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Mississippian bioherms of southwestern Missouri and northwestern Arkansas

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MISSISSIPPIAN BIOHERMS OF SOUTHWESTERN MISSOURI AND NORTHWESTERN ARKANSAS

BY

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A

THESIS

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ABSTRACT

Lenticular bodies of massive limestone, flanked by thin crinoidal beds, crop out in southwestern Missouri and northwestern Arkansas. They are within the St. Joe limestone of the Lower Mississippian.

Strata underlying these bodies typically are downwarped, those on the flanks lapping against, finally passing completely over the limestone core. Dips away from the "reef" are commonly around 5 degrees, but reach as much as 30 degrees. Conglomeratic detritus, originating from the core, occurs in flanking beds at their contact with it.

Thin sections of these masses show no more than 15 per cent of the limestone to consist of fossil remains. These are chiefly encrusting bryozoans and crinoid fragments, with occasional ostracods and brachiopods. The matrix is microspar, its particles ranging from about three to 10 microns in diameter. A minor amount of disseminated clay was observed.

Flanking beds and inter-reef limestones differ in being composed of 50 to 75 per cent fossils; the matrix is more variable and in places coarser than in the core. The clay content, although minor, is apparent along partings.

The lenticular cores, or bioherms, are interpreted as minor elevations caused by entrapment of fine mud by non-calcareous plants in an environment of low energy. Reef-building calcareous organisms are virtually absent. Wave and current action as a formative agent are negated

by the presence of fine mud in the bioherm.

Genetic interpretations of certain bioherms from different areas and varying parts of the Paleozoic and Tertiary were discussed and rejected as an explanation for these phenomena.

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INTRODUCTION

Reef-like bodies of massive limestone, enclosed by bedded strata, have had a number of genetic interpretations. They have been explained by submarine erosion, crinoidal or bryozoan biohermal origin, and algal reef formation. Rock masses of this general kind are known from Precambrian through the Cenozoic section.

Limestone features of this general type, occuring in the Mississippian System of southwestern Missouri and northwestern Arkansas, were the objective of a detailed field and laboratory study, directed toward the location, description, and genesis of these phenomena. Conventional field methods were used, supplemented by a petrographic analysis of hand specimens and 167 thin sections. As a result, it is concluded that the Missouri-Arkansas "reefs" differ markedly from similar known geologic forms, and that they are a previously unrecognized fossil analogue of certain mud banks of the Recent environment.

Plant baffle entrapment is a mechanism producing reef-like banks in shallow protected marine waters. The phenomenon is closely like the fixation of sand dunes by terrestrial plants. Vegetable matter is not preserved, and the remainder of the associated biota cannot account for entrapment of the mud of the banks. This situation, in its objective elements, is duplicated precisely by the bioherms of the Missouri-Arkansas area. No other explanation can be supported, and plant baffle entrapment is accepted without reservation as the origin of these limestone masses.

PREVIOUS INVESTIGATIONS

Massive reef-like bodies of limestone in the Eureka Springs-Harrison Quadrangle area were first reported by Purdue and Miser (1916, p. 11) who, however, failed to recognize them as such. They reported an apparent "unconformity" within the St. Joe limestone member of the Boone formation on Davis Creek northwest of the community of Yardelle, Newton County, Arkansas. The section was described as two lithologic units: a lower sequence of limestones, thin and platey in places and massive in others; and an upper unit containing pinkish limestone beds. The "unconformity" was presumed to have been due to submarine erosion. Siebenthal (according to Purdue and Miser) had studied similar phenomena near the same stratigraphic position in the Wyandotte Quadrangle of northeastern Oklahoma and southwestern Missouri but interpreted them as having been caused by ocean current action such as produces sand bars. Purdue and Miser reported a similar "unconformity" near the base of the Boone formation on War Eagle Creek at the settlement of War Eagle in the eastern portion of the Eureka Springs Quadrangle, listing the stratigraphic section as described by Ulrich. Only sixteen feet of the St. Joe member are exposed there and the "unconformities" are found in beds overlying the St. Joe.

Croneis (1930, p. 47) stated that a number of apparent "unconformities" were found in the St. Joe limestone of Arkansas as exemplified by those occurring at Yardelle and War Eagle.

Cline (1934, p. 1141) discussed anomalous dips in the St. Joe at Noel, Missouri, and cited Purdue and Miser's account of similar features near Yardelle, Arkansas. He agreed with their conclusion that the structures are unconformities formed by submarine erosion.

Laudon (1939, pp. 325-327) discussed crinoidal bioherms in the St. Joe limestone of northeastern Oklahoma. He described the bioherms as lenticular, varying from a few feet to two miles in length, and up to eighty feet thick.

Clark (1941, pp. 96-100), in his account of the Mississippian stratigraphy of the Cassville Quadrangle, Barry County, Missouri, described massive features in his Compton member of the St. Joe formation. He described the structural and stratigraphic relations at some length, as well as the texture of the beds involved. Clark further discussed several possible explanations for these rock bodies such as structural deformation, bioherms with an organic framework, and off-shore bars and knolls due to wave action. He favored the latter hypothesis.

In 1950 Kaiser, in a paper on the stratigraphy of the Lower Mississippian of southwest Missouri, reported that "no crinoidal bioherms such as are developed in northeastern Oklahoma are found in the St. Joe limestone of southwestern Missouri".

Laudon again (1957, p. 965) discussed a crinoidal bioherm exposed on the west bank of the Illinois River near the "Eagles Nest" north of Talequah, Oklahoma.

Moore (1957, p. 123) said there are no " . . . structures of biohermal nature . . ." observed anywhere in the Mississippian formations of the Ozark region.

In 1957 Harbaugh reported on a number of bioherms in the St. Joe and Keokuk members of the Boone formation of northeastern Oklahoma. He concluded they were the result of growth and accumulation of crinoids in place.

To summarize: Very little work has been done on bioherms in northwestern Arkansas and southwestern Missouri. Conclusions drawn by previous workers vary so widely that a detailed investigation of these massive mounds of fine-grained limestone is required.

GEOGRAPHY OF THE AREA

LOCATION AND SIZE

The present study was confined to extreme southwestern Missouri and northwestern Arkansas (Bioherm Location Map, Plate I., p. 9). Counties involved are McDonald, Barry, Stone, and Taney in Missouri; Benton, Washington, Carroll, Madison, Newton, and Boone in Arkansas. Dimensions of the area are approximately 100 miles easterly from the Arkansas-Oklahoma border, and 30 miles north and south of the Missouri-Arkansas boundary.

Topographic maps used in the study were the Wyandotte, Noel, Rocky Comfort, Cassville, Shell Knob, Reeds Spring, Galena, Garber, and Branson sheets of Missouri and the Fayetteville, Eureka Springs, and Harrison of Arkansas (U. S. Geological Survey).

In addition, the Harrison and Tulsa 1/250,000 maps of the Army Map Service were utilized.

CULTURE

Several Federal Highways, including routes 62, 65, and 71 traverse the area, as well as numerous state highways and well-kept county roads.

The largest city is Fayetteville, Arkansas, with other large towns including Siloam Springs, Springdale, Rogers , Bentonville, Berryville, and Harrison, all in Arkansas. The larger towns in Missouri are Branson, Cassville, and Noel.

Cultivated areas are found mainly along stream and river bottoms in Missouri, although in Arkansas around Bentonville and Rodgers much of the upland is devoted to cultivation.

General farming and stock raising are the main sources of income.

The area is rapidly becoming a resort area owing to the construction of Bull Shoals, Taneycomo, and Table Rock lakes all on the White River. Beaver Dam, a future resort attraction, is now under construction near the town of Beaver in north Arkansas, again on the White River. Roaring River State Park near Cassville and the town of Noel both in Missouri have long been known as recreational areas.

PHYSIOGRAPHY

The region of the report lies in the southwest portion of the Ozark Plateau Physiographic Province. More specifically the western portion of the area is a part of the Springfield Plateau; the eastern portion is the extreme southwest margin of the Salem Plateau; and the southern tip is the northern edge of the Boston Mountains.

The history of the Ozark Plateau Province is marked by several periods of uplift. It was domed at some time during the latter part of the Paleozoic, remaining a land mass ever since (Fenneman, 1938).

Its structural form is that of an asymmetrical dome of Paleozoic sedimentary rocks with a Precambrian core. The beds are inclined more steeply on the east than west and dip off abruptly to the south.

The Springfield Plateau consists of a gently rolling surface which slopes to the west and is underlain by cherty limestones of Mississippian age. It is of significance, also, that the surface of the upland almost parallels contacts between the various lithologic units. The plateau has been dissected by streams in places exposing the section from lower Ordovician through middle Mississippian.

The Salem Plateau is set apart from the Springfield Plateau by the Eureka Springs Escarpment which separates regions underlain predominantly by Mississippian rocks (Springfield Plateau) from those underlain by Ordovician strata (Salem Plateau). The escarpment can be seen projecting across portions of Taney, Stone, and Barry Counties in Missouri. In Arkansas the counties of Benton, Carroll, and Boone contain the escarpment.

That portion of the Salem Plateau seen in the thesis area has been thoroughly dissected by the White River and its tributaries. The rocks exposed are mainly Ordovician dolomites.

The Boston Mountains constitute a dissected plateau capped by sandstone of Pennsylvanian age. Summit levels of the mountains slope toward the Arkansas Valley to the south and the beds dip in the same direction only at greater angles than the summit slopes. These mountains are found mainly in the southeastern part of Carroll County and the southwestern portion of Boone County in Arkansas. Outlying hills of the Boston Mountains, however, are found as far north as the southern portion of Barry County in Missouri.

TOPOGRAPHY AND DRAINAGE

The topography of the Springfield Plateau is that of a gently rolling upland containing many youthful streams on its upper reaches with predominantly mature streams developed on its southern margins. Elevations commonly run as high as 1400 to 1560 feet on the Cassville, 1200 to 1500 feet on the Rocky Comfort, and 1100 to 1300 feet on the Noel Quadrangles of Barry and McDonald Counties, Missouri.

Principal streams draining the Springfield Plateau include the Elk and Illinois Rivers and their tributaries which drain to the southwest and the White River and its tributaries which drain to the east.

The White River, an entrenched meandering stream, and its tributaries also drain the Salem Plateau. The depth of the White River Valley is up to about 600 feet. The topography of the plateau is dissected and in a mature stage of regional development.

Elevations of the summits of the Boston Mountains in the southern parts of the Eureka Springs and Harrison Quadrangles are commonly 2000 to 2250 feet. Stream valleys in this area lie in many instances 500 to 1200 feet below the summit levels.

GENERAL GEOLOGY

STRATIGRAPHY

Introductory Notes

The ensuing discussion considers the general stratigraphic features of the exposed Paleozoic rocks of southwestern Missouri and northwestern Arkansas, insofar as they are related to the St. Joe bioherm problem (see plate II., p. 12 for the general stratigraphic section). Only a summary discussion of the Ordovician and Devonian Systems is given.

Ordovician System

<u>General Statement</u>.

The Ordovician is widely exposed in southwest Missouri and northwest Arkansas forming the main surface of the Salem Plateau. To the west and south, in the Springfield Plateau area, it crops out as inliers along stream valleys where erosion has penetrated local stratigraphic highs.

<u>Jefferson City-Cotter Dolomite</u>.

The Jefferson City-Cotter dolomite as the term will be used herein will include both the Jefferson City dolomite below, and the Cotter dolomite above. Both of these units have been defined as separate formations.

The writer realizes that most of the uppermost dolomites exposed in his thesis area are actually Cotter beds and the purpose of the grouping of the two units herein is by no means intended as any sort of revision of the nomenclature, but merely to simplify the situation for sake of discussion.

According to information published by the Missouri Geological Survey, the Jefferson City-Cotter varies from about 400 feet thick in the northwest portion of the thesis area to 600 feet in the southwest corner of McDonald County, Missouri.

The predominant lithology of this unit is dolomite though thin beds of sandstone, shale, and oolite may be present. The total aggregate thickness of sandstone, shale, and oolite is minor. The strata are gray to buff, fine-grained, thin to thick bedded and argillaceous. "Cotton rock" type dolomite is present in many outcrops and chert nodules are often present scattered through the beds.

The Jefferson City-Cotter dolomite overlies the Roubidoux formation and is usually overlain directly by either the Sylamore sandstone, Chattanooga shale, or St. Joe limestone. However, in the southern part of the area other units of Ordovician age rest on the Jefferson City-Cotter.

Other Formations of Ordovician Age.

Other formations of Ordovician age are present in the southern part of the area in Arkansas.

A fine-grained, gray, shaly dolomite, the Powell dolomite, is exposed in Newton, Boone, Carrol and Benton Counties, Arkansas. It ranges from 0 to 200 feet thick and rests on the Jefferson City-Cotter.

The Everton formation consisting of alternating limestones, sandstone, and arenaceous dolomite, is widespread and

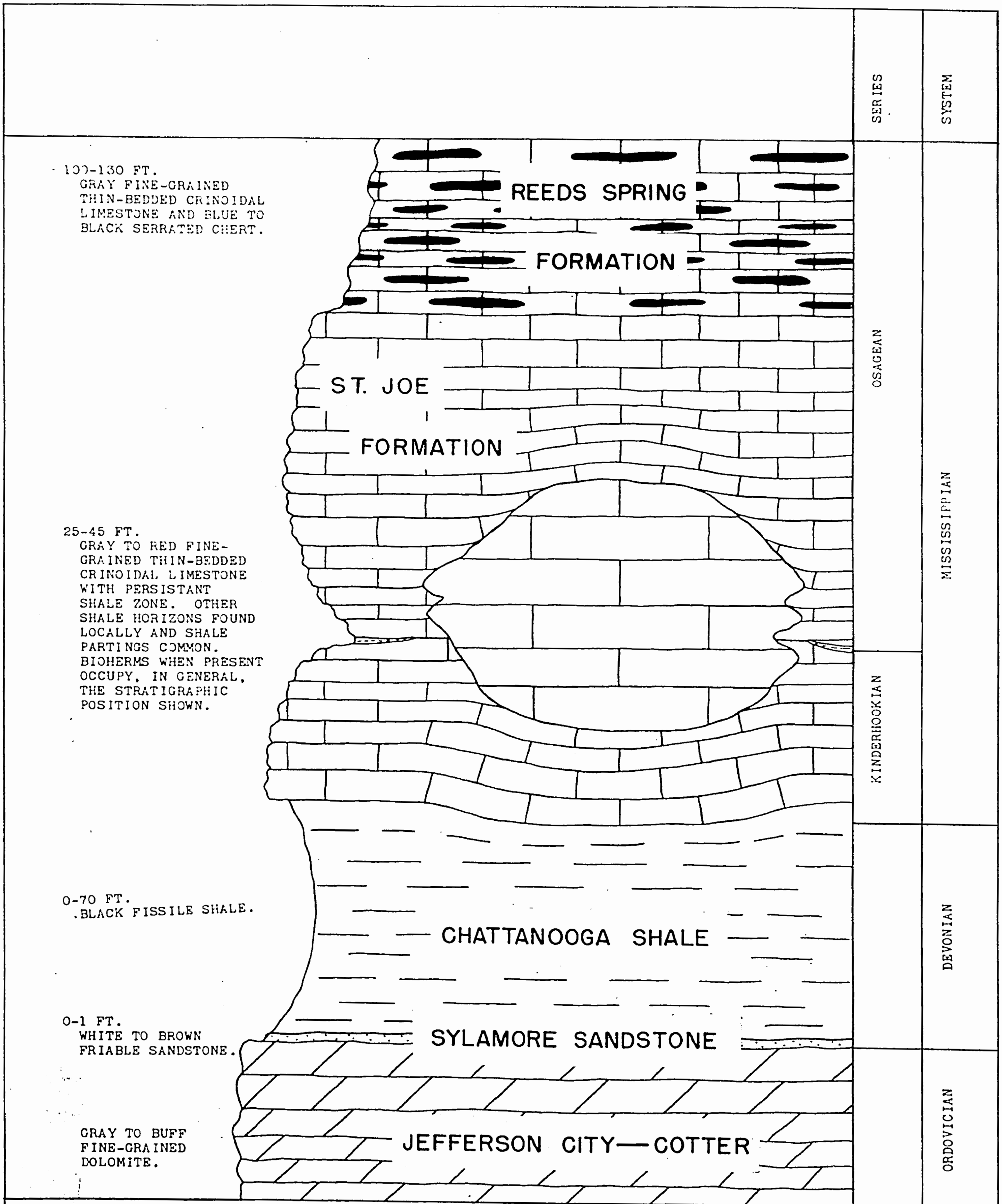


PLATE II. GENERALIZED STRATIGRAPHIC COLUMN highly variable in thickness averaging perhaps 100 feet. It commonly overlies the Powell dolomite.

The St. Peter sandstone, a well-sorted, well-rounded, medium-grained, massive white to buff unit, crops out in the eastern and southern portions of Newton County, Arkansas. It is up to 70 feet thick and overlies the Everton.

The Joachim dolomite is found only in the southern and eastern portions of Newton County, Arkansas. Lithologically it consists of gray dolomite and limestone which contain thin beds of sandstone. Overlying the St. Peter, it is up to 150 feet thick.

The reader is referred to Adams and Ulrich (1905), Purdue and Miser (1916), and Croneis (1930) for a more detailed description of the Ordovician strata.

Devonian System

General Statement.

Rocks of Devonian age underlie Mississippian sediments over most of the area. These rocks, together with the Ordovician, are important in that they formed the depositional surface upon which Mississippian strata were laid down.

Sylamore Sandstone.

The Sylamore is exposed throughout southwest Missouri and northwest Arkansas although it may be absent locally. Lack of the Sylamore is usually associated with stratigraphic highs and is due perhaps to the depositional topography or erosion subsequent to Sylamore deposition.

Thickness is highly variable; the Sylamore is 75 feet thick near Springdale, Arkansas, however, over most of the area it ranges from several inches to three feet.

It is largely composed of medium-grained translucent quartz grains which are rounded to well-rounded and display frosting, pitting and secondary crystal faceting. The sandstone is normally friable, containing small phosphate and limonite grains. Frequently quartz grains are stained with iron oxide. The Sylamore is commonly white to light brown or moderate brown. Bedding is usually massive and the upper surface appeared to be ripple-marked at several outcrops visited by the writer.

This sandstone rests unconformably upon different formations at different places. Mostly it lies upon the Jefferson City-Cotter dolomite or Powell dolomite. In the western part of the area the Sylamore is overlain by the Chattanooga shale but in the east where the Chattanooga is absent the Sylamore may be overlain by the St. Joe limestone or a green shale at the base of the St. Joe.

It is of interest that the Chattanooga shale normally overlies the sandstone without incorporating sand grains in it. Investigators have in the past used this as evidence for saying that the Chattanooga shale overlies the Sylamore conformably.

The age of the Sylamore is problematic, but it is considered upper Devonian by many workers.

Chattanooga Shale.

The Chattanooga shale of northwest Arkansas was called such by Adams and Ulrich (1905), when it was supposedly correlated with the Chattanooga shale of Tennessee. Earlier names for this unit were the "Eureka shale", a name which was preoccupied, and the "Noel shale". The controversy lies with the faunal equivalence of this black shale in the Ozark region and that of the Chattanooga shale outcropping in Tennessee.

This shale is present in southwest Missouri in McDonald County and part of Barry County, but is absent east of the eastern portion of the Shell Knob Quadrangle. In northern Arkansas the shale is present in Benton, Washington, Madison, and Carroll Counties.

It ranges from 0 to 70 feet in thickness and is thickest in Washington County, Arkansas, but thins to the east becoming absent in Madison and Carroll Counties. In southwest Missouri the shale increases in thickness from about 20 feet in Roaring River State Park to 38 feet at Pineville and 60 feet on the Arkansas-Missouri state line north of Sulphur Springs, Arkansas.

Lithologically, the Chattanooga consists of a carbonaceous black shale, which is fissile and commonly weathers to a gentle slope between St. Joe limestone ledges above and Ordovician dolomites below. Jointing is also prominent with most of the joints vertical. The shale is commonly black on outcrop, but when weathered it may be lead gray. Pyrite is common as disseminated nodules whose outer periphery has usually been altered to limonite.

At the top of the black shale a less fissile green shale is commonly developed. There has been controversy as to whether this shale represents an upper erosion zone of the Chattanooga, produced by subaerial exposure when the seas supposedly retreated after deposition of the black shales, or whether it is a basal shale member of the St. Joe formation. At one locality in central McDonald County, Missouri, the writer examined an outcrop containing at least three separate green shale zones several feet beneath the shale in question. These "tongues" may indicate a facies relationship between the St. Joe and upper Chattanooga, at least in certain localities.

The Chattanooga shale has been regarded as Upper Devonian in age (Hass, 1956). Maybe this is the case, but one should not overlook the possibility that perhaps the Chattanooga is in part Devonian and in part Mississippian with deposition being continuous from Late Devonian into Mississippian.

Mississippian System

General Statement.

Mississippian strata are exposed, for the most part, along the edge of the highly irregular Eureka Springs Escarpment and to the west and south forming the main surface of the Springfield Plateau. These rocks consist of limestones and cherty limestones, the basal beds which crop out along the escarpment and along stream valleys within the plateau where erosion has uncovered them.

The exact physical relationship between many of the lithogenetic entities is at best vaguely understood, thus formational nomenclature has been in the past, and still is, in a state of flux.

St. Joe Formation.

Nomenclatural History.-- The St. Joe limestone was first documented by Hopkins (1893, p. 253) who stated "The St. Joe marble is the name given by the State Geologist J. C. Branner to the prominent bed of red limestone which occurs widely distributed over nearly all the counties of Arkansas north of the Boston Mountains. It is so named for the village of St. Joe in Searcy County, Arkansas, where it was first studied by the Survey." The St. Joe was considered to be the basal unit of Boone chert by Hopkins (1893, p. 10).

Adams and Ulrich (1905, p. 3), Purdue and Miser (1916, pp. 9-11), Moore (1928, pp. 3, 160) and Croneis (1930, pp. 45, 46) all regarded the St. Joe as the lowermost limestone member of the Boone formation.

Cline (1934, p. 1134) stated that the term Boone is synonymous with Osagian of the upper Mississippi Valley and that Osagian should be used in place of Boone since it has priority. He further elevated the St. Joe limestone to formational rank and designated the rock units overlying the St. Joe, the Reeds Spring and Burlington.

McNight (1935) followed the pattern set by earlier workers in regarding the St. Joe as a member of the Boone formation.

Clark (1941) gave the St. Joe the rank of formation and recognized four members - the Compton, Northview, Pierson, and an upper unnamed unit. The Compton, Northview and Pierson are considered as separate formations in Green, Christian and Stone Counties and thus Clark's units resulted when he concluded that the St. Joe was a correlative of the three formations found in the above counties.

Branson (1944) abandoned the terms Boone and St. Joe in favor of the Chouteau group consisting of the Compton, Northview, Pierson, and Reeds Spring formations.

Kaiser (1950) theorized that the St. Joe and Pierson are synonyms and suggested that the term Pierson be dropped as a synonym for St. Joe for reasons of identical stratigraphic position, similar lithologic character, and identical fauna. He thought that his St. Joe overlies the Sedalia, Northview, Sylamore, Chattanooga, and in places, the Ordovician unconformably.

Beveridge and Clark (1952), following Clark (1941), designated the St. Joe as a group (in Barry County, Missouri) and recognized the following formations: the Compton, Northview and Pierson.

Differences in interpretation are obvious from the foregoing resume. Some of these were caused by different fundamental bases for delineating stratigraphic units. Lithostratigraphic and biostratigraphic units, however, must be recognized as separate distinct entities if uniformity in correlation is to be anticipated (Schenck and Muller, 1941).

Usage in this Thesis.-- Since the primary purpose of this investigation is to report a study on bioherms, formational nomenclature used herein will be that commonly applied to these rocks in the field. Most frequently the name St. Joe formation is applied to the thin-bedded crinoidal limestone unit overlying the Chattanooga shale, Sylamore sandstone, Jefferson City-Cotter dolomite or other stratigraphic units of Ordovician, Silurian, or Devonian age. Others might apply to the same limestone names mentioned in the above discussion but the author prefers the name St. Joe because: the name has been widely used previously in both Arkansas and Missouri; little is known of the exact physical relationship between these rocks and those in adjacent areas, and thus application of other names would be largely based on conjecture at this time. Should future detailed field studies warrant the application of different rock-stratigraphic terms, usage of the nomenclature proposed will allow for ready transposition of terms. The unit consisting of blue to black chert and crinoidal limestone overlying the St. Joe will be referred to as the Reeds Spring formation, again, as the name is commonly applied in the field.

Distribution.-- The St. Joe limestone is of wide areal extent, cropping out as occasional outliers within the Salem Plateau, along the Eureka Springs Escarpment, and along the courses of streams which dissect the Springfield Plateau. In southwest Missouri the outcrops on the Springfield Plateau are along the courses of streams having cut through local stratigraphic highs.

Thickness.-- The thickness of the St. Joe averages about 30 to 40 feet in southwest Missouri. In the northwest corner of McDonald County the St. Joe is 30 feet thick. It is 37 feet thick at Noel, 30 feet between Pineville and Cyclone in central McDonald County, 37 feet at Powell in eastern McDonald County near the McDonald-Barry County line, 35 feet at Cove, and 45 feet in Roaring River State Park southwest of Cassville.

Topography.-- The St. Joe limestone characteristically stands out as low, almost vertical bluffs along the walls of stream valleys. The bluffs are normally underlain by gentle slopes formed on the Chattanooga shale. Many times the St. Joe displays two sets of vertical joints at almost right angles to one another.

Jointing produces the vertical bluffs and a jagged pattern of bluff faces. In many places large "float blocks" of St. Joe, formed by undermining of the Chattanooga shale, may be seen below on the Chattanooga slope.

In the vicinity of Noel, McDonald County, Missouri, large overhanging St. Joe bluffs form a very attractive scene. In this same locality a small two inch shale bed commonly forms a pronounced re-entrant between lower and upper limestone bluffs.

Bioherms found in the St. Joe weather out as large rounded massive lenticular bodies of limestone, reminiscent of an igneous outcrop. They usually project out from limestone bluffs or appear as huge rounded massive boulders from which the enclosing sediments have been removed by erosion leaving these more resistant bodies behind.

The Reeds Spring normally does not form vertical faces but rather rounded gentler slopes covered with chert fragments.

Lithic Character.-- The St. Joe formation consists primarily of thin-bedded crinoidal limestones, scattered thin shales and shale partings.

West of Roaring River State Park in western Barry County and throughout McDonald County in Missouri, as well as in western Benton County in Arkansas, the St. Joe generally consists of three and perhaps four distinct lithologic units. These are a basal green shale which is questionable as to whether it belongs to the Chattanooga or St. Joe, a gray limestone unit, a thin green calcareous shale, and an upper section of gray limestone.

East of a line running from Roaring River Park through Rogers, Arkansas, the St. Joe differs from the above description by containing red limestone. The general sequence is a lower gray limestone with overlying beds of alternating red and gray limestones. In certain localities thin gray, green, and red shales may be present.

The limestones of this formation are crinoidal with crinoid fragments usually of medium to coarse sand-size. Microspar is the main matrix component. The beds are commonly two inches to one foot thick with wavy bedding planes.

Shale is present as partings within the limestone strata and as thin beds. The presence of this constituent indicates a quiet depositional environment.

Chert is not entirely absent from the St. Joe though it is not abundant. The common occurrence is as scattered brown, tan, red or blue nodules. The most frequent type is the brown variety which may be present locally at the Reeds Spring contact.

Bioherms occuring in the St. Joe in southwest Missouri and northwest Arkansas appear typically as massive lenses of microspar flanked and enclosed by thin-bedded crinoidal limestones. In almost all instances development began in the lower gray crinoidal limestone unit and continued into the overlying limestone strata.

Stratigraphic Relations.-- The St. Joe formation as previously stated rests on either the Chattanooga shale, Sylamore sandstone, Jefferson City-Cotter or other units of Ordovician age. It is found below thin-bedded crinoidal limestone and blue to black cherts of the Reeds Spring formation. When resting on the Jefferson City-Cotter or Sylamore sandstone there is, without question, an unconformity between the units, but when resting upon the Chattanooga the presence or absence of an unconformity is uncertain. Relations between the St. Joe and Reeds Spring are also a matter of question; however, it appears that at least in certain localities the St. Joe-Reeds Spring relations are conformable and transitional.

Age and Correlation.-- The age of the St. Joe is at present a matter of question. Beveridge and Clark (1952) regarded the lower part of the St. Joe Kinderhookian, and the upper portion Osagian. A. C. Spreng of the School of Mines is, at present, engaged in a study of fossils collected from the St. Joe, but this investigation has not as yet been completed for more collection and study are needed.

Reeds Spring Formation.

Above the limestones of the St. Joe formation lie the crinoidal limestone and blue to black cherts of the Reeds Spring formation.

The limestones are characteristically light to medium gray containing crinoid fragments disposed in a matrix of microspar and subordinate shale occurring mainly as partings.

Blue to black chert is present throughout the formation. It typically occurs both as beds which alternate with limestone and as scattered nodules. The difference in color between the chert and limestone produces a mottled appearance on bluffs of Reeds Spring which set it apart from the St. Joe.

According to Harbaugh (1957) the Reeds Spring varies from 75 to 150 feet in thickness in northeast Oklahoma. Branson (1944) lists a section 131 feet thick in Barry County, Missouri.

STRUCTURE

The structure of the Ozark Region is relatively simple. The general setup is a large asymmetric dome whose structural center is the St. Francois Mountains of southeastern Missouri. These mountains consist of a nucleus of Precambrian igneous rocks from which early Paleozoic strata dip radially away, hence successively younger rocks are encountered in all directions away from the mountains. Dips are greater on the east and south than on the west and north. Over much of the dome surface in south central Missouri, as well as in the southwest part of the state, inclination of the strata is very slight, commonly less than one degree and in places the beds are actually horizontal. However, the regional dip in the thesis area is to the south or southwest at angles on the order of one to two degrees. In the Boston Mountains the dip increases to values on the order of five degrees as the strata begin to plunge beneath the Arkansas Valley to the south.

In both the Salem Plateau and the Springfield Plateau the regional dip is frequently altered by local folds and minor faulting. Some of the larger folds and faults can be noted on the geologic maps of Missouri (1939) and Arkansas (1929). Most of the folds seen in McDonald County, Missouri, can be accounted for by dips of only one to one-one half degrees.

Data for some of the structural discussion described in the chapter on bioherms (see p. 53) was obtained from Searight, Thiel and Wells (1959).

INTERBIOHERMAL LITHOLOGY

GENERAL NOTES

In order to compare the lithologies of the St. Joe limestone proper and its biohermal facies, six complete, representative sections of the St. Joe were measured in McDonald and Barry Counties, Missouri. Thin sections were analyzed from three of the measured sections; photomicrographs of some of the slides are reproduced in Plate VI., p. 52. A field description of each section will be presented, then a summary of the petrography of that section will be discussed, followed by a field description and petrographic summary of the next section.

SECTION NORTHWEST OF NOEL, MCDONALD COUNTY, MISSOURI

Location

The section is located on the Elk River northwest of Noel, Missouri, 0.8 mile west of U. S. Highway 71 on a county road passing along the north edge of the Elk River floodplain. Specifically, the location is at the point where the road and the river come together; S. 1/2, SW 1/4, SW 1/4, SW 1/4, Sec. 10, T. 21 N., R. 33 W.; bluff trending west-northwest by south-southwest; north side of road.

Description

	Thickness Feet	Thickness Inches
Reeds Spring formation		
8. Limestone: Light gray to medium light gray; very fine grained and hard; beds three to eighteen		

inches thick and containing serrated lenses and nodules of light gray, blue, and tan chert; beds fracture unevenly and are a darker gray than the underlying St. Joe; weathers to resistant bluff above the St. Joe limestone. not measured

St. Joe limestone

7. Limestone: Light gray to medium light gray when fresh, weathers yellowish gray; coarsely to very crystalline with finely crystalline matrix; crinoid plates and columnals up to 5 mm. in length, very abundant and much larger in size than those in underlying unit; large brachiopod shells present occasionally; fossil fragments angular and unabraded; tan shale partings and tan to light brown nodular chert in upper four feet; beds up to 1 foot thick with undulatory bedding planes; weathers to slight re-entrant between the underlying limestone unit and the overlying Reeds Spring. 6 4

6. Limestone: Light gray to medium light gray on fresh surface, weathers yellowish gray to dusky yellow and brownish gray. Lower part - medium to coarsely crystalline calcite grains with finely crystalline calcite matrix; crinoid fragments abundant and medium-sand sized imparting the crystalline appearance to the rock; small widely disseminated subhedral pyrite grains up to 1 mm. in diameter; small thinly laminated partings of dusky yellow shale are scattered through the rock; pyrolusite dendrites present in places; stylolitic. Upper part - medium crystalline with finely crystalline matrix; crinoid fragments

	abundant, especially noticeable on weathered surfaces; stylolitic; shale partings less prominent than in lower portion. This entire unit weathers to an overhanging bluff, with the lower part less resistant; beds three inches to one foot thick with undulating bedding planes; underlain by thin calcareous shale.	19	6
5.	Calcareous shale: Greenish gray on fresh surface; weathers yellowish gray to dusky yellow; shale thinly laminated with distinct salt and pepper appearance under hand lens due to presence of abundant highly disseminated pyrite of silt to fine sand size; large euhedral medium sand sized pyrite grains are scattered; breaks into small one-inch pieces; small crinoid fragments up to 0.5 mm. in length are scattered through the shale; unit weathers to prominent re-entrant between overlying and underlying limestone bluffs.	0	3
4.	Shaley limestone: Limestone light gray to medium light gray and olive gray when fresh, weathers dusky yellow; shale pale olive to yellowish gray and grayish yellow green; limestone finely crystalline with scattered medium crystalline calcite; shale present as scattered paper thin partings and laminae; rock splits along shale partings; limestone beds crinoidal and one inch to six inches thick with laterally discontinuous shale beds up to one and one-half inches thick; weathers to slight re-entrant above unit 3.	3	3
3.	Limestone: Light gray to light brownish gray and light olive gray on fresh surface, weathers grayish yellow and medium light gray; beds four inches to one		

foot thick; coarsely crystalline calcite with finely crystalline matrix; crinoid fragments abundant, especially on weathered surfaces; shale, green gray, present as stringers and partings, prominent in basal one foot of unit, decreasing in amounts at center of unit, then increasing and becoming yellowish brown in upper part; underlain by green shale bed.	8	0
St. Joe (?)		
2. Shale: Green and greenish gray; not as fissile as underlying black shale.		
Chattanooga shale		
1. Shale: Black, fissile; breaks into hard thin plates; base not exposed.	14	6

Petrography

Introductory Notes.

Petrographic study of thin sections of the Noel section reveals that the limestones consist predominantly of crinoid and bryozoan fragments, comprising about 60 per cent of the rock cemented by a matrix of microspar. Up to 15 per cent clay was noted in thin sections near the base of unit 3 and within unit 4. The matrix varies in grain size from approximately three to some 40 microns, averaging somewhere in the neighborhood of 10 to 15 microns.

Rock names have posed a problem for the writer. In an attempt to apply some type of descriptive name to these rocks many different classification schemes were investigated. Common terms such as crinoidal calcarenite, crinoidal limestone, fossiliferous fragmental limestone, and semi-crinoidal limestones have been applied to carbonates such as these in the past. However, there is a serious objection to such terms. Although these conventional terms tell us what the larger sized fraction of the rock is, they do not convey any idea as to the composition of the matrix. The best descriptive terms that the writer has found are those proposed by Folk (1959). Under this classification the above rocks would be called crinoidal bryozoan biomicrosparites or microsparry crinoidal bryozoan calcarenites; the two terms meaning the same thing, the difference being that the former term is an abbreviated manner for describing the latter. This descriptive classification indicates both the matrix and grain components and all limestones studied in this thesis are classified according to this scheme.

In connection with the usage of the above classification, three types of calcite used in the classification will have to be clarified. The first is microcrystalline calcite ooze, of which Folk says, "This type of calcite forms grains 1 - 4 microns in diameter, generally subtranslucent with a faint brownish cast in thin section." He refers to sparry calcite which he maintains averages 20 to 100 microns in diameter and is clear and translucent, i.e., not turbid. Another type discussed is that whose grain size falls between the lower limit of spar and the upper limit of microcrystalline ooze. This material ranges from five to perhaps 15 microns instead of one to four and is considered to result from recrystallization of microcrystalline ooze. Since much of the matrix of the limestones under consideration herein is of five to 15 microns in size, the term microspar is used.

Petrography of Units 3 and 4.

Limestones below the calcareous shale are microsparry crinoidal bryozoan calcarenites. They consist of crinoid fragments and bryozoan debris disposed in a matrix of microspar usually containing clay, especially near the base of unit 3. Clay content increases near the top of the unit and is present throughout unit 4. The elongate, cylindrical, or tabular crinoid debris tends to lie with its long axis parallel to the planes of stratification although many times this is not the case. Crinoidal parts make up 30 to 60 per cent of the rock and consist of disassociated components of the stem, calyx and arms. Stem elements (columnals) and plates (brachial and calyx) are scattered through these rocks. These parts are readily identified from their characteristic shapes, fine pored reticulate structure, and the fact that skeletal remains are single calcite crystals.

Crinoid plates and columnals are scattered rather uniformly through the limestone. They may be arranged in a manner in which their longest dimension is oriented either parallel to the depositional surface or at some angle to it. Many fragments in such a position appear to "stand on their ends", hence indicating that they either fell into the mud in such a fashion or were laid down horizontally and subsequently disrupted by currents, slumping, or scavengers which reworked the sediment. Crinoid remains are highly variable in size, up to 2 mm. in length, with an average in the neighborhood of 0.75 to 1.0 mm. The fragments, where not altered by interstratal solutioning, are highly angular, unabraded, and have not been sorted. Preservation is generally poor, i.e., the reticulate or honeycombed structure is in a deteriorated condition, and in many places sparry calcite crystals up to 30 microns in diameter have developed within the fragments due to recrystallization. Crinoid debris is transected in many places by grains of the matrix up to 30 and 40 microns in diameter. The peripheries of the fragments are often corroded and interpenetrated by matrix grains. Perhaps lack of smooth fragment boundaries indicate recrystallization, wherein grains of the matrix have grown in size and penetrated edges of the fossils.

Frequently crinoidal remains appear crumbly, as if they would readily disintegrate into numerous pieces if separated from the rock and a number of them display twinning.

Where one crinoid fragment is in contact with another there may be a mutual interpenetration of the two. Differential pressure and solution have removed portions of both fragments developing a tooth-like irregular seam between them. Thus, fragment and probably total rock volume have been reduced by this process.

Bryozoans comprise five to 25 per cent of the rock. They contain tubular and sacklike chambers and do not develop radiating partitions or transverse walls as do the corals, for example. Wall structure appears as a dense laminated network of fine threads that lie parallel to the wall surfaces. Most of the colonies present appear to be the encrusting types such as the fenestrates, the most abundant form in these rocks. Another type of bryozoan not numerous but noted in many thin sections are rhomboporids. The colonies are highly clastic with sharp, projecting, and unabraded edges. Longer dimensions of the fragments display an affinity for a position roughly parallel to the bedding surface. In some thin sections or parts thereof, bryozoans appear both stratified and disrupted. Average length of the detritus is difficult to determine due to pronounced variability, but the common range is from 0.35 to 1.5 mm. Individual autopores may be filled with sparry calcite or microspar, which generally has a size range from 20 to 30 microns. Wall structure preservation varies from fragment to fragment with some altered more than others. Altered parts appear less fibrous, and many times small anhedral, equidimensional grains of sparry calcite are present within the wall. Contacts between bryozoan debris and surrounding matrix are usually sharper than in the case with crinoid segments, hence corrosion has not attacked bryozoan remains as much as crinoid parts. This, of course, could possibly indicate that wall structure of bryozoan fragments is more resistant to the action of intrastratal solutioning and differential pressure than are crinoid plates and ossicles.

Brachiopod, mollusk, and ostracod shells constitute up to 10 per cent of the rock. The bivalves are present both as articulated, and disarticulated specimens. Normally they appear as disarticulated and broken shell debris. Brachiopod detritus often displays a fibrous wall structure which is poorly preserved. These fragments are normally 0.3 to 0.5 mm. in length, thin, and unabraded.

Several thin sections contain small tubular organisms with a distinct bulb on one end. They appear very dark under uncrossed nicols, are approximately 20 microns in diameter and up to 0.4 mm. in length. Walls consist of discrete granular calcite up to three microns in diameter, with sparry calcite filling the tubes. The tubular organisms have a superficial similarity to the alga Girvanella, but Girvanella typically appears as twisted tubes without a bulbous end. Because the "tests" appear to be constructed of detrital grains, possess a bulbous end, lack any twisting of the "test", and have suitable diameters and lengths, these organisms have been tentatively identified as the foraminifera Hyperammina and Hyperamminoides of authors.

Rock matrix is highly variable in grain size. The grains usually range from around five microns up to perhaps 30 microns with the average around seven to 15. Very noticeable is the fact that normally the large and small grains appear mixed uniformly together, but localized portions of the rocks may be very uniform in size. These localized spots may be coarser than average, perhaps 20 microns or so, or they may be distinctly smaller, averaging less than 10 microns. The grains are usually equidimensional and anhedral with highly irregular borders, and are tightly interlocked with pore space absent. Grain boundaries normally are distinct under a magnification of 75x. This matrix is generally turbid and subtranslucent with a faint brownish tint. In many instances fossil fragment and matrix grain boundaries are not sharp, rather there is an interpenetration of matrix grains into the organic detritus and vice versa. The exact boundary between fossil and matrix is irregular and gradational, often vaguely perceptable.

It is also significant that recrystallized portions of crinoid plates and ossicles are similar in size, shape, and general appearance to matrix grains. This similarity may afford valuable evidence for recrystallization of the rock matrix.

Near the base of unit 3, and within unit 4, thin laminae of argillaceous material accentuate the bedding of the rock. Locally clay may comprise as much as 10 to 15 per cent of the limestone. It is dark brown (uncrossed nicols). Close examination reveals that solution has progressed along the clay laminae corroding and partially dissolving crinoidal remains. Perhaps many of these laminae are original clay layers laid down with the sediment and are in place, but others may have resulted from redistribution by solutions. Insoluble residues were prepared from a number of the samples and examined with a petrographic microscope. The predominating clay mineral present, as determined by optical means, was illite.

Very infrequently crinoid fragments have a clear sparry fringe. In places this appears to be the result of addition of calcite to the fragment by grain growth, but in other instances the rims may have resulted from a recrystallization of the fragment itself because the spar exactly dilineates the original outline of the fragment.

Small euhedral reddish brown fringed white dolomite crystals are present in local areas within the rock. These may be abundant enough locally to constitute five per cent of the limestone, and are usually up to 30 microns in size and are seen to lie within fossil fragments, within the rock matrix, or projecting from matrix into the preserved animal remains.

Traces of anhedral pyrite and limonite are present in scattered places. In some instances these minerals replace parts of fossils, and in others they form isolated particles within the calcite matrix.

Examination of the sections shows that elongated fossil fragments are oriented, in general, with the long axis parallel or subparallel to the bedding surface. However, in many cases much of the debris is inclined obliquely, or stands in a vertical position with respect to bedding planes.

Petrography of Units 6 and 7.

Limestones above the green calcareous shale are also microsparry crinoidal bryozoan calcarenites, that is, they consist of crinoid and bryozoan fragments with a microspar matrix. Clay, present at the base of unit 6, gradually decreases in amount upward and is practically non-existent in the upper beds. Patchy mosaics of clear sparry calcite are present in the upper half of unit 6.

Crinoid plates and columnals are up to 3 mm. in length, averaging 0.75 to 1.0 mm. The fragments are sharp, angular, and have not been segregated according to size. Presence of sharp angular fragments, which are not sorted or rounded, indicate the lack of persistent current action. Most of this material displays evidence of corrosion and recrystallization. Recrystallized grains are similar in size, shape, and appearance to those of the rock matrix. Contacts between crinoid fragments and rock matrix, between crinoid fragments themselves, and crinoid and bryozoan fragments may be unaltered or microstylolitic. In places the fragments display cleavage fractures, and limonite has replaced parts of them, although on a very minor scale.

Bryozoans are numerous, occupying 20 to 25 per cent of the limestone. Size is variable, up to 5 mm., with 0.5 to 1 mm. most common. The zoaria are broken, unabraded, and are mainly fenestrate forms. Fragments usually display slightly corroded edges and in a few instances portions of them contain a few grains of spar developed by recrystallization of wall structure.

Brachiopod, mollusk, and ostracod shells are usually broken, angular, and up to 2 mm. in length. They comprise, at most, five per cent of the rock. The shells are very thin and give the impression that if conditions of wave and current action had been severe and persistant the delicate fragments would have been destroyed. A few scattered, articulated brachiopods, up to 0.7 mm. in length are occasionally seen.

The matrix of the rock consists of brown microspar which is anhedral, equidimensional, and of highly variable grain size. Microspar is normally six to 15 microns in diameter, with grains of 30 and 40 microns numerous. Commonly, grains are hard to distinguish, especially when of smaller sizes. Scattered patches containing darker brown and more turbid microspar of smaller size are present. Matrix grains may project into fossil fragments or fossil peripheries may be smooth, thus not corroded by solution and recrystallization.

White sparry calcite commonly fills voids within fossils and is seen in small mosaics between fossil fragments. Where in contact with crinoid fragments calcite tends to underlie the fragment and is in optical continuity with it.

Occasionally spar is seen transecting, surrounding, and obliterating portions of fossils.

Small traces of limonite can be observed within fossil fragments where it has replaced parts of them. This material is normally anhedral and patchy in appearance.

Elongated organic fragments tend to lie in positions either parallel to the bedding surface or in variously inclined positions. In instances the debris will be parallel, but in others it varies so much in orientation that the bedding surface would be extremely difficult to ascertain by thin section examination alone.

SECTION AT POWELL, MCDONALD COUNTY, MISSOURI

Location

This section is a composite from Bee Bluff 0.8 mile northwest of Powell, Sec. 16, T. 22 N., R. 30 W.; and along a bluff on the east side of the road in Bentonville Hollow, one mile south of Powell, W. 1/2, SW 1/4, Sec. 21, T. 22 N., R. 30 W.

Description

	Thickness Feet	Thickness Inches
Reeds Spring limestone		
8. Limestone: Light gray to medium light gray containing nodules and lenses of gray and blue chert.	not measured	
St. Joe limestone		
7. Limestone: Yellowish gray to grayish olive when fresh, weathers dusky yellow; coarsely crystalline with finely crystalline matrix;		

crinoid fragments abundant; thinly laminated pale olive shale partings common, especially at base of unit; beds two inches to one foot thick with crenulated bedding surfaces; stylolitic; pyrolusite dendrites occasionally present; weathers to overhanging bluff above unit 6.	27	11
6. Calcareous shale: Greenish gray when fresh, weathers yellowish gray; thinly laminated; weathers to pronounced re-entrant between resistant bluffs of crinoidal limestone.	0	2
5. Limestone: Yellowish gray to pale olive when fresh, weathers yellowish gray and dusky yellow; coarsely crystalline with finely crystalline matrix; crinoid fragments common; papery partings of pale olive green shale present in places; disseminated pyrite up to 2 mm. in diameter and partially altered to limonite; rock tends to break along shale partings; beds three to four inches thick with crenulated bedding surfaces; weathers to resistant projecting bluff above black Chattanooga shale.	9	1
St. Joe (?)		
4. Shale: Green; not as fissile as underlying unit.	0	2
Chattanooga shale		
3. Shale: Jet black when fresh; highly fissile breaking into tough platy chips; weathers to gentle slope below the St. Joe limestone.	45	0
Sylamore sandstone		
2. Sandstone: Fine to medium grained; white to light gray and light brown; friable to		

hard; overlies dolomite. 0 6

Jefferson City-Cotter dolomite

1. Dolomite not measured

Petrography

Limestones from the Powell section are microsparry crinoidal bryozoan calcarenites. Fossil detritus constitutes 50 to 70 per cent of the limestone, microspar 20 to 40 per cent, spar 5 to 10 per cent, shale up to 5 per cent, and dolomite is present in scattered places in amounts up to 10 per cent.

Crinoid fragments usually range from 0.4 to 1 mm. in length averaging perhaps 0.5 mm.; however, much more finely divided debris is also present. Plates and ossicles are distributed throughout the entire section comprising 20 to 40 per cent of these carbonates. Elongated or tabular detritus is not aligned parallel to the bedding surfaces, but is disposed at various angles to them. Crinoid parts are broken, highly angular, and unabraded, even where not corroded. The preponderance of the fragments shows signs of recrystallization and peripheries are serrated in appearance. Matrix grains can be observed projecting into the edges of the debris and not infrequently matrix-fragment boundaries appear gradational due to partial obliteration of the plates and ossicles, and inter-penetration of fossils and matrix. A common feature is bored crinoid parts, the cavities being filled with 6 to 9 micron microspar. Reticulate structure is practically absent in a few fragments; cleavage fractures as well as polysynthetic twinning may be developed on some of the remains. A few widely scattered parts appear to have suffered little, if any, alteration for they have smooth uncorroded edges.

Bryozoans, mostly fenestrates, average 1 mm. in length although many smaller bits are also seen. These organisms constitute from 15 to 40 per cent of the rock, with highly broken and angular zoaria. Commonly, only several autopores, at most, accompany a fragment. Preservation in places is good, in others poor. Fibrous calcite wall structure may be partially obliterated owing to recrystallization, wherein 3 to 6 micron microspar has developed which is similar in texture to the rock matrix. Fragment edges may appear corroded due to pressure and/or solution. Orientation is much more random and unsystematic than with crinoid parts, for bryozoan parts may lie at any angle to the bedding surface.

Broken bits of delicate thin-shelled ostracods and brachiopods, with a few articulated specimens and complete single valves, comprise up to 5 per cent of the rock. Orientation of elongated fragments is random and shell wall structure has normally suffered some recrystallization. Length of the valves and valve fragments ranges up to perhaps 1 mm.

Remains of Hyperammina and Hypermminoides are seen constituting up to 2 per cent of the limestones. They are dark, composed of discrete calcite grains, are up to 0.25 mm.

in length and 0.04 mm. in diameter. Orientation is random and the "tests" are straight tubes with a bulbous end.

Microspar matrix is brown and turbid with grain size ranging from 3 to 30 microns. Most particles, however, are less than 10 microns and are seen in amounts ranging from 20 to 40 per cent of the total rock. The grains are anhedral, equidimensional, and have irregular peripheries. Local isolated, more turbid spots within the matrix or within cavities in fossil remains are 1 to 6 microns in size with grains having shapes as described above. Some of the larger matrix particles are without question fossil fragments. Some clay is present which usually occurs as small thin laminae. It is abundant at the base of unit 5, at the top of unit 6, and in the base of unit 7.

Sparry calcite proper is seen in amounts up to 10 per cent of unit 7. It appears as white equidimensional anhedral crystals 40 to 80 microns in diameter and is present both as veins which cut vertically through the rocks transecting fossils, or as patchy mosaics. Where spar underlies fossil debris directly, it could possibly be due to void fillings, but where vein-like it may owe its origin to either filling along burrows, recrystallization or fracture filling.

Euhedral dolomite crystals, 40 to 75 microns in grain diameter, are present as traces, but locally comprise up to 10 per cent of the limestone in unit 7. Dolomite rhombs may be seen within the matrix, within bryozoan autopores, or within crinoid fragments where they have replaced part of the fossil. Normally they have a reddish brown crystal border. The crystals occur most frequently in rocks which have been altered, as they are usually seen along zones where solution has been most active.

Stylolites are rare but when present roughly parallel bedding surfaces. Crinoid fragments which have been intersected by stylolites appear microstylolitic and dark brown insouble clay material is ordinarily present along these structures.

SECTION IN ROARING RIVER STATE PARK,
BARRY COUNTY, MISSOURI

Location

The section is located on Missouri Highway 112 along the line between NE 1/4 and NW 1/4 of NE 1/4, Sec. 34, T. 22 N., R. 27 W.; on the right side of the road proceeding south in Roaring River State Park; 6 miles southeast of Cassville, Barry County, Missouri.

Description

	Thickness Feet	Inches
Reeds Spring		
13. Limestone: Light to medium gray when fresh, containing nodules and interbeds of gray to blue chert; limestone, finely crystalline matrix with grains of coarsely crystalline calcite; crinoidal.	not measured	
Reeds Spring (?)		
12. Limestone: Contains scattered nodules of chert and thin fissile shales; finely crystalline limestone which is yellowish gray to		

pale olive and light gray with beds three inches to one foot thick; chert is gray and blue to black with tan to red-brown fringes, nodular, and found mainly in thicker limestone beds; shale is grayish yellow green and finely laminated. 17 0

St. Joe

11. Limestone: Yellowish gray to pale olive; finely to coarsely crystalline in beds two inches to one-one half thick with greenish yellow gray shale partings; coarsely crystalline in appearance due to abundance of crinoid fragments; thin papery light olive gray shale laminae and partings; pyrolusite dendrites common; pyrite present, many times altered to limonite; overlain by limestone containing nodules of blue chert. 9 6

10. Shale: Alternating grayish yellow green and grayish red; fissile; crinoid fragments present occasionally; weathers to re-entrant between limestone ledges. 2 0

9. Limestone: Alternating beds yellowish gray to light olive gray and grayish red when fresh, weathers dusky yellow and reddish brown; finely crystalline matrix, coarsely crystalline grains; coarse crystalline appearance due to presence of crinoid fragments; thinly laminated papery grayish red and greenish gray shale partings; pyrolusite dendrites conspicuous; beds three inches to two feet thick with red beds dominant; overlain by shale unit. 11 0

8. Limestone: Alternating yellowish gray to light gray and

	grayish red; finely crystalline sprinkled with coarsely crystalline grains; crinoidal; thinly laminated grayish red shale partings in red beds; pyrolusite dendrites present occasionally; overlain by a darker red and gray limestone.	11	0
7.	Shaley limestone: Grayish red and yellowish gray; very fine-grained; thinly laminated to laminated; overlain by alternating beds of red and gray limestone.	1	6
6.	Calcareous shale: Yellowish gray and grayish red; thinly laminated; crinoidal; weathers to thin plates; overlain by shaley limestones.	0	3
5.	Shaley limestone: Yellowish gray to pale olive and dusky yellow limestone with pale olive papery shale partings; limestone finely crystalline with scattered coarse sand sized crinoid fragments; overlain by calcareous shale.	2	6
4.	Limestone: Light gray to yellowish gray and light olive gray when fresh, weathers dusky yellow; medium to coarsely crystalline with finely crystalline matrix; crinoid fragments abundant; thin papery dusky yellow shale partings common; pyrolusite dendrites; beds three to 18 inches thick.	11	0
Chattanooga shale			
3.	Black shale: Jet black except for upper inch or so which is green; highly fissile, breaking into thin plates; causes pronounced bench on side of hill.	22	0

Sylamore sandstone

2.	Sandstone: White to moderate brown; fine to medium grained with secondary overgrowths on many grains; rounded to well-rounded; indurated.	0	6

Jefferson City-Cotter

1.	Dolomite	not measured

Petrography

Petrography of Units 4 and 5.

Limestones found in this unit are microsparry and sparry crinoidal bryozoan calcarenites.

Crinoid fragments range in amounts from 40 to 75 per cent of the rock with plates and columnals of variable sizes distributed evenly through the beds. There is a definite tendency for the elongated fragments to lie in a position either parallel to, or at a slight angle to, bedding surfaces; however, not infrequently fragments with a vertical orientation are seen. Size is variable from around 0.05 mm. to 4 mm. with an average of perhaps 0.5 to 1.0 mm. This debris is broken, angular, unabraded and lacks sorting. Preservation is usually poor with many fragments displaying highly irregular corroded edges, and when two parts lie in contact microstylolites have developed. Reticulate structure has often ~~times~~ been destroyed by recrystallization. In places detached crinoid parts have recrystallized to microspar and/or sparry calcite. Some pieces have been perforated by boring organisms, and the resulting cavities are not straight, but rather are sinuous. These were later filled with calcite mud and spar, and when both are present geopetal structure is usually displayed. Sparry calcite is present as rim cement on a few plates and columnals.

Bryozoans, mostly fenestrates, comprise from 10 to 40 per cent of the limestones. They are highly variable in size, up to 2 mm. in length, are broken, and have not been abraded. Peripheries are often corroded, irregular and lack preferred orientation. In places the fragments have been crushed between overlying and underlying crinoid plates or ossicles. Fibrous wall structure is well preserved in some fragments, but in others has been obliterated by recrystallization.

Disarticulated and broken bits of thin, and often recrystallized, brachiopod shells are strewn randomly through the strata and a trace of <u>Hyperammina</u> and <u>Hypermminoides</u> is present in a few slides.

Spar and microspar are the most abundant matrix components. They are often transitional one into the other; however, microspar is dominant in amounts ranging from 10 to 40 per cent of the rock. Spar, on the other hand, ranges from 2 to 20 per cent.

Microspar grains are turbid and brown, 3 to 15 microns in diameter, anhedral, equidimensional, and irregularly shaped. In some instances where microspar surrounds corroded and poorly preserved crinoid parts the boundaries between the fossils and matrix are hard to delineate.

Clear spar, up to 200 microns in diameter, stands out in marked contrast to the more turbid and smaller grains. It is found as a rim cement on crinoid remains, filling in between fossil fragments, in recrystallized patches in fossils, or as pore fillings in fossils.

Brown clay is present as thin laminations throughout unit 5.

Petrography of Units 8, 9, and 11.

Limestones of these units are also mainly microsparry crinoidal bryozoan calcarenites, but sparry crinoidal bryozoan calcarenites occur not infrequently.

Crinoid fragments occupy 30 to 50 per cent of the rock and appear corroded, unabraded, partially recrystallized, and are of the same size as the fragments in units 4 and 5, but differ in that microstylolites in these upper limestones are much more numerous and pronounced. Red clay and red iron oxide are concentrated along the stylolite seams, and red iron oxide is found in the pores of crinoid fragments imparting a red color to them. Fragments which have undergone severe recrystallization may have small spots of red iron oxide occurring as patches in the recrystallized areas.

Bryozoans comprise 10 to 30 per cent of these calcarenites and are very similar to the bryozoans in units 4 and 5 in type, size, shape, orientation, color and state of preservation as well as fragmented condition.

Broken bits of brachiopod and ostracod shells are seen in most of the thin sections in amounts up to perhaps

5 per cent of the rock. Preservation is usually poor.

Only a trace of the foraminifera Hyperammina and Hyperamminoides are seen as noted in the petrography of units 4 and 5.

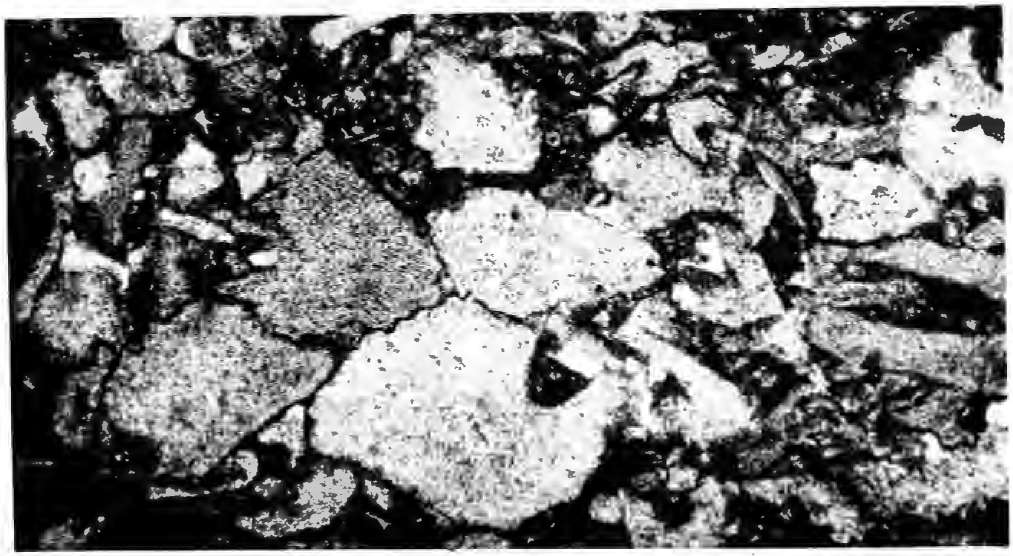
Rock matrix is somewhat variable although microspar is by far the most abundant component. Other constituents are red clay, especially abundant in the red limestones, clear spar, and dolomite rhombs. Microspar is similar in texture to that found in units 4 and 5, but spar is much more common than in the lower limestones. Normally spar is found beneath fossil fragments which is probably an indication that its presence is due to void fillings. Red clay is found in amounts up to perhaps 10 per cent in the red limestones where it is found in laminae and concentrated along stylolites. Together with red iron oxide it imparts the grayish red color to the red beds in the sequence. Dolomite rhombs locally may constitute up to 10 per cent of the rock. They are euhedral, up to 80 microns in size, and seem to be more abundant along stylolites where solutioning has been more pronounced.

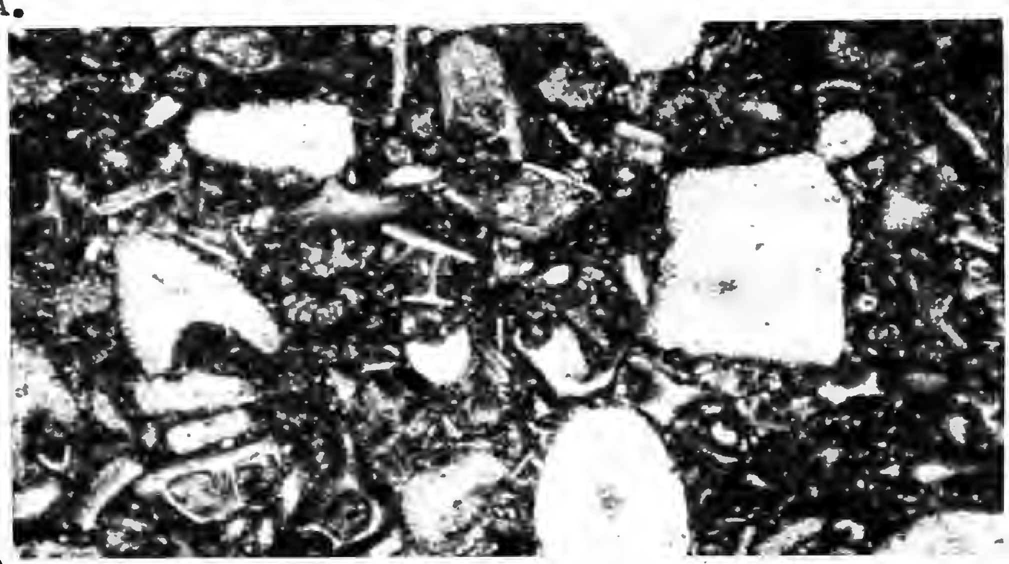
PLATE III. PHOTOMICROGRAPHS OF INTERBIOHERMAL STRATA. (All photographs normal to bedding with top of bed toward top of page, x 35.)

A. Abundant crinoidal fragments showing microstylolites. Note reticulate structure. (Roaring River State Park Section)

B. Crinoid fragments and fenestrate bryozoan detritus. Note random orientation. (Noel Section)

C. Crinoid and bryozoan remains with microspar matrix. (Noel Section)


A.


B.


C.

BIOHERMAL LITHOLOGIC FACIES AND ASSOCIATED SEDIMENTS

GENERAL NOTES

Massive lenses of fine-grained limestone, thick with respect to their horizontal dimensions, crop out on top of, or upon, the flanks of Ordovician stratigraphic highs in southwest Missouri and northwest Arkansas. Exposures occur mainly along stream cuts which have dissected the St. Joe limestone exposing its lowermost beds.

Before beginning a discussion of these features, an investigation of past usage of the terms reef and bioherm must be reviewed. According to Webster's New International Dictionary, a reef is " . . . a chain or range of rocks or ridge of sand lying at or near the surface of the water, esp. one where there is not more than six fathoms at low water". In the sense of navigators, reefs are ridges, knolls, or the like, which rise to the surface or in enough proximity to it to form an obstruction for shipping. In order to escape many of the restrictions posed by definitions such as listed above, Cumings and Shrock (1928) proposed the term "bioherm" from the Greek roots "bios" and "herma", herma meaning a reef, bank, or mound. Cumings (1932, p. 333) stated that he and Shrock (1928) " . . . proposed the term bioherm . . . for reef-like, mound-like, lens-like, or other circumscribed structures of strictly organic origin, embedded in rocks of different lithology". He further discussed coral and algal reefs, algal banks, crinoidal bioherms, shell banks, etc., as main types of bioherms and biostromes. Several of the questions which have been raised with regard to Cuming's original definition are: whether the term bioherm refers to the entire body including both the core as well as the enclosing strata; and whether the massive body was formed by organisms having the biologic potential to erect a wave-resistant structure. Many workers have proposed to restrict usage to include only those biogenic structures which have built up into the zone of wave action forming a rigid wave-resistant body; thus their usage of the term corresponds closely with the definition of a reef in the nautical sense. Other authors have not used the term because of its vagueness. Pray (1958, p. 271) related "although various authors have . . . attempted to restrict the usage of 'bioherm' to a narrower sense, the main utility of the term appears to be its very few genetic restrictions. Often the genetic aspects can only be determined by thorough study of specific structures and a 'wastebasket' term serves a useful function".

The writer heartily agrees with Pray's observations and use of the term in this paper will be in this unrestricted sense. The question of whether or not the bioherms were wave-resistant structures will be dealt with in a succeeding chapter.

As a matter of convention, then, the term "bioherm" will be used for the reef-like, lens-like, or mound-like structures of biogenic origin embedded in rocks of different lithology. As used here "core facies" or simply "core" will be considered synonomous with bioherm. Rocks of different lithology which are laterally adjacent to the core, but do not extend completely over it without pinching out, will be referred to as the "flank facies." Beds which are in near proximity to the bioherm, extending completely over it without pinching out, are defined as the "upper enclosing beds". Correspondingly, beds laterally adjacent to interbiohermal sediments which are seen to extend completely under the core without pinching out are called the "lower enclosing beds". Lower enclosing beds then are actually the substrata upon which the bioherm developed. "Interbiohermal facies" is the bedded or stratified rocks which were deposited essentially contemporaneously with the bioherms, but in areas outside their influence.

General locations of the bioherms found and visited in the course of this investigation are shown on the Bioherm Location Map (Plate I., p. 9), and detailed locations for 37 bioherm localities are listed in the Appendix (see p. 107). Sketches of six biohermal associations are shown on Plate VII., p. 84, photomicrographs of representative core thin sections may be seen on Plate VIII., p. 86, and Plates IV., V., and VI., pp. 81-83, contain photographs of "reef" exposures and related sediments. The discussion which follows deals with a number of representative bioherms which serve to illustrate nearly all of the features which have been seen in the area.

BIOHERMS EXPOSED NEAR PINEVILLE, MCDONALD COUNTY, MISSOURI

General Notes

Three bioherms are seen to crop out near Pineville, McDonald County, Missouri. One is seen in the NW 1/4, SW 1/4, NE 1/4, Sec. 34, T. 22 N., R. 32 W., the other two are found in the NW 1/4, SE 1/4, SE 1/4, Sec. 34, T. 22 N., R. 32 W. Only the latter two will be discussed for they are a better example of the lithologic and structural features of the cores and related rocks. The outcrop is a south facing bluff at the confluence of the Little Sugar Creek and an east-west bluff 1/4 mile north of the settlement of Havenhurst, McDonald County.

Stratigraphic and Structural Relations

The two bioherms exposed southeast of Pineville and north of Havenhurst are very massive and weather resistant features. Structurally they are located on a local Ordovician high seen on the Geologic Map of Missouri (1939). The base of the St. Joe is well exposed along the high at an approximate elevation of 1000 feet. This is considerably higher than in the vicinity of Pineville where elevations are commonly around 700 to 900 feet. If the St. Joe-Chattanooga contact is followed upstream from the Havenhurst location the St. Joe limestone can be seen dipping very gently in this southeasterly direction, disappearing into the subsurface. Five miles southwest of Havenhurst at Jane, Missouri, the base of the St. Joe is again exposed as it rises onto another high. The very same structural picture is present both up the Big Sugar River to the northeast and down the Elk River to the southwest from Pineville.

At the locality in question the top of the Ordovician Jefferson City-Cotter dolomite is exposed. Several apparent cryptozoan algal structures crop out a short distance up the small eastward trending intermittent stream which intersects the Little Sugar at its confluence with bluff under consideration. The Sylamore sandstone is also present up the same stream and is 1-1/2 inches thick. The Chattanooga black shale is 38 feet thick and overlain by 13 inches of light green to dusky yellow shale. The contact of the St. Joe limestone with the underlying green shale is sharp.

Two massive bioherms crop out in the south facing bluff over a horizontal distance of 550 feet. They will be referred to as the eastern and western bioherms; both weather into massive featureless gray bodies having much the appearance of a resistant igneous outcrop. Huge boulders of core material up to 20 feet in diameter have been weathered out and tumbled down into the stream.

The western core is exposed for a lateral distance of 150 feet and is 23 feet thick in its thickest portion near the western margin. The body tapers laterally toward its periphery where it intertongues with the enclosing sediments.

Another bioherm is present 100 feet to the east of the feature described above. Because of the lack of outcrops between the two bioherms it is impossible to determine whether the eastern core is a separate body or another lateral manifestation of the same lithosome. From a study of the "reefs" over the entire region there is reason to believe that they are not necessarily circular in shape, but may be of various and sundry shapes such as elongated, ellipsoidal, discoid, or consist of a central mass with tongues projecting in various directions, etc. This being the case, these outcrops may be of two separate bioherms or lenses of the same body. For sake of discussion, it is treated as two bioherms.

The eastern core is 300 feet in length and a maximum of 27 feet thick near the center of the structure. It intertongues with the enclosing limestones.

The "reef" substratum consists of thin bedded crinoidal limestones averaging 6 feet in thickness. The bottoms, as well as the tops, of cores are convex and the substrata are depressed beneath the thickest portion of the bioherms.

The western core is flanked by and intertongued with predominantly crinoidal limestones. These limestones are bedded and conglomeratic, containing in places rounded pebbles of core material up to several inches in diameter. The conglomerates are more abundant immediately adjacent to the structure decreasing rapidly westward away from it, giving way to thin-bedded crinoidal strata typical of the interbiohermal facies. The conglomerates have evidently been derived from parts of the core and dumped off on the flanks.

Bedded crinoidal limestones and conglomeratic limestones lap against the cores both on the east and west, giving way to calcarenites which continue across the structures with constant thicknesses. Flanking and upper enclosing beds described above are arched and dip as much as 20° away, both to the east and west. The lateral change in dip is gradual and close examination shows that the beds also dip northward into the bluff as well as to the east and west. This indicates that prior to erosion beds dipped quaquaversally away from the structures.

Considering the stratigraphic position of the "reefs" with respect to the normal St. Joe interbiohermal limestones, whose lithic characters were discussed in the preceeding chapter, the base of the cores north of Havenhurst are approximately 6 feet above the base of the formation. The thin green shale zone whose stratigraphic position is roughly 9 feet above the St. Joe base is absent but can be seen pinching out several hundred yards west of the western core. Thus biohermal growth began during the deposition of the lower St. Joe limestone beds and was able to prevent the development of the thin shale unit within and in near proximity to the bioherms by growing at a faster rate than shale accumulation forcing terrigenous deposition to pinch out on the far flanks of the "reef" deposits.

Petrography of the Core Facies

Bioherms examined in southwest Missouri are extremely uniform in lithology, the only notable differences are a slight variation in the percentages of the rock constituents. This being the case, the Pineville "reefs" were chosen for a thorough petrographic study. A total of 42 thin sections were cut from Pineville bioherms and their associated sediments. As for the core facies, thin sections were taken both parallel and perpendicular to the bedding surfaces. A detailed resumé of the lithologic features of the Pineville bioherms will be presented and a more general summary of features seen in the other structures will be described under the separate bioherm headings.

On the outcrop the cores appear to consist predominantly of light olive gray to light gray very fine-grained calcite (microspar) when fresh, weathering to yellowish gray and pale olive. Under close examination fine hair-like irregular veins of sparry calcite can be seen, especially on fresh surfaces. Stylolites may be locally abundant, along which yellowish brown argillaceous material is concentrated. Larger patchy mosaics of spar are locally present as well as small spar patches which usually are crinoid remains.

The cores are mainly bryozoan microsparites. Thin sections usually contain 8 to 15 or perhaps 20 per cent fossils, 5 per cent sparry calcite and between 80 and 90 per cent microspar. Rarely, localized quartz concretions may be present as well as minor traces of pyrite, limonite, and argillaceous material.

Crinoid debris, bryozoans, ostracods, and brachiopods are the most abundant organisms seen in this limestone. Fossils "float" in the microspar matrix and are reminiscent of raisins in raisin bread, i.e., they do not form a rigid framework as found in limestones in which environmental energy has been great enough to winnow-out or prevent deposition of the finer grained sediments leaving only the larger fossil fragments behind to be subsequently cemented with sparry calcite.

Disassociated parts of crinoid skeletons are distributed randomly through the rock with lack of preferred orientation as there is no systematic arrangement of longer dimensions of the fragments. These parts comprise up to 5 per cent of the core. Columnals and plates are variable in length, up to 3 mm. However, the greater abundance of them range between 0.4 and 0.8 mm. Several remarkable characteristics of these constituents are lack of abrasion, lack of sorting and excellent preservation. Regarding lack of abrasion the original outline of many plates are present. Reticulate structure is well-preserved and there is a notable absence of recrystallization on the scale it is seen in the inter-biohermal limestones. Under careful examination, grains of microspar can be seen projecting into many fragments on their fringes. This feature is especially noticeable when viewed with crossed nicols for when the stage is rotated until the crinoid part has reached extinction, a very thin microspar border can be seen surrounding the fossil. Indeed this may represent very slight recrystallization. In a few widely scattered places parts of crinoid remains as well as other fossil fragments have been transected by veins and patches of sparry calcite. In other spots spar can be observed in optical continuity with the fragments, but this development is noted rarely. Fragments, when in contact with one another, usually do not show microstylolitic seams as commonly seen in some of the interbiohermal deposits.

Broken byrozoan zoaria are rather evenly spread through these cores constituting up to 15 per cent of the rock but averaging around 5 per cent. Several assorted kinds of these animals are present, most of them encrusting forms with fenestrates most prominent. The individual fragments are usually elongated showing no pattern of arrangement, but giving the impression that they fell into a soft lime mud in a haphazard fashion, remaining in the random positions as mud accumulated and finally buried them. Length of this debris varies from less than .02 mm. up to 4 or 5 mm., however, most of it is on the order of 0.2 to 1 mm. Preservation of wall structure is good except in a few scattered places. Where veins or patchy mosaics of sparry calcite intersect bryozoan remains they may surround and/or obliterate a portion of the fragment. Autopores are usually filled with microspar but 15 to 200 micron spar occurs not infrequently. One important feature not to be overlooked is the fact that the zoaria have suffered very little, if any, abrasion for they characteristically display thin delicate projections which most certainly would have been broken off had current action rolled the fragments back and forth over the bottom.

Brachiopods and ostracods collectively may represent up to 2 per cent of this carbonate. They occur as articulated, disarticulated, complete single valves and broken shell fragments. The remains are scattered but striking in appearance for they are thin shelled and well preserved. It is readily apparent that depositional diagenetic or other conditions have not been too severe for the thin ostracod shells of hair-like thickness are still preserved. Some of the brachiopod shells have recrystallized to spar while others display original fibrous calcite. Orientation of the remains is noteworthy for they, too, have fallen into the soft mud in a random manner. Single valves follow this same pattern. Valves are usually filled with both microspar and spar; in places microspar is seen beneath clear sparry calcite and the line of junction between the two was the depositional surface. This structure was produced by a partial filling of the shell during deposition with the remaining voids being later filled with spar. From this relationship the top of the bed can be distinguished from the bottom, and the structures are thus geopetals in a true sense of the word.

Thin linear spiculite-like streaks of sparry calcite are occasionally present. They may be up to 0.5 mm. in length, and 15 microns thick. These structures, together with unidentifiable shell fragments too small and fragmentary to allow positive identification, are present as mere traces in the rock.

The matrix of this rock is largely microspar whose texture is very uniform. As previously mentioned, fossil fragments float in this matrix. The general matrix appearance is turbid and greenish brown. Grain size is most commonly 3 to 6 microns with a few grains up to 15 or 20. Grain shape is anhedral with individual particles tightly interlocked. The particles are equant and display no laminations or suggestions of such. As mentioned above, where microspar is in contact with some crinoid fragments it may show a slight interpenetration with the fragments. Slight variations in grain size are often apparent wherein circular areas in which the matrix is very fine-grained appear darker and are surrounded by aureoles of slightly coarser, hence more transparent microspar.

In some places part of the rock has been recrystallized to spar leaving small patches of microspar behind surrounded entirely by spar. Two other types of veins and patchy mosaics of sparry calcite occur at random through the sections. One type is related to the feature described above wherein patchy mosaics of coarse spar cut through the rocks, intersecting fossils which they may partially obliterate or surround; in this case the grain size of the spar is highly variable (0.3 to 4 mm.), hence the texture is heterogeneous. The other type is one in which the mosaic has a straight base and a very irregular upper surface. Below the mosaic the microspar is of a slightly larger grain size than is normal. This mosaic type infallibly allows one to distinguish top and bottom of the bed, hence it is a geopetal. Beside the occurrences of spar as described above, it also occurs as fillings within cavities in fossils.

Stylolites are not too numerous but are present nevertheless. Along these structures clay or other argillaceous material as well as simple voids and spar may be seen. The only notable presence of clay that can be readily detected is that found along the stylolites.

Listed below is a chemical analysis of a composite sample taken from the western bioherm. (Analysis provided by the Missouri Portland Cement Company, St. Louis, Missouri.)

SiO_2	4.60 %
Fe_2O_3	0.56 %
Al_2O_3	1.07 %
CaO	92.83 %
MgO	1.01 %
Total:	100.07 %

Ignition loss - 42.29 %

Petrography of the Substrata

These rocks show regular bedding and are microsparry bryozoan crinoidal calcarenites. They consist of about 60 per cent fossil debris, 35 per cent microspar and up to

5 per cent sparry calcite. The only notable difference between these beds and the biohermal strata is that ostracods and brachiopods remain better preserved in the substrata. The presence of well preserved ostracod and brachiopod shells is perhaps an indication that "reef" growth was initiated rather soon after deposition of these beds which prevented scavenging organisms from disturbing these sediments to the extent that they were able to rework the interbiohermal limestones. That these sediments were partially disrupted by scavengers cannot be denied for there is no parallelism of longer dimensions of fossil debris which would normally be expected, however, the presence of many preserved ostracod and brachiopod shells argues for only minor reworking.

Crinoid fragments comprise up to 10 per cent of the rock. They are variable in length, up to 3 mm. as a maximum. They are more commonly around 0.5 mm. but have not been sorted by current action. There is a definite lack of abrasion for columnals and plates are highly angular and some of the pieces display sinuous cavities filled with microspar. The fragments were apparently bored by organisms and later filled with mud. Some of the pieces are partially recrystallized to sparry calcite, but this is not common.

Bryozoan zoaria are highly broken and fragmentary, constituting up to 40 per cent of these carbonates. Most of them are fenestrates although other types are present. Size is extremely heterogeneous with 2 mm. as a maximum. Many of the fragments are merely broken hash. Again, current action was not severe for there is a lack of abrasion of the particles. Preservation is fair with the fibrous wall structure in places undistrubed, but in others it has been partially recrystallized to 15 to 30 micron spar. Autopores are normally filled with microspar.

Brachiopod, ostracod, and mollusk (?) shells may be abundant enough to make up 5 per cent of the limestones. They are up to 2 mm. in size with both articulated and disarticulated shells present. Preservation is variable, with the wall structure usually showing signs of recrystallization.

A trace of Hyperammina and Hypermminoides of authors is present. They are up to 0.5 mm. in length and 0.1 mm. in diameter.

Rock matrix is dominated by 3 to 15 micron microspar with the grains averaging perhaps 6 microns. It is greenish brown, dark and fills in around and within fossil detritus.

Localized veins and patchy mosaics of clear sparry calcite are up to 5 per cent in amount. In places it has replaced parts of fossil fragments. A few scattered circular mosaics of spar are seen which possibly represent fillings of voids in the sediment. When filling ostracod and brachiopod shells spar normally shows geopetal structure.

Petrography of the Bioherm Flanking and Upper Enclosing Beds

As with the "reef" substrata flank and upper enclosing beds are mainly microsparry crinoidal bryozoan calcarenites.

Limestone conglomerates with pebbles of core material grade laterally into these calcarenites away from the core, as was described above.

Since the flanking beds are identical with interbiohermal limestones as described in the sections at Powell and northwest of Noel, they will not be described here. However, the upper enclosing beds differ somewhat and will be discussed.

Beds which overlie the core are highly crinoidal, consisting of 80 to 90 per cent fossil debris, with the rest variable amounts of microspar and sparry calcite. They are poorly sorted with the components angular and displaying no evidence for abrasion. There is a tendency for the elongated fragments to lie with their longest dimensions parallel to the bedding surfaces.

Crinoid fragments may constitute up to 60 per cent of the rock with broken bryozoan zoaria as abundant as 30 per cent. The fragments are commonly up to 5 mm. in length, averaging around 1 to 1.5 mm. Sparry calcite is much more abundant here than in interbiohermal beds which suggests that much of the finer matrix was winnowed out allowing the spar to crystallize as void filling. These rocks are also characterized by microstylolitic particle boundaries which evidently owe their origin to differential solution and pressure.

The conclusion, then, is that winnowing action and differential solution and pressure have been important for they were able to remove the finer matrix, concentrating the fossil debris.

BIOHERMS EXPOSED IN THE VICINITY OF ELKHURST, MCDONALD COUNTY, MISSOURI

Location

Several bioherms are exposed northwest of Noel, Missouri, in a bluff on the east side of the Elk River; 1.7 miles west of U. S. Highway 71 in SW 1/4, NE 1/4, Sec. 9, T. 21 N., R. 33 W.

Stratigraphic and Structural Relations

One large elongated "reef" and several smaller in size are along the road as described above. They are massive lense-like bodies exposed by road construction, permitting one to examine a largely unweathered outcrop. The structural position is on the periphery of a local stratigraphic high whose upper surface is perhaps 100 feet higher in elevation than points radially away from the center of the high. Neither the base of the St. Joe nor the base of the larger bioherms is exposed, but when flank beds are traced laterally it can be ascertained that development began in the limestone beds below the thin olive shale unit that is so persistent in the area and continued through the shale into the upper St. Joe limestone beds.

The largest bioherm is exposed for a lateral distance of 187 feet, although all of it is not revealed. It is up to 10 feet thick with a lenticular shape.

From the south the main "reef" rises from beneath the road and projects up over a sequence of very fine-grained, slabby limestones with shale partings. It can be traced northward where it lenses out within the same slabby limestones. Near the center of the mass a small stream has been able to cut partially through the core exposing the mid-portion.

Another type of lithology can be observed laterally adjacent to and locally beneath the bioherm. These limestones are platy with rounded to angular corners and were evidently swept off the bioherms by wave or current action and dumped in quiet waters on the flanks.

The platy limestone substrata are not to be confused with slabby beds just described because they are not of the same lithology or texture.

Regular bedded St. Joe limestone laps against the limestones just described. These beds, by successive overlap of one another, were finally able to extend in an uninterrupted fashion across the complex. Dips of the flanking and upper enclosing beds are up to 5°. On the south side of the exposure the core can be seen intertonguing with the flanking beds.

If the flanking and upper enclosing beds are followed in a southeasterly direction along the road the thin persistant shale unit of the St. Joe can be seen thinning out toward, and becoming absent, several hundred yards away from the "reef".

Northward, about 20 yards from the large core previously described, some 3 to 4 feet of a small lenticular bioherm is exposed. This body is perhaps 10 to 20 feet long, grading laterally into bedded crinoidal limestone. It has a fine-grained matrix but is more crinoidal than the large body described above. Limestones overlying this small core are high crinoidal, too.

Other smaller cores, some of them only a foot or so in thickness and several feet long, are seen.

Petrography of the Core Facies

Core facies of the larger bioherms are fossiliferous microsparites. They consist of 5 to 25 per cent fossil debris, 2 to 5 per cent spar, and 70 to 90 per cent microspar. Occasionally traces of limonite and pyrite are seen. On the outcrop these limestones appear as a very fine-grained, dense, structureless mass with occasional fossil fragments, spar lenses and veins. Fossil debris shows no systematic arrangement and has not been sorted or abraded by current action.

Bryozoan zoaria, most of them fenestrates, are broken and fairly well preserved. The constitute up to 15 per cent of the core and are of variable sizes, commonly up to 1.5 mm. in length. Autopores are filled with both spar and microspar.

Crinoid plates and columnals are well preserved, constituting 7 per cent of the rock. They are angular and unabraded, ranging up to 2.5 mm. in length.

Impressive components, though comprising only a trace of the total limestone, are brachiopod and ostracod remains. They are thin-shelled and delicate but nonetheless occur as both articulated, disarticulated, complete valves and broken shell debris. Articulated specimens may be up to 3 mm. in length and show geopetal structure with microspar below and clear spar above. Shell walls have commonly been recrystallized to spar.

Small, thin-shelled gastropods have also been noted but only in very minor amounts.

The predominant rock component is microspar of 3 to 10 microns in particle diameter. It is dark greenish brown and anhedral with individual particles equant. Irregular streaks and patches of the microspar may be seen which are lighter colored and slightly coarser in grain size. These spots may simply be areas in which the matrix has recrystallized to a greater degree than normal.

Spar is seen filling voids in fossils, in recrystallized shell walls and in veins and patchy mosaics which are very irregular in distribution. Geopetal spar mosaics are found in these thin sections. Not unlike those described in the Pineville "reefs" these structures characteristically display a straight base which is somewhat transitional to underlying microspar. The upper surface, however, is very irregular but underlying the spar-microspar boundary is sharp and not gradational.

Stylolites are not uncommon and usually show voids, sparry calcite, or argillaceous material along their surfaces.

Argillaceous material when present occurs dessimenated through the limestone or concentrated along stylolites.

Pyrite is rarely present, but that which is, is normally subhedral to euhedral. Limonite is observed as pseudomorphs after pyrite.

Petrography of the Slabby Limestones which Underlie the Core

These beds are bryozoan microsparites. They consist of 10 to 20 per cent fossils, 5 per cent spar, and around 75 to 85 per cent microspar. Fossil detritus displays a definite tendency to lie with its long dimension parallel to the bedding surface. The fragments are highly angular, unabraded, and have not been sorted as to size.

An examination of animal remains discloses that bryozoans are the most abundant organisms. They appear as fragments, averaging 0.5 to 1 mm. in length, and are well preserved. Crinoid plates and columnals, the next most abundant constituents, are also well preserved averaging around 1 mm. Minor components include thin-shelled and delicate ostracods and brachiopods, many of them articulated.

Microspar, averaging 3 to 10 microns in grain diameter, is the dominant matrix component though occasional lenses and patchy mosaics of spar are present. Traces of pyrite and limonite occur disseminated through the matrix.

These rocks which underlie the core were probably deposited in quiet water which was protected by the growing bioherm itself. Continued growth of the bioherm eventually allowed it to encroach upon the slabby limestones, finally covering them.

Petrography of the Flank Facies

Flank facies, which lap against the core, are crinoidal bryozoan calcarenites. Crinoid parts are dominant rock constituents and are usually parallel to the bedding planes.

Fossils, dominated by crinoid ossicles and plates, constitute 60 per cent of the limestone with spar ranging from 10 to 25 per cent, microspar 10 to 25 per cent, with pyrite, euhedral dolomite crystals and clay present in only very minor amounts.

Occasional intraclasts of core material are found in the crinoidal beds.

Spar probably owes its origin to winnowing action of currents which removed the finer calcite muds, concentrating the crinoid parts and leaving voids between them. The voids were later filled with spar.

BIOHERMS EXPOSED AT NOEL, MCDONALD COUNTY, MISSOURI

Location

Several large bioherms are exposed in an elongated northeast facing bluff on the west side of the Elk River at Noel, Missouri. These are immediately to the north of the U. S. Highway 71 Elk River Bridge; NE 1/4, SW 1/4, SW 1/4, Sec. 14, T. 21 N., R. 33 W.

Structural and Stratigraphic Relations

The bluff under discussion is about 1/2 mile long and some 120 feet high. Along its northwestern extremity the upper few feet of the Chattanooga shale are exposed, together with 5 inches of olive green shale at the top of the Chattanooga. An entire section of St. Joe limestone can be seen together with a sizeable portion of the Reeds Spring formation. The St. Joe-Chattanooga contact dips in a southerly direction and is absent less than 100 yards south of the reef exposure. The above mentioned contact dips away from a stratigraphic high whose greatest elevation is found several miles north of this locality. The difference in elevation between the St. Joe-Chattanooga contact here and on top of the high is about 80 feet.

The bioherms present in the bluff are massive lense-like features which are disposed within bedded crinoidal limestones (see Plate VII., p. 84). As evidenced from an examination of the outcrop these may be three separate cores or perhaps one with several fingers which on outcrop simulate the appearance of three separate bodies. With the above thought in mind we will, for purposes of discussion only, consider the outcrop as consisting of three bioherms.

Approaching the outcrop from a southeasterly direction one resistant core can be seen rising and thickening from a position 8 to 10 feet above the base of the St. Joe to perhaps 20 to 25 feet up into the formation. The maximum thickness of exposure is 10 to 15 feet. One small tongue can be seen projecting into the bedded limestone on top of the body. Another bioherm is exposed a few feet to the east.

It is 10 to 15 feet thick on its southern side thinning to the north, with the base located 6 to 8 feet above the base of the St. Joe. The horizontal dimension of combined core exposures is approximately 180 feet. On the northern extremity of the bluff, some 20 yards north of the core just described, another massive and resistant "reef", about 15 feet thick, is exposed.

On the southern end of the bluff the thin olive green shale unit is well developed; however, it begins to thin gradually toward the bioherms and is absent 75 to 100 yards south of them.

Limestones below the green shale contain lenses of tan-bordered blue chert. The limestone beds rise up, overlap one another and pinch out onto the bioherms. These beds are truncated by overlying beds as shown in Plate VII.

Beneath, and laterally adjacent to, the bioherms rounded nodules of very fine-grained limestone are present. Since this material is of identical lithology to the core, it presumably represents fragments removed from the bioherm by severe wave action and dumped on the flanks. The presence of these nodules beneath the core in this outcrop leads to the conclusion that the core was developed later than the body from which the nodules were removed, or represents continued lateral growth of the same body.

As noted above, bedded crinoidal limestones, by progressive overlap, are finally able to extend completely over the "reefs". These beds dip up to 10° away from the bioherms.

The bioherms do not project up into Reeds Spring limestone, but are overlain by the St. Joe.

Petrography of the Core Facies

The cores are byrozoan microsparites which contain 10 to 15 per cent fossil remains, 10 per cent spar and 80 per cent microspar. Traces of pyrite and clay are also present. An examination of the outcrop shows that the cores are typically very fine-grained, containing small vein-like crevices filled with spar. Most of the spar-filled crevices are probably joints produced by weathering of the cores, with spar representing secondary filling. Fossil remains include bryozoans, crinoid parts, brachiopods, and ostracods. Bryozoans, most of them fenestrates, are most abundant, and are broken, unabraded, well-preserved, and reveal no preferred orientation. Crinoid debris, second only to bryozoans, appears broken, angular, and well-preserved. Thin-shelled and delicate brachiopods and ostracods are present though only in minor amounts. Both articulated and disarticulated shells are present.

Rock matrix is composed of spar, which occurs in patchy mosaics, veins, lenses, and within cavities in fossils; and, the main rock component, microspar, is very uniform in texture, averaging 6 to 9 microns in particle diameter. The grains are equant, dark, and tightly interlocked.

Pyrite and limonite occur as mere traces with limonite pseudomorphic after pyrite.

Petrography of the Substrata

These beds are crinoidal bryozoan calcarenites consisting of some 60 per cent fossil fragments, 5 per cent sparry calcite, 30 per cent microspar and traces of anhedral dolomite crystals.

Crinoid fragments constitute up to 45 per cent of the rock. They average 1 mm. or so in length, are angular, unabraded, unsorted, with most of them corroded by intrastratal solutioning. A number of these fragments display patchy recrystallization to spar and crushing due to compaction. The debris is rather evenly distributed with poor stratification.

Other animal remains present include bryozoans, which are seen in amounts up to 20 per cent of the rock, brachiopods, and ostracods. Bryozoans occur as fragmented zoaria while all that remain of brachiopods and ostracods are broken bits of shells.

Spar is seen mainly as a filling within bryozoan zoaria and occasionally as rim cement in optical continuity around crinoid fragments whereas microspar fills in between fossil fragments and is coarser than the microspar in the bioherms, averaging around 10 to 15 microns.

Small euhedral dolomite rhombs up to 30 microns in diameter are scattered through the rock, mainly along zones in which solutioning has been active, and minor amounts of clay are also seen scattered through the limestone.

BIOHERMS IN THE VICINITY OF ELK SPRINGS, MCDONALD COUNTY, MISSOURI

Location

Four bioherm associations are exposed near Elk Springs, McDonald County, Missouri. One is located on the east flank of a neck of the north projecting finger-like bluff at NW 1/4, NE 1/4, SW 1/4, Sec. 1, T. 21 N., R. 33 W. The others are across the river in a bluff on its east side at SE 1/4, NE 1/4, NE 1/4; SE 1/4, NE 1/4, SE 1/4; and SW 1/4, NE 1/4, SE 1/4, Sec. 1, T. 21 N., R. 33 W.

Structural and Stratigraphic Relations

As can be noted on the Geologic Map of Missouri (1939) these "reefs" are located on the periphery of an Ordovician high. Only the bioherm in the NW 1/4, NE 1/4, SW 1/4, Sec. 1, T. 21 N., R. 33 W. will be discussed for it is representative of the entire group.

One large core and several smaller ones are exposed. The largest is 300 feet long and 30 feet in maximum thickness while the smallest is perhaps 5 feet in maximum thickness and 10 to 20 feet in length.

The lens-like bodies are thickest near their centers, tapering toward their peripheries. The large "reef" inter-tongues with enclosing sediments and beds lap against it, finally continuing over the body without truncation. Upper enclosing beds as well as flanking beds are arched, dipping away at angles up to 13°.

Below the largest bioherm some 2 feet of regular thin bedded crinoidal St. Joe limestone is exposed. These beds sag beneath the center of the body. The base of the St. Joe limestone is not exposed though the slope developed below the outcrop is that typical of the Chattanooga shale.

Petrography of the Core Facies

These bioherms consist of around 10 to 20 per cent fossils, 10 per cent spar and 70 to 80 per cent microspar. Bryozoan, crinoid, and brachiopod fragments are disposed at random through the limestone showing highly random and unsystematic arrangement. Bryozoans, the dominant fossil components, are mostly fenestrates. They are highly fragmented, angular and well preserved with a variable length up to 2 mm. Crinoid plates and ossicles are also well preserved and average 0.5 to 1 mm. in length. Spar is found as fillings within fossils, in patchy mosaics and veins. Some of the patchy mosaics are geopetals which have flat bottom surfaces and irregular upper surfaces. Microspar, the dominant rock component, is uniform in texture with the grains equant and averaging 3 to 9 microns in size.

A.

B.

PLATE IV. BIOHERMS AND ASSOCIATED SEDIMENTS NORTHEAST OF NOEL, MISSOURI. (Appendix, locality 1)
A. Thin-bedded limestones southwest of exposed core. Note shale re-entrant (arrow) disappearing toward the northeast.
B. Massive core (arrow) enclosed by thin-bedded limestones.

A.

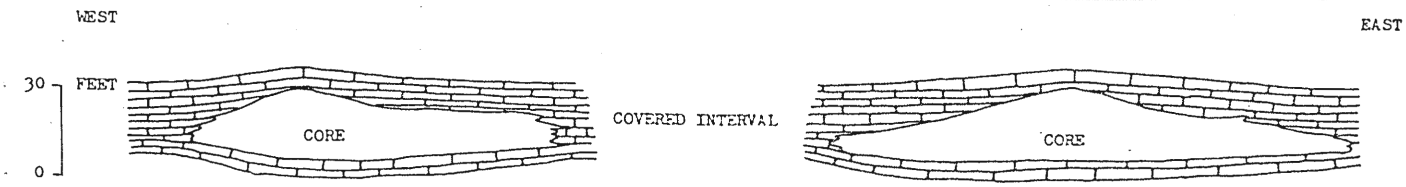
B.

PLATE V. BIOHERMS AT NOEL AND NORTHWEST OF NOEL, MISSOURI.
A. Bedded limestones beneath and lapping against core. Note Chattanooga shale below. (Appendix, locality 2)
B. Limestones lapping against massive "reef". (Appendix, locality 3)

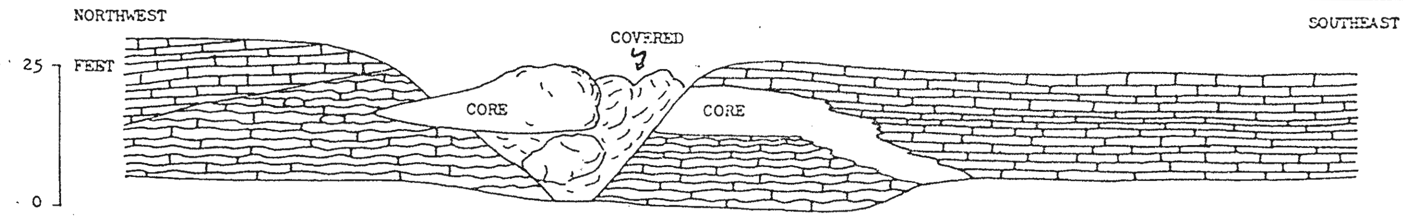
A.

B.

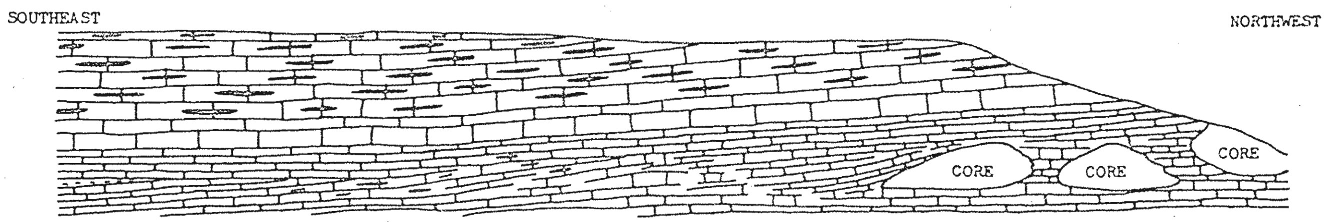
PLATE VI. BIOHERMS NORTH OF HAVENHURST AND SOUTH OF POWELL, MISSOURI.
A. Massive core. (Appendix, locality 14)
B. Bioherm flanked by dipping beds. (Appendix, locality 17)



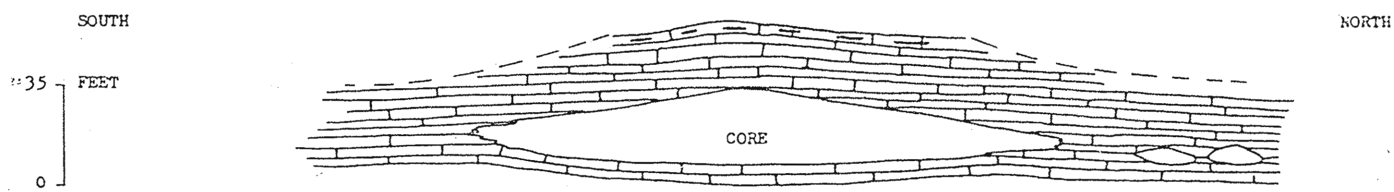
A. Biohorms exposed north of Havenhurst. Note bedded limestones lapping against cores. Beds sag beneath "reef", and flank beds dip away.



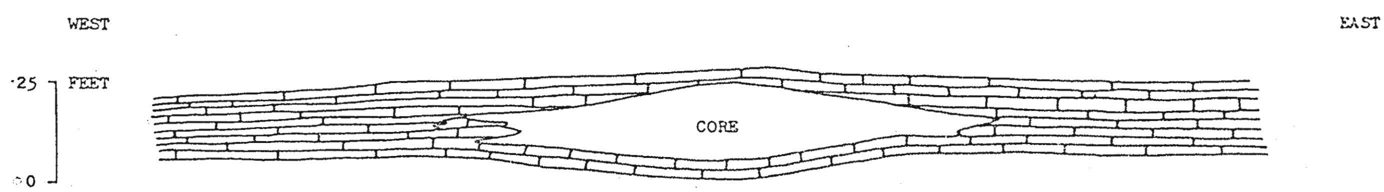
B. Biohermal exposure near Elkhurst. Massive core overlies slabby limestones. Bedded crinoidal limestones lap against core on southwest and slabby limestones on northwest.



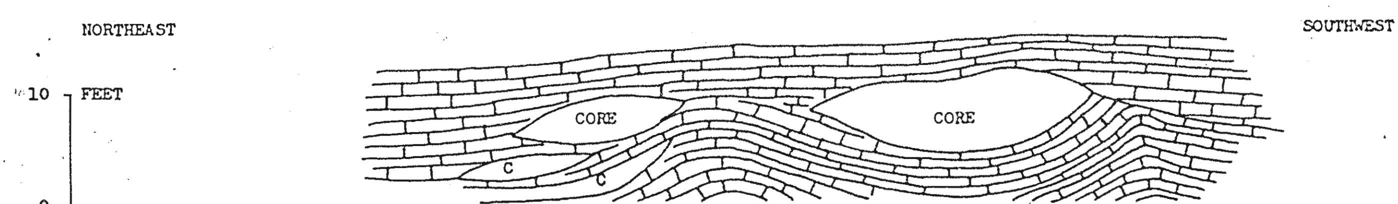
C. Biohermal outcrop at Noel (not to scale). Bluff approximately 120 feet high, cores 15 to 20 feet thick and crop out a distance of some 240 feet.



D. Thin-bedded crinoidal limestones lapping against large bioherm at Elk Springs. Note two small cores. Top portion of bluff omitted.



E. Bioherm at Cyclone. Core interfingers with flank beds.



F. Exposure on Davis Creek 1/4 mile northwest of Yardelle, Arkansas. Note substrata sagged beneath cores. Length of outcrop 200 feet. Redrawn from Purdue and Miser (1916) with modification.

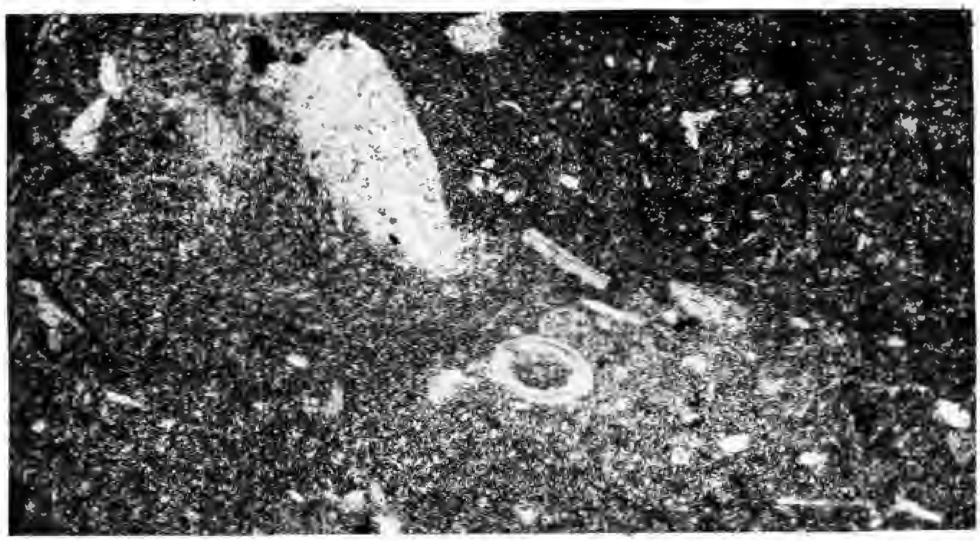
PLATE VII. SKETCHES OF REPRESENTATIVE BIOHERMS OF SOUTHWEST MISSOURI AND NORTHWEST ARKANSAS.

PLATE VIII. PHOTOMICROGRAPHS OF BIOHERMS. (All photographs normal to bedding with top of bed toward top of page, x 35.)

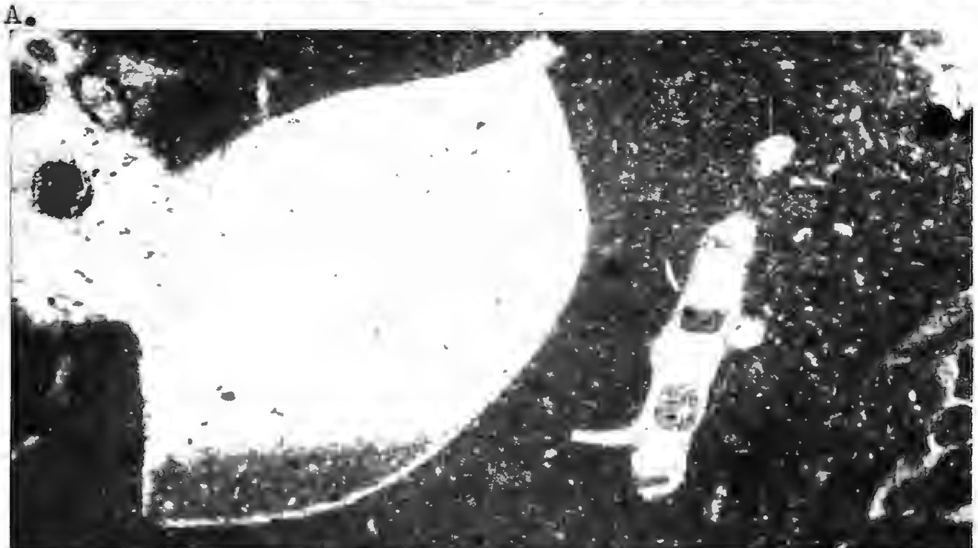
A. Microspar with shell debris and an articulated ostracod filled with spar. (Noel Bioherm)

B. Microspar matrix with fenestrate bryozoan fragment and thin-shelled brachiopod. Brachiopod filled with microspar below and spar above - line of junction of the two is depositional surface. (Bioherm north of Havenhurst and southwest of Pineville)

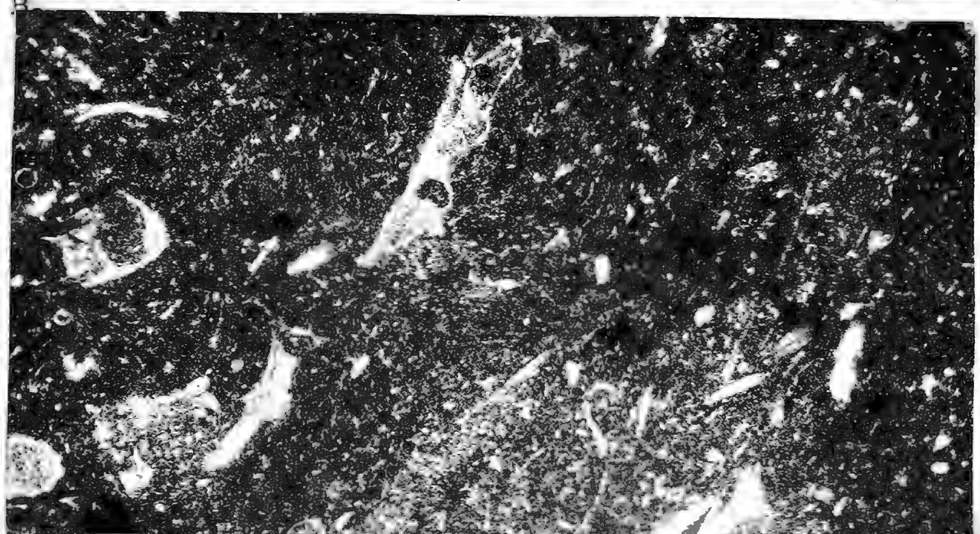
C. Fenestrate bryozoan fragments "floating" in microspar matrix. Note absence of lamination. (Bioherm east of Cyclone)



A.



B.



C.

RÉSUMÉ OF STRATIGRAPHIC AND LITHOLOGIC FEATURES OF BIOHERMAL AND INTERBIOHERMAL FACIES

INTERBIOHERMAL FACIES

Regional Aspects

The St. Joe formation of extreme southwestern Missouri and northwestern Arkansas, west of a line connecting Roaring River State Park (south of Cassville, Missouri) and Rodgers, Arkansas, consists predominantly of gray limestones with shale partings, and a shale zone 9 to 11 feet above the base of the formation. East of this line alternating red and gray limestone beds, with red shale partings and scattered thin beds of gray, red, and green shale are present.

Stratigraphic and Structural Relations

The interbiohermal sediments are characterized by well bedded limestones, ranging from a few inches to 1 1/2 feet thick. Locally, some crosbedding was noted in this facies. Dips of the strata are normally less than 1 degree, but near the "reefs" the dip changes where influenced by the bioherms and their associated sediments. Local stratigraphic highs disguise the regional dip in southwestern Missouri.

Lithologic Features

Lithologically, the interbiohermal sediments are composed of a framework of organic debris with a matrix of microspar. Shale partings and scattered thin shale beds are common. Some chert was seen in the section, mainly in the uppermost beds.

The limestones are microsparry crinoidal bryozoan calcarenites. The dominant fossil constituents are sand-sized crinoid plates and ossicles and a few bryozoan remains. Only very minor amounts of ostracods, brachiopods, mollusks, and corals were noted. In very rare instances trilobite remains were observed. Typically, fossils are fragmental, angular, and unsorted. Recrystallization of this material was noted in various degrees in different thin sections, but rarely are the particles recrystallized beyond recognition. Identifiable organic constituents are randomly oriented.

Argillaceous material can be seen in most thin sections. In the field it typically appears as paper thin laminae and, in some instances, thin beds.

BIOHERMAL FACIES AND ASSOCIATED SEDIMENTS

Stratigraphic and Structural Relations

Reconnaissance studies of bioherms in the St. Joe limestone of southwestern Missouri and northwestern Arkansas show that their growth began in the lower 6 to 10 feet of the formation, and continued accumulation allowed some of these features to build up into the upper beds of the St. Joe. No bioherms observed were covered by Reeds Spring strata.

Bioherms in Missouri flank Ordovician stratigraphic highs. West of the Eureka Springs Escarpment, basal St. Joe strata are not exposed between highs. Evidence for the restriction of these features to highs is seen in the Galena Quadrangle (see locality 31, Appendix). According to Robertson (1960), this bioherm is found in the St. Joe where the formation is situated on a local stratigraphic high. No other bioherms were observed in the quadrangle. This occurence, then, offers merger evidence for a definite restriction of these features to highs. Other evidence which supports this conclusion, elsewhere in Missouri, is the position of bioherms near the apex of highs. On their fringes, where the St. Joe base is still observable, bioherms are seldom, if ever, seen. Thus reconnaisance studies of the bioherms strongly suggest that their development was in local areas of shallower water.

The outline of the "reefs" in plan view is unknown, but available evidence indicates that a variety of shapes exist, such as elongate, elliptical, and roughly circular. Numerous tongues and projections seem to extend irregularly from the cores.

In contrast to the limited information on shape in plan view, evidence for vertical profile is much more abundant. The "reefs" range in thickness from perhaps one foot to 30 feet, the thickest portion usually being in the center of the structure. The massive structures taper toward their edges, where they may interfinger with enclosing strata. Normal range in thickness of the bioherms is 10 to 20 feet.

Length of the cores is also variable, up to 250 feet. The longest cores are the thickest.

Interbiohermal beds undergo changes as they approach the "reefs". Beds which extend beneath the core show slight downwarping due to the weight of the overlying body. Bedded strata also become conglomeratic and pinch-out or thin over the reefs. Upper enclosing beds show dips up to 30° away from the cores, but values of 3° to 5° are more common. A single persistent shale zone, in McDonald County, laps against the far flanks of the "reef" flanking beds.

Lithologic Features

The core facies is composed primarily of microspar, 6 to 10 microns in particle diameter, the particles displaying no evidence of lamination.

Thin sections of these masses show no more than 15 per cent of the rock to consist of recognizable fossil remains. Skeletal debris consists mainly of broken zoaria of encrusting bryozoans and a few crinoid plates and columnals. Minor numbers of ostracods and brachiopods and traces of mollusks usually are present. The remarkable characters of the fossil constituents are their lack of abrasion, lack of sorting, random orientation, and good preservation. Rather striking are the very thin-shelled ostracods and brachiopods which are most delicately preserved.

Substrata, flanking beds, and upper enclosing beds differ from the massive cores in consisting of a sand-sized framework dominated by fragments of crinoids and bryozoans.

Normally these beds consist of 50 to 75 per cent fossils, with a microspar matrix which is more variable in texture than the core.

THEORIES OF ORIGIN

A number of theories have been proposed to explain the origin of the Mississippian bioherms in Arkansas and elsewhere, as well as for similar features in Cambrian and Eocene strata. Some of these are discussed below.

UNCONFORMITIES CAUSED BY SUBMARINE EROSION

Purdue and Miser (1916) discussed the massive lenses in the St. Joe formation northwest of Yardelle, Arkansas, as unconformities caused by submarine erosion. They apparently envisioned an accumulation of evenly bedded calcareous sediments. Post-depositional storm waves (by implication) were able to disrupt the bottom sediments, sweeping them locally into small mounds.

Critical investigation of the cores invariably shows that they consist mainly of microspar, with only a minor percentage of organic remains. Sediments forming the flank facies and upper enclosing beds are composed of a framework of organic detritus, mainly crinoid parts, with a matrix of microspar. If submarine erosion was responsible for the accumulation of the massive beds then the sediment heaped into the mounds would consist of at least as much organic detritus as the enclosing bedded limestones. Wave action strong enough to gather sediment also would winnow out some of the finer material thus producing a core containing a greater concentration of detrital organic remains than the enclosing sediments. This is not the case, however, for the cores are definitely deficient in organic remains when compared to the enclosing bedded limestones. The presence of well preserved and delicate ostracods and brachiopods, many of them articulated, is in itself an argument against violent disturbance, for otherwise these shells would have been crushed and broken. Submarine erosion, therefore, was not the cause of construction of the bioherms.

CRINOIDAL BIOHERMS

Crinoidal bioherms of the Mississippian of Indiana, Kentucky, and Tennessee are well documented. Recently Harbaugh (1957) described crinoidal bioherms from the St. Joe formation of northeastern Oklahoma. Laudon (1957, p. 967) in discussing the Indiana, Kentucky, and Tennessee occurrences wrote that, "They consist of masses of disarticulated crinoid skeletal parts . . . [and] the crinoidal accumulation is in definite beds that intertongue with the enclosing relatively unfossiliferous . . . silty sediments".

Harbaugh (1957, p. 2531) reported that bioherms 10 to 40 feet thick in the St. Joe formation in northeast Oklahoma consist of "massive lenses of crinoidal limestone and flanking thin-bedded crinoidal limestones . . .". He attributed the origin of the bioherms to the accumulation of gregareous crinoids in favorable situations. The bioherms were also considered to be organic reefs because he regarded them as wave-resistant structures.

This theory as an origin for the bioherms in Missouri and Arkansas is untenable because of the paucity of crinoid remains. Normally, except in very localized pockets, only 5 per cent plates and columnals can be observed in a core. If the bioherms resulted from growth and accumulation of crinoids in place, copious remains would have been deposited. Such, however, is not the case. Some other explanation of these fine-grained structures is required.

BRYOZOAN BIOHERMS

Pray (1958) discussed fine-grained, relatively unfossiliferous bioherms from the Lake Valley formation (Mississippian) of the Sacramento Mountains of New Mexico. He described them as being up to 350 feet thick and consisting of dark, massive "aphanitic" calcite and sparry calcite, which collectively form two-thirds or more of the core volume, the remainder being fossils, mostly fenestrate bryozoans. The cores are said to be flanked by bedded calcirudites and calcarenites, the main components of which are echinoderm remains, with sparry calcite as cement.

Pray reported bryozoans in amounts rarely exceeding 20 per cent of the core, but maintained that this is a sufficient quantity to furnish a framework for bioherm accumulation. He considered the fenestrates acting both as sediment trap when in growth position and as sediment-retaining mats when fragmented. The action of crinoids as framebuilders was discounted because they are less abundant than bryozoans and in places are lacking. Other organisms said to constitute less than one per cent of the massive cores are brachiopods, cephalopods, corals, and ostracods.

If this mechanism of growth and accumulation of bioherms in Missouri and Arkansas is tenable, the presence of bryozoan fronds intact and in growth position is a requisite. Yet an intensive thin section study of the bioherms over the region demonstrates the presence of very few fronds, only an insignificant number of which in any way approach growth position. The bryozoan remains are highly fragmented and in positions which were determined by chance. The writer concludes, after examination of thin sections, that these organisms were broken and dropped into a soft lime mud, assuming random positions as they filtered down from a zone of somewhat more turbulent water into a layer of quiet water.

One might also argue that encrusting bryozoans, if they were the responsible organism, would have to grow to a sufficient height above the bottom to create a non-turbulent zone necessary to allow fine muds to settle out. Such is not the case with these encrusting forms. As bryozoans lack external mucous to provide the ability to fix sediment on contact, the role bryozoans played in development of the "reefs" could not have been that of trapping and binding the carbonate mud.

ALGAL BIOHERMS

Cloud and Barnes (1948, p. 154) describe stromatolitic bioherms in the Point Peak shale member of the Wilberns formation (Upper Cambrian) of central Texas. They reported them as being 30 to 60 feet thick where exposed along the Llano River southwest of Mason in Mason County, Texas. These bodies consist of very fine-grained calcite which is well laminated but otherwise structureless.

These structures are thought to have resulted through the influence of algae, either by precipitation, or better yet, through the action of adhesive films or mats of algae that were able to fix particles on contact.

Bioherms of unquestionable calcareous algal origin occur in the tropical facies of Cenozoic rocks. Examples of these are the Atascadero limestone of northwestern Peru and San Educardo limestone of Guayaquil, Ecuado (Frizzell, 1960). The writer has seen several thin sections of the San Eduardo limestone.

The Missouri and Arkansas bioherms lack the fine-lamination characteristic of stromatolitic deposition, thus this explanation is not justified. One might argue that recrystallization has destroyed lamination but evidence from the skeletal remains present in the cores points toward a non-laminated accumulation. Also, though there has been some recrystallization of the cores, it has not been on a large enough scale to destroy lamination completely.

ORIGIN OF THE BIOHERMS

None of the theories of biohermal origin outlined above provided a suitable explanation for the origin of the fine-grained bioherms of Missouri and Arkansas.

On theoretical ground the problem resolved itself to this: no organism of the bioherm could have trapped the fine mud of the core, nor were physical explanations adequate. Could entrapment by a non-calcareous organism be postulated? The existence of non-calcareous sea-weed is well known to Recent ecologists, and their preferential habitat is recognized. This line of reasoning led to the conclusion that entrapment by plants, of which no remnant was preserved, was the unavoidable explanation.

This interpretation made completely independently agrees perfectly with Ginsberg and Lowentam's (1958) account of Florida Bay sedimentation. Their summary (p. 317) expresses perfectly the situation regarding the Mississippian bioherms: "No fossil analogues of the Recent grass baffles described here have been reported from the fossil record. But perhaps some of the rapid local facies changes in ancient limestones were produced by grass or algal baffles. . . . in order to infer the existence of an organic baffle, one needs to show selective fixation or the formation of a protected habitat that could not have been produced by local variation in physical environment."

FLORIDA BAY STRUCTURES

The following discussion describes the geographic, sedimentary and biologic conditions in Florida Bay in the hope that it will serve to clarify the conditions of accumulation of bioherms in the St. Joe formation in Missouri and Arkansas. The discussion is largely a summary from Ginsburg (1956), Ginsburg and Lowenstam (1958), and Trask (1939).

Florida Bay is an area of quiet, warm, shallow water with a subtropical climate. The bay is bound on its southern, eastern, and northeastern borders by the Florida Keys and by the Florida Peninsula on the north. The general shape may be likened to the profile of a curved cone, that is, it is very broad on its southwestern fringe, tapering to the northeast where culminated by landward projections from Key Largo to the mainland.

The bay has a solid limestone floor overlain by numerous calcite mud banks with the floor between banks covered by a thin veneer of shell debris and mud (Trask, 1939, p. 293). Depth range is 0 to 10 feet with a maximum local relief of 6 feet; banks, 4 to 8 feet high, form the only relief, rising to within 2 feet or less of the surface in most instances (Ginsburg, 1956, p. 2396). Bank shapes vary widely; in the northwestern part of the bay they appear as rather broad and elongated bodies with numerous finger-like projections; to the southeast and northeast they are much narrower and sinuous, again with many finger-like projections.

Circulation is restricted by barriers, the Florida Peninsula on the north and the Keys on the east, permitting only limited tidal exchange. Larger fluctuations are produced by seasonal changes in ocean level and by winds causing a change in water level by piling water against the Keys.

Persistent winds of 15 m.p.h. or greater are reported to cause enough turbulence to render a milky appearance to the water. Winds of this magnitude prevail for about half of the year.

Bay sediments have been examined as to grain size and composition. Ginsburg (1956, p. 2422) published sample analyses showing that about 50 per cent of the mud in the banks is comprised of particles less than 1/16 mm. in diameter; the remainder is comprised of sand-sized fragments of mollusks, with only minor amounts of Foraminifera and ostracods. Algal remains occur as traces. Trask (1939, p. 293) reported that the mud particles show a "median diameter" of 5 microns.

Ginsburg and Lowenstam (1958, p. 313) stated that the banks are covered everywhere with turtle grass - even portions exposed during periods of low-water. Grass acts as a trapping and binding agent. Dense carpets extend up to a foot above the banks, checking the turbulence of the water, rendering it practically motionless, and allowing fine sediment to accumulate. Were it not for the grass baffles fine material would not be deposited. Trapped sediment finds its way in among roots, where it may remain without being subjected to the winnowing action of waves or currents. The banks support a fauna dominated by mollusks with numerous Foraminifera. A few ostracods are present.

In a discussion of habitats which grass baffles may provide for benthonic organisms Ginsburg and Lowenstam state that "The erect leaves can support numerous epiphytes sic! such as algae, Foraminifera, bryozoans, etc. which require surfaces for attachment or food gathering. The baffle also provides food, protection, and a favorable substratum for numerous invertebrates - mollusks, echinoderms, and crustaceans. Furthermore, the protective grass carpet can preserve delicate skeletal remains from fragmentation by mechanical erosion."

From the above discussion we can note the geographic, sedimentary, and biologic conditions which exist in Florida Bay today.

INTERBIOHERMAL DEPOSITION

The interbiohermal deposits consist of thin-bedded limestones containing an abundance of crinoid and bryozoan remains together with minor occurrences of brachiopods, corals, mollusks, ostracods, and trilobites. Shale partings and thin shale zones, present in the limestones, are important in environmental interpretation. The presence of clay in the interbiohermal limestones indicates the lack of strong or persistent currents or a high energy environment, that is, one which would have winnowed out the fine muds leaving only the coarser sand-sized fossil detritus behind.

Evidence which supports the interpretation above is furnished by fossil debris. Thin section and hand specimen studies demonstrate the lack of abrasion of fossil fragments which would round the particles. One is impressed with the high angularity shown by the fossils.

The general lack of orientation of the larger discoid or tabular organic fragments in a layered fashion is evidence for the existence of scavenging organisms which could work the bottom over disrupting and mixing the sediments.

Calcite matrix which fills in between fossil detritus was evidently dominated by calcium carbonate ooze. The rock matrix as seen today consists of calcite on the order of 10 to 30 microns in size; however, isolated patches are finer-grained, representing portions of the rock which have not recrystallized to the same extent. Other evidence for recrystallization is the highly irregular grain size of the calcite and the presence of recrystallized organic fragments. Admittedly, the fragments have not been totally recrystallized, but the greater abundance of them show some signs of alteration. Certainly if the fossil remains have been altered, it follows that the particles which fill in between them also would be affected.

In certain places sparry calcite fills in between fossil fragments as the cementing material. These occurrences are seen mainly in the beds which lap against and extend over the bioherms. The beds normally contain a greater abundance of crinoid remains which were evidently concentrated by the winnowing action of currents which removed the finer materials. Later on sparry calcite filled the voids between fossils. Additional arguments for this interpretation are the presence of intraclasts and bedded conglomerates of core material which signify the presence of currents of enough magnitude and duration to accomplish a washing of the sediments.

DEPOSITION OF THE BIOHERMS

The bioherms consist of microspar of a particle size averaging 6 to 10 microns. These particles show no evidence for lamination. Thin section studies indicate that there has been slight recrystallization of this limestone. In some places small patches of calcite of 5 microns and less are seen which appear to be remnants of much finer matrix. Also, spots of slightly coarser calcite are present as well as patches of spar.

Spar patches in some instances represent voids in the original muds, later filled by crystallization of calcite. Other spar occurrences which are seen to transect fossil fragments represent patchy recrystallization of the matrix to spar.

Fossils seen in the cores are recrystallized to a lesser extent than those in the interbiohermal strata. Interbiohermal strata have been subjected more to the action of intrastratal solution and other secondary phenomena which have resulted in a greater degree of recrystallization of the interbiohermal beds. This conclusion is based upon the more heterogeneous matrix grain size and more advanced recrystallization of organic detritus in the interbiohermal strata.

Investigations of Recent marine sediments demonstrate that the grain size of calcium carbonate oozes forming today are on the order of 0.003 to 0.005 mm. in particle diameter (Cloud and Barnes, 1948, p. 83). Some of the patchy occurrences of finer calcite in the reef cores are of a grain size comparable to this. Perhaps the muds of the biohermal and interbiohermal beds were of much a similar grain size and have subsequently been recrystallized leaving remnants of the original matrix behind. Origin of the mud is uncertain. Conceivably it was due to chemical and biochemical precipitation as well as attrition and fragmentation of shells of organisms.

Bioherm development began in the St. Joe seas after a few feet of basal strata had been deposited (6 to 10 feet). They appear to have been associated with local stratigraphic highs, that is, conditions for growth and accumulation were more favorable on the highs.

The seas were warm, shallow and protected from strong and persistent current action which would have winnowed out the fine muds from the interbiohermal deposits. Depth is a matter of speculation - present day marine grasses and algae prefer depths of less than 300 feet and are more prolific at depths of less than 100 feet. Bedded conglomerates associated with the "reefs" are evidence for depths above the bioherms at a maximum on the order of 30 to 50 feet. Waves and currents would hardly disrupt sediment at depths greater than these. Interpretations as to depth of the seas would be enhanced if more were known about the relations between the Chattanooga and St. Joe and the geography of Chattanooga seas.

Interfingering between bioherms and enclosing strata indicates that bioherms did not build up to their maximum thickness before deposition of flanking strata. They did project up above the bottom, however, due to selective action of non-calcareous plants which trapped sediment.

Dips on bioherm cores are primary. If they were due to differential compaction the bioherms would be expected to compact to a greater degree than the bedded crinoidal-bryozoan strata because of the lack of a supporting structure, that is, the presence of a framework of organic detritus in the interbiohermal beds limits the amount of compaction they could undergo, while such is not the case with the cores. The conclusion regarding dips on the enclosing strata is that they have actually decreased since the time of deposition due to differential compaction.

The term reef has been variously defined. Geologists are apt to classify any localized thick carbonate lense a reef and navigators are prone to consider as a reef any structure that presents a hazard for shipping. Recent marine ecologists, however, regard reefs as wave resistent topographic structures consisting of a rigid entanglement of calcareous skeletons. Lowenstam (1950, p. 433) expresses this sentiment when he defines a reef as " . . . the product of the actively building and sediment binding biotic constituents, which, because of their potential wave resistance have the ability to erect rigid, wave-resistant topographic structures." The term is herein accepted in this latter sense. This being the case, the bioherms found in the St. Joe limestone of Arkansas and Missouri are not reefs because they were not constructed by organisms which were able to build up into strong turbulent waters, forming wave-resistant structures.

These structures in the St. Joe should be called mud banks. They developed in a warm, shallow, protected sea where non-calcareous plants grew in localized spots on the bottom. The plants apparently were a dense growth with part of them extending up above the bottom. The dense carpets were able to curtail the motion of water, allowing fine sediment to settle out that would normally be drifted about over the bottom. Selective entrapment by plant baffles provided a resting place for the sediment where it would not be subjected to resuspension by waves or currents.

Portions of the plants which extended above the bottom afforded a habitat for certain organisms. Byrozoans lived on the "leaves" while mollusks, crinoids and brachiopods dwelled in among plants on the bottom. Ostracods were also present in this protected environment. As the organisms died, the bryozoans accumulated as fragments in the mud while many articulated specimens of brachiopods and ostracods were buried by fine muds which were almost continually filtering down. Evidently most of the plates and columnals were separated from the organism upon its death, to be preserved as individual fragments rather than whole skeletons.

CONCLUSIONS

The St. Joe formation of northwestern Arkansas and southwestern Missouri contains a number of fine-grained bioherms up to 30 feet thick and up to 250 feet in length lacking organisms which could account for their development. Examination of thin sections shows only minor occurrences of bryozoan, crinoid, brachiopod and ostracod remains disposed in a matrix of microspar. Sediments which enclose the bioherms are well-bedded crinoidal limestone containing a matrix of microspar with shale partings. The interbiohermal strata dip away from the bioherms and flanking beds lap against them.

Evidence was demonstrated for a selective fixation of sediment that could not have been produced by local variations of the physical environment. This led to the conclusion that these features are mud banks formed by plant baffle entrapment of calcium carbonate ooze. The baffle afforded a protected habitat for bryozoans, ostracods, crinoids, and brachiopods which remain preserved in the cores. The sediment binding carpets accumulated faster than the enclosing sediments, hence they built up mound shaped prominences on local stratigraphic highs in the St. Joe seas.

The seas are interpretated as having been warm, shallow, and protected from violent wave and current action.

APPENDIX

TABLE OF BIOHERM LOCATIONS

	State	Topographic Map	General Location	Specific Location	Remarks
1.	Mo.	Noel (15')	NE of Noel	NE 1/4, NE 1/4, NE 1/4, Sec. 15, T. 21 N., R. 33 W.	Bioherms seen on opposite walls near mouth of NW trending hollow emptying into Elk River.
2.	Mo.	Noel (15')	At Noel	NE 1/4, SW 1/4, SW 1/4, Sec. 14, T. 21 N., R. 33 W.	Bioherms crop out in bluff just north of Elk River Bridge on U. S. Highway 71.
3.	Okla.	Wyandotte (30')	NW of Noel	SE 1/4, NE 1/4, Sec. 9, T. 21 N., R. 33 W.	Bioherms exposed in bluff along road at confluence of road and Elk River.
4.	Mo.	Noel (15')	SW of Noel	N. 1/2, NE 1/4, SW 1/4, Sec. 30, T. 21 N., R. 33 W.	Bioherms present on either side of road just south of Mill Creek.
5.	Mo.	Noel (15')	SW of Noel	NW 1/4, SW 1/4, NW 1/4, Sec. 31, T. 21 N., R. 33 W.	Bioherm in bluff NW of SW trending stream; NW of farmhouse.
6.	Mo.	Noel (15')	S. of Noel	NE 1/4, SW 1/4, NW 1/4, Sec. 31, T. 21 N.,	Bioherm on south side of hill west of road.

	State	Topographic Map	General Location	Specific Location	Remarks
7.	Mo.	Noel (15')	S. of Pineville	SW 1/4, NW 1/4, NW 1/4, & NE 1/4, NE 1/4, NW 1/4, Sec. 31, T. 21 N., R. 31 W.	Bioherm on either side of Brush Creek.
8.	Mo.	Noel (15')	S. of Pineville	NE 1/4, SW 1/4, SW 1/4, Sec. 20, T. 21 N., R. 31 W.	Bioherm in small hollow west of road; south bank of hollow.
9.	Mo.	Noel (15')	Near Elk Springs	NW 1/4, NE 1/4, SW 1/4, Sec. 1, T. 21 N., R. 33 W.	One large bioherm and and several smaller ones exposed in bluff west of meander of Elk River; south of Elk Springs.
10.	Mo.	Noel (15')	Near Elk Springs	SE 1/4, NE 1/4, NE 1/4, Sec. 1, T. 21 N., R. 33 W.	Several bioherms in NE-SW bluff on west bank of Indian Creek.
11.	Mo.	Noel (15')	Near Elk Springs	SW 1/4, NE 1/4, SE 1/4, & SE 1/4, NE 1/4, SE 1/4, Sec. 1, T. 21 N., R. 33 W.	Two bioherms both exposed near corner of bluff on north side of Elk River.
12.	Mo.	Noel (15')	Between Pineville and Elk Springs	NW 1/4, SE 1/4, SW 1/4, Sec. 5, T. 21 N., R. 32 W.	Bioherm located up small south trending hollow; St. Joe shows abnormal dip here.
13.	Mo.	Noel (15')	At Pineville	NW 1/4, SW 1/4, NE 1/4, Sec. 34, T. 22 N., R. 32 W.	Bioherm along stream draining Dog Hollow; within a few yards of bridge over stream, bridge on road to Cyclone.

	State	Topographic Map	General Location	Specific Location	Remarks
14.	Mo.	Noel (15')	North of Havenhurst	NW 1/4, SE 1/4, SW 1/4, Sec. 34, T. 22 N., R. 32 W.	Two large bioherms in south-facing bluff 0.3 mile north of Havenhurst at confluence of bluff and river.
15.	Mo.	Noel (15')	W. of Cyclone	SW 1/4, NE 1/4, NW 1/4, Sec. 22, T. 22 N., R. 31 W.	Bioherm west of Cyclone in south-facing bluff on west side of a small southward draining hollow.
16.	Mo.	Noel (15')	E. of Cyclone	NW 1/4, SW 1/4, NE 1/4, Sec. 23, T. 22 N., R. 31 W.	Bioherm crops out in bluff on bend of Big Sugar Creek on corner of west-facing bluff and westward draining hollow.
17.	Mo.	Rocky Comfort (15')	S. of Powell	SW 1/4, NW 1/4, NE 1/4, Sec. 28, T. 22 N., R. 30 W.	Bioherm is in west-facing bluff 1.2 miles south of Powell, on road which follows Bentonville Hollow.
18.	Mo.	Rocky Comfort (15')	N. of Powell	NE 1/4, NE 1/4, SW 1/4, Sec. 16, T. 22 N., R. 30 W.	Bioherm in south-facing bluff at the mouth of Mikes Creek.
19.	Mo.	Rocky Comfort (15')	W. of Powell	SW 1/4, SW 1/4, NE 1/4, Sec. 17, T. 22 N., R. 30 W.	Bioherm crops out in bluff on west side of Big Sugar Creek.

	State	Topographic Map	General Location	Specific Location	Remarks
20.	Mo.	Rocky Comfort (15')	W. of Powell	SW 1/4, SW 1/4, NW 1/4, Sec. 18, T. 22 N., R. 30 W.	Bioherm seen in bluff on west side of Big Sugar Creek.
21.	Mo.	Rocky Comfort (15')	W. of Powell	SW 1/4, SW 1/4, NE 1/4, Sec. 18, T. 22 N., R. 30 W.	Bioherm in bluff on on west side of Big Sugar Creek.
22.	Mo.	Rocky Comfort (15')	NE of Powell	SE 1/4, SE 1/4, NE 1/4, Sec. 12, T. 22 N., R. 30 W.	Bioherms located in south-facing bluff at the mouth of Sugarcamp Hollow; near confluence of the hollow stream and Mikes Creek.
23.	Mo.	Rocky Comfort (15')	NE of Powell	SE 1/4, NE 1/4, SW 1/4, Sec. 1, T. 22 N., R. 30 W.	Bioherm in east-facing bluff on Mikes Creek.
24.	Mo.	Rocky Comfort (15')	NE of Powell	NE 1/4, SE 1/4, NE 1/4, Sec. 6, T. 22 N., R. 29 W.	Bioherm in south-facing bluff on Star Hollow; west of junction of the hollow stream and Mikes Creek.
25.	Mo.	Rocky Comfort (15')	NE of Powell	SE 1/4, SE 1/4, NE 1/4, Sec. 20, T. 21 N., R. 29 W.	Bioherm in south-facing bluff on Star Hollow.
26.	Mo.	Rocky Comfort (15')	N. of Jacket	SE 1/4, SW 1/4, NW 1/4, Sec. 20, T. 21 N., R. 29 W.	Bioherm in northeast-facing valley wall.

	State	Topographic Map	General Location	Specific Location	Remarks
27.	Mo.	Cassville (15')	N. of Eagle Rock	SE 1/4, SW 1/4, NW 1/4, Sec. 33, T. 22 N., R. 26 W.	Bioherm in west side of hill.
28.	Mo.	Cassville (15')	E. of Cassville	SW 1/4, SE 1/4, SW 1/4, Sec. 21, T. 23 N., R. 26 W.	
29.	Mo.	Cassville (15')	E. of Cassville	NE 1/4, SW 1/4, NW 1/4, Sec. 16, T. 23 N., R. 26 W.	
30.	Mo.	Reeds Springs (7.5')	W. of Cape Fair	NW 1/4, NE 1/4, NE 1/4, Sec. 2, T. 23 N., R. 24 W.	Bioherm exposed along road on north side of Emerson Hollow.
31.	Mo.	Galena (7.5')	N. of Reeds Springs	SW 1/4, SE 1/4, NE 1/4, Sec. 14, T. 24 N., R. 23 W.	Bioherm crops out on both sides of stream.
32.	Mo.	Garber (7.5')	W. of Branson	NW 1/4, SE 1/4, SE 1/4, Sec. 27, T. 23 N., R. 22 W.	Bioherm seen on top of hill north of Dewey Bald.
33.	Ark.	Eureak Springs-Harrison (30')	S. of Ponca	NW 1/4, Sec. 36, T. 16 N., R. 23 W.	Bioherm in west valley wall on Buffalo River; 2.4 miles south of Ponca.
34.	Ark.	Eureka Springs-Harrison (30')	S. of Ponca	SW 1/4, Sec. 35, T. 16 N., R. 23 W.	Bioherm in west valley wall on Buffalo River; several hundred yards SW of "reef" listed above.

	State	Topographic Map	General Location	Specific Location	Remarks
35.	Ark.	Eureka Springs-Harrison (30')	N. of Jasper	NE 1/4, Sec. 8, T. 16 N., R. 21 W.	Bioherm present in south trending hollow which empties into the Buffalo River.
36.	Ark.	Eureka Springs-Harrison (30')	At. Yardelle	NW 1/4, Sec. 4, T. 16 N., R. 19 W.	Bioherm exposed in NE-SW bluff on Davis Creek.
37.	Ark.	Fayetteville (30')	N. of Sulphur Springs	SW 1/4, Sec. 1, T. 21 N., R. 33 W.	Bioherm crops out at the head of a very short valley on the north side of the road.

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