IOWA GEOLOGICAL SURVEY
IOWA CITY, IOWA
H. GARLAND HERSHEY, Director and State Geologist

REPORT OF INVESTIGATIONS 6

A BIOHERMAL FACIES IN THE SILURIAN OF EASTERN IOWA

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Cornell College, Mt. Vernon, Iowa

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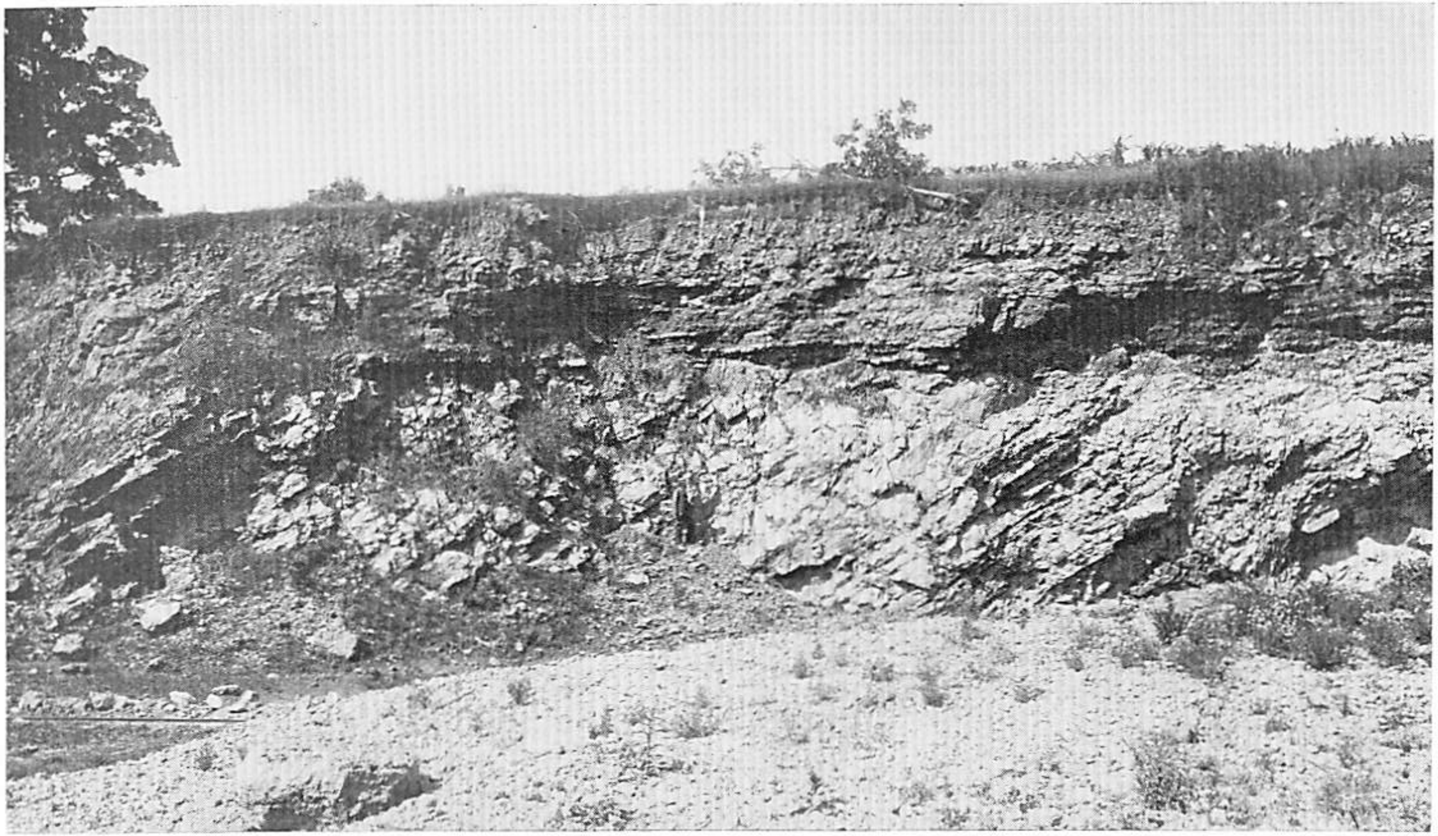

FRONTISPIECE

Steeply dipping flank beds of a Silurian bioherm are shown truncated and overlain by flat-lying Devonian strata in this exposure at the Lime City quarries, southern Cedar County. Samuel Calvin, who, with W. H. Norton, did much early work on bioherms in the State of Iowa, is pictured standing adjacent to the face. This picture was taken about 1900.

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A BIOHERMAL FACIES IN THE SILURIAN OF EASTERN IOWA

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EUGENE E. HINMAN

ABSTRACT

The bioherms present in the Silurian of eastern Iowa are confined to the Niagaran Series and are largely restricted to the Gower Dolomite. Those described here are solely Goweran.

Four of the bioherms were chosen for detailed study from the hundreds present, as being typical of the Iowa structure and individually offering exposures of elements which no single bioherm displayed. Typically, they are oval mounds of undisclosed heights some exceeding 180 feet. They range from a few tens of feet to at least a quarter mile in diameter.

The bioherm consists of two parts: a central unstratified core, and peripheral, well stratified flank beds which abut against the core on the one hand and dip radially away from it, merging with the flat-lying inter-reef facies on the other. The core and flanks are petrographically nearly identical but structurally and paleontologically dissimilar.

The core is the most abundantly fossiliferous of the facies, both in variety of species and in numbers present. The coelenterates are the most abundant group, with the pelmatozoans and brachiopods of secondary numerical importance. The flanks have fewer fossils, with pelmatozoans and brachiopods being the most abundant. The presence of stratification in the flanks is the most obvious contrast between them and the core, however.

Both the flanks and core are characteristically porous, the result of solutional activity and attendant fracturing. The initial solution activity at least is a function of the amount and size of the fauna present. For this reason the core is by far the more porous and the more highly fractured.

In some locations collapse breccia and clay fillings form extensive deposits, particularly in the core. Solution activity and the resultant brecciated nature of the core have made this part of the bioherm much less resistant to stream erosion.

The develpment of the flanks is not entirely dependent upon core debris. Much, if not most, of the flank material is autochthonous.

Although generally similar in architecture and composition, the bioherms display textural, structural, and faunal variations. These variations are ultimately dependent on faunal differences. The most obvious explanation for faunal differences is that the bioherms are a polyphylitic conglomeration unified only by their mound-like outline. Faunal differences also may be explained as the result of growth-stage variations or significant age differences.

The general lack of coarse debris in the bioherm indicates that they must have develped under much less violent energy conditions than those of Illinois. It is concluded that the Iowa structures were formed in a shallow, lagoonal environment near the western shore of the Niagaran sea. The protection thus afforded reduced turbulence.

The bioherms included in this study represent but a small fraction of those present. Certainly they exist in the hundreds within the outcrop belt of the Gower in eastern Iowa.

INTRODUCTION

The bioherms present in the Niagaran Series of east-central Iowa have been of interest to geologists and to the quarrying industry of the state for many years. The origin of these anomalous structures has been a source of controversy since the time of their first description by Hall and Whitney (1858).

The high porosity and good burning qualities of the biohermal rock made it much sought after for the quick-lime industry in the 1880's and early 1900's. Use of this rock declined with the demise of the quick-lime industry until other properties, such as the rock's hardness and resistance to wear, were recognized. Then biohermal materials became highly prized for road metal and concrete aggregate. As a result, the quarrying industry in eastern Iowa depends heavily upon biohermal structures as a source of top quality stone. This heavy exploitation has spurred exploration for these features as well as interest in methods for their location. Despite the increased interest and demand, little detailed work has been done with bioherms in the state of Iowa.

Hall and Whitney (1858) first mentioned the presence of these sedimentary structures but mistakenly considered them to be anticlinal folds. Later works by White (1870), Calvin (1895, 1896), and Norton (1895, 1899, 1901) presented brief discussions of the origin of the structures and their correlation. These papers were chiefly discussions of general stratigraphy concerned primarily with correlation and dealt only generally and incidentally with the biohermal structures.

More recent work has been done by Rowser (1929, 1932) and Smith (1967). Rowser studied the Silurian as exposed in Cedar County. He briefly described and speculated on the origin of the bioherms occurring in the Gower Formation. The report of his 1932 investigation of the Gower Formation and its fauna also described the bioherm structures present in the formation in a discussion of the lateral variation within the Gower. Smith (1967) has made a petrographic study of several bioherms in Cedar County and investigated the diagenetic processes affecting these structures.

These features also have been studied in adjacent states. In eastern Wisconsin, T. C. Chamberlin (1877) carried out a detailed study of bioherms which was enlarged upon by Shrock in 1939. The definitive works on bioherms were done by Cumings and Shrock (1928) and Cumings (1930, 1932) in Indiana. Illinois' structures have been studied by Fenton (1931), Lowenstam (1949, 1950, 1952, 1957), Ingels (1963), and currently by Carozzi.

It was the purpose of the author to undertake the first general study of these structures in the state of Iowa in order to examine as many of their facets as possible. With this in mind, it was the author's intention to delimit as many of these bioherms as practicable on a small scale map and to investigate in detail four bioherms which offer the best exposure of particular aspects of the structure, noting in these the lithologic, structural, and paleontologic characteristics.

ACKNOWLEDGMENTS

I am indebted to Dr. W. M. Furnish for his aid during the course of the investigations and the writing of the manuscript. Thanks are due also to Mr. Steward D. Mettler, of Concrete Materials Division, Martin-Marietta Corp., for his aid and for making available core and logs of the Meyer quarry.

Dr. A. J. Boucot, California Institute of Technology, kindly identified the brachiopod fauna, and Mr. Harrell L. Strimple, Curator, Geology Department, University of Iowa, identified the echinoderms.

I am grateful also for the aid given me by members of the Iowa and U. S. Geological Surveys. Mr. Fred H. Dorheim gave generously of his time and experience during the course of the field work. Mrs.

Mary C. Parker, Mr. Orville Van Eck, and Mr. W. L. Steinhilber were equally generous, critically reading the manuscript and spending long hours in its editing.

This paper could never have been completed without the generous and cheerful help of my wife, Dorothy, who participated in every phase of the research and writing. To her goes my special gratitude.

GEOLOGIC AND GEOGRAPHIC SETTING

The Silurian of Iowa is represented by the Alexandrian and Niagaran Series. The Alexandrian includes the Edgewood and Kankakee formations. The basal Edgewood rests unconformably on Late Ordovician rock. The Niagaran Series includes the Hopkinton and Gower formations which are in turn overlain unconformably by Lower or Middle Devonian strata. The bioherms are confined almost entirely to the Gower Formation, although a few such structures have been reported in the underlying Hopkinton (Calvin, 1896, and Thomas, 1917).

The Gower Dolomite contains at least two readily distinguishable lithologic facies. The Anamosa facies is a soft, light yellowish-brown, dolomite. It is a thinly bedded, horizontally stratified unit. The Le Claire facies is a tough, grayish-blue dolomite, in which bedding varies from very thin to massive and from horizontal to vertical in attitude.

The Gower Dolomite is exposed discontinuously beneath Pleistocene drift along a belt 20 to 30 miles wide, which extends from the eastern portion of Linn County in a southeasterly direction to the Mississippi River (see index map, fig. 1). The unit extends into Illinois (across the Mississippi) where it has been designated the Port Byron. In Iowa the northeast boundary of the Gower lies along a line a few miles northeast of the Wapsipinicon River and nearly parallel with it. The southwest boundary of the Gower is the Cedar River. Within these boundaries exposures of Gower are present in Cedar, Clinton, Jones, Linn, and Scott Counties, and to a very limited extent in Muscatine County along the Cedar River.

The unit has a regional dip to the southwest of approximately 20 to 30 feet per mile. Its total thickness has not been determined accurately because of great variations in local thickness, incomplete surface exposures, plus a difficulty in defining the contact with the underlying Hopkinton in the subsurface through well cuttings. Norton (1901) reported a thickness of 112 feet at the type section of the

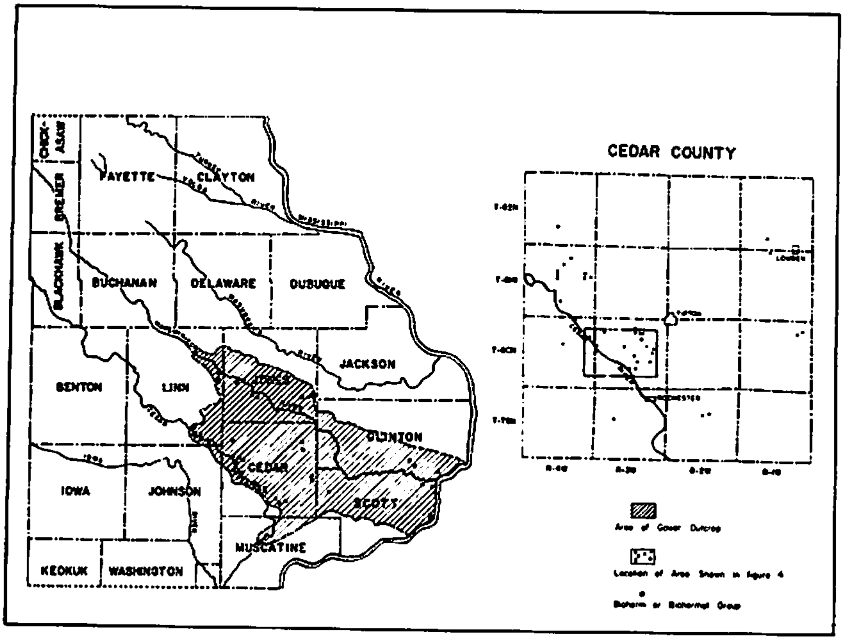

Figure 1. Index Map.

Gower in Cedar Valley. It is known to be in excess of 142 feet from well cuttings taken from the town well at Clarence in Cedar County (Dorheim, 1962, personal communication) and is estimated to be on the order of 180 feet in thickness at the Palisades Park in Linn County (Mettler, 1962, personal communication).

Within the belt of Gower outcrop, literally hundreds of bioherms are exposed. Some are exposed naturally as klintar only partially covered by Pleistocene tills, or in bluffs along stream courses. Others have been exposed artificially by quarrying operations or road cuts. Probably several times as many more are yet to be discovered.

Where the till sheet is fairly thin, a bare knoll, rolling topography, or an irregular woodlot surrounded by tilled fields may indicate the presence of a bioherm. In areas where Pleistocene cover is thicker and develops its own terrain, the local drainage pattern may aid in the location of these structures, as streams' courses are often deflected around the flank beds of the bioherm. Hence, aerial photos may be of help in exploration by quarry operators.

The index map (fig. 1) indicates the location of bioherms visited by the author. It also includes some observed by W. M. Furnish and F. H. Dorheim.

STRATIGRAPHY AND CORRELATION

General Discussion and Description

The Silurian in the state of Iowa is represented by four formations that range in age from lower Alexandrian through lower Cayugan.

The lowest, the Edgewood Limestone, rests unconformably on the Maquoketa Shale, of Upper Ordovician (Cincinnatian) age. The Edgewood consists of a light yellowish-brown to gray, fine-grained, dolomitic limestone which contains nodules of chert that are parallel with the bedding and a shaly transition zone in the lower portion. The unit ranges from 5 to 100 feet in thickness.

Overlying the Edgewood is the Kankakee Limestone, a light yellowish-brown, thinly bedded, dolomitic limestone with alternating thin beds of white chert. The Kankakee ranges from 17 to 60 feet in thickness.

Lying disconformably above the Kankakee is the Hopkinton Dolomite of middle Niagaran age. It consists of a light yellowish-brown, thinly bedded dolomite with discontinuous bands of chert. This unit contains an abundant fauna of corals and pentamerid brachiopods. It ranges in thickness from 40 to 200 feet.

The Gower Dolomite overlies the Hopkinton. The Gower consists of two facies, the Anamosa and the Le Claire, which are differentiated on the basis of texture, toughness, color, and structure. The Gower has a maximum thickness in excess of 180 feet. The biohermal structures described in this paper occur in the Hopkinton and Gower, with the vast majority confined to the latter.

History of Nomenclature and Correlation

Literature on the Silurian formations in the state of Iowa is not very extensive. Much of the material in the literature, because of rapid changes in terminology and correlation, is more confusing than edifying. Therefore it seems appropriate to present a review of the development of the current nomenclature and to include a chart illustrating the modification of the Iowa Silurian section (table 1).

One of the earliest references to the Upper Silurian was made by D. D. Owen (1840) in his Report on the Mineral Lands of Iowa, Wisconsin, and Part of Illinois. In it he mentioned the Upper Magnesian limestone which he divided into three units. The uppermost of these probably is what is now called the Hopkinton Formation since he made reference to the chert layers and *Pentamerus* in the unit. As a matter of fact, his map in a later report (1852) referred to this terrane as the "coralline and *Pentamerus* beds of the Upper Magnesian limestone," which he correlated as equivalent to the Clinton and Niagara groups of the Upper Silurian.

Hall and Whitney (1858), in their report on The Geological Survey of the State of Iowa, termed this unit the Niagara Limestone. At this time they also introduced the name "Leclaire" (their spelling), after the town of Le Claire, for a sequence which they placed above the Niagara. Hall and Whitney correlated the unit tentatively with the Galt Limestone of upper Canada, which was then recognized as equivalent to the basal Onondaga Salt group, and noted a then-unnamed yellowish magnesium limestone overlying the Le Claire as being the equivalent of the upper part of the Onondaga Salt group. (This unit is now recognized as the Anamosa facies of the Gower Formation.)

A. H. Worthen (1862) took exception to Hall's and Whitney's interpretation, stating that the unnamed Upper Onondaga and Le Claire were equivalent. Further, he felt that paleontological evidence clearly indicated a Niagara age assignment for the unit. In the Report on the Geological Survey of Iowa, C. A. White (1870) agreed with Worthen's conclusions. It is interesting to note that his interpretation of their equivalency finally was accepted as correct some thirty-seven years later (Norton, 1899).

A. G. Wilson (1895) reviewed the history of nomenclature and correlation of the Upper Silurian and proposed a five-fold division of the lithology between the summit of the Maquoketa shales and the top of the building stone of the Niagara. From the descriptions accompanying the nomenclature, it would appear that his "beds of passage" are equivalent to the Edgewood, while the "lower coralline" is now Kankakee. The "*Pentamerus* beds" presently are called Hopkinton. The modern counterpart of the "coralline beds" is probably what now is termed Gower, as no other comparable strata occupy that position.

During the same year Norton, in his Geology of Linn County, proposed slightly different nomenclature for the Upper Silurian. His lowest exposed unit, the "*Pentamerus* beds", was assigned to a Delaware Stage, a term to be proposed the following year by Calvin (1896). The "upper coralline" beds of Wilson were called Le Claire, which was designated as a substage of the Anamosa, although Norton was more or less convinced of the Le Claire-Anamosa equivalency. He placed the Bertram and Coggan beds above the Anamosa

D.D. OWEN 1852	DEVONIAN	
	U SIL	CORALLINE & PENTAMERUS BEDS
	LOWER SILURIAN, UPPER MAGNESIAN	LEAD BEARING BEDS SHELL BEDS
	LOWER SILURIAN, LOWER MAGNESIAN	
HALL & WHITNEY 1858	DEVONIAN	HAMILTON & CHEMUNG
	UPPER SILURIAN, [illegible]	UPPER ONONDAGA LECLAIRE
	UPPER SILURIAN	NIAGARA
	LOWER SILURIAN	HUDSON GALENA TRENTON BLACK RIVER CALCIFEROUS POTSDAM
C.A. WHITE 1870	DEVONIAN	HAMILTON
	UPPER SILURIAN	NIAGARA
	LOWER SILURIAN	MAQUOKETA GALENA TRENTON POTSDAM
C.R. KEYES 1893	DEVONIAN	CEDAR VALLEY
	UPPER SILURIAN	LE CLAIRE NIAGARA
	LOWER SILURIAN	MAQUOKETA GALENA TRENTON
A.G. WILSON 1895	DEVONIAN	
	UPPER SILURIAN	BUILDING STONE BEDS UPPER CORALLINE BEDS PENTAMERUS BEDS LOWER CORALLINE BEDS BEDS OF PASSAGE
	TRENTON	MAQUOKETA
W.H. NORTON 1895	DEV	[illegible]
	UPPER SILURIAN	LE CLAIRE CORAL-LINE BEDS [illegible]
S. CALVIN 1896	U CARB	
	NIAGARAN	BERTRAM ANAMOSA LE CLAIRE DELAWARE
	TRENTON	MAQUOKETA
W.H. NORTON 1899	M. DEVONIAN, WAPSIPINICON	[illegible] STAGE OTIS
	NIAGARAN, GOWER	ANAMOSA LE CLAIRE
		UNEXPOSED
J.A. UDDEN 1905	UPPER CARB	DES MOINES
	NIAGARAN	GOWER DELAWARE
	TRENTON	MAQUOKETA
S. CALVIN 1907	M. DEV	WAPSIPINICON
	NIAGARAN	GOWER HOPKINTON
	TRENTON	MAQUOKETA
C.R. KEYES 1912	HAMPTON	COGGAN
	GOWERAN	BERTRAM ANAMOSA LE CLAIRE
	NIAGARAN	MONTICELLO HARTWICK COLESBURG SUBULA
	MAQUOKETAN	BRAINARD ATKINSON CLERMONT ELGIN
T.E. SAVAGE 1914	M DEVONIAN	
	NIAGARAN	GOWER HOPKINTON
	ALEXANDRIAN	WAUCOMA WINSTON
	TRENTON	MAQUOKETA
T.E. SAVAGE 1926	M DEVONIAN	
	NIAGARAN	GOWER HOPKINTON
	ALEXANDRIAN	KANKAKEE BRASSFIELD EDGEWOOD
	TRENTON	MAQUOKETA
W.H. NORTON 1933	CAYUGAN	SALINA
	NIAGARAN	GOWER HOPKINTON
	ALEX.	WAUCOMA
	TRENTON	MAQUOKETA
A.H. SUTTON 1935	CAYUGAN	
	NIAGARAN, GOWER	LE CLAIRE [illegible]
	NIAGARAN	HOPKINTON
	ALEXANDRIAN	KANKAKEE (WAUCOMA) EDGEWOOD (WINSTON)
	TRENTON	MAQUOKETA
T.E. SAVAGE 1942	CAYUGAN	
	NIAGARAN	BERTRAM GOWER HOPKINTON
	ALEXANDRIAN	WAUCOMA WINSTON
	TRENTON	MAQUOKETA
T.E. SAVAGE 1942	CAYUGAN	
	NIAGARAN	GOWER HOPKINTON
	ALBION	WAUCOMA WINSTON
BOUCOT & BERRY 1962	LUDLOVIAN	GOWER
	WENLOCKIAN	HOPKINTON
	LLANDOVERIAN	KANKAKEE EDGEWOOD

Table I. History of Silurian Nomenclature in Iowa

Stage. Nowhere in the report is the term Niagara used. It also is interesting to note that Norton used the term Mt. Vernon throughout the text of his report, but in the stratigraphic column (p. 122) he used Anamosa, a term urged upon him by Samuel Calvin. The situation developed when a choice had to be made between the law of priority of usage and the better type locality. "Anamosa stone" was quarried at Stone City but had become known commercially by the name of its shipping point. Because Anamosa was not the type section, Norton urged the name Mt. Vernon since the unit was well exposed there and contained fossils, a rarity in this formation. Calvin felt, however, that to redesignate a unit already well known in the building trades, if not in the literature, would cause confusion and prevailed on Norton to use the term "Anamosa".

In Calvin's 1896 Geology of Jones County, he formally proposed the term "Anamosa" for beds formerly called Onondaga by Hall and Mt. Vernon by Norton. In the stratigraphic column (p. 42) Calvin placed the Anamosa above the Le Claire, but in the text material no specific mention of their relative position was made. A subsequent paper (1897) presented the same column.

In The Geology of Scott County, Norton (1899) used Niagara for series and proposed the term "Gower" as the stage which included both the Anamosa and Le Claire substages (p. 423).

> There are two distinct lithological types of the Gower limestone. The pure, hard, crystalline dolomite, free from chert and especially adapted to the manufacture of lime, known as the Le Claire limestone for its occurrence at the village of that name. The light-buff, granular dolomite, evenly bedded and extensively used for building stone, has been named by Calvin by the term long used in commerce, the Anamosa stone. These subdivisions have been ranked hitherto as distinct stages, but the evidence at hand does not seem to warrant any chronological separation. The terms "Le Claire" and "Anamosa" will therefore be used merely as convenient designations of different lithological varieties of rocks of the same stage. Regarding both building stone and lime rock as practically contemporaneous, a name for the stage of their deposition becomes needful. None so appropriate suggests itself as Gower, the name of a township in Cedar County in which occurs so many outcrops of both the Le Claire and Anamosa stone, and in which are situated the famous Bealer quarries at Cedar Valley.

Udden (1905) omitted the terms "Le Claire" and "Anamosa" entirely, recognizing only the Gower and Delaware Stages.

In 1907 Calvin proposed the term "Hopkinton" to replace Delaware, which was preoccupied in the Devonian of Ohio: "All the characteristics of this stage are well displayed in quarries and ravines within a radius of two or three miles around Hopkinton in Delaware County, Iowa" (p. 196).

A complete reversal in trend was presented by Keyes (1912), who reintroduced the units of Wilson (1895) but with appropriate geographic names. The "Goweran" Series was subdivided from top to bottom into Bertram, Anamosa, and Le Claire, without comment as to equivalency of the units included.

Norton, with Simpson (1912), listed the Silurian System in his stratigraphic column, with no mention of series or group, and indicated but two formations present, the Niagara Dolomite and an overlying Salina Formation. Up to this time the term "Niagara" had been used to indicate all units from formation to series.

The first reference to strata now considered to be Lower Silurian in the state of Iowa was made by Savage (1914). At that time he subdivided the basal Hopkinton into two units which he considered to be of Alexandrian age. The lower unit was designated Winston, the upper Waucoma. At the time of the designation Savage recognized their equivalence to previously named units in Illinois but considered them to be depositional products of another province, as suggested by Schuchert (1910) and Ulrich (1911), and therefore worthy of separate appellations.

Howell (1924) noted the occurrence of the Alexandrian in Iowa in his columnar section. No units were named and the interval was described as 0 to 40 feet of limestone and dolomite. This is probably the interval now recognized as the Edgewood Limestone.

In 1926 Savage recognized the equivalency of the Winston Dolomite with Edgewood and the Waucoma with Kankakee (Brassfield), and recommended abandonment of the former terms.

This was followed by a paper by Kay and Apfel (1929) which listed Upper Silurian strata for the first time. In their chart they listed Cayugan with a question mark and the notation that it was nowhere exposed. The Niagaran Series was represented by the Gower and Hopkinton formations with the Alexandrian represented by the Waucoma Formation. A paper by Norton (1935) included this same section.

That same year Sutton (1935, p. 275) presented the Iowa section as it appears today, bracketing Savage's old terms for western Illinois beneath the Kankakee (Brassfield) and the Edgewood. Sutton did not recognize any Cayugan in the state of Iowa, but considered the Bertram a part of the Niagara.

Scobey (1938), in his study of the Alexandrian, agreed with Savage's correlation of Winston for Edgewood. However, he placed the Waucoma as also equivalent with the Edgewood.

In the National Research Council Correlation Chart (1942) Savage retained the Niagaran Series of Sutton but listed the Alexandrian representatives as Winston and Waucoma. This is interesting in light of his previous statement of their equivalency with the Edgewood and Kankakee, and recommended abandonment (Savage, 1926).

Boucot and Berry, in an as yet unpublished correlation chart, retain the Sutton nomenclature but make changes in the stratigraphic position of these units. A comparison of this new correlation with that of Savage (1942) shows these important distinctions. The Winston (Edgewood) and Waucoma (Kankakee) of Savage (1942) are placed in lower, but not lowest Llandovery, and the hiatus separating the Waucoma (Kankakee) Limestone from the overlying Hopkinton extends nearly to Wenlockian. The Hopkinton, together with the Gower-Bertram, extends to nearly middle Ludlovian. In contrast, Boucot and Berry place the Edgewood at the base of the Llandovery, the Edgewood and the overlying Kankakee extending nearly to the top of the Llandovery (C-4). The overlying Hopkinton Dolomite is separated by a much narrower hiatus beginning in upper C-5 of the Llandovery and extending through to uppermost Wenlockian. The overlying Gower Dolomite includes all of Ludlovian time.

The Gower Dolomite

The Gower Dolomite was named by Norton (1899), but the history of the unit begins in 1858 when Hall and Whitney described and named the "Leclaire", which was later to be designated as a facies of the Gower, as follows (1858, p. 73):

> A gray or whitish limestone, sometimes yellowish gray on fresh fracture. The whole mass is semicrystalline, very porous, and vesicular from the solution and removal of fossils. It is sometimes so extremely and uniformily vesicular as to resemble the porous lavas or amygdaloids. The surface is harsh to the touch, and, on fresh fracture, has the sharpness and harshness of a siliceous rock. It would nevertheless appear to be a magnesium limestone, but is reputed to make the best lime in that region of the country.

As a result of the present study, the description of the Le Claire might be amended as follows. The Le Claire facies is a hard, brittle,

Figure 2. Fretwork resulting from weathering of Le Claire dolomite. This exposure is in Wapsipinicon State Park, near Anamosa, in Jones County.

dolomite ranging in color from light gray through pinkish-, bluish- and yellowish-gray to dark gray, locally weathering to light yellowish-brown. In most localities it has a vesicular or porous texture, caused by the removal of fossil remains, which is usually accentuated by weathering (see fig. 2). However, the Le Claire occasionally is quite dense. Its texture ranges from microcrystalline to coarse, with the rock of finer textures fracturing subconchoidally. The Le Claire has a harshness to the touch which reminds one of a siliceous rock; however, chert is almost entirely absent. This facies can be found either as biohermal masses which consist of a central massive core with peripheral dipping but well stratified flanks, or it may be found as essentially flat-lying strata.

Hall and Whitney (1858, p. 76) also noted but left unnamed "a thin and evenly bedded drab-colored limestone," which is now designated as the Anamosa facies of the Gower. Hall and Whitney considered this unit as overlying the Le Claire.

Norton (1895) reported the presence of both units in Linn County and discussed their possible equivalency. However, because of the lithologic and biotic differences, he resisted the practice of some authorities to use the term Le Claire for both units.

The following year Calvin (1896) named the drab-colored dolomite Anamosa. Though noted by Hall and Whitney, and named by Calvin, the Anamosa was best described by Norton (1901, p. 305):

> [It] consists of soft, laminated, light buff, granular limestone . . . the texture is porous or vesicular and the luster dull, relieved by occasional shining facets of minute crystals. Bedding planes are even and parallel and commonly the rock quarries to dimension stone a foot or less in thickness. Joints are distinct and vertical. Fossils are exceedingly rare. Fucoid markings are sometimes seen, and surfaces are not infrequently covered with small rod-like, flexuous bodies, whose nature is a matter of conjecture.

Although not mentioned in the descriptions, chert is found in the Anamosa as bands or disseminated nodules. This characteristic is in marked contrast with the Le Claire in which chert is exceedingly rare.

By 1899 Norton was convinced that the Anamosa and Le Claire were indeed "lithologic phases of contemporaneous deposition" (p. 422). The following year in the Cedar County Report of 1901 he suggested the name Gower for a formation which would include both of these units (p. 304):

> It receives its name from Gower Township, Cedar County, where its various lithological phases are well developed . . . It includes the beds which have been designated as the Anamosa in the earlier reports of the Survey, together with those long known as Le Claire.

These two units have also been referred to as reef and inter-reef facies by several authors (Sutton, 1935, p. 236):

> The Gower is represented by two distinct lithologic phases, (1) the Le Claire, and (2) the Anamosa and Bertram formations. The former represents the 'reef' type and the other two divisions consist of the more normal type of sediments deposited away from the 'reefs'.

Such a connotation is, however, an oversimplification not supported by the field evidence nor the literature. Calvin (1896, p. 51) mentioned the fact that the Le Claire "differs from every other limestone of Iowa in *frequently* exhibiting the peculiarities of being obliquely bedded on a large scale" (my italics). Norton (1899, p. 424) remarked:

> A distinguishing characteristic of the Le Claire rock is the absence or abnormal disposition of its bedding plane. Like the Racine limestone of Wisconsin, it *often* forms high mounds in which scarcely a trace of stratification is visible (my italics).

Nowhere, however, was it suggested that oblique or abnormal bedding alone characterized the Le Claire. The clearest possible injunction against equating reef structure with the Le Claire facies was made by Norton in 1901 (p. 306), who, after mentioning the mounds of unstratified material, noted:

> A second aspect of the Le Claire is thus presented in which it is distinctly stratified . . . In this phase the layers may lie, as in the Anamosa, nearly horizontal, but commonly they are inclined or tilted, and sometimes at angles surprisingly high.

Le Claire lithology is present over wide areas of Clinton County, at least, as nearly horizontal, evenly bedded strata. In fact, most of the Le Claire presently exposed in the town of Le Claire, its type section, consists of essentially flat-lying, well bedded dolomite.

The Gower has been and continues to be of great importance in the state. Hall's and Whitney's 1858 report noted that the Le Claire was reported to make the best (quick) lime in that region of the country. The Anamosa phase was also important, as it was quarried as dimension stone for foundations, bridge piers, and buildings. In fact it was known locally as "the building stone of the Niagara" for many years. Many large quarries were opened to extract either or both facies. Some supported sizeable communities, such as that at Stone City where the Anamosa phase was quarried extensively and where the type section of the unit is located. The community of Cedar Valley arose adjacent to the Cedar River because of the extensive Bealer quarries which extracted both Le Claire and Anamosa and which became the type section of the Gower. In southern Cedar County on Sugar Creek, Lime City arose at a place where both facies were quarried. These are but a few examples of many such communities supported entirely by or greatly dependent upon quarrying of the Gower.

With the decline of both the quick lime and building stone industries these communities have dwindled. The town of Cedar

Figure 3. Quarrying operation at the Weber Company Stone Quarry, Stone City, Jones County, Iowa. This quarry is operated in the Anamosa facies of the Gower Dolomite. The evenly bedded dimension stone in the foreground is typical of the unit.

Valley has almost vanished, but two of the lime kilns still stand. The Bealer quarries are now water filled. The type section of the Gower has been thus obscured. The town of Lime City has also disappeared though several local quarries are now in operation in the vicinity. Stone City remains as a very small community with two or three operating quarries (see fig. 3). Some of the original buildings still stand, made from the very stone which built the town.

However, the death of the quick lime business and decline of the building stone industry has not meant abandonment of quarrying in the Silurian of Iowa. The road building industry, together with the advent of commercial blasting powders and the introduction of modern crushing machinery, has allowed a change of emphasis in the trade which has seized upon other characteristics of both facies which make them of considerable importance today. The Anamosa, soft and granular, is now being used widely as agricultural lime and to a limited extent for road metal, although generally it is inferior for this use. The Le Claire, because of its toughness and purity, is in great demand as concrete aggregate and road metal. The resurgence of demand for these facies of the Gower has resulted in the reopening of many of the old quarries and a search for many new quarry sites.

PREVIOUS INVESTIGATIONS OF BIOHERMS

Introduction

Organic mounds of bioherms have been noted in the literature for over 100 years. The earlier discussions of ancient features attributed their origin to causes ranging from mineralization to tectonics. This controversy could be typified as the organic versus inorganic origin problem. The general acceptance of the organic origin of these structures came rather slowly despite concurrent investigations on modern reefs (Darwin, 1842; Agassiz, 1852; Murray, 1880, 1888; etc.) which pointed up the striking similarities between the ancient and modern structures.

After an organic origin had been accepted generally, a second controversy arose concerning the relative conformation or relation of the structure to the surrounding strata at the time of formation. This later dispute might be termed the reef versus bioherm controversy.

The Bioherm Controversy

In 1842 Darwin published his Structure and Distribution of Coral Reefs, a treatise on modern corals and the structures they develop. Darwin made no mention of any possible ancient counterparts, however. This work stimulated interest in reef study and initiated a debate on the origin of the coral islands of the Pacific which is yet to be resolved.

The following year James Hall (1843) described a mass and accompanying arching of strata in the Lockport (Niagara) Limestone two miles south of Lockport on the Erie Canal. Although the accompanying diagram showed typical biohermal structure and Hall's report noted the presence of corals, he considered the structure to have been caused by mineralization. The earliest reference to such structures as reefs was made by Murchison (1847) in his paper on the Silurian rocks of Gotland.

The Silurian structures of Iowa were observed early in the history of biohermal investigation. Hall and Whitney (1858, p. 74), in their report on the Geological Survey of Iowa, described a new stratigraphic unit in the town of Le Claire (on the Mississippi River). They characterized the exposure as "in a folded and uplifted condition . . . as it approaches and recedes from the anticlinal and synclinal, the dip varies from 5-35°." Working on that assumption Hall and Whitney estimated the unit to be in excess of 600 feet in thickness. It is this and other structures like it which now are accepted to be of organic rather than tectonic origin. Before this acceptance, however, came a long period of disagreement and controversy. Worthen (1866), for example, believed that Hall had mistaken the lines of false bedding for true stratification since the unit was nowhere known to exceed 80 feet in thickness. But White (1870) after observing the Le Claire in two localities where dipping strata were present, agreed with Hall's original hypothesis. White stated (p. 183) that:

> A line of disturbance of the strata of this formation passes into Iowa in a direction almost corresponding to the direction of its trend; crossing the Mississippi River at Le Claire, and being last recognized in the valley of the Wapsipinicon about 3 miles west of Anamosa. This disturbance apparently partakes more of the nature of an abrupt fold than a true fault, leaving the general dip of the strata on each side of its axis seemingly unchanged from what it would have been if the disturbance along the axis had not taken place.

Had White investigated the area between Le Claire and Anamosa he would have seen hundreds of isolated quaquaversals which would have made his conclusion untenable.

By 1877 the controversy had gone full cycle with Chamberlin's discussion of Silurian bioherms in his work on the Geology of Eastern Wisconsin (p. 364).

> It seems to be possible to draw but one rational conclusion . . . (1) that the last mentioned irregular mass stood as a reef in the depositing sea; and (2) that the alternating layers were deposited on its slope, while (3) these, in quiet waters at a little distance from the reef, were replaced by a deposit of finer silt which formed the compact layers. The unusual phenomena of cross lamination harmonizes with this view.

Chamberlin's paper is a classic and his ideas are the basis of many of the more modern studies of similar structures. Although almost all of his conclusions are currently accepted, they met with resistance initially.

A closely parallel hypothesis for the origin of these structures was put forth by Ringueberg (1882). He noted the lenses of fossils in the Clinton and Niagaran and although correctly concluding the mounds were organic, believed them to be accumulations of organisms swept together by eddies and currents.

Growing concurrently with the organic hypothesis of origin was the idea that "reefs" were formed principally or entirely of corals. Work by Guppy (1887) and Gilbert and Gulliver (1895), to name a few, refuted this idea, but the misconception persists even today.

In 1895 Norton published his Geology of Linn County which reviewed three hypotheses to explain the "deposition of the Mt. Vernon (Anamosa) beds in these deep hollows of the Le Claire" (p. 134).

(1) The theory of unconformity with a long time interval during which the troughs in the Le Claire were eroded.

(2) By unconformity, the troughs in the Le Claire formed by synclinal folds.

(3) By simultaneous deposition of the two limestones under different conditions, the "Limerock" (Le Claire) representing the irregular aggregations of coral reefs, and the granular (Anamosa) limestone, off-shore deposits of calcareous sediments derived largely from the reefs.

Norton concluded that paleontological evidence together with lithological graduation between the two phases precluded the first two possibilities, leaving the third most acceptable but not, officially at least, accepted. The controversy over origin of the bioherms continued through the late 1800's and into the early 1900's.

The definitive work on biohermal structures was published in 1928 by Cumings and Shrock. They began their investigations of the structures in Indiana. The resulting paper put to rest most of the remaining questions covering the organic origin of these structures some eighty years after Murchison suggested such an origin for the "reefs" of Gotland, and fifty years after Chamberlin's masterful work leading to the same conclusion.

Cumings' and Shrock's paper, though settling one problem, presented another which has yet to be resolved. The authors coined the term "bioherm" for these structures. They recognized the ambiguity of the terms "reef" and "coral reef" (p. 599).

> Reef has many other connotations and coral reef encourages the common misconception that reefs are largely made of coral, whereas many of them were formed by other organisms . . . The authors have for some time used the term "bioherm."

An explicit definition of the term "bioherm" was given by Cumings (1930, p. 207).

> A bioherm . . . is defined as consisting of any dome-like, mound-like or otherwise circumscribed mass, built exclusively or mainly by sedentary organisms such as corals, stromatoporoids, algae, brachiopods, mollusca, crinoids, etc. and enclosed in normal rock of different lithologic character.

Debate arose concerning the merits of the terms and possible criteria to determine if indeed a bioherm was a reef. The addition of another term, "organic reef", was proposed to include organic structures which stood above the surrounding floor, leaving "reef" to cover inorganic features of the same configuration and "bioherm" for organic mounds which may or may not have stood above the surrounding sea floor. In an effort to clarify the problem, Cumings (1932) drew attention to the wide usage of the term "reef" (p. 332).

> . . . . The geological literature of the past quarter of a century contains every possible application and misapplication of the terms "reef" and "coral reef." We find innumerable writers using the term for bedded structures that certainly did not rise above the surrounding sea bottom and consequently do not fit any admissible definition of either reef or coral reef; . . . totally inorganic structures such as the reefs of the navigator; the edges of highly inclined layers of rock, such as the "reefs" of the Australian gold mines . . . The dictionary meaning of the word *"reef" . . . a narrow ridge or chain of rocks, shingle or sand lying at or near the surface of the water* . . . There is no intimation, nor should there be . . . that the structure is organic or otherwise; but there is the clearest possible

> specification that it is a structure rising close to the surface of the water, from presumably navigable depths, and having a ridge-like or rib-like form.

In other words, a reef must stand above the surrounding bottom and extend up to near the water's surface. A bioherm, on the other hand, need display no such characteristic. The bioherm's fossilized remains, however, would look the same when surrounded by another lithology, since both reef and bioherm would be mound-like in outline. Therefore all organic reefs are bioherms, but not all bioherms are reefs. Cumings (1932) reviewed and discarded two terms proposed previously: "chapeiro", proposed by Fenton (1931), was not acceptable since the original features described by Hartt (1870) were small and slender and would never compare with the Indiana structures; the term "klint" also was deemed unworthy since in its original usage it denoted a topographic feature rather than a sedimentary form. Cumings coined a term for bedded organic structures (1932, p. 334).

> For purely bedded structures, such as shell beds, crinoid beds, coral beds, etc., consisting of and built mainly by sedentary organisms, and not swelling into mound-like or lens-like forms, I propose the name "biostrome."

Despite the careful phrasing of Cumings and Shrock (1928) and Cumings (1932) the terms "reef", "organic reef", and "bioherm" were thoroughly confused in the literature. Ladd (1944), in an effort to correct the situation, restated the case for the terms "bioherm" and "biostrome." He also suggested that in studying elevated organic structures the term "reef" be applied only to the structures that show clearly that they were wave-resisting structures.

The premise that bioherms are the result of organic agencies—principally the algae, coelenterates, bryozoans, echinoderms, brachiopods, and molluscs—now is nearly universally accepted. The controversy over the terms "reef" versus "bioherm" remains though it need not. If the original letter and spirit of the definition of bioherm (Cumings, 1930 and 1932), and further amplified by Ladd (1944), were followed, no problem would exist.

TYPICAL EASTERN IOWA BIOHERMS

Introduction

The Silurian bioherms of eastern Iowa are low, oval mounds with diameters that range from a few tens of feet to approximately a quarter of a mile. Because of truncation of the tops of the bioherms on the one hand and no exposures of the bases on the other, the maximum height has yet to be ascertained. The bioherms consist of two parts: a central core and flank beds. The core is composed primarily of unstratified, porous, well fractured, highly fossiliferous dolomite. The fauna consists predominantly of sessile organisms which include coelenterates, echinoderms, brachiopods, and molluscs. Clay is found along fractures or bedding planes or in solution cavities in varying amounts together with boulders.

Peripheral to the core are flank beds which are well stratified and dip radially away from the core, abutting against it on the one hand and merging with the flat-lying inter-reef facies on the other. The flank beds usually are less porous than the core, contain fewer and smaller voids, and also are less thoroughly fractured. The material of the flank beds is lithologically quite similar to that of the core and can be distinguished from it solely on the basis of the stratification of the flank material. The flank beds are also fossiliferous; echinoderms and brachiopods are the dominant fauna with the coelenterates much reduced in number and usually present as transported debris.

The Silurian bioherms of eastern Iowa generally are smaller than those of similar age described in Indiana (Cumings and Shrock, 1928, and Cumings, 1930) and Illinois (Lowenstam, 1949, and Carozzi, 1960) and approximately equal in size to those described in Wisconsin (Chamberlin, 1877, and Shrock, 1939). They are much larger than the Niagaran "reefs" noted in the vicinity of Lockport, New York (Kindle and Taylor, 1913 and Zenger, 1965).

The reduced size of the Iowa bioherms, as compared with the Illinois and Indiana structures, is compensated for by their great number. In a 24-square mile area in Cedar County, 17 bioherms have been located in an area which is thickly mantled with glacial drift. (See fig. 1 and fig. 4.) It appears that in many areas the occurrence of these structures would average one or more per square mile. The outcrops occur along the drainage network, the result of attendant thinning of the overburden. This type of exposure gives an apparent delineation to the biohermal distribution which does not, in fact, exist.

Although all of the bioherms studied display similarity in over-all architecture, lithology, and fossil content, each exhibits differences which collectively preclude a general characteristic description. For this reason four bioherms, which appear to represent the range in variation of these structures as they occur in eastern Iowa, are described: Mitchell quarry, Hunt quarry, Brady quarry, and Sneckloth quarry.

Typical Iowa Bioherms

Mitchell Quarry

The Mitchell quarry, south of Lisbon, Iowa (NE¼ sec. 24, T. 82 N., R. 5 W., Linn County), offers a rather unique cross section of a bioherm. The quarry has been cut through both flank and core rock and the relationship of the two is exposed.

The bioherm consists of light gray to yellowish-gray dolomite which weathers to medium gray and various shades of light brown. The rock is very fine to coarsely crystalline with textural variation in both flank and core much wider than any detectable difference which might separate them. The rock is very hard, breaks into sharp subconchoidal fragments, and contains pores which appear to be divisible into two groups: tiny pores, in the millimeter range, and much larger cavities with dimensions in inches and feet. Stylolites are present in core and flanks.

The porosity probably owes its origin to three general causes: solutional removal of fossils, secondary brecciation, and dolomitization. Most of the small vugs are a result of solution while the larger vugs have been formed by solution and brecciation. The role of dolomitization in the origin of porosity is problematic. The secondary brecciation has promoted solution, which has increased porosity of the facies and has resulted in the accumulation of green clay in many fractures, vugs, and slumps. Secondary growth of medium to coarsely crystalline dolomite has proceeded in several zones to the extent that no original structures or outlines remain.

The core lithology is the most prominantly exposed. It is characterized by lack of stratification and the presence of numerous larger vugs. Because of the abundant vugs and intense secondary brecciation the core has the appearance of a mound of poorly sorted and loosely compacted coarse debris. Despite this first impression close examination reveals few instances of primary brecciation or transportation of materials coarser than grit size.

The core is surrounded by inclined stratified flank deposits. Nearest the core the dips of the beds range from 31° to 45° and decrease

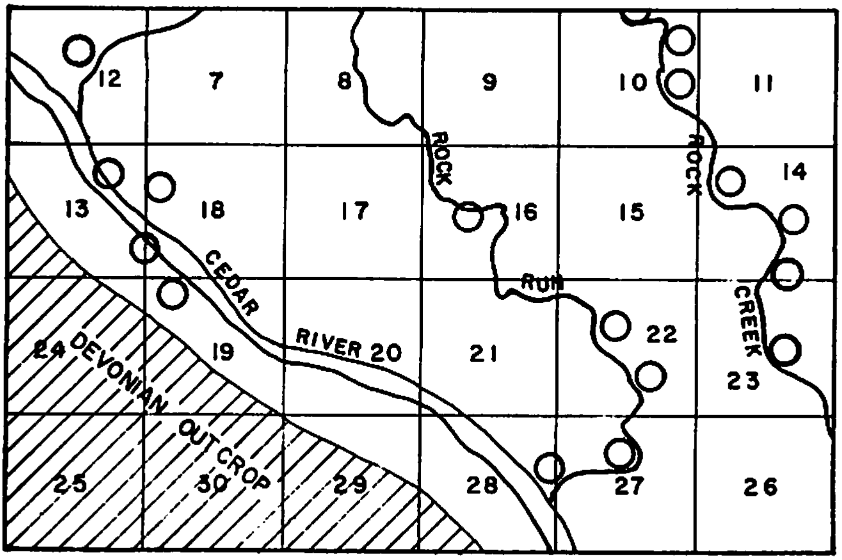

Figure 4. Distribution of bioherms in a 24-square mile area of Cedar County. The seeming linearity of their distribution is the result of their exposure by streams.

to 9° to 12° at the most distant exposures of flank beds. The presence of stratified layers and the reduced size of the vugs in the flank beds are the most obvious differences between core and flank. The beds range from 2 feet to 6 inches in thickness; the thicker beds are nearer the core. These thicker beds also are more irregular than the flank beds more distant from the core. Most of the features of solution and secondary brecciation are confined to the core portions. However, local slumps with contorted bedding and clay-wrapped, solution-pitted boulders are present in the flanks. Along the western face of the quarry the flank beds overlay an unstratified mass separate from the main core. This may represent either an isolated boss of the main core or a separate core which constitutes a portion of a small reef complex.

Quarry faces which expose core rock are severely fractured in the Mitchell quarry. Fractures are present also in two other quarries in which core rock is exposed. In all places vertical fracturing is most prominent. Other quarries which expose only flank beds show little natural brecciation. The fractures appear to be a phenomenon which is associated with the core facies. T. C. Chamberlin (1877, p. 362) observed a similar predominance of vertical fracturing in Wisconsin. This fracturing, together with the dolomitization, obscures any primary brecciation. Nevertheless, a close examination of the biohermal mass, both core and flanks, fails to disclose the presence of any large fragments that could be attributed to erosion contemporaneous with reef development.

Crinoids are a conspicuous faunal representative, in many places so abundant that isolated columnals and continuous lengths of stem make up the rock in its entirety. The calyces are less abundant and are very poorly preserved. Crinoidal debris can be found almost everywhere in the quarry and certainly everywhere fossils are present. They are more abundant in the flanks and the upper portions of the core than in the central mass. The coelenterates constitute another important faunal element. Both stromatoporoids and corals are present; the corals are represented by favositid, halysitid, and diplophyllid types as well as solitary rugose corals. The stromatoporoids are unidentifiable because of the obliteration of their structures by dolomitization. Here and in the Hunt quarry the stromatoporoids are most numerous and made an important, if not preponderant, contribution to the fauna. Most of the corals and stromatoporoids appear to be in their living positions. Some rolled associations of tabulate coral and stromatoporoids were observed, however. The coelenterates are most abundant in the upper portions of the core.

The fauna also includes brachiopods, which are numerically insignificant to the total but are locally abundant; the brachiopods are concentrated along bedding plane surfaces in the flank beds and also are present within the beds either as single faunal elements or mixed with crinoidal debris. The brachiopods include rhynchonellid, atrypid, trimerellacid, and spiriferid types, all rather poorly preserved as casts or internal and external molds.

Cephalopods, gastropods, cystoids, bryozoans, and trilobites are present also, but they play relatively minor roles. No traces of algae were noted, but this is to be expected in such intensively dolomitized rocks and does not preclude their existence.

Hunt Quarry

The Hunt quarry (center sec. 10, T. 81 N., R. 4 W., Cedar County) is cut almost entirely into core rock with flank beds exposed only along the tops of the surrounding quarry walls and in an old cut in the southwest corner of the quarry.

The rock of the Hunt quarry is, with few exceptions, indistinguishable from that of the Mitchell quarry. The texture ranges from very fine to coarsely crystalline, again without any systematic variation

Figure 5. Typical core facies in the Hunt quarry, Cedar County, displaying molds of favositid corals and stromatoporoids. The smaller pores mark the removal of brachiopod and pelmatozoan remains.

which might separate flank from core. An additional similarity is the presence of numerous stylolites. Generally, the porosity is slightly higher than that at the Mitchell quarry because of an increase in the size of pores and in the number of them present. The greater porosity is attributed to the solution and removal of the coelenterate fauna which was present in greater numbers than at the Mitchell quarry. This solution of the coelenterates has resulted in the development of lenticular to oval vugs whose diamters range from a few inches to more than 2 feet (fig. 5). Most of these are oriented in growth position with their long dimension in a nearly horizontal direction. Often these vugs occur in discontinuous planes which gives the affect of interrupted bedding in many exposures. These vugs may contain nearly complete specimens of the fossils but more commonly contain "ghosts" or recrystallized molds of the animals. Many of the small vugs which were formed by the same process on smaller fauna have been entirely closed by the redeposition of medium to coarsely crystalline dolomite. Some vugs remain as external molds which faithfully reproduce the removed fossil's external morphology, but most vugs contain a drusy coating of crystalline dolomite.

Also present are bands, 2 to 3 inches thick, which consist of calcareous grit ranging from 1/2 to 3 millimeters in diameter. These bands are fossil debris, essentially crinoidal, which have been dolomitized. The structure has been obliterated further by the interstitial growth of dolomite.

Here, as in the Mitchell quarry, there is a decrease in porosity in the flank beds. The decrease is more striking here because the core contains more abundant coelenterate fauna which is the conspicuous contributor to the porosity.

The fauna of the Hunt quarry is the most profuse, both in number and in kind, of any quarry investigated. Preservation, typical of the Le Claire, is poor. The fossils consist of internal and external molds and casts which display only the gross morphology. Some of the best preservation is in pockets of light yellowish-brown, Anamosa-like lithology, where concentrations of brachiopods and molluscs are found in well preserved profusion. The softer rock in these pockets parts easily which permits easy collection of nearly complete fossils. As would be expected in a core, framework organisms are prominent.

Stromatoporoid and favositid-type corals are abundant, pitting the face of the quarry with "ghosts" and external molds (fig. 5). Favositid colonies as much as 2 feet in diameter and stromatoporoid remains whose diameters are in excess of 4 feet are present. The stromatoporoids are displayed as narrow, lenticular bands; the favositids generally are narrow but with a greater vertical development which produces an inverted pyramid or cone-shaped outline. These forms appear to share equally the role of major faunal element and in places amount to half the volume of the rock. Their orientation in parallel, discontinuous bands is a striking feature, giving a pseudo-stratification to the rock (see fig. 6). Although stromatoporoids and corals are present in flank beds, they are much smaller (2 to 3 inches in diameter) than those present in the core and many appear to have been transported.

Diplophyllids, heliolitids, zaphrentids, and the stromatoporoid-tabulate association described in the Mitchell quarry are present also.

Crinoids are second only to the coelenterates in abundance; columns and columnals are the most predominant, but many molds and casts of calyces also are present. As with the coelenterates, the crinoids are concentrated in bands, particularly in the flank beds. The highest concentration of crinoidal remains occurs in the flank beds, as in the Mitchell quarry.

The molluscs constitute a third faunal element, represented by orthocone, cyrtocone, and brevicone cephalopods; gastropods; and pelecypods. The cephalopods, with few exceptions, occur in "nests" of three or more; the gastropods also occur in concentrations. These concentrations are no doubt a death association in places of local quiet-water conditions. Though both cephalopods and gastropods are found in the Mitchell quarry, the variety of these groups found in the Hunt quarry is much greater. A pelecypod fauna, which is lacking at the Mitchell quarry, occurs here.

Brachiopods are represented by rhynchonellid, spiriferid, and pentamerid types, which are preserved as casts and external molds. The brachiopods appear to be more abundant in the core portion than in the flanks, but this may be a result of a much higher ratio of core exposure.

Fenestellid bryozoans also are present but are rare. Those observed are in the core.

The similarity of the exposure here and at the Mitchell quarry is noteworthy. The most obvious similarity is that of the fauna found at each. Both contain large amounts of stromatoporoid and coralline fragments, which are much less abundant in non-core outcrops. However, the Hunt quarry shows a higher total coelenterate content than does the Mitchell. There is also an apparent variation in faunal balance in that diplophyllids are more prominent here than in the Mitchell quarry. Whether this represents a genuine variation in faunal balance or is merely a function of exposure or preservation is conjectural. A. J. Boucot (1964, personal communication) believes that the fauna of the Hunt quarry is older than that of the other quarries described. Perhaps age differences also may explain faunal variations. There are other slight variations in fauna. Pelecypods are found in several locations in the Hunt quarry and none are found in the Mitchell quarry; the Mitchell's fauna includes some *Bumastus* and *Calymene* fragments and the Hunt assemblage is without any trilobite representatives. These slight differences, whether apparent or real, are more than outweighed by the similarities in the types and distribution of the majority of the fauna.

Like the faunal similarity, and related to it, is the close correspondence in visible porosity. Both quarries have the highest porosity

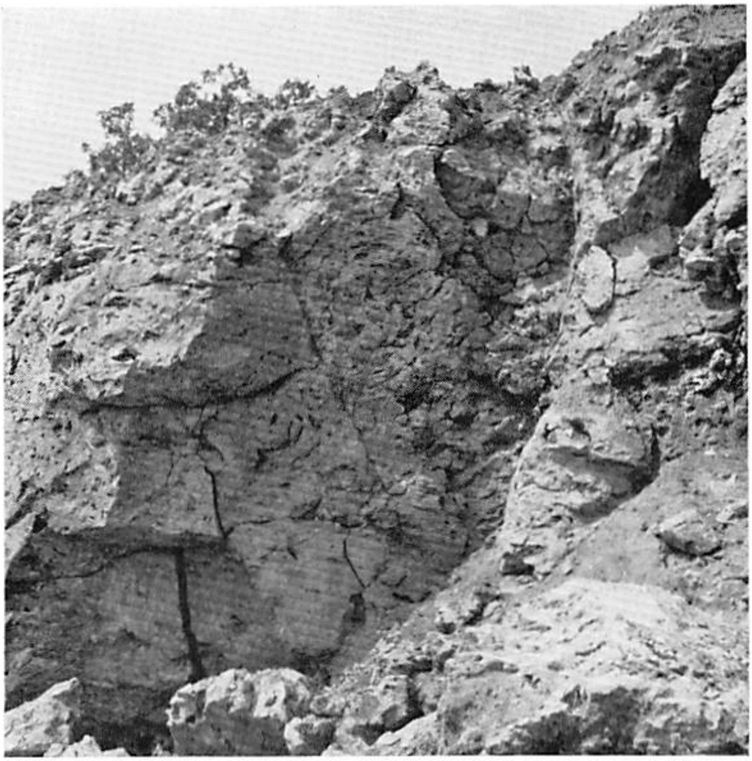

Figure 6. Biohermal core displaying nearly parallel orientation of favositid coral molds which approximate stratification, and also pronounced vertical fracturing as typical of cores. Hunt quarry, Cedar County.

in total volume and in size of the pores in the biohermal core. Both show a decrease in size of the pores and total porosity away from the core. As observed in the Mitchell quarry and corroborated in this quarry, the most obvious porosity is that due to removal of fossil remains by solution. Since size of pores derived from this source is controlled by the size of the fossil, it is obvious that the larger pores would develop where the larger faunal elements were concentrated, in the core. The few large pores in the flanks are derived from isolated fragments of the coelenterates which either grew on or were transported to the flanks. The cores also contain a great number of the smaller pores due to the removal of the crinoidal and brachiopodal fragments. This porosity is over-shadowed by the porosity due to larger vugs but is probably nearly as important in total pore space. These two vug types, as well as voids which are derived from fracturing and solution in the fracture system, combine to give the core rock a very high degree of porosity and moderate to high permeability. The flank beds, deprived of most of the large vugs and with reduced fracturing, owe almost all of their porosity to the formation of small vugs. The distribution of porosity is primarily a function of the distribution of the faunal elements, although fracturing is an important source of pore space also.

The fracture pattern is another incidence of similarity between the Mitchell and Hunt quarries, both in size of the fragments produced and in the predominantly vertical orientation of the fracture system (fig. 6).

Still another similarity between the two quarries is the clay pockets which occur so commonly in the core facies and occasionally in the flanks. These pockets develop in the parallel fracture systems and contain limestone fragments which show the effects of solution.

The chief difference between the Hunt and Mitchell quarries is the vaguely defined, stratified arrangement of the coelenterates which occur in portions of the upper surface in the Hunt quarry and which do not occur in the Mitchell quarry. Lowenstam (1957) mentions similar "sheety growth" in his study of Niagaran reefs in the Great Lakes area.

Because of the similarities between core exposures, generalizations can be made regarding the core rock. First, the fauna is much larger in number and in types than that of the flank facies. Second, core rock has a higher porosity than that of the flanks, due both to solution of fossil fragments and to brecciation. Third, the faunal content of core rock is constituted predominantly of sessile organisms which include coelenterates, echinoderms, and brachiopods. Coelenterates are the dominant organisms. Fourth, brecciation with vertical fractures predominant is characteristic of biohermal cores.

Brady Quarry

The Brady quarry (SE¼ sec. 14, T. 80 N., R. 3 W., Cedar County) has been cut into the western flank of a biohermal structure which forms a bluff along the bank of Rock Creek. The course of the stream is controlled by the bioherm. As the stream encounters the structure, the course of the stream parallels the strike of the flank beds. The manner of opening the quarry resulted in the exposure of flat-lying Anamosa lithology which grades into Le Claire lithology of flank-bed type and into core rock.

Typically the Anamosa is a fine-grained, thin-bedded, well stratified dolomite. It is light yellow to moderate yellowish-brown in color with a moderate to high porosity. Fossils are rare to lacking in this facies. The Anamsoa is soft and in many places friable. The Le Claire is a very fine-grained, thin-bedded to massive dolomite. It is light gray to light bluish-gray in color. Fossils, though less abundant than in previously described exposures, are present. The Le Claire is extremely tough and fractures with the difficulty and subconchoidal fracture of a chert.

The contrasts between the Anamosa and Le Claire are quite apparent; color is the most obvious difference. The interfingering of the Anamosa and flank beds of the bioherm can be seen even from a distance as a result of this color difference.

The flank rock is thinly bedded; strata which are 2 to 6 inches thick are most common. The bedding generally is even and persistent, but thins locally. Although only moderately fractured, the flank beds contain some bedding plane grooves and several flexures of varying magnitudes indicative of post-depositional movement (fig. 7). Clay pockets which contain limestone fragments are present along bedding planes and fracture systems, but the total clay content is lower here than in the core. The flank beds also contain two unstratified mounds near the top of the exposure. Because of their inaccessibility their detailed structure, hence origin, can only be speculative. One exposed on the north wall appears to be a slump feature. A 2- to 3-foot thick sequence has arched upper beds and brecciated and disrupted strata forming the core. A much larger feature on the south wall near the top of the quarry face (fig. 8) does not include flank strata and appears to truncate them. Because there is no other evidence of pronounced turbulence it is unlikely that the material consists of large fragments transported from the core. It seems more probable that the mound represents a "satellite" core developed on the flanks, or an extension of the main core itself which advanced over the flank beds at their expense.

The core is highly fractured, and brecciation here is the most intense observed at any exposure. These fractures are filled with clays amounting to nearly one half of the total rock volume in some portions of the core. The vugs, which are so typical of the core at other exposures, are greatly reduced in numbers. Those present are of the small vug variety, a type characteristic of the flanks of the other bioherms observed. As a result, even from a distance both the core and flanks have a much denser appearance. This difference in pore size is perhaps the most immediately obvious contrast with the other bioherms and reflects the faunal contrast, which also is quite sharp.

Figure 7. "S" fold, north wall, Brady quarry, Cedar County.

Coelenterates as a whole are greatly reduced in type and number. Diplophyllids, which are present in very minor numbers in the Hunt quarry, are the most abundant coral, accompanied to a much lesser degree by ramose favositid and zaphrentid types. The diplophyllids occur as short fragments of columns 1/2 to 2 inches in length and one-half inch in diameter. Nearly every specimen appears to have been transported and none demonstrably occur in growth position. The coelenterates in total constitute less than 10 percent of the rock, and only in local concentrations amount to more than 30 percent. The distribution of diplophyllids appears to be without pattern since they are present in about equal numbers in the flank and core.

The stromatoporoids which are common in the Mitchell quarry and abundant in the Hunt quarry are absent in the flanks and core exposures of the Brady structure. Also conspicuous by their absence are the pelmatozoans, and greatly reduced in number are the favositids which occur only as rare fragments.

Figure 8. Isolated "satellite" core, overlying and truncating typical flank beds, Brady quarry, Cedar County.

The other, perhaps largest, faunal element is the brachiopods. Their representation is closely parallel to previously mentioned quarries. Spiriferids, rhynchonellids, and atrypids are present. They are, however, reduced in total number and can be found only very locally in high concentrations. As before, they are preserved as external molds and casts and are present in the flanks and core. The cephalopods are sparse and are represented by a few orthocones. Gastropods and bryozoans are rare and no pelecypods have been found. A single receptaculitid and one ischaditid specimen have been collected in this quarry. These latter forms are noteworthy in their uniqueness, as they are the only specimens of these types observed in this study.

A problematic feature which may or may not be organic is much in evidence along bedding planes in certain portions of the flank beds. This feature consists of a network of tubules 15 to 20 millimeters in length and 2 millimeters in diameter which veneers the bedding-plane surfaces and which Norton (1901, p. 305) described as "small rod-like flexuous bodies whose nature is a matter of conjecture." They cover many bedding planes in the flanks with as much as 3/4-inch layers of overlapping and intertwining segments. Only the gross morphology of these structures is present in even the best specimens because of dolomitization and recrystallization. The presence of these structures in the Le Claire facies is noteworthy also as they are more typical of, and commonly occur in, the Anamosa facies.

In summary, the fauna is greatly reduced both in number of genera and in number of specimens. That which is present does not seem to correspond very closely to that found in the other bioherms. It may be that the contrasts in fauna from those previously described are to some extent the results of poorer exposure. The core is barely reached in the Brady quarry. Indeed, that delimited as core shows many characteristics of disturbed flanks. Here the boundary between flank and core is picked with great difficulty while at the other exposures where bedding and textural contrasts are much more obvious, demarkation is relatively easy.

Sneckloth Quarry

The Sneckloth quarry (center sec. 4, T. 81 N., R. 6 W., Cedar County) is similar to the Brady operation in that the original quarry was operated in the Anamosa lithology with a newer pit opened in the Le Claire. The transition between the two units in this location is covered. However, portions of the west and south faces of the old south Le Claire pit expose some Anamosa beds in the top half of the top step, and the Anamosa quarry contains two bands 2 to 3 feet

Figure 9. Band of organic debris derived from Sneckloth bioherm but interstratified with typical Anamosa beds.

thick of organic and lithologic debris derived from the bioherm (fig. 9). One band can be traced across the entire quarry face. The second layer is exposed only for a short distance into the Anamosa quarry.

The attitudes of beds exposed in and around the quarry indicate that at least two bioherms are present in the area and a third may be indicated by Norton's (1901) description.

The biohermal cluster has caused a tributary of Yankee Run Creek to be deflected from its easterly course: the tributary swings to the north at the western margin of the cluster and resumes its easterly course along the cluster's northern flank.

The beds of the northern half of the quarry were deposited on the flanks of two biohermal cores lying to the east and west of the pit. The flanks dip towards each other with the center of the quarry coinciding with the axis of the "syncline." Flank rock is exposed continuously along the north, west, and south faces of the quarry. The eastern face displays some transitional material which together with the steep dips indicate the near proximity of yet-unexposed core.

The Le Claire here is indistinguishable from the materials collected and described in the previous quarries. There are local variations in the number and size of pores within the flank facies, but since the core is unexposed no inter-facies variation can be noted. The presence of chert in the Le Claire here departs from the lithology previously described. Several large boulders of undoubtedly Le Claire rock contained chert bands, a feature very rare in the Le Claire.

Clay pockets are a conspicuous feature of the quarry and appear in all faces. In the north face the effect of solution is particularly evident. The top of the Le Claire in the center of the face just beneath the Pleistocene drift displays a rather large solution hole which contains collapsed breccia and is filled with reddish-brown clays. At the base of this cut, scattered exposures indicate the presence of a very large solutional feature which contains Le Claire boulders 2 to 3 feet in diameter (fig. 10).

A second solutional feature is exposed in the northwest corner of the quarry near the top of the wall. It contains the typical solution-pitted boulders (fig. 11) which are wrapped in greenish-gray clays. Overlying the boulders, however, are stratified clays and thin-bedded, medium-grained sandstones (fig. 12).

The fauna does not closely resemble any previously described assemblage, yet it contains elements which are similar to all previous exposures. The coelenterates are represented by stromatoporoids and corals including the diplophyllids, favositids, halysitids, and zaphrentids. They are not as abundant nor as large as those of the Hunt quarry, but locally their layer-like distribution is reminiscent of that quarry. Preservation of the coelenterates is especially poor in this quarry. Crinoids are present also in the Sneckloth quarry, but they are less abundant than at either the Hunt or Mitchell quarries. However, concentrations of "dwarf" crinoid stems like those in portions of the Hunt and Brady quarries are present. In common with the Mitchell quarry is the presence of trilobites, represented by both *Calymene* and *Bumastus*.

The Sneckloth quarry is similar to the Mitchell quarry in the presence of trilobites, which have not been noted in the other

Figure 10. Typical solution-pitted Le Claire boulders displaying knobs and pits, some clay remains, Sneckloth quarry, Cedar County.

quarries, but without the abundant to dominant crinoid display in the Mitchell operation. It is similar to the Hunt quarry in its abundance of cephalopods, but it lacks pelecypods and the dominance of stromatoporoids and favositids. Its common element with the Brady quarry is the brachiopod distribution. It differs from the Brady quarry in having a much larger fauna with more elements.

The Sneckloth operation exposes new facets of Iowa biohermal architecture and development previously unnoted or very poorly displayed in the other operations. These features range from slightly enlarged fractures to extremely large collapsed cavern structures which contain solution boulders 3 feet in diameter. It is interesting that these large solutional features are present in the flanks whereas at the previously described exposures their greatest development was in the core.

Figure 11. Solution-pitted boulders wrapped in clay, Sneckloth quarry, Cedar County.

The bioherms, because of their initial porosity, were loci for solutional activity which apparently culminated in the development of caverns. The rounded debris represents collapsed breccia that was dropped into clays and silts that had been deposited in these caverns that appear to have developed at all levels within the bioherms. Those in the lower portions were filled entirely with Le Claire materials. Nearer the top, however, collapse permitted younger sediments to be dropped, or allowed running water to deposit detritus in these channels. It is assumed that the deposits of stratified clays and sandstone at the top of the face in the northwest corner of the quarry are of such origin. Farnsworth (1888) noted similar filled solution pockets in the Niagaran limestone of Clinton, Iowa. He was unable to date the deposits but noted that some contained a considerable amount of white sand which may or may not be related to that of this structure. N. H. Winchell (1873) also described several pockets and cavities in

Figure 12. Stratified solution-cave filling, Sneckloth quarry, Cedar County.

the Silurian limestone at Mankato, Minnesota. Lowenstam, *et al* (1956) noted cavities occurring in the Thornton, Illinois, klint which are filled with materials he dates as Devonian.

The layers of organic and lithic debris found interstratified with Anamosa lithology in the quarry immediately adjacent to the southwest closely resemble, except for thickness, similar features in the Brady bioherm. Their presence in the inter-biohermal facies is no doubt the result of periods of agitation which produced currents capable of transporting much coarser materials than the sands and silts normally derived from the core portion. This greater turbulence is evidenced also by the condition of the fossils present in the bands. The coelenterates, both tabulate and rugose corals, are highly fragmented, as are the crinoid stems. The only complete organisms are very small brachiopods which could have been transported and deposited intact. The presence of conglomeratic layers within the flank beds seems to further substantiate the inference of periods of increased turbulence during reef formation at this location.

SUMMARY AND CONCLUSIONS

The bioherms included in this study are believed to be typical of these features in Iowa and since no one exposure exhibits all facets of the bioherm, each was selected to display a particular aspect which, when taken together, would present a composite picture representative of all.

From a study of these structures, certain generalizations can be made regarding their size and component parts, as well as their structural characteristics. It must be said at the onset that only generalizations can be made concerning most characteristics since each bioherm presents some unique attributes which set it apart from the rest, while at the same time enough similarity is present to make their generic affinities obvious. The bio- and lithotopes indigenous to one reef were not identical with those of similar structures. Conditions, although not strictly definable, must have varied slightly in these structures as evidenced by the resultant depositional features. In this respect they are similar to variants found in modern-day reefs.

The bioherms of eastern Iowa are oval mounds of undisclosed heights, some in excess of 180 feet. They range from a few tens of feet to at least a quarter of a mile in diameter. They consist of core and flank facies which are lithologically nearly identical but are structurally and paleontologically dissimilar. Their lithology consists of light to medium bluish-gray, very finely crystalline to coarsely crystalline dolomite which in some places is dense but mainly is vuggy and has a peculiar harshness to the touch. The textural variation in the finer grades (sand-silt size) within each of the facies is greater than that between the facies and therefore not usable as a criterion to distinguish between these elements. The coarser materials, larger than sand size, generally are found in the core. The rock is brittle and fractures subconchoidally; the brittleness plus the harshness results in the erroneous impression that the rock is siliceous. Porosity appears to be moderate to high and is the result of solution and brecciation, and perhaps, in part at least, is a product of dolomitization. Permeability also appears to be moderate, particularly in the core. The vugs, formed by the removal of fossil fragments, fall into two general groups based on their diameters: the smaller group range in size from fractions of millimeters to 10 millimeters in diameter; and the second group, generally much larger, have diameters as much as several inches across. The small vugs owe their origin principally to the removal of crinoidal and brachiopodal remains and in some places remain intact as external molds of these animals. The large vugs are attributed to the solution of larger fossils, mostly coelenterates, and secondary enlargement of some fractures. Some of these larger vugs are rimmed by coarsely crystalline secondary dolomite, as are the small vugs, and others are clay filled. The remaining vugs contain, albeit poorly preserved, superficial outlines or "ghosts" of the removed fossils.

The core of the bioherm is an essentially unstratified mass built by the accumulation of sessile rock-forming coelenterates. The stromatoporoids and the rugose and tabulate corals, together with the pelmatozoans and perhaps algae, produced a rigid framework rising above the sea floor. The rock is highly fractured dolomite containing abundant vugs of both size ranges. Many of the fractures and vugs are clay filled. The fracturing in the core is extensive and varies in intensity, at some places producing pebble-size breccia and at other places very large boulders. The favored fracture direction is vertical.

This phenomenon of core fracturing with a prominent vertical orientation has been noted by Chamberlin (1877) and Cumings (1932). It is caused supposedly by a reduction in volume which took place during the dolomitization process and also by solution. Solution was responsible for large-scale collapse structures as shown in the Sneckloth quarry. The residual boulders 2 or more feet in diameter are found surrounded by a clay matix which fills cavities (fig. 11) that are as much as 10 feet in height. The abundance of stylolites in both the core and flanks is a feature also indicative of solutional activities in these structures. The solution is aided and controlled by the initial porosity present in the structure. The core is usually more strongly affected since it is more thoroughly fractured, but flanks also display some fracturing and clay pockets are present in fracture fillings, vugs, and bedding-plane partings.

Some collapse features are filled with exogenous materials including sandstones and shales. Clay, in variable amounts, is present in all bioherm cores and to a lesser extent in the flanks as void and fracture fillings and sometimes along bedding planes.

The core is the most abundantly fossiliferous of the facies, both in variety and in number. The coelenterates, including the stromatoporoids and tabulate and rugose corals are predominant, with the pelmatozoans, including crinoids and cystoids, of secondary prominence. The pelmatozoans are not limited to this facies and in some cases constitute the major faunal element of the flanks. Brachiopods are present in both facies; in the core they occur either disseminated or as pockets of high concentration, together with gastropods. Cephalopods and other molluscs are found in abundance in core or near-core facies. Where present they occur in "nests" of several forms.

The flank beds border the core and are characterized by stratification. These beds grade laterally into the flat-lying inter-reef facies (Anamosa) and steepen in dip towards the core where they abut against or overlap it. The development of the flank beds has long been assumed to depend entirely upon the contribution of detritus derived from the core. The role of indigenous fauna as a contributor was ignored. Paradoxically Norton (1901, p. 307), summarizing the salient features of these then unexplained structures, stated, "Even on the most steeply inclined bedding planes fossils lie as if they had there lived and died, no evidence being seen of their having been swept thither by currents". The steeply dipping beds, for the most part, consist of finely crystalline-textured rock associated with crinoidal and/or brachiopodal debris. It is suggested that the organisms which inhabited the steeper slopes would by their presence promote deposition and stabilization of the very fine debris contributed from the core. However, much if not most of the material is autochthonous, derived from these organisms which inhabited the flanks. Crinoids are the most conspicuous contributors with brachiopods next in abundance. Cumings (1932) described bioherms as composed entirely of crinoidal debris in parts of Illinois and Indiana. The Mitchell bioherm displays, as well as any, the volume of sediments which crinoids can contribute to both the core and flank.

The flank, therefore, was not passively developed as a submarine talus slope surrounding the core, but another biotic community living upon and among the sediments derived from the core and growing upward at a pace with, but below, the core itself.

LeCompte (1962, personal communication) has expressed doubt as to the utter dependence of the flanks on the core for their growth. He cites the tremendous volume of flank when compared with the cores in the Gotland area and also feels the contributions of organisms living within the flanks are a more likely source of sediment.

The core did, of course, contribute to the flank facies. Coral and stromatoporoid debris in over-turned or broken condition can be found in the flanks as can lenses of angular particles ranging from sand to pebble size. These bands are, however, noteworthy in their rarity. Unless dolomitization is responsible for a decrease in grain size, as suggested by Walther (1855), most of the debris donated by the core is of the silt and clay fraction.

The most obvious distinction separating the core and the flanks is the stratification in the flanks. The core expanded upward and outward by virtue of coelenterate, stromatoporoid and algal (?) growth. This expansion would be of a type totally unsuited for the development of stratification since no layering, except in the case of the favositids' growth, would occur.

Conditions on the flanks, however, were different. Few framework structures were present to act as deterents to stratification. Any detritus swept from the core would be distributed on the floor adjacent to the reef and would be deposited as sheets among the sessile organisms living on the floor peripheral to the reef where food gathering would be at an optimum. The principal organisms living in this biotope were the pelmatozoans, echinoderms, and brachiopods, all biostrome formers. These organisms encouraged deposition by reducing the current velocity near the depositional interface, but they did not interfere with the development of stratification. In fact, their skeletal remains contribute significantly to the volume of these sediments. Periodic deposits of large amounts of detritus or periods of exceptional turbidity might kill a local population and their remains would form the organic bands so much in evidence in the flank rock. The inevitable result of these types of sedimentation is stratification.

The general lack of coarse clastic debris has undeniable implications. Small fragments connote low energy conditions. These reef structures, then, were not subject to the violent attack of the waves as were those of Illinois. Lowenstam (1957) concludes that the seas were indeed less turbulent than those of Illinois. He proposes a shallow, reef-surrounded, lagoonal environment for northeast Iowa during Gower times. Such an assumption seems valid on uniformitarian grounds and is substantiated by the presence of ripple marks and dessication cracks (Norton, 1901, p. 308) in the inter-reef facies and by Ingel's (1963) paleo-reconstruction of the Thornton reef.

Assuming a prevailing westerly wind, the position of the Iowa reefs near the western shore would result in reduced fetch and less turbulence than that experienced by the Illinois structures. This might explain, at least in part, the evidence of increased turbulence at the Sneckloth structure. It lies further to the east and was presumably in deeper, less protected and more turbulent water.

Because biohermal bases are nowhere exposed in Iowa, information as to the sub-strata or any possible environmental controls for their development cannot be obtained. Nor is it possible to determine which faunal element acted as the foundation for the biohermal mass. The coelenterates seem to dominate in the cores, at least in those portions observable, and may have been the initial organisms producing the platform for reef growth. Algae were believed to be present, and crinoids and other pelmatozoans inhabited both flanks and core in great numbers. Therefore, it may be that scattered crinoid meadows acted as centers of growth from which the bioherms developed.

Inquiry into the development of the bioherms is further complicated by variations in their lithology, fauna, and structure. Each reef investigated, however, is exposed in a slightly different way at least. Such differences in exposure could result in variations which are more apparent than real. Textoris and Carozzi (1964) were able to subdivide Silurian bioherms of Indiana into 8 microfacies. It may be that variations here in Iowa might be explained as exposures of different microfacies. Whether or not microfacies can explain the diversity in lithology and structure, diversity must be attributed to variation in the fauna present. The local populations have controlled: the formation of stratification or lack of it; pore size; and the texture of the rock, to some extent at least. The control of faunal variation is more difficult to isolate. At least three possibilities suggest themselves.

The most obvious explanation is that the reefs are a polyphylitic conglomeration unified only by their mound-like outline and rough contemporaneity. Significant variations in local sea-floor environments would result in different local populations so that coelenterate bioherms and crinoidal bioherms might develop as separate and distinct structures. If the bioherms were essentially contemporaneous then close geographic proximity would rule out salinity and temperature variation. Local depth, turbulence, turbidity and the nature of the substrate may have been factors, however.

A second possible control was suggested by Boucot when he noted that the Hunt fauna appeared older than that of the other bioherms.

If these structures are of significantly different ages, faunal variation due to broad ecological and environmental changes is to be expected.

The faunal differences can also be explained as growth stage variations. If the bioherms went through successive growth stages, each with a characteristic fauna, contrasting microfacies would develop. Philcox (1965, personal communication) believes that distinct facies can be delineated in the bioherm. Whether or not they represent growth stages is another matter.

Whatever their origin, the bioherms resemble each other and diagenetic and post-diagenetic changes have acted upon them fairly uniformly.

Because of their high initial porosity and permeability, particularly in the core portion, ground-water activity was more prominent in the reef facies than in the non-reef facies. The work of this agent is manifested in the abundant stylolites, solution cavities and pits, and resultant collapse features found in the bioherms.

It is the author's opinion that the brecciated nature of the biohermal core has made this facies more susceptible to erosion. Because solution activity was less extensive in the flank facies, they display a greater resistance to erosion. These erosional differentials exert some control on stream-course development. The Palisades of the Cedar River is but one of many examples of stream dissection of a bioherm core. Such erosion leaves high, nearly vertical walls of flank beds which dip away from the stream on both sides.

The Gerber bioherm (SW½ sec. 23, T. 80 N., R. 3 W., Cedar County) is another example of preferential removal of core rock by a stream which breaches a structure. The core forms a low-angle slope bordered to the northwest, west, and southwest by a semi-circle of nearly vertical walls 30 to 50 feet higher than the core itself. Rock Creek flows in a fairly narrow channel at the base of the cliffs. These walls consist essentially of flank rock which dips away from the core at fairly steep angles. The attitudes of these beds and their over-all structure suggest a near proximity to core rock. It thus appears that the stream has transected the core and has removed it and now has adjusted its channel to an arc coincident with the core-flank contact (fig. 13). This relationship is repeated at many other sites along the Cedar River where bioherms have been breached.

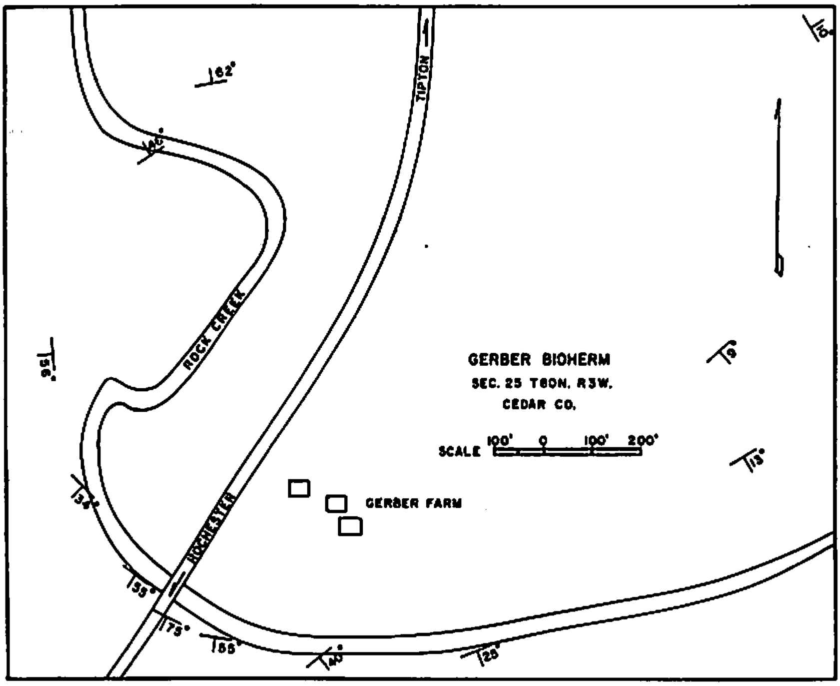

Figure 13. Structure of Gerber bioherm, Cedar County.

The Brady bioherm illustrates a contrasting situation in which a stream's course was controlled by the structure. Here the stream encountered flank beds and was turned aside by their resistance. As a result the stream developed a nearly right-angle bend at this contact.

The bioherms investigated in this study represent but a fraction of those exposed in the state of Iowa. The great numbers of bioherms previously have gone unnoticed, but academic and economic interest in them is increasing. Their particular lithology, so ideal for concrete and road metal, has encouraged more active exploration for them by the quarry industry. Interest in carbonate research and paleo-reconstruction should also result in more investigations of these structures. It is hoped that this report will represent a beginning in a more active program in exploration for and investigation of these structures in Iowa.

APPENDIX

FAUNAL LIST

	MITCHELL	HUNT	BRADY	SNECKLOTH
BRACHIOPODS				
Amphistrophia sp.			x	
Atrypa reticularis	x	x	x	x
Chilidiopsis ?			x	
Eospirifer sp.	x	x	x	x
Hyattidina sp.			x	
Leptaena sp.	x	x		
Macropleura cf. *eudora*	x	x		
Pentamerid indet.		x		
Platystrophia sp.		x		
Protathyris sp.			x	
Protomegastrophia sp.	x			
Resserella sp.	x			
Rhipidomelloides sp.		x		
Rhynchonellid indet.	x	x	x	x
Stegerhynchus sp.	x			
Trimerella sp.	x			
CEPHALOPODS				
Dawsonoceras sp.		x		
Euryrizoceras sp.		x		x
Euryrizoceras cf. *percurvatum*	x			
Lechritrochoceras sp.	x			x
Sactoceras cf. *depressum*	x			
GASTROPODS				
Holopea sp.		x		x
Subulites sp.		x		
Present but unidentifiable	x	x	x	x
PELECYPODS				
Present but unidentifiable		x	x	

	MITCHELL	HUNT	BRADY	SNECKLOTH
RECEPTACULITID				
Ischaditid indet.			x	
Present but unidentifiable			x	
TRILOBITES				
Bumastus sp.	x			x
Calymene sp.	x			x
ECHINODERMS				
Caryocrinites sp.		x		
Eucalyptocrinites ornatus ?		x		
Ithyocrinus subangularis		x		
Macrostylocrinus sp.	x			
Marsupiocrinus sp.	x			
Present but unidentifiable			x	x
CORALS				
Diplophyllid indet.	x	x	x	x
Favositid indet.	x	x	x	x
Halysitid indet.	x			x
Heliolitid indet.		x		
Syringoporid indet.				x
Zaphrentid indet.	x	x	x	x
STROMATOPOROIDS				
Present but unidentifiable	x	x	x	x
BRYOZOANS				
Present but unidentifiable		x		x

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