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OKLAHOMA GEOLOGY NOTES

Cover Picture

Sole Marks in Sandstone of the Atoka Formation

In eastern Oklahoma the Atoka Formation is rather widely exposed in the frontal belt of the Ouachita Mountains and on the southwest flank of the Ozark Mountains to the north. The Atoka in the latter area is a relatively thin sequence of coastal and shallow marine terrigenous deposits; however, the formation in the Ouachita Mountains is as much at 13,000 feet thick and is characterized by turbidity-current deposits. Contemporaneous faulting was apparently responsible for the changes in thickness and differences in depositional environment between the two outcrop areas.

The cover photograph of a fractured block from an Atoka sandstone bed shows flute casts on the bottom surface. These features are produced apparently as sand fills the depressions formed by turbulent water of a turbidity current impinging on a muddy sea floor. In the photograph the flute casts indicate a uniform paleocurrent direction from lower left to upper right, which in the field corresponds to an east-west direction. Location is in the Winding Stair range north of Talihina, immediately north of the Windingstair fault, 2.3 miles along the Bengal road in the SW¼ sec. 25, T. 4 N., R. 21 E.

—*John W. Shelton*

Salt Produced by Solar Evaporation on Big Salt Plain Woods County, Oklahoma

Kenneth S. Johnson

Abstract—High-purity salt (halite) is produced by solar evaporation of brine on the 4,000-acre Big Salt Plain on the Cimarron River in northwestern Oklahoma. Salt-saturated ground water, containing 343 grams of dissolved solids per liter of brine, is pumped at a rate of 500 to 1,000 gallons per minute into earthen evaporating pans from wells 40 to 100 feet deep. NaCl makes up more than 98 percent of dissolved solids in the natural brine and over 98 percent of the solar salt. Blackmon Salt Company sold nearly 7,300 tons of salt in bulk, bag, and brine during 1969: salt was used primarily to de-ice roads, and brine was used as drilling fluid in oil and gas test wells. Annual production potential on Big Salt Plain is herein estimated at 1,000 tons of salt per acre of evaporating pan.

INTRODUCTION

Big Salt Plain comprises about 4,000 acres of flat, salty bottom land adjacent to the channel of the Cimarron River between Woods and Woodward Counties (figs. 1, 2). The sandy alluvium is nearly saturated with brine and is totally barren of vegetation. Salt crusts 6 to 12 inches thick form around brine springs during dry spells (Snider, 1913), and these natural encrustations were scraped up and hauled away by Indians and early-day explorers and settlers. For a while, a

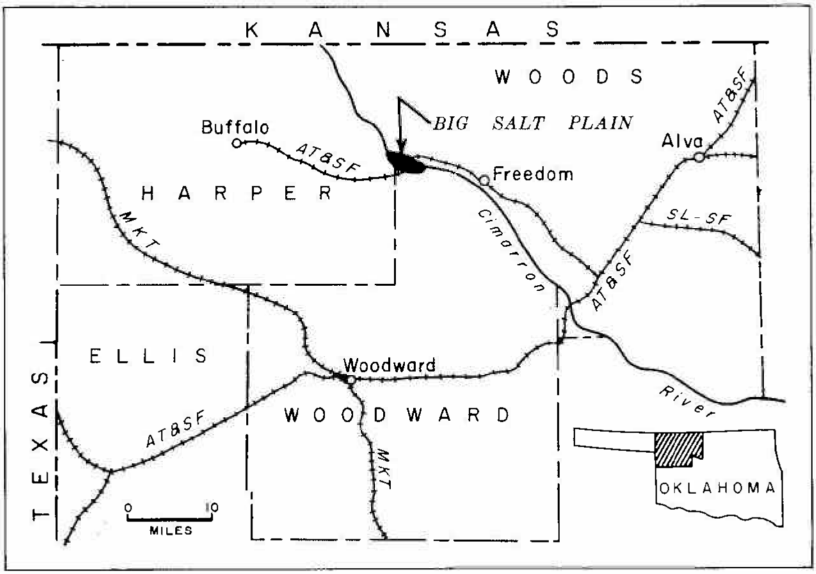

Figure 1. Index map showing location of Big Salt Plain in northwestern Oklahoma.

successful small-scale industry consisted of selling salt to meet the demand locally and in parts of Kansas, but business nearly stopped in the late 1800's with discovery and mining of underground salt beds in Kansas and with delivery of cheaper salt on newly constructed railroads.

Climatic conditions in northwestern Oklahoma are favorable for solar evaporation of brine. The averages of daily maximum temperatures during July and August exceed 95 degrees, and they are above 80 degrees each month from May through September (table I). Mean annual precipitation (1931-1960) near Big Salt Plain is about 23 inches (Oklahoma Water Resources Board, 1969), and annual evaporation of fresh water from lakes during 1946-1955 averaged about 63 inches (Kohler et al., 1959; Meyers, 1962). Evaporation here is greatest during the summer: nearly 40 percent of annual evaporation occurs in June, July, and August, and 70 percent occurs in May through October (Kohler et al., 1959).

Ezra S. Blackmon acquired land on Big Salt Plain in the 1920's and has been gathering and selling salt intermittently since that time. At first he harvested salt crusts from around the springs, but later he dug earthen pans and scraped salt from the bottom of the pans after evaporation of entrapped brine.

Blackmon Salt' Company, Route 1, Freedom, Oklahoma 73842, is owned and operated by Mr. Blackmon and his wife, Alta. It is the only salt company operating in northwestern Oklahoma. The plant with its facilities is 8 miles west of Freedom in E½ sec. 20, T. 27 N., R. 19 W., Woods County (fig. 2). It is 2 miles south of U. S. Highway 64 and adjacent to the Atchison, Topeka and Santa Fe Railway. The company employs two men full time and occasionally several part-time workers. Thanks are due Mr. Blackmon for information on the company's operation and production.

TABLE I.—CLIMATIC DATA, FREEDOM, OKLAHOMA, 1949-1960[1]

MONTH	MEAN DAILY MAXIMUM TEMP. (°F)	MEAN DAILY MINIMUM TEMP. (°F)	MEAN DAILY TEMP. (°F)	RECORD HIGH TEMP. (°F)	MEAN NO. OF DAYS WITH HIGH OF 90°F OR ABOVE	MEAN NO. OF DAYS WITH LOW OF 32°F OR BELOW
Jan.	49.9	20.6	35.2	81	0	27
Feb.	55.9	26.2	41.3	90	0	22
Mar.	61.8	31.5	46.7	91	0	18
Apr.	74.0	44.0	59.0	99	3	4
May	81.3	55.0	68.2	109	8	0
June	91.5	64.7	78.2	114	18	0
July	95.4	68.2	81.8	114	25	0
Aug.	95.7	65.7	80.8	110	27	0
Sept.	88.2	57.1	72.7	106	11	0
Oct.	77.6	45.0	61.7	102	4	4
Nov.	62.4	29.9	46.3	88	0	19
Dec.	52.8	22.8	37.5	88	0	26
Annual	73.9	44.2	59.1	114	96	120

[1]Data provided by Mr. B. R. Curry, E. S. S. A. State climatologist, from **Climatic Summary of the United States, Supplement for 1951 Through 1960—Oklahoma,** by the U. S. Department of Commerce Weather Bureau, 1965.

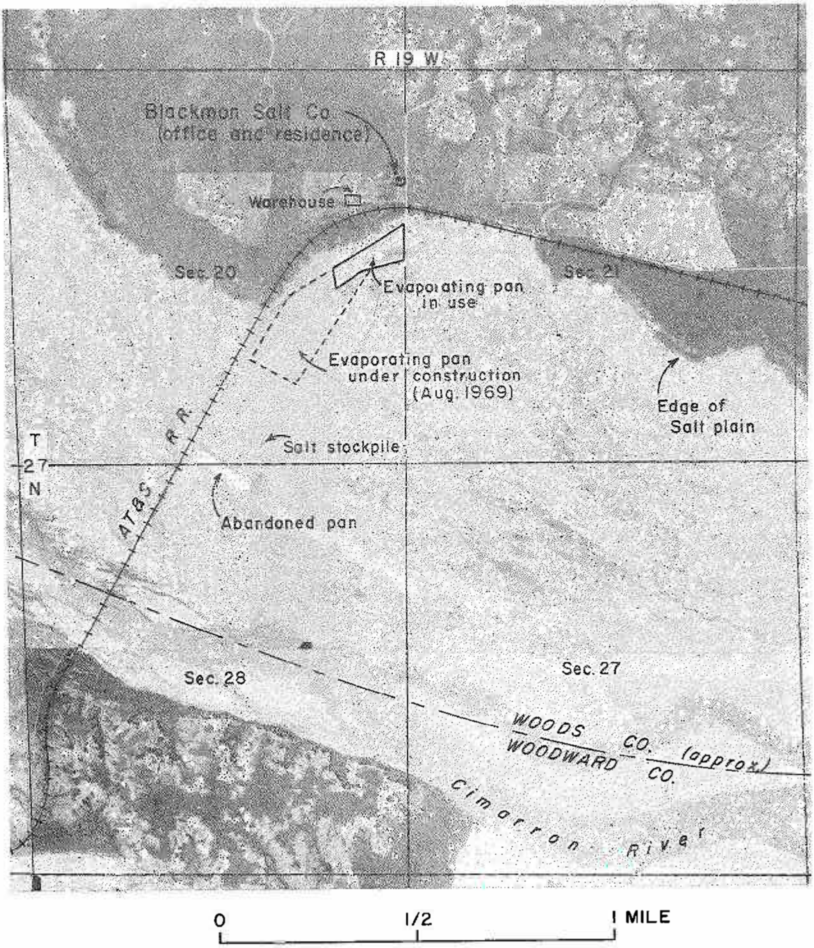

Figure 2. Aerial photograph showing part of Big Salt Plain and facilities of Blackmon Salt Company.

GEOLOGIC SETTING

Recent reports by Ward (1961a, 1961b), Jordan and Vosburg (1963), and Fay (1965) have outlined the widespread occurrence of Permian salt in northwestern Oklahoma as well as the geology of Woods County and Big Salt Plain. They show that at Big Salt Plain the Flowerpot salt, locally only 30 feet below surface, comprises layers of rock salt interbedded with lesser amounts of reddish-brown shale. Brine, formed when ground water dissolves Flowerpot salt here and farther west, carries 2,500 tons of NaCl upward into the alluvium and to the surface each day, making this the major site for salt-water pollution of the Cimarron River. Federal agencies, principally the U. S. Army

Corps of Engineers, and State agencies are now investigating this area, looking for the best means of controlling brine emission and improving the quality of water supplies downstream.

Saturated brine not only permeates the alluvium but also flows through solution caverns in the Flowerpot salt: brine-filled cavities were encountered in layers of rock salt 40 to 100 feet below the surface in a number of production wells (Mr. Blackmon, oral comm., 1969). Although the brine in bedrock is under artesian pressure, it barely reaches ground level in only one or two wells and must therefore be pumped. Production wells are pumped at a rate of 500 to 1,000 gallons per minute.

CHEMICAL AND SIEVE ANALYSES

Brine used by Blackmon Salt Company is saturated with respect to salt. It has a specific gravity of 1.208, and Na+Cl is about 337 grams per liter (table II). Na and Cl make up about 98.1 percent of dissolved solids in the brine, and the principal impurities, Ca and SO_4, are about 1.8 percent of dissolved solids. Other published analyses of brines from various parts of Big Salt Plain are similar. Solar salt produced from the brine is 98.02 percent NaCl, and its chief impurities

TABLE II.—CHEMICAL ANALYSES OF SOLAR SALT AND BRINE BLACKMON SALT COMPANY[1]

(Samples obtained August 22, 1969)

	SALT	BRINE
Sp. G. (60° F)		1.208
pH		6.9
	WEIGHT %	GRAMS/LITER
Na	——	131.587
Ca	0.921	2.250
Mg	None	0.340
Cl	——	205.076
Br	0.020	0.048
I	0.003	0.010
SO_4	0.869	4.036
HCO_3	0.013	0.036
Si	0.10	——
Mn	0.001	——
Fe	0.004	——
Al	0.05	——
Bi	0.002	——
Cu	0.0002	——
Ti	trace[2]	——
Sr	0.001	——
Ba	trace[2]	——
NaCl (by diff.)	98.016	——
Total	100.000	343.383[3]

[1]Analyses by U. S. Bureau of Mines, Bartlesville Petroleum Research Center, under the direction of Robert T. Johansen. Standard wet chemical methods used in analysis of Na, Ca, Mg, Cl, Br, I, SO_4, and HCO_3 in salt and brine; other elements determined semiquantitatively from salt sample by emission spectrograph.

[2]Less than 0.0001%.

[3]Equivalent to 284.3 g/kg, or 28.43% by weight.

are Ca and SO_4, occurring mainly as gypsum, and Si, occurring mainly as quartz. Blackmon's salt is generally purer than the sample tested for this report. Salt sampled on August 22 had accumulated for nearly 1 year since the last harvest, and it contains excessive amounts of Ca, SO_4, and Si. Mr. Blackmon reports (oral comm., 1969) that a number of chemical analyses of his salt show a purity of 99.18 to 99.82 percent NaCl.

Accessory minerals, identified by petrographic and X-ray diffraction techniques, in the solar salt include gypsum, quartz, glauberite, and possibly sylvite. Gypsum, occurring as colorless laths 0.5 to 1.0 mm long, and the glauberite and sylvite(?) are precipitated from brine along with halite; whereas quartz, in grains 0.02 to 1 mm in diameter, is windblown material.

Sieve analysis shows that Blackmon's salt is well suited for de-icing roads. Salt ranging in size from minus 0.5 inch to plus 12 mesh is almost universally used, and nearly 76 percent of Blackmon's product is within this range (table III). It was widely used, with satisfactory results, on highways and city streets of central and western Oklahoma during the winter of 1968-1969.

TABLE III.—SIEVE ANALYSIS OF SOLAR SALT, BLACKMON SALT COMPANY[1]

	INCHES		U. S. STANDARD SERIES						
Sieve No.	0.5	0.25	5	8	10	12	16	20	pan
Weight %	4.78	12.96	23.17	26.36	7.03	6.43	9.53	7.84	1.90

[1]Dry salt sieved 30 seconds in electromagnetic vibrating siever. William E. Bellis, analyst.

The importance of grain size in de-icing stems from the fact that proper-sized salt will dissolve only partially as it melts to the bottom of an ice sheet. The brine produced by further melting spreads out in all directions beneath the ice and breaks the ice-pavement bond. Unbonded chunks and layers of ice are then easily broken up by plows and passing traffic.

PRODUCTION

Saturated brine is pumped by Blackmon Salt Company from the natural caverns in underground beds of rock salt and is channeled into 2-foot-deep, flat-bottomed earthen pans. As water is evaporated by the sun's heat, the brine becomes supersaturated and salt crystals settle to the bottom of the pan. Brine is added intermittently to maintain a water depth of about 12 inches. Although salt is produced throughout the year, most of it forms during the hot, dry summer months. During the summer of 1969 only one 10-acre pan was in use, but a second 25-acre pan was being constructed. In spring 1970 (Mr. Blackmon, oral comm.) still another 25-acre evaporating pan was being built, bringing the total to about 60 acres of pans in use or under construction.

Harvesting is done when the salt crust on the floor of the pan is about 6 inches thick, and then only the top half is removed. The bottom several inches of salt are left in place permanently to provide a fairly firm base and to prevent intermixing of salt with underlying sand. Workers harvest about 2 tons of salt per minute and truck the salt to a nearby outdoor stockpile for drying. A warehouse was constructed recently for storage of bulk and bagged salt.

Blackmon Salt Company sold 7,268 short tons of salt during 1969 in the form of solar salt and brine (table IV); this was a record high for the company. Until recently, Blackmon's salt was used primarily for

TABLE IV.—SALES OF SALT AND BRINE BY BLACKMON SALT COMPANY, 1963-1969[1]

	SOLAR SALT		BRINE		
YEAR	TONS	VALUE	TONS OF SALT IN BRINE	BARRELS (APPROX.)	VALUE
1963	133	$1,117	1,914	33,700	$5,050
1964	199	1,680	3,069	53,900	8,081
1965	309	2,613	2,960	51,900	7,793
1966	556	3,765	4,340	76,300	11,429
1967	291	2,332	3,305	58,000	8,702
1968	2,939	17,309	2,349	41,200	6,186
1969	4,005	21,496	3,263	57,200	8,590

[1]Data provided by Blackmon Salt Company.

stockfeed and as a recharger for water softeners. The sharp increase in sales during 1968 and 1969 resulted from a large demand for salt to de-ice streets and roads. Nearly 5,000 tons of salt were trucked to northwestern, central, and south-central Oklahoma during the winter of 1968-1969. Annual brine production since 1963 has averaged 53,170 barrels, containing just over 3,000 tons of salt. Brine, sold by the truckload, is being used as drilling fluid in oil and gas test wells.

Salt is sold at the plant for $5.00 a ton bulk and $10.00 a ton in bags, and brine is selling for $0.15 a barrel.

It is herein estimated that the average annual production on Big Salt Plain could be about 1,000 short tons of salt per acre of evaporating pan. This is determined, as shown below, using average annual climatological data for Woods County:

Lake evaporation, fresh water	63 inches
Precipitation	23 inches
Excess evaporation over precipitation	40 inches

However, the evaporation rate of saturated brine is variously estimated at only 70 to 80 percent that of fresh water (Adams, 1934; Bonython, 1966; Harbeck, 1955; Koenig, 1958). Using the more conservative evaporation rate of 70 percent, I estimate that average annual net evaporation here would be about 28 inches of saturated brine. Saturated NaCl brine contains 430 tons of salt per acre-foot (2.65 pounds of salt per gallon of brine), so 28 inches of brine evaporated in 1 year would yield 1,000 tons of salt per acre.

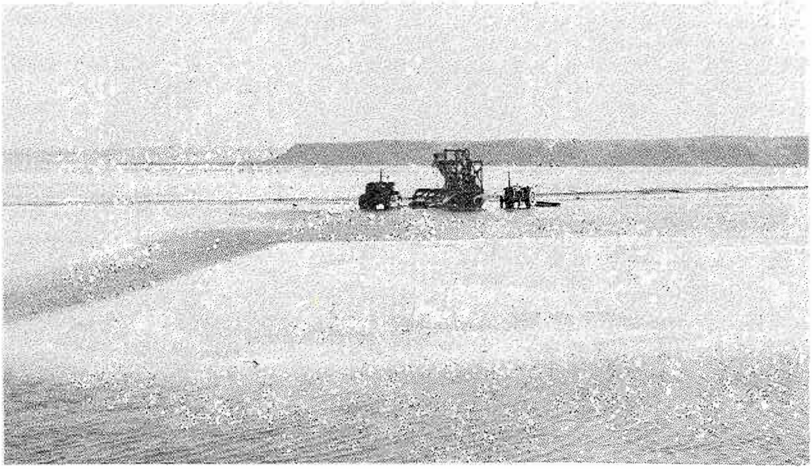

Figure 3. Brine-filled earthen pan and harvesting machinery of Blackmon Salt Company on Big Salt Plain. White crust of solar salt is visible in foreground. View looking south to gypsum-capped escarpment 1.5 miles away.

In any given year, rainfall at Big Salt Plain may range from 12 to 35 inches; as a result of this and other variables that affect evaporation rates (i. e., humidity, temperature, number of cloudless days, and wind speed), production may be as much as 50 percent more or less than the calculated annual average. In most years, however, rainfall is within 3 or 4 inches of average, and production should be 800 to 1,200 tons per acre.

Expanded use of high-purity brine resources at Big Salt Plain would serve the dual purpose of increasing Oklahoma's mineral production and of decreasing the pollution of a major river . It is paradoxical that a State with salt reserves estimated at over 20 trillion tons has to import most of the salt it consumes each year. In 1968, Oklahoma used 101,000 tons of salt for all purposes and imported 94,000 tons of this total from other states. Increasing salt production at Big Salt Plain should result in a corresponding reduction of the amount of brine reaching the surface and contaminating the Cimarron River.

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New Editor for the Survey

After 10 years with the Oklahoma Geological Survey as geologist-editor, Alex. Nicholson resigned his position in October 1969 to become the editor for the New Mexico State Bureau of Mines and Mineral Resources in Socorro. Finding a replacement for Alex. has been no easy task, and several months have been spent seeking and screening applicants. At the end of February, however, the Survey extended an offer to William D. Rose, editor for the Kentucky Geological Survey. He accepted the position and assumed his new duties in May.

Bill is originally from Nashville, Tennessee, and has his bachelor's and master's degrees in geology from Vanderbilt University in Nashville. From 1953 to 1956 he was a subsurface geologist with Gulf Oil Corporation in Fort Worth and Midland, Texas, and since 1956 he has been with the Kentucky Geological Survey in Lexington. While with the Kentucky Survey he did extensive work on Illinois basin petroleum geology, becoming full-time editor and head of the publications section in 1966.

As secretary-treasurer of the Association of Earth Science Editors, Bill is well acquainted with the problems involved in technical editing, and he has been very active in this organization.

His duties for the Survey include a review of existing editorial policy and implementation of changes necessary in keeping with changes in the Survey's needs. In addition to policy review, he will be supervising editorial and printing activities as well as reviewing and editing manuscripts submitted for publication.

Chitinozoa from the Viola and Fernvale Limestones
A Review

Patrick K. Sutherland

Those interested in the geology of the Arbuckle Mountains and, more particularly, in the age and correlation of their Ordovician rock units will welcome W. A. M. Jenkins' description of the *Chitinozoa from the Ordovician Viola and Fernvale Limestones of the Arbuckle Mountains, Oklahoma,* Palaeontological Association of London Special Paper No. 5, 44 pages, 9 plates, 10 figures, 3 tables. No doubt the paper will also be of great value to those working on lower Paleozoic chitinozoans. Chitinozoans are organic-walled "micro-micro" fossils of uncertain biological affinity that have been shown only in recent years to occur fairly widely in some types of lower and middle Paleozoic rocks, particularly in the so-called "graptolite facies." Dr. Jenkins' paper shows that potentially they may provide a basis for at least broad-scaled stratigraphic correlation on an intercontinental scope.

Dr. Jenkins summarizes from the literature the biostratigraphic and lithostratigraphic evidence concerning the disputed occurrence of a regional unconformity at the contact of the Viola and "Fernvale"* Limestones. For the area in which he studied the sequence, Dr. Jenkins states: "No faunal or stratigraphical evidence for a break in deposition has been detected at the base of the Fernvale Limestone."

The paper includes descriptions of 10 genera and 20 species of chitinozoans, of which 6 species are new. Most occur throughout major parts of the Viola Limestone and form, according to the author (p. 38), "an essentially continuous faunal succession, whose unity is more apparent than its divisibility." Dr. Jenkins recognizes five faunal zones based primarily on the appearance and/or disappearance of particular species.

Only one distinct faunal break occurs in the sequence. It lies within the upper part of the Viola lithology. There is apparently no physical evidence for an unconformity, but Dr. Jenkins believes (Abstract) "that a significant hiatus exists here and indicates that the uppermost Viola-Fernvale strata are substantially younger than the beds immediately below." An examination of table 3, a range chart, shows that the evidence for the time break is the disappearance of 6 species and the appearance (in the next sample taken 20 feet higher in the section) of 2 new species, but 3 species continue across the interval.

A major shortcoming of the paper, which the author recognized, is that collections were made from only one stratigraphic section in a Viola-"Fernvale" outcrop area extending across the whole of the Arbuckle Mountains and Criner Hills, an area covering about 2,000 square miles. It is impossible to know if the biostratigraphic zones set up by the author are consistent across the outcrop area and—more important—if the single distinct faunal change, discussed above, rep-

*The term "Fernvale" is placed in quotation marks in this review because of the unit's extremely tenuous correlation with the Fernvale Limestone of Tennessee.

resents an unconformity reflecting a significant time break, as the author contends. The author states (p. 4): "The direction in which the Fernvale Limestone thickens is essentially opposite to that in which the Viola Limestone thickens but, to my knowledge, no satisfactory explanation for this reversal in the direction of thickening has been published." On Sycamore Creek, where Dr. Jenkins collected his samples the "Fernvale" is about 30 feet thick, and the faunal break described by the author lies within the Viola lithology, about 30 feet below the base of the "Fernvale." In the area where the "Fernvale" Limestone has thickened to 100 feet and the Viola Limestone has thinned, it would be of interest to know if such a chitinozoan faunal break occurs and, if so, its position in relation to the Viola-"Fernvale" contact.

This paper is a most welcome and worthy addition to the scanty knowledge of chitinozoan occurrences in North America, and it provides an additional tool for the evaluation and correlation of Ordovician rocks in Oklahoma.

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Clifford A. Merritt Retires

After 44 years on the faculty of the School of Geology and Geophysics, The University of Oklahoma, Dr. Clifford A. Merritt is retiring at the end of this semester; he will be greatly missed by both his colleagues and students. As part of the team of professors who were important to the early thrust of the school into national prominence, he has had a lasting influence on the direction of geologic studies at O. U.

A Canadian, Dr. Merritt received his B.S. and M.S. degrees from the University of Manitoba and his Ph. D degree from the University of Chicago before moving to Norman. He became an associate professor in 1935 and full professor in 1939. During his academic career he has written many articles and bulletins. He has contributed academically to thousands of students, and his extensive studies of the State's geology, particularly igneous rocks in the Wichita and Arbuckle Mountains, have greatly expanded our knowledge of this region. His contributions to the mineral industry of the State are particularly noteworthy, especially his work on copper deposits as written up in *Copper in the "Red Beds" of Oklahoma,* Mineral Report No. 8 of the Oklahoma Geological Survey. Dr. Merritt intends to continue his studies on igneous rocks of the Wichita Mountains after retirement.

A banquet in his honor is to be given on June 12 at 8:00 p.m. at the Holiday Inn, Norman, with a reception to be given at 7:00 p.m. prior to the banquet. Further information can be obtained from the School of Geology and Geophysics, The University of Oklahoma, 830 Van Vleet Oval, Room 107, Norman 73069.

GSA Southeastern and South-Central Section Annual Meetings

April 1-4, 1970

The following are abstracts of papers related to Oklahoma geology presented at the Annual Meetings of the Geological Society of America, Southeastern and South-Central Sections. Permission of the authors and of the Society to print these abstracts is gratefully acknowledged.

Oklahoma Geology Notes should not be given as the primary source in citations of or quotes from the abstracts. The correct citation is Geol. Soc. America, Southeastern Sec. (or South-Central Sec.), 1970 Ann. Mtg., Program, vol. 2, no. 3 (or no. 4), p. ——. Page numbers are given in brackets at the lower right of each abstract.

Southeastern Section Meeting, Lexington, Kentucky

Some Middle and Upper Ordovician Brachiopods from Oklahoma, Missouri, and Tennessee

LEONARD P. ALBERSTADT, Department of Geology, Vanderbilt University, Nashville, Tennessee 37203

Studies of the interiors of species of *Lepidocyclus* and *Platystrophia* show that within each genus there are considerable differences in the muscle patterns of the brachial valves. Individuals that are usually referred to *L. capax* have a much simpler muscle pattern than do members referred to *L. cooperi* and *L. oblongus*. The numerous species of *Platystrophia* have always been differentiated on the basis of external characteristics. Analysis of the interiors shows distinct differences in the brachial muscle patterns and in the cardinalia, particularly the brachiophore bases. Some species of *Platystrophia* do not have the simple four quadrate muscle scars, but rather have two "J-shaped" posterior adductor scars. In several specimens of *Platystrophia* from Tennessee the brachiophore bases are well defined and inclined inward and rest on a median septum. In some species this structure is similar to a spondylium [should read "similar to a cruralium"].

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.

Information regarding the stratigraphic distribution of some of these brachiopods is only reliable for Oklahoma. In the Viola and "Fernvale" Formations *Lepidocyclus oblongus* occurs lower in the section than *L. cooperi* and *L capax*. Also, species of *Platystrophia* possessing the normal "orthoid" muscle pattern in the brachial valve occur much lower in the section than species with "J-shaped" scars.

Additional studies on the interiors of the many species of both these genera may yield valuable information which will be useful in interpreting their evolutionary histories and thereby increase their biostratigraphic value.

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South-Central Section Meeting, College Station, Texas

An Unusual Palynological Assemblage from the Ordovician of Oklahoma

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Trilete spores, dinoflagellates, scolecodonts, chitinozoans, acritarchs, and vascular plant tissue comprise an unusual assemblage of Ordovician age recovered from the Viola formation. The vascular tissue, spores and dinoflagellates of this assemblage, if not contaminants, are probably the oldest examples known.

The trilete spores include types exhibiting a distal hilum and have probable affinities with the bryophytes. The vascular tissue includes circular openings which may be stomatal or tracheary in nature.

Most of the dinoflagellates are unusually small, rarely exceeding 30 micra, and most exhibit a girdle, apical and antapical horns, archeopyles and indistinct to distinct plate tabulation.

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Palynology and Environmental Analysis of Upper Pennsylvanian Strata, Keystone Reservoir Area, Oklahoma

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The environmental significance of palynomorphs and tracheids has been determined for Missourian and Virgilian outcrop samples in the Keystone Reservoir area, Oklahoma. These outcrops consist of sandstone and shale with thin limestone markers.

G. Visher of the University of Tulsa has analyzed the textural characteristics of the sandstones from several outcrops in the area of interest and plotted the grain size variations. These sands vary in thickness from 20 feet to over 40 feet. The individual sands are highly variable but predominantly deltaic and fluvial-flood plain types. An environmental study of the interbedded shales was made using palynologic parameters to aid in the environmental interpretation of the sands.

The composition of the palynomorph assemblages studied has allowed the interpretation of the following depositional environments: (1) floodplain-fluvial, (2) deltaic, (3) marsh or lake, and (4) marine shale. Recycling of palynomorphs is evident and the upland flora is well represented in the palynomorph assemblage.

[297-298]

A Re-Examination of a Magnetic Survey on the Spavinaw Granite

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In 1952, J. Hawes published in Geophysics "A Magnetic Survey of the Spavinaw Granite Area, Oklahoma". This paper was an attempt to relate natural remanent magnetization (NRM) of the granite to local surface magnetic anomalies. It also has significance as an early work in paleomagnetism, for Hawes had obtained what is probably the first systematic evidence for geomagnetic field reversal in the Pre-Cambrian. At about the same time as Hawes did his work, J. Hospers had obtained clear evidence for polar reversal in the late Tertiary and early Quarternary lavas in Iceland.

Hawes original magnetic declination-inclination data has been replotted on stereographic equatorial and polar projections, and the vectors representing the magnetization of oriented granite samples fall into two groups of 43 and 49 points. These groups give two mean poles and dispersion parameters, and the poles are 166 degrees apart. The polarities appear to be related to depth, with downward or normal polarity above. A rate-of-cooling mechanism is suggested to explain the presence of this magnetic "horizon" in the granite.

The radiometric age and paleomagnetic measurements of this and other Pre-Cambrian rocks have been compared and found in good agreement. H. Spall has remeasured the NRM of the Spavinaw granite and confirms Hawes norman-reversed results. The application of the 166 degree reversal to polar wandering is considered.

[294-295]

Palynology of the Mineral Coal, Desmoinesian Series of Oklahoma and Texas

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A palynologic study of four sections of the Mineral Coal, Desmoinesian Series of Oklahoma and Kansas shows a spore flora that occurs in patterns and associations of species indicating that plant succession was a factor in the coal swamp development. It is obvious when studying the distribution of the spores over the extent of the Mineral coal seam that this succession existed at different stages in different parts of the coal swamp. The northernmost section shows a more complete successional picture and the stages are progressively younger to the south. The spore patterns appear to be related to geographic location. Sedimentation in the southern parts of the swamp may have begun somewhat earlier than those to the south. The coal in the south also shows successional repetition during its developmental history. The repetition is probably related to its marginal position which would subject it to minor fluctuations of swamp condition.

Densosporites appears to be related to abnormal circumstances in the developmental history of the coal swamp. Evidence suggests that *Densosporites* flourishes when an influx of clastic sediment modifies the typical swamp environment.

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Displacement by Flow in Imbricate Thrust Fault Belts

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The total displacement for imbricate thrust fault belts is frequently calculated by adding the displacement of each individual imbricate, this sum supposedly representing the total displacement of a master sole fault at the rear of the imbricate belt. Moving along a decollement, thrust faults are said to generate the displacement by simple overlapping of non-cohesive rock sheets. The stratigraphic unit carrying the decollement contributes nothing of itself to the total displacement. However, the decollement should not be viewed as a simple detachment surface, but as a relatively ductile bed. Thrust faults not only follow this bed but exist because of it. Individual imbricates root in a pinched or flattened segment, from which they have flowed. As in a flexural fold, relatively brittle beds must be stretched around the thickened areas. Moreover, if part of the displacement of an imbricate belt is due to flow, then the displacements need not be cumulative, for at least part of the overlap is not due to translation alone but to pinching of the bed at the root of each individual imbricate. How much depends upon the thickness of the ductile bed and the amount of pinching and flow. Conceivably at the rear of an imbricate belt, total displacement could be zero. To support the hypothesis, I cite examples of imbricate thrust faulting from penecontemporaneous structures, from mud lump islands off the Mississippi delta, and from the Black Knob Ridge area of the Oklahoma Ouachitas.

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Palynology of Oklahoma's Ten-Foot Coal Seam

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The Lower and Upper seams of the Hartshorne coal (Des Moines Series, Pennsylvanian) are combined in the vicinity of Wilburton, Oklahoma and constitute a deposit of coal that is ten feet thick. The two seams are separated by a clay parting of four inches approximately in the middle of the deposit and represents sediment resulting from a rise in sea level that destroyed the mature floristic structure of the region and caused inception of a new successional development. In the lower coals of the Des Moines Series palynological succession generally begins with a dominance of *Laevigatosporites* spores. This is followed by a mixed assemblage of *Lycospora, Densosporites, Calamospora, Triquitrites, Cirratriradites, Granulatisporites,* and others less common. The climax of succession in these seams is marked by dominance of *Endosporites* and *Densosporites*. The lower five feet of the seam contains the above stages in marked degree and the succession was abruptly terminated at the shale parting. The shale contains a mixed assemblage of spores carried into the marine deposit from the adjacent upland. The upper five feet of coal contains a repetition of the same stages as below but the final *Densosporites* stage is shorter and less marked. An understanding of palynological successional stages and their distribution in coal seams can be an aid to mapping the paleoecology in coal swamps and can refine the stratigraphic use of fossil spores and pollen.

[304-305]

Clay Mineralogy and Geochemistry of the Upper Flowerpot Shale in Major and Blaine Counties, Oklahoma

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Excellent exposures of the upper Flowerpot Shale in Blaine and Major Counties, Oklahoma, permitted a detailed examination of the geographic, stratigraphic, and particle size variation in mineralogy and chemistry of this mudstone and shale sequence. The upper Flowerpot Shale in these counties is primarily a redbed sequence with isolated layers of dolomite and gypsum. The red shales are mottled with greenish-grey spots and intercalations of greenish-grey silty shale and siltstone is also common. The greenish-grey color is attributed to the reduction of ferric iron oxides to the ferrous state by oxidation of organic matter. In addition, the circulation of solutions in the more permeable siltstone and silty shale units is believed to be responsible for the reduction in total iron content of these units.

The clay minerals present in the upper Flowerpot Shale are mainly illite with some swelling chlorite and regular chlorite. Kaolinite is absent. The swelling chlorite is present only in the uppermost portion of the Flowerpot Shale and is concentrated in the shale bed beneath the uppermost dolomite bed. The swelling chlorite is believed to be either an alteration product of normal chlorite or an authigenic development of incomplete brucite layers in degraded three-layer clay minerals.

The sediments seem to have been derived from the south or southeast and deposited in a shallow, low energy environment under semiarid to arid conditions. The boron and vanadium content of the shale samples suggests a marine environment with moderate to high salinity and the presence of analcite suggests high alkalinity and high sodium content.

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University of Kansas

Devonian Rocks in Kansas and Their Epeirogenic Significance

PAUL LORENZ HILPMAN, University of Kansas, Ph.D. dissertation, 1969

In Kansas, Devonian rocks are restricted to the subsurface and knowledge of these strata is severely limited. Previous investigations have not included discovery of diagnostic fossils adequate to subdivide the sequence or to permit correlation with distant outcrops in surrounding states.

On the basis of cores from 27 wells, supplemented by more than 2,500 sample, geophysical, and drillers' logs, Devonian rocks are subdivided into eight distinct lithologic units. Conodonts recovered from insoluble residues of cores indicate that two units are Middle Devonian in age, three units are early Late Devonian in age, and three units range in age from Late Devonian to Early Mississippian. No evidence of Early Devonian rocks was found, and widespread erosion is inferred to have occurred in this time interval.

The distribution and lithologic character of the units indicate that the Middle Devonian seas were restricted to the North Kansas basin and earliest Late Devonian (Frasnian) seas occupied the Southwest Kansas basin. Late Devonian (Famennian) and Early Mississippian (Kinderhookian) seas were widespread throughout the state, and rocks deposited during this interval lie unconformably on older rocks and are unconformably overlain by younger strata (Osagian Stage).

In this study, interpretations of epeirogenic events differ from those of Sloss, Wheeler, and Ham and Wilson.

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