L. 41, NO. 3 JUNE 1981

OKLAHOMA GEOLOGY NOTES

OKLAHOMA GEOLOGICAL SURVEY, THE UNIVERSITY OF OKLAHOMA

On the cover—

Oklahoma's "Chat" Industry

"Chat" is the name given the tailings produced by the mining and milling of lead and zinc deposits in northeastern Oklahoma (Ottawa County), southwestern Missouri, and southeastern Kansas, an area collectively known as the Tri-State Mining District. The deposits occur principally in the Boone Formation (Mississippian), a dolomite largely replaced by chert: hence the name "chat."

In Oklahoma, mining began at Peoria as early as 1890. Most operations included a processing mill, so that chat piles were scattered over a very large area.

A sharply increased demand for zinc during World War I, coupled with improved recovery techniques, resulted not only in an acceleration of mining but also in the reworking of many of the chat piles.

A similar condition prevailed during World War II, with many of the chat piles being reworked again. The last significant mining operations were terminated about 1970.

Now the chat piles are being reworked once more. In this cycle, however, the tailings are put—some after 80 years—to their terminal use, providing road metal, railway ballast, cement aggregate, and gravel. The durability and angularity of the fragments make the chat particularly suitable for these purposes.

Typically, as shown on the front cover, the chat is brought from the pile (background) by truck, dumped through a coarse-screened hopper (middle ground) to eliminate any large fragments, and then conveyed either directly into large tractor-trailer rigs (as here) or into railroad cars for shipment. In many small operations the chat is cleaned and sized for various purposes and sold on-site.

Some of the piles, which are snowy white, are as high as 142 feet and cover several areas. These chat piles provide an excellent topography for dune-buggies and off-trail bikes, and they also offer a pleasant relief to the surrounding flat countryside.

The Oklahoma Geological Survey currently is making an inventory of the remaining chat as part of a larger study in the area (see *Oklahoma Geology Notes,* v. 41, no. 1, p. 28, Feb. 1981).

Donald A. Preston

Oklahoma Geology Notes

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

Oklahoma Geology Notes 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; yearly subscription, $4. 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.

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OKLAHOMA GEOLOGY NOTES

OKLAHOMA GEOLOGICAL SURVEY, THE UNIVERSITY OF OKLAHOMA

Contents

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URANIUM, CHROMIUM, AND SELENIUM CONCENTRATIONS IN WATER FROM GARBER–WELLINGTON AQUIFER (PERMIAN), CENTRAL OKLAHOMA

Salman Bloch,[1] Christine D. Gay,[2] Debra E. Dunbar[3]

Abstract—Concern has been expressed recently regarding possible uranium, chromium, and selenium contamination of water in the Permian Garber–Wellington aquifer in central Oklahoma. Results of a study of the Oklahoma City 1° by 2° Quadrangle, undertaken as a part of the U.S. Department of Energy's Hydrogeochemical and Stream Sediment Reconnaissance (HSSR) program, show that concentrations of these three elements in the water from most wells sampled meet the U.S. Environmental Protection Agency (EPA) standard for drinking water.

The concentration of selenium in water from all wells sampled (189 wells) was found to be much below the upper limit of the standard for drinking water set by the EPA (the upper limit for selenium is 10 ppb, parts per billion). Samples from four wells exceeded the upper limit of the EPA standard for chromium in drinking water (50 ppb). However, two of these samples showed an excess of only 1 ppb. Water from 18 wells exceeded the *proposed* upper limit, 14.8 ppb (or 10 picocuries per liter), for uranium in drinking water.

Introduction

The quality of water in the Garber–Wellington aquifer (Permian) in central Oklahoma recently has become the subject of considerable interest (see, e.g., articles in *The Norman Transcript*, March 24, 1981, p. 1–2; *The Norman Transcript*, March 27, 1981, p. 1; *The Sunday Oklahoman*, March 29, 1981, p. 20-A; and *The Norman Transcript*, April 3, 1981, p. 1). Concern has been expressed regarding contamination of the water by uranium, chromium, and selenium. The purpose of this note, based on the results of the U.S. Department of Energy's (DOE's) Hydrogeochemical and Stream Sediment Reconnaissance (HSSR) program, is to show that concentrations of the three elements in question in the water from most wells sampled

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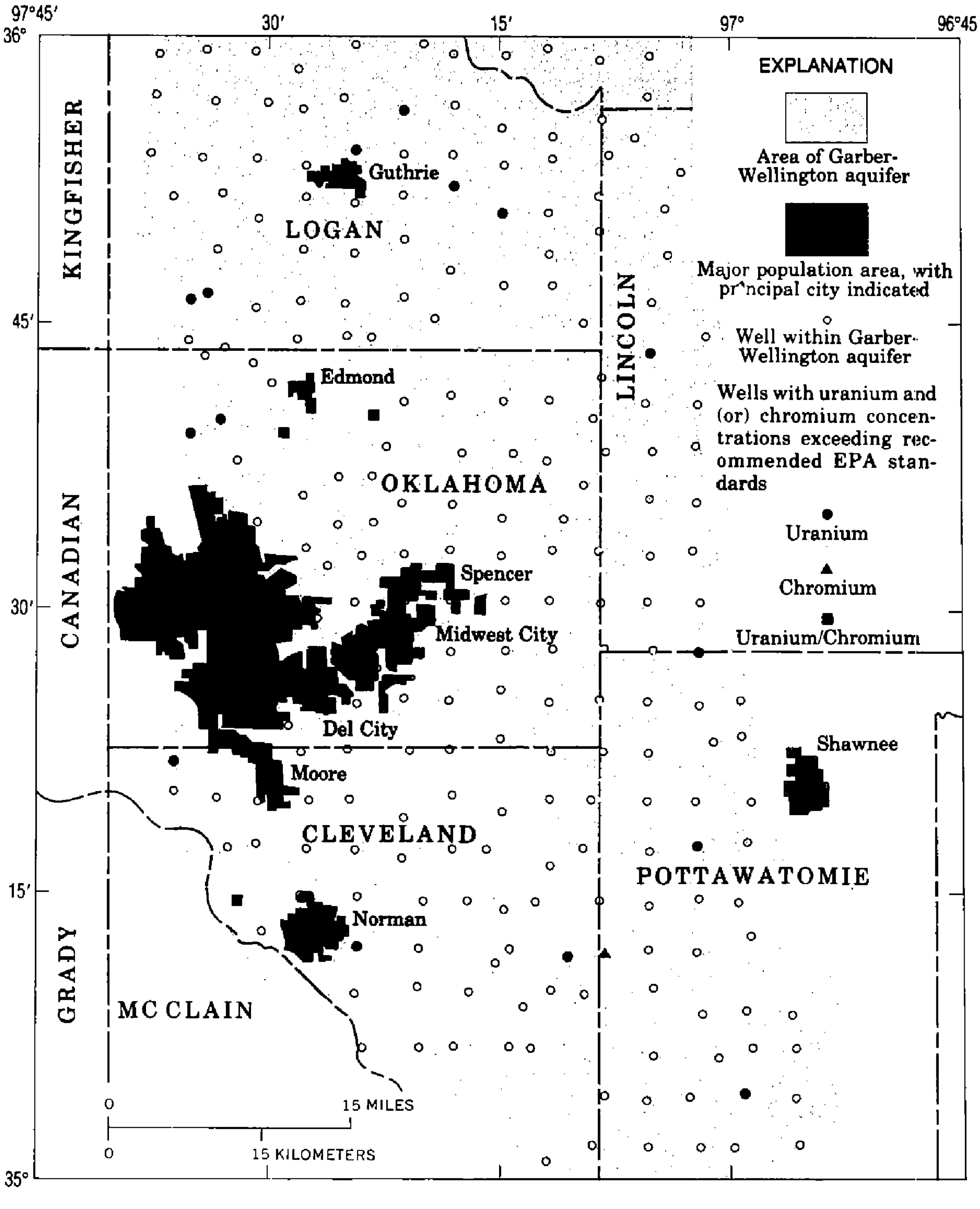

Map of part of 1° by 2° Oklahoma City Quadrangle showing location of wells within the Garber-Wellington aquifer that were sampled as part of NURE program.

meet the standard for drinking water established by the U.S. Environmental Protection Agency (EPA).

The Garber–Wellington aquifer provides a major source of water for the residents of central Oklahoma. In terms of basic geographic units, designated by the National Topographic Map Series (NTMS) quadrangles, central Oklahoma falls within the 1° by 2° Oklahoma City Quadrangle (scale, 1:250,000). This quadrangle covers a surface area of approximately 20,126 km^2 (7,774 mi^2) between 35° and 36° north latitude and 96° and 98° west longitude and includes the following counties: all of Oklahoma and Lincoln; almost all of Cleveland, Pottawatomie, Seminole, and Okfuskee; most of Creek and Logan; and parts of Hughes, Pittsburg, Kingfisher, Canadian, Grady, McClain, Okmulgee, and Payne.

In addition to the HSSR evaluation, the quadrangle was evaluated in terms of its potential for economic uranium mineralization as part of DOE's National Uranium Resource Evaluation (NURE) program.

In all, 809 water wells were sampled, and the water was analyzed for alkalinity, pH, dissolved oxygen, conductivity, sulfate, arsenic, selenium, uranium, silver, aluminum, boron, barium, beryllium, calcium, cobalt, chromium, copper, iron, lithium, magnesium, manganese, molybdenum, nickel, phosphorus, scandium, vanadium, yttrium, zinc, and zirconium. Ground-water samples were collected from the nearest available water well to the node of a 3.2-mile (5.1-km) grid. Uniform geographic distribution of data points (one per 10 mi^2 or 26 km^2) was obtained in this way. During the course of the investigation, 189 wells from the Garber–Wellington aquifer were sampled. The sampling was done by the Oklahoma Geological Survey (Charles J. Mankin, project director). The analytical work was conducted by the Oak Ridge Gaseous Diffusion Plant of Union Carbide Corp., Oak Ridge, Tennessee (S. W. Arendt, project manager).

The well-water sampling was initiated in October 1977 and completed in February 1978. The final report was published in July 1978 (Union Carbide Corporation, 1978). The discussion in this note is based on data published in the HSSR report for the Oklahoma City Quadrangle. Additional information on water resources of the Oklahoma City Quadrangle is provided in Bingham and Moore (1975).

Discussion

Uranium in Garber–Wellington Water

There is no established limit for uranium (U) in the standards set by the EPA for drinking water. The following analyses were done by fluorometry;

the detection limit for uranium in water by this method is 0.2 ppb (parts per billion):

Number of wells sampled	*Concentration range of U (in ppb)*
79	1 or less
58	1.1–5.0
18	5.1–10.0
16	10.1–14.8
6	14.9–30.0
6	30.1–50.0
5	50.1–100.0
2	>100.0

If the limit of uranium in drinking water is set at 10 pCi/L (picocuries per liter), as proposed by the EPA, 19 wells with uranium concentrations above 14.8 ppb would exceed the standard (for conversion of pCi units to ppb of uranium, see Appendix).

The median for the samples reported above is 1.3 ppb uranium, and the mean, 8.8 ppb. The 85th percentile value of uranium is 12.3 ppb.

Possible Factors Controlling Uranium Concentration in Garber–Wellington Water

Uranium mobility in solution is governed by the stability of its two natural valence states, U^{4+} and U^{6+} (or UO_2^{2+}). Because of the general immobility of uranium in its tetravalent oxidation state, primary uranium minerals (e.g., uraninite and coffinite) are stable under reducing conditions. In general, sandstones containing coalified wood, pyrite, or hydrogen sulfide may provide hosts for uranium deposits. In contrast, under oxidizing conditions in surface waters and shallow ground waters, tetravalent uranium phases (if originally present) become soluble owing to oxidation to the hexavalent state. Uranium in its hexavalent state is characterized by high mobility and occurs in the form of the UO_2^{2+} cation or its complexes (Langmuir, 1978). The mobility of uranium in oxidizing environments depends on the mineralogical form of this element. If uranium occurs in resistant minerals, such as zircon, it can be transported only mechanically and not chemically.

The uranyl (hexavalent) ions react in various ways with the geological environment. In the presence of vanadium ions or ionic complexes, stable uranium vanadates (e.g., carnotite and/or tyuyamunite) may form. In the absence of vanadium or suitable reductants, uranium is dispersed in the ground-water–rock system.

The oxidized "red-bed" nature of the Garber–Wellington aquifer precludes the occurrence of any major uranium accumulations in the system. However, minor shows, similar to the ones in north-central Oklahoma, might be present in the subsurface. In the Enid 1° by 2° Quadrangle, north-central Oklahoma, several "red-bed" uranium–copper occurrences are known in the Oscar Group (uppermost Pennsylvanian) and in the Wellington Formation. The mineralization is associated with plant debris and is confined to small, gray, fine-grained sandstone lenses within a red-bed sequence. The most reasonable source for the copper and uranium is the red beds, with copper and uranium released by subsurface breakdown of minerals, (Bloch and Johnson, 1981). The maximum uranium concentration was found to be 125 ppm.

It must be emphasized that the amount of uranium in natural waters is controlled not only by the initial concentration of this element in the rock in the zone of water flow but also by the rate of flow, the rate of chemical weathering, and the migration capacity of uranium. The migration capacity depends, in turn, on the concentration of common ligands, Eh–pH, and the sorptive properties of the rocks.

The geochemical properties of uranium, mentioned previously, may cause a water sample from a well close to a uranium deposit in a reduced part of an aquifer to contain less uranium than a sample from a barren oxidized part of an aquifer. Childers (1979) reported water samples that contained less than 2 ppb uranium from reduced aquifers close to ore bodies. In oxidized aquifers, such as the Garber–Wellington, relatively high uranium concentrations in ground water could build up from disseminated sources in rocks with a "normal" content of a few ppm (parts per million) of uranium.

Perhaps the most reliable indicator of the presence or absence of a subsurface ore body is the state of saturation ("saturation index") of the ground water with respect to uranium ore minerals (e.g., Bloch, 1979; Langmuir and Chatham, 1980; Runnells and others, 1981). Saturation indices are available, at this time, for only one of the Garber–Wellington water samples with a relatively high (60.1 ppb) uranium concentration. The data indicate that this water is strongly undersaturated with respect to all uranium phases. For example, the saturation index for uraninite is −4.9; coffinite, −5.4; carnotite, −4.5; tyuyamunite, −2.0 (the value of −4.9 for uraninite indicates that the ion-activity product for this mineral is only $1 \times 10^{-4.9} = 0.000012$ as large as the solubility product for uraninite). These results are a further indication that the relatively high uranium concentrations are not caused by the presence of major uranium accumulations in the subsurface.

Finally, it should be pointed out that the water from the Garber–Wellington aquifer is not likely to have any significant concentrations of radium-226, a daughter product of uranium-238. Radium-226 in high concentrations is believed to create a radiological health hazard. The lithology of the Garber–Wellington rocks is such that any radium-226, generated by decay of uranium-238, will partition with the rock rather than with the water. Thus, radium in the water can be expected to occur in concentrations well below the EPA limit for this element in drinking water (5 pCi/L). For a detailed discussion of the geochemistry of radium, see Bloch and Key (1981) and Bloch and Craig (1981).

Chromium in Garber–Wellington Water

The water was analyzed for chromium (Cr) by plasma-emission spectrometry. The detection limit for chromium in water by this method is 4 ppb. The maximum limit for chromium in the EPA standards for drinking water is 50 ppb.

Number of wells sampled	*Concentration range of Cr (in ppb)*
160	4 or less
12	5–10
8	11–20
6	21–50
3	51–100
1	>100

Selenium in Garber–Wellington Water

Selenium (Se) in the water was measured by atomic-absorption spectrometry. The detection limit for selenium in water by this method is 0.2 ppb. The upper permissible limit for this element in EPA standards for drinking water is 10 ppb.

Number of wells sampled	*Concentration range of Se (in ppb)*
130	0.2 or less
55	0.3–1.0
3	1.1–5.0
1	5.1–10.0

It is interesting to note that recent research indicates that relatively high selenium concentrations may be beneficial in drinking water. According to a paper presented by D. Frost at a NAS–NRC meeting on "Diet, Nutrition and Cancer" in November 1980 (reported in *Interface*, 1981):

"the labeling of Se as a carcinogen by the FDA in 1943 followed the induction of liver cirrhosis from the feeding of seleniferous wheat or corn or of potassium ammonium sulfoselenide at toxic levels to rats. Some tumors, which did not metastasize, grow out of the cirrhotic livers. In 1966 it was reported that the feeding of selenite or selenate at grade levels did not cause cancer in rats, but this did not alter the FDA's view of Se as a proven carcinogen. In 1969, evidence came that cancer mortality appears lower in areas of high ambient Se than in areas with low ambient Se. This indicated possible value of Se against cancer. The value of selenicals to cause cancer regression was known and is again under study, now to regress transplanted tumors."

Other studies also suggest that selenium may be a potent tool in chemiprevention of cancer.

Summary

Water samples from 189 wells pumping from the Garber–Wellington aquifer in central Oklahoma were analyzed for a number of elements, including uranium, chromium, and selenium, as part of the HSSR program. The sampling density was one well per approximately 10 square miles. The concentration of selenium in all samples was found to be much below the upper limit (10 ppb) of the EPA standard for drinking water.

Samples from four wells exceeded the upper limit (50 ppb) of the EPA standard for chromium in drinking water. However, two of these samples showed an excess of only 1 ppb.

Nineteen wells exceeded the *proposed* EPA upper limit for uranium in drinking water of 14.8 ppb (or 10 pCi/L). These wells represent about 10 percent of the total sample population.

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Appendix

Three isotopes of uranium occur naturally: U-238, U-235, and U-234. The abundance, activity percent, and half-lives of these isotopes are given in the table below.

Isotope	*Abundance (wt. %)*	*Activity % (radio-active-decay events per unit of time)*	*Half life*
U-238	99.28	48.9	4.51×10^9 years
U-235	0.71	2.2	7.1×10^8 years
U-234	0.0054	48.9	2.48×10^5 years

The suggested limit for uranium in drinking water is 10 picocuries per liter (10 pCi/L). One picocurie is equal to one-trillionth (10^{-12}) of a curie. In 1950 a joint commission of the International Union of Pure and Applied Chemistry and the International Union of Pure and Applied Physics adopted the following definition of a curie: "The curie is a unit of radioactivity defined as the quantity of any radioactive nuclide in which the number of disintegrations per second is 3.700×10^{10}."

The pCi/L units are commonly used in health and environmental sciences, while geologists and geochemists use parts per billion (ppb) to express concentrations of uranium in various media. It would be instructive, therefore, to convert units of disintegration rate (pCi) to units of concentration (ppb) for uranium. As an illustration, we can calculate the weight, *W*, in ppb of 1 pCi of U-238 (see Friedlander and others, 1964, p. 82):

$$1.\ \lambda = \frac{0.693}{4.51 \times 10^{9} \times 3.156 \times 10^{7}} = 4.88 \times 10^{-18}.$$

(λ is the decay constant for U-238, 0.693 = *ln* 2, and $4.51 \times 10^{9} \times 3.156 \times 10^{7}$ is the half life of U-238 in seconds.)

$$2.\ -\frac{dN}{dt} = \lambda N = \lambda \frac{W}{238} \times 6.02 \times 10^{23} = 1.23 \times 10^{4} W.$$

($-\frac{dN}{dt}$ is the rate of decay, 238 is the mass number of U-238, and 6.02×10^{23} is the Avogadro number, with $-\frac{dN}{dt} = 3.7 \times 10^{-2}$ disintegrations per second (1 pCi).

$$3.\ W = \frac{3.7 \times 10^{-2}}{1.23 \times 10^{4}} = 3 \times 10^{-6} g.$$

Thus for U-238, $\frac{1 pCi}{L} = 3$ ppb.

As pointed out in the table, the activity percent for U-238 is 48.9 or 4.89 pCi/L allowable in drinking water. For U-238, 4.89 pCi/L translates into 14.7 ppb.

Similar calculations can be made for U-235 and U-234.

The contribution of each of the three uranium isotopes toward a total disintegration rate of 10 pCi/L of uranium will be as follows:

U-238	$\frac{4.89 pCi}{L}$	14.7 ppb
U-235	$\frac{0.22 pCi}{L}$	0.1 ppb
U-234	$\frac{4.89 pCi}{L}$	0.8×10^{-3} ppb

For naturally occurring uranium in isotopic equilibrium, $10 \frac{pCi}{L}$ is equal to 14.8 ppb.

HARRISON APPOINTED CHAIRMAN OF SEPM RESEARCH GROUP

William E. Harrison, petroleum geologist and geochemist with the Oklahoma Geological Survey, has accepted an appointment as chairman of the Society of Economic Paleontologists and Mineralogists' (SEPM) Research Group on the Organic Geochemistry of Sediments. He began a 2-year term of office at the annual meeting of The American Association of Petroleum Geologists (AAPG), which was held recently in San Francisco. SEPM is a division of AAPG.

The research group, sponsored by the national SEPM research committee, was formed to promote the practical application of methods and the results of investigations in organic geochemistry as they relate to energy resources. Harrison says that research colloquia offered at national AAPG–SEPM meetings "are designed to provide a rapid means to exchange information on topics of common interest." He reports that to achieve this purpose, recent meetings of the group have presented sessions on "Paleoenvironmental Indicators in Petroleum Exploration" and "Geomicrobiological Applications in the Petroleum Industry."

As chairman, Harrison will organize and preside over the 1982 meeting of the research group to be held in Calgary, Alberta, Canada, and the 1983 meeting, which will be held in Dallas, Texas.

AEG CONVENTION SET FOR PORTLAND

The Association of Engineering Geologists has scheduled its annual convention for September 27–October 1 of this year in Portland, Oregon.

The meeting will include technical sessions and field trips relating to nuclear-waste disposal, nonnuclear-waste disposal, instrumentation, ground water and hydrology, risk analysis, a liability symposium, and a number of other events.

A special session and field trip will make a survey of affected areas near Mount St. Helens. The group will take a charter flight into red-zone and blast-zone areas, as well as over the crater left by the explosion.

Speakers from the USGS, USACE, and USFS will go along with the group to provide detailed explanations of the event.

For more information, contact David K. Rankin, Editor, AEG Newsletter, Kelly/Strazer Associates, Inc., 3906 S.W. Kelly Avenue, Portland, Oregon 97201.

OGS ISSUES INDEXES TO GEOLOGIC MAPPING

Two sets of map indexes delineating areas that were mapped in the State between 1901 and 1976 have been released by the Oklahoma Geological Survey as Geologic Map 21 and Geologic Map 22.

Map GM-21, *Index to Surface Geologic Mapping in Oklahoma (through 1976)*, compiled by John F. Roberts, Kenneth V. Luza, and James A. Corff, consists of two plates: "Index to Published Surface Geologic Mapping in Oklahoma, 1901–1976," and "Index to Unpublished Surface Geologic Mapping in Oklahoma, 1949–1976." An inset map outlining regionally mapped areas is included on the first plate.

Map GM-22, an *Index to Subsurface Mapping in Oklahoma (1967—1976)*, contains three plates with the mapped areas separated in chronological order of mapping. Plate 1 is an "Index to Subsurface Mapping in Oklahoma, 1967–1970"; plate 2 shows mapping from 1971 through 1973; and plate 3 contains an "Index to Subsurface Mapping in Oklahoma, 1974–1976." Plate 1 has an inset regional map; regional mapping is superimposed on the other two plates of this series. GM-22 was compiled by John F. Roberts with assistance from Timothy Drexler, Elizabeth A. Ham, Kurt Hollocher, Kathryn N. Jensen, Kenneth V. Luza, and Matthew W. Totten.

Areas outlined on each of the five maps are numbered, with numbers corresponding to numbers of the bibliographic references listed on each map. In all, 343 references were used in compiling the map indexes.

The maps of GM-21 supersede previously published indexes, while those of GM-22 supplement them.

Maps GM-21 and GM-22 represent the culmination of a project begun by John F. Roberts in 1967 to update previous map indexes published by the OGS. Roberts, a long-time petroleum geologist with the Survey, died in 1978.

Map GM-21 and Map GM-22 can be obtained from the Oklahoma Geological Survey at the address given inside the cover. The price is $4 for GM-21, and $5 for GM-22.

ROY D. DAVIS RETIRES AFTER 27 OGS YEARS

Roy Derrell Davis, Oklahoma Geological Survey cartographer, retired June 12 after 27 years of service to the Survey and the University.

Roy joined the survey staff July 6, 1954, as geological draftsman, advancing through the years to become chief geological draftsman and later chief of the cartographic section. He retired as cartographic draftsperson II, a new classification established with reorganization of the section in 1979.

Roy's 27 years represent the establishment of a record for full-time continuous service at the Oklahoma Geological Survey. Malcolm C. Oakes, who died in 1977, served a total of 42 years as an OGS geologist, but 17 years were spent as a half-time consultant. William E. Ham was on the staff from 1941 to 1970 as geologist, assistant director, interim director, and associate director, but took a year's leave of absence in 1966–67 to serve as visiting professor at The University of Kansas and during an earlier year he was on leave to complete residence work toward a Ph.D. at Yale University.

So that leaves the record with Roy D. Davis, who has become known in the field of geology (and elsewhere) for the excellence of his craftsmanship in ink drawings and in the reproduction of maps, graphs, charts, tables, and figures.

He is perhaps even more widely known for what he calls his "mud paintings"—reproductions painted on stone with natural, earth-derived pigments. His work includes ancient cave paintings; Aztec, Toltec, Mixtec, and Egyptian paintings; and aboriginal bark paintings. Examples of his work now hang in homes and private collections in many places of the world.

ROY D. DAVIS

Roy was born near Ft. Towson in southeastern Choctaw County, Oklahoma, which is about as far south as you can go without entering Texas. When he was 6 years old, the family moved to Valliant, in McCurtain County, where he attended schools, graduating from Valliant High School. His interest in art began at an early age. He promoted the establishment of an art class when he was in the seventh grade, and later became art editor of his high school paper.

By the time he became 18, this country had entered into the great struggle of World War II. Roy joined the U.S. Navy and served for 2 years as a carpenter, working in ship repair. Part of his tour of duty was spent on Midway Island in the Pacific theater. Later he worked in the Oklahoma City area at Tinker Air Force Base, where he supervised the installation of wood paneling in aircraft.

During his time at Tinker, he attended night classes at Oklahoma City University, and found a practical application for his artistic bent through training in graphics and engineering drawing. He has been at it ever since, with ever-increasing expertise.

The survey will miss his skills and professional advice, but that doesn't represent the full impact his absence will have. Following this article is a humorous yet accurate job description for a possible replacement for Roy's position. It explains in part what will be lacking at the OGS. It was prepared for presentation along with a going-away gift at a luncheon given in his honor by Roy's friends and family.

Roy is a devoted family man, and he and his wife, Bonnye, have nine children of all ages. He plans during his "retirement" to stay at home but to continue to work in cartography on a contract basis and to produce more mud paintings.

We all wish him well.

Job Description: Replacement for ROY D. DAVIS

The person for this position must display the highest degree of skill in the performance of the following complex duties:

1. When receiving assignments that are accompanied by notes and sketches, he or she must know instinctively what the author really wants.
2. Must determine the necessary cartographic operations and materials required for a job, then wait until Mary Ellen Kanak leaves the room and take the necessary materials from her desk.
3. Must display proper telephone etiquette by shouting "Halo Statue" the moment any phone rings.
4. Must make all persons feel welcome with a good morning hug or a greeting of "Good morning, Sunshine."
5. Must demonstrate the expert skills of a surgeon when using an X-Acto knife.
6. Must know a lot of off-color but not crude jokes.
7. Must be willing to listen kindly to sad tales.
8. Must have an *unquenchable* appetite for stale popcorn.
9. Must complain bitterly when an editor offers a good suggestion.
10. Must have the ability to coordinate with the editor and geologist by proceeding as he or she sees fit.
11. Must make adjustments to accommodate new methods, materials, and concepts—if it suits his or her fancy.
12. Must have a down-home saying for all occasions.
13. Must have an amazing repertoire of two songs, be able to whistle two more, and to dance a jig to all.
14. When leaving the office, must announce that he or she will be "Rat back."

NOTES ON NEW PUBLICATIONS

Preliminary Report on Uranium Deposits at Cement, Caddo County, Oklahoma

The DOE has issued this report which resulted from uranium investigations carried out by the U.S. Atomic Energy Commission during the 1950's to 1970's. It is being made public to provide information concerning the occurrence of uranium, as well as to record past exploration activities of the AEC.

Compiled by E. P. Beroni and T. E. Latta, this 20-page report is available in microfiche only.

To order: Send $3.50, check or money order, to Bendix Field Engineering Corp., Technical Library, P.O. Box 1569, Grand Junction, Colorado 81502.

CAT Map-Data Catalog

In order to help users gain better, faster, low-cost access to the cartographic holdings of federal, state, and private agencies, this catalog tells how to order a wide range of mapping byproducts that may help to fill one or more special needs.

For each such product, the catalog describes and illustrates the product offered, explains the scope of geographic coverage available, lists typical uses of the product, and explains how to order the needed products. Prices for the variety of products, formats, and sizes are contained in a separate and periodically updated list. The price list is available free upon request from any National Cartographic Information Center office.

To order the catalog, send check or money order for $6, made payable to the U.S. Geological Survey, to Distribution Branch, Text Products Section, U.S. Geological Survey, 604 South Pickett Street, Alexandria, Virginia 22304.

Geology of Eastern Part of Marathon Basin, Texas

Professional Paper P 1157, by P. B. King, consists of 40 pages plus a plate in pocket.

Order from: Distribution Branch, Text Products Section, U.S. Geological Survey, 604 South Pickett Street, Alexandria, Virginia 22304. Price: $3.50.

A Guide to Obtaining Information from USGS

Compiled by P. F. Clarke, H. E. Hodgson, and G. W. North, this

42-page publication was published as Circular C 0777.

Order from: Distribution Center, U.S. Geological Survey, 604 South Pickett Street, Alexandria, Virginia, 22304.

Selected Water-Level Records for Oklahoma, 1979–80

This 59-page report was written by W. B. Mills and D. E. Spiser. Report OF 80-0975.

Order from: Oklahoma Water Resources Board, 12th Floor, NE 10th and Stonewall, Oklahoma City, Oklahoma 73105. Price: $3.50 microfiche, $7.50 paper copy.

Seismic Stratigraphy of Baltimore Canyon Trough

This 76-page report by J. S. Schlee is cataloged as Open-File Report OF 80-1079.

Order from: Open-File Services Section, Branch of Distribution, U.S. Geological Survey, Box 25425, Federal Center, Denver, Colorado 80225.

Price: $3.50 microfiche, $9.75 paper copy.

Preliminary Synthesis of Subsurface Stratigraphy of Niobrara Formation (Upper Cretaceous) in Northern Great Plains

Issued as Open-File Report OF 80-1266, this publication by G. W. Shurr and Jayne Sieverding consists of 19 pages plus six over-sized sheets, scale 1:1,000,000.

Order from: Open-File Services Section, Branch of Distribution, U.S. Geological Survey, Box 25425, Federal Center, Denver, Colorado 80225.

Price: $21 paper copy, $6.50 microfiche.

The Mineral Industry of Oklahoma

Preprinted from the 1978–79 U.S. Bureau of Mines' *Minerals Yearbook,* this 14-page booklet provides statistical information on the nonfuel minerals industry in Oklahoma. Authors are Robert H. Arndt and Kenneth S. Johnson.

Also included is information on legislation and government programs, employment and wages, and production values.

A limited number of single copies of this booklet are available from the Oklahoma Geological Survey at the address given on the inside of the front cover.

RURAL WATER SYSTEMS EXAMINED BY OWRB

This large (11 inch × 17 inch), attractive volume published by the Oklahoma Water Resources Board (OWRB), is an atlas of maps and data sheets of rural water systems in 75 of Oklahoma's 77 counties. Only Ellis and Cimarron Counties have abstained from this program, under which nonprofit organizations have been formed to provide rural water and sewer systems to isolated communities and families.

The introductory text of the publication presents a highly informative and detailed history of the development of the program, which had its beginnings following the disastrous period of the Dust Bowl and the Great Depression of the 30's.

In 1933, the federal government established a Soil Erosion Service that was later incorporated into the U.S. Department of Agriculture's Soil Conservation Service. Watershed and flood protection was instituted in 1936, as was rural electrification. Loans and grants for rural water systems were authorized in 1961, all under national direction, but it was determined shortly thereafter that State action was necessary to set up the rural districts as public bodies authorized to borrow from the federal government.

In Oklahoma, the first act for this purpose was passed by the 29th Legislature in 1963, and the first district, Nowata County Rural Water District No. 2, was organized the same year.

The program was expanded later to encompass water, sewage, solid-waste disposal, and natural-gas distribution. Coverage in Oklahoma has increased to include 398 systems.

Maps in the atlas are arranged alphabetically county-by-county, and display color-coded districts in each county. Survey data and water-quality analyses for each district are presented on facing sheets.

Rural Water Systems in Oklahoma, OWRB Publication 98, is available free on request from the Oklahoma Water Resources Board, Northeast 10th Street and Stonewall, Oklahoma City, Oklahoma 73105. Requests should be marked to the attention of Susan Lutz.

SECOND ANNUAL ALUMNI DAY A BIG SUCCESS

The second annual University of Oklahoma School of Geology and Geophysics Alumni Day was held at Gould Hall on April 24 of this year. Sponsored jointly by the OU Student Chapter of The American Association of Petroleum Geologists and the Gamma Chapter of Sigma Gamma Epsilon, the day's events featured presentations of student papers, a noon cookout, and an evening awards banquet.

Alumni Day, scheduled to coincide with the School's Alumni Board and Alumni Council spring meetings, provides an opportunity for students and alumni to meet on a formal or informal basis. In particular, it is intended that alumni learn of current activities and research in the geosciences at OU through student exhibits and presentations.

This year's Alumni Day also served as Professional Day, sponsored in alternate years by the Sigma Gamma Epsilon Chapters of The University of Oklahoma and Oklahoma State University. Professional Day activities included presentations of papers by geoscience students at both universities. Papers are judged, and the authors of the best three are given awards.

This year, 13 papers were presented by undergraduate and graduate students in topics ranging from seismology to biostratigraphy. First place in the contest was awarded to R. Kent Grubbs for his graduate thesis research on "Pennsylvanian Stratigraphy and Conodont Biostratigraphy of the Mill Creek Syncline, Arbuckle Mountains, Oklahoma." John R. Groves won the second-place award for the oral presentation of his thesis, "Foraminifers and Calcareous Algae

Page 88: *Left,* Graduate Douglas Neese at the technical session. *Right,* graduate student John Groves, Prof. Patrick Sutherland, and Prof. Harvey Blatt.

from the Type Morrowan (Lower Pennsylvanian) Region, Northwestern Arkansas and Northeastern Oklahoma.

Also presenting his master's thesis, Steven H. Tennant won third place with "Lithostratigraphy and Depositional Environments of the Upper Dornick Hills Group (Lower to Middle Pennsylvanian) of the Northern Part of the Ardmore Basin, Oklahoma." All three winners are graduate students working on master's degrees at The University of Oklahoma.

Other activities took place during, between, and after the oral reports. The sponsoring student organizations displayed literature, Oklahoma Geological Survey geologists presented poster sessions, and field-trip photographs were exhibited. In addition, a scale model of an oil rig—on loan from OU's Petroleum Engineering Department—was displayed, and the functions of a Schlumberger well-logging truck and OU's Norden seismic truck were demonstrated. Students showed off their cooking skills by rustling up a barbecued hamburger lunch with all the "fixin's."

The festivities resumed in the evening with the awards banquet sponsored by the School of Geology and Geophysics. After dinner, Dr. John S. Wickham, director of the School, recognized the alumni who had served on the Board and Council, as well as those students who had earned scholarships and those who had made outstanding contributions. Dr. Charles Mankin, director of the Oklahoma Geological Survey and national secretary of Sigma Gamma Epsilon fraternity, distributed that organization's awards for the year to: Greg Webb, outstanding junior; Jerry Tebo, outstanding senior; and Steve Mrkvicka, outstanding graduate student. Awards for student paper presentations were then handed out by Art DeGraffenreid, Sigma Gamma Epsilon treasurer. He also distributed the first annual

Page 89: *Left,* A demonstration of the famous Norden seismic truck. *Right,* Mrs. Craig Ferris and Dr. John Wickham.

Prof. David Stearns sharing a laugh with graduate students Hans Bisewski, Gary Stewart, and Leroy Mattingly.

faculty and graduate-student "Rockhead Awards" of dubious distinction. Students "voted" for the "Rockhead" recipients by placing pennies in coffee cans, each bearing the name of a faculty member or graduate student. The individuals with the most pennies at the end of the day won the awards . . . and the pennies. The winners were Dr. Harvey Blatt and Bob Goldhammer, professor and graduate student respectively.

Dr. David W. Stearns, Monnett Professor of Geology, presented the grand finale to a successful day and an enjoyable evening: a slide-show travelogue of the Bob Marshall Wilderness Area in the Sawtooth Mountains of Montana.

Elizabeth H. Bartlett

OKLAHOMA ABSTRACTS

GSA Annual Meeting, South-Central Section
San Antonio, Texas, April 13–14, 1981

The following abstracts are reprinted from *Abstracts with Programs, 1981,* of The Geological Society of America, v. 13, no. 5. Page numbers are given in brackets below each abstract. Permission of the authors and of John C. Frye, executive director of GSA, to reproduce the abstracts is gratefully acknowledged.

Morrowan Strata in the Arkoma Basin of West-Central Arkansas

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The Arkoma Basin of north-central Arkansas is an elongate structural trough bounded to the north by the Northern Arkansas Structural Platform and to the south by the Ouachita Fold Belt. The Morrowan sequence within the basin directly overlies the Mississippian Pitkin Formation and is overlain by the Atoka Formation of Pennsylvanian age. Sedimentation occurred in a variety of shallow marine and non-marine environments.

The basal Cane Hill Member of the Hale Formation is predominantly a shale succession with thin interbeds of sand and occasional massive sand bodies that accumulated on a shallow tide-dominated shelf. The overlying Prairie Grove Member is composed of several massive, calcareous sandstone units that accumulated in coastal sand environments during a southeast to northwest transgression interrupted by several regressive pulses. This transgression ultimately inundated the shelf and a carbonate and shale succession assigned to the basal Brentwood Member of the Bloyd Formation accumulated.

Regression after Brentwood sedimentation allowed the development of coastal plain environments to the west and fluvial systems to the east in which terrestrial shale and siltstone (Woolsey Member) and fluvial sand-

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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.

stone (Cannon Member) accumulated. The coastal plain setting was transgressed forming a widespread marine shale (Dye Shale Member) across the basin.

Facies patterns and thickness trends within the Morrowan succession indicate that deposition was completed prior to the development of the Arkoma Basin as an east-trending structural feature. [237]

Aspects of the Trace Element Geochemistry of Wichita Granites

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Rb and Sr have been determined by XRF techniques for 38 selected samples representing the 5 presently recognized Wichita Granites (Mt. Scott, Headquarters, Reformatory, Lugert, Quanah) from the Wichita Mountains, Oklahoma. Data on concentrations (ppm) of U(3.5-4), Th(12-15), Zr(530-540), Hf(13), Ta(4.5), and the rare earths in the Mt. Scott Granite were obtained by INAA. These data, when combined with bulk rock chemistry, provide further characterization of this unique province of Cambrian A-type granites.

Myers and Gilbert (1980, EOS *61*, 1155) defined 3 chemical classes within the Wichita Granite Group. Rb-Sr for these are

class	average *Rb* (ppm)	average *Sr* (ppm)
Mt. Scott (wt% SiO_2: 71.5-73.5)	126	160 (90; 260)
Reformatory (74.0-74.7)	129	64
Mountain Park (75.3-77.5)	174	39

Interestingly, the Sr values for Mt. Scott Granite are bimodal: extreme values of about 260ppm for the far eastern and western outcrops; 90ppm for the central outcrops. The high Sr samples probably represent the sill margins; low Sr ones are the last to crystallize and closer to the magma conduit. In general for the classes, Rb values are less variable whereas Sr can show wide scatter. Such variation, if primary, may indicate late crystal fractionation.

REE data for Mt. Scott show a distinct Eu anomaly and a deficiency in heavy rare earths. This may reflect early plagioclase and hornblende removal. Mt. Scott presently carries ovoid plagioclase as a diagnostic feature and hornblende as the principal dark mineral. [237]

Laramide-Style Basement Deformation in the Ouachita–Marathon Foreland[1]

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Late Paleozoic deformation was not restricted to the margins of the North American craton, but produced a province of basement uplifts which occupies the regions of Texas, New Mexico and Colorado. For the most part, these uplifts and the intervening asymmetric basins are recognized from sub-surface data, making recognition of the style of deformation difficult. In several instances, however, the uplifts appear to be bounded by high-angle reverse faults (north side of Amarillo–Wichita Uplift, southwest side of Uncompaghre Uplift and west side of Central Basin Platform) and the geometry of other uplifts demands dominantly vertical displacements. A number of similarities exist between these uplifts and uplifts of the middle Rocky Mountains of Wyoming and Montana. These are: 1) Isolated basement block uplifts are bounded on at least one side by a major fault; 2) Adjacent basins are asymmetric toward uplifts; 3) Motion of adjacent crustal blocks was both up and down with respect to sea level; 4) Extensive contemporaneous magmatism is lacking; 5) Provinces are bounded by active fold and thrust belts; 6) At least some uplifts are bounded by high-angle reverse faults. Thus, it is proposed that the two provinces had a similar origin. Considering the unresolved questions concerning the origin of the middle Rockies despite good exposure and detailed knowledge of Pacific–North American plate interactions, proposed origins for the Ouachita–Marathon foreland province are speculative.

Foraminiferal/Algal Microfacies in Type Morrowan (Lower Pennsylvanian) Rocks, Northwest Arkansas and Northeast Oklahoma

JOHN R. GROVES, School of Geology and Geophysics, The University of Oklahoma, Norman, Oklahoma 73019

Foraminifers and calcareous algae occur abundantly in carbonate rocks in the type Morrowan region in northwest Arkansas and northeast Oklahoma. Recurrent associations of dominant taxa facilitate in the recognition of foraminiferal/algal microfacies, which in turn aid in the reconstruction of depositional environments. High diversity–high abundance biotas throughout much of the Arkansas section reflect open shelf carbonate deposition. Less diverse biotas, dominated mainly by encrusting algae, suggest shallow water,

[1]Publication authorized by the Director, Bureau of Economic Geology, The University of Texas at Austin.

restricted conditions in contemporaneous environments in Oklahoma.

Keys to the recognition of open shelf conditions in northwest Arkansas (Evansville Mountain) are various associations of millerellids, archaediscids, monotaxids, and stacheiin algae. Within the sequence, distinctive associations can be recognized in the lower Brentwood Ls., upper Brentwood Ls. and Dye Sh., and Kessler Ls. Characteristic associations are less easily identified in the Oklahoma sequence at the Arkansas River, 40 miles to the southwest, with the exception of *Archaeolithophyllum–Cuniephycus*–asphaltinellid algal facies in the Braggs Mbr. of the Sausbee Fm. Otherwise, the Oklahoma sequence is characterized by tetrataxid and palaeotextulariid foraminifers to the exclusion of well developed millerellid–archaediscid–monotaxid faunas.

Chronostratigraphic correlation between the Arkansas and Oklahoma sections is made difficult by the paucity of potentially useful foraminifers in Oklahoma. However, the documentation of the abundant and diverse biota at the type Morrowan section in northwest Arkansas should make possible greatly refined correlations to that section from open shelf sequences elsewhere in North America. [238]

Pennsylvanian Stratigraphy and Conodont Biostratigraphy of the Mill Creek Syncline, Central Arbuckle Mountains, Oklahoma

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The Mill Creek syncline contains a lower and middle Pennsylvanian sequence that has not previously been critically examined. These strata have been removed by erosion elsewhere in the Arbuckles, and are structurally isolated from coeval exposures in the Ardmore Basin, northeast flank of the Arbuckles, and the frontal Ouachitas. Three major stratigraphic units are recognized at Mill Creek: a lower unit, dominated by carbonate grainstones (400′); a middle sandstone that thins westward (25-100′); and a variable upper unit containing carbonates, cherts, shales, and chert pebble conglomerates (450′).

A preliminary examination of the conodont faunas of the lower and upper units has revealed relationships that may bear on the current problem of Morrowan–Atokan boundary placement. The lower unit has yielded *Neognathodus kanumai, Idiognathoides convexus,* and *I. ouachitensis* (= *N. kanumai–I. ouachitensis* zone of Grayson, 1979), indicating an upper Morrowan (?) age. This zone is missing in the type Morrowan sequence in Washington Co., Ark. (Grayson and Sutherland, 1977; Grayson, 1979). Thus, its presence at Mill Creek provides further evidence for an erosional gap in the type Morrowan section. Further study of conodont and fusulinid ranges in the lower unit at Mill Creek will more accurately define its age. The base of the upper unit has produced a prolific fauna including *Diplognathodus orphanus, Neognathodus bothrops,* and *N. medadultimus*. These, which occur along with *Eusulinella* sp., suggest a mid-Atokan age. These relationships indicate a basal Atokan unconformity at Mill Creek if an upper Morrowan age for the lower unit is confirmed. A basal Atokan unconformity is recognized along the northeast flank of the Arbuckles (Rowett, 1963). [239]

Structural Framework of the Ouachita Mountains, Arkansas

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In most previous investigations the deformed Paleozoic rocks of the Ouachita Mountains of Arkansas have been divided into three poorly defined structural parts; the "core area", the "frontal zone" or "frontal belt" to the north, and the "southern Ouachitas" or "southern belt" to the south. Through recent studies of the surface geology we have divided the area into six generally east-west trending structural belts. Each belt is a unit having similar structural features and bounded by major fault systems. From north to south these belts are named Rover, Aly, Mount Ida, Little Rock, Hopper and Amity. The Mount Ida and Little Rock Belts include most of the older Paleozoic rocks and are the most intensely deformed.

The Belt concept suggests the following simplified sequential phases in the structural development of the Ouachita Mountains: (A) extensional faults and minor igneous intrusions, (B) major uplift with folding and décollement of the more competent units; (C) thrust faulting; (D) folding with further décollement; (E) thrust faulting and related backfolding; (F) cross faulting and folding with arching; and (G) further arching. It is suggested that Step A took place during the Early to Middle Paleozoic, Steps B-D during Middle to Late Pennsylvanian, Steps E-F during Late Pennsylvanian through Permian and possibly Triassic, and Step G from Triassic to Recent.

We conclude that: (1) the Ouachita Mountains in Arkansas are allochthonous and formed by northward overriding imbricately faulted thrust plates with major sole faults; (2) some thrust plates possibly involved Precambrian rocks in the subsurface; (3) the structural deformation likely narrowed the initial width of the Ouachita depositional basin by as much as 300 miles; and (4) a northward (?) dipping fossil Benioff subduction system was present to the south of the Ouachita Mountain outcrop belt. [239]

The Nature of the Mississippian–Pennsylvanian Unconformity in Portions of Cherokee, Muskogee, and Sequoyah Counties, Northeastern Oklahoma

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An unconformity of regional extent separates Mississippian and Pennsylvanian strata on the Ozark Uplift. The Pitkin Limestone, the highest Mississippian unit, wedges out to the north below the unconformity. The unconformity is easily recognized in the field because of the contrast between the dense, light gray-weathering, oolitic limestones of the Pitkin Formation, which contain no quartz grains, and the brown weathering sandy grainstones of the overlying Sausbee Formation (Lower Pennsylvanian). The Sausbee locally has at its base a cobble conglomerate of Pitkin Limestone clasts. The unconformity is regionally of low relief with karst features present but rare.

A north-south trending pre-Pennsylvanian valley feature can be delineated in Cherokee and Sequoyah Counties by west to east cross sections. An isopach map of the Pitkin in this area shows that the valley ranges in width from 2.0 to 3.7 miles and that it is at least 15 miles long. The relief on the unconformity is as much as 50 feet in this local area where it diverges from the regional norm. The Pitkin is locally removed with the Sausbee resting directly on the underlying Fayetteville Shale.

The features here developed are now being used as part of a regional analysis of the Mississippian–Pennsylvanian unconformity in the southern Ozark Uplift region. [259]

Depositional Systems of the Spiro Sandstone, Atoka Formation (Pennsylvanian) Within the Arkoma Basin of Arkansas

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The Arkoma Basin is an arcuate structural trough situated in west-central Arkansas. Extending approximately 250 miles along an east-west trend, the basin in Arkansas is bounded to the north by the Northern Arkansas Structural Platform and to the south by the front of the Ouachita Fold Belt System.

Paleozoic strata that comprise the basin-fill range from Cambrian to Pennsylvanian in age, and attain thicknesses of approximately 30,000 feet in the southern part of the basin adjacent to the Ouachita front. Northward the basin fill thins to around 4000 feet adjacent to the southern margin of the structural platform.

The Atoka Formation is a thick sequence of fine-grained sandstone units separated by laterally extensive black marine shales. The Spiro Sandstone is the basal unit of the Atoka Formation and directly overlies strata of the Bloyd Formation (Morrowan) in Arkansas. The unit is essentially confined to the subsurface of the basin and data used to establish its stratigraphic and sedimentological characteristics were obtained from mechanical logs of wells in west-central Arkansas.

An analysis of isopach and sandstone isolith maps indicates that sediment was transported from the north through south-flowing fluvial systems, forming a succession of elongate valley-fills. These systems fed elongate delta systems that prograded southward across the marine shelf.

Marine processes reworked deltaic sediments into interdeltaic areas. These processes formed an extensive blanket sand unit with superimposed trends of thickened strata in fluvial and deltaic settings and thinner sand units interbedded with shale in interdeltaic areas. [260]

Transport and Depositional History of the Wedington Sandstone of Northwestern Arkansas

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The Wedington Sandstone Member of the Fayetteville Formation is a Chesterian age, fluvial to marine deltaic depositional sequence. This predominantly fine to medium grained sandstone of thin to moderate thickness and limited lateral extent was deposited from eastern Oklahoma to central Madison County in northwestern Arkansas in a belt approximately 40 miles wide. The Wedington is situated in the middle to upper part of the Fayetteville Shale Formation.

The Wedington is composed of single-to-multiple sandstone units interbedded with shale and coal-bearing shale. The multiple sandstone units are composed of large scale, trough cross-stratified sets. Each set truncates the upper portion of the underlying set indicating several phases of in-channel deposition. Where the channel facies predominates, the member ranges from 30 to 80 feet thick and is composed of three to five distinct channel sequences. Paleocurrent measurements taken from in-channel cross stratification indicate a southwest-to-southeast current direction.

The Wedington Member not within the channel facies is generally less than 30 feet thick and is composed of only one or two sandstone units. [261]

Application of the WATEQF Computer Model to Hydrogeochemical Exploration for Uranium Mineralization in West-Central Oklahoma

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A number of uranium occurrences in the Clinton 1° × 2° Quadrangle in west-central Oklahoma have been reported in the last 25 years. The surface mineralization may be indicative of shallow subsurface U accumulations. Groundwater sampling offers a means of tracing such accumulations, if the chemistry of the waters can be properly interpreted. Because the amount of uranium in water is controlled by the rate of flow, the rate of chemical weathering, and the migration capacity of the uranium—not by the initial

concentration of U in the rock in the zone of water flow only—interpretation of hydrogeochemical data is very difficult. Results of the HSSR program in the Clinton Quadrangle indicate that a very poor interrelationship exists between the concentration of uranium and elements often found useful in delineating potential sedimentary U deposits (pathfinder elements: As, Mo, Se and V). In an attempt toward better understanding of data generated by the HSSR program and follow-up studies, approximately 700 groundwater analyses have been interpreted using the WATEQFC computer model. WATEQFC describes, among others, the solubility and speciation of the minerals and elements known to be important in sedimentary U deposits. As a whole, maps of saturation indices generated for the Clinton Quadrangle (an area of about 19,000 km^2) are no more useful in locating specific sites of interest than a map of total dissolved U. In such a large area it is very difficult to delineate meaningful trends and anomalies, in any parameter, with so few samples. However, modeling of the groundwater from smaller, selected sites has yielded suggestions as to possible targets for further investigation. [261]

Common Lead Analysis of Glen Mountains Layered Complex and Mt. Scott Granite, Wichita Mountains, Oklahoma

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Two plagioclase samples from the Glen Mountains Layered Complex and alkali feldspar from the Mt. Scott Granite were analyzed for common Pb isotope ratios. These samples were stepwise dissolved in HF and feldspar in each step was analyzed for Pb isotope composition and U and Pb content. The isotopic composition of Pb varied considerably among the steps of each sample and the isotope ratios of each step required correction for U decay. Pb isotope ratios of Mt. Scott Granite were corrected using their measured age of 525 m.y. Common Pb for this sample, defined as the least radiogenic corrected Pb ratios, has $^{207}Pb/^{204}Pb = 15.510$ and $^{206}Pb/^{204}Pb = 17.726$, which yield a model age of 509 m.y.

Because the age of the layered complex is unknown, isotope ratios of these two samples were corrected for all ages between 1500 and 100 m.y., in order to determine at what correction age their common Pb ratios were most similar. This correction age was 600 m.y. and common Pb thus corrected has $^{207}Pb/^{204}Pb = 15.544$ and $^{206}Pb/^{204}Pb = 17.789$ for one sample, and $^{207}Pb/^{204}Pb = 15.546$ and $^{206}Pb/^{204}Pb = 17.794$ for the other. These isotope ratios yield a model Pb age of 518 m.y.

These data strongly support a late Cambrian age for both units. All three samples plot close to the mantle Pb growth curve, which is consistent with mantle derivation of layered complex magmas. The lower common Pb isotope ratios of Mt. Scott Granite suggest an origin by partial melting of

U-depleted, metamorphic crustal rock. It is possible that layered complex magma was the heat source for this melting event. [262]

Deep-Water Deposition of Ordovician Strata in the Ouachita Mountains, Arkansas and Oklahoma

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Early workers in the Ouachita Mountains placed the Ordovician strata in deltaic and restricted shallow-water marine depositional environments. Subsequent investigators generally followed this regime until the early 1950's when concepts of deep-water marine depositional environments were applied to portions of the Ordovician through Middle Pennsylvanian rocks. Recent workers in the Ouachita Mountains may be grouped into two general categories concerning models for Ordovician deposition: (1) all the rocks were deposited in deep-water marine environments; or (2) all or most of the rocks were deposited in deltaic or shallow-water marine environments.

During our studies over the past decade we have not found any indigenous shallow-water marine sedimentary structures, invertebrate fossils, or trace fossils in Ordovician rocks of the Ouachita Mountains. However, there are lithic units with bottom marks, trace fossils and other features considered to be of deep-water marine origin. Numerous thin-bedded, dense, blue-gray limestones are thought to represent *in situ* deep-water marine deposits formed above the carbonate compensation depth. Lithologies and features that have been misinterpreted as being shallow-water marine origin include: (a) cross-laminations; (b) cleavage refraction in sandstones; (c) slump and slurry intervals containing flowage structures and superposed erratic blocks; and (d) transported bioclastic, oolitic and pelletoidal limestones.

We conclude that all Ordovician strata in the Ouachita Mountains from the Early Ordovician Collier through the Late Ordovician Polk Creek Formations are proto-Ouachita bathyal platform or trough deposits and represent either: (1) indigenous pelagic or hemipelagic deposits; or (2) turbidity or bottom current–submarine fan and related facies, combined with episodes of slump and slurry detachments all derived from "northerly" flanking shelf, slope, and submarine ridge sources. [263]