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Volume 30 December 1970 Number 6

OKLAHOMA GEOLOGY NOTES

Cover Picture

Radar Imagery of the Potato Hills

The illustration on the cover was produced from Side-Looking Airborne Radar (SLAR) imagery of the Potato Hills in parts of Pushmataha and Latimer Counties in southeastern Oklahoma. The image was acquired for NASA in September 1965 using a Westinghouse K-band system (wavelength 1.13-1.69 cm) and was constructed by photographing a traveling light beam whose intensity is modulated by the radar energy returned from the ground.

Radar imagery is a spatial presentation of the relative differences in the way surface features back-scatter radar energy. The low hills of Paleozoic rocks shown on the cover give a strong back-scattering of radar energy, thus enhancing the topographic relief and providing a good display of major folds. The effect of foreshortening is dependent on the radar-look direction, which is toward the southeast, giving the appearance of a black-and-white photograph taken at a low angle of illumination with the light coming from the northwest. A more extensive discussion of radar-investigation techniques is given on page 127.

—*P. J. Cannon*

Remote-Sensing Investigations Near Mill Creek, Oklahoma[1]

L. C. Rowan[2] and P. J. Cannon[2]

INTRODUCTION

The U.S. Geological Survey has been investigating various remote-sensing techniques for several years in an effort to augment traditional field observations. In 1967 a new group, Remote Sensing Geophysics, was established within the Branch of Regional Geophysics to provide emphasis on an interdisciplinary approach of physics and geology with close coordination between controlled field experiments and laboratory and theoretical analyses.

The confidence with which remote-sensing techniques can be applied to geologic problems depends upon an understanding of (1) the physical principles that govern the reflection and emission of electromagnetic energy (ultraviolet to radar wavelengths) from natural surfaces, (2) the practical limitations imposed by the major perturbing influences of the atmosphere and the surface state (including texture, roughness, and chemical and vegetative coatings), and (3) the geologic setting of the area observed.

In order to evaluate the factors listed in (1) and (2) above, we selected areas with good exposures of relatively simple rock types for exploration with remote-sensing techniques. Studies at the Mill Creek, Oklahoma, test site were extensive and yielded considerable insight into some of the capabilities and limitations of remote-sensing techniques in geologic exploration. This note briefly describes some of the results. A detailed report on thermal infrared studies in the area is scheduled for publication in the near future (Rowan and others, in press).

Location.—The Mill Creek test site includes part of the Arbuckle Mountains south of Sulphur, Oklahoma, and west of the towns of Mill Creek and Troy, covering parts of Johnston, Murray, and Carter Counties (fig. 1). Within the test site, controlled field experiments were conducted in an area bounded on the south and west by the Washita River, on the east by Rock Creek, and on the north by the Pennsylvania Glass Sand Corp. quarry; the western and southwestern part of this area is locally known as Rock Prairie.

Geologic setting.—The Arbuckle Mountains consist of folded and faulted Paleozoic and Precambrian rocks (Ham, 1950). On the east, north, and west, these rocks are covered by gently westward-dipping Pennsylvanian and Permian strata and on the south by gently southward-dipping Cretaceous sedimentary rocks. The main folds trend northwest-southeast, and, in most places, their limbs are disrupted by steeply dipping faults that, in general, parallel the folds. Numerous minor faults occur throughout the area, and most of these are orthogonal or nearly orthogonal to the main faults.

Stratigraphic and structural relations in the Arbuckle Mountains were described in detail by Ham (1950, 1955, 1969) and Ham and

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[1]Publication authorized by the director, U.S. Geological Survey. These studies were supported by the National Aeronautics and Space Administration (NASA) under contract 160-75-01-43-10. The writers are indebted to Kenneth Watson and Allan Kover for helpful suggestions resulting from review of the manuscript.

[2]U.S. Geological Survey, Denver, Colorado, and Flagstaff, Arizona.

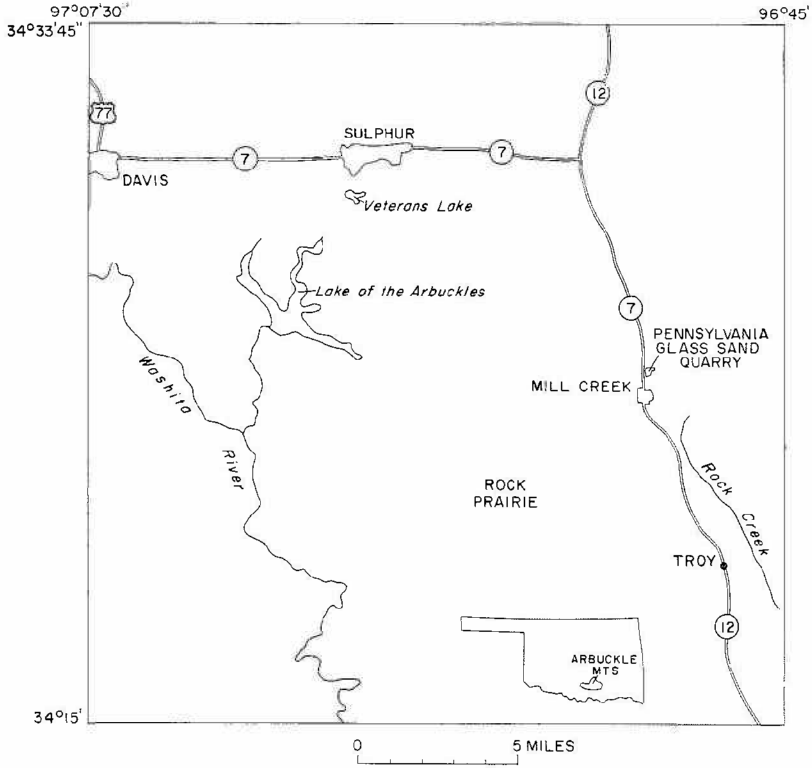

Figure 1. Index map of the Mill Creek, Oklahoma, test site.

others (1964). The area of controlled field experiments was mapped by Ham (1949), and many of the data pertaining to rock types, weathering characteristics, and mineralogical impurities came from his work.

REMOTE-SENSING ANALYSIS

General statement.—By means of 3 NASA Earth Resources aircraft missions and 2 NASA-sponsored radar missions, data have been obtained from altitudes up to 50,000 feet above mean terrain as well as from an Apollo IX color photograph that covers part of the area.

These data provide a large amount of information on the reflection and emission characteristics of rocks and soils in the Mill Creek test site. Although the study is not yet complete, the usefulness of infrared images in discriminating several major rock units is clear. Radar images have been especially useful for delineating regional and local structural features, particularly faults and fractures. Examples of each of these types of images are discussed.

Radar imagery.—Side-Looking Airborne Radar (SLAR) imagery of the area between Mill Creek and Sulphur, Oklahoma, was secured in July 1966 by use of the Westinghouse AN/APQ-97 system. This system transmits monochromatic energy to the ground at a wavelength of approximately 1 cm (K-band). The energy is reflected in a complex fashion; the brightness of an object on the image is determined by the amount of energy back-scattered to the receiver. Trees, for example, are bright on the image (fig. 2) because much of the energy is reflected to the system; lakes, however, are dark because much of the energy is specularly reflected and therefore not received by the system. A more detailed discussion of the geomorphic factors that influence the use of radar imagery in geologic investigations has been written by Rydstrom (1967).

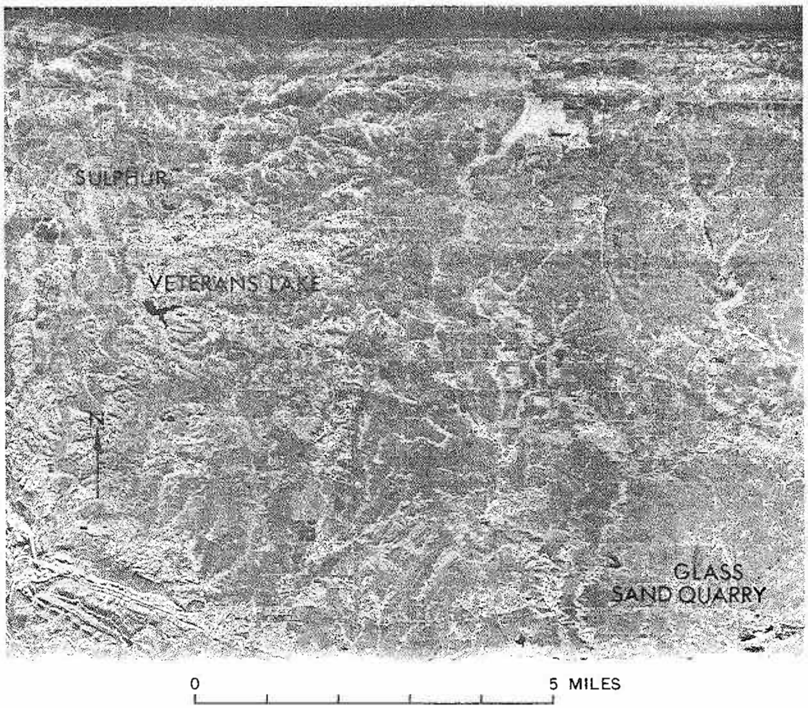

Figure 2. Side-looking radar image of the area between Mill Creek and Sulphur, showing numerous lineaments that reflect geological and cultural features. The small range of hills in the lower left-hand corner of the image is the northwestern extension of the Tishomingo anticline.

The area shown in the radar image (fig. 2) is underlain by gently folded, severely faulted pre-Pennsylvanian rocks in the east; in the west and northwest, Pennsylvanian sandstone and conglomerate of the lower part of the Pontotoc Group lie unconformably on the pre-Pennsylvanian rocks (fig. 3). The pre-Pennsylvanian rocks are well-stratified limestones, sandstones, and shales. The major folds and faults in these rocks trend northwest-southeast (Ham, McKinley, and others, 1954).

Conglomerates, which make up much of the Pennsylvanian rocks southeast of Sulphur (fig. 3), commonly lack the extensive structures that might show offsetting. Rubble along the trace of a fault appears similar to the parent rock. Obviously, recognition and location of faults in conglomerates can be difficult, even with meticulous field work.

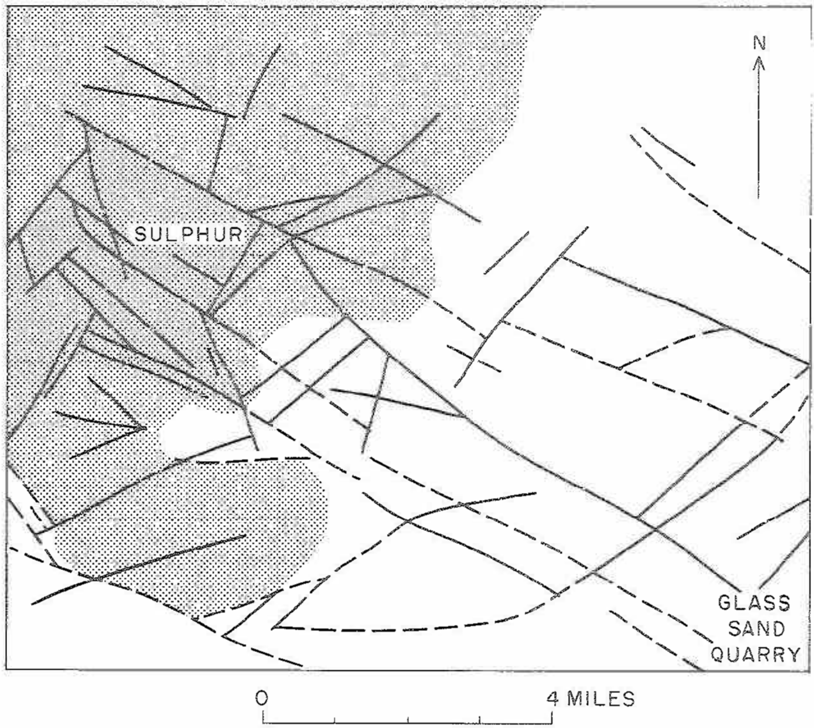

Figure. 3. Map of the same area shown in figure 2, showing lineaments taken from an analysis of that figure. The dashed lines are lineaments on the radar imagery that correspond to faults previously mapped in the area (Ham, McKinley, and others, 1954). The solid lines are lineaments that represent unmapped faults and fractures. The stippled pattern indicates the areal extent of Pennsylvanian rocks, which lie unconformably upon the pre-Pennsylvanian rocks.

The enhancement of subtle topography and vegetation on the radar image (fig. 2) reveals many small tectonic anomalies or lineaments that transect the test site. The lineaments were mapped (fig. 3) and compared with structural features previously mapped in the area (Ham, McKinley, and others, 1954). The comparison indicates that the imagery presents a good representation of the faults that were previously mapped from photographs and field work.

Lineaments in the image that do not correspond to previously mapped faults were checked in the field. Several lineaments proved to be extensions of previously mapped faults that had not been mapped and that had not been obvious on aerial photographs. A few of the lineaments on the imagery occur in areas where the vegetation had been removed for power lines or roads, and these are not shown in figure 3.

Large-scale cultural features present familiar patterns on radar imagery and are easily identified; examples are the city of Sulphur and the large pits at the glass-sand quarry north of Mill Creek. The bright regular lines in the image that are parallel to the section lines are due to the strong back-reflection from vegetation along fences or possibly to the reflection from the fences themselves.

Infrared images.—Infrared (8-14μm) images, records of the thermal flux and hence related to ground temperature, were secured at different times during a diurnal cycle as part of the controlled field experiments in the area southwest of Mill Creek. The system used, a Reconofax IV (HRB Singer RX-IV), has an instantaneous field of view of 3 milliradians[3] and an angular scanning width of 120° perpendicular to the flight path. The flight altitude was 6,000 feet above mean ground surface; identification resolution of thermally contrasting objects, such as streams, is estimated to be 30 feet near the nadir. The stated or instrumental thermal resolution is 0.25°C. Although the images are geometrically distorted on the edges and no internal drift correction is incorporated in the scanner, most significant variations in the thermal flux of ground features are clearly defined.

The field-experiment area is in the axial zone of the northwest-plunging Tishomingo anticline. Rocks in the area consist of Precambrian granite, Cambrian dolomite, limestone, and sandstone, and Ordovician limestone (Ham, 1949). The distribution of these rocks is shown in figure 4, a black-and-white photograph obtained in September 1969.

The eastern part of the area is underlain by medium- to coarse-grained biotite granite. Although most of the outcrops are fresh, a lichen and moss cover of as much as 70-80 percent is common. Tree cover is moderately dense.

Cambrian arkosic sandstone and sandy to fairly pure dolomite occupy narrow north-south-trending belts west of the granite. Outcrops of these rocks are moderately abundant. The amount of tree and lichen cover on the sandstone is similar to that on the granite; on the dolomite, the amount of tree cover varies from very sparse to about that on the granitic terrane.

The dolomite and sandy dolomite are overlain by alternating beds of limestone and dolomite in the southern part of the area (fig. 4); in the northern part, dolomite is considerably more abundant than limestone because of a facies change (Ham, 1949). The limestone and dolomite unit and those units above it to the west are well exposed, support a sparse growth of grass, and form flat to gently rolling prairies.

A relatively thick sequence of Cambrian dolomites overlies the limestone and dolomite sequence (fig. 4). West of the dolomites, Ordovician limestones occupy the remainder of the study area.

In general, the color and texture of the dolomites and limestones in the area are in contrast: the dolomites, in most places, weather to a medium gray to dark gray and occur as pitted ledges or castellated pedestals, whereas the limestones are somewhat impure in places and occur as light-gray to bluish-gray, platy, rubbly outcrops. The dolomites of the main sequence are relatively pure. East of this sequence the principal impurities in the limestones and dolomites are arkosic sand and silt; to the west the Ordovician limestones have dolomitic zones (Ham, 1950), small sandstone beds, and some chert as the main impurities (Ham, 1949, p. 84-89). Some of the limestones to the east of the main dolomite sequence are dolomitic and weather light to medium gray.

Of the three infrared images obtained in December 1968, the predawn (6:00 a.m., CST) image is most useful for discriminating

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[3]A milliradian is equivalent to 0.058° of arc or approximately 1 foot on the ground per 1,000 feet altitude.

the limestone, dolomite, and granite. The daytime (11:00 a.m. and 2:00 p.m., CST) images have proved to be particularly useful for structural studies (Rowan and others, in press).

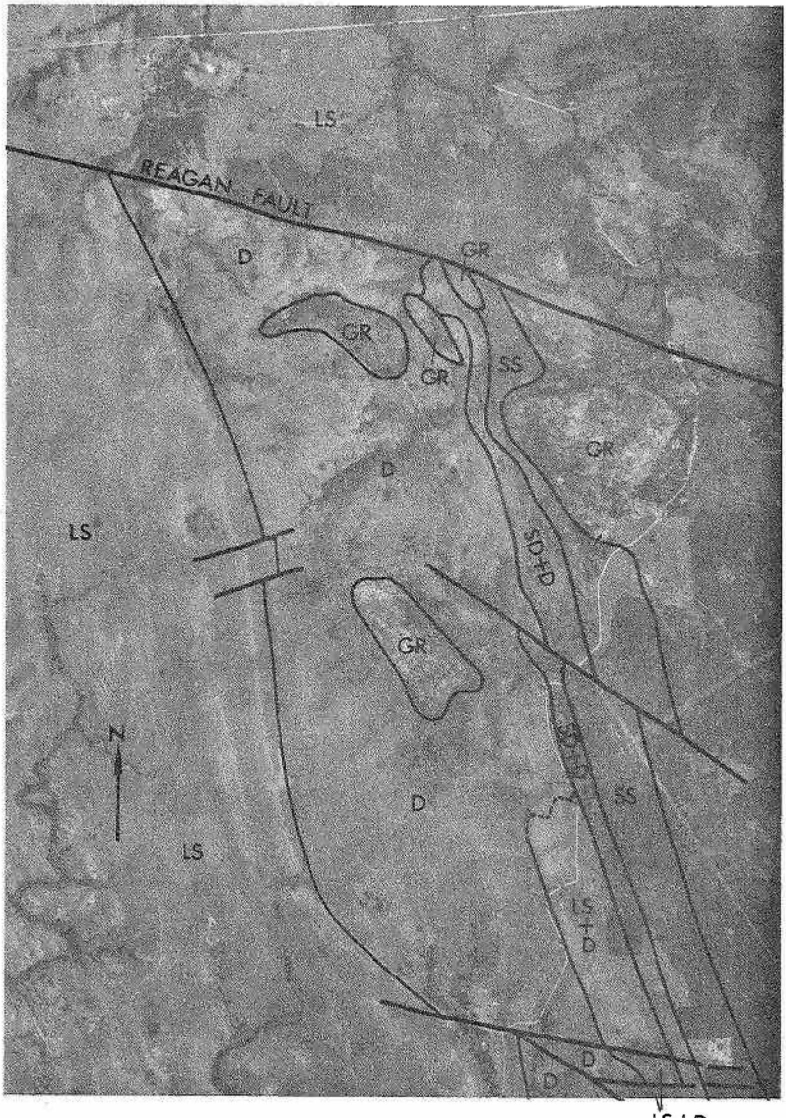

Figure 4. Black-and-white photograph of the area southwest of Mill Creek, showing the distribution of main rock types: LS—limestone, D—dolomite, GR—granite, LS+D—limestone and dolomite, SD+D—sandy dolomite and dolomite, SS—sandstone. Contacts are light lines and major faults are heavy lines (Ham, 1949); dashed line shows approximate location of a facies change.

Near the center of the predawn image (fig. 5), an anomalously bright (warm) band approximately 1.25 inches wide trends generally

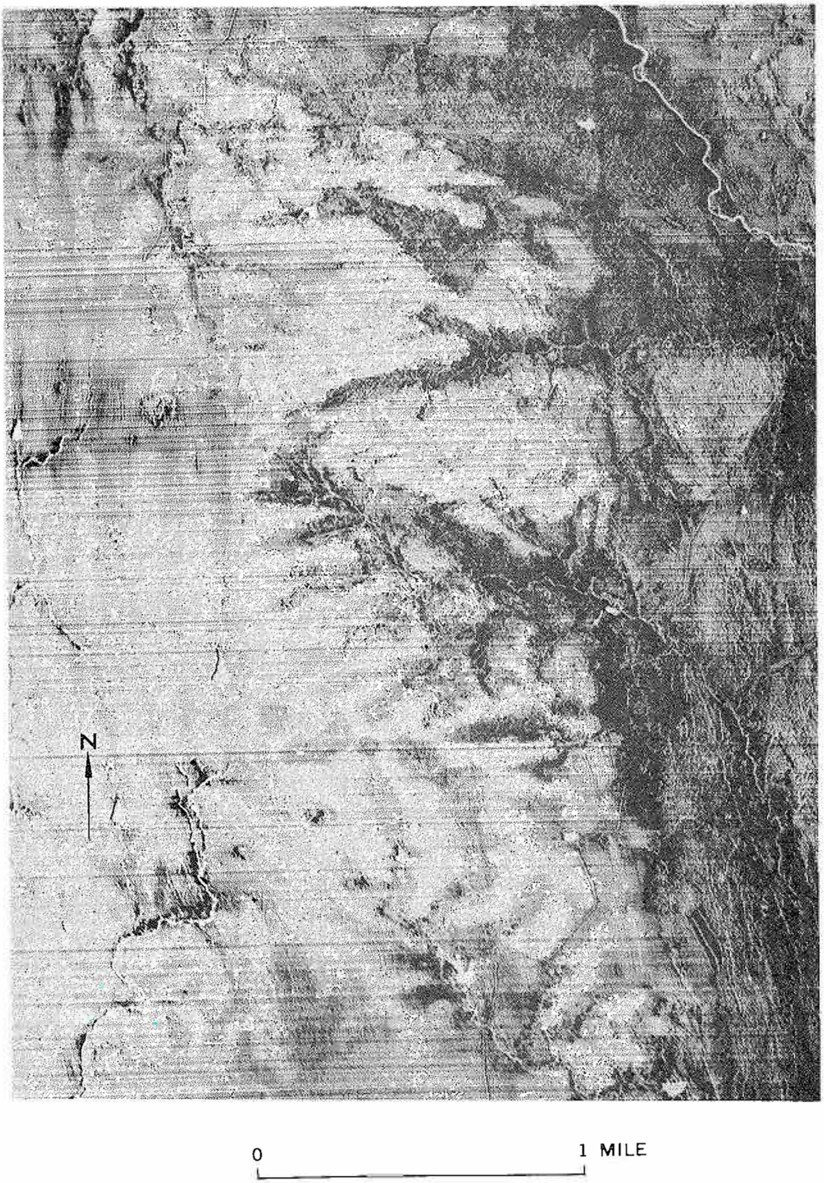

Figure 5. Predawn (6:00 a.m., CST) infrared (8-14μm) image of the area southwest of Mill Creek. Bright (warm) area near center consists of dolomite and granite; dark (cool) area to the west is limestone; tree-covered sandstone, dolomite, and granite on the east.

north-south. The rocks of this area are the main sequence of dolomite and three inliers of granite that are shown in figure 4. On the west, the Ordovician limestones are relatively dark (cool). On the southeast, the interbedded limestones and dolomites appear as alternating dark (cool) and bright (warm) bands, respectively. These bands become uniformly bright to the north, consistent with the facies change from limestone to dolomite (Ham, 1949, p. 40).

The sandy dolomite and dolomite east of the alternating limestone and dolomite unit appear warm where tree cover is absent and where exposures occur. Because the arkosic sandstone and the granite are partly covered by trees, their thermal flux is obscured. In the largest granite inlier and in the triangular mass of granite about 1.25 inches east-northeast of this inlier, the granite can be seen to be relatively warm, and it can be discriminated from the dolomite by its reticulate pattern. This texture apparently is due to the presence of fractures in the granite.

All the above units terminate at the northwest-trending Reagan fault, and the dolomites narrow to the south owing to faulting.

Other features that appear on the image by virtue of their thermal contrast with their surroundings are the cool valley slopes and areas of dense foliage, such as those underlain by the granite; streams and ponds are conspicuously warm.

The distinction between limestone and dolomite by radiometric character is similar to the distinction between sandstone and siltstone noted by Sabins (1967) and the distinctions between various rock types noted by Friedman (1968).

A mathematical model was constructed (Watson and Pohn, 1970) to treat the diurnal temperature variation as a function of rock properties (thermal inertia, albedo, emissivity), atmospheric effects (transmission, air temperature), site location (latitude), and season (sun's declination). The model provides a satisfactory explanation of differences between limestone and dolomite recorded in the infrared images of the Mill Creek site when representative thermal-inertia and albedo values were used.

SUMMARY

Remote-sensing investigations by the U.S. Geological Survey at Mill Creek, Oklahoma, have demonstrated the usefulness in the test site of side-looking radar images for delineating fractures and faults and of infrared (8-14μm) images for discriminating limestone, dolomite, and granite. The thermal contrast of the limestone and dolomite in the predawn image can be explained in terms of the thermal and reflectivity properties of the two rock types.

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First Uranium Shipped from Kerr-McGee Plant in Oklahoma

Kerr-McGee Corporation recently made its first shipment of natural uranium hexafluoride (UF_6) from its new Sequoyah facility to the Atomic Energy Commission's gaseous diffusion plant at Oak Ridge, Tennessee. The shipment contained 38,000 pounds of UF_6, valued at approximately $250,000, and is but a small part of the total UF_6 ordered in a contract with Consumers Power Company of Jackson, Michigan.

The $25 million Sequoyah plant, 17 miles west of Sallisaw in eastern Oklahoma, was dedicated last April. It has a design capacity of 5,000 tons with portions of the facilities installed to expand to 10,000 tons of uranium per year. It is one of only two such facilities in the nation designed to convert uranium oxide (U_3O_8), or yellow cake, into uranium hexafluoride (UF_6). The process utilized is a modification of the classical conversion process wherein the U_3O_8 is first refined by solvent extraction, after which the refined uranium is hydrofluorinated with anhydrous hydrofluoric acid and then fluorinated with elemental fluorine. The plant's product, UF_6, is then enriched by further processing at one of the Atomic Energy Commission's enrichment facilities.

Other contracts involving future deliveries from the Sequoyah plant have been signed with Arkansas Power and Light Company of Little Rock, Arkansas, and Rochester Gas and Electric Corporation of Rochester, New York. The agreement with Arkansas Power and Light provides for a delivery of approximately 4,400 tons of UF_6, valued without escalation at more than $90 million, over a 14-year period beginning in 1975.

Paleomagnetism of Basement Granites in Southern Oklahoma: Final Report[1]

Henry Spall[2]

Abstract—The Troy and Tishomingo Granites from the Arbuckle Mountains have a natural remanent magnetization (NRM) that is not stable to thermal and alternating-field (AF) demagnetization. A 1,107-m.y. mafic dike in Troy Granite gives a paleomagnetic pole, common to thermal and AF demagnetization, in the range 121-128°W, 30-32°S. This is remote from other poles of similar age from North America; evidence from the initial NRM directions indicates that the dike was remagnetized during the Cambrian. Demagnetization of 67 samples of granite and rhyolite from the Wichita Mountains yielded poles at 147°E, 13°N (at 700 oersteds), and 164°E, 4°N (at 500°C). These results do not wholly support previous interpretations (Spall, 1968). The possibility exists for a self-reversal process in these rocks and the North American Cambrian-field axis having ranged up to 30°N latitude.

INTRODUCTION

During the course of a regional paleomagnetic survey of Precambrian igneous rocks from the western United States (Spall, 1970), preliminary results from the Wichita and Arbuckle Mountains were reported in *Oklahoma Geology Notes* (Spall, 1968). Studies on further collections are the subject of the present discussion, and, despite the fact that they have not led to a clear understanding of the magnetic history of basement rocks in southern Oklahoma, I feel that they will be of value to workers interested in the geophysical aspects of this region.

ARBUCKLE MOUNTAINS

Geologic setting and previous work.—Ham and others (1964) designated an extensive terrane of surface and subsurface rocks in southern Oklahoma as the Eastern Arbuckle Province. In the Arbuckle Mountains (96.7°W, 34.3°N), these rocks are exposed as the coarse-grained Tishomingo Granite, the medium-grained Troy Granite, and mafic dikes.

Muehlberger and others (1966) summarized isotopic ages from this province. Surface samples of both types of granite give a spread in ages from 1,250 to 1,400 m.y., using various methods. Subsurface granite and diorite consistently give younger ages (1,050 to 1,160 m.y.), but they may be related to cataclastic structures. The age spread may possibly represent two separate periods of activity and a consequent resetting of the isotopic clocks by a younger episode, as advocated by Ham and others (1964). Muehlberger and others (1967) remarked that exact correlation of this area is still a problem. At present, an age of 1,350-1,400 m.y. must be considered to be near the maximum for the granitic rocks.

[1]I am very grateful to Rodger E. Denison for his interest in this study and for many helpful discussions. I thank Charles E. Helsley for the use of his paleomagnetic facilities and for partial financial support from NSF Grant GP 2205 and American Chemical Society Grant PRF 1829 A2. Edwin E. Larson kindly allowed me the use of his Curie balance. Field work was made possible through a Penrose Research Grant from the Geological Society of America.

[2]Visiting Research Fellow, Cooperative Institute for Research in Environmental Sciences, University of Colorado, Boulder, Colorado.

Yaskawa and others (1966) reported that directions of the natural remanent magnetization (NRM) from granites in the Arbuckle Mountains were unchanged by thermal demagnetization. They considered that the corresponding paleomagnetic poles coincided with other Precambrian poles from North American rocks. Spall (1968) found considerable dispersion among the NRM directions. This was reduced by alternating-field (AF) demagnetization to 700 oersteds (oe), and he quoted a paleomagnetic pole, after correction for the dip of the overlying Reagan Sandstone, at 150°W, 17°N.

Since most of the original specimens and data were lost in an interlaboratory move, a further collection was recently made from four sites in the Arbuckle Mountains. Collection from a fifth site was planned where a 6-foot-wide diorite dike intrudes the Troy Granite, but unfortunately this quarry is now disused and under water. However, enough material from this site remained from the preliminary study to enable further studies to be made. R. E. Denison very kindly dated a sample of the dike and obtained a K/Ar whole-rock age of 1,107 ± 22 m.y. from 5 replicate analyses of 2 whole-rock splits. Block samples were collected at the four sites (table 1) and oriented by sun and magnetic compass (assuming a declination of 8.5°E). The discrepancy between the two methods was about 2°.

Demagnetization studies.—Progressive thermal and AF demagnetization experiments were made on at least 1 specimen from each sample at the 5 sites, using facilities at The University of Texas at Dallas. The instruments used included a PAR spinner magnetometer, Model SM-1; AF coils in which fields of 1,400 oe peak intensity could be generated; and a non-inductively wound furnace for thermal-demagnetization experiments. The demagnetization equipment is in a shielded room and is described by Helsley and Spall (in press).

The new data obtained indicate two types of magnetic behavior in the two granites, *stable* and *unstable*. These are reflected either in very little response to AF or thermal demagnetization or in a large amount of random movement. In several cases heating the granite specimens more than once or twice above 400°C was not possible because they disintegrated. The stable group, regardless of rock type and location, contributed to the mean direction at 700 oe quoted by Spall (1968). All the directional data were corrected for a dip of 12° in a direction 200° east of true north, observed in the overlying Cambrian Reagan Sandstone at Royer Ranch.

Site 5 is discussed first because these specimens give the most consistent response to demagnetization. This response can be divided into dike behavior and baked-margin behavior.

TABLE 1.—SAMPLING DETAILS

SITE	LOCATION	ROCK TYPE	NUMBER OF SAMPLES
1	Blue River bridge on State Highway 7	Troy Granite	6
2	Devil's Den Park, 3 miles west of State Highway 7	Tishomingo Granite	8
3	Capitol quarry, Troy	Tishomingo Granite	6
4	Century quarry, 2 miles north of Troy	Troy Granite	7
5	Small quarry opposite Century quarry (1964 collection)	a. Diorite dike	3
		b. Baked margin of Troy Granite	5

The initial NRM directions of the dike specimens are reversed at a shallow angle to the west. Figure 1 shows the mean paths obtained during AF and thermal demagnetization by combining the data using Fisher's methods (1953). Both procedures give the same qualitative result. The dike direction at 700 oe is questionable because the dispersion, measured by k, the precision parameter, is only a factor of 1.4 from indicating a random distribution (Stephens, 1964). Low fields of 88 oe are required to move the initial NRM directions into the lower hemisphere. During thermal demagnetization this did not occur until 580°C; above this temperature the directions were randomly oriented. These results imply that a soft magnetization of low coercive force dominates the initial NRM but that a harder magnetization is revealed at temperatures up to the Curie point of magnetite. The initial and cleaned directions are not anti-parallel, so there is no convincing reason to suspect a self-reversal phenomenon.

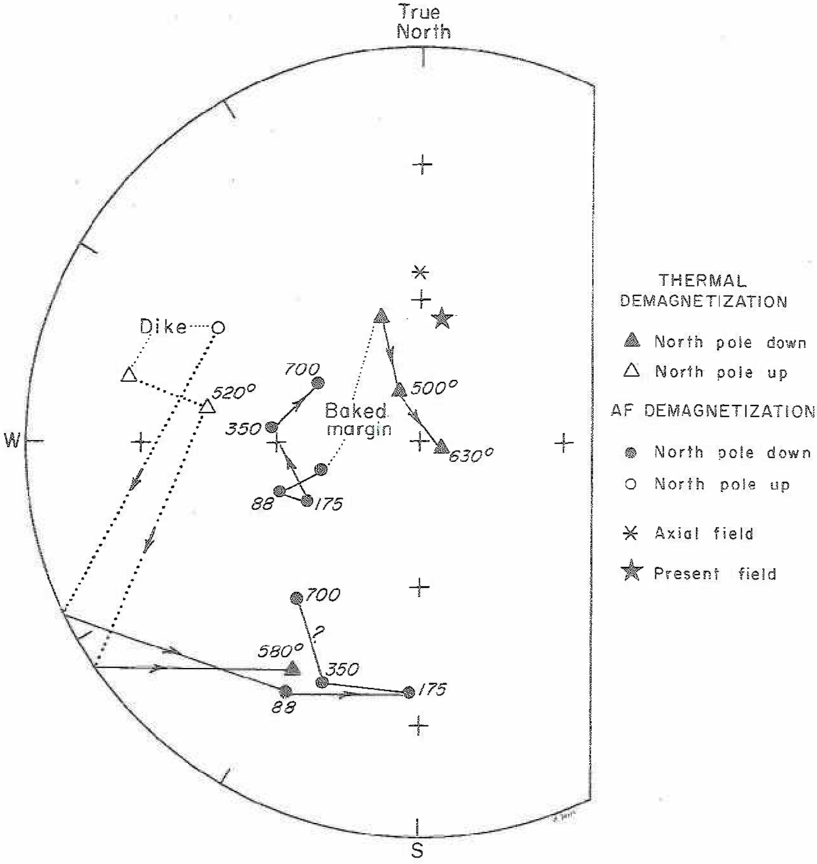

Figure 1. Mean thermal and alternating-field (AF) demagnetization paths for the dike and its baked margin at site 5, plotted on an equal-area projection. Temperatures in °C; fields in oersteds.

Rather different behavior is observed for 12 specimens from baked margins of the Troy Granite. The NRM of these specimens is fairly stable in fields up to 700 oe and temperatures up to 630°C (fig. 1), although the between-specimen dispersion of the NRM directions is poorer at these stages. This implies that the NRM is due to a hematite phase. The surprising fact is that the baked-margin directions differ from the dike direction (at 350 oe) by about 50°, which is considerably outside the two error (α_{95}) circles. As well as the discrepancy between the dike and baked-margin directions, the further implication is that the dike has been remagnetized at another time (giving the initial upward direction).

Sites 1 and 4 are discussed next because they are also in the Troy Granite. However, their response to demagnetization is very different from that of site 5. Representative demagnetization paths for specimens from both sites are given in figure 2. In particular, none of the specimens is very stable to either form of demagnetization, and thus there is no systematic convergence of the NRM directions at any field or temperature. The interesting fact is that, despite the erratic changes after each demagnetizing stage, duplicate treatments at the *same* stage gave directions repeatable to within 10°. This suggests that no spurious moments were being induced during demagnetization. The initial directions of NRM at site 1 are predominantly reversed; those at site 4 are all downward seeking.

Sites 2 and 3 are in the Tishomingo Granite, and the initial NRM directions are all downward seeking. As with the main body of the Troy Granite, the specimens are generally unstable to progressive demagnetization, and there is no systematic convergence of the NRM directions. Representative demagnetization paths are given in figure 3.

The normalized NRM decay curves corresponding to the specimens in figures 2 and 3 show differences between the more stable dike and baked-margin specimens from site 5 and the generally unstable specimens from other sites. They are plotted in figure 4 on a log-log scale for the AF decay curves and on a semi-log scale for the thermal decay curves.

Three types of AF decay curves are shown, respectively, by the main granite, dike, and baked margin: all show a fairly sharp decrease in moment in high fields. At various stages for the main granite, the intensity begins to fluctuate (the minimum-intensity situation of Irving and others, 1961), accompanied by large, erratic changes in the direction. Although a similar rate of decrease in moment is seen in the dike and baked-margin specimens, the minimum-intensity situation does *not* seem to appear, and this is commensurate with little direction change after high field treatment. The dike specimens show a spike after 88 oe, which probably indicates complete removal of the component responsible for the reversed direction of initial remanence.

The thermal-decay curves for the main granite show a wide range in blocking temperatures, indicating thermally distributed components of magnetization (Irving and Opdyke, 1965) and, in many cases, a minimum-intensity situation above 400°C. Decay curves for the dike and its baked margin reveal more thermally discrete components (Irving and Opdyke, 1965), with a sharp knee above 540°C.

Opaque mineralogy.—Reflected-light studies indicated that the main Fe-Ti oxides are large titanomagnetites and ferrian-ilmenites in advanced stages of unmixing to titanohematite.

Titanomagnetite occurs as large composite grains up to 600μ (microns) across. Direct oxidation to hematite takes place along fractures and grain margins but mainly along feather-shaped 111 lamellae in the host. Maximum development of hematite is about 25 percent within a grain. Many of the titanomagnetites contain rounded spinels.

Discrete ferrian-ilmenites up to 200μ long are in various stages of unmixing to titanohematite, which is further breaking down to ferrian-ilmenite and titanohematite. This process occurs in two modes. One is the production of irregular-shaped blebs of titanohematite within the host ferrian-ilmenite. The second is the exsolution of trains of small lozenges of titanohematite along 0001 planes in the host. In more advanced exsolution these become segregated into lances of titanohem-

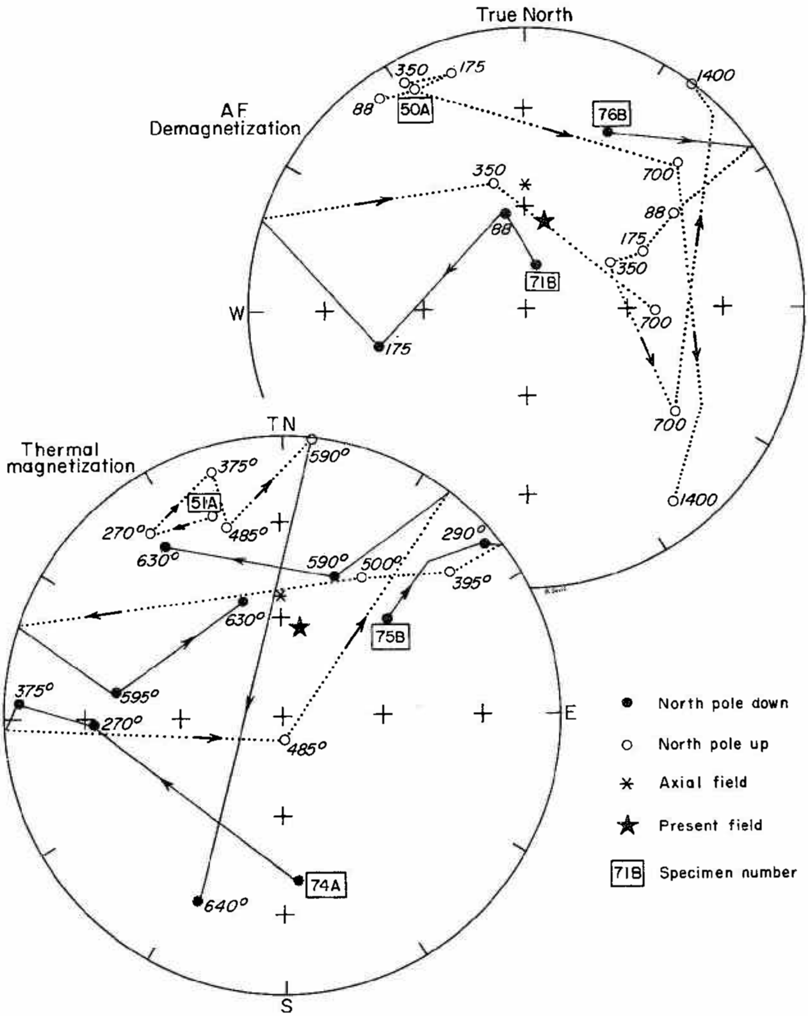

Figure 2. Representative thermal and AF demagnetization paths for specimens of the Troy Granite from sites 1 and 4. Temperatures in °C; fields in oersteds. Equal-area projection.

atite that cross the entire ferrian-ilmenite grain. This is accompanied by the development of parallel ferrian-ilmenite spindles within the titanohematite and titanohematite within the host ferrian-ilmenite (seriate distribution). In many ferrian-ilmenites, all three stages are visible.

Long needles of rutile are distributed throughout the rock, not necessarily associated with the ilmenohematite minerals. All the specimens contain varying amounts of pyrite and goethite generally of colloform texture, but often prismatic, as well as the alteration of Fe-Ti oxides to sphene.

Specimens from the baked margin of the granite show the same opaque mineralogy as the main granite. They are distinguished only in having a large fraction of titanomagnetite less than a few microns in dimension. The dike specimens possess cubic titanomagnetites that

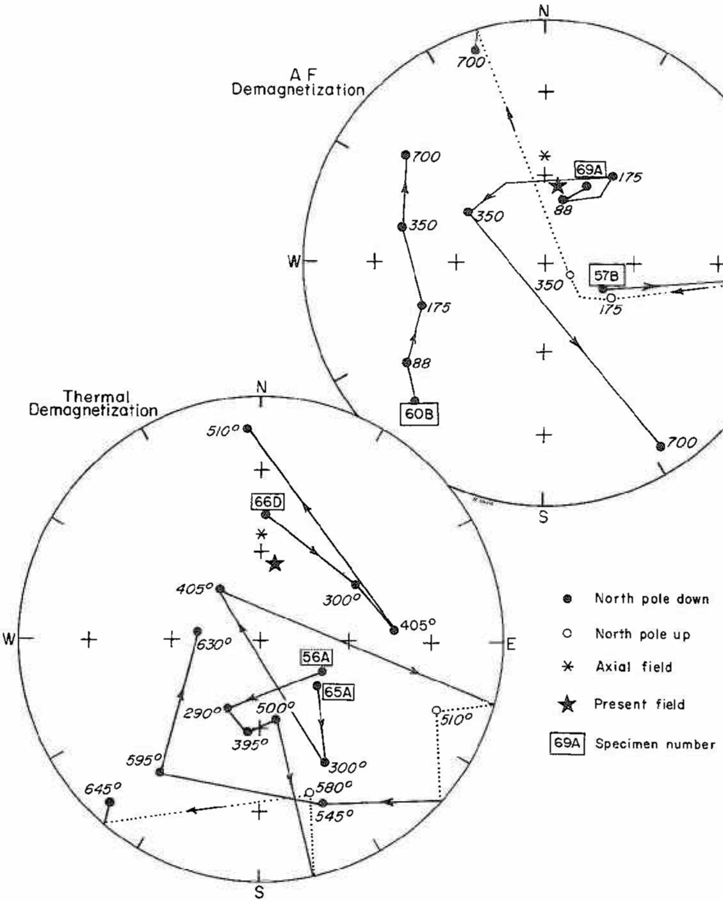

Figure 3. Representative thermal and AF demagnetization paths for specimens of the Tishomingo Granite from sites 2 and 3. Temperatures in °C; fields in oersteds. Equal-area projection.

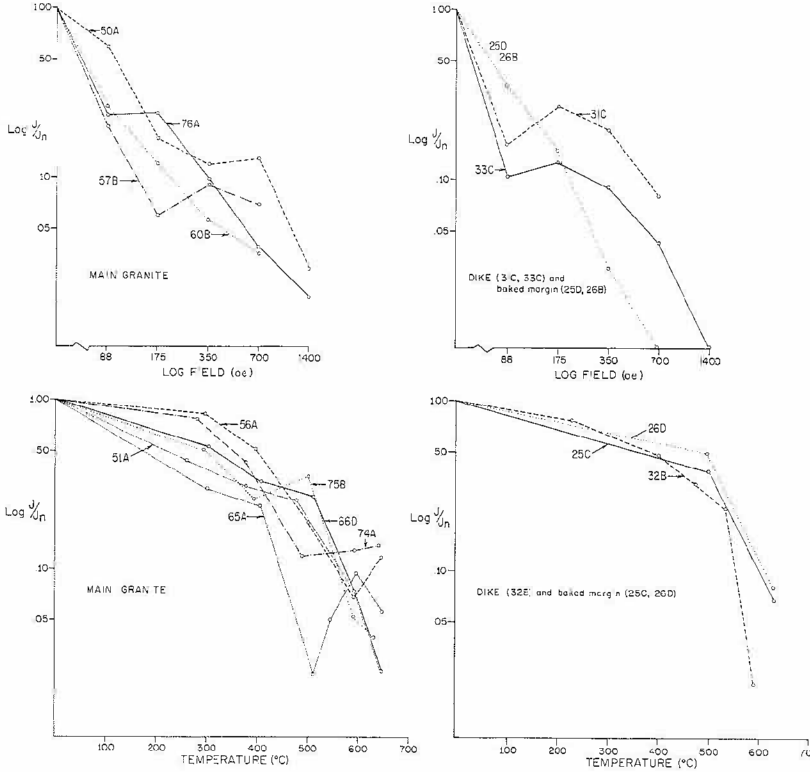

Figure 4. Normalized thermal and AF demagnetization curves for specimens of the dike, its baked margin, and the main granite (see also figs. 2 and 3). **Numbers are specimen numbers. J_n is the initial natural remanent magnetization (NRM) moment; J is the NRM moment after demagnetization.**

are about 50 percent oxidized to thin ilmenite lamellae and thus are in a low oxidation state. The grain size ranges from 100μ to a few microns. Many of the opaque oxides are in graphic intergrowth with silicate minerals.

Two electron-microprobe qualitative scans were very kindly made by J. L. Carter at The University of Texas at Dallas. They indicated that the titanomagnetites in both the Tishomingo and Troy Granites are virtually free of titanium, which is supported by the microscopic observation of direct oxidation to hematite.

Curie points.—Three Curie points were determined in a field of 2,000 oe on a balance at the University of Colorado (fig. 5). They indicate that the dike, baked-margin, and main granite specimens all possess a spinel phase as the dominant carrier of the saturation remanence. These have Curie points close to 590° to 595°C, with an error of ±10°C, and thus indicate a virtually titanium-free titanomagnetite; all the curves are reversible.

Mossbauer spectra were very kindly run by W. A. Gose at The University of Texas at Dallas. They confirm, for specimens of the dike

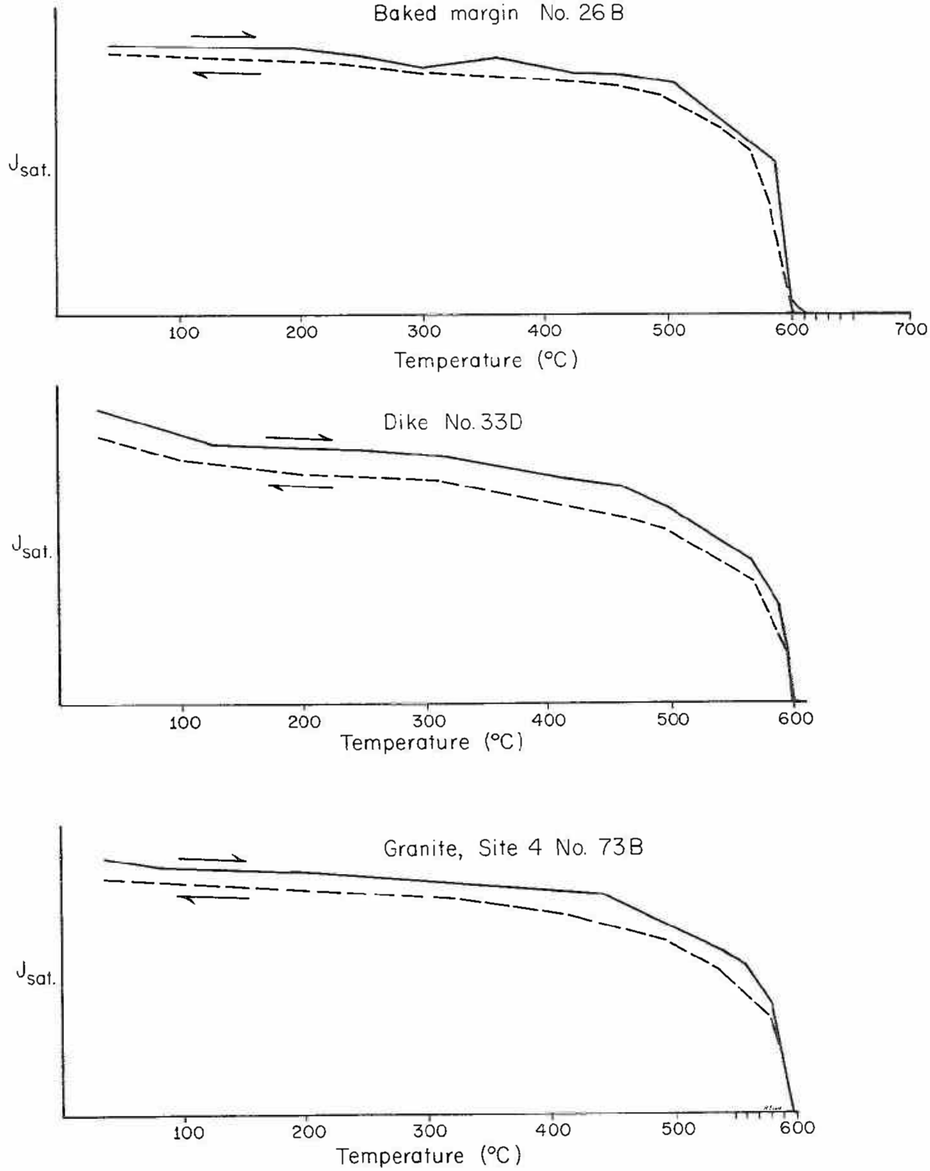

Figure 5. Curie-point determinations in a field of about 2,000 oersteds.

and its baked margin, that magnetite dominates the magnetic fraction. These observations of a single spinel phase are rather surprising in view of the hematite observed microscopically and indicated by thermal-demagnetization experiments on baked-margin specimens. They may be explained by the difference in the values of the saturation magnetization for each mineral: that for magnetite is a factor of at least 200 greater than for hematite, so only a very small fraction of magnetite is required to mask a much larger fraction of hematite. It should also be noted that, with the Mossbauer technique, amounts less than 10 percent are difficult to detect (W. A. Gose, pers. comm.).

Intensities, susceptibilities, and Q′ ratios.—The overall intensity/susceptibility ranges in the main granite are small and the Q′ ratios[3] uniformly low, with medians varying from 0.1 to 0.3 (table 2). The anomalously high values at site 1 are considered to be due to lightning (Strangway, 1965), particularly as the susceptibility range at this site is similar to that at other sites in the granite.

The distinctly higher intensity of the baked margins seems to indicate either remagnetization or metasomatic introduction of material across the contact. However, the susceptibility range is similar to that of the main granite, suggesting the same overall Fe-Ti oxide composition. Coupled with the microscopic observation that there is abundant material in the few-micron size, this fact implies that the high moment of the baked margin is due to a partial thermoremanence (TRM) acquired when the dike was intruded. Nevertheless, recall that the NRM directions from the baked margin were *not* the same as the dike directions (the baked-margin test of magnetic stability, Everitt and Clegg, 1962), although they remained unchanged to 630°C; this might imply that the contact rocks were raised to at least this temperature.

Discussion of directions of magnetization.—Not all the specimens in the collection were demagnetized. However, the present data, representing at least one specimen from each sample, seem to have revealed neither a consistent direction of magnetization for the Arbuckle granites nor a stability toward demagnetization. Even if these features were revealed by demagnetizing *all* the specimens (and this is always a desirable procedure), their relevance would be questionable because of the anomalous behavior observed during the pilot demagnetization experiments.

Two observations can be made by combining all the data presently available. First, many of the NRM directions for the main granite

TABLE 2.—INTENSITY, SUSCEPTIBILITY, AND Q′ RATIO FOR SPECIMENS FROM ALL SITES

SITE	INTENSITY $\times 10^{-4}$ EMU/CC RANGE	INTENSITY MEDIAN	SUSCEPTIBILITY $\times 10^{-4}$ EMU/OE/CC RANGE	SUSCEPTIBILITY MEDIAN	Q′ (INTENSITY/SUSCEPTIBILITY) RANGE	Q′ MEDIAN
1	0.8 - 22	2	4 - 12	8	0.1 - 2.8	0.3
2	0.5 - 7	1	8 - 27	9	0.1 - 0.8	0.2
3	1.0 - 5	2	8 - 19	13	0.1 - 0.3	0.1
4	0.8 - 3	2	7 - 27	10	0.1 - 0.2	0.1
5 Margin	2.0 - 22	15	11 - 17	15	0.1 - 1.3	0.9
5 Dike	18.0 - 68	52	38 - 52	42	0.5 - 1.4	1.3

[3]The ratio Q′ is modified from the Koenigsberger ratio Q (Koenigsberger, 1938), which is defined as:

$$Q = \frac{\text{Intensity of NRM}}{\text{Bulk susceptibility} \times \text{Strength of inducing field}}$$

Q′ is simply the ratio of intensity of NRM and bulk susceptibility, without the necessity of assuming a value for strength of inducing field.

are close to the present field. This is illustrated by figure 6, which shows data from sites 1 and 4 (Troy Granite) and from sites 2 and 3 (Tishomingo Granite). The site 1 directions are somewhat similar to the initial dike directions from site 5, although high Q′ ratios caution that some samples have been affected by lightning. The NRM directions from other sites are not especially related to the baked-margin data of site 5.

Second, directions obtained from the main granite above 600°C all have westerly declinations (fig. 7), despite the fact that many of the specimens show fluctuating intensities and directions above 400°C. Overall they show some affinity for the cleaned directions observed from the dike and its baked margin at site 5 but with a very large dispersion ($\alpha_{95} = 22°$, $k = 3.2$). It is impossible to say whether these high temperature directions are due to hematite that has been oxidized from titanomagnetite or exsolved out of ferrian-ilmenite.

It remains puzzling (1) why the directions in the dike and its baked margin should be dissimilar and (2) why only the dike was apparently remagnetized at a later time whereas its high Q′ ratio and similar response to both types of demagnetization argue that a stable remanence resides in the rock.

The abundance of titanomagnetite and ilmenohematite exsolution in the main granite suggests the presence of self-reversal phenomena of the type suggested by Merrill and Grommé (1969) for a diorite. This seems particularly likely in the case of the Arbuckle granites because of the advanced stages of exsolution. However, as Hargraves (1959) noted, anomalous behavior in rocks containing titanomagnetite

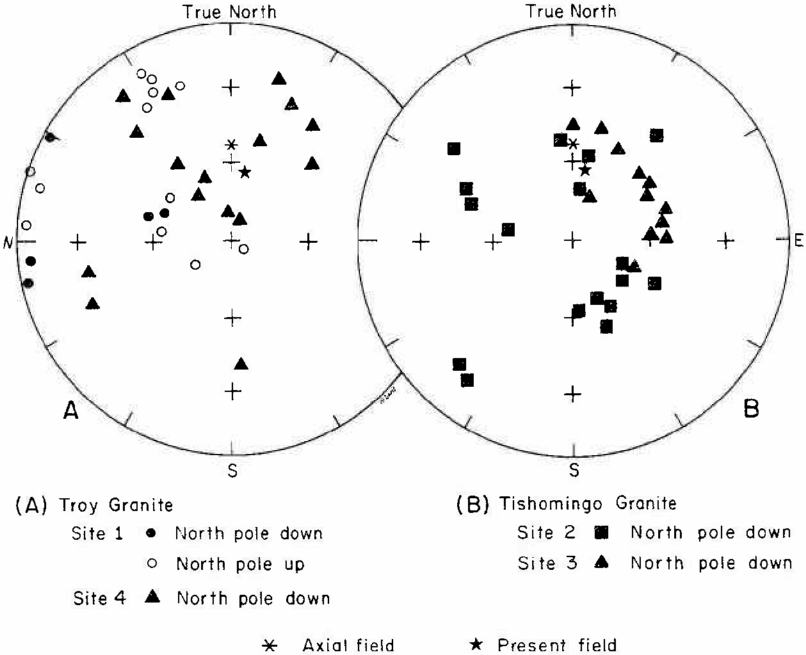

Figure 6. Initial NRM directions for (A) Troy granite, sites 1 and 4, and (B) Tishomingo granite, sites 2 and 3. Equal-area projection.

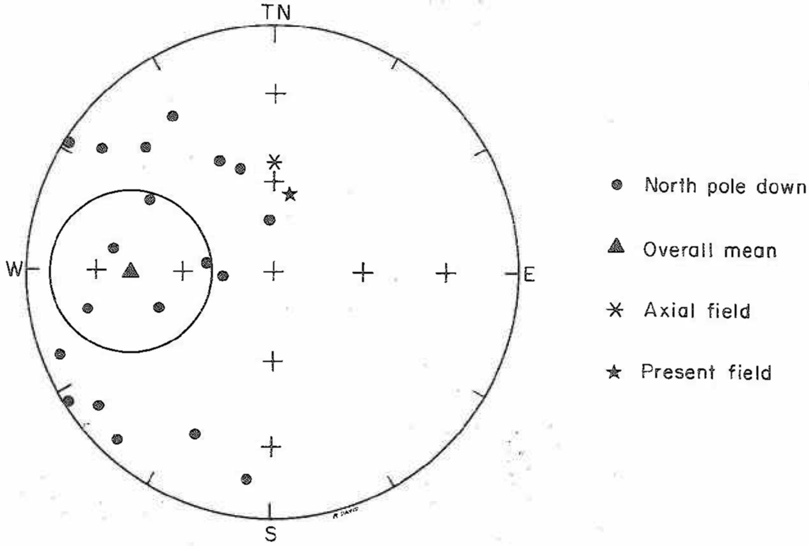

Figure 7. NRM directions above 600°C for specimens of the main granite, with the overall mean (triangle) and its circle of 95-percent-level confidence (table 3) plotted on an equal-area projection.

and ilmeno-hematite phases may well be due to anisotropy in the latter.

Paleomagnetic poles.—In conclusion, it is considered that the Arbuckle granites do not yield reliable information about the Precambrian field, although they do permit some speculations. Therefore, various mean directions obtained by Fisher's method (1953) are listed in table 3 and include those for the initial NRM directions for each site, those for the main granite above 600°C, and those at 350 oe for the dike and its baked margin (as this field produced lowest dispersion among the NRM directions). In this respect, a minority of all the directions from the main granite at 350 oe lies in the vicinity of the mean for the baked margin, although the high dispersion of these directions could equally well argue for a distribution around the present field.

Figure 8 shows paleomagnetic poles for the dike (initially, at 350 oe and at 580°C), the baked margin at 350 oe, the main granite at 600°C, and the result for the main granite at 700 oe, quoted by Spall (1968). It is interesting, although possibly fortuitous, that the three granite results lie within 10° of one another (mean at 157°W, 19°N; $\alpha_{95} = 15$; $k = 69$), although the dispersion is high for each pole. In actual fact, the poles lie close to one determined for the 1,200 to 1,350-m.y. St. Francois granitic rocks from Missouri (Hays and Scharon, 1966), so the Arbuckle granite poles may well be *qualitative* indicators of the field at that time.

From a comparison with lower Paleozoic poles summarized in Helsley and Spall (1966), the initial NRM directions for the diorite dike may be due to remagnetization during the lower Paleozoic, very possibly at the time of the Cambrian Wichita igneous events (Ham and others, 1964). This would accord with the conclusion of Naeser

TABLE 3.—SELECTED MEAN DIRECTIONS OF MAGNETIZATION FOR ARBUCKLE ROCKS, STRUCTURALLY CORRECTED

Dec is declination of the north-seeking magnetic vector, east of true north; **Inc** is its inclination, positive downward; R is the length of N unit vectors, one per specimen; k = (N-1)/(N-R); α_{95} is the semiangle of the cone of 95-percent-level confidence; **Long** and **Lat** are the longitude and latitude, respectively, of the paleomagnetic pole; δp and δm are the semi-minor/major axes of the oval of 95-percent-level confidence.

SITE	TREAT-MENT	DEC	INC	N	R	K	α_{95}	LONG	LAT	δp	δm
1	0	301	−39	17	11.719	3	25	137E	11N	18	30
2	0	240	84	17	12.970	4	21	108W	28N	40	41
3	0	50	61	13	12.244	16	11	32W	50N	12	16
4	0	342	60	16	12.206	4	21	156W	74N	25	32
All (thermal)	600°C	271	42	19	13.369	3	22	166W	14N	17	27
5 Dike	0	300	−40	5	4.430	7	31	136E	9N	23	38
AF	350 oe	202	35	5	4.790	19	18	121W	32S	12	21
5 Dike	0	283	−26	5	4.693	13	22	154E	3N	13	24
thermal	580°C	209	35	5	4.666	12	23	128W	30S	15	26
5 Margin	0	255	69	9	8.456	15	14	135W	18N	20	24
AF	350 oe	276	59	8	7.657	21	13	154W	25N	14	19

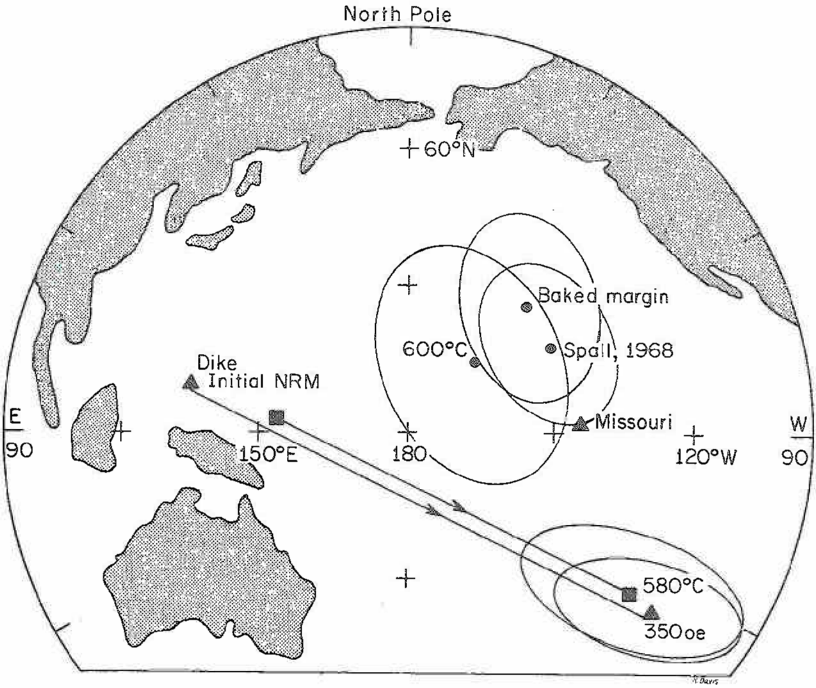

Figure 8. Paleomagnetic poles according to the various mean directions in table 3, with their associated ovals of 95-percent-level confidence. Also plotted is a pole for 1,200-1,350-m.y. granitic rocks from the St. Francois Mountains, Missouri.

and Faul (1969) that fission-track dates on apatite from the Tishomingo Granite indicate a thermal event at about 500 m.y.

Despite the stability of the dike specimens, it would be unwise to say that the cleaned dike directions represent a pole for the time 1,107 m.y. because of the failure of the baked-margin test. Furthermore, they are considerably removed from poles for other mafic rocks of similar age, for example, 1,115-1,120-m.y. Duluth gabbro (DuBois, 1962) and 1,140-1,150-m.y. Sierra Ancha sills (DuBois, 1964; Helsley and Spall, in press).

K. Yaskawa and S. A. Vincenz (pers. comm.) have found three distinct groups of initial NRM directions in the granites, which they correlate with grain-size variations and possible magnetic-age differences. Thermal demagnetization did little to change the directions, and these workers interpret the data in terms of changes in the orientation of the Precambrian-field axis. These conclusions are in striking contrast to the instabilities reported in this present study. Further illumination of the problem will no doubt come from publication of these authors' work.

WICHITA MOUNTAINS

Introduction.—Ham and others (1964) extensively studied the age and stratigraphy of igneous rocks in the Wichita Mountains (99.0°W, 34.8°N). Rhyolites and granites are the youngest rocks in the Wichita Mountain province and are isotopically dated as 525 ± 25 m.y. The several facies in the Wichita Granite Group are intrusive equivalents of the extrusive Carlton Rhyolite.

Several attempts to obtain paleomagnetic information from the Wichita Mountain rocks have met with varying success and changeable conclusions (Ku and Scharon, 1966; Yaskawa and others, 1966; Ku and others, 1967; Spall, 1967, 1968).

New magnetic measurements.—Using sun-compass orientation, 67 samples were collected from 11 sites in the area so that the different facies of the granite and rhyolite were represented. Particular emphasis was placed on the tilted rhyolite sequence at Bally Mountain and the green (unoxidized?) facies of the granite at Long Mountain. AF- and thermal-demagnetization studies were carried out on most of the samples.

The paleomagnetic results are disappointing. They do not conclusively support any of the previous theories. According to Spall (1968), AF demagnetization in 700 oe and thermal demagnetization to 500°C should provide evidence for two components of remanence corresponding, respectively, to magnetization during the Late Pennsylvanian and the Cambrian. Although the directions are highly scattered, both demagnetization procedures support evidence for a preferred axis in the southeast quadrant, which corresponds to a "reversed" geomagnetic pole. Mean directions (Fisher, 1953) listed in table 4 show that paleomagnetic pole positions are obtained that are intermediate between the "Cambrian" and "Late Pennsylvanian" poles quoted by Spall (1968), although with high dispersion of the individual specimen directions.

E. E. Larson (pers. comm.) has obtained paleomagnetic poles for some Cambrian intrusives from the Wet Mountains of Colorado that also have a reversed polarity and are near late Paleozoic poles from North American rocks. Yet the NRM is very stable to both AF and thermal demagnetization. The interesting possibility thus arises that the shallow downward direction to the southeast in the Wichita Mountain rocks *does* represent a true (and reversed) Cambrian-field

TABLE 4.—MEAN DIRECTIONS OF MAGNETIZATION FOR WICHITA ROCKS (STRUCTURALLY CORRECTED)
(Legend as in table 3)

TREATMENT	DEC	INC	N	R	K	α_{95}	LONG	LAT	δP	δM
AF 700 oe	115	22	23	15.598	3	21	147E	13N	12	22
Thermal 500°C	97	8	33	21.994	3	18	164E	4N	9	18

direction and that the axis of almost opposite polarity referred to by Spall (1968) reflects some form of self-reversal phenomenon. Whether this is a titanomagnetite-hematite, or hematite-ilmenite, interaction may be difficult to distinguish because all three minerals occur in the granite and rhyolite.

CONCLUSIONS

1. The Troy and Tishomingo Granites from the Arbuckle Mountains have a natural remanence that is not stable to thermal and AF demagnetization.

2. A 1,107-m.y. dike in Troy granite gives a paleomagnetic pole common to thermal and AF demagnetization in the range 121-128°W, 30-32°S. This is remote from other poles of similar age from North America; there is evidence for remagnetization of the dike during the Cambrian.

3. Troy granite, baked by the dike, is stable to thermal and AF demagnetization but yields a pole removed from the dike at 154°W, 24°N.

4. The baked Troy granite, together with NRM data from the main granites above 600°C and an earlier determination for the Arbuckle rocks (Spall, 1968), yields a mean pole at 157°W, 19°N. This is considered a speculative index of the field axis at 1,350-1,400 m.y.

5. Demagnetization of 67 samples of granite and rhyolite from the Wichita Mountains yields poles at 147°E, 13°N. (at 700 oe), and 164°E, 4°N (at 500°C). This does not wholly support previous interpretations (Spall, 1968): the possibility exists for a self-reversal process in these rocks and the North American Cambrian-field axis having ranged up to 30°N latitude.

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AESE Meets in Washington, D.C.

Over 60 guests and members of the Association of Earth Science Editors descended on Washington, D.C., October 11-13, for the fourth annual conference of the association, which took place at the American Chemical Society's headquarters. Arrangements for the meeting were handled by our Washington members, including those from the American Geological Institute and the U.S. Geological Survey.

The USGS cartographic section hosted a tour through both its map-making and printing divisions, and another tour was conducted through Kaufmann/Graphics, Inc., printing facilities.

Panel discussions highlighted this year's meeting. The topics presented were on information systems, attitudes of the reader, writer, and editor toward methods of handling manuscripts, and future goals for writers and editors.

Plans for the fifth annual meeting are now under way, including a tentative location for the conference in Kansas City, Missouri.

Alex. Nicholson, Jr.

1921-1970

Alex. Nicholson, Jr., died from a stroke on November 11, 1970, at his home in Socorro, New Mexico. He had moved to Socorro in October 1969 after having worked for the Oklahoma Geological Survey as geologist-editor for 9 years. Services and burial were in Socorro. He is survived by his wife, Betty; his three children, Gregory, 5, Thaddeus, 4, and Johnathan, 11 months; his mother in Hollywood, Florida; and his sister, Mrs. Margaret Tiedeman, in New York City.

Alex. was born on March 24, 1921, in Flushing, New York, and was graduated from high school in Brooklyn in 1941. He received his B.S. degree in geology, cum laude, from Brooklyn College in 1950 and did graduate work at Harvard University (1950-52) and Iowa State University (1956-58). He was a member of Phi Beta Kappa and the Association of Earth Science Editors.

Prior to becoming geologist-editor with the Oklahoma Geological Survey in 1960, he had been a geologist for the U.S. Geological Survey's Ground Water Branch in Albuquerque, New Mexico, from 1952 to 1956, geologist with the Geological Survey of Canada in Manitoba in 1957, and technical editor for the Fifth World Petroleum Congress in New York City from 1959 to 1960. He served with the U.S. Army from 1941 to 1945 in Australia, New Guinea, and the Philippines.

Alex. brought to the Oklahoma Geological Survey a breadth of academic and professional experience that was to serve him well in facing the many problems of his position as editor and publication manager. His editorial efforts resulted in a much improved format and increased clarity in Survey publications. His painstaking detail in editing Survey manuscripts, although frequently exasperating to authors, resulted in high-quality publications that are now a source of great pride to all concerned. During his 9 years with the Survey he was responsible for the publication of 30 bulletins, 25 circulars, 8 guidebooks, 10 geologic maps, 1 hydrologic atlas, 3 indexes to geologic mapping, and 108 issues of *Oklahoma Geology Notes*. In addition, he also assisted Dr. Patrick K. Sutherland of the School of Geology and Geophysics in editing the first three numbers of the Memoir series of the *Journal of Paleontology*.

These efforts might have been sufficient for most men in an entire career, but Alex. was not like most men. He was a restless, inquisitive, and concerned human being. His gruff and seemingly abrasive personality provided only a flimsy camouflage for the true love and concern he felt for his fellow men.

My fondest recollections of Alex. came from the frequent "bull sessions" generated during coffee breaks and social functions. It was on these occasions that the "true Alex." emerged. All of the dreams and aspirations would come forth mixed with the almost boyish enthusiasm that all of us found contagious. Alex. insisted on sharing his moments of supreme happiness with all of his friends. We were present when he was married to Betty and lived with him during the birth of Gregory, his first son. These and other events characterized his happy and eventful life.

One of Alex.'s fondest dreams was to return to New Mexico, where he first began his career as a professional geologist and where he had fallen in love with the land. The opportunity came when the New Mexico Bureau of Mines and Mineral Resources began searching for an editor. Alex. possessed superior qualifications for the position and thus was presented with an attractive offer. The decision was perhaps the most difficult Alex. had ever made. Through his work with the Oklahoma Geological Survey he had established himself as a peer among earth science editors, and the great loyalty he felt toward the Survey was severely challenged.

After much deliberation, he finally accepted the offer and assumed his new position in October 1969. This chapter of his life, albeit much too brief, was nevertheless filled with the same infectious approach that garnered him friends from every walk of life. In the short span of slightly more than a year he had developed the same close personal relationships in Socorro that he had found in Norman.

The intensity and enthusiasm that Alex. radiated was stimulating and contagious. His passing has created a sense of loss and sadness for all who knew him.

—*Charles J. Mankin*

Memorial Fund Established for Alex. Nicholson

Colleagues of Alex. Nicholson at the New Mexico Bureau of Mines and Mineral Resources have established the "Nicholson Memorial Fund" to assist in the education of the three small Nicholson children, Gregory, Thaddeus, and Johnathan. Contributions to the memorial fund should be made to the "Nicholson Memorial Fund" and may be forwarded to the Director's Office, State Bureau of Mines and Mineral Resources, New Mexico Tech, Socorro, New Mexico 87801. The contribution is tax deductible.

OKLAHOMA GEOLOGICAL SURVEY

Annual Report

July 1, 1969 - June 30, 1970

No major changes were made in the program of the Oklahoma Geological Survey during the 1969-70 fiscal year. Several projects were completed and new projects initiated, with a continuing emphasis on expansion of activities in mineral and water-resources investigations. The cooperative program with the U.S. Bureau of Public Roads involving geologic investigation along Interstate 35 in the Arbuckle Mountains was completed. The cooperative program with the Water Resources Division of the U.S. Geological Survey resulted in completion and publication of Hydrologic Atlas 1 (Fort Smith quadrangle). Hydrologic Atlas 2 (Tulsa quadrangle) was field completed and submitted to the cartographic section. Field work is in progress on Hydrologic Atlas 3 (Ardmore-Sherman quadrangles) and Hydrologic Atlas 4 (McAlester-Texarkana quadrangles). The economic evaluation of carbonate rocks in northeastern Oklahoma was begun by Dr. Rowland. The initial phase of this investigation involves a detailed petrologic study of Morrow rocks, and the project will be expanded to include similar investigations of Mississippian strata in adjacent areas. A detailed evaluation of selected mineral resources of Osage County is now in progress under the direction of Mr. Bellis. This project is funded in part by a grant from the Osage Tribal Council and is expected to be completed shortly. Dr. Fay compiled a library on environmental geology and later presented a pilot-project outline for an environmental-geology program for greater Oklahoma City. As more funds are made available, such environmental studies will be expanded. Other cooperative projects are continuing with the Oklahoma Water Resources Board, the American Association of Petroleum Geologists, the U.S. Bureau of Mines, the U.S. Army Corps of Engineers, and the Oklahoma Industrial Development and Parks Department. Informal cooperative arrangements are being continued with numerous other organizations.

Publications of the Survey during the fiscal year included, in addition to Hydrologic Atlas 1, six issues of *Oklahoma Geology Notes,* a directory of mineral producers, a catalog for the core and sample library, a guidebook to Alabaster Cavern and Woodward County, and a mineral map of Oklahoma (appendix A).

One staff member resigned and two were added to the Survey during the fiscal year. At the end of the fiscal year, Dr. William E. Ham, a senior research member, died of a heart attack. The Survey currently has two vacant positions on its professional staff and two vacant positions on its technical staff.

The Survey's core and sample library continued to expand in activity. Core samples from 183 wells in 2,910 boxes were received and shelved. Cutting samples from 142 Oklahoma wells were processed and shelved. Cores in 1,504 boxes and 331 sample sets were shipped out for examination or examined in the library by professional geologists. Library space for cores and samples will become a major problem during the next fiscal year, and unless additional space is provided, the library's activities will be substantially curtailed.

All professional staff members have continued to be active in professional, scientific, educational, and civic groups, and several hold offices in professional and scientific organizations. More than 25 lectures to professional, scientific, and public-service organizations have been presented, and numerous technical papers were published through the Survey and other professional and scientific organizations (appendixes B and C). Each professional staff member participated in at least one regional, national, or international meeting.

The annual mineral-resources analysis for the State of Oklahoma (*Oklahoma Geology Notes*, v. 30, p. 3-4) shows that, for the third consecutive year, the value of Oklahoma's gross mineral production exceeded $1 billion. The dependence of Oklahoma on its natural-resource base for both economic expansion and tax revenue places a major responsibility on the Survey to expand its program in order to place greater emphasis on development of the State's mineral resources and on environmental geology. Diversification of the natural-resource base from its primary dependence on fossil fuels is a major objective of the Survey's development program.

Charles J. Mankin, *Director*

APPENDIX A

List of Survey Publications Issued, 1969-1970 Fiscal Year

Guide Book XV.—Guide to Alabaster Cavern and Woodward County, Oklahoma, by Arthur J. Myers, A. M. Gibson, Bryan P. Glass, and Carol R. Patrick. 38 pages, 41 figures. Issued September 1969.

Hydrologic Atlas 1.—Reconnaissance of the water resources of the Fort Smith quadrangle, east-central Oklahoma, by Melvin V. Marcher. 4 color sheets, scale 1:250,000. Published cooperatively with the U.S. Geological Survey. Issued October 1969.

GM-15.—Mineral map of Oklahoma (exclusive of oil and gas fields), by Kenneth S. Johnson. 1 color sheet, scale 1:750,000. Issued February 1970.

Directory.—Mineral producers in Oklahoma, 1969, compiled by John F. Roberts. 50 pages (multilith). Issued November 1969.

Catalog.—Core catalog 4, compiled by John F. Roberts. Complete list of cores acquired by the University of Oklahoma Core and Sample Library through February 1970. 34 pages (multilith). Issued March 1970.

Oklahoma Geology Notes. Six bimonthly issues (August 1969 through June 1970), containing 140 pages.

APPENDIX B

Publications by Survey Staff, 1969-1970 Fiscal Year

THOMAS W. AMSDEN

A widespread zone of pentamerid brachiopods in subsurface Silurian strata of Oklahoma and the Texas Panhandle: Jour. Paleontology, v. 43, p. 961-975.

The genus: a basic concept in paleontology, *in pt. C of* Proceedings of the North American Paleontological Convention [Sept. 5-7, 1969]: Chicago, Field Mus. Nat. History, p. 156.

CARL C. BRANSON

Recently issued topographic maps: Oklahoma Geology Notes, v. 29, p. 146-147.

Oklahoma topographic maps in 1970: Oklahoma Geology Notes, v. 30, p. 40-41.

ROBERT O. FAY

Geology of the Arbuckle Mountains along Interstate 35, Carter and Murray Counties, Oklahoma: Ardmore Geol. Soc. Guidebook, 75 p.

Geology of Region V, *in* Appraisal of the water and related land resources of Oklahoma—Regions Five and Six, 1969: Oklahoma Water Resources Board Pub. 27, p. 18-25.

Economic geology of Region V, *in* Appraisal of the water and related land resources of Oklahoma—Regions Five and Six, 1969: Oklahoma Water Resources Board Pub. 27, p. 128-129.

Geology of Region VI, *in* Appraisal of the water and related land resources of Oklahoma—Regions Five and Six, 1969: Oklahoma Water Resources Board Pub. 27, p. 26-31.

Economic geology of Region VI, *in* Appraisal of the water and related land resources of Oklahoma—Regions Five and Six, 1969: Oklahoma Water Resources Board Pub. 27, p. 130-131.

Geology, *in* Appraisal of the water and related land resources of Oklahoma—Region Seven, 1970: Oklahoma Water Resources Board Pub. 29, p. 18-29.

Economic geology, *in* Appraisal of the water and related land resources of Oklahoma—Region Seven, 1970: Oklahoma Water Resources Board Pub. 29, p. 124-125.

WILLIAM E. HAM

The mineral industry of Oklahoma, 1968, *in* Minerals Yearbook, 1968: U.S. Bur. Mines, v. 3, p. 597-613 (with Arel B. McMahan).

Burial cementation in the Wapanucka Limestone (Pennsylvanian) of Oklahoma: Bermuda Biol. Sta. for Research Spec. Pub. 3, p. 152-157 (with T. L. Rowland).

KENNETH S. JOHNSON

Oklahoma mineral raw materials for chemical industry (exclusive of petroleum and coal): Oklahoma Geology Notes, v. 29, p. 100-106.

Devil's Den in the Arbuckle Mountains: Oklahoma Geology Notes, v. 29, p. 134.

Mineral map of Oklahoma (exclusive of oil and gas fields): Oklahoma Geol. Survey Map GM-15, scale 1:750,000.

Bibliography and index of Oklahoma geology, 1969: Oklahoma Geology Notes, v. 30, p. 19-39 (with Alex. Nicholson).

Salt produced by solar evaporation on Big Salt Plain, Woods County, Oklahoma: Oklahoma Geology Notes, v. 30, p. 47-54.

CHARLES J. MANKIN

Oklahoma Geological Survey, annual report, July 1, 1968-June 30, 1969: Oklahoma Geology Notes, v. 29, p. 111-116.

ALEX. NICHOLSON

Aerial view of southeastern Oklahoma: Oklahoma Geology Notes, v. 29, p. 90.

Bibliography and index of Oklahoma geology, 1969: Oklahoma Geology Notes, v. 30, p. 19-39 (with Kenneth S. Johnson).

Malcolm C. Oakes

Hugh Dinsmore Miser (memorial): Oklahoma Geology Notes, v. 29, p. 129-130.

Carol R. Patrick

Guide to Alabaster Cavern and Woodward County, Oklahoma: Oklahoma Geol. Survey Guide Book 15, 38 pages (with Arthur J. Myers, A. M. Gibson, and Bryan P. Glass).

Effects of the underground stream in Alabaster Cavern: Oklahoma Geology Notes, v. 29, p. 110.

John F. Roberts

Statistics of Oklahoma's petroleum industry, 1968: Oklahoma Geology Notes, v. 29, p. 91-98.

Directory of mineral producers in Oklahoma, 1969: Oklahoma Geol. Survey, 50 p.

Oil and gas, *in* Appraisal of the water and related land resources of Oklahoma—Regions Five and Six, 1969: Oklahoma Water Resources Board Pub. 27, p. 126-127.

Core catalog 4: Oklahoma Geol. Survey, 34 p.

New core catalog issued: Oklahoma Geology Notes, v. 30, p. 43.

Oil and gas, *in* Appraisal of the water and related land resources of Oklahoma—Region Seven, 1970: Oklahoma Water Resources Board Pub. 29, p. 122-123.

Leonard R. Wilson

Palynology in the university curriculum, *in pt. A of* Proceedings of the North American Paleontological Convention [Sept. 5-7, 1969]: Chicago, Field Mus. Nat. History, p. 46-53.

APPENDIX C

Papers Presented by Survey Staff at Professional Meetings, 1969-1970 Fiscal Year

North American Paleontological Convention
Chicago, Illinois, September 5-7, 1969

Leonard R. Wilson

Function of palynology in the university curriculum.

American Association of Petroleum Geologists, Mid-Continent Section Meeting
Amarillo, Texas, October 1-3, 1969

Leonard R. Wilson

Factors in palynological stratigraphic control of deep basin rocks.

Oklahoma Academy of Science, Annual Meeting
Edmond, Oklahoma, December 5-6, 1969

Robert O. Fay

Geology of Interstate 35.

Kenneth S. Johnson

Mineral industries of Oklahoma.

Leonard R. Wilson

Pennsylvanian megafossil floras of Oklahoma.

Geological Society of America, South-Central Section Annual Meeting
College Station, Texas, April 2-4, 1970

Charles J. Mankin

Clay mineralogy and geochemistry of the upper Flowerpot Shale in Major and Blaine Counties, Oklahoma (with Dah Cheng Wu).

Leonard R. Wilson

Palynology of Oklahoma's ten-foot coal seam.

American Institute of Professional Geologists, Oklahoma Section Monthly Meeting
Oklahoma City, Oklahoma, April 14, 1970

ROBERT O. FAY
Environmental geology.

Society for Economic Botany, Annual Meeting
College Station, Texas, April 29, 1970

LEONARD R. WILSON
Contributions of palynology to petroleum exploration.

American Institute of Professional Geologists, Oklahoma Section Monthly Meeting
Oklahoma City, Oklahoma, June 9, 1970

CHARLES J. MANKIN
Oklahoma's mineral resources.

APPENDIX D

Survey Staff, 1969-1970 Fiscal Year

Professional

Thomas W. Amsden
William H. Bellis
Carl C. Branson
Robert O. Fay
William E. Ham[1]
Kenneth S. Johnson
Charles J. Mankin
Malcolm C. Oakes
John F. Roberts
T. L. Rowland[2]
Leonard R. Wilson

Part-Time Professional

Lewis M. Cline
(University of Wisconsin)
George G. Huffman
(The University of Oklahoma)
John A. E. Norden
(The University of Oklahoma)
John W. Shelton
(Oklahoma State University)
James H. Stitt
(University of Missouri at Columbia)
Patrick K. Sutherland
(The University of Oklahoma)

Technical

Editorial

Alex. Nicholson[3]
Carol R. Patrick
William D. Rose[4]

Cartographic

Marion E. Clark
Roy D. Davis
Billy J. Felton[5]
Johnny O. Langford III

Geological Technician

Odus M. Abbott

Laboratory Technician

Linda Hare[6]

Secretarial

Helen D. Brown
Jean M. Fiore[7]
Linda K. Hoogendoorn[8]
Gwendolyn C. Williamson

Core and Sample Library

Billy D. Brown
Wilbur E. Dragoo

[1]Deceased July 1970.
[2]Appointed September 1969.
[3]Resigned September 1969.
[4]Appointed May 1970.
[5]Resigned March 1970.
[6]Appointed April 1970.
[7]Resigned August 1969.
[8]Appointed August 1969.

AAPG-SEPM Meeting, Gulf Coast Section
Shreveport, Louisiana
October 28-30, 1970

The following abstracts are reprinted from the September 1970 issue, v. 54, of the *Bulletin* of the American Association of Petroleum Geologists. Page numbers appear in brackets below each abstract. Permission of the authors and of A. A. Meyerhoff, managing editor of AAPG, is gratefully acknowledged.

Channel Sequences and Braided-Stream Development in South Canadian River, Hutchinson, Roberts, and Hemphill Counties, Texas

L. G. KESSLER II, Department of Geology, University of New Mexico, Albuquerque, New Mexico, and FRED G. COOPER, School of Business, University of Texas, Austin, Texas

The South Canadian River in the eastern Texas Panhandle and western Oklahoma has produced a complex anastomosing channel system. At least 8 aggradational channel sequences (including the present channel system) are present in this part of the Canadian River valley, and are distinguished on aerial photographs and in the field by vegetational changes and overlapping stratigraphic relations. Earlier channel sequences are represented by remnants of earlier active braided-channel systems.

Analysis of daily discharge data from 1938 to 1966 reveals, that though average flow in the Canadian River is quite low, a few large floods with a flow in excess of 20,000 cu ft/second have altered severely floodplain and channel morphology. These flash events eradicate parts of earlier channel sequences and set the stage for channel braiding under lower discharge rates.

Longitudinal and transverse bars are observed in the active and younger inactive channel sequences of the river. Average orientation of these bars is nearly parallel with the orientation of the active channel in a given reach. Despite the similar average direction, there is wide variation of bar orientation in all reaches studied.

Unvegetated areas of the Canadian River floodplain show widespread eolian-dune alteration. These dunes parallel the orientation of the river valley.

Channel-wall instability and variable discharge rate are the principal factors causing braiding in the Canadian River. Serious doubts are raised about the importance of stream gradient as cause of braiding in the Canadian River system.

[1786]

OKLAHOMA ABSTRACTS is intended to present abstracts of recent unpublished papers on Oklahoma geology. 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.

Depositional Systems in Woodbine Formation (Upper Cretaceous), Northeast Texas

WILLIAM B. OLIVER, Department of Geological Sciences, University of Texas, Austin, Texas

The Woodbine Formation (Upper Cretaceous) in northeast Texas is a sequence of terrigenous clastic rocks derived largely from Paleozoic sedimentary and mildly metamorphosed sedimentary rocks exposed in the Ouachita Mountains of southern Oklahoma and Arkansas and deposited in a complex of nearshore environments along the margins of a broadly subsiding basin. On the basis of a regional outcrop and subsurface investigation in which external geometry of framework sands was integrated with observations of lithology, sedimentary structures, fossil occurrence, and bounding relationships, 2 principal depositional systems are recognized in Woodbine rocks—a fluvial system and a highly destructive delta system.

The tributary-channel facies and the highly meandering channel facies, both components of the fluvial system represented by massive sand and gravel bodies of the lower Woodbine (Dexter) lithosome, are dominant north and northeast of a line from Dallas to Tyler. On the south and southwest, the highly destructive delta system is persistent throughout the entire section. The 4 component facies of the delta system include: progradational distributary-mouth bar facies; coastal-barrier sand facies, developed either lateral to or basinward of the distributary mouth; prodelta mud facies; and embayment-strandplain facies, developed laterally adjacent to principal deltaic facies.

Following or near the end of deposition of Woodbine rocks and before their transgression by Eagle Ford Shale, emergence of the Sabine uplift resulted in erosion of Woodbine material and its redeposition along the margins of the uplift in a lithosome designated the "Harris Sand."

[1788]

GSA Annual Meetings, Milwaukee, Wisconsin November 11-13, 1970

The following abstracts are reprinted from the Annual Meetings Program of the Geological Society of America and Associated Societies, v. 2, no. 7. Page numbers are given in brackets below eash abstract. Permission of the authors and of Mrs. Jo Fogelberg, managing editor of GSA, to reproduce these abstracts is gratefully acknowledged.

A Late Ashgillian (Ordovician) Brachiopod Fauna from the Edgewood Formation, Illinois and Missouri

THOMAS W. AMSDEN, Oklahoma Geological Survey, Norman, Oklahoma 73069

The Edgewood Formation crops out along the Mississippi River in eastern Missouri and southwestern Illinois. Twenty-eight species of articulate brachiopods are present in this formation, most being represented by numerous well-preserved, silicified shells. The younger Edgewood strata have a brachiopod fauna which is at least in part of Early Silurian (early Llandoverian) age, whereas the oldest beds, those immediately above the Maquoketa Shale, yield a Late Ordovician

(late Ashgillian) fauna. These Late Ordovician brachiopods are of particular interest because they include several taxa similar to those from the *Hirnantia* fauna of Europe, this being the first time that elements of this fauna have been recognized in North America. Common Edgewood brachiopods with affinities to *Hirnantia* species include representatives of *Dalmanella* (similar to *D. testudinaria*), *Cliftonia* (similar to *C. oxoplecioides*), *Leptaenopoma* (similar to *L. trifidum*), and *Eostropheodonta* (similar to *E. hirnantensis*). An Ashgillian type *Dicoelosia* (similar to *D. anticipata*) is present. These lower Edgewood beds also include some elements of the older Cincinnatian faunas such as *Thaerodonta* and *Strophomena* ss. Halysitid corals and rare specimens of *Dictyonella* sp. are present in the older Edgewood strata. The Keel Formation of southcentral Oklahoma is believed to be at least in part correlative with the lower Edgewood strata.

[482-483]

Conodont Zonation of the Uppermost Cambrian and Lowest Ordovician

JAMES F. MILLER, Department of Geological & Geophysical Science, University of Utah, Salt Lake City, Utah 84112

A detailed conodont zonation is possible for rocks of uppermost Cambrian (Trempealeauan) and lowest Ordovician age. In sections from Oklahoma, Texas, Nevada, Utah, South Dakota, Minnesota, and Wisconsin the conodont zonation has a consistent relationship with the trilobite zonation.

The base of the lowest zone is at the first *Proconodontus muelleri muelleri* and begins just below the base of the *Saukiella junia* Subzone of the *Saukia* (trilobite) Zone (Trempealeauan). The top of the lowest of the three subzones is in the middle of the *S. junia* Subzone; the top of the middle subzone is at the top of the *S. junia* Subzone. The base of the second conodont zone (= top of the first zone) is at the first *Cordylodus proavus* and *C. oklahomensis*, at the base of the *Corbinia apopsis* Subzone of the *Saukia* Zone. This conodont zone also has three subzones. The lowest includes the *Corbinia apopsis* Subzone (Cambrian) and part of the *Missisquoia* Zone (Ordovician). The middle subzone includes the remainder of the *Missisquoia* Zone and part of the *Symphysurina* (trilobite) Zone. The remainder of the second and all of the third conodont zone are within the *Symphysurina* Zone.

The third conodont zone begins at the first *Cordylodus rotundatus; C. prion* and *C. angulatus* (*sensu lato*) are also found in this zone. This fauna was reported from the lower Upper Tremadocian of Sweden by Lindström (1955) and permits an approximate correlation of the Lower/Upper Tremadocian boundary of Europe to the United States.

[624]

Distribution and Extension of Some Flysch Deposits, Ouachita Mountains, Arkansas and Oklahoma

FRANTIŠEK PÍCHA and ALAN R. NIEM, Department of Geology and Geophysics, University of Wisconsin, Madison, Wisconsin 53706

The areal extent and distribution of individual beds in flysch series is still a matter of vigorous debate. The writers tried to study these problems by detailed investigation of lithological variations in a stratigraphic interval between two tuffs in the Stanley Group of the Ouachita Mountains.

Three lithologic subdivisions and a few key beds were recognized and compared in four stratigraphic sections. However, individual layers are too discontinuous to be correlated over the area of approximately 600 square kilometers. The horizontal extension of psammitic beds is limited to several tens of kilometers and their thicknesses change at a mean rate of 2.6 percent per kilometer.

A general northward decrease in the number and thickness of psammitic beds, in the psammitic-pelitic ratio, in grain size as well as the distribution of internal structures and extension of tuffs in the area studied indicate a southern, lateral source of sediments. The flysch beds probably were deposited in the form of a large fan at the mouth of submarine canyon(s).

In addition to this regional pattern the local alternation of "proximal" sandy facies and "distal" shaly facies was observed in each section regardless of whether it is in a more proximal or distal portion of the trough. It is suggested that sandy facies were deposited in or near submarine channels, whereas the shaly facies were originated in a more quiet environment between channels. The migration of channels was probably the main factor influencing the distribution of these local facies.

[653]

The University of Oklahoma

Clay Petrology of the Atoka Formation, Eastern Oklahoma

HER YUE WONG, The University of Oklahoma, Ph.D. dissertation, 1970

The rocks of the Atoka Formation consist of shale, sandstone, siltstone, and a few limestone layers. From a textural study, it may be concluded that the rocks have undergone no metamorphism. Authigenic minerals and secondary grain enlargement are insignificant throughout the formation.

The clay minerals of the Atoka Formation are illite, chlorite, kaolinite, mixed-layer illite-montmorillonite, vermiculite, and dickite in order of decreasing abundance. The vermiculite is considered to be a present-day weathering product. The vermiculite derived from chlorite will not collapse to 10 after treatment with potassium acetate, but that derived from illite or mixed-layer illite-montmorillonite will readily collapse to 10 Å with the same treatment. A small amount of authigenic illite and kaolinite as diagenetic products are present but have no quantitative significance.

The high-iron chlorite, which is trioctahedral, is considered to have been derived from high-ranked metamorphic rocks. The source area may have been on the southwest side of the Appalachian Mountains.

The polytypism of the illite included 2 M_1, 1 M_1, and 1 Md which would indicate that multiple source materials were involved. From the size-fraction coarser than 0.5 microns, 2 M_1 is concentrated, and the 1 M illite is concentrated in the size-fraction finer than 0.5 microns. The illite is dioctahedral with a high aluminum content but with an increasing iron content in the finer fractions. No change in the polytypism of the illite by diagenetic mechanism has been observed. The decreasing mixed-layer illite-montmorillonite content with depth could reflect alteration to illite by diagenetic processes.

The increase in boron content in the finer size fractions is related to the abundance of aluminum content rather than only size variation.

The explanation of this phenomenon is that the boron is absorbed on the surface of the clay mineral first and then migrates into lattice sites, instead of direct incorporation or precipitation as a gel. The relative abundance of aluminum and boron has a correlation coefficient of about 0.6-0.7.

The deposition of the Atoka Formation in the southern one-half of the Arkoma Basin was in a deltaic environment and the northern one-half was a shallow water, marine, near-shore environment. The sediments contributed to the delta were from the east and northeast. The northern shallow marine environment derived its sediments partly from the north and partly from the river system which built the delta westward.

(Reprinted from Dissertation Abstracts,
Pt. B, v. 30, no. 11, p. 5105-5106-B)

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