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Cover Picture

UPPER CAMBRIAN ROCKS IN OKLAHOMA

The Old Hematite Quarry

The quarry shown in the cover photograph is at the northwest edge of the Wichita Mountains in the limestone hills area, sec. 17, T. 4 N., R. 12 W.

The exposed sedimentary strata are composed of flat, ovoid grains of oölitic hematite. At this exposure, the oölitic hematite beds are 34 feet thick and are overlain and underlain by beds of quartzitic sandstone. The hematite beds, found only in this area, are approximately midway within a 200-foot section of Reagan Sandstone.

The Reagan Formation represents the basal deposits of the Upper Cambrian sea that transgressed over weathered igneous rocks, which had a topographic relief of at least several hundred feet. The Reagan Formation is exposed in the Arbuckle and Wichita Mountains and is found in subsurface commonly around the above-mentioned mountain areas.

The Reagan, where exposed, consists mainly of angular quartz grains with irregular feldspar fragments and some glauconite. The feldspathic fragments and pebbles were derived from the underlying igneous rock, and, inasmuch as the Reagan Formation lies upon Tishomingo Granite in the eastern Arbuckle Mountains and upon porphyritic flow rocks in the western Arbuckles and the Wichita Mountains, this basal material varies considerably.

From this coarse basal material the Reagan grades upward into coarse-grained, gray to reddish-brown sandstones and occasional interbedded, green shales. Locally, the sandstone beds are quartzitic, or on the other hand very friable. They may have poor sorting and obscure or cross-laminated bedding surfaces, or the beds may be well defined and evenly stratified.

At least three quarries, similar to the one shown on the cover, are along the escarpment face of the northeastward-dipping Reagan Formation. The quarried oölitic hematite material was crushed and treated with oils for the manufacture of paint. The venture was unprofitable and has long since been discontinued. According to Merritt (1939) the percentage of iron in the oölites is too low for use as a source of iron. He reported a representative sample of the ore as containing

SiO_2	63.22	percent
Al_2O_3	4.42	"
FeO	1.18	"
Fe_2O_3	30.80	"
MnO_2, TiO_2	—	trace
CaO, MgO, K_2O & other oxides	—	trace

Reference Cited

Merritt, C. A., 1939, The iron ores of the Wichita Mountains, Oklahoma: Econ. Geology, vol. 34, p. 268-296.

—E. A. F.

The Mineral Industry of Oklahoma in 1962*
(Preliminary)

Robert B. McDougal†

The mineral industry of Oklahoma produced 12 minerals and 5 mineral fuels valued at an estimated $827.1 million in 1962, according to the Bartlesville, Oklahoma, office of the Bureau of Mines, U. S. Department of the Interior, and was more than 4 percent greater than the revised 1961 value of $791.8 million. Production value gains were reported in helium, natural gas, natural-gas liquids, petroleum, cement, clays, gypsum, lead, salt, sand and gravel, stone, tripoli, and zinc. Mineral fuels accounted for more than 90 percent of the total value in 1962; nonmetals accounted for most of the remainder.

MINERAL FUELS

Coal.—Coal production in Oklahoma declined in 1962 for the fifth consecutive year and was 10 percent less than the previous year's output. The estimated output of 925,000 tons reported in 1962 was from 10 counties of which Haskell, Rogers, and Le Flore Counties led.

Natural gas.—Marketed production of natural gas from 65 counties in 1962 was 8 percent more than 1961 production and 9 percent greater in value.

Natural-gas liquids.—Natural-gas liquids recovered at 67 natural-gasoline plants and 5 cycling plants reached a new record of 1,338 million gallons for 1962, a slight increase from 1961. Four new natural-gasoline plants were placed on stream in 1962, two in the Dover-Hennessey area of Kingfisher County, one in the Southwest Enville field of Love County, and one in Beaver County.

Underground storage capacity for LP gases was further increased by completion of two new facilities, one in a Grant County salt layer for 150,000 barrels of butane and one in a Beaver County salt layer for 35,000 barrels of LP gas.

Petroleum.—An estimated output of 198.5 million barrels of crude petroleum was reported in 1962, an increase for the second consecutive year. Final 1961 figures indicated production was up slightly from 1960 and the 1962 output was about 3 percent greater than the 193 million barrels in 1961.

The *Oil and Gas Journal* reported a total of 4,748 exploratory and development wells drilled in the first 11 months of 1962 compared with 5,290 wells for the same period in 1961. This is a drop of 9 percent in development drilling and a decline of 19 percent in test-well drilling from the first 11 months in 1961. A new State depth production record

*This report, U. S. Bureau of Mines, Mineral Industry Surveys Area Report IV-151, has been prepared under a cooperative agreement for the collection of mineral data, except mineral fuels, between the Bureau of Mines, U. S. Department of the Interior, and the Oklahoma Geological Survey, Dr. William E. Ham, Geologist.

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was reached late in the year by Mobil Oil Co. in the Chitwood pool of Grady County. Production was from 16,572 to 17,076 feet in the First, Second, and Third Bromide.

On January 1, 1962, Oklahoma had 14 refineries operating according to the *Oil and Gas Journal.* These had a total capacity of 423,352 barrels of crude oil per calendar day, an increase of more than 3 percent from 1961. Midland Cooperatives, Inc., completed expansion of crude-oil charge capacity from about 13,000 to 15,500 barrels per day at its Cushing refinery.

HELIUM

Marketable production of helium in 1962, extracted from natural gas at the Federal Bureau of Mines' Keyes plant, was 7 percent less than in the previous year; value was 74 percent greater due to a price increase from $19 to $35 per thousand cubic feet in November 1961 under the Helium Act of 1960. The Keyes plant was connected to the 400-mile pipeline from Bushton, Kans., to Amarillo, Tex., which was

TABLE I.—MINERAL PRODUCTION IN OKLAHOMA[1]

Mineral	1961 Quantity	1961 Value (thousands)	1962 (Preliminary) Quantity	1962 (Preliminary) Value (thousands)
Clays[2] (thousand short tons)	792	$ 801	810	$ 820
Coal (thousand short tons)	1,032	6,784	925	[3]
Helium (thousand cubic feet)	313,244	5,872	291,576	10,205
Lead (recoverable content of ores, etc.) (short tons)	980	202	3,150	580
Natural gas (million cubic feet)	892,697	108,016	964,100	117,600
Natural-gas liquids:				
Natural gasoline and cycle products (thousand gallons)	521,237	33,358	552,900	34,300
LP gases (thousand gallons)	817,082	30,141	810,300	31,600
Petroleum (crude) (thousand 42-gallon barrels)	193,081	561,866	198,502	577,641
Salt (common) (thousand short tons)	3	19	6	38
Sand and gravel (thousand short tons)	5,310	5,513	5,600	5,800
Stone (thousand short tons)	14,981	16,561	15,557	17,216
Zinc (recoverable content of ores, etc.) (short tons)	3,148	724	10,500	2,415
Value of items that cannot be disclosed: Bentonite, cement, coal (1962), gem stones (1961), gypsum, lime, pumice, and tripoli	----	21,920	----	28,892
Total Oklahoma	----	$791,777[4]	----	$827,107

[1]Production as measured by mine shipments, sales, or marketable production (including consumption by producer).
[2]Excludes bentonite; included with "Value of items that cannot be disclosed."
[3]Included with "Value of items that cannot be disclosed."
[4]Revised figure.

completed about mid-October and much of the subsequent production was used to fill the line.

NONMETALS

The estimated value of nonmetals (cement, clays, gypsum, lime, pumice, salt, sand and gravel, stone, and tripoli) produced in Oklahoma during 1962 totaled $46.6 million, nearly 4 percent greater than in 1961.

Dewey Portland Cement Co., Division of American-Marietta Corp., returned to full production in January at its Dewey plant; however, in April, plans were announced that a partial cutback in operations would terminate employment for more than 100 workers. Later in the year, an expansion program at Oklahoma Cement Co., was completed, doubling the plant's capacity.

Total construction outlays for the first 10 months of 1962 were 20 percent above the volume in the same period of 1961. Residential building contributed most to the gain in total construction although commercial building, manufacturing building, and public-utility construction rose and public-works construction declined slightly.

Construction by the U. S. Army Corps of Engineers (Tulsa District) continued at three dams: Oologah dam on the Verdigris River, Eufaula dam on the Canadian River, and Keystone dam on the Arkansas River. Construction of the Markham Ferry dam on Grand River was begun in January by the Grand River Dam Authority (GRDA) and at yearend was ahead of schedule. Efforts were made by GRDA to relocate 18 miles of track of the Kansas, Oklahoma & Gulf Railroad to be inundated by the reservoir near Salina. The GRDA condemned the right-of-way for $3.1 million when these attempts were unsuccessful, and the railroad petitioned the Interstate Commerce Commission for permission to abandon its line from Okay, Okla., north to Baxter Springs, Kans., a distance of nearly 104 miles.

METALS

Mine production in terms of recoverable lead and zinc, all from Ottawa County, increased 221 percent and 234 percent, respectively, from 1961 output. Concentrates recovered in 1962 amounted to 3,150 tons of recoverable lead and 10,500 tons of recoverable zinc.

Smelters.—Three horizontal-retort zinc plants operated in 1962: American Metal Climax, Inc., at Blackwell; National Zinc Co., at Bartlesville; and The Eagle-Picher Co., at Henryetta. At Blackwell, about 100 employees were laid off in June owing to a shortage of supplies, and a strike at the Bartlesville smelter closed the plant for two months beginning June 1.

Tri-State district.—Funds for administering the Lead-Zinc Stabilization Act of 1961 became available in January. Authority to administer the program was delegated by the Office of Minerals Exploration of the Department of the Interior to the General Services Administration. Oklahoma produced 68 percent of the district's lead concentrate and 70 percent of the zinc concentrate; Kansas produced 32 percent of the district's lead concentrate and about 30 percent of the zinc concentrate. No output was reported from the southwest Missouri portion of the district in 1962.

Stratigraphic Position of *Eoasianites globosus*

James Harrison Quinn

The type of *Eoasianites globosus* was collected by Easton (1943, p. 153, pl. 24, fig. 16) from his locality 16 "near top of coarse crystalline limestone at top of Pitkin in quarry at Cane Hill, Arkansas." This locality is the same as Easton's (1942, p. 32-33) columnar section 3, "in SW¼ SW¼, section 4, T. 14 N., R. 32 W., ½ mile north of Cane Hill." Easton (1943, p. 126-127) mentioned the Pennsylvanian aspect of "several Pitkin elements" and stated that A. K. Miller had indicated that *E. globosus* is more primitive than *E. oblatus* Miller and Moore (1938). At that time it was supposed that strata of the type locality of *E. oblatus* (Gaither Mountain) were of Hale age, but it is now known that they are contained within the Bloyd Formation (Quinn, 1962, p. 118, fig. 2).

In the old quarry at Cane Hill, Arkansas, about 20 feet of Pitkin Limestone is exposed on the quarry face (figs. 1, 2). Above the limestone is a thin bed of shale and conglomerate which marks the base of the Hale Formation of Early Pennsylvanian age. Above the shale and conglomerate is about 6 feet of siltstone and above that calcareous sandstone conglomerate interfingering with platy sandstone and siltstone of the Cane Hill Member of the Hale Formation. This unit has yielded some 200 specimens of *Eoasianites globosus* as well as the remains of several additional genera of goniatite cephalopods also found elsewhere in many places in the Hale strata.

The type of *Eoasianites globosus*, which is partly embedded in matrix, was kindly loaned to me by the University of Chicago. The matrix adhering to the type is indistinguishable from the fossil-bearing rock of the Hale Formation and differs markedly from the limestone of the Pitkin Formation. Insofar as the matrix of the type is concerned, *Eoasianites globosus* belongs with Pennsylvanian goniatites and not with the Pitkin assemblage.

The bryozoan *Archimedes* is abundant in the Pitkin section but, with the exception of reworked specimens in conglomerate, it has not been found in Arkansas in Pennsylvanian rocks.

In Washington County, Arkansas, where strata are demonstrably referable to the type section of the Pitkin Formation, goniatites have not been found. The Pitkin section is mainly limestone with thin shale partings and erosional unconformities above and below. The thickness of the unit in Washington County is variable but is nowhere appreciably more than 50 feet.

Farther east, in the vicinity of Leslie, Arkansas, a much thicker section of Mississippian strata rests upon the Fayetteville Formation. The section essentially includes a massive bed of limestone at the base, as much as 40 feet of overlying shale, a second massive limestone containing the goniatites *Eumorphoceras bisulcatum* Girty and *Cravenoceras richardsonianum* (Girty), and perhaps an additional 100 feet of shale, sandy limestone conglomerate, and siltstone containing near the top a second group of goniatites. These include *Eumorphoceras* cf. *E. bisulcatum*, *Cravenoceras* sp., *Anthracoceras*, *Dele-*

pinoceras, and some unidentified forms. The section contains numerous *Archimedes.*

Whether all or part of the eastern section is equivalent to the Pitkin Formation is not known. The entire section may represent an expansion of the Pitkin Formation. One of the three units may be equivalent to Pitkin rocks. The upper and lower units may be repre-

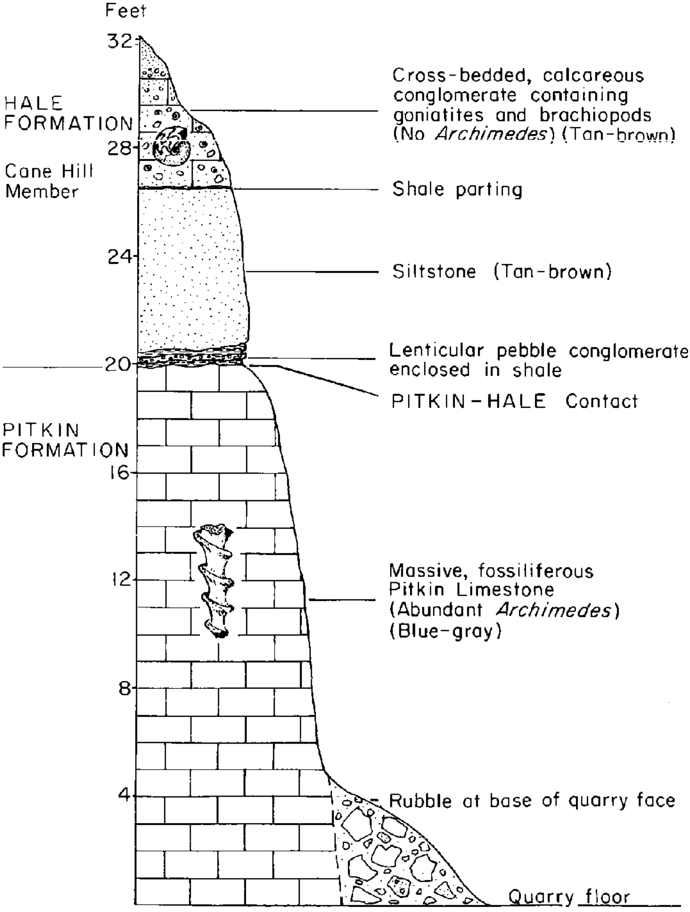

Figure 1. Quarry face at Cane Hill rock quarry. The measurements are approximate because the thicknesses of stratigraphic units change considerably from place to place along the quarry face.

Figure 2. View of the north end of the Cane Hill quarry face. Protruding block at upper right (under geologist) is an unleached portion of the calcareous, sandy conglomerate lens which, in a second outcrop farther to the right, furnished the specimens of Eoasianites globosus. **The irregularity of the unconformity and the Cane Hill strata are evident in this view.**

sented in Washington County by unconformities. It is unlikely but not impossible that the entire section is older or younger than the Pitkin of Washington County. Until equivalent goniatites are found in the Pitkin Formation, a satisfactory solution to the problem may not be found.

Even though Late Mississippian goniatites are known from Arkansas and the strata containing them cannot be referred to the Pitkin Formation, their aspect is clearly distinct from that of the *Eoasianites globosus* assemblage, adding to the inprobability that the type could have been derived from Pitkin rather than Hale strata.

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Type Species of the Paleozoic Pollen Genus *Florinites* Schopf, Wilson, and Bentall, 1944*

L. R. Wilson

When the genus *Florinites* was established by Schopf, Wilson, and Bentall, *F. antiquus* Schopf was chosen as the type species (Schopf and others, 1944, p. 56-60). Because of wartime circumstances, the writer did not see the holotype and consequently its similarity to the species *Endosporites pellucidus* Wilson and Coe, 1940, was not realized until 1958 when a restudy of the latter species resulted in its transfer to the genus *Florinites* (Wilson, 1958). At that time the conspecific nature of *F. pellucidus* and *F. antiquus* was suspected, but the holotype of the latter was not seen until 1960, at which time the suspicion was confirmed.

An additional observation may be noted concerning the over-all size of the species. In the 1958 description of *F. pellucidus,* the length was given as 70 to 76 microns and the width as 50 to 58 microns. In Schopf's graph of *F. antiquus* (Schopf and others, 1944, p. 59) the length is recorded as from 55 to 90 microns and the width as 45 to 60 microns. Measurements of approximately 100 specimens of *F. pellucidus* from the original collection give the following over-all range of size: length 51 to 92 microns and width 41 to 63 microns. These size ranges include those of specimens which appear to be immature and of others that have been either altered slightly during preservation or overmacerated by chemical processing. Specimens of nearly all these sizes have been found in the same pollen masses. Ten cotypes were used in the original description. In 1958 none was suitable for photographic illustration because the glycerine-jelly mounting medium had desiccated; therefore a lectotype was chosen from the same preparation. This specimen is on Slide 152 P-2 in the palynological collection of the Oklahoma Geological Survey. The lectotype was illustrated in Wilson, 1958, plate I, figure 3, its measurements being: length 72.5 microns, width 57.5 microns, central body 25 by 35 microns.

Therefore because *pellucidus* is the earlier specific epithet, it becomes the correct designation of the type species of the genus *Florinites* Schopf, Wilson, and Bentall, 1944. The synonymy of *Florinites pellucidus* is as follows:

Florinites pellucidus (Wilson and Coe, 1940) Wilson, 1958.
Endosporites pellucidus Wilson and Coe, 1940.
Florinites antiquus Schopf, 1944.

References Cited

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Wapanucka-Atoka Contact in the Eastern and Northeastern Arbuckle Mountains, Oklahoma

Charles L. Rowett

INTRODUCTION

The question of the establishment of an "Atoka Series," to include post-Morrow pre-Des Moines (Lower Pennsylvanian) strata has stimulated interest in this stratigraphic interval in Oklahoma. The purpose of this report is to describe the contact between the Wapanucka Formation (Morrowan Series) and the superjacent Atoka Formation where this contact is exposed in Pontotoc, Coal, and Johnston Counties, Oklahoma.

Geologic maps of this region suggest that the Atoka Formation forms the basal part of a transgressive sequence, which is now exposed along the eastern and northeastern flanks of the Arbuckle Mountains. Field evidence of this transgression is limited owing to poor exposures in the area. A number of localities where the Wapanucka-Atoka contact is well exposed (fig. 1) were found by the writer during the course of a biostratigraphic study of the Wapanucka Formation (Rowett, 1962).

This formational contact and the character of the adjacent strata are highly variable throughout the area studied. In southeastern Pontotoc County, along the southern edge of the Franks graben, the upper part of the Wapanucka Formation consists of highly fossiliferous argillaceous limestone. These strata are overlain by unfossiliferous calcareous shales and cross-bedded sandstones of the Atoka Formation. In Coal County, on the northern side of the Hunton arch, the upper part of the Wapanucka consists of a widespread oölitic limestone member. In this area, the lower part of the Atoka Formation is characterized by shales, siltstones, sandstones, and locally by thin, laterally discontinuous limestone conglomerates. In southwestern Coal County and in northern Johnston County, along the southern limb of the Clarita anticline and near the axis of the Wapanucka syncline, the highest strata in the Wapanucka are oölitic, cherty, and bioclastic limestones. Here, the basal part of the Atoka Formation consists of a well-developed limestone conglomerate which contains pebbles, cobbles, and boulders. This conglomerate is up to five feet thick and has been traced for almost two miles along the contact. It is overlain by gray concretionary shales and sandstones.

Visible relief along the contact of these two formations does not exceed two or three feet at any locality, but evidence presented herein indicates post-Wapanucka pre-Atoka erosion to a depth of at least 30 feet in some areas.

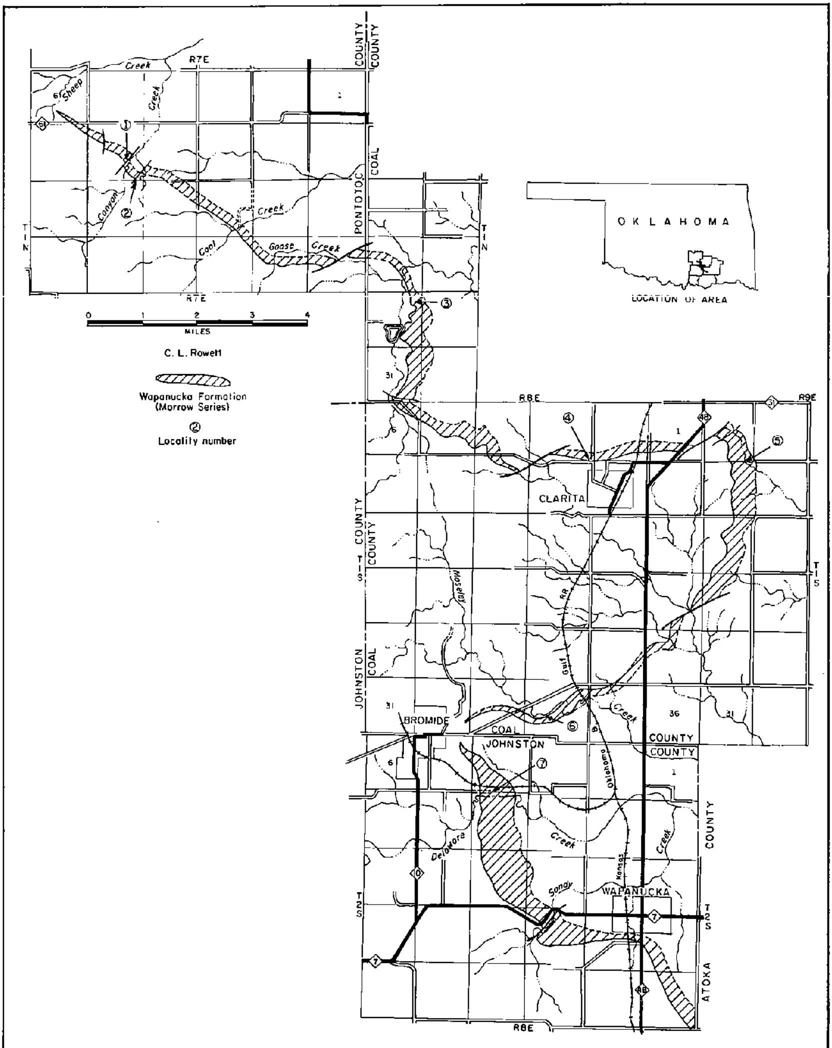

Figure 1. Outcrop map of Wapanucka Formation in Pontotoc, Coal, and Johnston Counties, Oklahoma.

1. NE¼ NW¼ SE¼ sec. 8, T. 1 N., R. 7 E., Pontotoc County. —At this locality approximately 180 feet of section in the Wapanucka Formation and the lower 15 feet of the Atoka Formation are exposed along Canyon Creek. Resistant sandstones in the Atoka Formation form a prominent ridge which trends northwest and is offset to the northeast by a cross fault at this locality. Strata strike N70° W and dip 35-40° NE.

This area was described by Morgan (1924, p. 57) and by Kuhleman (1948, localities 10, 11). The highly fossiliferous strata of the Wapanucka Formation at this site are frequently collected and have yielded more than 80 species of fossil invertebrates. The section was measured and described by Rowett (1962, loc. PO 3), as follows:*

Basal Atoka Formation: Sandstone, siltstone, and shale: sandstone, fine- to medium-grained; weathers buff to yellow brown; bedding, thin to medium, regular; locally cross-bedded; shales, calcareous, light-gray, unfossiliferous.
Exposed thickness .... 15 feet

Wapanucka Formation (upper part): Limestone and brachiopod coquina: limestone, arenaceous, argillaceous, medium-crystalline, tan; weathers yellow-brown; bedding, thin, irregular; interbedded with zones of shell coquina which is predominately crushed and disarticulated brachiopod valves; other fossils common. **Petrographic description:** oölitic biosparrudite.
Thickness, variable; maximum .... 10.2 feet

These strata are exposed as a series of ledges which overhang the bed of Canyon Creek. The Wapanucka-Atoka contact is undulatory and has as much as 1.5 feet of relief. The upper beds in the Wapanucka Formation are oxidized to a depth of about one-half foot and are deep maroon. Less than one mile to the northwest (NE¼ SW¼ sec. 6, T. 1 N., R. 7 E.), a branch of Sheep Creek exposes the lower part of the Wapanucka Formation. Here, the Wapanucka is unconformably overlain by sandstones and shales of the McAlester Formation, an indication that the intervening Atoka Formation has been completely removed in the short distance between these two localities.

2. NE¼ SE¼ SE¼ sec. 8, T. 1 N., R. 7 E., Pontotoc County. —Sandstones in the lower part of the Atoka Formation form a high ridge which trends northwest in this area. Although beds dip to the northeast, the only exposures are on the northeast side of the ridge (dip slope) due to an oblique fault which displaces the ridge about 400 yards to the northeast.

*Petrographic names are those proposed by R. L. Folk (1959); in the description of bedding, the classification proposed by McKee and Weir (1953) is used, here adapted as follows:

massive bedding	no visible bedding
very thick-bedded	over 3 feet
thick-bedded	from 1 to 3 feet
medium-bedded	from 4 to 12 inches
thin-bedded	from 1 to 4 inches
laminated	less than 1 inch

This locality was first described by Morgan (1924, loc. 28). The crinoid fauna of the Wapanucka Formation subsequently was collected by Harrell Strimple, who described several forms from these beds. The section was measured and described by Rowett (1962, loc. PO 4), as follows:

> **Basal Atoka Formation:** Sandstone, limestone, and shale: sandstones, fine-grained, tan; weather brown; cement, calcareous; bedding, thin, regular; limestones, arenaceous, medium-crystalline, tan; weather dark brown; shales, covered.
> Section exposed on dip slope, not measurable
>
> **Wapanucka Formation** (lower part): Limestone, oölitic, tan to blue-gray; weathers dark brown; bedding, thin, irregular; pelmatozoans (crinoids and blastoids) common. **Petrographic description: Millerella** biosparrudite, oösparite, and pelletiferous biosparite.
> Thickness ------------------------------------ 2.0 feet

The oölitic limestone described above and a highly fossiliferous shale which underlies this unit are identifiable in the lower part of the section at Canyon Creek (Rowett, 1962, loc. PO 3; no. 1 of this report) as units A and B. At both localities the basal clay shales contain a characteristic fauna of solitary rugose corals and crinoids. At the present locality, faulting is probably primarily responsible for the absence of the upper part (135 feet) of the Wapanucka section. Abrupt changes in the attitude of strata at the contact provide clear evidence of a fault contact.

3. NE¼ NE¼ sec. 30, T. 1 N., R. 8 E., Coal County.— The Wapanucka and Atoka Formations form separate subparallel ridges which trend north-northwest in this area. In the western ridge is exposed a section of the Wapanucka Formation, 136 feet thick. The Wapanucka-Atoka contact occurs on the dip slope of the ridge. Strata at this locality strike N50°W and dip 10-15°N.

Fossil invertebrates were collected near this locality by Kuhleman (1948, localities 22 and 23), but the section was not measured or described. The section was measured and described by Rowett (1962, loc. C 27):

> **Basal Atoka Formation:** Limestone conglomerate; clasts mostly of pebble size, composed of several limestone types; chemical cement micrite and sparry calcite, extensively stained by oxides of iron; matrix contains abundant fossil debris. **Petrographic description:** clasts variously composed of micrite, **Millerella**-bearing oösparite, biosparite, and biosparrudite; chemical cement sparry calcite, stained by iron oxide.
> Thickness, variable; maximum observed ---------- 3.0 feet
>
> **Wapanucka Formation** (upper part): Limestone, oölitic, gray to white; weathers yellow white to gray; bedding, thin, regular; cement, sparry calcite; fauna dominantly crinoids. **Petrographic description:** oösparite.

The Wapanucka-Atoka contact is mostly covered by debris on the dip slope of the ridge but it seems to have little or no relief. The limestone conglomerate at the base of the Atoka Formation is discontinuous laterally and is absent at a locality less than 200 yards to the southeast, where it is replaced in the section by arenaceous limestones. The conglomerate is overlain by red-brown ferruginous sandstones and gray shales.

Examination of this conglomerate from cut and polished surfaces indicates that it was derived primarily from the underlying strata in the Wapanucka Formation, chiefly the oölitic limestone described above.

4. SE¼ SE¼ sec. 3, T. 1 S., R. 8 E., Coal County.—Here a low ridge, which trends almost due west, is formed by limestones in the Wapanucka Formation. The strata dip 10°N and strike N88°W. The thickness of the Wapanucka section (base covered) is 74.2 feet. The Wapanucka-Atoka contact is exposed in a section-line road between sections 2 and 3 of this township.

A measured section in the Wapanucka at this locality was described by Wallis (1915, p. 50). The locality is also recorded by Kuhleman (1948, loc. 29) who did not, however, measure the section. The section was remeasured and described by Rowett (1962, loc. C 12):

> **Basal Atoka Formation:** Shale and siltstone, interbedded: shales, dark-gray, calcareous, locally fossiliferous; interbedded with thin siltstones and a few thin sandstones which are laterally discontinous and lenticular.
> Thickness, approximate .... 250 feet
> **Wapanucka Formation** (upper part): Limestone, oölitic, yellow-white; weathers gray; bedding, thick, regular; extensively jointed; sparsely fossiliferous. **Petrographic description:** Fossiliferous oösparite; oölites less than 1 mm in diameter, well sorted; chemical cement, sparry calcite.
> Thickness .... 15.9 feet

The upper oölitic limestone in the Wapanucka Formation is exposed at the crest of the ridge, and the Wapanucka-Atoka contact is mostly covered on the dip slope. Approximately 250 feet above the base of the Atoka Formation is a zone of fusulinids *(Fusulinella prolifica)*, which is best exposed in the section-line road. The shales and siltstones in the Atoka Formation are replaced by sandstones and shales to the east which thicken rapidly to form a lenticular unit in the Atoka Formation described by Harlton (1938, p. 908) as the "Barnett Hill." This formational name has not gained recognition in Oklahoma.

5. NW¼ SW¼ SE¼ sec. 6, T. 1 S., R. 9 E., Coal County.—The contact between the Wapanucka and Atoka Formations is exposed in an abandoned and partly flooded quarry at this locality. The exposures include the upper 20 to 30 feet of the Wapanucka Formation and approximately 50 feet of section in the Atoka Formation. Beds strike N30°W and dip 10-20°E.

Fossils were collected from the Wapanucka Formation a short distance to the north of this locality by Kuhleman (1948, loc. 35), where the upper oölitic limestone carries an unusual crinoid fauna (*Paragassizocrinus* spp.). The present quarry is about one-quarter mile south-southeast of a locality described by the writer (1962, loc. C 26) in the Wapanucka:

Basal Atoka Formation: Sandstone and shale: sandstones, fine-grained (0.05 mm to 0.25 mm), angular to subangular; major bedding units, thick, regular; local cross-bedding prominent; cement, calcareous, deeply leached and oxidized; shales, calcareous; 3 to 6 feet in thickness; alternate in the section with sandstones; unfossiliferous except at contact with subjacent Wapanucka Formation.
Thickness exposed .... 50 feet

Wapanucka Formation (upper part): Limestone, oölitic, and shale: limestone, gray to white; weathers yellow white; bedding, thick to massive, regular; jointing, extensive; cross-bedding in oölites prominent in some beds; interbedded with yellow-brown fossiliferous shales up to 1 foot in thickness. **Petrographic description:** oösparite; oölites, in part superficial, average 1 mm or less in diameter; cement, sparry calcite.
Thickness, maximum .... 30 feet

The Wapanucka-Atoka contact at this locality is undulatory, and has from two to three feet of relief. The contact is exposed in the east side of the quarry, about three feet above the present water level, and is marked by a thin (one to three inches) layer of conglomeratic debris which consists predominantly of reworked Wapanucka fossils. This material is oxidized and is gray green to maroon.

6. N½ NE¼ SW¼ sec. 34, T. 1 S., R. 8 E., Coal County.—Outcrops in this area occur along the south bank of Moseley Creek, where a narrow ridge of Wapanucka limestone is overlain by a limestone conglomerate and concretionary shales in the Atoka Formation. Strata strike due west and dip 20-25°S, toward the axis of the Wapanucka syncline. The Wapanucka section (base covered) has a thickness of 89.6 feet where measured, and approximately 30 feet of section in the Atoka Formation is also exposed.

Kuhleman (1948, p. 33) recorded a measured section about one-quarter mile east of this locality. The present locality was first described by Rowett (1962, loc. C 5):

Basal Atoka Formation: Shale, tan to olive, concretionary: limonitic concretions up to 1.5 feet in diameter are locally common; shale unfossiliferous where examined.
Thickness, approximate .... 30 feet

Wapanucka Formation (upper part): Limestone, oölitic, light-gray to tan; weathers dark gray; bedding, thick to massive, regular; jointing, extensive; joints, both open and calcite-filled; upper part cross-bedded, glauconitic. **Petrographic description:** oösparite; oölites in part superficial, less than 1 mm in diameter, well sorted; chemical cement, sparry calcite.
Thickness .... 71.2 feet

The upper surface of the Wapanucka Formation at this locality seems to represent a solution surface which underwent a limited amount of reworking prior to deposition of the conglomerate. The thickness of this zone ranges up to about three feet, and it is characterized by thin, irregular or cross-bedded layers of oölitic and glauconitic limestone. Interclasts of oölites occur throughout the zone, and the matrix contains free oölites. The contact with the overlying limestone conglomerate is undulatory and has an estimated two feet of relief. The conglomerate contains some clasts which are oölitic but is predominantly composed of material derived from higher strata in the Wapanucka which are not preserved at this locality. Glauconite is also present in the lower one foot of the conglomerate.

LIMESTONE CONGLOMERATE AT DELAWARE CREEK

7. Along south line, sec. 4, T. 2 S., R. 8 E., Johnston County.— In this area the basal part of the Atoka Formation consists of a well-developed limestone conglomerate which overlies a thick section in the Wapanucka Formation. The Wapanucka ridge at this locality is

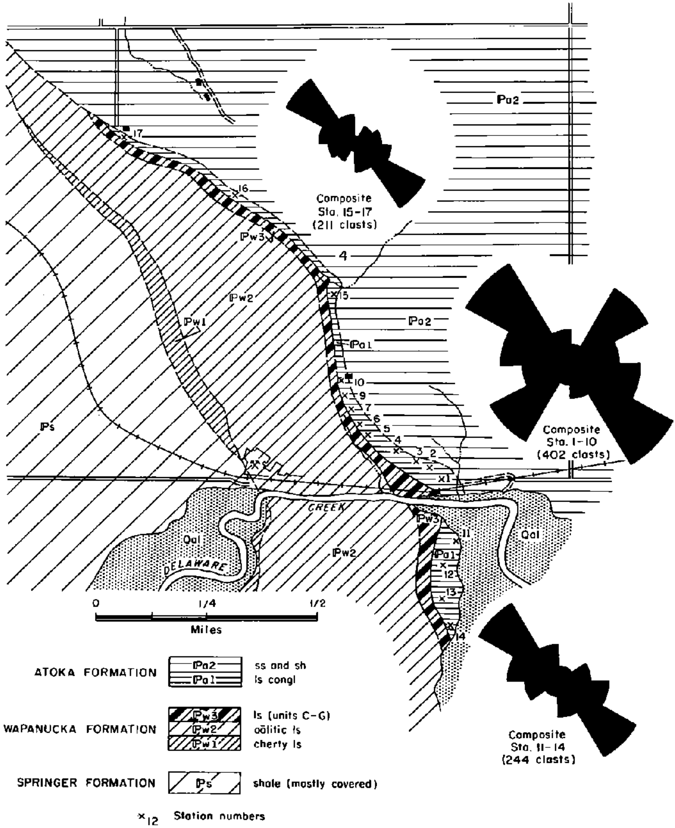

Figure 2. Distribution and petrofabric characteristics of limestone conglomerate in secs. 4, 9, T. 2 S., R. 8 E., Johnston County, Oklahoma.

cut by the superposed channel of Delaware Creek. Exposures are along a railroad cut, which is approximately parallel to the south line of this section. The measured thickness of the Wapanucka Formation (base covered) is 99.4 feet, and about 40 feet of section in the Atoka Formation is also partly exposed.

The resistant limestones in the Wapanucka strike N40°W and form a prominent strike ridge. Strata dip 10-15°NE, toward the axis of the Wapanucka syncline. The ridge terminates about one and one-quarter mile to the northwest, in NE¼ sec. 5, at or near the axis of the syncline. Less than one-half mile to the northeast of this point, near-vertical limestones of the Wapanucka Formation are exposed along the north limb of the syncline (south limb of the Clarita anticline), and strike N60°E.

The Wapanucka-Atoka contact is exposed at the foot of the dip slope of this ridge in Johnston County. The best exposures are immediately north of Delaware Creek (fig. 3), in SW¼ SE¼ sec. 4.

A detailed study of the entire section (Wapanucka and Atoka) was undertaken, as follows: (a) measurement and petrographic description of all lithic units; (b) determination of the areal extent and stratigraphic relationships of the conglomerate; (c) petrographic and statistical analysis of the limestone conglomerate; (d) petrofabric study of the conglomerate; (e) discussion of the significance of the oölite-filled channels in the Wapanucka; and (f) interpretation of the age and provenance of the conglomerate. The results are summarized below in this order.

Figure 3. Unconformable contact of Wapanucka Formation (unit G) with basal limestone conglomerate of the Atoka Formation (at head of hammer), near C SW¼ SE¼ sec. 4, T. 2 S., R. 8 E., Johnston County.

Section at Delaware Creek.—Section measured parallel to and along the north side of railroad tracks (along south line sec. 4, T. 2 S., R. 8 E.).

Unit	Description	Thickness (ft)
Lower Atoka Formation:		
J	Sandstone and shale, interbedded: sandstone, brown, fine-grained (0.5 mm to 0.25 mm); grains, angular to subangular; bedding, medium, uniform; cement, calcareous, deeply leached and oxidized; detrital? glauconite common; interbedded with shale intervals. (Thickness undetermined)	
I	Shale, tan to olive, concretionary; concretions limonitic, up to one foot in diameter, varigated, locally abundant; concretions commonly contain small goniatite cephalopods; shale unfossiliferous. Thickness, approximate	20.0
H	Limestone conglomerate; fresh and weathered surfaces, tan, gray, blue-gray; clasts of pebble, cobble, and boulder sizes (pebbles predominate), angular to subangular, composed of several limestone types; interbedded with thin lenticular zones of cross-bedded fossil debris, chiefly crinoid parts. Crystals of authigenic? pyrite common. Thickness (maximum observed)	5.0
Wapanucka Formation:		
G	Limestone, fine-crystalline, blue-gray; weathers tan to brown; bedding, medium, regular; nodules and stringers of dark-brown and blue chert concentrated along bedding planes; unfossiliferous. **Petrographic description:** spiculiferous, pelletiferous intramicrosparite; spicules small (average length, 0.3 mm); intraclasts composed of spiculiferous micrite. Thickness	5.0
F	Limestone, oölitic, tan; weathers gray; bedding, medium, regular; oölites abundant in lower part, upper beds partly covered; sparsely fossiliferous. **Petrographic description:** Oösparite; oölites, concentrically layered, less commonly superficial, well-sorted; average 0.3 mm in diameter maximum diameter 0.7 mm; chemical cement, sparry calcite, stained by oxides of iron. Thickness	11.0
E	Limestone, coarse-crystalline, crinoidal, brown; weathers dark brown; bedding, thin, irregular; abundant fossil debris. **Petrographic description:** Biosparrudite; fossils dominantly pelmatozoan parts, but include brachiopod valves, bryozoans; the orthochems (cement) are clear sparry calcite and microspar; free oölites and superficial oölites common in matrix. Thickness	2.0
D	Limestone, fine- to medium-crystalline, blue to gray; weathers gray; bedding, medium, regular; beds form prominent ledge; sparsely fossiliferous. **Petrographic description:** Intraclast biomicrite; chemical cement, sparry calcite and microspar; tests of fusulinid **Millerella** common. Thickness	4.5

C Limestone, fine- to medium-crystalline, argillaceous, gray; weathers tan; bedding, medium, regular; contains fossil fragments; intraclasts composed of oölites; deeply leached at surface.
Petrographic description: Oölitic intrasparrudite; intraclasts are composed of spiculiferous micrite, oösparite; algae common; chemical cement, sparry calcite, extensively stained by ferric iron hydrate.
Thickness 6.5

B Shale, gray to black, blocky; thickness, variable, may be discontinuous laterally unfossiliferous.
Thickness 0.5

A Limestone, oölitic, tan; weathers gray to chalk white; bedding, thick to massive, commonly lenticular; major bedding units are cross-bedded; fauna includes corals, bryozoans, pelecypods, cephalopods.
Petrographic description: Oösparite; oölites principally superficial, less commonly concentrically formed; sorting, poor; oölites average 0.5 mm in diameter, maximum diameter observed, 1.1 mm. **Millerella** common.
Thickness (base covered) 71.9

Total 126.4 feet

Areal distribution of the limestone conglomerate.—The limestone conglomerate at the base of the Atoka Formation was traced along strike to the northwest for almost one mile. At the northern extremity of its exposures in Johnston County (SE¼ NE¼ NE¼ sec. 5, T. 2 S., R. 8 E.), it is covered by soil derived from higher units in the

Figure 4. Block of limestone conglomerate containing pebbles, cobbles, and cross-bedded pelmatozoan debris (upper part), in SE¼ SW¼ SE¼ sec. 4, T. 2 S., R. 8 E., Johnston County.

Atoka Formation. This conglomerate reappears in the section at Moseley Creek (locality 6) at a stratigraphically lower position.

To the south of Delaware Creek, the conglomerate can be traced less than one-half mile, into NE¼ SW¼ SE¼ sec. 9, T. 2 S., R. 8 E., where it is covered by alluvium from Delaware Creek. This unit is fairly consistent in thickness throughout its exposures in Johnston County (fig. 2), but is somewhat thinner in southwestern Coal County.

Composition of the limestone conglomerate.—Petrographic study of this rock indicates that it was derived almost entirely from strata of the underlying Wapanucka Formation. All rock types described above (except unit B, a thin black shale) are well represented in the conglomerate and together account for about 94 percent if its volume.

One extraneous rock type, herein designated "X," constitutes about 6 percent of the conglomerate. Petrographically, this rock seems to be a recrystallized micrite with a low organic content. It is yellow-white and commonly contains crystals of authigenic pyrite. These characteristics render it easily identifiable in the conglomerate.

The matrix of the conglomerate consists of fossil material, free oölites (both true oölites and superficial oölites)and sparry calcite. Post-depositional staining has affected much of the calcite cement, and crystals are coated with a thin film of ferric iron hydrate.

An estimate of the composition of the conglomerate was derived by measuring the long and short axes of 771 clasts on cut and polished surfaces. The surface area of each particle was then approximated by calculating the area of a circumscribing ellipse. The total surface area occupied by each rock type (also designated A through G, and X) is assumed to approximate its volume percentage in the conglomerate because sampling procedures and the orientation of cuts were random. These data are presented below (table I).

TABLE I.—COMPOSITIONAL AND VOLUMETRIC ANALYSIS OF LIMESTONE CONGLOMERATE

Rock type	Number of clasts	Total surface area (mm^2)	Volume percentage of clasts	Volume percentage of rock
X	263	18,946	11.5	6.4
G	228	56,475	34.3	18.9
F	139	36,148	21.3	12.1
E	23	14,798	9.0	5.1
D	25	4,179	2.5	1.4
C	14	4,854	2.9	1.6
A	79	29,020	17.6	9.7
Matrix	—	133,120	—	44.8

The total surface area examined was 297,540 mm^2; clasts account for 55.2 percent of this area, and the remainder is matrix. As noted above, these values are assumed to approximate the volume percentage of each rock type in the conglomerate.

Rock type X almost certainly represents the erosional remnants of strata with stratigraphic position higher than unit G in the preserved section. It is unlikely that there were any intervening units of significant thickness because the limestone conglomerate contains essentially no material which is not identifiable as having been derived from one of the described lithic units. It is nevertheless impossible to judge the original total thickness of the Wapanucka section (including unit X), as there is little correspondence between the volume percentage of the preserved section for a given unit and the volume percentage it comprises in the conglomerate. This comparison is shown in table II.

TABLE II.—VOLUMETRIC COMPARISON OF LIMESTONE CONGLOMERATE AND SOURCE ROCKS

Rock type	Volume percentage of preserved section	Volume percentage of conglomerate
X	?	6.4
G	12.8	18.9
F	28.2	12.1
E	5.2	5.1
D	11.5	1.4
C	16.6	1.6
A	25.7	9.7
Matrix	—	44.8

These figures suggest that the oölitic units (A and F) contributed about equally to the formation of both clasts and matrix, whereas the coarsely crystalline limestones (units C and D) provided a much higher percentage of their original volume toward the formation of the matrix of the conglomerate. Formation of limestone conglomerates suggests rapid erosion and comparatively little solution. Although solution possibly accounts for a loss of no more than 10 percent of the total original volume, this factor cannot be accurately evaluated and introduces a rather large margin of error in the values shown in table II. Interpretations based upon these data therefore are speculative.

The size distribution of clasts for each lithic type (A through G, and X) in the conglomerate was determined by recording the number of clasts which fell into the standard (Wentworth, 1922) size classes (table III). The data are inaccurate in at least two respects. First, clasts in the boulder-size range are common in some outcrops of the conglomerate, but could not conveniently be sampled. This category (256 mm plus) therefore is vacant in the plots shown. Secondly, measurements were made on cut and polished surfaces, and the true maxima are slightly higher. The data shown, however, probably approach the actual values closely, and the size classes are proportionately correct.

Graphic plots of the size distribution of each lithic type indicate that most of the clasts are in the pebble-size range (4 mm to 64 mm), with minor increments in the cobble and granule ranges (fig. 5). The composite histogram (fig. 5h) shows a marked unimodal distribution

TABLE III.—SIZE DISTRIBUTION OF CLASTS IN LIMESTONE CONGLOMERATE

	Rock Types							Total
	A	C	D	E	F	G	X	
256 mm	—	—	—	—	—	—	—	0
128 mm	—	—	—	—	—	—	—	0
64 mm	4	—	—	—	5	1	2	12
32 mm	16	4	3	11	27	43	6	110
16 mm	24	6	6	8	54	83	19	200
8 mm	22	2	13	3	48	85	120	293
4 mm	11	2	3	1	14	36	103	170
2 mm	2	—	—	—	—	7	11	20
1 mm	—	—	—	—	—	—	—	0
Total	79	14	25	23	148	255	261	805

in this size class, which agrees with similar size analyses of beach pebbles by others, notably Krumbein and Griffith (1938).

It is interesting to note that the postulated stratigraphic position of (hypothetical) unit X seems to be supported by the data shown in figure 5. This rock type accounts for only 6.4 percent of the conglomerate but is represented by a disproportionately large number of clasts (261, or about 32 percent of all clasts). Most clasts are of pebble size, and particles of cobble size are uncommon, facts which suggest comparatively prolonged reworking prior to final deposition and burial. It is more probable, however, that composition was the dominant controlling factor.

The matrix of the conglomerate was subjected to X-ray analyses in an attempt to identify the iron compound which initially was thought to have replaced much of the sparry calcite. Diffraction patterns indicate that iron is volumetrically unimportant in the conglomerate matrix, and the only significant peaks are produced by calcite. It is concluded that calcite crystals are stained by a thin film of ferric iron hydrate which produces the red color.

Petrofabric of the limestone conglomerate.—Measurements of the long axes of 857 pebbles were made in the field at 17 stations along the outcrop of the conglomerate (fig. 2). The orientation (azimuth) of the long axes for each clast was recorded, and plots were compiled as histograms (classes equal to 10 degrees azimuth) and as rose diagrams (classes equal to 30 degrees azimuth). The composite rose diagrams in figure 2 show a distinct preferred orientation of clasts in a northeast-southeasterly direction. Boulders up to two feet in diameter are present in the conglomerate south of Delaware Creek (section 9) and in N½ sec. 4, but were not observed elsewhere. Pebbles and cobbles do not vary significantly in average size throughout this area, and there is no obvious imbrication of clasts.

A bimodal distribution of clasts is present in SE¼ sec. 4, with a secondary concentration of clasts whose orientation is southwest-northeast. This is shown on the composite rose diagram in figure 2. This tendency diminishes northward, with a corresponding increase in the number of clasts whose orientation is northwest-southeast (fig. 6).

Significance of oölitic limestone member of the Wapanucka.—The thick oölitic limestone at the base of the Wapanucka section in this area is interpreted (Rowett, 1962) as the result of deposition in a deep tidal (?) channel cut through stratigraphically lower units in this formation (not exposed at Delaware Creek, but present in the section a short distance to the north and south). This channel has at least 60 feet of relief at its axis, but its configuration is known only from observations made at the outcrops near Delaware Creek. The oölite

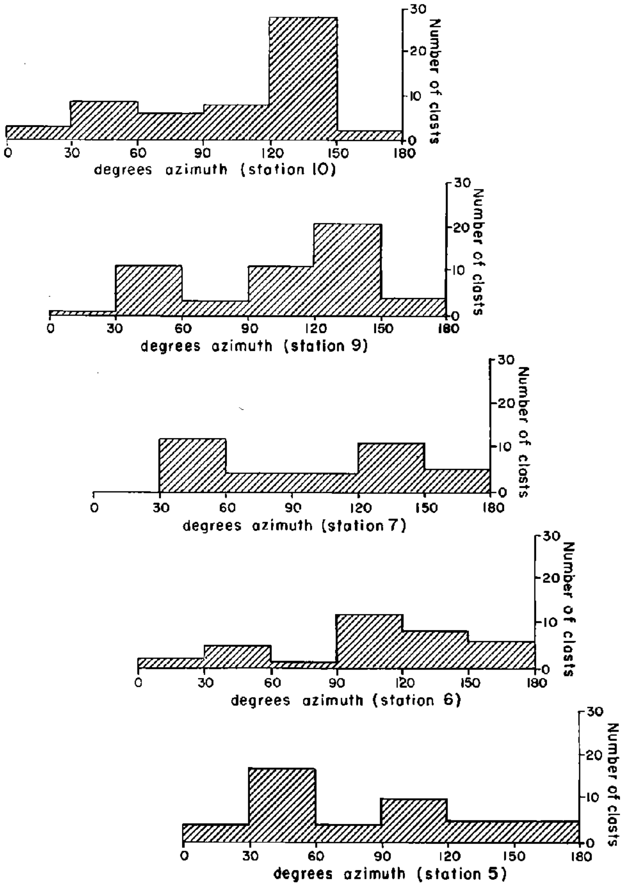

Figure 5. Size distribution of clasts (by lithic type) in conglomerate.

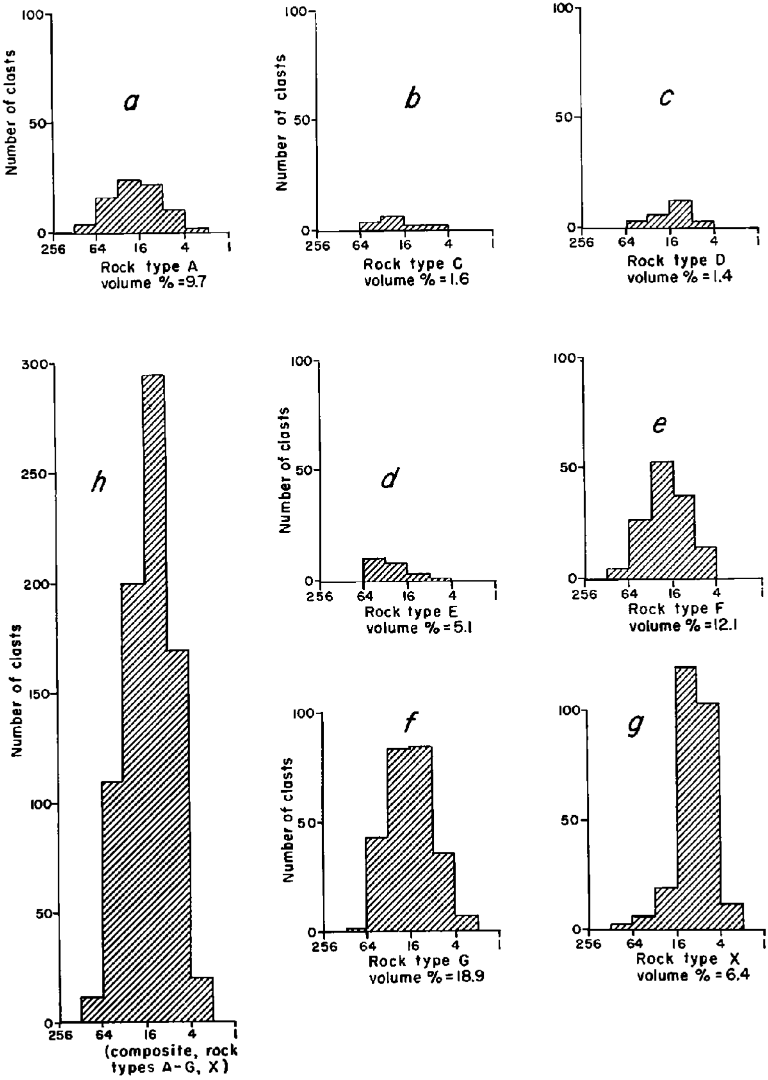

Figure 6. Orientation of clasts, SE¼ sec. 4, T. 2 S., R. 8 E.

is exposed in two abandoned limestone quarries at the crest of the ridge at Delaware Creek (SW¼ SE¼ SW¼ sec. 4, T. 2 S., R. 8 E.), where large-scale cross-bedding of the oölites is emphasized by differential weathering (fig. 7). The base of this unit (A) is covered by talus and large slump blocks, but it is believed to rest unconformably upon shales of the Springer Formation in the axis of the channel. Major bedding units are lenticular and thicken rapidly toward the axis of the channel, with the result that the entire unit thickens from a few feet 200 yards north and south of Delaware Creek to a maximum of more than 72 feet at the quarries. South of Delaware Creek at the crest of the Wapanucka ridge are several small channels which differ from the main channel only in size. The oölite rests unconformably upon cherty, fossiliferous limestones north and south of Delaware Creek, and these beds are truncated toward the major channel (fig. 8).

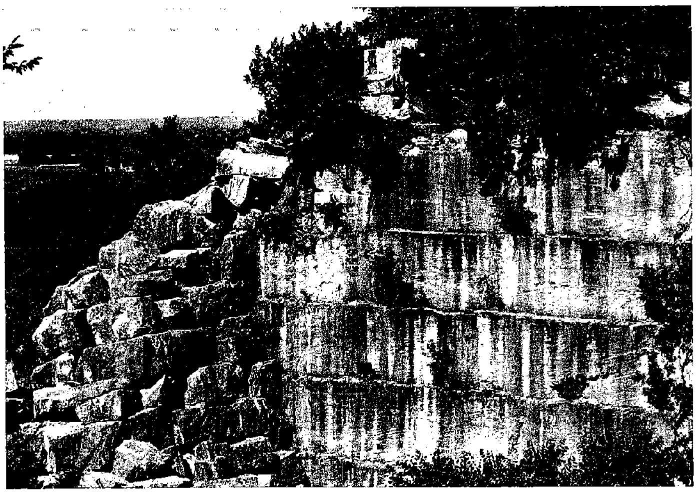

Figure 7. Thick oölitic limestone in the Wapanucka Formation (unit A) exposed in quarry near Delaware Creek. Quarry tiers are approximately eight feet high. Note large-scale cross-bedding in quarry walls. SW¼ SE¼ SW¼ sec. 4, T. 2 S., R. 8 E., Johnston County.

The bimodal distribution of clasts in the southeast quarter of this section (noted above) may be related to the position of this channel. It was observed that the secondary mode (SW-NE) diminishes northward, away from this channel. It is possible that the lesser resistance of the oölite to wave action produced a local irregularity in the shoreline and thus indirectly affected the orientation of beach pebbles nearby. Of greater importance is the observation that at Moseley Creek (loc. 6) the limestone conglomerate at the base of the Atoka Formation rests directly upon the oölitic member of the Wapanucka Formation. If units B-G were consistent in thickness throughout this distance, this relationship would indicate erosion to a depth of at least 30 feet at Moseley Creek (the calculated thickness of unit X is not considered). It is probable that the relief of this erosion surface was considerably greater.

Age of the conglomerate.—Thus far it has been tacitly assumed that the limestone conglomerate is Atokan in age. A number of identifiable fossil invertebrates were collected from this rock, including tabulate corals (*Michelinia* sp.; *Michelinia scopulosa* Moore and Jeffords, 1945; and *Chaetetes* sp.); and solitary rugose corals (*Koninckophyllum* cf. *K. simplex* (Moore and Jeffords), 1945; *Stereocorypha* sp.). *Millerella* is common in many of the limestone clasts. With the exception of *Chaetetes,* these fossils are characteristic of the Wapanucka Formation in southern Oklahoma. *Chaetetes* colonies are common in the basal part of the Atoka Formation in Johnston County, but have nowhere been observed in the Wapanucka Formation by the writer despite intensive collection of the Wapanucka over a period of several years. All fossils recovered from the conglomerate are deeply eroded and clearly are reworked.

It is concluded that this rock represents the basal deposit of the Atoka Formation in this area.

SUMMARY AND CONCLUSIONS

The physical evidence observed at the Wapanucka-Atoka contact in the area studied confirms the transgressive relationship suggested

Figure 8. Intraformational unconformity (hammer head, upper left) at base of oölitic limestone (unit A), 200 yards northwest of quarry shown in figure 7. Note truncation of beds below unconformity.

by regional geologic maps. The Atoka Formation represents the initial phase of a transgressive sequence deposited in a sea which advanced generally from east to west, overlapping and truncating the subjacent Wapanucka Formation. The shoreline was affected by differential resistance to erosion of the underlying rocks, and in Johnston County trended northwest-southeast. The depth and vigor of marine erosion along the advancing shoreline was affected by the variable relief of the invaded areas, and the basal deposits of the Atoka Formation reflect this variation. Implicit in the foregoing is the suggestion that eastward tilting of strata of Morrowan age took place before the invasion of the Atokan sea.

The study of the section at Delaware Creek indicates that the limestone conglomerate at the base of the Atoka Formation in that area was deposited as a beach gravel. This rock was derived almost entirely from submarine erosion of strata in the Wapanucka Formation. Identified lithic types in the Wapanucka contributed in varying proportions to the conglomerate, depending chiefly upon their lithology and possibly upon their stratigraphic position. One stratigraphic unit (X) is absent at Delaware Creek and is thought to have occupied a position higher than unit G in the preserved section. Measurements of pebble orientations indicate that the trend of the beach was northwest-southeast (Fraser, 1935, p. 978, Twenhofel, 1932), with minor irregularities. A previous study of the Wapanucka Formation (Rowett, 1962) indicated that in this area the deposits constituted a limestone shelf with locally developed fringing reefs. It is probable that this linear wave-resistant feature affected the direction of transgression in this area, causing the sea to advance at right angles to the strike of the strata.

The angularity of the limestone clasts in this conglomerate suggests a source not more than one-half mile distant, and probably adjacent to the site of deposition (Pettijohn, 1957). The direction of the source area was of necessity to the west or northwest of the present position of the conglomerate. The relationship of the conglomerate to the underlying strata at Moseley Creek indicates erosion to a depth of at least 30 feet.

In Coal County, smooth benchlike solution surfaces are present at localities 4 and 5, and relief in these areas apparently was low. Areas of intermediate relief, where thin discontinuous limestone conglomerates were deposited, may be represented by the conditions described at locality 3. The Wapanucka-Atoka contact at Canyon Creek (loc. 1) seems to represent deposition during a late phase of transgression over a comparatively uneroded surface.

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