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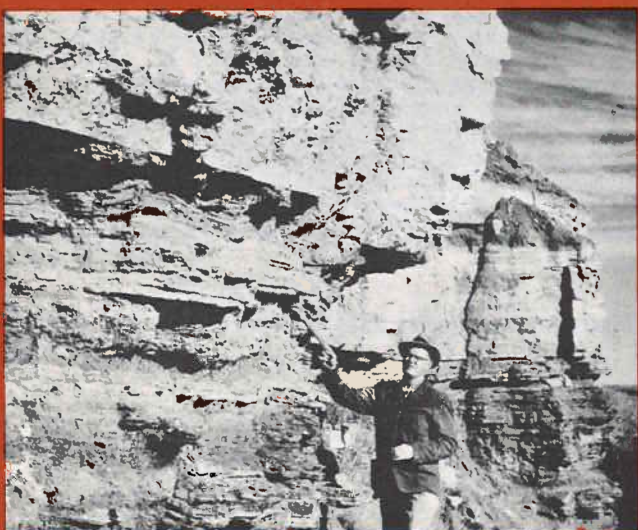

Cover Picture

Permian Studies of W. E. Ham

Although Dr. William E. Ham was known mainly for his studies of carbonates and for field investigations in the southern Oklahoma mountain areas, of nearly equal significance were his contributions on the Permian geology of western Oklahoma. Twelve of his more than 80 publications deal with the geology of the Permian and cover stratigraphy and economics as well as the occurrence of red beds, evaporites, borates, apatite, copper, and barite.

Bill is pictured here examining the Blaine-Flowerpot contact west of Mangum, in Greer County (sec. 2, T. 4 N., R. 23 W.). The Haystack Gypsum Bed at the base of the Blaine Formation, 17 feet thick at this point, caps a conspicuous bluff of Flowerpot Shale overlooking the Salt Fork of the Red River. Near the bottom of the bluff Bill discovered a spore- and pollen-bearing shale containing key middle Permian palynomorphs. The widespread pollen genus *Hamiapollenites* Wilson, 1962, was named to honor Bill for this discovery and for his important work on the Permian geology of Oklahoma.

—*Kenneth S. Johnson*

(Cover photograph by L. R. Wilson, January 1959)

William E. Ham
1916-1970

Dr. William Eugene Ham, research geologist and specialist in carbonate rocks and industrial minerals at the Oklahoma Geological Survey, died of a heart attack on July 10, 1970, in St. Joseph's Hospital, Victoria, British Columbia, Canada. He was 54. He had been hospitalized 2 weeks earlier following a first attack that struck while he and his wife, Betty, were vacationing in Canada after attending the annual meeting of the American Association of Petroleum Geologists-Society of Economic Paleontologists and Mineralogists at Calgary.

Bill was widely known and highly respected as a geologist and as an individual, and his death is a great loss to all who knew him and worked with him. He had a distinguished national and international reputation as a lecturer, educator, and consulting geologist. His scientific contributions were many, particularly in the study of carbonate rocks, evaporites, basement rocks, economic geology, stratigraphy, and structural geology, and he was recognized as the authority on the geology of the Arbuckle Mountains.

Born on February 3, 1916, in Guthrie, Oklahoma, Bill attended Guthrie High School and then came to The University of Oklahoma where he received B.S. and M.S. degrees in geology in 1938 and 1939. His master's thesis, "Origin and Age of the Pawhuska Rock Plain of Oklahoma and Kansas," was the subject of his first major lecture at the 1939 meeting of the Geological Society of America in Minneapolis. While a student at OU he met Elizabeth (Betty) Awbrey, who was also receiving her M.S. degree in geology, and they were married on June 1, 1940. Bill stayed on at The University of Oklahoma as an instructor in geology (1939-41), teaching courses in mineralogy and petrology.

Bill joined the staff of the Oklahoma Geological Survey in 1941. He took a year's leave of absence from the Survey to attend Yale University on a Stanolind Research Fellowship, receiving his Ph.D. degree in 1951. His dissertation is entitled "Geology and Petrology of the Arbuckle Group in the Arbuckle Mountains, Oklahoma." He was named state geologist and acting director of the Survey from 1952 to 1954 and associate director from 1959 to 1966.

Bill worked long hours, often 6 and 7 days a week, on diverse problems, though most of his early efforts centered on the Arbuckle Mountains and mineral deposits of Oklahoma. As a field geologist he was unexcelled, and his contributions to Oklahoma geology rank with those of Taff, Gould, Miser, and Hendricks. When in the field he was out from dawn till dusk. His field assistants and co-workers were hard pressed to keep up with his work pace, but they benefited greatly from the experience and always enjoyed discussing the day's events with him over refreshments.

All his colleagues turned to him at various times for information gleaned during his years of field investigations. His memory of what he had observed and his ability to simplify and unravel complex geologic problems made him one of the most knowledgeable men on the overall geology of Oklahoma and surrounding areas. Through the years he led at least 40 field trips to the Arbuckle, Ouachita, and Wichita Mountain areas of southern Oklahoma for universities, geological societies, and company research groups.

Writing was a precise art to Bill. He published more than 80 articles and books, and his method of organization and planning enabled him to write clearly and concisely without wasted effort. Major publications include *Basement Rocks and Structural Evolution of Southern Oklahoma,*[1] "Paleozoic Epeirogeny and Orogeny in the Central United States,"[2] *Regional Geology of the Arbuckle Mountains, Oklahoma,*[1] *Geologic Map and Sections of the Arbuckle Mountains, Oklahoma,*[1] and *Geology and Glass Sand Resources, Central Arbuckle Mountains, Oklahoma.*[1] In addition, he was editor for *Classification of Carbonate Rocks, a Symposium,* Memoir 1 of the American Association of Petroleum Geologists. He also published a number of well-balanced geologic and economic reports on Oklahoma deposits of limestone, dolomite, gypsum, barite, manganese, copper, zinc, asphalt, and volcanic ash. These reports and his unpublished investigations were instrumental in attracting dozens of companies to develop Oklahoma's mineral resources.

In addition to his regular duties with the Survey, Bill was visiting professor and later professor of geology at The University of Oklahoma from 1964 until his death. He taught a course in carbonate sediments and rocks and directed many theses and dissertations. He took leave of absence from his work in Norman during the school year 1966-67 to become a visiting professor at the University of Kansas, where he taught graduate courses in carbonate petrology and tectonics of the central United States. Testimony of student appreciation for his teaching came in the form of an honorary plaque presented to him by his Kansas students.

Bill's study of carbonates carried him throughout the United States. He did research and collecting in the Bahamas in 1961 and spent 3 weeks in study, research, and lecturing at the Bermuda Biological Station in the summer of 1963. These experiences, along with constant and thorough literature research, enabled Bill to bring to his students the most current ideas and techniques in the study of carbonate rocks and sediments.

Bill was widely known and sought as a talented lecturer. Much careful planning went into his preparation of text and slides for a lecture, and his delivery was dynamic, largely extemporaneous, and

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[1]Published by the Oklahoma Geological Survey.

[2]Published in the **American Journal of Science.**

appeared effortless. In 1963-64 he was honored by being chosen a distinguished lecturer for the American Association of Petroleum Geologists and lectured on his basement-rock studies at 30 universities and AAPG-affiliated societies throughout the United States. He also gave lectures before the International Geological Congress in Copenhagen (1960) and the Geologic Domain Committee of the American Petroleum Institute in Littleton, Colorado (1961), and was invited to lecture at the universities of Wisconsin and Tulsa as well as at several exploration-company research schools. He read nine papers at national meetings of the Geological Society of America, the American Association of Petroleum Geologists, and the American Institute of Mining, Metallurgical, and Petroleum Engineers and lectured many times before geological societies in Oklahoma and Texas.

Bill was active in many professional organizations. He was a member of the American Association of Petroleum Geologists, the Society of Economic Paleontologists and Mineralogists, the American Institute of Mining, Metallurgical, and Petroleum Engineers, the Geochemical Society, Sigma Xi, and Sigma Gamma Epsilon and was a fellow in the Geological Society of America and the Oklahoma Academy of Science. Service to these organizations included his chairmanship of 10 committees and technical sessions of AAPG, SEPM, GSA, and AIME. In addition, he was a member and delegate to the International Geological Congresses at Mexico City (1956) and Copenhagen (1960).

As an occasional consultant in industrial minerals and petroleum geology, Bill traveled widely in the United States; he also took several trips to Canada and made investigations during a 2½-month trip around the world. He was most in demand for his experience in carbonates and evaporites, and he appeared as an expert witness for the U.S. Department of Justice in a number of lawsuits involving limestones and dolomites.

He thrived on new experiences and on discovery. Each new professional or personal event in his life was approached with enthusiasm and scientific curiosity, and he especially enjoyed the recounting of these events.

In June 1969, Bill was struck by a back injury and subsequent surgery, which immobilized him for several months. His slow recovery, which included relearning to walk, was nearly complete a year later when he left for the meeting in Calgary. It seemed to be a good sign that he felt strong enough to make the trip, so the heart attack that felled him in Victoria was unexpected.

Surviving Bill are his wife and three sons, William Edward, Robert Powell, and Donald Stuart, along with the memories of all who were privileged to have known him.

—*Kenneth S. Johnson*

Memorial to William E. Ham Under Consideration

The Alumni Advisory Council of the Foundation of Geology and Geophysics will soon establish a fitting memorial to Dr. Ham. Suggestions received include an endowed fellowship and an endowed chair. Further suggestions on a fitting tribute would be welcomed by the council and can be sent to the School of Geology and Geophysics, The University of Oklahoma, 830 Van Vleet Oval, Room 163, Norman, Oklahoma 73069.

Petrography of the Johns Valley Boulders Ouachita Mountains

Gerald L. Shideler[1]

Abstract—The boulder assemblage of the Late Mississippian-Early Pennsylvanian Johns Valley Formation of the central Ouachita Mountain province is extremely heterogeneous, being composed of clasts belonging to 9 major petrographic groups that encompass 19 petrographic classes. Carbonate clasts are highly dominant, constituting 75 percent of the boulder assemblage. Most carbonate boulders are dolomitic limestones, which consist of several petrographic varieties. Siliceous rocks constitute 18 percent of the boulders, most of which are weathered chert nodules. Clastic specimens are least abundant, constituting only 7 percent of the boulders, most of which are arenites. On the basis of petrographic and megascopic properties, the boulders appear to have been derived from stratigraphic units indigenous to the Arbuckle and Ozark facies of the foreland province, as well as from units of the frontal and central Ouachita Mountain provinces.

INTRODUCTION

The Late Mississippian-Early Pennsylvanian Johns Valley Formation in the central Ouachita Mountain province of southeastern Oklahoma and southwestern Arkansas is a predominantly argillaceous unit whose most distinguishing attribute is the presence of numerous disseminated boulders. The boulders are distributed within an east-west-trending curvilinear belt extending from Atoka County, Oklahoma, to Scott County, Arkansas (fig. 1). Most boulders are of exotic foreland lithologies and are completely foreign to the indigenous flysch facies of the Ouachita geosyncline. This report summarizes the petrographic nature of the Johns Valley boulder assemblage, thereby complementing a published study on Johns Valley boulder provenance (Shideler, 1970).

GENERAL PETROGRAPHIC DISTRIBUTION

On the basis of petrographic analyses, 400 sampled Johns Valley boulders were differentiated into 9 major petrographic groups (fig. 2), which encompass 19 petrographic classes.

The carbonate boulders are those specimens with a carbonate fraction that exceeds 50 percent of their bulk composition. They are highly dominant, representing 75 percent of the sampled Johns Valley boulders. Carbonate specimens account for 7 of the 9 major petrographic groups and are differentiated largely in accordance with the classification system of Folk (1959), slightly modified by the present writer to meet the needs of this study. Each carbonate group, as defined in this study, is described as follows.

1. Intraclastic carbonates: specimens that contain over 10 percent allochems, of which at least 25 percent are intraclasts. Included in this group are both the intrasparite and intramicrite classes, which are differentiated on the basis of the dominant interstitial material. Interstitial sparry cement is dominant in the former class, whereas a microcrystalline matrix (1-4 microns) dominates in the latter.

[1]Assistant professor, Department of Geophysical Sciences, Old Dominion University, Norfolk, Virginia.

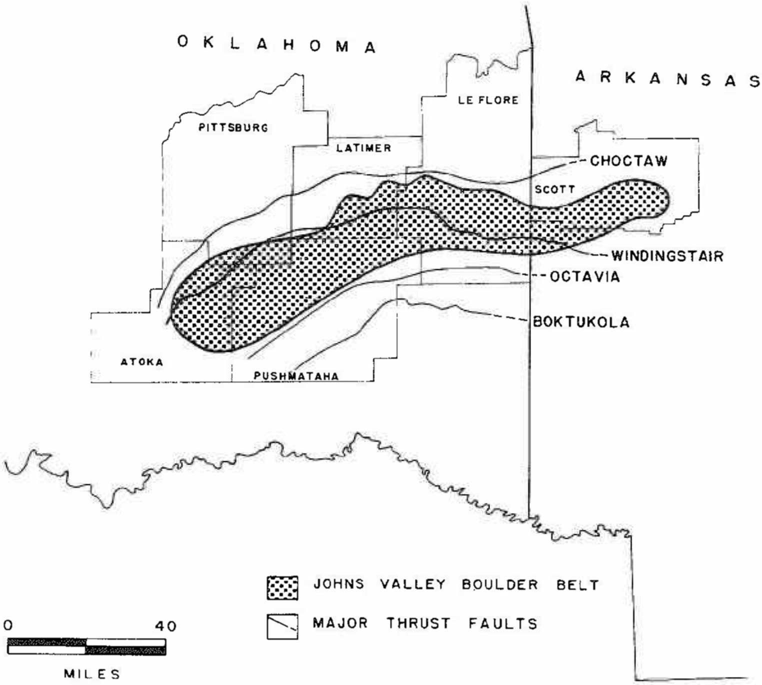

Figure 1. Areal distribution of Johns Valley boulders (Shideler, 1970, fig. 4).

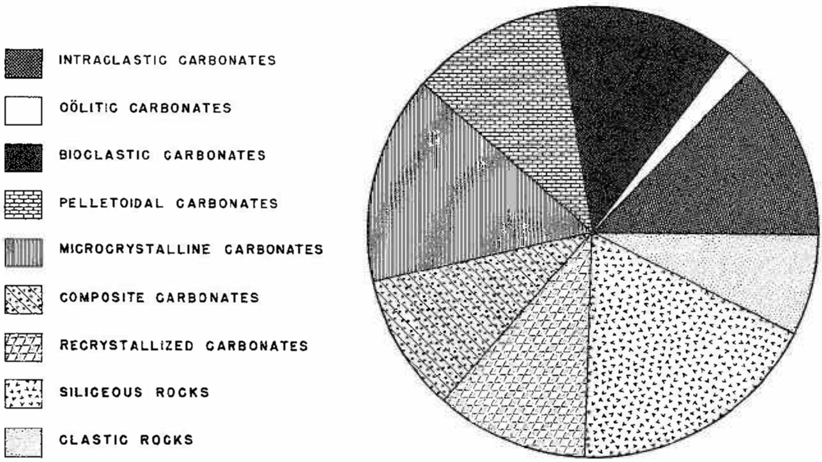

Figure 2. Petrographic distribution of Johns Valley boulders, based on analyses of 400 representative boulder specimens.

2. Oölitic carbonates: specimens that contain over 10 percent allochems, of which intraclasts constitute less than 25 percent and oölites exceed 25 percent. Included in this group are both the oösparite and oömicrite classes, in which sparry cement or microcrystalline matrix constitutes the dominant interstitial material, respectively.

3. Bioclastic carbonates: specimens that contain over 10 percent allochems, of which neither intraclasts nor oölites exceed 25 percent and fossil detritus dominates over the pelletoidal fraction. Included in the group are both the biosparite and biomicrite classes, differentiated on the basis of the dominant interstitial material.

4. Pelletoidal carbonates: specimens that contain over 10 percent allochems, of which neither intraclasts nor oölites exceed 25 percent and pellets exceed the bioclastic fraction. The group includes both the pelsparite and pelmicrite classes, differentiated on the basis of the dominant interstitial material.

5. Microcrystalline carbonates: specimens that contain less than 10 percent allochems, with the bulk of the rock being composed of microcrystalline carbonate. The group includes both the micrite and dismicrite classes, which are differentiated on the basis of structure. Micrites are essentially homogeneous throughout, whereas dismicrites exhibit a notably disturbed structure consisting of irregular spar-filled voids and patches, resulting in a conspicuous "birdseye" appearance.

6. Composite carbonates: a group originated by the writer to include heterogeneous specimens composed of two distinct lithologies in nearly equal proportions.

7. Recrystallized carbonates: specimens whose textures consist entirely or largely of a granoblastic crystalline mosaic. The group is divided on the basis of mineralogy into dolomite and microsparite classes.

Siliceous rocks constitute one petrographic group, which includes all boulders whose silica content exceeds 50 percent of their bulk composition. Siliceous rocks make up 18 percent of the sampled Johns Valley boulders and are differentiated on the basis of petrographic and megascopic properties into three distinct classes: replacement cherts, bedded cherts, and spiculites.

Clastic rocks also constitute a single petrographic group, which includes all specimens that contain a terrigenous detrital fraction exceeding 50 percent of their bulk composition. Clastic rocks make up 7 percent of the sampled Johns Valley boulders and are divided on a textural basis into rudaceous, arenaceous, and argillaceous classes.

CARBONATE BOULDERS

Carbonate mineralogy.—The mineralogy of all carbonate specimens was determined by both petrographic techniques and by staining with an Alizarin Red S solution. On the basis of relative percentages of the minerals calcite and dolomite, all carbonate specimens were classified into the following four lithologic types: (1) limestones (dolomite = 0-10 percent), (2) dolomitic limestones (dolomite = 11-50 percent), (3) calcitic dolomites (dolomite = 51-90 percent), (4) dolomites (dolomite = 91-100 percent). The relative distribution of each lithologic type is diagrammatically illustrated in figure 3. Dolomitic limestones are highly dominant, constituting 56 percent of the carbonate boulders. Next in abundance are calcitic dolomites (18 percent), followed by limestones (16 percent), and dolomites (10 percent).

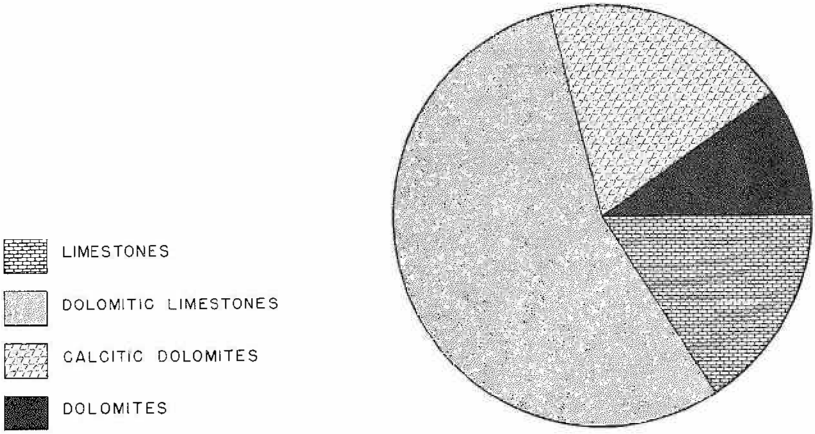

Figure 3. Mineralogical distribution of carbonate boulders.

Intraclastic carbonates.—Specimens of the intraclastic carbonate group make up 13 percent of the Johns Valley boulders, of which 12 percent belong to the intrasparite class. The intrasparites contain a wide variety of intraclast lithologies, generally with two or more types occurring in an individual specimen (fig. 4A). Micrite intraclasts are highly dominant, with pelmicrite and pelsparite clasts also relatively abundant. Texturally, the intrasparites vary in size from medium calcarenites to coarse calcirudites and are generally poorly sorted. Many of the calcirudite specimens are of the "edgewise-conglomerate" variety, in which ellipsoidal intraclasts have assumed a preferred fabric (fig. 4B). The intraclasts are cemented by sparry calcite, finely to coarsely crystalline depending on initial packing density.

Allochem admixtures are generally present in variable concentrations. Pellets are present in most specimens, where they normally constitute the dominant allochem admixture. Most specimens are fossiliferous, but the bioclastic admixture is generally subordinate to the pelletoidal fraction. Oölites are commonly present in small quantities and occasionally constitute the dominant allochem admixture (fig. 4C).

Intrasparite faunules are dominated by echinoderm fragments, mollusks, ostracodes, and algae; however, trilobites, brachiopods, and bryozoans are also relatively abundant. Most fossils are unoriented and fragmented, with the majority of bivalves notably disarticulate. Algae constitute a large portion of the biotas, occurring both as incrustations on allochems and as discrete fragments that often simulate micritic intraclasts (fig. 4D).

Mineralogically, the intrasparites consist of dolomitic limestones (69 percent), limestones (17 percent), and calcitic dolomites (14 percent).

Intramicrite specimens constitute only 1 percent of the Johns Valley boulders. The intraclasts are generally composed of micrite and are homogeneous in a given specimen as contrasted with the lithologic diversity often exhibited in intrasparite specimens. Textures, allochem admixtures, and faunules are essentially similar to those exhibited by intrasparites; however, terrigenous admixtures are substantially lower. Mineralogically, all intramicrites studied are dolomitic limestones. Evidence for a penecontemporaneous or early diagenetic stage of dolomitization is afforded by some specimens in which micritic intraclasts embedded in a dominantly micritic matrix are selectively dolomitized. In addition, a second subsequent stage of dolomitization is occasionally recorded by the presence of isolated rhombohedra indiscriminately transecting both matrix and allochems.

On the basis of petrographic and megascopic properties, intraclastic carbonate boulders appear to have been derived largely from an intrasparite facies of the West Spring Creek, Kindblade, and Fort

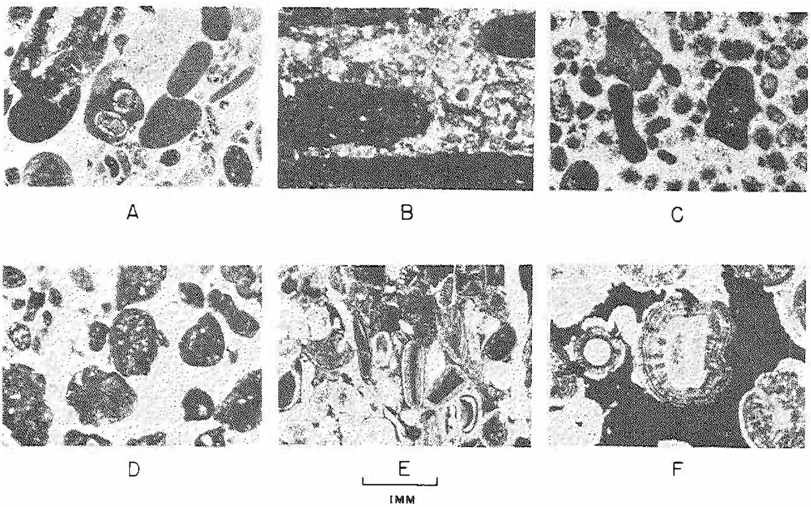

Figure 4. Photomicrographs of intraclastic and oölitic carbonates.

- A. Intrasparite boulder (Arbuckle Limestone) illustrating lithologic heterogeneity of intraclasts, which are composed of micritic, bioclastic, oölitic, and pelletoidal lithologies. Plane-polarized light.
- B. Pelletoidal intrasparite boulder (Fort Sill Formation). Edgewise conglomerate illustrating preferred orientation of elongated micritic intraclasts. Plane-polarized light.
- C. Oölitic intrasparite boulder (Wapanucka Formation). Oölites contain nuclei of micritic intraclasts and pellets and constitute the dominant allochem admixture. Large micritic intraclasts are partially recrystallized. Plane-polarized light.
- D. Intrasparite boulder (Kindblade Formation) composed of micrite intraclasts and Girvanella bioclasts; large Girvanella bioclasts in center. Crossed nicols.
- E. Arenaceous oösparite boulder (Wapanucka Formation). Partially silicified oölites with fossil nuclei; many oölites are superficial. Note sagittal section of fusulinid at top center. Plane-polarized light.
- F. Oömicrite boulder (Chimneyhill Limestone). Cerebroid oölites with nuclei of echinoderm fragments, showing peripheral replacement by interstitial matrix. Several patches of sparry calcite (light areas). Plane-polarized light.

Sill formations. Subordinate quantities of intrasparite boulders were also identified with the following units: Bois d'Arc Limestone, Chimneyhill Limestone, Fite Limestone, Jasper Limestone, Joins Formation, Viola Limestone, and Wapanucka Formation. All intramicrite boulders were identified with the Viola, West Spring Creek, and Kindblade formations.

Oölitic carbonates.—The oölitic carbonate group makes up 2 percent of the Johns Valley boulders, of which oösparites and oömicrites are in approximately equal proportions. The oölitic fraction of oösparite specimens varies in size from fine calcarenite to fine calcirudite. The oölites generally exhibit multilayered envelopes with well-defined concentric and radial structures; however, oölites of the superficial variety were also commonly observed. Oölitic nuclei consist predominantly of fossil fragments, but detrital quartz grains, intraclasts, and pellets are relatively common. Oölite morphology is variable, being a function of nucleus type, development stage, and degree of compactional deformation (fig. 4E); however, most oölites are spherical to highly ellipsoidal in shape.

Bioclastic material constitutes the dominant allochem admixture, with fossil fragments occasionally consisting of up to 55 percent of the allochem fraction. The faunas are generally disarticulate and fragmented. The dominant fossils are echinoderm fragments, but other common organisms include mollusks, bryozoans, ostracodes, brachiopods, and algal fragments. Pellets and intraclasts rarely constitute significant admixtures.

Silicified oölites are relatively common, with the silica exhibiting various paragenetic relationships that generally indicate more than a single episode of silicification in some specimens. Mineralogically, the oösparite specimens studied consist of dolomitic limestones (67 percent) and calcitic dolomites (33 percent).

Oömicrite specimens are petrographically similar to the oösparites, with the exception of their dominant interstitial microcrystalline matrix. In addition, many of the oölites in oömicrite specimens are of the "cerebroid" variety (Carozzi, 1960, p. 247) as a result of peripheral replacement by the microcrystalline matrix (fig. 4F). Mineralogically, the oömicrite specimens consist of equal proportions of dolomitic limestones and calcitic dolomites.

Oölitic carbonate boulders appear to have been derived from an oösparite facies of the Wapanucka Formation and an oömicrite facies of the Chimneyhill Limestone. In addition, possible oölitic carbonate boulders from the West Spring Creek and Golf Course formations were noted.

Bioclastic carbonates.—Bioclastic carbonate specimens constitute 13 percent of the Johns Valley boulders, of which 10 percent belong to the biomicrite class. The bioclastic frameworks of most biomicrites are composed of a mixed biota; however, certain organisms are notably dominant in most specimens (fig. 5A). Faunas that dominate most frequently are echinoderm fragments, ostracodes, sponge spicules, and mollusks. Also commonly present in substantial quantities are bryozoans, trilobites, brachiopods, and radiolaria; however, these organisms are rarely dominant. In addition, occasional graptolites, algae, spore exines, and worm tubes were observed. Generally, the fossils are randomly oriented, and articulate bivalves are relatively common. States of partial silicification and pyritization were frequently observed.

Allochem admixtures are present in half of the biomicrite speci-

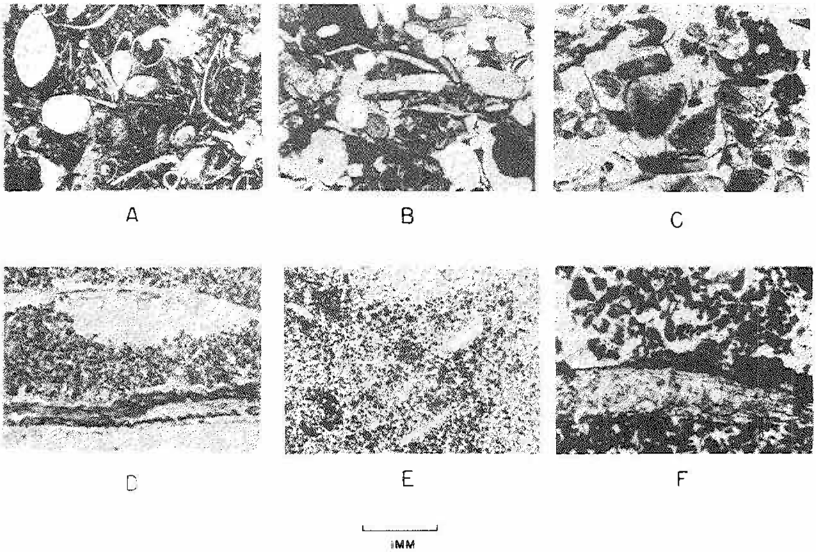

Figure 5. Photomicrographs of bioclastic and pelletoidal carbonates.

A. Ostracode biomicrite boulder (Chimneyhill Limestone). Note random orientation of mixed biota. Plane-polarized light.

B. Arenaceous biosparite boulder (Wapanucka Formation). Mixed biota dominated by echinoderm fragments. Note dense packing and fragmentation of bivalve organisms. Plane-polarized light.

C. Echinoderm biosparite boulder (Fernvale Limestone). Mixed biota dominated by echinoderm fragments in optical continuity with sparry cement. Plane-polarized light.

D. Pelletoidal brachiopod biosparite boulder (Simpson Group). Note preferred orientation of partially silicified brachiopod valves and well-developed geopetal structures. Large pelletoidal admixture of probable fecal origin. Plane-polarized light.

E. Fossiliferous pelsparite boulder (Viola Limestone). Textural uniformity of pellets and associated bioclastic admixture indicate a fecal origin. Pellets are selectively dolomitized. Plane-polarized light.

F. Fossiliferous pelsparite boulder (Viola Limestone). Fragmentation of algal incrustation on brachiopod valve, producing detrital pellets and intraclasts. Plane-polarized light.

mens, with pellets being most numerous, often constituting up to 40 percent of the allochem fraction. Oölites and intraclasts were occasionally observed in small quantities.

The microcrystalline matrices of the biomicrites occasionally exhibit a uniform texture but are generally grumous in appearance. Some exhibit areas gradational into coarser textured microspar (5-15 microns), much of which appears to have originated through recrystallization of 1-4-micron ooze. Some small patches of sparry calcite are also present, both interstitially and in veinlets.

Mineralogically, the biomicrites are a heterogeneous class, being composed of limestones (12 percent), dolomitic limestones (55 percent), calcitic dolomites (26 percent), and dolomites (7 percent).

Biosparite specimens make up 3 percent of the Johns Valley boulders. The bioclastic frameworks invariably consist of mixed faunal assemblages, with brachiopods and echinoderm fragments being the usually dominant fossils (fig. 5B, C, D). Also generally present in abundance are ostracodes, trilobites, bryozoans, and mollusks. Algae, radiolaria, and coral fragments were also observed. Bryozoans and algae occur both as incrustations and as discrete fragments. With the exception of many ostracodes, most bivalved organisms are notably fragmented and disarticulate. Brachiopod valves commonly have a preferred orientation and display well-developed geopetal structures (fig. 5D).

Allochem admixtures are present in half of the biosparites, with pellets being the dominant type. In some occurrences, pellets constitute up to 40 percent of the allochem fraction and appear to be dominantly of fecal origin. Oölites and intraclasts were rarely observed. Mineralogically, the biosparites consist of limestones (38 percent) and dolomitic limestones (62 percent).

Bioclastic carbonate boulders appear to have been derived from several stratigraphic units. Biomicrite boulders were identified with Caney concretions as well as with the Viola Limestone, Chimneyhill Limestone, Henryhouse Limestone, Bois d'Arc Limestone, and the Bromide Formation. Biomicrite specimens of the Viola Limestone are most abundant. In addition, possible biomicrite specimens of the Kindblade, Joins, and Wapanucka Formations were noted. Boulders of the biosparite facies were identified with the Fernvale Limestone, Viola Limestone, Joins Formation, and Wapanucka Formation. Biosparite specimens of the Fernvale Limestone appear to be most abundant.

Pelletoidal carbonates.—Pelletoidal carbonate specimens constitute 11 percent of the Johns Valley boulders, of which 9 percent are pelsparites. The pellets that constitute the major framework component of the pelsparites are rounded, structureless bodies of microcrystalline carbonate, with an arbitrary maximum size limit of 0.2 mm. In the specimens studied, the pellets appear to be polygenetic. In some specimens, they are well-sorted, spherical to ellipsoidal bodies, the textural uniformity of which is indicative of a fecal origin, especially where accompanied by bioclastic admixtures (fig. 5E). In other specimens, the pellets appear to represent pseudotextures resulting from the recrystallization of metastable microcrystalline ooze into microspar. In addition, many of the pellets appear to be detrital in origin, having been derived either by the diminution of micritic and pelletoidal intraclasts or by the fragmentation of micritic algal incrustations (fig. 5F).

Bioclastic debris constitutes the most common allochem admixture, occasionally constituting up to 45 percent of the allochem fraction. Micritic and pelletoidal intraclasts are also prominent admixtures, whereas oölites are relatively scarce.

Pelsparite faunules are dominated by brachiopods, mollusks, ostracodes, and echinoderm fragments. Also relatively abundant are trilobites, sponge spicules, bryozoans, and algae. The biotas are randomly oriented, with bivalves most commonly occurring in a disarticulate state. Partial silicification and pyritization of fossil shells were frequently observed.

Mineralogically, the pelsparites are composed of limestones (23 percent), dolomitic limestones (60 percent), and calcitic dolomites (17 percent). In dolomitic specimens, the mineral dolomite typically exhibits paragenetic relationships that indicate two distinct stages of dolomitization (fig. 6A).

Pelmicrite specimens make up 2 percent of the Johns Valley boulders. With the exception of their dominant microcrystalline matrix, the pelmicrites are petrographically similar to the pelsparites just described. In many specimens, the pellet fraction is difficult to distinguish from the micritic matrix; however, in other specimens, pellets are readily distinguishable by a higher organic content, possibly reflecting a fecal origin (fig. 6B). Many thin sections exhibit continuous gradations between pelmicrite and pelsparite lithologies. Min-

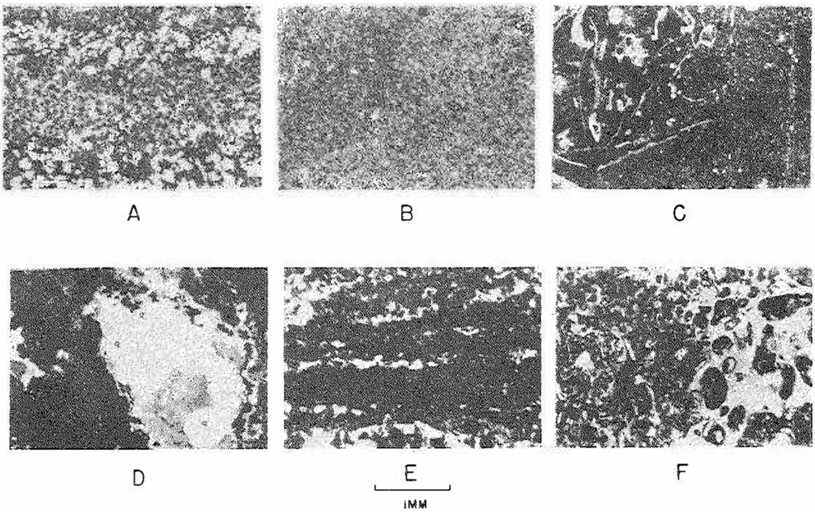

Figure 6. Photomicrographs of pelletoidal, microcrystalline, and composite carbonates.

- **A. Dolomitic pelsparite boulder (West Spring Creek Formation) illustrating two stages of dolomitization. Laminae of dolomitized pellets in sparry calcite cement alternating with laminae of later stage dolomite rhombohedra, many of which truncate pelletoidal layers. Plane-polarized light.**
- **B. Fossiliferous pelmicrite boulder (Bromide Formation). Higher organic content of pellets indicates a fecal origin. Plane-polarized light.**
- **C. Fossiliferous micrite boulder (Bromide Formation). "Fossil pocket" at left contains an anomalously high concentration of mixed bioclastic debris, a possible result of organic burrowing. Plane-polarized light.**
- **D. Dismicrite boulder (Bromide Formation). Large void filled with sparry calcite, partially replaced by authigenic quartz euhedra (q) and peripheral hematite (dark margin). Crossed nicols.**
- **E. Pelletoidal dismicrite boulder (Chimneyhill Limestone). Note crude lamination of voids (probable algal stromatolite). Plane-polarized light.**
- **F. Composite intrasparite-biomicrite boulder (Viola Limestone). Gradational lithologic transition, with intraclasts of pelletoidal biomicrite incorporated into overlying intrasparite. Plane-polarized light.**

eralogically, the pelmicrites are composed of limestones (33 percent) and dolomitic limestones (67 percent).

Pelletoidal carbonate boulders appear to have been derived from a pelsparite facies of the Sycamore Limestone, Viola Limestone, Wapanucka Formation, Kindblade Formation, Bois d'Arc Limestone, West Spring Creek Formation, Moorefield Formation, Pinetop Chert, Jasper Limestone, and McLish Formation. Pelsparite specimens of the Sycamore, Viola, Wapanucka, and Kindblade formations are most abundant. Possible pelsparite boulders of the Fite, Joins, and Oil Creek formations were also observed. Boulders of pelmicrite lithology were identified with the Fite Limestone, Kindblade Formation, and West Spring Creek Formation. Possible pelmicrite specimens of the Sycamore Limestone, Chimneyhill Limestone, and Wapanucka Formation were also noted.

Microcrystalline carbonates.—The microcrystalline carbonate group constitutes 15 percent of the Johns Valley boulders, of which 7 percent are of the micrite class. The 1-4-micron microcrystalline frameworks of the micrite specimens occur in both laminated and structureless varieties, the textures of which are variable. Many specimens are texturally homogeneous. However, most exhibit a clotted or grumous texture that appears to be the combined result of both partial dolomitization and partial recrystallization of microcrystalline ooze into coarser textured microspar (5-15 microns).

The small allochem fractions of the micrites are dominated by fossils, but pellets are commonly present; intraclasts and oölites were not observed. Most micrites are sparsely fossiliferous, containing mixed biotas randomly dispersed throughout the matrix; however, some of the bioclastic debris is localized into "fossil pockets" in anomalously high concentrations (fig. 6C). Such localized concentrations appear to be the result of organic burrowing. Micrite faunules are dominated by ostracodes, sponge spicules, and radiolaria. In addition, numerous mollusk and echinoderm fragments, as well as occasional bryozoans, trilobites, and brachiopods, are present.

The micrite boulders are mineralogically diversified, consisting of limestones (16 percent), dolomitic limestones (37 percent), calcitic dolomites (37 percent), and dolomites (10 percent).

Dismicrite specimens constitute 8 percent of the Johns Valley boulders. Their disrupted "birdseye" structures consist of voids that are either crudely laminated or arranged in irregular anastomotic networks. Voids are generally filled with finely to very coarsely crystalline sparry calcite, but occasional silica- and hematite-filled voids were observed. In some instances, two or three mineral species were observed occupying the same voids, their paragenetic relationships indicating sequential replacement (fig. 6D). The voids appear to be polygenetic; however, most specimens exhibit crude laminations in both thin section and hand specimen, which indicate algal stromatolitic structures (fig. 6E).

The dominant allochems in most dismicrite specimens are pellets, often grading by size into micritic intraclasts. Most specimens are sparsely fossiliferous, the most common fauna being ostracodes, mollusks, sponge spicules, and radiolaria. Mineralogically, the dismicrite boulders are composed of limestones (20 percent), dolomitic limestones (77 percent), and calcitic dolomites (3 percent).

Microcrystalline carbonate boulders of the micrite class appear to have been derived from the Viola Limestone, West Spring Creek

Formation, Bromide Formation, Chimneyhill Limestone, Kindblade Formation, and Caney concretions. Micrite boulders of the Viola Limestone are most abundant. Possible micrite boulders of the Fort Sill Formation, Bois d'Arc Limestone, and Henryhouse Limestone were also observed. Dismicrite boulders were identified with the Bromide Formation, Chimneyhill Limestone, Fite Limestone, Jasper Limestone, and West Spring Creek Formation. Dismicrite specimens of the Fite and Bromide formations proved most abundant. In addition, possible dismicrite boulders of the McLish, Wapanucka, and Kindblade formations were noted.

Composite carbonates.—The composite carbonate group accounts for 10 percent of the Johns Valley boulders and comprises specimens that exhibit a wide spectrum of lithologic combinations. A total of 18 different lithologic combinations were observed, with the following being the most frequently noted: pelsparite-pelmicrite, pelsparite-micrite, pelsparite-biomicrite, intrasparite-intramicrite, intrasparite-biomicrite, and intrasparite-micrite.

The composite carbonates appear to have originated both in response to varying sedimentological regimes and through subsequent diagenetic modifications. Many specimens are distinctly primary in origin and are composed of alternating dissimilar laminae, the lithologies of which apparently reflect variations in environmental parameters. In several specimens, clasts of one lithology have been incorporated as allochems in the lithology of the overlying lamina, apparently in response to fluctuations in energy level of the hydraulic regime. Some lithologic transitions are gradational (fig. 6F), whereas others are abrupt across a diastemic contact, denoting a conspicuous hiatus (fig. 7A). In addition to the composite specimens that indicate a primary origin, others appear to have originated through post-depositional processes. Diagenetic recrystallization of microcrystalline ooze appears to have been a dominant process in the formation of several specimens, as indicated by continuous gradations of two lithologies in a random or chaotic fabric without any apparent control by primary structures. Other specimens that exhibit a chaotic fabric, but whose lithologic contacts are more abrupt, may be the result of animal burrowing near the depositional interface (fig. 7B).

Mineralogically, the composite carbonate group is composed of limestones (12 percent), dolomitic limestones (74 percent), and calcitic dolomites (14 percent).

Composite carbonate boulders appear to have been derived from the Viola Limestone, West Spring Creek Formation, Kindblade Formation, Joins Formation, Fite Limestone, Sycamore Limestone, Fort Sill Formation, Wapanucka Formation, and Bois d'Arc Limestone. Composite carbonate specimens of the Viola Limestone are most abundant. Possible composite carbonate boulders of the McLish and Bromide Formations were also noted.

Recrystallized carbonates.—The recrystallized carbonate group accounts for 11 percent of the Johns Valley boulders and consists of specimens that are composed entirely or largely of a granoblastic crystalline mosaic. Mineralogically, the group consists of limestones (5 percent), dolomitic limestones (8 percent), calcitic dolomites (27 percent), and dolomites (60 percent). On the basis of carbonate mineralogy, the recrystallized group is differentiated into the dolomite and microsparite classes.

The dolomite class accounts for 10 percent of the Johns Valley

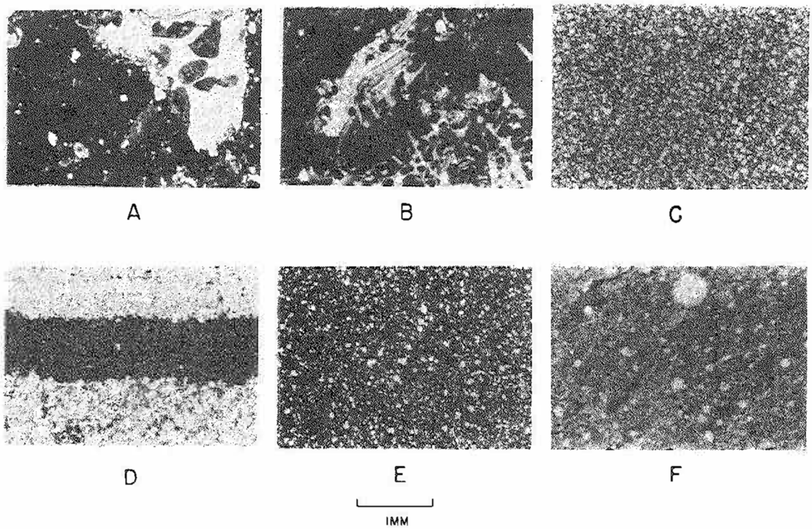

Figure 7. Photomicrographs of composite and recrystallized carbonates.

A. Composite intrasparite-intramicrite boulder (West Spring Creek Formation). Abrupt diastemic surface developed on dolomitic intramicrite, which supplied intraclasts for overlying intrasparite. Plane-polarized light.

B. Composite pelletoidal biosparite-micrite boulder (Joins Formation). Chaotic fabric and sharp lithologic contacts suggest organic burrowing. Plane-polarized light.

C. Ferruginous dolomite boulder (West Spring Creek Formation). Structureless granoblastic mosaic of anhedral to euhedral dolomite crystals, with interstitial hematite and limonite. Plane-polarized light.

D. Arenaceous calcitic dolomite boulder (West Spring Creek Formation). Laminations of light-colored granoblastic dolomite and dark-colored calcitic micrite. Plane-polarized light.

E. Intensely weathered ferruginous dolomite boulder (Tyner Formation). Selective leaching of dolomite rhombs produced well-preserved dolomolds (light) in ferruginous matrix. Plane-polarized light.

F. Radiolarian microsparite boulder (Caney concretion). Dispersed radiolaria in a granoblastic mosaic of microspar: probable recrystallized biomicrite. Plane-polarized light.

boulders and includes all recrystallized specimens in which the mineral dolomite constitutes over 50 percent of their bulk composition. In most specimens, the granoblastic crystalline mosaics appear to be metasomatic products of dolomitization, which has obliterated primary textures. In a few specimens the crystalline mosaics may actually be primary textures; however, no attempt was made to separate primary and secondary dolomites during the course of this study, and both were included in the recrystallized group. Mosaic textures vary from finely to coarsely crystalline, with individual grains varying in shape from anhedral to idiomorphic rhombohedra. Most textures are essentially equigranular; however, size gradations were observed in some thin sections. Specimens of the dolomite class are generally characterized by structureless mosaics (fig. 7C), but several dolomite boulders were observed that are well laminated (fig. 7D) as well as a few specimens that are conspicuously crossbedded.

Allochems are quantitatively insignificant components of dolomite boulders and were observed only occasionally as relicts. The most frequently noted relicts are fossils that consist mainly of mollusks but also include occasional ostracodes and echinoderm fragments. Detrital quartz varying from silt to coarse sand is a prominent accessory; the grains are generally disseminated throughout the specimen but occasionally occur in distinct laminae. Iron oxides are also ubiquitous, with hematite and limonite occurring interstitially in most specimens. In some boulders, dolomite rhombs were selectively leached by intense weathering, leaving a network of dolomolds in a concentrated ferruginous matrix (fig. 7E).

The microsparite class accounts for only 1 percent of the Johns Valley boulders and includes all recrystallized specimens in which the mineral dolomite constitutes less than 50 percent of their bulk composition. The granoblastic mosaics of microsparite specimens are composed primarily of calcitic microspar (5-15 microns). All mosaics appear to be secondary textures, having originated largely through recrystallization of microcrystalline calcitic or aragonitic ooze. A recrystallized origin is indicated in thin section by continuous size gradations from microspar to micrite and by the loose packing of allochems, which would appear to have required an original micritic matrix (fig. 7F).

Allochems were observed in some specimens in sparse quantities, with fossils being dominant; a few pellets and intraclasts were also noted. The microsparite faunules are dominated by radiolaria and sponge spicules, but some ostracodes and mollusk fragments are present.

Recrystallized carbonate boulders of the dolomite class appear to have been derived from the West Spring Creek Formation, Cotter Dolomite, and Tyner Formation. Dolomite boulders of the West Spring Creek Formation are most abundant. Possible dolomite boulders of the Kindblade and Sallisaw Formations were also observed. Most recrystallized boulders of the microsparite class were identified as Caney concretions; however, possible microsparite specimens of the West Spring Creek and Kindblade Formations were also noted.

SILICEOUS BOULDERS

The siliceous rock group represents 18 percent of the sampled Johns Valley boulders. On the basis of petrographic and megascopic properties, boulders of this group were differentiated into three varietal classes, which are described as follows.

Replacement cherts.—Most of the siliceous rocks belong to the replacement-chert class, which accounts for 13 percent of the Johns Valley boulders. Specimens belonging to this class are those whose petrographic properties clearly illustrate a limestone-replacement origin.

Their epigenetic nature is generally demonstrated by several petrographic features. All specimens are calcareous in varying degrees, with the carbonate fraction occurring as residual patches of host rock, residual fossils, and isolated or clustered carbonate rhombohedra, all of which are enclosed in siliceous matrices (fig. 8A, B). Host-rock inclusions occur both as dark-brownish patches of finely disseminated microcrystalline calcite and as deeply embayed sparry calcite crystals. Residual carbonate rhombohedra appear to be remnants of the original host rock, which represent carbonate phases less prone to silicification. The rhombs appear to be mainly dolomite; however, abundant iron staining also suggests the possibility of ferroan-dolomitic, sideritic, or ankeritic compositions. In some specimens, silica pseudomorphs after carbonate rhombs were observed, apparently illustrating the silicification of even the more resistant phases.

Matrices of the replacement cherts are composed primarily of microcrystalline silica, with occasional gradations into subordinate quantities of cryptocrystalline silica. Rarely does the cryptocrystalline

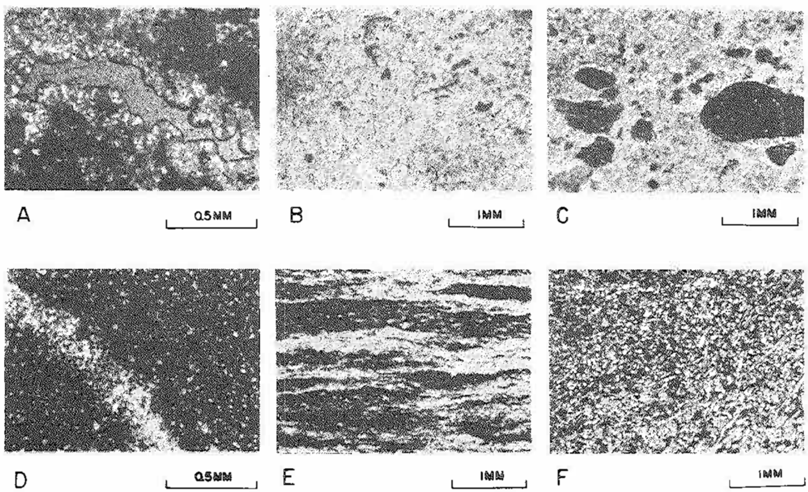

Figure 8. Photomicrographs of siliceous rocks.

A. Replacement-chert nodule illustrating calcareous host-rock residua in chalcedonic and microcrystalline matrix. Deeply embayed sparry calcite crystals and residual patches of microcrystalline calcite (dark) illustrate epigenesis. Plane-polarized light.

B. Replacement-chert nodule illustrating a residual calcareous faunal assemblage in matrix of microcrystalline silica: silicified bioclastic carbonate facies. Plane-polarized light.

C. Replacement-chert boulder (Woodford Formation). Epigenetic origin illustrated by relict intraclastic texture; intraclasts replaced by cryptocrystalline silica, with matrix replaced by microcrystalline silica. Plane-polarized light.

D. Bedded-chert boulder (Arkansas Novaculite). Matrix of cryptocrystalline silica (dark) traversed by veinlet of microcrystalline silica. Both matrix and veinlet are indiscriminately transected by numerous epigenetic carbonate rhombs. Crossed nicols.

E. Bedded-chert boulder (Bigfork Chert). Thin laminae of spiculitic cryptocrystalline chert (light) alternating with cherty carbonaceous laminae (dark). Plane-polarized light.

F. Arenaceous spiculite boulder (Chickachoc Chert). Mat of monaxon sponge spicules with interstitial argillaceous and carbonaceous matrix. Plane-polarized light.

variety make up the bulk of a specimen. The microcrystalline matrices commonly exhibit patches of coarser textured granular quartz, and continuous size gradations between the two varieties indicate progressive diagenetic recrystallization. Fibrous chalcedony is commonly present in subordinate quantities in replacing fossil debris, in surrounding carbonate inclusions, or in isolated patches within the microcrystalline matrix.

Relict host-rock features are frequently discernible, thus further illustrating a replacement origin. Most replacement cherts are fossiliferous, with the fauna occurring not only as calcareous inclusions but also as partially or completely silicified pseudomorphs. The dominant fossils of the replacement cherts are monaxon sponge spicules, ostracodes, echinoderm fragments, and radiolaria. Additional organisms include mollusks, brachiopods, bryozoans, graptolites, and trilobites. Besides fossil pseudomorphs, other relict features of the original carbonate host rock include remnant bedding as well as pelletoidal and intraclastic carbonate textures (fig. 8C).

Accessory constituents of the replacement cherts include substantial quantities of ferruginous minerals, which could be a reflection of iron liberated from the lattice structure of iron-bearing carbonate phases during the silicification process.

On the basis of megascopic properties, replacement cherts were differentiated into nodular and nonnodular varieties, the latter being much less numerous. Specimens of the nonnodular variety were arbitrarily distinguished on the basis of morphology and by the fact that they have retained the initial megascopic appearance of the original carbonate host rock. They appear to have been derived from the Pinetop Chert, Woodford Formation, and silicified Viola Limestone.

Replacement cherts of the nodular variety are highly dominant and are distinguished by their morphology and by a complete lack of preservation of host-rock megascopic properties. Three megascopically distinct types of nodules were recognized.

The first nodular type is characteristically dark bluish gray with common bluish-white mottling; stringers and patches of yellowish calcareous host-rock inclusions are clearly discernible in hand specimens. Nodules of this type are generally irregular in shape and weather in a notably rough and vuggy style. These nodules are relatively abundant, and one representative specimen was found to have recognizable fragments of the Viola Limestone still attached to its outer surface. Using this specimen as a "holotype," the writer believes that many nodules of this variety may have been derived from a Viola host rock.

A second megascopic type of nodule that is also relatively abundant is characteristically dark brown to brownish black and commonly mottled by lighter brown patches of calcareous host-rock inclusions. In hand specimens, remnant bedding is frequently discernible, and weathered nodules generally exhibit a case-hardened exterior. A thin section of one representative specimen revealed unsilicified residual fossils reminiscent of a Wapanucka assemblage. In addition, nodules of this variety are megascopically similar to nodules sampled from the Wapanucka Formation; consequently, many nodules of this megascopic type may have been derived from a Wapanucka host rock.

A third type of nodule characteristically exhibits a mottled light-brown to gray color and a waxy to vitreous luster. Weathered nodules of this megascopic type exhibit white case-hardened exteriors. Specimens of this variety are somewhat distinct petrographically in that fibrous chalcedony constitutes a greater percentage of the matrix than in the other two varieties. Nodules of this type are scarce and their genetic affinities least certain. Their megascopic and petrographic properties are most similar to chert nodules sampled from Silurian strata in the Ozark facies of northeastern Oklahoma.

Bedded cherts.—Quantitatively, specimens of the bedded-chert class are highly subordinate to the replacement cherts, representing only 4 percent of the Johns Valley boulders. They are distinguished by the fact that they are generally well laminated and offer no compelling petrographic evidence of a limestone-replacement origin.

The carbonate content of bedded-chert specimens is generally low to nonexistent. When present, the carbonate fraction generally occurs only as isolated or clustered rhombohedra within the siliceous matrix. No petrographic evidence was observed to indicate that the carbonate rhombs are residua of replaced limestones; in fact, carbonate rhombs in some specimens exhibit paragenetic relationships that illustrate their successful replacement of the siliceous matrix in which they occur. Some of the best examples of epigenetic carbonate rhombs are in boulders that were identified as Arkansas Novaculite (fig. 8D). The presence of such rhombs in the upper member of the Arkansas Novaculite was well established by Honess (1923, p. 130-139) and by Goldstein and Hendricks (1953, p. 430-432). These authors considered the rhombs to be composed of manganiferous carbonate or rhodochrosite; however, in thin sections studied by the present writer, abundant limonite staining of the rhombs indicates an iron-bearing phase as well, possibly siderite. The two phases are further indicated by the pronounced zoning of many of the rhombs, possibly suggesting a hydrothermal origin for the rhombs in which both manganese and iron-bearing phases crystallized out of a rhodochrosite-siderite solid-solution system.

Matrices of the bedded cherts consist of either microcrystalline or cryptocrystalline silica, both varieties being nearly equal in occurrence. Fibrous chalcedony and granular quartz are occasionally present in small quantities, occurring both in veinlets and as small isolated patches. The isolated patches of chalcedony appear to be void fillings, whereas the patches of granular quartz appear to have resulted largely from partial recrystallization of microcrystalline silica.

Bedded-chert specimens are invariably fossiliferous, with sponge spicules, radiolaria, and occasional ostracodes being the dominant fauna. Most fossils are recrystallized relicts.

Accessory constituents include substantial quantities of argillaceous and carbonaceous material and matter of a sapropelic origin, both of which commonly constitute distinct laminae (fig. 8E).

The specimens of bedded chert appear to have been derived from the Arkansas Novaculite, Bigfork Chert, and Boone Formation. Specimens of Arkansas Novaculite are most abundant.

Spiculites.—Siliceous specimens belonging to the spiculite class are relatively scarce, making up less than 1 percent of the Johns Valley boulders. Specimens of this class are distinguished from other spiculitic rocks solely on the basis of spicule quantity. The spicules themselves constitute the rock framework.

The spiculite boulders all consist of a laminated mat of monaxon sponge spicules with an interstitial argillaceous and carbonaceous matrix (fig. 8F). The spicules are composed of chalcedonic and granular silica. They are well preserved and exhibit clearly discernible axial canals. The only other fossils are occasional radiolaria.

Accessory constituents include abundant detrital quartz, substantial glauconite, and iron oxides.

All observed spiculite boulders appear to have been derived from the Chickachoc Chert, a siliceous facies of the Wapanucka Formation.

CLASTIC BOULDERS

The clastic rock group represents 7 percent of the sampled Johns Valley boulders. On a textural basis, specimens of this group were differentiated into rudaceous, arenaceous, and argillaceous classes in accordance with the classification system of Pettijohn (1957).

Rudaceous rocks.—The rudites in the Johns Valley Formation are orthoconglomerates, which contain individual clasts that range in size from granules to boulders. Orthoconglomerates account for approximately 2 percent of the Johns Valley boulders and consist of three lithologic varieties.

The most common variety is a calcareous conglomerate that exhibits a high degree of compositional heterogeneity and mineralogical immaturity. Specimens of this variety have frameworks composed primarily of metastable carbonate lithic clasts (fig. 9A). Individual clasts represent a variety of lithologies, which include micrite, biomicrite, biosparite, dolomite, pelsparite, pelmicrite, intrasparite, and oösparite. In addition to lithic clasts, other calcareous components include large admixtures of bioclastic debris as well as occasional oölites and pisolites. The faunules include echinoderm fragments, bryozoans, brachiopods, mollusks, and algal fragments. In addition, *Endothyra* was observed within some of the individual lithic clasts. Calcareous material constitutes the bulk of the specimens, but subordinate quantities of chert as well as arenaceous and argillaceous lithic clasts are present.

Interstitial components of the calcareous conglomerates consist primarily of detrital quartz grains and ferruginous cement, the relative proportions of which appear to be a function of framework-clast size. Interstices of specimens varying from granule to fine-pebble conglomerates are dominated by a hematite-limonite cement, with detrital quartz strongly subordinate. In contrast, interstices of coarser textured conglomerates are dominated by matrices of quartz sand, with only minor quantities of ferruginous cement. In general, specimens tend to have a distinct bimodality with larger sizes of framework clasts, with quartz sand constituting the secondary mode.

The lithic clasts and fossils constituting the calcareous conglomerates represent exotic detritus that has been concentrated into discrete beds. Individual clasts are lithologically identical to the larger isolated boulders within the Johns Valley Formation. Specimens of calcareous conglomerate account for most of the rudites and grade by size decrease into lithic calcarenites that exhibit identical lithologic properties.

A second rudaceous variety is represented by a single specimen of chert conglomerate, which consists of pebble-size clasts composed entirely of cryptocrystalline and microcrystalline silica. The subrounded lithic clasts are notably fractured, and some contain relict structures indicating a replacement origin. Individual clasts are tripolitic and poorly indurated with small quantities of ferruginous cement. The specimen has been highly weathered and appears to denote a multicycle origin. It is lithologically similar to conglomerates in the Jolliff Member of the Golf Course Formation.

The third rudaceous variety is represented by a few specimens

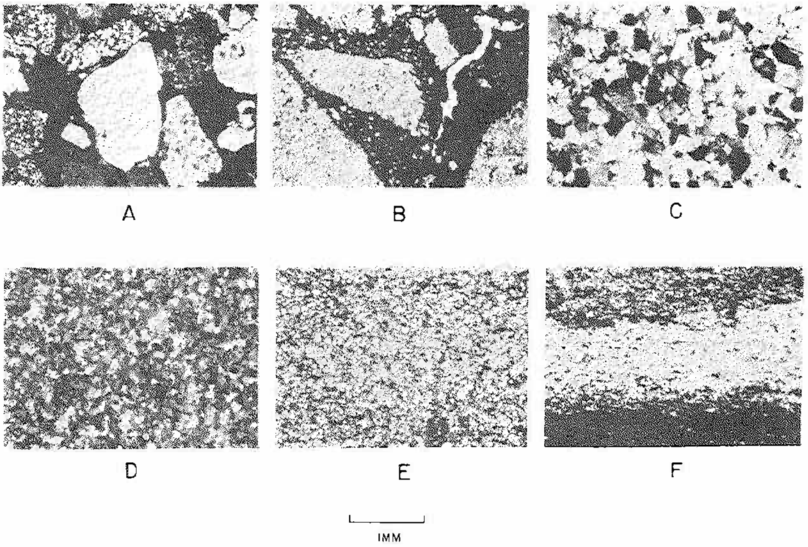

Figure 9. Photomicrographs of clastic rocks.

- **A.** **Calcareous granule-conglomerate boulder composed of exotic carbonate clasts with interstitial ferruginous cement. Heterogeneous assemblage of lithic clasts includes biosparite, pelsparite, pelmicrite, micrite, and dolomite lithologies. Plane-polarized light.**
- **B.** **Boulder of a cataclastic dolomite breccia: angular and highly fragmented dolomite clasts cemented by hematite. Probable fault breccia of dolomitized Sycamore Limestone. Plane-polarized light.**
- **C.** **Calcareous protoquartzite boulder (Wapanucka Formation). Faunule includes Millerella (center). Crossed nicols.**
- **D.** **Dolomitic orthoquartzite boulder (Oil Creek Formation). Polycrystalline mosaic of detrital quartz grains cemented by siliceous secondary overgrowth; mosaic is partially replaced by dolomite crystals. Plane-polarized light.**
- **E.** **Rolled sandstone boulder of subgraywacke variety. Specimen is composed of subangular quartz with an argillaceous matrix and is lithologically identical with sandstone members of Johns Valley Formation. Plane-polarized light.**
- **F.** **Siliceous carbonaceous shale boulder (Woodford Formation). Alternating laminae of calcareous microcrystalline chert (light) and carbonaceous shale. Plane-polarized light.**

of a cataclastic dolomite breccia composed exclusively of angular and highly fragmented dolomite clasts (fig. 9B). The clasts are silty and exhibit faint relict pelletoidal textures as well as a few relict fossils. Interstitial components consist of hematite cement and highly subordinate quantities of chalcedony. A cataclastic origin is evidenced both by clast homogeneity and by pronounced fragmentation and angularity of the individual clasts. Specimens of this rudaceous variety are interpreted as fault breccia, possibly derived from dolomitized phases of the Sycamore Limestone.

Arenaceous rocks.—Arenites represent 4 percent of the Johns Valley boulders and consist of several varieties.

One common variety can be classified as a ferruginous lithic calcarenite. Specimens of this variety are composed of coarse sand-size exotic detritus consisting mainly of calcareous lithic clasts and bioclastic debris. Also present are subordinate admixtures of chert lithic clasts and quartz sand grains. The detrital fraction is indurated with a hematite-limonite cement. Specimens of lithic calcarenite are petrographically identical to and gradational in size with specimens of the previously described calcareous granule orthoconglomerates (fig. 9A). Calcarenites of this variety occur in discrete beds within the Johns Valley Formation and were derived from the same sources that provided clasts for the calcareous orthoconglomerates. Lithic calcarenite specimens are here referred to as "exotic sandstones," in an effort to distinguish them from the normal quartzose sandstone members of the Johns Valley.

A second variety of arenites consists of calcareous protoquartzite boulders (fig. 9C). Specimens of this variety are composed mainly of medium- to coarse-grained detrital quartz. They are generally poorly sorted and contain large calcareous admixtures of lithic clasts, fossils, and oölites. Faunules consist of echinoderm fragments, brachiopods, bryozoans, mollusks, algae, trilobites, and occasional fusulinids. Accessory constituents include occasional noncalcareous lithic clasts, chert and polycrystalline quartz grains, iron oxides, and glauconite. Interstitial material consists of a carbonate cement and minor quantities of authigenic silica. Specimens of this variety appear to have been derived from an arenaceous facies of the Wapanucka Formation, such as described by Cline and Laudon (1959, p. 31-32) in the frontal Ouachita Mountain province.

A third variety of arenaceous boulders can be classified as a dolomitic orthoquartzite (fig. 9D). Specimens of this variety consist of fine- to coarse-grained detrital quartz cemented by siliceous secondary overgrowth into polycrystalline quartz mosaics. The siliceous mosaics are partially replaced by dolomite crystals. Some specimens of this variety are devoid of fossils, whereas others contain fragments of echinoderms, ostracodes, and mollusks. This variety appears to have been derived from an arenaceous facies of the Oil Creek Formation.

In addition to the foregoing varieties of arenaceous boulders, all of which are exotic lithologies, indigenous ellipsoidal rolled sandstone masses are abundantly disseminated throughout the Johns Valley Formation. They are megascopically and petrographically identical to the dense, greenish-brown quartzose sandstone members of the Johns Valley, from which they appear to have been derived. The rolled sandstone masses were not considered part of the Johns Valley boulders during this study, but are described for the purpose of completeness.

Petrographically, the rolled sandstones vary from protoquartzites to subgraywackes (fig. 9E). The detrital quartz fraction is generally fine to medium grained, subangular, and moderately sorted. Detrital accessories include mica, chert, polycrystalline quartz, lithic fragments, and feldspar grains. Interstitial components consist of argillaceous matrices composed largely of chlorite and sericite as well as occasional small quantities of calcareous cement.

The origin of the rolled sandstone boulders has generally been attributed either to soft sediment or to tectonic deformation, or possibly to both (Cline, 1966, p. 103).

Argillaceous rocks.—Argillites represent less than 1 percent of the Johns Valley boulders and consist entirely of carbonaceous shales of both siliceous and nonsiliceous varieties.

The siliceous specimens consist of alternating laminae of carbonaceous shale and calcareous microcrystalline chert (fig. 9F). Chert laminae appear to have originated largely through the silicification of original calcareous laminae. Faunules consist primarily of sponge spicules but also include relicts of brachiopods, ostracodes, and mollusks; fossils are generally localized within the calcareous chert laminae. Minor accessories include substantial quantities of disseminated pyrite and small amounts of quartz silt.

The nonsiliceous argillaceous specimens are highly carbonaceous with essentially no other admixtures. Their faunules consist of abundant sponge spicules and a few well-preserved radiolaria. The only accessory components are occasional grains of quartz silt.

Siliceous specimens appear to have been derived from the Woodford Formation, whereas nonsiliceous specimens were identified with the Caney Shale and possibly the Polk Creek Shale.

SUMMARY

The Johns Valley boulder assemblage is characterized by petrographic heterogeneity, being composed of specimens belonging to 9 major petrographic groups, which encompass 19 petrographic classes. Carbonate specimens are most diversified, accounting for 13 of the petrographic classes. The carbonate clasts are quantitatively dominant, representing 75 percent of the boulder assemblage. Siliceous rocks constitute 18 percent of the boulder assemblage, and clastic rocks are least abundant, constituting only 7 percent.

Lithologic comparisons of the Johns Valley boulders with specimens of a stratigraphic reference suite indicate the boulders were derived from several stratigraphic units, which vary in age from Late Cambrian through Early Pennsylvanian. The boulders are identified with stratigraphic units of both the Arbuckle and Ozark facies of the foreland province, as well as with units indigenous to the transitional and geosynclinal facies of the Ouachita mobile belt.

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Rock Handled Efficiently at Texas Gypsum Company Quarry Fletcher, Oklahoma[1]

Kenneth S. Johnson[2]

Texas Gypsum Company, after beginning production of gypsum at Fletcher in 1962, has increased quarry efficiency and raised annual production to over 90,000 tons, making it the third largest gypsum producer in Oklahoma. A system of conveyor belts, screening station, and two crushers was installed early in 1967 to channel high-purity rock from the quarry to waiting railroad cars and enable stockpiling of several sizes of crushed gypsum. Crude gypsum is loaded into open-topped gondolas on a siding of the St. Louis-San Francisco Railway for shipment to the company's wallboard plant near Dallas, Texas. Texas Gypsum Company is a subsidiary of Temple Industries, Inc., one of the South's major building-products manufacturers. The quarry, which originally operated under the name Castile Mining Company, is in northeastern Comanche County, about 60 miles southwest of Oklahoma City and 18 miles north-northeast of Lawton.

Gypsum mined at Fletcher is 97 to 98 percent pure and is a 65-foot-thick massive bed at the base of the Permian Cloud Chief Formation (Johnson, 1965). Current mining operations are in the north end of the deposit where the gypsum is 50 feet thick. The company now works two benches: an upper bench 15 feet thick and a lower bench 35 feet thick (fig. 1).

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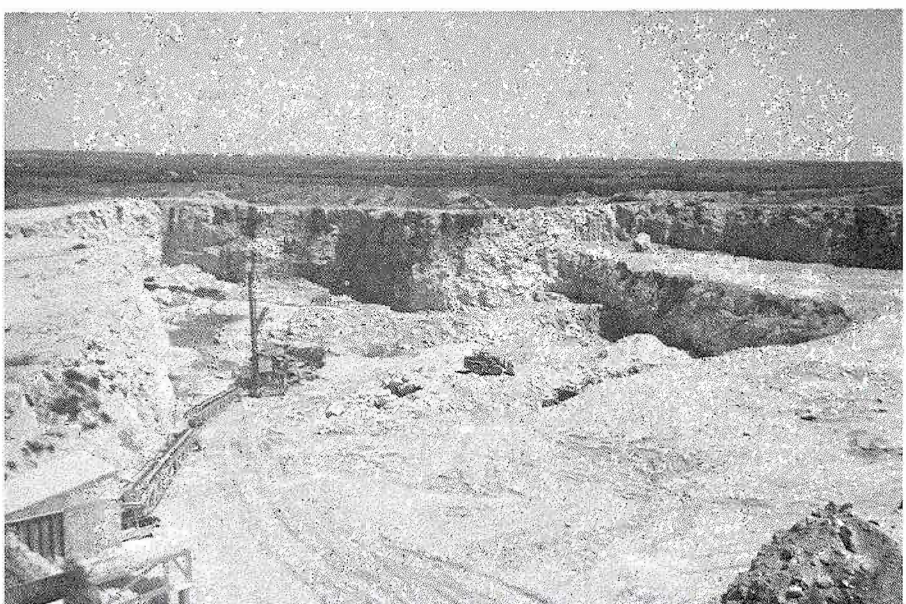
[1]Assistance and cooperation in gathering information about the operation have kindly been provided by Myron Hemmingson, quarry superintendent, and Ted E. Armstrong, president of the company, in Irving, Texas.

[2]Geologist, Oklahoma Geological Survey.

Figure 1. Texas Gypsum Company quarry at Fletcher is in the 65-foot-thick Cloud Chief gypsum. From primary crusher (left center), rock is conveyed to ground level.



Gypsum blasted from the working face is moved by front-end loader to the primary crusher in the floor of the quarry. Minus 8-inch rock is discharged from the crusher to a partially tunneled conveyor belt leading from the quarry up to ground level, where a secondary crusher further reduces the stone to minus 4 inches (fig. 2). Minus 4-inch gypsum is conveyed through the screening station next to the control tower, from which point it either is loaded directly in railroad

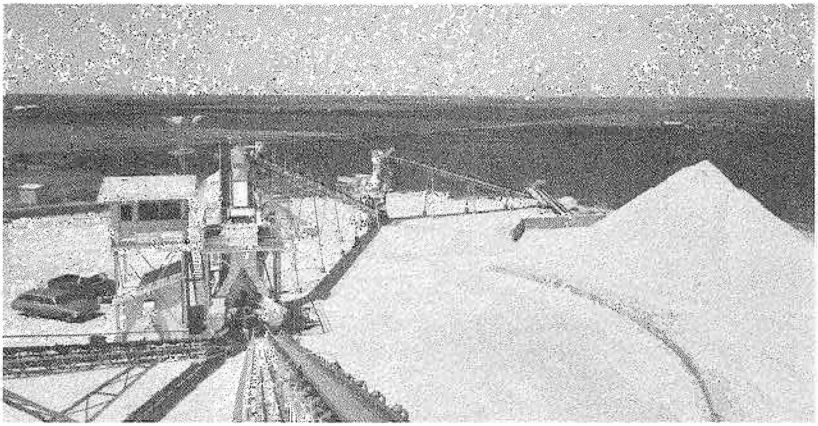


Figure 2. Gypsum on conveyor belt from quarry emerges (right center) at ground level, is fed to secondary crusher (center), and travels to screening station next to control tower (left center). Large stockpile of coarse gypsum at far right overlies tunneled conveyor from quarry.

cars, is fed to the coarse stockpile, or is screened and sent to separate stockpiles for medium-sized rock (2-½ inch) and fines. Screening, distribution, and all ground-level operations are automatically handled by one man from a console in the control tower (fig. 3).

The coarse-gypsum stockpile is for storage of material that is later chuted to the underlying tunneled conveyor leading up from the quarry and is recycled for loading on gondolas or for screening to fines and mediums. Medium-sized rock is held aside for shipment during wet weather because the absence of fines greatly reduces moisture absorption while in transit. Fines are sold at the quarry as agricultural gypsum for soil conditioning.

Myron Hemmingson, quarry superintendent, manages all operations at Fletcher with the help of two men: one in the quarry and the other in the control tower. Texas Gypsum Company has mined about 91,000 to 92,000 short tons of crude gypsum in each of the past 3 years (1967-1969) and has mined a total of 542,493 tons since opening in 1962.[3] The company is the third largest of eight gypsum producers in Oklahoma, having mined 10 percent of the 916,102 tons mined in 1968, but leads in tons of gypsum produced per man-hour worked (t/mh): Texas Gypsum Company produced about 14.2 t/mh in 1968 compared to a Statewide average of 6.9 t/mh.[3] Oklahoma ranks

[3]Based on data in **Annual Reports of Oklahoma Department of Mines, Chief Mine Inspector.**

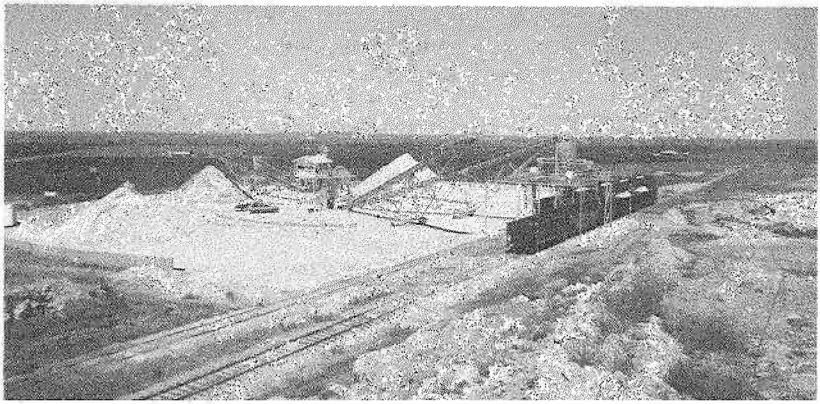


Figure 3. From screening station gypsum is conveyed to gondolas or to stockpiles for coarse (center), medium (extreme left), or fine gypsum (left center).

fifth among the United States in annual gypsum production, having contributed nearly 10 percent to the national output in 1968.

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National AIPG Meeting in Oklahoma City

The seventh annual meeting of the American Institute of Professional Geologists is scheduled to be held in the Skirvin Hotel in Oklahoma City on October 16-17. Featured speakers will include Oklahoma Governor Dewey F. Bartlett, Dean A. McGee, chairman of Kerr-McGee Corporation, and Gene P. Morrell, deputy assistant secretary of the U. S. Department of the Interior for mineral resources. General sessions will cover these topics: internal affairs of the institute, the institute and the geological profession, and the institute and the public. Nonmembers are welcome to attend. The fee for registration is $15.00. The fee for advance registration is $11.00 and should be mailed to:

Wilbur E. McMurtry
601 City National Bank Building
Oklahoma City, Oklahoma 73102

THE OCCURRENCE OF *Pterotocrinus* IN OKLAHOMA

D. W. BURDICK[1] AND H. L. STRIMPLE[2]

There are few fossil groups within the type sections of the Chester Series that reflect rapid evolution and allow correlation with other areas. Fortunately, species of the crinoid genus *Pterotocrinus* Lyon and Casseday did evolve rapidly and allow correlation within their small geographic range. Occurrences of *Pterotocrinus* are well known in the Eastern Interior and have been used in correlating strata in Kentucky, Tennessee, southern Illinois, southern Indiana, and northern Alabama.

Pterotocrinus is known only from Chester-age (Late Mississippian) rocks in the United States. Complete crowns are rare, but distinctively modified tegmen spines, termed "wingplates," are locally abundant. Five wingplates appeared on each individual. The plates are usually laterally flattened blades with a base that attached to a longitudinal facet on the tegmen. The wingplates kept the arms separated, possibly strengthened the tegmen, and aided in keeping a minimal portion of the calyx in contact with the substrata while the animal was inactive. The lower side of the blade is usually more knife edged than the upper, suggesting a keel-like function. The upper edge of the wingplate is thicker or even flat to concave in some species; thus a current direction from that side does not seem logical. When the animal was active the column was flexed, allowing the proximal portion to which the column was attached to face into the current. In this position, if the arms moved just slightly away from the tegmen, the pinnules could then bend out beyond the backs of the arms and allow the organism to feed or respire.

The wingplates underwent rapid evolution, and several lineages are recognized by Sutton (1934). The rapid morphologic changes reflected in the distinctive shapes of the plates have made them one of the better stratigraphic tools within Chester-age sediments. Thin-bladed types are the most common forms and persisted throughout Chester time. The wingplates of lower Chester forms commonly have a shaft or petiole with a greatly expanded (vertically fan-shaped) distal end. In middle Chester time a great variety of forms occurred, including bulbous and forked ones. Upper Chester species are characterized by thin-bladed wingplates having high bases and somewhat pointed distal ends (Swann, 1963, p. 79; Gutschick, 1965).

The present writers question the identification of materials previously ascribed to *Pterotocrinus* from strata west of the Mississippi River. Only two occurrences have been reported in the literature (Easton, 1943; Elias, 1957).

The material collected from the Pitkin Limestone in Arkansas and ascribed to *Pterotocrinus* sp. by Easton (1943, p. 126, 130) has been examined by Strimple. The specimen is an elongate spine with a widened proximal end. Its general shape and structure are that of an axillary brachial found in several genera of inadunate crinoids. *Pterotocrinus* is a camerate crinoid and does not have such a structure.

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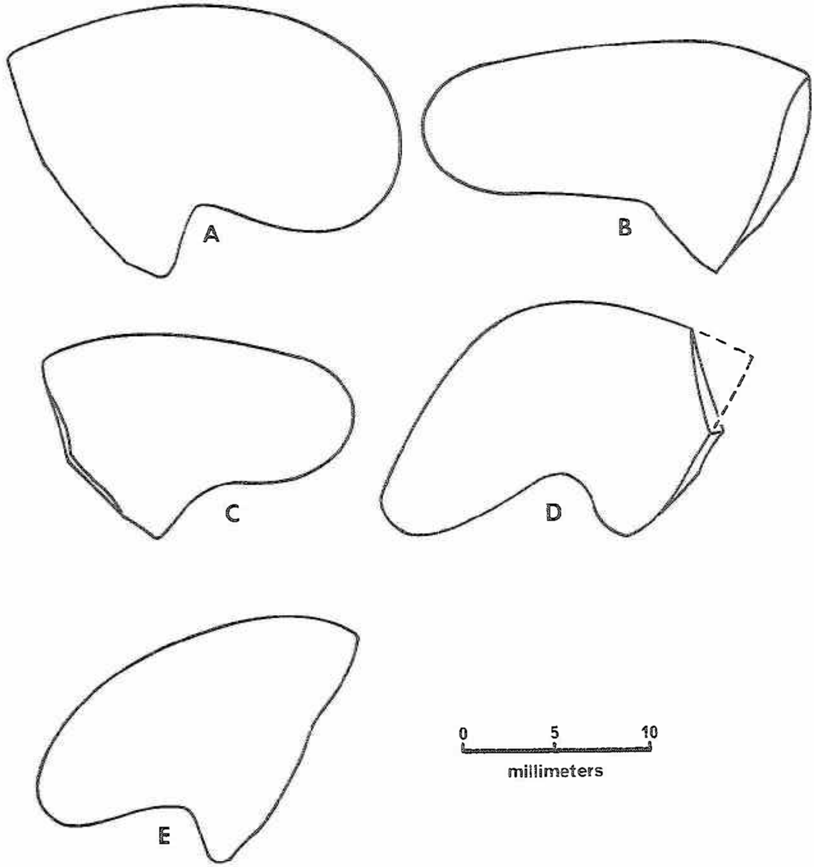

Figure 1. Pterotocrinus sp. cf. P. tridecibrachiatus **Gutschick. Camera lucida drawings of side view of five tegmen plates ("wingplates") from Fort Gibson Dam, Muskogee County, Oklahoma. A and C oriented with attachment region to the left; B, D, and E oriented with attachment region to the right. All specimens are on small slabs and are abraded.**

A fragment described as *Pterotocrinus*? *springerensis* Elias, 1957, from the Redoak Hollow Formation of southern Oklahoma does not resemble anything previously referred to *Pterotocrinus*. The specimen is very small and, judging by the illustration (Elias, 1957, pl. 41, fig. 11), is rounded and probably well abraded. Both the figure and description cast doubts on the species relation to *Pterotocrinus*. The specimen appears more likely to be the abraded cardinal process of a brachiopod. The specimen is reported to be deposited at the Nebraska Geological Survey, but the specimen could not be located.

Pterotocrinus is herein reported from two localities in the upper Fayetteville Formation of Oklahoma. A single basal plate (SUI 34416) was collected from a hill southeast of Hulbert, Cherokee County (NW1/4, NW1/4, sec. 31, T. 17 N., R. 21 E.), and five wingplates

(SUI 34415) that resemble *P. tridecibrachiatus* Gutschick, 1965, were collected from slabs near Fort Gibson Dam, Muskogee County. The basal plate is a large, relatively flat form similar to *P. tridecibrachiatus* and not comparable to the small, arched forms like *P. depressus* Lyon and Casseday, 1860. The wingplates most closely resemble *P. tridecibrachiatus* but show some gradation into *P. edestus* Gutschick, 1965. The two latter species are reported from the Kinkaid Limestone (upper Chester) of southern Illinois and western Kentucky (Gutschick, 1965, p. 638, 639). Material that closely resembles the two species is also known to occur in the Pennington Formation and upper Bangor Limestone in northern Alabama (*see* Drahovzal, 1967, p. 21). All known occurrences of *P. tridecibrachiatus* and *P. edestus* are indicative of a late Chester age.

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New Theses Added to OU Geology Library

The following masters' theses have been added to The University of Oklahoma Geology Library recently:

Master of Science Theses

Conodont biostratigraphy of the Morrow Formation (Lower Pennsylvanian) in portions of Cherokee, Sequoyah, Muskogee, and Adair Counties, northeastern Oklahoma, by Thomas Wood Henry.

Subsurface stratigraphic and statistical analysis, Cherokee, Marmaton, and Kansas City-Lansing Groups, Major and Woods Counties, Oklahoma, by Ernest G. Miller.

Areal geology of western Washita County, Oklahoma, by Jimmie L. Richardson.

Subsurface stratigraphic analysis, "Cherokee" group, northern Noble County, Oklahoma, by Jerry Douglas Scott.

Reminder to 24th International Geological Congress Participants

Geologists planning to attend the 24th International Geological Congress, which will be held in Montreal on August 21-30, 1972, are reminded to send in their completed application forms from the First Circular, which was distributed late last year. Otherwise, the IGC computer will not have your name in its memory, which will be jogged at the time the Second Circular is mailed out. Over 6,900 geologists have already sent in their forms, so now is the time to act. Completed forms should be returned to the Secretary General, 24th IGC, 601 Booth Street, Ottawa, Canada.

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