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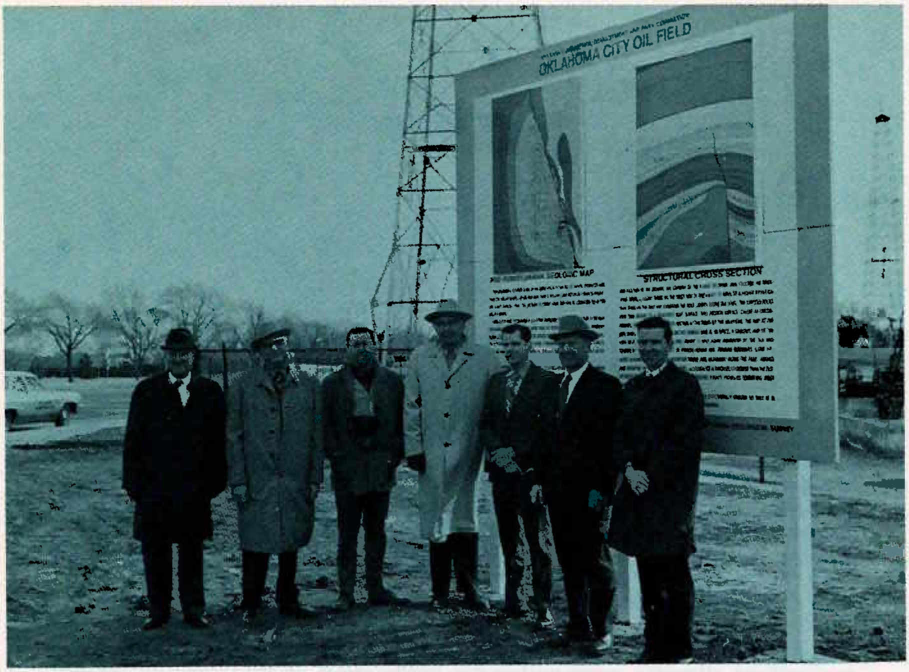

OKLAHOMA GEOLOGY NOTES

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Cover Picture

Dedication of Sign Depicting Geology of Oklahoma City Oil Field

A sign commemorating the discovery and depicting the geology of the giant Oklahoma City oil field was dedicated January 16. During the dedication ceremony, held just south of the State Capitol Building, the importance of geology's role in the development of Oklahoma's petroleum and other mineral resources and its contribution to the economy of the State was stressed. The discovery well of the Oklahoma City field, staked on the recommendation of petroleum geologists, was drilled in December 1928 by the Indian Territory Illuminating Oil Company (later Cities Service).

The dedication paid tribute to a number of individuals and organizations directly responsible for completion of this first of a series of 15 signs to be erected pointing out significant geologic features throughout the State. Individuals shown on the cover picture are, from left to right: Jerry B. Newby, consulting geologist and honorary member of the American Association of Petroleum Geologists; Robert H. Breeden, executive director of the Oklahoma Industrial Development and Park Department; Herbert G. Davis, president of the Oklahoma City Geological Society; George H. Shirk, president of the Oklahoma Historical Society and former mayor of Oklahoma City; David R. Matuszak, president of the Tulsa Geological Society; Lloyd E. Gatewood, consulting geologist; and Charles J. Mankin, director of the Oklahoma Geological Survey. Leroy Gatlin, president of the Oklahoma section of the American Institute of Professional Geologists, was unable to attend the ceremony.

The 10- by 8-foot sign is constructed of porcelain-enameled steel. Its most striking features are two detachable color panels showing, at left, a pre-Pennsylvanian geologic map of the field and, at right, a structural cross section of the field. The derrick behind the group and to the left of the sign marks the site of a well directionally drilled to produce oil from beneath the Capitol Building.

Jerry Newby, in recounting the geological sign project from its inception late in 1967, noted that it was inspired by an earlier project of geological markers erected in the Arbuckle Mountains by the Ardmore Geological Society. The sign was financed jointly by contributions of individual geologists and geological societies and by the Oklahoma Industrial Development and Park Department.

Localities for which similar signs are planned include the lead and zinc district of northeastern Oklahoma, the Arkoma basin, the Ouachita Mountains, the Wichita Mountains, and Black Mesa at the western tip of the Panhandle.

—*William D. Rose*

Origin of Greenish-Gray Spots and Layers in the Upper Flowerpot Shale (Permian) Northwestern Oklahoma

Dah Cheng Wu[1]

Abstract—Based on data from quantitative chemical analyses of iron and silicon by X-ray fluorescence, emission-spectrographic analyses of the trace elements cobalt, nickel, and vanadium and size analyses by pipette method, the greenish-gray spots and layers in the red-bed sequence of the upper Flowerpot Shale (Permian, lower Guadalupian) are attributed to the reduction of ferric iron oxides to the ferrous state by the 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 greenish-gray units.

INTRODUCTION

Most of the rocks present in the upper Flowerpot Shale (Permian, lower Guadalupian) in northwestern Oklahoma are reddish-brown shale mottled with greenish-gray spots, some with dark centers (fig. 1). Intercalations of greenish-gray silty shale and siltstone are very common (fig. 2). The red-bed sequence also contains some isolated layers of dolomite and gypsum. Clay minerals of the upper Flowerpot Shale include mainly illite, with some chlorite and swelling chlorite (Wu, 1969).

Tomlinson (1916) attributed the green spots, which are so common in the red beds of the western United States, to the former presence of undetermined minute organisms that reduced the ferric iron in their immediate vicinity.

Based on statistical comparison, Swineford (1955, p. 121) concluded that there is no evidence that the iron content of Permian red shales and green or gray shales is different. However, the 6 red-shale and 3 green-shale samples used by Swineford (1955) as the basis of statistical comparison were scattered through a wide stratigraphic interval in the Upper Permian section of Kansas. In addition, her chemical data consisted of a collection of analyses from several sources. It is questionable whether those samples can be assumed to have been drawn from the same population with the same variance required for Student's "t" test.

The purpose of this investigation was to study the variation in mineralogy, chemistry, and particle size between greenish-gray shale and reddish-brown shale to determine if this would account for the distinct color difference. Samples were collected upward along the cliff faces of six measured sections of the upper Flowerpot Shale in the area of Blaine and Major Counties, Oklahoma (for chemical analyses, samples of five sections were used).

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Figure 1. Reddish-brown shale mottled with greenish-gray spots (light spots above and below hammer), some with dark centers (enclosed by dotted line), in lithologic unit B-E-2.

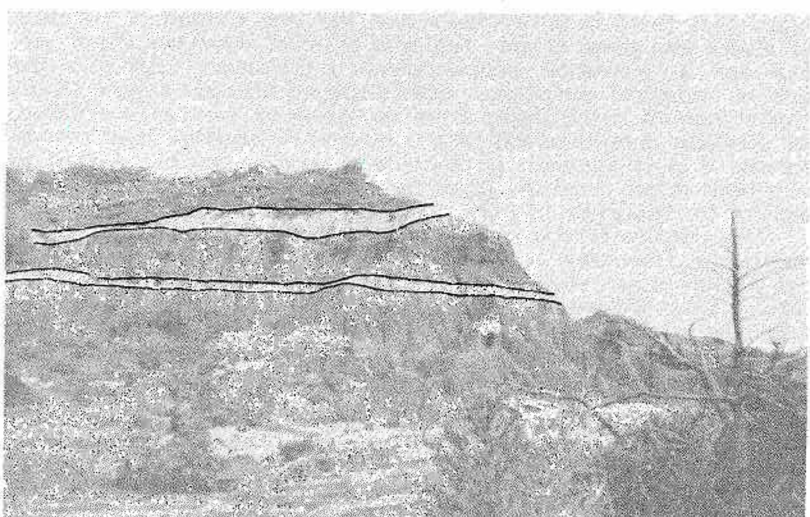

Figure 2. Greenish-gray shale interbeds (delineated by black lines) in reddish-brown shale in basal portion of measured section B-F.

PROCEDURE

Bulk shale samples for chemical analyses were ground so that they would pass through a 230-mesh screen. This process eliminated coarser grained quartz, feldspar, and other coarse-fraction iron-bearing minerals, whose presence in the sample would affect the relative percentage of total iron. Thus, some samples were processed to collect the less-than-1-micron clay material by standard decantation and centrifugation.

The greenish-gray samples selected for the pipette analysis were those in which amounts of silt were insignificant. Pipette-analysis techniques followed the procedures of Folk (1968).

The standards used for the quantitative X-ray-fluorescence analysis are U.S. Geological Survey silicate-rock standards (Flanagan, 1967). Standards used for quantitative emission-spectrographic analysis were made with spectrographically pure compounds diluted with a silicate matrix that was approximately the composition of the shale. SnO_2 was used as an internal standard.

RESULTS

No difference in mineral types between greenish-gray shale and reddish-brown shale was detected by X-ray-diffraction methods. As revealed from petrographic study (Wu, 1969), the red coloration in the shale is due to hematite staining and finely disseminated hematite particles. The staining coats all components of the shale. The hematite content is higher in the shale than in any other red-bed rock types and decreases with an increase in silt. The concentration of hematite in the clay fraction was further confirmed by the more intense red color and higher total iron content of the clay fraction than in the bulk shale sample, as shown in tables 1 and 2.

As shown in table 1, the greenish-gray shale has a lower total iron content and higher nickel, cobalt, and vanadium contents than the reddish-brown shale. As the higher silica content in the greenish-gray shale beds is evident (table 1), the lower total iron content in the greenish-gray shale may be explained by the existence of more quartz.

TABLE 1.—ANALYSIS OF BULK SHALE SAMPLES FOR SOME MAIN AND TRACE ELEMENTS

SAMPLE NUMBER	WEIGHT (PERCENT)		PARTS PER MILLION			FEET BELOW BASE OF MEDICINE LODGE GYPSUM
	Fe_2O_3[1]	SiO_2	Co	Ni	V	
M-A-14 (red)	9.88	50.09	38	68	111	16.5
B-F-28 (red)	8.26	53.93	31	53	90	42.1
M-A-10 (red)	--	--	33	54	108	50.7
M-B-3 (red)	9.44	50.12	35	60	110	129.7
M-B-2 (green)	5.11	59.15	51	124	148	131.7
B-F-16 (green)	2.47	69.52	59	65	118	138.2
B-F-15 (red)	6.89	60.66	32	57	95	140.3
M-A-1 (red)	9.09	54.60	40	70	168	161.0
M-A-1 (green spot)	6.46	54.02	54	112	590	161.0

[1]Total iron expressed as Fe_2O_3.

TABLE 2.—ANALYSIS OF TOTAL IRON IN CLAY MATERIAL LESS THAN 1 MICRON IN SIZE

SAMPLE NUMBER		WEIGHT (PERCENT) Fe_2O_3[1]	FEET BELOW BASE OF MEDICINE LODGE GYPSUM
M-A-19	(green)	8.05	2.0
M-A-14	(red)	13.24	16.5
B-D-21	(red)	13.24	19.2
M-A-13	(green)	7.82	19.5
B-D-20	(green)	7.53	21.3
B-E-18b	(red)	12.05	23.4
B-E-18a	(red)	11.43	26.4
B-F-41	(red)	12.07	31.7
B-D-14	(red)	13.38	33.6
B-F-28	(red)	11.92	42.1
B-E-8	(red)	13.10	53.7
B-F-20	(red)	13.16	81.0
M-A-5	(red)	11.66	109.9
B-F-15	(red)	12.08	140.3
B-F-14	(green)	7.92	143.2
B-F-10	(red)	13.98	156.2
M-A-1	(red)	12.19	161.0

[1]Total iron expressed as Fe_2O_3.

However, the "F" test and the "t" test were performed on the mean Fe_2O_3 content of 13 reddish-brown-shale and 4 greenish-gray-shale samples on the same size clay fraction (table 2). The observed value of "F," with 12° and 3° of freedom, is 11.1, which is less than the critical value of 14.3 at the 0.025 level. The calculated value of the "t" statistic is 12.360 for 15° of freedom. For 15° of freedom, "t" must not be less than 4.073 to be significant at the 0.05-percent level. The statistic shows that if the mean iron content of the reddish-brown shale and the greenish-gray shale were the same, the observed difference of the total iron content between the two could occur by chance in less than 5 out of 10,000 trials.

The question arose: might the total iron content of those samples collected from different stratigraphic levels be a function of stratigraphic position? The correlation coefficient between the Fe_2O_3 content and the depth below the base of Medicine Lodge Gypsum (table 2) was therefore computed and was found to be as low as 0.21. Accordingly, the total iron content does not tend to vary with stratigraphic position.

The correlation coefficients between Ni, Co, and V and the total iron content of 22 clay and bulk samples were computed. These values were 0.13, −0.15, and 0.02 for Ni-Fe_2O_3, Co-Fe_2O_3, and V-Fe_2O_3 pairs, respectively (Wu, 1969). The very low correlation coefficients between Fe_2O_3 and Ni, Co, and V imply that Ni, Co, and V do not tend to vary with increasing or decreasing total iron content in the shale.

Pipette analyses were performed to determine whether a difference in size distribution exists between the greenish-gray shale bed and the underlying and overlying reddish-brown shale beds and between the greenish-gray spots and the surrounding reddish-brown shale. As shown in figure 3, histograms of the greenish-gray shale tend to be skewed toward the coarse silt size as compared with those of under-

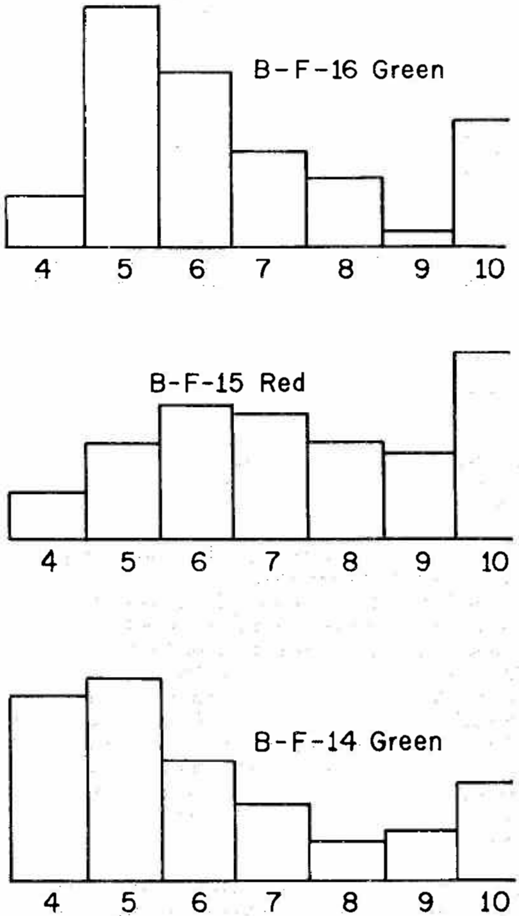

Figure 3. Histograms showing grain-size distribution of two greenish-gray shale beds and the intervening reddish-brown shale bed. Size scale in phi units.

lying and overlying reddish-brown shale beds. As shown in table 3, the greenish-gray shale bed has a higher silt content (from 4 to 8 phi) than the overlying and underlying reddish-brown shale beds. However, the greenish-gray spots and the surrounding reddish-brown shale display similar size distribution.

DISCUSSION OF RESULTS

The greenish-gray spots scattered in the reddish-brown shale are not reworked shale fragments. Rather, they formed by reduction and subsequent color change owing to the presence of organic ma-

TABLE 3.—PERCENTAGE OF DIFFERENT SIZE FRACTIONS, TOTAL WEIGHT OF CLAY AND SILT

SIZE IN PHI UNITS	SAMPLE NUMBERS M-A-1 GREEN SPOT	M-A-1 RED	M-B-1 RED	M-B-2 GREEN	M-B-3 RED	B-F-14 GREEN	B-F-15 RED	B-F-16 GREEN
4 to 5	1.57	3.17	4.37	16.72	9.21	24.68	6.19	6.69
5 to 6	3.66	3.17	10.37	8.55	7.79	26.77	12.39	31.86
6 to 7	9.41	10.57	8.73	10.89	9.92	15.47	17.34	22.82
7 to 8	12.03	14.27	7.10	11.66	12.04	9.82	16.52	12.20
8 to 9	15.69	15.32	8.19	10.11	9.21	4.76	12.39	8.65
9 to 10	12.03	13.74	16.92	7.00	7.08	5.95	10.73	1.18
>10	45.61	39.75	44.32	35.07	44.76	12.55	24.44	16.60
Total silt	26.67	31.38	30.57	47.82	38.98	76.74	52.44	73.57
Total clay	73.33	68.82	69.43	52.18	61.04	23.26	47.56	26.43

terial. The presence of dark organic material in the center of some greenish-gray spots and no textural, structural, or mineralogical difference between the greenish-gray spots and the surrounding reddish-brown shale support this explanation. How can we explain the higher Co, Ni, and V content in the greenish-gray shale? Several possible answers may be considered.

Degens (1965, p. 244) stated, "Iron and manganese oxides and hydroxides are known for their ability to scoop up trace elements such as vanadium and nickel in amounts up to 1000 ppm (Krauskopf, 1955; Keith and Degens, 1959)." These elements could also substitute in iron compounds and would be absorbed onto the clay minerals with the iron or substitute for iron in the clay lattice on the basis of the similar chemical properties of iron and these three metallic elements (transition elements). Nevertheless, the very low correlation coefficients between Fe_2O_3 and Ni, Co, and V, respectively, cannot support these hypotheses in the present application.

The precipitation of cobalt, nickel, and vanadium sulfides or coprecipitation with ferrous sulfide in the greenish-gray shale under a reducing environment might account for the higher content of Co, Ni, and V. But lack of sulfide minerals in these greenish-gray shale beds and the failure to form insoluble cobalt, nickel, and vanadium sulfides in sea water (Krauskopf, 1956) seem to exclude this possibility.

It is a well-known fact that rare metals are commonly enriched in organic sediments. Based on many studies on the concentration of rare metals in marine organisms, Krauskopf (1956) concluded that the metals vanadium, nickel, and possibly cobalt are probably controlled largely by organic reactions. Vanadium and nickel may be extracted from sea water by organisms that utilize them in the form of metal-organic porphyrin compounds, according to Mason (1967, p. 243); he also noted (p. 243) that the porphyrin compounds are exceedingly stable and have been recognized in shales and asphalts dating back to the Paleozoic. Thus these porphyrin compounds are evidently able to withstand the ordinary process of diagenesis. V. M. Goldschmidt (cited in Mason, 1967, p. 242-243) favored a concentration of trace elements during the decay of plant remains whereby the more soluble elements are leached out, leaving other elements retained either as insoluble compounds or as metal-organic complexes.

Accordingly, the presence of organic materials that reduce iron from the ferric to the ferrous state can account for the greenish-gray color of the shale.

As cited in Curtis (1964), Bader (1962) pointed out that soluble organic matter is an important constituent of almost all terrestrial water. He also demonstrated that certain clay minerals will quickly and strongly adsorb up to 350 percent of their own mass of soluble organic matter from solution. The organic material responsible for the greenish-gray color of siltstone, silty shale, and spots in the reddish-brown shale was probably introduced by streams in association with clay minerals or in an organic colloidal state. Certainly some organic materials such as pollen and spores were carried into the depositional basin in suspension by water and wind (Wilson, 1962; Clapham, 1968). The general absence of a fauna, which may have been due to penesaline conditions, probably rules out a significant contribution of organic matter directly from marine organisms. Thus, the organic materials may have been oxidized, and ferric iron in iron oxides, occurring as stains and finely disseminated discrete particles, simultaneously reduced to the ferrous state and removed before the time of lithification. The circulation of intrastratal solutions through the more permeable siltstone and silty shale units may have been responsible for the removal of the reduced iron oxides, resulting in the observed lower iron content of the greenish-gray beds.

Chemical analysis by X-ray fluorescence cannot distinguish FeO from Fe_2O_3. However, further clues to discrimination can be obtained by wet chemical analysis on some shale samples. Thereby, determination that a higher FeO/Fe_2O_3 ratio exists in the greenish-gray shale than in the reddish-brown shale is made possible. The dark organic materials in the centers of some greenish-gray spots might be assayed by biochemical means, which could throw light on their origin.

CONCLUSIONS

According to pipette analyses, the greenish-gray beds contain more silt than the overlying and underlying reddish-brown beds. A higher silt-size quartz content in the greenish-gray beds was confirmed by the comparatively higher silica content as revealed from the chemical analysis by X-ray fluorescence.

A higher nickel, cobalt, and vanadium content in the greenish-gray beds and spots is believed due to the presence of organic materials that contain a high proportion of these metallic elements. The greenish-gray color of beds and spots can be attributed to the reduction of ferric iron to the ferrous state by the oxidation of organic matter. The removal of iron from the greenish-gray spots and beds was verified by finding a lower total iron content in the greenish-gray shale than in the reddish-brown shale, as revealed from chemical analyses by X-ray fluorescence. The circulation of intrastratal solutions through the more permeable siltstone and silty shale units is believed to be responsible for the removal of the reduced iron oxides.

LOCALITIES SAMPLED

Measured section M-A.—NE¼ SW¼ sec. 22, T. 22 N., R. 13 W., on east face of butte capped by Medicine Lodge Gypsum, immediately behind roadside park on north side of State Highway 15, 6 miles west of Orienta, Major County.

Measured section M-B.—SW¼ NW¼ sec. 6, T. 21 N., R. 13 W., on west end of mesa capped by Medicine Lodge Gypsum, 1 mile east of Cheyenne Creek, 1 mile northeast of curve in section-line road, Major County.

Measured section B-D.—Center NE¼ SW¼ sec. 10, T. 19 N., R. 12 W., on north face of escarpment capped by Medicine Lodge Gypsum, 0.4 mile west of section-line road and 0.2 mile south of small creek, 4.5 miles east of Longdale, Blaine County.

Measured section B-E.—NE¼ NE¼ NE¼ sec. 26, T. 19 N., R. 12 W., on south face of escarpment capped by Medicine Lodge Gypsum, at T-intersection of section-line roads, ½ mile north of Ideal, Blaine County.

Measured section B-F.—SW¼ NE¼ SE¼ sec. 23, T. 18 N., R. 12 W., on south face of escarpment capped by Nescatunga Gypsum, the north side of Salt Creek Canyon, 2 miles east of State Highway 51A, Blaine County.

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The Mineral Industry of Oklahoma in 1970[1] (Preliminary)

Robert H. Arndt[2]

The value of minerals produced in Oklahoma in 1970 was $1,131 million, a net gain of 3.7 percent over 1969, according to the Bureau of Mines, U.S. Department of the Interior. Gains in value were made in all of the mineral fuels, which collectively supplied 94.2 percent of the total value of minerals produced, and in metals. Helium and nonmetallic minerals had values less than in 1969.

MINERAL FUELS

The value of mineral fuels, excluding helium, rose to $1,066 million, 4.6 percent above the value in 1969. However, the quantity of petroleum produced fell below that of 1969, despite monthly oil-production allowables being at 125 percent of the basic depth-acreage formula during much of the year. The decline indicates that developed resources were exploited at or near existing production capacity. Increased production of coal to supply power plants in Missouri and of metallurgical coal for export to Japan more than offset production losses from prolonged local strikes. An application for permission to construct coal-barge loading facilities on Sans Bois Creek in Haskell County indicates anticipation of extensive future shipments of Oklahoma coal on the Arkansas River navigation system.

HELIUM

The total value of helium produced ($7 million) was about 21 percent less than in 1969. Reduction in output of high-purity helium resulted in value losses that more than offset value gains from a 63-percent increase in production of crude helium.

NONMETALS

A general decline in production and value of the individual nonmetals reduced their total value to less than 5 percent of the State's gross mineral value. Tripoli value suffered the greatest loss, 27 percent, and cement the next greatest, 19 percent. Bentonite, clays, gypsum, sand and gravel, and stone individually declined less than 9 percent in value. Increases in production and value were recorded only for salt and lime.

METALS

The value of metals recorded a 6-percent net increase, influenced by gains of 21 percent in the combined values of recovered copper and silver and a substantial reduction in the combined values of produced lead and zinc. The closing of the State's only remaining zinc and lead mill in October, because of the high cost of operating pollution controls, virtually doomed the zinc- and lead-mining industry in the Tri-State district.

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[1]This U.S. Bureau of Mines Mineral Industry Surveys report was prepared January 1, 1971.

[2]Liaison Officer-Oklahoma, U.S. Bureau of Mines, Bartlesville Office of Mineral Resources, Bartlesville, Oklahoma.

TABLE 1.—MINERAL PRODUCTION IN OKLAHOMA[1]

MINERAL	1969 QUANTITY	1969 VALUE (THOUSANDS)	1970 (PRELIMINARY) QUANTITY	1970 (PRELIMINARY) VALUE (THOUSANDS)
Clays[2] (thousand short tons)	802	$ 1,182	754	$ 1,131
Coal (bituminous (thousand short tons)	1,838	10,662	2,520[3]	15,000[3]
Gypsum (thousand short tons)	980	3,912	882	3,663
Helium				
High-purity (thousand cubic feet)	220,500	7,718	151,500	5,302
Crude (thousand cubic feet)	132,900	1,123	216,800	1,715
Lead (recoverable content of ores, etc.) (short tons)	605	180	[4]	[4]
Natural gas (million cubic feet)	1,523,715	233,128	1,579,061	252,650
Natural-gas liquids:				
LP gases (thousand 42-gallon barrels)	27,304	34,403	28,240	45,466
Natural gasoline and cycle products (thousand 42-gallon barrels)	14,621	38,931	14,990	40,773
Petroleum (crude) (thousand 42-gallon barrels)	224,729	701,155	224,500	711,665
Salt (thousand short tons)	9	51	15	[4]
Sand and gravel (thousand short tons)	5,262	7,156	4,841	6,584
Stone (thousand short tons)	18,799	23,650	18,423	23,414
Zinc (recoverable content of ores, etc.) (short tons)	2,744	801	[4]	[4]
Value of items that cannot be disclosed: bentonite, cement, copper, lime, silver, tripoli, volcanic ash, and value indicated by footnote 4	----	26,758	----	23,751
Total	----	$1,090,810	----	$1,131,114

[1] Production as measured by mine shipments, sales, or marketable production (including consumption by producers).
[2] Excludes bentonite; included with "Value of items that cannot be disclosed."
[3] Based primarily on railroad-car loadings, adjusted in part to monthly figures supplied by State agencies.
[4] Included with "Value of items that cannot be disclosed."

Intercontinental Occurrence of *Ophiurocrinus hebdenensis* Wright, a Carboniferous Crinoid[1]

D. W. Burdick[2] and H. L. Strimple[3]

Abstract—Ophiurocrinus hebdenensis Wright, 1950, previously known only from British Carboniferous strata, is reported from the lower Fayetteville Formation in Arkansas. This occurrence represents the first crinoid species reported from the type area of the Fayetteville Formation and only the second common to Upper Mississippian strata in the United States and equivalent strata outside North America.

A crinoid recently collected from the lower portion of the Fayetteville Formation is herein assigned to *Ophiurocrinus hebdenensis* Wright, 1950. This species was previously known only from three specimens from "Midge Hole, north of Hebden Bridge, Yorkshire," northern England (Wright, 1950, p. 23). The specimen collected from the Fayetteville Formation is slightly larger than the holotype of *O. hebdenensis* and, other than bearing a few pustulose granulations, is identical to that specimen. It is possible that the holotype also has granulations, for those of the Fayetteville specimen were evident only after preparation with an air abrasive machine. The specimen figured by Wright (1950, pl. 6, figs. 4, 5) was prepared by scraping.

The Fayetteville specimen was collected from the lower portion of the Fayetteville Formation, immediately southwest of Fayetteville, Washington County, Arkansas, from exposures along a 4-lane-highway bypass presently under construction (NW¼ SW¼ sec. 20, T. 16 N., R. 30 W.). Ammonoid taxa from this interval are well known from several localities in the immediate vicinity and are characteristic of the Upper Mississippian (Chesterian). This interval has been correlated with the basal Namurian E_1 Zone of Europe (W. B. Saunders, pers. comm.). According to Wright (1950, p. 23), *Ophiurocrinus hebdenensis* occurs in the "Namurian, Millstone Grit (R_1)," although no more detailed stratigraphic information or mention of associated species is given. The R_1 Zone correlates with the lowermost Pennsylvanian (basal Morrowan) of Arkansas and Oklahoma. If the occurrence data of the British specimens are correct, these two occurrences imply that *O. hebdenensis* is a relatively long-ranging species.

Ophiurocrinus hebdenensis appears to be a primitive crinoid species because it has a proportionally large-diameter stem that does not bear cirri as well as a conical cup bearing five uniserial arms. Both occurrences of the species are in black shale, a factor that may be coincidental or that may indicate an ecological preference. The

[1]The authors are greatly indebted to Paul Thompson, graduate student at the University of Arkansas, who collected the crinoid specimen described in this paper and allowed it to be reposited at The University of Iowa. Dr. James H. Quinn, Department of Geology, University of Arkansas, recognized the importance of the specimen and sent it to us for investigation. Occurrence data of the specimen and associated goniatites from the type area of the Fayetteville Formation were prepared by W. Bruce Saunders, professor at Bryn Mawr College.

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[3]Research associate and curator, Department of Geology, The University of Iowa, Iowa City.

latter would seem somewhat remarkable because such a lithology is commonly attributed to an oxygen-poor (reducing) environment not capable of sustaining most benthonic organisms. Although the prominent column of *Ophiurocrinus hebdenensis* shows that the species was benthonic, the large-diameter stem could have supported the organism well above the toxic substrata. Attachment of the crinoid larva to the substrata could have occurred during a time when bottom conditions were more conducive to supporting benthonic life forms.

Only one other Upper Mississippian (Chesterian) crinoid species is thought to occur outside North America. The possible occurrence of *Phanocrinus formosus* Worthen was reported by Termier and Termier (1950, p. 226, pl. 221, figs. 1-8) from upper Viséan strata 5 kilometers southwest of Igli, Algeria. Pareyn (1961) recorded this locality as uppermost Viséan, P_2 Zone. That zone is correlated with the Chester Series of the Illinois basin region (Weller, 1948; Horowitz and Perry, 1961). The specimens figured by Termier and Termier and the holotype of *P. formosus* are the only specimens described in the literature that we consider conspecific. A specimen referred to that species by Kirk (1937, p. 603-604, pl. 84, figs. 1, 2) is considered conspecific with *P. cylindricus* (Miller and Gurley, 1894). The holotype of *P. formosus* was merely recorded as being from the Chester Series, with more precise occurrence data lacking. Specimens that closely resemble *P. formosus* are known to occur in lower Chesterian strata and range upward through the Glen Dean (middle Chesterian). *P. alexanderi* Strimple, 1948, from the lower Fayetteville Formation near Vinita, Oklahoma, and undescribed specimens from the lower and middle Bangor Limestone in Alabama also appear to be closely related to *P. formosus.*

In addition to the two intercontinental species occurrences discussed herein, Horowitz and Perry (1961, p. 866, 867) remarked on other similarities. They stated that *Aphelecrinus dilatatus* Wright, 1945, and *Onychocrinus liddelensis* Wright, 1954, from British Viséan strata are "very similar" to *A. oweni* Kirk, 1944, and *O. pulaskiensis* Miller and Gurley, 1895, from North American Chesterian strata. Specimens referred to *O. liddelensis* were originally referred to *O. pulaskiensis* by Wright. The former species does not have the spinose brachials characteristic of the latter. *O. liddelensis* also has coarser ornamentation.

SYSTEMATIC DESCRIPTION

Genus **Ophiurocrinus** JAEKEL, 1921

Ophiurocrinus JAEKEL, 1921, p. 62; WANNER, 1924, p. 178; RAMSBOTTOM **in** WRIGHT, 1960, p. 337.

Occurrence.—Carboniferous, Eurasia (U.S.S.R., Great Britain); Upper Mississippian (Chesterian), North America (U.S.A.).

Ophiurocrinus hebdenensis WRIGHT, 1950

Fig. 1

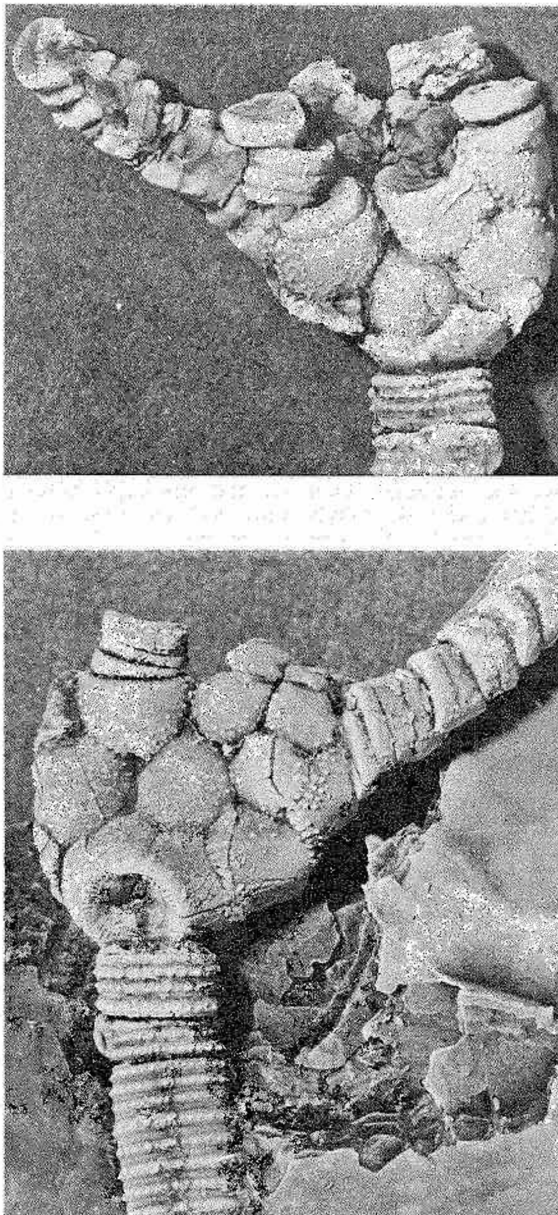
Ophiurocrinus hebdenensis WRIGHT, 1950, p. 23-24; pl. 6, figs. 4, 5.

Diagnosis.—Cup measures about as wide as high; infrabasals and basals measure about as long as wide; suture intersections depressed. Brachials short and all of uniform thickness.

Description.—Dorsal cup is dicyclic and crushed into a near planar form, but, if reconstructed, would be low, cone-shaped, and about as long as its maximum width; proximal diameter would be about two-fifths that of distal width; cup plates large and ornamented by a few granulations near sutures; plate regions at suture intersections common to radial or anal plates, except for the most proximal intersection of each radial plate, slightly depressed. Proximal parameter of the infrabasal circlet slightly constricted; just distal to this constriction is a single row of granulations extending around infrabasal circlet. Infrabasals are upflared about as long as wide, appear pentagonal in side view, and extend to about one-fourth height of cup; greatest width across distal portions of inter-infrabasal sutures. Basals hexagonal (except in *CD* interray where anal plates are inserted), about as long as wide, and constitute longest elements of cup; greatest width occurs across distal portions of interbasal sutures. Radials pentagonal (except for *C* of anal interray) and slightly wider than long; greatest width across distal portions of interradial sutures; articular facets consist of crenulae that radiate from ambulacral groove. In the *CD* interray, the radianal, anal *X*, and the right tube plate are in normal position and well within cup; two other plates of anal series were in distal contact with anal *X*; the one to left is missing but extended slightly into cup; the one to distal right of anal *X* and a single plate above right tube plate occupy a straight distal suture common to anal *X* and the right tube plate. Only proximal portions of arms known. Brachials short and uniserial; interbrachial surfaces bear crenulae similar to those found on radial articular facets. No axillaries present and no brachials preserved in ray *A*. Five primibrachs preserved in ray *B*, 10 in ray *C*, 3 in ray *D*, and 2 in ray *E*. Column flattened owing to compaction; apparently had a circular cross section and was penetrated by a large lumen also with a circular cross section. Columnals consist of nodals alternating with internodals; each nodal has a single row of granules around its circumference.

Measurements (mm).—Distal width of cup (distorted owing to compaction), 10.4; proximal width of cup, 3.8; length of cup, 6.4 (near *CD* interray); width of *D* infrabasal, 2.5; length of *D* infrabasal, 2.4; width of *BC* basal, 3.9; length of *BC* basal, 3.3; width of *D* radial, 4.0; length of *D* radial, 3.5; width of column (distorted owing to compaction), 4.0.

Remarks.—Six species are presently assigned to *Ophiurocrinus*. Three of these—*O. originarius* (Trautschold, 1867: the type species), *O. dactyloides* (Austin and Austin, 1847), and *O. beggi* (Wright, 1938)—have cups that are longer than wide, elongate infrabasal and basal plates, and elongate proximal brachials. The other three species —*O. arbiglandensis* (Wright, 1934), *O. hebdenensis* Wright, 1950, and *O. gowerensis* Wright, 1960—have lower cups and proportionally shorter infrabasals and basals. The specimen described in the present paper has the lower cup exhibited by species of the second group. *O. arbiglandensis* has a longer primibrach *1* than the presently described specimen and also has more cuneiform brachials. *O. gowerensis* also has longer proximal brachials but does bear granular ornamentation such as that of the specimen described. The presently described specimen bears closest resemblance to *O. hebdenensis*. Besides having the low cup of the presently described specimen, *O. hebdenensis* also has the low proximal brachials, depressions at the suture intersections, and a column composed of nodals and internodals.



1

2

Figure 1. Ophiurocrinus hebdenensis **Wright, 1950, from the Fayetteville Formation southwest of Fayetteville, Arkansas.** $\times 4$. 1, **view of AE interray;** 2, **view of CD interray.**

The articular facets of the British specimens of *Ophiurocrinus hebdenensis* were not described and cannot be discerned from the illustrations. The radial articular facets of the specimen from Arkansas bear radial crenulae. This type of facet is peculiar and is described only in the genus *Rhabdocrinus* Wright, 1944. Ramsbottom (*in* Wright, 1960, p. 336) considered the facets to be distinctive enough to erect the family Rhabdocrinidae for that genus. The general characters of the cup and the nature of the articular facets intimate close affinities between *O. hebdenensis* and *Rhabdocrinus*. The articular facets of *O. dactyloides* are known to have the conventional ridge and ligament furrow type of radial articular facet (Wright, 1950, p. 20). Future investigations of the articular facets on the type species and other species will probably necessitate assignment of some species of *Ophiurocrinus* to other genera.

Repository.—The specimen is reposited in the Repository, Department of Geology, The University of Iowa, and is numbered SUI 34543.

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New Thesis Added to OU Geology Library

The following doctoral dissertation was recently added to The University of Oklahoma Geology and Geophysics Library:

Lithostratigraphy and carbonate petrology of the Morrow Formation (Pennsylvanian), Braggs-Cookson area, northeastern Oklahoma, by Tommy Lee Rowland.

Geologic Field Trips in Oklahoma

Oklahoma has many areas within its boundaries that show fine examples of the results of geologic processes, but pinpointing such locations often takes a great deal of time and travel. To facilitate this effort, the Oklahoma Geological Survey has initiated a series called *Guidebook for Geologic Field Trips in Oklahoma* by Kenneth S. Johnson, which will contain eight sections, each covering a different area of the State. The first of these is an introduction to the series and has just been released as *Book I: Introduction, Guidelines, and Geologic History of Oklahoma.* The guides are being issued as "preliminary versions" so that changes and additions recommended by users can be incorporated in a final printed copy. All eight preliminary versions should be available by mid-1972, after which time they will be revised and submitted for final printing. The books are being written as non-technical reports designed primarily for use by high school earth-science teachers in leading field trips and for use by the public.

This series will be prepared and distributed by the Oklahoma Geological Survey in cooperation with the National Science Foundation and the Oklahoma Curriculum Improvement Commission, the Instructional Division, and the Curriculum Section of the Oklahoma State Department of Education. Compilation and preparation of the material is financed through a grant from the National Science Foundation (Grant GW-5726), and publication is made possible by funds from Title V, Section 503, of the Elementary and Secondary Education Act of 1965 through the Oklahoma State Department of Education.

The field-trip guides are being printed by the Oklahoma State Department of Education and will be issued free within the Oklahoma school system as they are completed (1 every 3 months, approximately). Copies will also be printed by the Oklahoma Geological Survey and made available to the public for 25 cents each. Comments and recommendations for improvement of the guidebook series may be sent to: Editor, Oklahoma Geological Survey, 830 Van Vleet Oval, Room 163, Norman, Oklahoma 73069.

Highway Geology Symposium

The Oklahoma State Highway Department and the Oklahoma Geological Survey are co-sponsoring the 22nd annual Highway Geology Symposium, which will be held on April 22 and 23, 1971, in the Forum Building at The University of Oklahoma in Norman. On April 22, a field trip will be conducted to the Arbuckle Mountains and Ardmore area in southern Oklahoma, and on April 23, papers will be presented at technical sessions in Norman. The registration fee of $20.00 also covers the cost of the field trip and the banquet. Featured speaker for the banquet on Monday night will be William R. Muehlberger, director of geological activities for Apollo missions, NASA. Co-chairmen for the meeting are Mitchell D. Smith, physical science engineer with the Highway Department, and Charles J. Mankin, director of the Survey.

The 11 papers to be presented cover a wide range of subjects and deal with problems encountered in the United States, Africa, and

South America. The research is applicable not only in highway planning but also in many other fields where earth materials are used in foundations or construction.

Further information on the meeting may be obtained from W. E. Kinnebrew, 1700 Asp Avenue, Room 105, Norman, Oklahoma 73069 (telephone (405) 325-1931).

OKLAHOMA ABSTRACTS

The University of Wisconsin

Trace Fossils and Paleoecology of the Ouachita Mountains of Southeastern Oklahoma

CHARLES KENT CHAMBERLAIN, The University of Wisconsin, Ph.D. dissertation, 1970

Trace-fossil assemblages collected from the Mississippian-Pennsylvanian rocks of the Ouachita Mountains, southeast Oklahoma, define a basin to shoal bathymetric profile. The assemblages include the deep basin *Nereites* assemblage in the Central Ouachitas, transitional sub-*Nereites* assemblage in the lower Atoka Formation of the Frontal Ouachitas, intermediate and deep shelf *Cruziana* and *Zoophycos* assemblages in the Wapanucka Limestone and shallow shelf *Cruziana* assemblage in the upper Atoka Formation of the Arkoma Basin.

Trace fossils fitting Seilacher's (1953b, 1964) Cubichnia behavioral category found in the Ouachita Mountains are *Lockeia siliquaria* James and *Asteriacites munira* n. ichnsp. Those belonging to the Domichnia category include ?*Arenicolites; Conostichus* sp. (3) that have the form, symmetry, and behavior of burrowing actinarians; *Lanicoidichna metuluta* n. ichngn.-sp.; and *Pilichnia elliptica* n. ichngn.-sp. Repichnia are represented by *Scolica* sp. (*Bolonia lata* Meunier, *Curvolithus multiplex* Fritsch, *Psammichnites plummeris* (Fenton & Fenton), *S. vada* n. ichnsp., ?*S. prisca* de Quatrefages, *S. parkerensis* (Fenton & Fenton), *S. virgamontis* n. ichnsp.), *Octichnus amenentus* n. ichngn.-sp., and *Laminites kaitiensis* Ghent & Henderson. *Paleodictyon* sp. (2) that developed a nearly perfect hexagonal net by simple, precise, overlapping meanders; *Squamodictyon* sp.; *Helminthropsis labyrinthica* Heer; ?*H. lutufartis* n. ichnsp.; ?*H. faecefartis* n. ichnsp.; *Spirophycos bicornus* Heer, *Scalarituba missouriensis* Weller that made lateral sand ridges as it processed sediment for food and not as a result of plowing through the sediment; *Sustergichnus lenadumbratus* n. ichngn.-sp. are representatives of the Pascichnia. Fodinichnia are represented by *Aster-*

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.

ichnus lawrencensis Bandel, *Asterosoma radiciforme* Otto, *Biformites sila* n. ichnsp., *B. hydra* n. ichnsp., *Chondrites* sp. (4), *Häntzschelinia ardelia* n. ichnsp., *Mammillichnis aggeris* n. ichngn.-sp., *Micatuba verso* n. ichngn.-sp., *Lophoctenium comosum* Richter that plucked sediment from overhead and pressed it to the back of the burrow in transverse chevrons and overlapped preceding chevrons as compared to other *Lophoctenium* that do not overlap, *L. ramosum* (Toula), *L. sp.* aff. *richteri* Delgado, *L. haudimmineri* n. ichnsp., *Phycosiphon incertum* Fischer-Ooster, *Rosselia socialis* Dahmer, *Stelloglyphus floris* n. ichnsp., *Taenidium serpentinium* Heer, *T. annulata* (Schafhäutl), and *Zoophycos circinnatus* (Brongniart).

The persistence of widespread distinctive trace fossil assemblages in the Central Ouachitas, mainly pascichnial forms, through approximately 25,000 feet of Mississippian-Pennsylvanian rocks attests to the continuous hospitability of the flysch environment in the deep basin. In the Frontal Ouachitas a shallow water environment and trace fossil assemblage, mainly domichnial and fodinichnial forms, were replaced by a subflysch facies with mainly pascichnial and fodinichnial trace fossils as the north slope of the geosyncline migrated to the north. The shoal facies of the Arkoma basin may have persisted from the beginning or may have undergone a history of subsidence and uplift.

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