Oklahoma City, OK 73116; phone (405) 231-4256. A limited number of copies are available free of charge.

Hydrogeologic Maps of the Central Oklahoma Aquifer, Oklahoma

Scott C. Christenson, Robert B. Morton, and Benard A. Mesander completed this hydrologic investigations atlas as part of one of the pilot studies of the USGS National Water-Quality Assessment Program. The maps were prepared by measuring water levels in wells during the winter of 1986 and 1987, examining geophysical logs to determine the altitudes of the top of selected geologic units and the base of fresh ground water, and compiling existing information on the stratigraphy of selected geologic units and the base of fresh ground water. The maps are printed on three sheets at a scale of 1:250,000. Each sheet measures 40 by 28 inches (all in color).

Order HA 0724 from: U.S. Geological Survey, Map Sales, Box 25286, Denver, CO 80225. The price is $8.50; add 25% to the price for foreign shipment. A $1 postage and handling charge is applicable on orders of less than $10.

OKLAHOMA ABSTRACTS

The Oklahoma Geological Survey thanks the Geological Society of America and the authors for permission to reprint the following abstracts of interest to Oklahoma geologists.

Lithologic Mapping of the Arbuckle Group Formation in the Slick Hills of Southwestern Oklahoma, Utilizing Geographic Information Systems/Remote Sensing

M. DENEICE COLLERAIN, KEN MORGAN, R. NOWELL DONOVAN, and ARTHUR BUSBEY, Texas Christian University, Fort Worth, TX 76129

The main objective of this study was to determine the presence of dolomite within lithologic sequences of the Arbuckle Group in the Slick Hills, using Landsat TM data. Samples from six formations of the Arbuckle Group were collected and spectral curves made using a spectral radiometer in lab. These spectral curves were then compared with each band of Landsat TM in search of dolomite spectral patterns.

Using ERDAS, GRASS and MultiSpec image processing and GIS software, multi-band combinations, ratios and principle components computer processing was performed and analyzed. The result was a Landsat derived image that differentiates dolomite from limestone in the Slick Hills.

Reprinted as published in the Geological Society of America *Abstracts with Programs, 1993,* v. 25, no. 1, p. 7.

Using Landsat TM, a Spectrometer, and a GIS for Lithologic Mapping in a Portion of Eastern Slick Hills, Oklahoma

STACEY J. SAVELL, KEN M. MORGAN, R. NOWELL DONOVAN, and ARTHUR B. BUSBEY, III, Center for Remote Sensing, Texas Christian University, Fort Worth, TX 76129

When Landsat TM images of the Eastern Slick Hills of Oklahoma were manipulated using standard processing techniques, the result was a banding pattern which appeared to correspond to the mapped lithologic units. The primary objective of this study was to determine whether vegetation, lithology, or soils produced the spectral reflectances recorded by Landsat TM.

Using ERDAS and a twenty-four bit color display, standard band combinations, ratios, and principle component analyses were performed on a Landsat TM image of the study area. Further a geographic information system (GIS) was utilized to determine any relationships between the processed image, and published lithologic and soil maps. A spectrometer was used to obtain spectral reflectance curves for the soil, vegetation, and rock surfaces collected along a transect of the Eastern Slick Hills. The set of spectral curves obtained for each resource type was then compared

to the spectral readings that were acquired by the Landsat TM sensor. From this, it was determined that the rock outcrops caused the spectral patterns that occurred on the processed imagery.

Reprinted as published in the Geological Society of America *Abstracts with Programs, 1993,* v. 25, no. 1, p. 41.

A Transgression-Regression Event During the Deposition of the Upper Cambrian Honey Creek Formation in the Southern Oklahoma Aulacogen

COURTNEY McELMOYL and R. NOWELL DONOVAN, Dept. of Geology, Texas Christian University, Fort Worth, TX 76129

The transgression that inundated the Southern Oklahoma aulacogen during the upper Cambrian enveloped a landscape that consisted of hills of rhyolite up to 350 m high. Initial deposits on this topography have been interpreted as alluvium. These, together with succeeding tidally influenced marine siliciclastics form the Reagan Formation. The siliciclastics grains are made up of fragments of local origin (i.e., rhyolite), quartz (derived from a distal source) and authigenic glauconite. The upward passage from the Reagan to the Honeycreek Formation is defined by the addition to the siliciclastics of carbonate detrius in the form of tidally influenced grainstones, mostly composed of pelmatozoan fragments. The passage from the Honeycreek to the overlying Fort Sill Formation of the Arbuckle Group is marked by the incoming of beds of lime mudstone and the gradual disappearance of grainstones and siliciclastics. Evidence of the existence of rhyolite topography (i.e., an archipelago) can be detected to within 50 m of the top of the Fort Sill.

While the overall facies pattern undoubtedly records a widespread transgression, a newly discovered slightly angular unconformity within the lower part of the Honeycreek is best interpreted as a record of a temporary regression. Three distinctive lithologies are involved in this relationship: the lowest beds are light grey cross-bedded pelmatozoan grainstones with minor amounts of quartz and rhyolite grains. Syntaxial cements at the base of this unit are homogeneous under cathode luminescence, while cements near the top display up to 27 zones of reflectance, interpreted as a fluctuating marine-meteoric groundwater imprint. The overlying bed is a red-brown mud-supported limestone that contains abundant angular rhyolite pebbles and a rich trilobite fauna. Some of the pebbles are coated by pelmatozoans. This bed, which is from 0–3 m thick, is interpreted as a locally derived regressive deposit derived from adjacent rhyolite island shorelines. Variation in the thickness of the bed may be due to compactional draping around the rhyolite topography. The uppermost beds are a thinly bedded alternation of pelmatozoan grainstones and fine grained quartz sandstones. These beds, which overstep the underlying units, are interpreted as the basal deposits of a succeeding transgression, incorporating siliciclastics transported into the area during the regression. The unconformity can be traced throughout the Slick Hills of southwestern Oklahoma; while it may reflect localized tectonism associated with the evolution of the Southern Oklahoma aulacogen, it may also correlate with a craton-wide *"sub-Elvinia"* hiatus.

Reprinted as published in the Geological Society of America *Abstracts with Programs, 1993,* v. 25, no. 1, p. 38.

Paleokarstic and Karstic Features: Arbuckle and Hunton Groups, Oklahoma

ZUHAIR AL-SHAIEB, JIM PUCKETTE, and FELICIA MATTHEWS, School of Geology, Oklahoma State University, Stillwater, OK 74078; and MARK LYNCH, Unocal, 4005 N.W. Expressway, Oklahoma City, OK 73116

Cores of the Ordovician-age Arbuckle Group and Ordovician–Silurian–Devonian-age Hunton Group contain evidence of paleokarst. Arbuckle and Hunton Group rocks display surprisingly similar suites of distinct paleokarstic features. Vugs, solution-enlarged fractures, cavities, collapse breccias, and sediment-filled solution features are evident. Phreatic cements are more commonly observed than vadose cements, while primary speleothemic precipitates are rare.

A complex history of exposure, subsidence, and diagenesis is recorded in these rocks. Hunton and Arbuckle carbonates have been subaerially exposed for periods of variable intensity and duration during geologic history. Paleokarst appears to have developed subjacent to disconformities within and between formations of the Arbuckle Group and where these rocks subcrop below regional unconformities. Hunton paleokarstic horizons are apparent below the regional pre-Woodford unconformity, while evidence of inter- and intra-formational subaerial exposure is tenuous. This complex hierarchy of unconformities can produce numerous porous horizons. Porosity preservation may depend on subsidence rates or sea level rises rapid enough to prevent extensive low-temperature phreatic cementation and sediment infill of the existing pore network.

Caves in the Arbuckle Group in Murray County, Oklahoma contain many karstic features similar to those observed in cores. Cemented collapse breccia and sediment-filled solution cavities are evident in caves developed in the Cool Creek Formation. These caves are part of an extensive internal drainage system associated with Honey Creek near the crest of the Arbuckle anticline. Cave speleothems and surficial travertine deposits are by-products of karstification processes.

Reprinted as published in the Geological Society of America *Abstracts with Programs, 1993,* v. 25, no. 1, p. 1–2.

The Geological Significance of the Boundary between the Fort Sill and Signal Mountain Formations in the Lower Arbuckle Group (Cambrian)

RANDY HOSEY and R. NOWELL DONOVAN, Dept. of Geology, Texas Christian University, Fort Worth, TX 76129

During the upper Cambrian, a transgression inundated the Southern Oklahoma aulacogen enveloping a landscape that consisted of hills of Cambrian-aged rhyolite up to 350 m in height. Initial deposits on this topography—the Reagan Formation—consists of siliciclastics that were deposited as alluvium and succeeding tidally influenced marine sandstones and shales. The siliciclastics grains are made up of local rhyolite, quartz (derived from a distal source) and authigenic glauconite. The over-

lying Honeycreek Formation is defined by the addition of carbonate detritus in the form of tidally influenced pelmatozoan grainstones. The passage from the Honeycreek to the overlying Fort Sill Formation of the Arbuckle Group is marked by the incoming of beds of lime mudstone and the gradual disappearance of grainstones and siliciclastics. The Fort Sill has been divided into three *ad hoc* units, the topmost of which is an 80 m thick complex of thick-bedded light grey algal boundstones in which both stromatolites and thrombolites are common. This unit can be traced for over 30 km in the Slick Hills of southwestern Oklahoma. In the western part of the area it has been extensively dolomitized; isotope data suggest that this dolomitization was initiated in the late Cambrian or early Ordovician.

The contact between the Fort Sill and the overlying thinly bedded dark grey bioclastic limestones of the Signal Mountain Formation is one of the most distinctive horizons in the Arbuckle Group. The contact evidently marks a substantial change in depositional environment. Thus, (1) no boundstones are found in the Signal Mountain, (2) there is an abrupt upward increase in the amount of quartz silt and detrital clay, and (3) up to 5% glauconite is found in the basal Signal Mountain, none in the Fort Sill.

In detail the contact is sharp and shows evidence of minor erosion, although no karsting has been detected. Small pebbles of a dolomite similar in texture to that found in the underlying Fort Sill also suggest that some erosion has taken place. We suggest that the contact surface records a regression, perhaps associated with dolomitization and followed by some erosion. A regression is also indicated by the local occurrence of a laminated tidal flat unit with traces of evaporites that outcrops in the far west of the Slick Hills immediately below the formation contact. We suggest that the Signal Mountain as a transgressive unit, incorporating siliciclastics transported into the area during the regression. It has been suggested that the unconformity reflects localized tectonism associated with the evolution of the Southern Oklahoma aulacogen. On the other hand the surface may correlate with a cratonwide *"Sauxian"* hiatus.

Reprinted as published in the Geological Society of America *Abstracts with Programs, 1993,* v. 25, no. 1, p. 14–15.

Geochemical Evolution of Proterozoic Granitoid Magmas, Arbuckle Mountains, Oklahoma

EDWARD G. LIDIAK, Dept. of Geology and Planetary Science,
University of Pittsburgh, Pittsburgh, PA 15260

Major and trace element geochemistry indicate that the three main middle Proterozoic plutons (Unnamed granodiorite, Troy and Tishomingo granites) from the eastern Arbuckle Mountains of Oklahoma evolved independently from their respective source regions. Linear co-variance of elements suggests that mafic and felsic members of each pluton are related by separation of early formed minerals. Least squares calculations show that felsic members of the Unnamed granodiorite could have formed from mafic members by about 60% fractional crystallization of constituent plagioclase, hornblende, biotite, sphene, and magnetite. Felsic members of the Troy granite could have been derived from mafic members by the removal of about 33% plagioclase, K-feldspar, hornblende, biotite, sphene, and magnetite.

Similarly, elemental compositions in the Tishomingo granite suggest that mafic members are related to felsic members by the early removal of about 45% plagioclase, K-feldspar, hornblende, biotite, sphene, and magnetite.

Modeling of possible source regions of the granitoids is poorly constrained because the composition of the 1.9 Ga lower and middle crust beneath the Arbuckles is unknown. However, LILE and REE compositions of the Unnamed granodiorite can be closely approximated by assuming equilibrium batch melting (EBM) of about 20% average graywacke or about 30% EBM of partly hydrated lower crustal sialic granulite. Troy granite compositions are consistent with their derivation from about 20% EBM of an equal mixture of sialic amphibolite-grade and granulite-grade gneisses. The high LILE and REE compositions of the Tishomingo granite require a source region that is geochemically more evolved than most lower crustal sources, possibly a mixture of sialic amphibolite-grade gneisses and lower Proterozoic felsic basement rocks. High concentrations of LILE and REE in the Troy and Tishomingo granites essentially precludes their derivation by an AFC process.

Reprinted as published in the Geological Society of America *Abstracts with Programs, 1993,* v. 25, no. 1, p. 36.

Proposed Shallow Drilling at the Interface between the Southern Oklahoma Aulacogen and Ouachita Fold Belt, Arbuckle Mountains Region, Oklahoma

EDWARD G. LIDIAK, Dept. of Geology and Planetary Science, University of Pittsburgh, Pittsburgh, PA 15260; and RODGER E. DENISON, 15141 Kingstree, Dallas, TX 75248

Two major tectonic elements in southern North America are the southern Oklahoma aulacogen and the Ouachita foldbelt. The aulacogen is characterized by basement-cored high-angle fault blocks along which movement occurred throughout much of Paleozoic time. It is one of the most intensely deformed areas in the stable interior platform of the craton. The fold belt, in contrast, consists primarily of thin-skinned compressional structures that formed in Late Paleozoic time. These two prominent tectonic features strike at a high angle to one another and are juxtoposed in southeast Oklahoma where the contact is buried shallowly beneath Cretaceous rocks of the Gulf Coastal Plain. A drilling program comprised of a series of shallow holes drilled across the contact zone will establish the structural and stratigraphic relationships at this important tectonic interface. The results obtained should be critical in elucidating the effect that the transverse aulacogen structures had on the development of the Ouachita frontal zone.

Proposed drilling sites are in northern Bryan and Choctaw counties, Oklahoma, along the Tishomingo–Belton anticlines southeast of the basement-cored eastern Arbuckle Mountains. Crystalline rocks in this region are massive middle Proterozoic granitoid rocks overlain by Cretaceous sedimentary rocks. Farther southeast, rocks in the frontal zone consist mainly of Late Paleozoic flysh-type sedimentary rocks. Depths to Paleozoic and older rocks beneath the coastal plain deposits are about 300–500 meters so that targeted structures can easily be reached.

Reprinted as published in the Geological Society of America *Abstracts with Programs, 1993,* v. 25, no. 1, p. 36.

The Deese and Collings Ranch Conglomerates of the Arbuckle Mountains, Oklahoma: Evidence of Strike-Slip Movement During the Deformation Stage of the Southern Oklahoma Aulacogen

IBRAHIM CEMEN, KEVIN PYBAS, CRAIG STAFFORD, and ZUHAIR AL-SHAIEB, School of Geology, Oklahoma State University, Stillwater, OK 74078

It has been widely recognized that the Pennsylvanian conglomerates of the Arbuckle Mountains, Oklahoma, record the deformation stage of the Southern Oklahoma Aulacogen. Two of these units are the Desmoinesian Deese Conglomerate, exposed in the Mill Creek Syncline area between the Reagan and Mill Creek fault zones, and the Middle Virgilian Collings Ranch Conglomerate, exposed along the Washita Valley fault zone in the Turner Falls area.

We investigated clast size, geometry, and content, primary sedimentary structures, petrography, petrology, and diagenesis of the two conglomerate units, as well as the geometric relationship of their basins with nearby faults. Our evidence suggests that the two conglomerates were deposited as alluvial fans in basins formed by strike-slip movements. The Collings Ranch Conglomerate was deposited in a basin formed as the result of left-stepping along the nearby Washita Valley strike-slip fault zone. The Deese Conglomerate was deposited in a basin formed due to the combined effect of strike-slip and dip-slip movements along the Reagan and Mill Creek fault zones. In the Collings Ranch basin, the deposition was accomplished primarily by channel-fill and sieve deposits in the proximal region of the fan. The Deese Conglomerate was deposits as an alluvial fan or fans which included several channel deposits while, in the deeper parts of the basin, fine-grained materials and limestones were deposited.

These observations and their possible interpretations suggest that the Washita Valley, Mill Creek, and Reagan fault zones have experienced substantial strike-slip movement during the deformation stage of the Southern Oklahoma Aulacogen.

Reprinted as published in the Geological Society of America *Abstracts with Programs, 1993,* v. 25, no. 1, p. 6.

A Comparison of the Mineralogy, Ore Textures, Paragenetic Sequence, and Occurrence of the Permian Sandstone-Hosted Ag–Cu Deposit at Paoli, Oklahoma with the Permian Shale-Hosted Cu–Ag Deposit at Creta, Oklahoma

RICHARD D. HAGNI, Dept. of Geology and Geophysics, University of Missouri, Rolla, MO 65401

Although the sandstone-hosted (Wellington Formation, Leonardian Series) Ag–Cu deposit at Paoli in south-central Oklahoma and the shale-hosted (Flowerpot Shale, Guadalupean Series) Cu–Ag ore deposit at Creta in southwest Oklahoma are both contained in Permian sedimentary rocks, they differ in their mineralogy, ore textures, paragenetic sequence, and occurrence. At Paoli, chalcocite mineralization occurs as replacements of disseminated, diagenetic, pyritohedral pyrite crystals, as replacements of carbonate cement between clastic quartz sand grains (Thomas, Hagni, and Berendsen, 1991), and especially as replacements of hematite that replaces carbonate cement in the host sandstones. In contrast, at Creta the copper sulfide grains occur as replacements of megaspores, colloform pyrite, and pyrrhotite crystals.

Ore microscopic study indicates that the paragenetic sequence of ore minerals at Paoli is: pyrite (oldest)–goethite–hematite–covellite–chalcocite–digenite–bornite–chalcopyrite (youngest). Such a sequence is the reverse order of those deposited at Creta and for most copper ore deposits, of all types, elsewhere. The paragenetic sequence at Paoli is interpreted to indicate that the host red-bed sandstones experienced an early introduction of reducing fluids that formed disseminated and cementing pyrite. Subsequent oxidation of that pyrite to form hematite (and minor goethite) probably occurred at the leading edges of roll fronts of oxidizing groundwaters. The paragenetic sequence shows that the copper sulfide formation was from fluids that became progressively more reducing during the deposition of those copper sulfide minerals. The shapes of the ore deposits indicate that the copper ore fluids were ones that moved in the form of roll fronts along Permian stream channels.

Reprinted as published in the Geological Society of America *Abstracts with Programs, 1993,* v. 25, no. 3, p. 23–24.

How Shallow Drilling Would be Useful in Establishing a Reference Section for Syntectonic Pennsylvanian and Permian Sedimentation Patterns Adjacent to the Wichita Uplift

R. NOWELL DONOVAN, Dept. of Geology, Texas Christian University, Fort Worth, TX 76129

The Wichita uplift in southwestern Oklahoma is part of a record of Pennsylvanian and early Permian tectonism that affected the Southern Oklahoma aulacogen. The principal effect of this tectonsim was to either invert or accentuate the existing section into uplifts and syntectonic basins respectively. The greatest structural relief (~16,000 m) which resulted was that between the Wichita uplift and Anadarko basin. As a result of this partial inversion, the predominantly carbonate Lower Paleozoic sedimentary section of the aulacogen was sequentially stripped off the uplift, resulting in the eventual exposure of the Cambrian igneous fill of the aulacogen. In places up to 6,000 m of section was removed. At the same time sediments shed from the uplift, into the adjacent Anadarko (to the north) and Hardeman–Hollis (to the south) basins constitute an inverted record of this erosion. Collectively these sedimentary rocks are referred to as the "Granite Wash" in the subsurface and the "Post Oak Conglomerate" at the surface. In both situations the rocks were deposited as a complex of alluvial fans or fan deltas (in the case of the older Pennsylvanian). In addition to being a tangible record of contemporary uplift and erosion, these rocks also bear the imprint of a gradually changing climate (humid to arid) that reflects the northward drift of the craton.

Although the Granite Wash is encountered in drilling (and in places is a hydrocarbon reservoir), it is rarely cored and, because of the complexity of its facies, difficult to correlate. Similarly the overlying Post Oak Conglomerate is poorly exposed and equally difficult to correlate. Furthermore, the Post Oak is only a partial analogue of the Granite Wash in the sense that it is a deposit related to relief reduction rather than contemporary tectonism. It follows that a complete core or series of cores taken from both flanks of the Wichita uplift would be an invaluable reference to understanding the interactions between tectonic, climatic, depositional and diagenetic factors that have influenced these rocks.

Reprinted as published in the Geological Society of America *Abstracts with Programs, 1993,* v. 25, no. 1, p. 9.

Permian Karst Topography in the Wichita Uplift, Southwestern Oklahoma

R. NOWELL DONOVAN and ARTHUR B. BUSBEY, Dept. of Geology, Texas Christian University, Fort Worth, TX 76129

The Wichita uplift in southwestern Oklahoma is one part of a record of Pennsylvanian and early Permian deformation that affected the Southern Oklahoma aulacogen. The principal effect of this deformation was to either elevate or depress the existing section into uplifts and syntectonic basins respectively. The greatest structural relief that resulted was that between the Wichita uplift and Anadarko basin. As a result of this partial inversion, the Lower Paleozoic section of the aulacogen was sequentially stripped off the uplift, resulting in the exposure of ultrabasic rocks deep in the Cambrian igneous fill of the aulacogen. In places, up to 20,000 ft of section was removed. Following the late Paleozoic tectonism, the topography of the uplift was entombed beneath Permian sediments and remained essentially undisturbed until exhumation during the present erosional cycle. At the existing level of erosion, the Wichita Mountains display the eroded igneous core of the uplift; to north (the Slick Hills) and south (Mackenzie Hill) are much faulted inliers of Lower Paleozoic sediments. These are mostly sections of the Arbuckle Group, a 6–7,000 ft section of Cambro–Ordovician carbonates.

During the Permian the climate of southern Oklahoma became increasingly arid. As a result weathering processes operating on the uplift slowed dramatically until the rate of denudation was less then the rate of burial of the topography; consequently the existing early Permian topography was preserved. Modern erosion is gradually exposing this topography, permitting morphometric analysis of the Permian hill forms. Because of the variation of lithology in the uplift, it is possible to isolate the effects of weathering processes such as intense hydrolysis of the igneous rocks (producing, among other features, tor topography) and limestone dissolution, in the form of a surface and subsurface karst imprint. The latter process resulted in a network of small caves that are essentially fissures eroded along tectonic fractures. These small caves can be found in all the exposed areas of limestone. They are particularly noteworthy for three reasons: (1) In at least five examples they contain a complex fauna of Permain vertebrates (mostly fragmentary). (2) Speleothems in some examples contain hydrocarbon inclusions, derived from the underlying Anadarko basin. (3) Some of the caves yield evidence of post burial evolution in the form of clay infiltration from the surface and brine flushing from the underlying Anadarko basin.

Reprinted as published in the Geological Society of America *Abstracts with Programs, 1993,* v. 25, no. 1, p. 8.

Microgravity Monitoring of Recharge in a Karst Aquifer in Southwestern Oklahoma

ROGER A. YOUNG and JUDSON L. AHERN, School of Geology and Geophysics, University of Oklahoma, Norman, OK 73019

Natural and artificial recharge of a shallow karst aquifer in Harmon County, Oklahoma, is being studied by the Oklahoma Water Resources Board and the U.S. Bureau of Reclamation. The aquifer, the Permian Blaine Formation, consists of interbedded gypsum, shale, and dolomite. It is the only significant fresh water aquifer developed in evaporite rocks in the U.S.A.

The Blaine Formation forms major cave systems locally and generally consists of an intricate network of caves, cavities, sinks, and dissolution-collapse structures affecting the five gypsum bed subunits. At the recharge-demonstration sites, the Blaine is roughly 200 feet thick. At each site, observation wells cluster about a central recharge well which injects rainfall runoff at the depth of maximum void space (approximately 100 to 200 feet) determined from drilling.

Annual variation in water level is up to 50 feet. Local storms can cause a rise of several tens of feet in a few days and a gradual decrease over several weeks. This may lead to a regional increase in water table elevation near the recharge well ("mounding"), and localized filling of voids in the gypsum. Both of these effects are expected to cause changes in the local gravity field following a heavy rainfall. For example, the filling of a 5 meter radius cylindrical void at a depth of 25 meters would produce a 46 microgal anomaly, easily detectable by a microgravity meter after instrumental and tidal drift corrections are made. To look for these changes, microgravity profiles will be conducted across the recharge zones. If correlation of gravity with measured water levels and recharge volume is demonstrated, microgravity surveys may prove useful in siting recharge wells from surface measurements alone.

Reprinted as published in the Geological Society of America *Abstracts with Programs, 1993,* v. 25, no. 1, p. 47.

Karst in Permian Evaporite Rocks of Western Oklahoma

KENNETH S. JOHNSON, Oklahoma Geological Survey, 100 E. Boyd, Norman, OK 73019

Bedded evaporites (gypsum and salt) of Permian age have been dissolved naturally by ground water to form a major evaporite-karst region in western Oklahoma. The Blaine Formation and associated evaporites comprise 100–800 ft of strata that dip gently into broad, structural basins. Outcropping gypsum, dolomite, and red-bed shales of the Blaine display typical karstic features, such as sinkholes, caves, disappearing streams, and springs. Large caves are developed in gypsum beds 10–30 ft thick at several places, and a major gypsum/dolomite karst aquifer provides irrigation water to a large region in southwestern Oklahoma. Salt karst is present beneath much of western Oklahoma, where salt layers above and below the Blaine Formation have been partly dissolved at depths of 30–800 ft below the land surface. Salt dissolution causes devel-

opment of brine-filled cavities, into which overlying strata collapse, and the brine eventually is emitted at the land surface in large salt plains.

Reprinted as published in the Geological Society of America *Abstracts with Programs, 1993,* v. 25, no. 1, p. 16.

Hydrogeology of the Rush Springs–Marlow Aquifer in the Anadarko Basin, West-Central Oklahoma, U.S.A.

K. S. JOHNSON, Oklahoma Geological Survey, University of of Oklahoma, Norman, OK 73019; D. L. RUNKLE and M. F. BECKER, U.S. Geological Survey, Water Resources Division, 202 N.W. 66th St., Bldg. 7, Oklahoma City, OK 73116

The Anadarko Basin is a major sedimentary and structural basin that underlies about 60,000 square kilometers of western Oklahoma and the adjacent Texas Panhandle. The extensive Rush Springs–Marlow aquifer in rocks of Permian age is located in the upper portion of the basin's Paleozoic sedimentary deposits. The aquifer consists of 60 to 160 meters of reddish-brown, fine-grained, friable, and permeable sandstone interbedded with thin beds of gypsum/anhydrite, dolomite, siltstone, and shale. The hydrogeology is currently under investigation in an 8,000-square-kilometer area of Oklahoma where the aquifer is most intensively utilized. This report summarizes data collected in the first year of a 3-year project and historical records.

The Rush Springs–Marlow aquifer is the principal source of irrigation and drinking water in the project area. Water-level declines of 3 to 10 meters in intensively irrigated areas have prompted concern over the rate of ground-water withdrawal.

Ground-water recharge is 10 percent of precipitation. Average annual precipitation ranges from 60 centimeters in the west to 80 centimeters in the southeast. The estimated average hydraulic properties for the aquifer are: porosity, 32 percent; specific yield, 25 percent; and transmissivity, 124 meters squared per day. Most wells yield from 1,000 to 3,000 liters per minute, although some wells yield more than 4,000 liters per minute. Water is a calcium bicarbonate type in most of the project area, but it is a calcium sulfate type where the aquifer is overlain by the Cloud Chief Formation, and in the stream valleys and basin flanks where the aquifer consists primarily of the Marlow Formation. Dissolved-solids concentrations range from 300 to 3,000 milligrams per liter.

Reprinted as published in the *Proceedings of the International Conference on Groundwater in Large Sedimentary Basins,* Australian Water Resources Council Conference Series No. 20, 1991, p. 100.

Devitrification of the Carlton Rhyolite in the Blue Creek Canyon Area, Wichita Mountains, Southwestern Oklahoma

SARAH E. BIGGER, Dept. of Geology, Duke University, Durham, NC 27708; and RICHARD E. HANSON, Dept. of Geology, Texas Christian University, Fort Worth, TX 76129

The Cambrian Carlton Rhyolite is a sequence of lava flows and ignimbrites extruded in association with rifting in the Southern Oklahoma aulacogen. Rhyolite exposed in

the Blue Creek Canyon area consists of a single, originally glassy, porphyritic lava flow >300 m thick. Abundant flow banding is deformed by variably oriented flow folds present on both outcrop and thin-section scales. A variety of complex textures record the cooling, degassing, and devitrification history of the flow.

Acicular Fe, Ti-oxide crystallites aligned in the flow banding document nucleation and limited crystal growth during flow. Spherical microvesicles and larger lithophysal cavities up to 10 cm long crosscut flow banding, showing that degassing continued after flow had ceased. Pseudomorphs of quartz after cristobalite and tridymite are present on cavity walls and are products of high-T vapor-phase crystallization.

Devitrification textures overprint the flow banding and developed in two stages. Primary devitrification occurred during initial cooling and formed spherulitic intergrowths in distinct areas bound by sharp devitification fronts. Spherulites nucleated on phenocrysts, vesicles, and flow bands and show evidence of multiple episodes of growth. Rhyolite outside of the devitrification fronts initially remained glassy but underwent later, low-T hydration to form perlitic texture, which was followed by prolonged secondary devitrification to form extremely fine-grained, equigranular quartzofeldspathic mosaics. Snowflake texture (micropoikilitc quartz surrounding randomly oriented alkali feldspar) developed during both primary and secondary devitrification.

Spherical bodies up to 30 cm across are present in discrete horizons within the flow and weather out preferentially from the host rhyolite. These are compound spherulites that consist of numerous smaller, coalescing spherulites and typically have lithophysal cavities at the center; higher volatile contents in these parts of the flow favored spherulitic crystallization. Individual coalescing spherulites become smaller and more numerous out from the center of the compound bodies, indicating a decrease in crystal growth rate coupled with an increase in nucleation rate during primary cooling and devitrification.

Reprinted as published in the Geological Society of America *Abstracts with Programs, 1993*, v. 25, no. 1, p. 3.

Minor/Accessory Mineral Segregations in the Reformatory Granite

J. P. HOGAN, T. DEWERS, and M. C. GILBERT, School of Geology and Geophysics, University of Oklahoma, Norman, OK 73019

The Reformatory granite (Wichita Granite Group) is part of the Cambrian age Southern Oklahoma Aulacogen. Alkali–feldspar and quartz represent ≈90–95 modal % of the rock. Minor and accessory minerals include amphibole, biotite, magnetite, ±ilmenite(?), sphene, fluorite, zircon, ±apatite, ±allanite(?) and thorite(?). Major and minor/accessory minerals are segregated into distinct groups. Subhedral alkali–feldspar and quartz each form monomineralic glomerocrysts. Minor and accessory minerals are concentrated either as small domains or as multi-mineral glomerocrysts interstitial to the larger alkali–feldspar and quartz glomerocrysts. Occurrence of these minerals as individual inclusions in alkali–feldspar is less common.

Mechanisms previously proposed for this heterogeneous distribution include (1) liquid immiscibility, (2) synneusis, (3) local saturation within a boundary layer melt, and (4) appearance in the order of crystallization. However, these models do not entirely explain the textural characteristics observed for the mineral segregations in the Reformatory granite. Alternatively, Dewers et al. (1993; this session) propose that reaction-diffusion instability operating at less than equilibrium conditions is also a possible mechanism for formation of minor and accessory mineral glomerocrysts. In order to test this hypothesis we have constructed spatial maps of the modal distribution of minerals in the Reformatory granite from slabbed rock samples and thin sections. Variation in element distributions were determined from X-ray mapping via electron microprobe analysis. From this data we will determine spatial correlation functions which can be used to differentiate between different non-linear diffusion dynamic mechanisms. In particular we will discuss the effect of fluorine on initiating instabilities that lead to minor/accessory mineral glomerocryst formation in A-type granites.

Reprinted as published in the Geological Society of America *Abstracts with Programs, 1993,* v. 25, no. 1, p. 14.

Poorly Characterized Critical Rock Units within the Southern Oklahoma Aulacogen

M. C. GILBERT and J. P. HOGAN, School of Geology and Geophysics, University of Oklahoma, Norman, OK 73019;
R. E. DENISON, 15141 Kingstree, Dallas, TX 75248; and
E. G. LIDIAK, Dept. of Geology and Planetary Science, University of Pittsburgh, Pittsburgh, PA 15260

The Southern Oklahoma Aulacogen (SOA) apparently developed during late Proterozoic–early Cambrian rifting of the southern continental margin. This margin appears to be related to the Grenville "suture" formed when the Llano terrane was accreted to N.A. The SOA is representative, as well as the best exposed, of a series of penecontemporaneous rifts along the southern and eastern margin of the North American plate. Pronounced Pennsylvanian structural inversion has lifted the igneous basal sections of this rift (the SOA) to shallow crustal levels and exposed parts of it in the Wichita Mountains.

Two previously identified but poorly characterized rock units within the SOA, the Tillman Metasedimentary Group and the Navajoe Mountain Basalt/Spilite Group, do not crop out at the surface, having only been recognized from well cuttings. No well-described or well-dated samples exist. The Tillman may be the basement rock which was extended during initial rifting and hosted the igneous infill of the SOA. The Navajoe may represent the earliest phase of magmatism in the SOA. Isotopic dating and geochemistry, and textural/structural relations, of 100–500 m core sections in these two units would go a long way toward clarifying paleotectonic relations and crustal structure in the late Proterozoic. Several drill sites for scientific holes up to 1 km in depth targeted to these enigmatic units can be identified and the rationale for their selection will be presented.

Reprinted as published in the Geological Society of America *Abstracts with Programs, 1993,* v. 25, no. 1, p. 11.

Shallow Drilling Investigation of Contact Relationships in the Wichita Mountains Igneous Province

M. C. GILBERT and J. P. HOGAN, School of Geology and Geophysics, University of Oklahoma, Norman, OK 73019; and KENNETH V. LUZA, Oklahoma Geological Survey, 100 E. Boyd, Norman, OK 73019

Within the Wichita Mountains Igneous Province, a variety of mineralogically, texturally and compositionally diverse hybrid rock types (i.e., gabbro–diorites, monzonites and granodiorites) crop out at gabbro–granite contacts. Possible coeval sedimentary rocks associated with crustal rifting are restricted to a few scattered, isolated exposures of a mineralogically variable group of meta-quartzites (Meers Quartzite). Typically these outcrops of meta-quartzite are of limited areal extent and are surrounded by either gabbro, granite, rhyolite or a combination of these rock types. However, the origin of both the hybrid rock types and the Meers Quartzite remains enigmatic because outcrops containing complete and clear contact relationships are extremely rare. At present, direct testing of models is difficult as complete exposure of contacts between these units is extremely rare due to deposition of younger sedimentary units and severe degradation by weathering. Poor condition of existing samples has hampered geochemical and other petrologic methods in evaluating models.

Four potential drilling sites have been selected where critical contacts between major geologic units are interpreted to be present in the shallow subsurface (<300 ft). Objectives of drilling are (1) direct observation of contacts between rock units by retrieval of a complete core sample from the drill hole, (2) retrieval of freshest possible rock material for petrographic and geochemical analysis, and (3) retrieval of a complete transect beginning in Mount Scott Granite or Meers Quartzite across the hybrid rock zone and into the substrate gabbro to document variations associated with this transition.

Reprinted as published in the Geological Society of America *Abstracts with Programs, 1993,* v. 25, no. 1, p. 11.

Shallow Subsurface Geological Investigation near the Meers Fault, Oklahoma

KENNETH V. LUZA, Oklahoma Geological Survey, 100 E. Boyd, Norman, OK 73019

The Meers fault is part of a complex system of northwest-trending faults forming the boundary between the Wichita Mountains (south) and the Anadarko basin (north). The frontal fault system is dominated by moderately dipping to steeply dipping reverse faults which have a combined net vertical displacement of over 9 km. Of these faults, the Meers fault has a Pennsylvanian–Permian throw of about 2 km.

The Meers fault trends N. 60° W. and displaces Permian conglomerate and shale for a distance of at least 26 km, from near the Comanche–Kiowa County boundary to East Cache Creek. At the northwest end of the fault trace, the fault displaces lime-

stone-pebble conglomerates (Post Oak), whereas at the southeast end siltstones and calcrete-bearing shales of the Hennessey are displaced.

Multiple radiocarbon ages of soil-humus samples from 2 Canyon Creek trenches (S24, T4N, R13W) show the last surface faulting occurred 1,200–1,300 yr ago. In 1988–89, the Oklahoma Geological Survey drilled 4 core holes to basement in the vicinity of the trench sites. The holes were drilled along a 200-m-long transect normal to the strike of the Meers fault. Two holes were drilled on the north side of the fault and penetrated highly fractured and altered rhyolite at about 58 m. A third hole drilled 25 m south of the fault, intersected weathered and sheared gabbro at 58 m. The fourth hole, drilled 65 meters southwest of the third hole, penetrated basement at 52 m. The basement material in the fourth hole consisted of dark greenish brown, highly fractured and sheared rock.

The drill holes encountered Permian, poorly sorted, matrix-supported, 0.5–3 m thick, conglomerate interbedded with shale and siltstone. Drill holes 1–3 contained 3–5 m thick, granite cobble-boulder, clast supported conglomerate resting on rhyolite and/or gabbro. The core-hole information suggests the Meers-fault zone is at least 200 meters wide. Additional core holes will be needed to define the limits and geometry of the mafic-rich rock south of the Meers fault and more precisely define the width of the fault zone.

Reprinted as published in the Geological Society of America *Abstracts with Programs, 1993,* v. 25, no. 1, p. 37.