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December 1982

# OKLAHOMA GEOLOGY NOTES

OKLAHOMA GEOLOGICAL SURVEY THE UNIVERSITY OF OKLAHOMA

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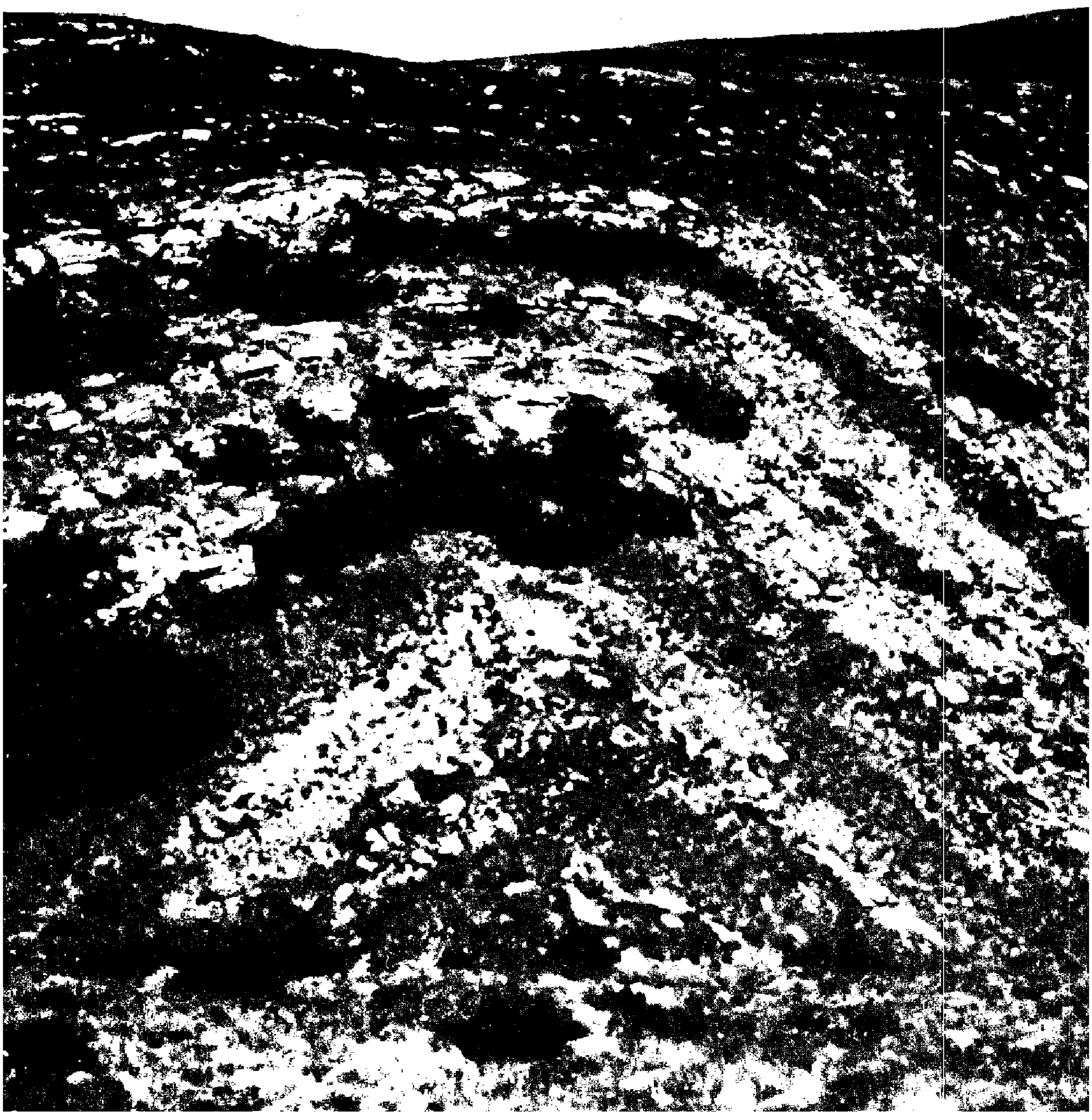

*On the cover—*

## Guidebook 21 Examines Wichita Mountains

The cover photograph shows a number of first-order fold axes in part of Blue Creek Canyon, located northeast of the Wichita Mountains Refuge in southwestern Oklahoma. These striking folds in rocks of the Arbuckle Group (Upper Cambrian and Lower Ordovician) are clearly displayed in the photo, figure 161 of the Oklahoma Geological Survey's recently released Guidebook 21, *Geology of the Eastern Wichita Mountains, Southwestern Oklahoma.*

The guide was edited and coordinated by M. Charles Gilbert, of the Department of Geological Sciences of Virginia Polytechnic Institute and State University, and visiting geologist with OGS, and R. Nowell Donovan, of the Department of Geology of Oklahoma State University. Descriptions of exposures at 11 field-trip stops cover all major aspects of the igneous geology and key lower Paleozoic sedimentary units, as well as some of the important structural features.

The stop descriptions are accompanied by detailed geologic maps on topographic bases, some of which include structure sections, and a series of explanatory articles of a more general nature that provide background information. These include discussions of the regional and local geology; the structure and geologic history of the Southern Oklahoma Aulacogen; age-dating as determined by uranium/lead tests of zircon; the geochemistry of the amphiboles; and detailed descriptions of some of the igneous, metamorphic, and sedimentary units that occur in the area.

Besides Gilbert and Donovan, 11 additional authors contributed to the articles and stop descriptions.

This 160-page guidebook represents a significant stage in a project undertaken by Gilbert in 1977 to coordinate and augment work done in the Wichita Mountains by previous investigators and to fill in gaps by mapping localities not previously covered. When completed, the project will result in a new, large-scale geologic map of the area.

Guidebook 21 is available from the Survey at the address given below. The price is $10.

**Oklahoma Geology Notes**

**Editor:** Connie Smith
**Editorial Staff:** Elizabeth A. Ham, William D. Rose

**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, reviews, and announcements of general pertinence to Oklahoma geology. Single copies, $1.50; yearly subscription, $6. All subscription orders should be sent to the Survey at 830 Van Vleet Oval, Room 163, Norman, Oklahoma 73019.

Short articles on aspects of Oklahoma geology are welcome from contributors. A set of guidelines will be forwarded on request.

VOL. 42, NO. 6 DECEMBER 1982

# OKLAHOMA GEOLOGY NOTES

OKLAHOMA GEOLOGICAL SURVEY, THE UNIVERSITY OF OKLAHOMA

## Contents



This publication, printed by the Transcript Press, Norman, Oklahoma, is issued by the Oklahoma Geological Survey as authorized by Title 70, Oklahoma Statutes, 1971, Section 3310, and Title 74, Oklahoma Statutes, 1971, Sections 231–238. 1,800 copies have been prepared for distribution at a cost to the taxpayers of the State of Oklahoma of $2,622.

# DEVELOPMENT OF THE OKLAHOMA GEOGRAPHIC INFORMATION RETRIEVAL SYSTEM FOR RESOURCE MANAGEMENT AND ENVIRONMENTAL ASSESSMENT

**W. Anthony Blanchard[1] and Stephen J. Walsh[2]**

**Abstract**—In addition to processing satellite data for landcover assessment, the Oklahoma State University Center for Applications of Remote Sensing (CARS) is developing the Oklahoma Geographic Information Retrieval System (OGIRS). An information system can be regarded as layers of data referenced to a geographic earth-coordinate-system, which is capable of being stored and manipulated through computer processing. Currently, the information system consists of data libraries detailing soils, geology, landcover, climate, topography, and hydrology for selected study areas, and specialized software to interrelate and map numerous variables. OGIRS is a highly interactive system, capable of handling large amounts of data, and can provide output in various graphic modes. The system is most applicable to resource management and environmental assessment, and is flexible enough to accommodate multiple and diverse users.

## Introduction

Environmental analysis is hampered by a host of information problems. Lack of data, deficiencies in the quality of data, and incompatibility of data derived from several sources cause obvious difficulties in land management, mineral exploration, and resource-allocation decisions. The development and implementation of a geographic-information system can successfully lessen data-integration problems and the time-consuming process of synthesizing tremendous amounts of information for problem analysis. An information system can input, manipulate, and analyze geographically referenced data in order to support the decision-making process of an organization (Federation of Rocky Mountain States, 1977, p. 22). In

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general, a geographic-information system can be regarded as layers of spatially oriented information (Cicone, 1977, p. 1129).

In light of fiscal reductions, rewriting of public-agency charters, and the profit motive of the private sector, the efficient appraisal and monitoring of our resources become extremely important. With advances in computer-hardware capabilities, geographically referenced information systems can be employed by numerous organizations requiring varied applications. Technologies of the 1980's include remote sensing and geographic-information systems. Their capability for large- and small-area analysis, integration of numerous variables into the evaluation process, and ease of updating the data base makes their use attractive (Estes, 1982, p. 25).

Applications of geographic-information systems are numerous, and include the evaluation of wildlife habitat, forest harvests, grazing potential, waste disposal, and mineral exploration.

The Oklahoma State University Center for Applications of Remote Sensing (CARS) is developing the Oklahoma Geographic Information Retrieval System (OGIRS), which is a highly interactive data collection, storage, and manipulation software package. OGIRS was developed in response to the need for a computer-based geographically referenced natural-resource information system within and around the State of Oklahoma. The primary objectives of the OGIRS software package are to provide a means for collecting data from disparate sources, to store all data in a common format, to provide data-editing capabilities, to convert stored data into symbol maps, to allow selective mapping from stored data, to provide composite map-building functions, and to provide a variety of output products.

## Program Description

OGIRS is programmed in FORTRAN VII; however, some system (Perkin-Elmer 8/32 OS32 operating system) dependent subroutines are required for file allocation and dynamic assignment of logical units. The program is currently structured as a main program with subroutines for allocation of indexed and contiguous disc files, opening and closing (assigning) logical units, file-name entry, editing, mapping, and data manipulation.

Data are stored as thematic libraries in indexed files. Each library is named for a natural-resource category. Currently, there are five libraries, which include soils, geology, topography, landcover, and climate. Individual data sets representing specific geographic areas and specific subjects are stored as concurrent channels within the thematic libraries (fig. 1). Every channel within a library is uniquely identifiable by its title and channel number.

OGIRS has four basic functions: data entry, data editing, data manipulation, and output-product generation. Data entry is by three methods: points from the graphic digitizer, input from a remote terminal, and as

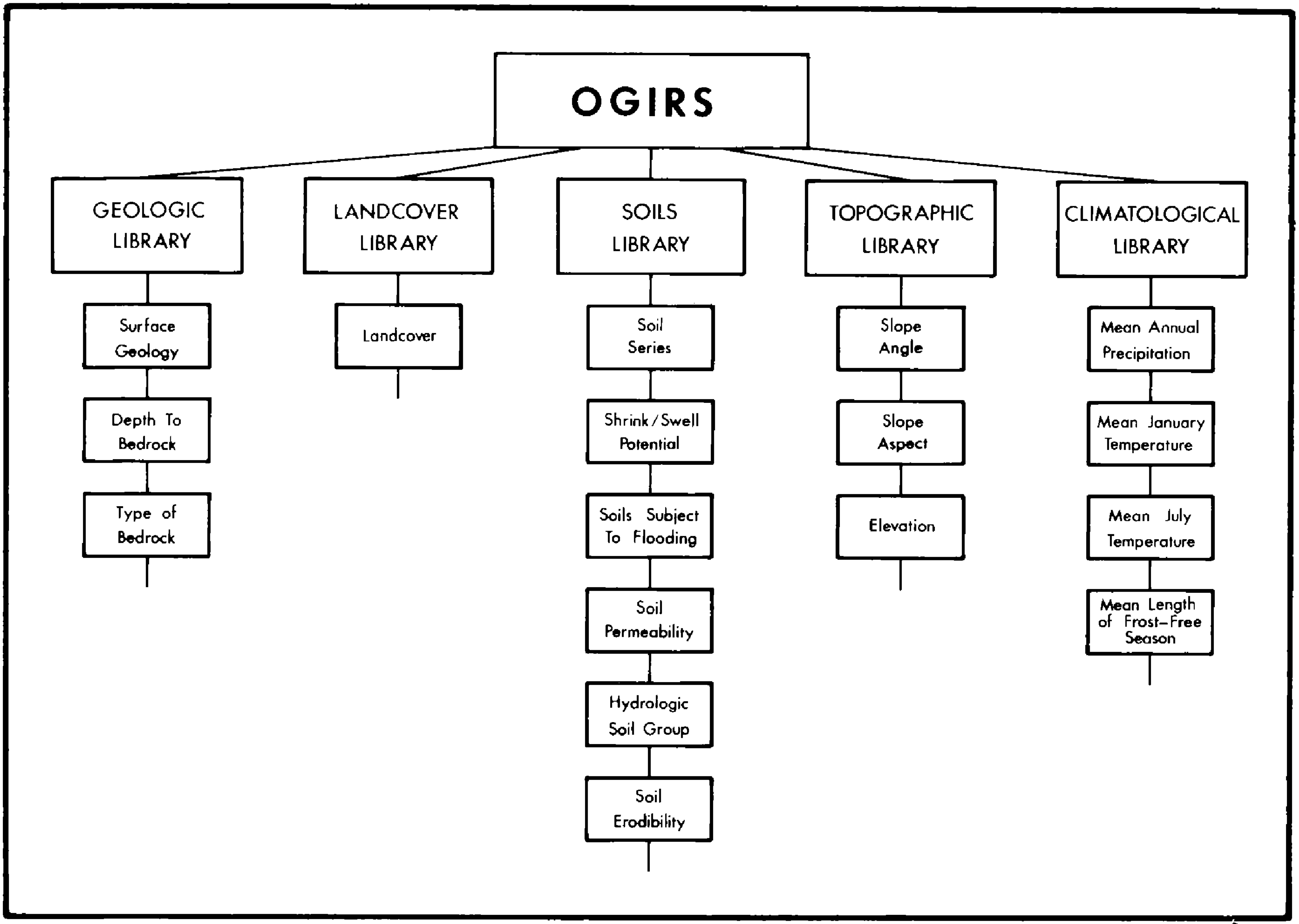


Figure 1. Diagram of the five libraries of information contained within OGIRS.

polygon data in an ELAS[3] digital-image format. Editing capabilities exist at the data-entry level and as a library-update function. Manipulation of stored data is by five value-selection modes and three mapping functions. The value-selection modes are equal value, greater than a value, less than a value, greater than and less than a value, and less than a value or greater than a value. The last two modes selectively isolate values in the data set either between the input values or on either side of the input values on the number line. The three mapping functions allow any number of individual data sets from any number of data libraries to be combined as the union, intersection or exclusion of the data sets. A variety of output products can be generated from the stored data. Line-printer symbol maps, electrostatic-printer/plotter maps and ELAS-format color images can be produced by the OGIRS program. For more detail regarding data entry, editing, manipulation, and output-product-generation capabilities of OGIRS, consult Blanchard (1982).

The theoretical basis for the data-manipulation methodology of the OGIRS software is derived from set theory. In its most simple case, the union of two data sets produces a data set containing all of the elements of each input set. When represented spatially, the resulting map shows those areas having values selected from both input sets. The OGIRS software is truly multidimensional; therefore, any number of data sets can be combined as a union of sets. The intersection of two sets evaluates the co-occurrence of data sets throughout a multidimensional data field. The exclusion function checks for the nonoccurrence of a value throughout the multidimensional array of data values.

## Applications

The ability to turn analog information into digital data, and then to edit, store, and display the data as maps or color images, has a wide variety of applications in natural-resources management and assessment. Maps or images displaying soil type, geology, land use, hydrology, and other natural-resource data are used on a daily basis by land-use planners, engineers, agriculturists, and many others. The advantages of archiving these data in a geographic-information system are ease of retrieval, variety of output products to fit almost any need, and the ability to discover and display information gained by testing the interactions between natural-resource phenomena.

The interactive capabilities of OGIRS allow the user selectively to isolate specific natural-resource features and to examine the consequences of interaction between disparate data sources. The location of a single soil type can be extracted from the soil-series map and the areas displayed as a

[3]Specialized computer software, termed "ELAS" (Earth Resources Laboratory Applications Software), is resident on the CARS computer system. ELAS was developed by NASA/Earth Resources Laboratory, Mississippi, to provide a flexible capability for analyzing and processing digital remotely sensed data.

separate map. Other relational modes may be used to generate a map showing all elevations over 150 m or all slope angles less than 8°. Features also can be bracketed to display slope aspects between north and northwest, or to display areas that receive less than 25 cm or greater than 100 cm of rain per year. The OGIRS software package is a very easy-to-use data-retrieval system, and with the wide variety of output products available, it is a potentially useful tool to the practicing natural-resources manager.

The concepts behind the OGIRS mapping functions and relational modes are simplicity and flexibility. Data-manipulation methods that are simple to use and understand are essential when the system is to be used by non-computer-oriented personnel. The massive amounts of data generally available to natural-resource-management personnel often exist in a wide range of formats, scales, and detail. OGIRS provides both a simple step-by-step method of reformatting the data into a consistent format, and the full capability to utilize the data constructively.

The OGIRS mapping functions are not models in the strict sense of the word; however, the mapping functions can be used to design user-specific models. The concept of providing generalized mapping functions rather than designing a set of static models affords a high degree of flexibility.

Many of the user-defined models can be of the suitability-analysis type. The basic suitability-analysis model locates and displays from the data base only those areas that contain all of the characteristics described by the user. By describing the requirements of soil type, slope angle, elevation, depth to bedrock, etc., the intersection mapping function isolates only those characteristics. The model-building capabilities of the OGIRS program are flexible enough to allow completely different activities to be described and yet still display the areas most suited to those activities.

In another application, the mapping functions can be used to compare the acreage planted in wheat for one soil type to that of another soil type also planted in wheat. The user extracts the areas with wheat from the general landcover data set and then intersects these data with the specific soil types to obtain a new map showing the locations where wheat grows on the specific soil types. The map explanation lists the areas for each map, and from this value the acreage comparison can be made.

The union mapping function is used to show the spatial distribution of two or more features on any map. For example, a map showing all upland forest land and all elevations over 300 m could be generated with the union function.

The exclusion mapping function can be used to display all areas where a specific condition is not present, or where the worst areas for a particular activity is not present, or where the worst areas for a particular activity exist. The exclusion function could also be queried to display areas that do not contain a specified crop on a specific soil type.

It is important to note that subsurface variables can also be input to the system and manipulated as described above. Library channels can include magnetic surveys, aquifer profiles, density, temperature, etc.

## Summary

The Oklahoma Geographic Information Retrieval System (OGIRS), developed by the Oklahoma State University Center for Applications of Remote Sensing, is a flexible data-collection, storage, retrieval, and manipulation system for geographic information. Its basic function is to provide a means to manage large volumes of disparate data with simple, clearly stated commands. OGIRS is a users' program. It is designed specifically with the non-computer-oriented person in mind. No prior knowledge of computer science or programming is required by first-time users. Very little pre-program-use direction is necessary, as the program has a logical flow and prompts the user in plain English when user input is required.

The OGIRS software package is modular in form and allows new modules to be easily incorporated within the system. A few restrictions must be observed to conform with the program's input/output and file allocation/assignment subsystems. Although OGIRS is not complete, it exists as a fully functional program that is capable of performing all of the tasks described.

## References Cited

**Blanchard, W. A.,** 1982, Oklahoma Geographic Information Retrieval System; Proceedings, National Conference on Remote Sensing for Energy and Resource Management, Baltimore, Maryland [in press].

**Cicone, R. C.,** 1977, Remote sensing and geographically based information systems: Proceedings, Eleventh International Symposium on Remote Sensing of the Environment, p. 1127–1137.

**Estes, J. E.,** 1982, Remote sensing and geographic information systems coming of age in the eighties *in* Proceedings, pecora VII symposium, remote sensing: An input to geographic information systems in the 1980's, p. 23–40.

**Federation of Rocky Mountain States,** 1977, A general design scheme for an operational geographic information system; Information systems technical laboratory, Fort Collins, Colorado, p. 1–44.

# HARRISON SCHEDULES UNIVERSITY VISITS

William E. Harrison, a petroleum geologist and geochemist at the Oklahoma Geological Survey, recently spent 2 days visiting the Geology Department at Eastern Illinois University in Charleston, Illinois. Harrison, one of 32 geologists designated as Visiting Petroleum Geologists by the American Association of Petroleum Geologists (AAPG), will visit several colleges and universities during the 1982–83 academic year.

The purpose of the Visiting Petroleum Geologist program is to encourage students to pursue careers in petroleum geology and to offer the petroleum industry's views on teaching and curriculum design to teachers and administrators. Such perspectives are particularly valuable to students and universities not located in petroleum-producing regions.

Harrison, who is currently serving a 9-month appointment as Klabzuba Professor in the School of Geology and Geophysics at OU, gave two technical talks during his visit. One talk, "Tar-Sand and Heavy-Oil Potential of Oklahoma," described an ongoing investigation to evaluate tar-sand deposits in south-central Oklahoma. The study is being funded by the U.S. Department of Energy and consists of a 20-hole program that will permit an accurate assessment of the quantity of bitumen-bearing sandstones at four tar-sand sites in Carter and Murray Counties.

OU currently is seeking patent protection for the exploration method described in Harrison's second talk, "Geochemical Prospecting for Stratigraphic Traps." This technique involves the hydrocarbons that can be liberated from reservoir-quality sandstones and limestones under mild heating, and is one of Harrison's present research interests.

Harrison will also visit the U.S. Naval Academy under the auspices of the AAPG Visiting Petroleum Geologist program.

# RESEARCH FINDINGS AVAILABLE AT OGS

The following master's thesis and Ph.D. dissertations are now available for public examination at the Oklahoma Geological Survey. The research involved was supported in part by funding from the OGS. The publications are:

*Stratigraphy, Petrology, Depositional and Diagenetic Environments of Lower–Middle Ordovician Boundary Beds, Arbuckle Mountains, Oklahoma,* by Timothy R. McHargue. 188 p., 35 figs., 2 plates, 1981 (Ph.D. dissertation).

*Stratigraphy, Petrography, and Depositional Environments of the Pawnee Limestone, Middle Pennsylvanian (Desmoinesian), Midcontinent, North America,* by Rex Clayton Price. 294 p., 56 figs., 1981 (Ph.D. dissertation).

*Petrology, Conodont Distribution, and Depositional Interpretation of the Lenapah Formation, Middle Pennsylvanian, Southeastern Kansas and Northeastern Oklahoma,* by Randall William Parkinson, 87 p., 28 figs., 1982 (M.S. thesis).

## *NOTES* SUBSCRIPTION PRICE INCREASES

Although *Oklahoma Geology Notes* has been able to hold the line on price increases since December of 1976, recent rises in paper and production costs have forced us to increase yearly subscription rates to $6 per year as of January 1, 1983. The price for single copies of the *Notes* will then be $1.50 per issue.

This small increase will allow us to maintain the size, frequency, and quality of the *Notes*, and absorb the increases that have occurred in postage rates in recent years.

## USGS PUBLISHES OKLAHOMA MAP INDEX

A *Geologic Map Index of Oklahoma,* compiled by Willard L. McIntosh and Margaret F. Eister, has been issued by the U.S. Geological Survey. The publication consists of three map-index sheets and four bibliographic-reference sheets, each measuring 11⅜ × 17¾ inches (45 × 29 cm). The sheets are folded into a cover sheet that carries a general explanation and lists depositories where the maps designated can be consulted.

As in the Oklahoma Geological Survey versions (Map GM-21, *Index to Surface Geologic Mapping in Oklahoma (through 1976),* Map GM-22, *Index to Subsurface Mapping in Oklahoma (1967-1976),* the forthcoming Map GM-26, *Index to Surface and Subsurface Geologic Mapping in Oklahoma (1977-79),* and earlier OGS map indexes), areas outlined on each map are numbered, with numbers corresponding to numbers of the bibliographic references.

The USGS and the OGS indexes differ in form of presentation: OGS plates are printed on large sheets, with index maps at a scale of 1:750,000 and with references and regional maps included on the sheets; USGS map indexes are offered on three small sheets that are differentiated on the basis of scales of maps covered, and references for all three plates are printed on one series of separate sheets.

Also, OGS indexes are issued with subsurface-map citations delineated on one plate, or set of plates, and areas covered by surface maps shown on another sheet or sheets. References for subsurface maps incorporate information concerning types of maps, map scales, and contour intervals.

The USGS *Geologic Map Index of Oklahoma* is available free on request from: Distribution Branch, U.S. Geological Survey, Box 25286, Federal Center, Denver, Colorado 80225.

OGS maps can be obtained from the Oklahoma Geological Survey at the address given on the inside front cover of this publication. The prices are $4 for GM-21, and $5 for GM-22.


Margaret Burchfield George

# PETROLEUM GEOLOGIST JOINS OGS

Margaret Burchfield George, the newest member of the Oklahoma Geological Survey's petroleum-geology section, stepped directly into an active role at the OGS through her involvement with a research project to evaluate tar-sand deposits in the State. The project is being funded by the U.S. Department of Energy. Burchfield George is now in charge of a related drilling program that has been recovering cores and well cuttings in the south-central part of Oklahoma.

Jane Weber, OGS chemist, is currently using the samples, which were taken from depths of approximately 200 ft, to extract bitumen to determine the exact weight-percent of the material in the sand.

Burchfield George's educational background includes an M.S. in geology in 1982 from Southern Illinois University, and a B.S. in geology from Southeast Missouri State University. Some Oklahomans may be acquainted with her through work that she did at the Oklahoma City Geological Society library during the summers of 1978 and 1979. Last summer she worked for Amoco Production Co. constructing subsurface cross sections in Michigan.

She will soon be working on a project that will examine geothermal resources in the eastern part of Oklahoma. Her interests are wide-ranging and include clay minerals and their application to petroleum geology.

Burchfield George is married to a geologist, Joseph George, who is working with Target Reservoir Analysis in Oklahoma City. The two met while in SIU's geology graduate program.

# ROSE RECEIVES GAVEL AT AESE MEETING

Oklahoma Geological Survey Geologist/Editor William D. Rose was formally recognized as the next president of the Association of Earth Science Editors (AESE) at that group's 16th Annual Meeting held October 3–6 in Colonial Williamsburg, Virginia. The gavel was passed to Rose, current vice-president, by AESE President Robert L. Bates. Rose will automatically succeed to the presidency on January 1, 1983.

A highlight of the meeting, which was attended by about a hundred editors, writers, and publishers, was the presentation of the prestigious AESE Award for Outstanding Editorial or Publishing Contributions to Wendell Cochran, editor of *Geotimes,* the well-known monthly geological magazine; *Earth Science,* a quarterly for the general public; and *Geospectrum,* a monthly newsletter. These three periodicals are published by the American Geological Institute.

Cochran was acclaimed for "his outstanding contributions as an earth-science communicator and for his work in editing, writing, publication, and education." Also acknowledged through this award was his service to the geological profession through a series of workshops and short courses in geowriting that he conducts throughout the country.

The award was presented to Cochran by AESE President Bob Bates, last year's recipient.

Also at the meeting, Bates announced that honorary membership was being bestowed on three long-time members: Robert W. Kelley, Thomas F. Rafter, Jr., and Marie Siegrist. They were cited for their outstanding service to AESE and the geological profession. Kelley and Rafter are former association presidents, and Siegrist was the second recipient of the AESE award.

John T. Dickman, of Chemical Abstracts Service of the American Chemical Society, is the incoming vice president and president-elect, and Wendell Cochran was elected to a 3-year term on the board of directors.

The Oklahoma Geological Survey was represented at the meeting by editorial-section members Elizabeth A. Ham, Connie Smith, and Rose, who, in addition to attending meetings of the board of directors, chaired a session on graphics and script preparation.

The University of Oklahoma was also represented by Jiri Zidek of the School of Geology and Geophysics faculty. Other Oklahomans attending included several members of the headquarters staff of the American Association of Petroleum Geologists, among them E. A. (Ted) Beaumont, science director, and Ronald L. Hart, projects manager.

The Association of Earth Science Editors was established in 1967 to foster education and to promote the interchange of ideas on general and specific problems of selection, editing, and publishing in the earth sciences. The association numbers about 320 members, mostly from North America.

# GEOMAGNETIC OBSERVATORY UPGRADED THROUGH PROJECT WITH USGS

Since August 1961, the Oklahoma Geological Survey's Geophysical Observatory, located near Leonard, Tulsa County, has been recording geomagnetic variations on an Askania magnetic variograph. The geomagnetic observatory, one of about 200 in the world and one of six in the conterminous United States, was defined because of its location as a "critical" observatory by the International Union of Geodesy and Geophysics. In all but one direction, the Observatory is more than 1,000 km from the nearest magnetic observatory.

Although the Askania magnetic variograph was making good recordings on photopaper, after 20 years of continuous operation, maintenance problems were serious and photopaper in 120-mm-wide rolls was expensive and difficult to find. The Askania recorded only variations of a few nanotesla. The "zero" or baseline (about 54,000 nanotesla, total field) was not determined for lack of absolute instruments. Many of the world's magnetic observatories determine baselines as often as weekly.

In November 1981, the U.S. Geological Survey supplied an EDA Instruments three-component fluxgate magnetometer to the Observatory. The sensor head is positioned in a shelter built about 25 m from the nonmagnetic building housing the Askania variograph. The shelter, about 1 m in all three dimensions, is built on a solid rock outcrop to allow precise leveling of the sensor. All sides are insulated to an "R" value of 20. With no control, the shelter reduces outside temperature fluctuations by a factor of 5. Two nonmagnetic light bulbs that are controlled by an electronic proportional control maintain the temperature within 0.1°C of 43.0°C, the highest outside air temperature expected.

The fluxgate electronic console and the proportional temperature electronics are in the original nonmagnetic building. The fluxgate electronics produce voltages that are carried by an underground cable to the main observatory building 120 m away. In the main building a strip-chart recorder continuously records the vertical magnetic intensity, the horizontal magnetic intensity, and the magnetic declination. The horizontal intensity is recorded at two sensitivity levels.

With the Askania instrument not recording, and with the fluxgate sensor remote from the nonmagnetic building, it is not necessary to maintain a perfectly clean magnetic environment in the building. As a matter of fact, the fluxgate and temperature electronics produce some contamination. The building is now used as a geomagnetic center for visitors where the magnetic field and instrumentation are explained through displays on the walls; current field readings from the fluxgate are displayed in the building. Visitors were previously taken to this building only at a cost of disturbing the magnetogram because of metallic objects (coins, zippers, etc), but they can now view the displays, readouts, and electronics without affecting the recordings.

In May 1982 the USGS supplied a declination-inclination magnetometer (DIM) and a proton precession magnetometer (PPM) to the Observatory for baseline measurements. The DIM is a fluxgate magnetometer mounted on a nonmagnetic theodolite. It is used to measure precisely the inclination and declination of the geomagnetic field. When declination and inclination are known, they are used along with the PPM-measured total-field intensity to calculate baseline values of horizontal and vertical intensity. The baseline observations are made weekly outdoors on a slab of sandstone that was used by the USGS for baseline measurements made at 3- or 4-year intervals. A small nonmagnetic building will be built over the rock.

All magnetograms are lent to the World Data Center in Boulder, Colorado, where they are microfilmed. The originals are archived at the Observatory. The World Data Center, which makes copies readily available to any interested scientist, also keeps microfilm copies of all the earlier photopaper magnetograms.

Because of the new cooperative program with the USGS, the Oklahoma Geophysical Observatory will enter into its third decade with greatly improved and expanded geomagnetic data for use by scientists.

## NITROGEN-INJECTION RESEARCH SPONSORED BY OU AND VENEZUELA

Three University of Oklahoma researchers will begin a three-part nitrogen-injection study under a funding agreement reached with INTEVEP, a Venezuelan government-owned agency set up to perform energy research.

The $100,000 contract was awarded by INTEVEP to the School of Petroleum and Geological Engineering and the School of Chemical Engineering and Environmental Science for a 1-year period beginning June 21, 1982.

Injection of high-pressured nitrogen gas into wells has been used on a limited basis to recover additional oil from producing wells. More research needs to be done before broader use of nitrogen injection is undertaken.

Dr. John Radovich, an OU chemical engineer, will initiate a study of the availability of nitrogen and the feasibility of different supply processes. Dr. Kenneth Starling, also a chemical engineer, will study the chemical changes that occur in nitrogen when it comes in contact with crude oil under varying temperature and pressure conditions.

Dr. Donald Menzie, an OU petroleum engineer, will conduct laboratory experiments to determine the appropriate amounts of nitrogen gas to inject into a well to displace the greatest amount of crude oil. Earlier nitrogen injection studies by Dr. Menzie were sponsored by OU's Energy Resources Institute.

Engineers from INTEVEP will be on campus later this year to work with the OU researchers.

# SHORT COURSE TO PRECEDE SME–AIME ANNUAL MEETING

The Society of Mining Engineers of AIME will conduct a short course on "Economic Principles for Industrial Mineral Property Valuations," Saturday and Sunday, March 5–6, 1983, at the Atlanta Hilton Hotel, Atlanta, Georgia. The course will precede the SME–AIME annual meeting to be held March 6–10, also at the Hilton.

This course is intended to familiarize engineers, geologists, and middle-management personnel with the economic principles associated with the evaluation of mineral properties. The course will address the concepts of property valuation using an industrial-mineral property as a model. The techniques developed can also be applied to mineral-industry ventures in general. Although the concepts and techniques commonly used for cost estimating are discussed, they do not constitute the primary objective of the course. Subjects will include input parameters for feasibility studies, development of cash-flow models with emphasis on tax considerations, project-evaluation techniques, and risk and sensitivity analysis. The course will also discuss the economic viability of the proposed mining venture from the standpoint of the investment community.

This short course is a revised and updated offering of a similar course presented by the instructors at the 1978 SME–AIME fall meeting and exhibit at Paradise Island, Bahamas. Presenting the course will be Donald W. Gentry, professor of mining engineering, Colorado School of Mines, Golden, CO 80401 (303–273-3712); and Matthew J. Hrebar, associate professor of mining engineering, Colorado School of Mines, Golden, CO 80401 (303–273-3718).

The course fee is $275 for AIME members and $400 for nonmembers. Course participants will receive 1.4 continuing education units for completing the course. A short-course manual in outline format will be supplied to all participants.

For more information on course content, contact one of the above instructors. To register for the course, contact General Member Services, SME–AIME, Caller No. D, Littleton, CO 80127 (303–973-9550). Telex: 45-0446.

The SME has scheduled nearly 70 technical sessions during the 1983 SME–AIME annual meeting.

Technical sessions have been planned by the four SME divisions (Coal, Industrial Minerals, Mining & Exploration, and Mineral Processing), the Minerals Resource Management Committee, the Society of Economic Geologists (SEG), and the Association of Exploration Geochemists (AEG).

For further information, contact SME Meetings Dept., Caller No. D, Littleton, CO 80127 (303–973-9550). Telex: 45-0446.

# TRAINING PROGRAM BEGUN AT ROGERS STATE COLLEGE

Graduates from Rogers State College's (RSC) new petroleum-technology program will qualify as the "arms and legs" of petroleum engineers, Gerold Allen, advisory-committee chairman for the program, said.

Collegiate engineering graduates do not have the technological experience to supervise well completion or deal with production problems and are having to be retrained by their respective oil companies to handle these tasks, Allen continued, noting RSC's emphasis on technology and on-site training in its new program.

The oil industry desperately needs technology specialists such as the RSC graduates, who would work "in between" the drillers and the engineers to provide a coherent flow of production, Allen, vice president of Helterbrandt Corp. in Oologah, said.

Allen and 13 other management persons from major petroleum companies have collaborated with RSC program director Renie Jobe to design the curriculum based on industry needs. The 15 students who currently are enrolled in the program, approved by State regents some three weeks before the 1982 fall semester convened, are participating in field trips to well sites, oil fields, and refineries through the introductory petroleum-technology course.

"Our program is different (than other state and nationwide collegiate programs) because specialists and consultants—'tops' in the industry—teach the courses rather than educators," Allen said, emphasizing that RSC students not only will have "book training" but hands-on experience as well.

Upon completion of the 70-credit-hour program, RSC petroleum-technology graduates will have earned 64 classroom credits, along with summer internship credit, and should be able to start out in $24,000- to $35,000-level positions with their associate of technology degree, Allen said.

Technologists don't need to learn an abundance about fluid mechanics, hydraulics, physics, thermo, and stress, but should concentrate on on-site training, he said, noting that most book statistics already have been calculated for oil companies.

At RSC, located in Claremore, the only 2-year Oklahoma school approved for a petroleum-technology program, the facilities, drilling sites, and equipment of local oil companies and drilling firms are used for on-site training.

The classroom curriculum will include algebra, geology, general chemistry, engineering drawing, formation evaluation, elements of drilling, well completion, methods of petroleum production, computer programming, natural gas, economics, and industrial safety.

# QUARRY AMONG NATION'S TOP TEN

Dolese Brothers Co. Richards Spur quarry in Comanche County was ninth in the nation in the production of crushed stone in 1981, according to the U.S. Bureau of Mines. The total output from Richards Spur and several other quarries operated in Oklahoma by Dolese was sufficient to place the firm sixth among the country's top producers of crushed stone.

While Dolese's output was entirely from within Oklahoma, each of its competitors had activities in at least three other states. None of the other companies produced as much stone in a single state as did Dolese.

Martin Marietta Corp., operator of a quarry near Tulsa, was able to place second among the producers of crushed stone through its enterprises in other states.

# DRILLING MUDS STUDIED AT OU

Drilling muds can have up to 2,000 chemicals mixed in them and represent the most complex fluids we know, says Dr. Edward Blick, of OU's School of Petroleum and Geological Engineering. As wells are drilled deeper, more and more expensive chemicals are added to drilling muds to allow them to function under the high temperatures and pressures encountered in deeper rock formations.

Under the sponsorship of OU's Energy Resources Institute (ERI), Blick is studying the water filtration properties of drilling muds under high temperatures and pressures to determine the best combination of chemicals to use in deep wells like those being drilled in the Anadarko Basin.

Grants awarded to faculty members by ERI are used to explore the feasibility of research ideas. Once preliminary results have been obtained, researchers write proposals to private and public funding sources to continue their studies.

Drilling muds serve several important purposes, Blick explained. The muds lubricate and cool the drill bit and pipe. Cuttings of rock from the bit are carried by the muds through the outside of the drill pipe back to the surface.

In addition, solids in the muds coat the well bore with a thin cake of mud. This filter cake helps to prevent the rock formation around the well from caving in on the drill pipe and keeps the liquids in the mud from invading the porous formations.

"Most muds are water-based," Blick said. "Water seeps through the filter cake and into the formation. Water loss creates two problems. First, the drilling muds become thicker as water is lost into the formation, and the increased thickness many impede the progress of the drill bit.

"Secondly, the shale in the formation may swell from the water. Drill pipe may become stuck as the shale squeezes in on the well bore.

"If the drill pipe becomes stuck, operations must stop while the crew tries to remove the string of drill pipe from the hole. If a piece of the pipe should break off because of the pressure the shale is putting on it, a 'fishing' crew is sent in to try to find the piece and remove it.

"A rule of thumb is that when the fishing job costs 50 percent of what is already invested in the well, the well is abandoned and plans for drilling nearby are begun. Thus, water loss from drilling muds is expensive in terms of dollars and downtime," Blick said.

Blick is currently studying the filter cakes formed by drilling fluids furnished by W. R. Grace Corporation. Using the mud-flow loop developed at OU, Blick can simulate a well bore under high pressure and temperatures. The mudflow loop at OU is the only one of its kind available for public research.

Mud is pumped through the porous core of the loop, while high pressures and temperatures are created on the outside of the core. A filter cake forms on the housing of the core; then, when specific pressure and temperature levels have been reached, measurements can be made to determine how thick the mud has become and how much water has been lost, Blick explained.

"Muds currently account for 7 to 10 percent of drilling costs," Blick said. "The cost of drilling muds for a deep well (greater than 15,000 ft) can exceed a million dollars.

"The water-filtration studies can aid a mud engineer in calculating which chemicals and what proportions of them to add to muds as wells are drilled deeper. Our research can help eliminate costly errors," Blick concluded.

# MSEG MARCH CONVENTION TO GATHER IN DENVER

The 36th Annual Midwest Convention of the Society of Exploration Geophysicists will be held in Denver, March 6–9, 1983. "Complex Geology — A Geophysical Challenge" captures the theme of the event.

Along with continuing-education seminars, after-hours entertainment, post-convention trips and spouses programs, a comprehensive technical program and geophysical exposition will enliven Currigan Hall, part of Denver's Convention Complex. Any company interested in exhibit space should contact Jack Barnes, Exhibits Chairman, at Denver Processing Center (303–571-1170).

For more information, contact the Denver Geophysical Society, P.O. Box 5226 TA, Denver, CO 80217 (303–425-5584).

# STATE PRODUCTION-DEPTH RECORD SET

A new production-depth record for Oklahoma has been established by Mesa Petroleum Co. with the completion of its 2-29 Tipton well in Beckham County, in the Anadarko Basin. The well, drilled in the E½E½W½NE¼ sec. 29, T. 11 N., R. 25 W., tested high-$H_2S$ gas from carbonate rocks of the Hunton Group through perforations from 24,928 to 24,969 ft.

The initial potential for the well was 14.1 million cubic feet of gas per day through a 17/64-in. choke, with a flowing tubing pressure of 4,884 p.s.i.

Mesa geologist Bill Lefler quoted the well cost as $14 million for drilling and completion, plus an additional $2 million for installation of an amine unit and sulfur plant. The company currently is waiting for a contract to sell the gas.

The previous record holder for deep production in Oklahoma was the MRT Exploration 1 Sanders, 6 mi southeast of the Tipton well in sec. 24, T. 10 N., R. 25 W. The MRT well produced from the Hunton at a depth of 23,920–24,924 ft.

# NOTES ON NEW PUBLICATIONS

*X-Ray Diffraction Mineral Identification Charts for Use in Studies of Uranium, Thorium, and Rare-Earth Deposits*

Open-File Report OF 82-0280, by M. H. Staatz and I. K. Brownfield, consists of 7 pages and 3 oversized sheets.

Order from: Open-File Services Section, Western Distribution Branch, U.S. Geological Survey, Box 25425, Federal Center, Denver, CO 80225. Price: $4.50 paper copy, $5 microfiche.

*The Energy Decade, 1970–1980*

Color graphs, 10-year energy statistics, and energy information on 100 countries are all included in this newly released summary of the previous decade. Cross-referenced by country, region, and energy commodity, the more than 550 pages in the book also cover macroeconomic indicators such as trade balances, exchange rates, gold vs. oil prices, and consumer-price indices to assess energy's impact on the general economy.

Order from: World Energy Industry, 4202 Sorrento Valley Blvd., San Diego, CA 92121. The price is $125, plus $16 postage for North America and $20 elsewhere.

# OKLAHOMA ABSTRACTS

## GSA Annual Meeting, New Orleans, Louisiana, October 18–21, 1982

The following abstracts are reprinted from *Abstracts with Programs* of the Geological Society of America, v. 14, no. 7. Page numbers are given in brackets below the abstracts. Permission of the authors and of the GSA to reproduce the abstracts is gratefully acknowledged.

### Ages of Ouachita Metamorphism

RODGER E. DENISON, Suite 1314, One Energy Square, Dallas, TX 75206

Along the length of the Ouachita foldbelt an interior zone has been subjected to greenschist facies metamorphism. The typical assemblage is characterized by quartz-albite-chlorite-muscovite and includes biotite, phlogopite, graphite, rutile, iron sulfides, sphene, tourmaline and epidote. K/Ar and a few Rb-Sr determinations on metamorphic micas have a decided bimodal distribution. The younger period is from about 320 to 250 m.y. and generally coincides with the accepted period of deformation in the foldbelt. A distinctly older period centers around 380 m.y. and is not well understood. The wide distribution and consistence of this earlier period of metamorphism suggests that it represents a genuine time of metamorphic activity. Supporting evidence for this earlier metamorphism can be found but is inconclusive. When methods and minerals used for isotopic determinations are considered, it is rather surprising that these older apparent ages escaped complete resetting during the younger metamorphic episode. [475]

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**OKLAHOMA ABSTRACTS** is intended to present abstracts of recent unpublished papers relating to the geology of Oklahoma and adjacent areas of interest. The editors are therefore interested in obtaining abstracts of formally presented or approved documents, such as dissertations, theses, and papers presented at professional meetings, that have not yet been published.

## Geochemical Indicators of Salinity Sources in Groundwater of the High Plains of Oklahoma and Southwest Kansas

NOEL C. KROTHE and JOSEPH W. OLIVER, Indiana University, Bloomington, IN 47405

The Ogallala Formation is the principal source of water for much of the High Plains. Identification of possible sources of salinity is critical to water management in the area. The Ogallala Formation in the study area is underlain by Mesozoic rocks in the west and Permian rocks in the east. The general direction of groundwater flow is from west to east. Average concentration of dissolved solids in groundwater from the Mesozoic rocks is 460 milligrams per liter and Permian rocks is 4,720 milligrams per liter. Average concentration of dissolved solids for water in the Ogallala Formation is 336 milligrams per liter where it overlies Mesozoic rocks and 569 milligrams per liter where it overlies Permian rocks. $S^{34}S$ ($SO_4=$) values range from a high of+3.6 0/00 in the west to a low of−25.1 0/00 in the east. Sulfate increases from about 20 mg/l to over 350 mg/l from west to east. Analysis of trace element ratios in the study area waters indicate that the salinity increases observed in some Ogallala groundwaters are most likely due to the influence of upward movement of solutes from Permian sources, and are not directly related to contamination by oil field brine water. Increasing concentration of dissolved solids, lighter $S^{34}S$ ($SO_4=$) values, and increasing sulfate in the east also implies that groundwater and (or) hydrogen sulfide from Permian rocks may be moving upward into the Ogallala Formation. [536]

## Crustal Structure of the Ouachita Mountains, Arkansas, from COCORP Seismic Profiles and Regional Gravity Data

ROBERT J. LILLIE, DOUGLAS K. NELSON, BEATRICE De VOOGD, JACK OLIVER, LARRY D. BROWN, and SIDNEY KAUFMAN, Cornell University, Ithaca, NY 14853

COCORP deep seismic reflection profiles across the Ouachita mountains of western Arkansas suggest that a large fraction of the crust in this region is composed of tectonically thickened Paleozoic sediments (and metasediments). A southward thickening wedge of layered reflections observed on the northern portions of the survey can be associated with approximately

12 km of Carboniferous flysch overlying thin, lower Paleozoic shelf strata in the Frontal Thrust Zone. At the core of the mountains the Benton Uplift is a broad antiform, apparently cored by crystalline basement at a depth of at least 7 km. Beneath the Southern Ouachitas and the adjacent Gulf Coastal Plain, a southward continuation of the wedge of layered reflections may represent up to 22 km of lower Paleozoic off-shelf strata and Carboniferous flysch.

Regional Bouguer gravity data show a minimum coincident with the thickest accumulation of flysch in the Frontal Thrust Zone. To the south, the Benton Uplift lies on a steep gravity gradient which is continuous along most of the Ouachita trend and which may be analogous to a gradient observed along the Appalachian chain. The Ouachita gradient can be modeled as a southward shallowing of the Moho (from 40 km in northern Arkansas to about 30 km just south of the Ouachitas), coincident with the tectonic thickening of the Paleozoic strata interpreted from the COCORP data. The resulting crustal section can be viewed as the remnants of an early Paleozoic passive margin which was subducted beneath a thick accretionary wedge in Carboniferous time. The Benton Uplift is viewed as a late-stage involvement of crystalline basement in foreland thrusting as the margin entered the subduction zone. [547]

## The Arkansas Novaculite: Facies and Depositional Setting

DONALD R. LOWE, Louisiana State University, Baton Rouge, LA 70803

In the southern part of the Benton Uplift, the Arkansas Novaculite (Sil.?, Dev.-Miss.) includes a Lower Division, consisting of lower chert-and-shale and upper novaculite members; a Middle Division of black chert and shale; and an Upper Division of novaculite. All show major facies changes within the Uplift. The chert-and-shale member, a subaqueous basinal deposit, grades northward into slope-related shale, quartzite, and chert-chip breccia. Lower Division novaculite is absent on the northern margin of the Uplift. It disappears in part by the development of internal exposure and erosion surfaces suggesting an approach to its northern depositional limit. Its upper contact is a regional unconformity marked by erosion, solution breccias, jaspers, and terra-rossa-like soil. The Middle Division, present in both northern and southern belts, was deposited under quiet, subaqueous conditions. Siliceous turbidites occur locally. In southeastern areas, however, Middle Division cherts show burrows, current structures, fenestral fabrics, and exposure surfaces indicating shallow-marine to subaerial deposition. Novaculite of the Upper Division grades northward into massive, non-fissile claystone. South of Hot Springs, it locally shows cryptalgal laminations, burrows, and fenestral fabrics.

The traditional interpretation of the novaculite as a silicified deep-water radiolarian ooze must be revised in view of numerous features indicating the local presence of marginal shallow-marine to emergent conditions. The bulk of the massive novaculite apparently accumulated in a quiet, subaqueous, commonly anoxic basin as fine carbonate containing admixed spicules, radiolarian tests, and carbonaceous matter. The basin was restricted, probably relatively shallow, and fringed by marginal zones in which oxygenated surface water supported a normal marine benthic community. The chert-and-shale units represent intervals characterized by deeper-water, more open marine conditions. [550]

**Paleontology and Depositional Environments of Pennsylvanian Low Oxygen Shales, Midcontinent North America**

JOHN MALINKY, University of Iowa, Iowa City, IA 52241

Middle and Upper Pennsylvanian sediments in the North American Midcontinent partly consist of black phosphatic fissile shales grading to less fissile, light-dark gray and brown clay shales. The black shale facies is normally overlain and underlain by thin gray shales, and locally grades laterally into phosphatic gray shale. These "core" shale facies are laterally continuous over wide areas. The black "core" shale facies in Kansas and northward contains a pelagic fauna including fish, probable pelagic conodonts, and possibly epiplanktonic orbiculoid and lingulid brachiopods. The lighter colored "core" shale fauna is dominated by brachiopods, echinoderms, bryozoans, corals, and rarely molluscs, hyoliths, rostroconchs, possible arthropods and "problematic" fossils. Diversity is high throughout the gray and brown shales; abundance decreases in darker shales with increasing organic content. High diversity indicates deposition in offshore marine environments with varying degrees of oxygen-deficiency, reflected in color differences. Contacts between black and lighter shale facies are sometimes gradational reflecting laterally adjacent and depositionally related environments. All facies in the "core" shale represent offshore environments with the black facies furthest offshore and therefore characteristic of anoxic environments which exclude invertebrate macrobenthos rather than dysaerobic environments. In the southern Midcontinent outcrop belt, the gray facies fauna is predominantly molluscan (mainly gastropods, bivalves and cephalopods), with rare non-molluscan elements. This may reflect high sedimentation rates and turbidity in this area, which excluded suspension-feeding non-molluscan organisms; aragonitic-shelled molluscs were well preserved by rapid burial. Scarcity of molluscs elsewhere suggests lower sedimentation rates, dissolution of molluscan shells, but preservation of calcitic skeletal elements of other organisms. [554]

## Crust Formation Age of the North American Midcontinent

BRUCE K. NELSON and D. J. DePAOLO, University of California, Los Angeles, CA 90024

Sm and Nd isotopic analyses of Precambrian basement rocks from the midcontinent region were made to determine the age of craton predominantly buried by Paleozoic strata. Samples are from drill cores and limited basement exposures. All samples have U-Pb (zircon) crystallization ages of 1.34 to 1.49 b.y. (VanSchmus & Bickford, *in* Precambrian Plate Tectonics, 1981). Rb-Sr and U-Pb data give no indication of crust older than 1.6 b.y. Samples are rhyolites and one-or two-mica granites of the ~ 1.4 b.y. anorogenic suite that extends from Labrador into S. California. Samples from Oklahoma to S. Wisconsin have $T_{DM}$ (crust formation) ages of 1.7 to 1.9 b.y. Apparently, the basement of this region was derived from the mantle at 1.8 ±0.1 b.y. with no involvement of Archean crust. The terrane extends west into New Mexico, Arizona and Colorado, where similar $T_{DM}$ ages are observed, is bounded on the north by Penokean rocks ($T_{DM}$=2.1-2.3), and on the south by the Precambrian of Texas ($T_{DM}$ ~1.3). Isotopic characteristics of the Wisconsin Penokean are similar to those inferred for basement in eastern Nevada (Farmer & DePaolo, 1982) and suggest a possible Penokean correlative in the S.W. U.S. The data also show that Penokean rocks are not predominantly recycled Archean crust.

Initial $\epsilon_{Nd}$ for the anorogenic suite range from −2.5 to +2.7, suggesting heterogeneous source materials. If the granites are melts from 1.8 b.y. crust, a wide spread in Sm/Nd is implied for the source regions. Alternatively, the higher initial $\epsilon_{Nd}$ values could be produced by variably contaminating mantle-derived magma with a more homogeneous low-Sm/Nd crustal source. The 1.8 b.y. crust forming event added, in some areas, a 1000 km-wide crustal belt to the N. American craton in $\lesssim$ 200 m.y. There is no apparent Cenozoic analog of similar scale and duration. $T_{DM}$ ages can be consistent over large areas, suggesting that this is an efficient method for mapping age provinces. [575]

## Structure of the Ouachita Mountains in Oklahoma

KENT C. NIELSEN, Programs in Geosciences, University of Texas at Dallas, Box 688, Richardson, TX 75080

The Ouachita Mountains of southeastern Oklahoma are a large ( ~15000 km$^2$) continuous exposure of deformed Paleozoic sediments along the Ouachita Orogen. The mountain belt can be subdivided into four structural zones. The Arkoma Basin contains folds and faults directly related to late Pennsylvanian Ouachita deformation. Broad synclines and relatively narrow asymmetric anticlines are associated with thrusts at depth. The frontal zone is characterized by imbricate faulting and tight folding of Atokan and Morrowan age sequences, principally flysch. Bounded on the north by the Choctaw fault and on the south by the Windingstair fault, the frontal zone becomes much narrower in the west. The imbrication appears more intense and stratigraphic separation increases along fewer major faults. The central zone is bounded by the Windingstair fault on the north and the Broken Bow Uplift on the south. Three large synclines dominate the central zone. These folds are northward verging and truncated by high angle reverse faults on the southern limb. The wavelength of these folds appears to be 8-16 km, and the offset of the faults characterized by a few kilometers of dip separation. The core zone is characterized by tight overturned, southward verging folds with well developed slaty cleavage. Later folding produced superimposed fold patterns and irregular cleavage development. These late folds indicate a counterclockwise rotation of the principal shortening direction during the late Pennsylvanian. The ductile events of the core zone involve the lower Stanley Formation (Mississippian). Preliminary data suggests that the reverse faults of the central zone post-date the slaty cleavage development. The late stage folds appear to post-date the central zone. The style and timing of these events form basic constraints for tectonic models. [577]

## Factors Controlling Uranium Distribution in Upper Devonian-Lower Mississippian Black Shales in Oklahoma

ROBERT K. OLSON, Amoco Production Co., Research Center, P.O. Box 591, Tulsa, OK 74102

Core and outcrop samples of the Upper Devonian-Lower Mississippian Woodford Shale and its lateral equivalents in Oklahoma and Arkansas contain between 0.9 and 121 ppm uranium. The uranium is primarily associated with the kerogen and generally increases with increasing organic carbon content. However, the uranium to organic carbon ratio was found to vary significantly between samples suggesting that other factors also influence the amount of associated uranium. Specifically, the effects of thermal maturation and mineralogy were investigated.

Thermal maturity was found to vary systematically across the study area increasing from immature (Ro<0.5) to advanced (Ro>2.0). Samples which had reached the very mature to advanced level (RO>1.5) contain significantly lower amounts of uranium than less mature samples. This observation suggests that urano-kerogen complexes are destroyed during the maturation process and uranium so liberated appears to migrate out of the shale.

Statistically significant correlations were found between uranium and various mineral components: specifically quartz and illite. Quartz is believed to be primarily biochemical in origin while the illite is thought to have been derived from an allocthonous source. The negative correlation between uranium content and illite is interpreted as reflecting relatively rapid burial of the organic matter, thus limiting the length of time available for uranium-organic interaction. On the other hand, biochemical sedimentation of silica (now quartz) is thought to have been a relatively slow process. Thus, burial to a depth where diffusion was no longer effective took longer and the opportunity for uranium-organic interaction was greater. [580]

## Tectonic Evolution of the Ouachita Orogen

GEORGE W. VIELE, University of Missouri, Columbia, MO 65211

In the Ouachita folded belt, recent seismic profiling (COCORP) confirms a tectonic history involving southward subduction of the North American craton beneath the Ouachita folded belt. Generally, throughout its length, rocks of the folded belt were translated along listric thrust faults toward the North American craton. In the Benton Uplift of Arkansas, however, thrust and fold nappes initially moved northward and subsequently were backfolded toward the south. Associated with the backfolding was the widespread development of type 3 (Ramsey) interference patterns and rotation of many parasitic fold hinges to form a girdle in north-dipping cleavage planes. This cleavage commonly transects at low angle north-dipping axial surfaces of second-phase chevron folds. In the western Benton Uplift, above zones of south-dipping seismic reflectors, south-verging chevron folds occur in lower Paleozoic rocks, but conjugate folds are common in the overlying Carboniferous rocks. Throughout the Benton Uplift, deformation decreases from north to south.

Several tectonic scenarios are possible. Rocks of the Benton uplift may have been squeezed from a trench and obducted southward over non-North American basement, thereby accounting for the southerly vergence. More likely, Ouachita rocks were obducted onto the North American plate, where at deep structural levels, additional telescoping and buckling nucleated chevron folds that propagated southward and upward, dying out in conjugate systems at higher structural levels. Continued plate movement maintained, in the higher Carboniferous strata, the general sense of translation toward the craton. [638]

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