LOCKPORT (MIDDLE SILURIAN) AND ONONDAGA (MIDDLE DEVONIAN) PATCH REEFS IN WESTERN NEW YORK

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INTRODUCTION

A recent flourish of oil and gas exploration in the . Appalachian Basin has increased the interest in Silurian and Devonian reefs in New York and surrounding states. Although the companies do not expect to find reefs as large as those in the Michigan Basin, recent production of natural gas from Onondaga reefs around Stuben County, N.Y. has been sufficient to bring about a search for other Devonian reefs as well as Silurian reefs.

Patch reefs in the Lockport Formation (Middle Silurian) and Onondaga Limestone (Middle Devonian) are exposed along the northern edge of the Appalachian Basin in Western New York and have been studied in detail. Lockport reefs, occurring in the Gasport Member have been studied by Crowley (1973) and one Onondaga reef near LeRoy, N.Y. has been studied by Poore (1969). The object of this paper and accompanying field trip is to compare the Gasport reefs with the Onondaga reef.

LOCKPORT REEFS

Stratigraphy

The following is a condensed version of a lithofacies and biofacies analysis of patch reefs in the Gasport Member of the Lockport Formation of Western New York and Ontario (Crowley, 1973).

The stratigraphy of the Lockport Formation has been well established in New York State by Zenger (1965) and in Ontario by Bolton (1957) and Sanford (1969). Although there is some change in nomenclature across the border there are no major problems of correlation in the study area (Fig. 1). The Gasport Member can be traced as a distinct unit from just west of Hamilton, Ontario eastward to Brockport, N.Y., a distance of 110 miles along the Niagara escarpment (Fig. 2). It is separated from the underlying Rochester Shale by the DeCew Member and is overlain by the Goat Island Member. Sanford (1969, p. 12) states that the Gasport is an eastward extension of the crinoid-rich Wiarton Member, and is defined as a separate member only where the DeCew separates it from the Rochester Shale. Sanford's statement is true only for the lower crinoidal facies of the Gasport and, as this study shows, does not apply to the other facies which are lithologically distinct.

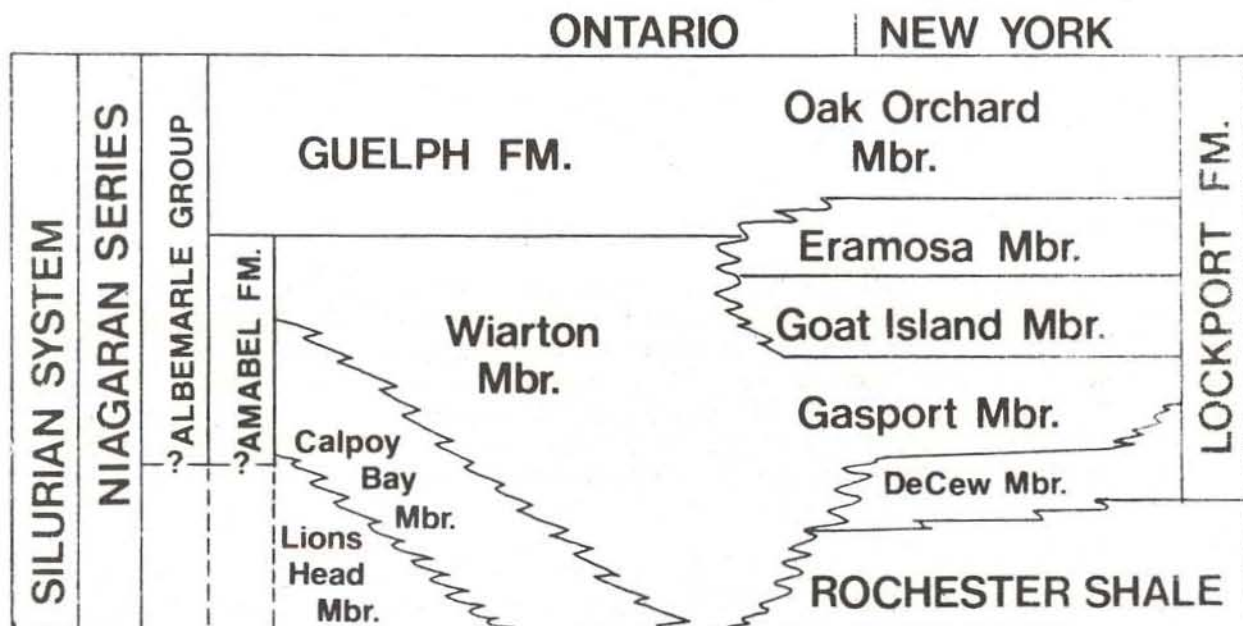|		ONTARIO	NEW YORK	

Fig. 1 - Stratigraphic equivalents of Lockport Formation in
New York and Ontario. Exact placement of the lower
boundaries of Albermarle and Amabel is in disagreement.
However, Lions Head is member of Amabel Formation.
From Crowley, 1973, (Compiled from Bolton, 1957;
Sanford, 1969; and Zenger, 1965).

Gasport Facies

Crinoidal Bar Facies. This facies, which is the most widespread
facies throughout the area (Fig. 2), is easily recognizable
because of its crinoidal content, although it does also contain
fragments of cystoids, corals, bryozoans and brachiopods. In
fact, the crinoidal composition is usually the basis for recog-
nition of the Gasport in the subsurface. The facies is 3 ft.
thick near Hamilton, Ontario and generally becomes thicker to
the east. Maximum thickness is 21 ft. just west of Niagara Falls,
but averages about 10 ft. in the eastern half of the study area.
Beds of coarse crinoidal sand 2 to 3 ft. thick grade laterally
into thinner beds of finer crinoidal fragments 3 to 4 in. thick.
Internal stratification is usually apparent in the thicker beds,
whereas the thinner beds, which are usually, but not always
finer grained, show less planar orientation of the fragments
and are more homogeneous, suggesting that they have been reworked
by burrowing organisms.

The thicker beds show cross-stratification dipping at angles of less than 10°, although individual sets are not well-defined. According to Imbrie and Buchanan's (1965) terms for describing carbonate sands, these are accretion deposits. The low amplitude, symmetrical ripples less than one foot high and at least 20 ft. in wavelength, seen at Lockport, N.Y., would probably be classed as para-ripples. Most cross-stratified beds occur from Lockport, N.Y. (loc. Z-29) west to Grimsby, Ont. (loc. B-9). Internal stratification is emphasized by weathering and subtle textural variations. In a few places, packed crinoidal biomicrite and sparsely-fossiliferous micrite form alternating inter-beds about one inch thick.

A few, very small bioherms are found in the crinoidal bar facies near Lockport, N.Y. STOP #2 of Field Trip These bioherms are lenses 1 to 10 feet in diameter and up to 10 feet thick and are composed of fine-grained dolomite with abundant massive, encrusting, and branching tabulate corals, as well as branching rugose corals, bryozoans, brachiopods and crinoids. Many of the corals are in growth position and numerous long segments of crinoid stems indicate less breakage and reworking by currents than elsewhere in the crinoidal facies. This lithology and fossil assemblage is essentially the same as that of the initial-reef subfacies discussed below. These localities are the only ones where bioherms are found within the crinoidal sand. The surrounding sand is composed of debris of most of the organisms found within the bioherms except that crinoidal fragments are more abundant. This same general mixture of organic debris is present throughout the study area with no noticeable trends in the relative abundance.

Additional constituents of this facies include the intraclasts of the DeCew lithology found in the basal one foot as well as other smaller intraclasts, pellets, and subhedral quartz grains found at all horizons. The amount of quartz increases significantly toward the east.

There is no significant trend in the amount of micrite present in the sand. Biosparites grade vertically and laterally into biomicrites. Where micrite is absent, the skeletal material is mostly calcite and well-preserved. Micrite matrix has undergone varying degrees of replacement by dolomite. In some samples only a few dolomite rhombs are present; whereas, in others the matrix has been replaced so much that it is difficult to recognize any of the original rock.

The crinoidal bar facies was a platform sand blanket much like those described by Ball (1967) in the Bahamas. The Gasport crinoidal sands are spread out for a distance of 110 miles and show many of the features found in the broad expanses of Bahama oolitic sand. Most of the Gasport sand blanket was probably subjected to storm waves producing submarine bars and low amplitude para-ripples like those described by Imbrie and Buchanan (1965).

West   **Ontario | New York**   East

Hamilton   Grimsby   Niagara Falls   Lockport   Brockport

B·23   B·14   B·9   B·1   Z·2   Z·14   Z·29   Z·37   Z·57   Z·63

DeCew Mbr.

Ont.
L. Ontario
W
E
L. Erie   N.Y.

Feet ⌐ 20
⌐ 10

5   10
Miles

Stromatoporoid Cap Facies

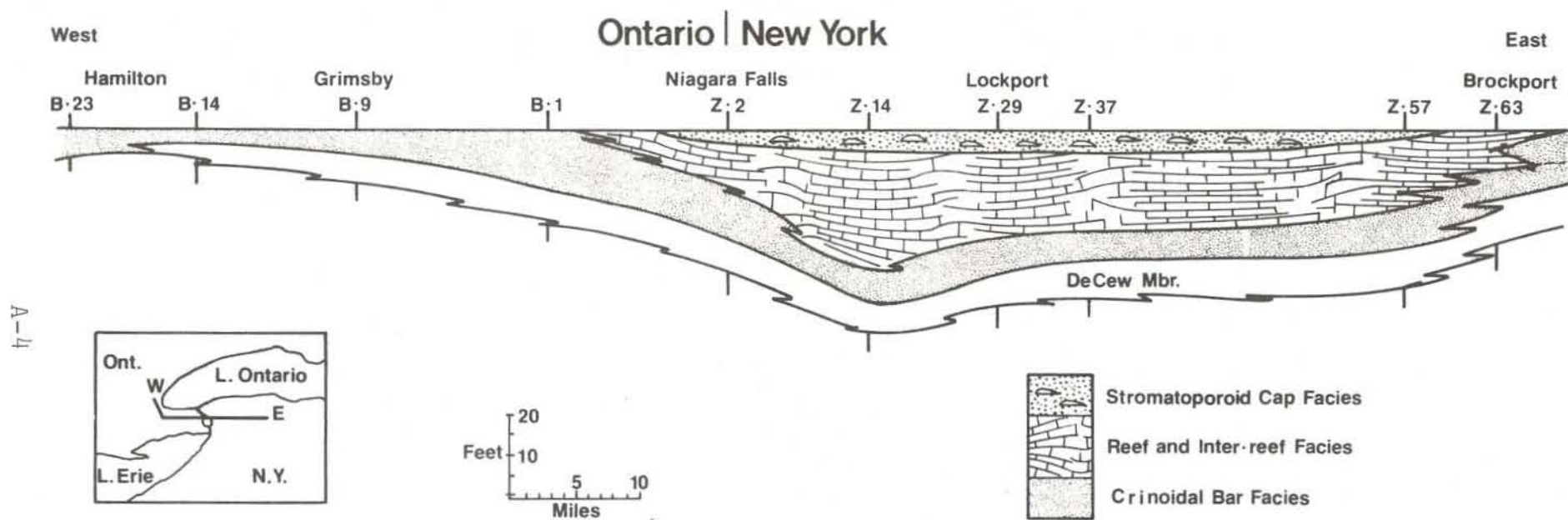Reef and Inter·reef Facies

Crinoidal Bar Facies

Fig. 2 - Gasport facies of New York and Ontario. Critical sampling localities are
referred to in text. In this figure and in text, B-localities are described
in Bolton (1957); Z-localities are described in Zenger (1965). From Crowley
(1973).

Inter-layered storm lag deposits of fine and coarse material are also present. More cross-stratification in the Gasport sands than Ball describes for the blanket sands in the Bahamas indicates exposure to more frequent high-energy conditions. The finer grained portions of the unit are burrowed and poorly-sorted, whereas the sandier portions are better sorted and show well-formed internal stratification. Subaerial lithification features were not found in this facies indicating that the crinoidal bar platform was below low tide level but still near enough to the surface for frequent reworking by waves.

Prolific growth of crinoids, along with branching tabulate and rugose corals, bryozoans, brachiopods and motile benthos such as gastropods and trilobites provided the skeletal debris for the sand. A uniform faunal assemblage throughout the area indicates that, although small bioherms were found preserved only in one small local area, they probably grew in other places as well but were broken up before the sand was finally buried.

Reef Facies. The Gasport reefs and associated facies crop out in a zone 60 miles long, from Clarendon, N.Y. (Loc. Z-57) to just across the border in Ontario (Fig. 2). Inter-reef facies and over-lying stromatoporoid cap facies are developed only within this reef zone leaving the crinoidal bar facies as the only lithology of the Gasport extending eastward and westward.

The reefs are easily seen from a distance at the outcrop because they stand out as slightly lighter gray, massive lenses inter-reef dolomite. They vary in height from 10 to 35 ft. and average 25 ft., commonly stand slightly above the top of the inter-reef facies, and depress the crinoidal bar facies beneath. The contact of the reef facies with the underlying crinoidal sand is commonly sharp except where the upper layers of the crinoidal bar facies are fine-grained. The width of the reefs vary from about 10 ft. up to about 100 ft. but most commonly is approximately 25 ft.

Dolomitization has completely obliterated all primary textures and fossils of most of the reefs, but a few have been relatively unaltered. This selective dolomitization occurs even within the confines of a single quarry (Loc. Z-29) where as many as 10 reefs are exposed a few yards to 300 yards apart. (STOP #3 of Field Trip) Perhaps only 2 out of 10 reefs in any one locality will have fossils preserved even though the shape of the reefs and their massive-bedded character are the same. The cause of this selective dolomitization is now known.

Where preservation is good, it is possible to delineate sub-facies of the reefs and demonstrate systematic, vertical changes in the growth forms and assemblages of the reef-forming organisms.

Initial-reef subfacies - As the name implies, this subfacies represents the lower, beginning part of the reef (Fig. 3). Compared to the surrounding flank subfacies and inter-reef facies, the initial reef subfacies contains fossils in growth position and is thicker and more irregularly bedded. The initial-reef subfacies can be distinguished from the upper, reef-core subfacies by the fossil assemblage--mainly small, delicate, branching corals instead of the large stromatoporoids that later become the dominant reef former. Ecologically the fossil assemblage of this subfacies might be considered the pioneer reef community.

Fossils found in growth position are Halysites, branching tabulates (mainly Cladopora), branching, colonial rugose corals (Palaeophyllum), and branching trepostome bryozoans (Hallopora). Fragments of these as well as other tabulate rugose corals, bryozoans, brachiopods, and crinoids are mixed with the fossils still in growth position. Encrusting forms of Girvanella algae, trepostome bryozoans, and the tabulate coral, Alveolites fibrosus are also part of this assemblage. Interstitial material is micrite and fine-grained dolomite.

Girvanella is probably the only one of the encrusting forms that effectively bound the skeletal debris. It is almost everywhere associated with black, clotted interstitial micrite. Recrystallization and replacement by dolomite makes it difficult, in many instances, to distinguish micrite from recrystallized Girvanella. In fact, some of the micrite may have been derived from algae as has been suggested by Wolf (1965) and Klement and Toomey (1967). The initial-reef assemblage is also found where Girvanella and dark micrite are rare or absent so that the binding function does not appear to be necessary for the initiation of reef development.

The other interstitial material of this subfacies is fine-grained, greenish-gray dolomite that is common in the reef-core subfacies as well. Transition from micrite to this fine-grained dolomite has been noted in thin section. The origin of the dolomite, therefore, is assumed to be from micrite. The dolomite contains burrows whose outlines are accentuated by very fine-grained pyrite. In many cases the original, burrow-mottled sediment appears to have been plastically deformed and squeezed into voids between the skeletal framework. Similar burrowed textures have been reported in limestones and dolomites by Roehl (1967, Fig. 15) in the Ordovician, Metherell and Workman (1969, Plate 3) in the Devonian, and Rupp (1969, Fig. 4) in the Mississippian. None of these reports, however, describes this type of burrow-mottling associated directly with reefs, or mentions plastic deformation of the burrows.

The establishment of this pioneer coral thicket on the under-lying crinoidal sand bar presumably slowed down the sediment-laden current resulting in the accumulation of fine-grained carbonate mud. As the mud settled within this organic lattice,
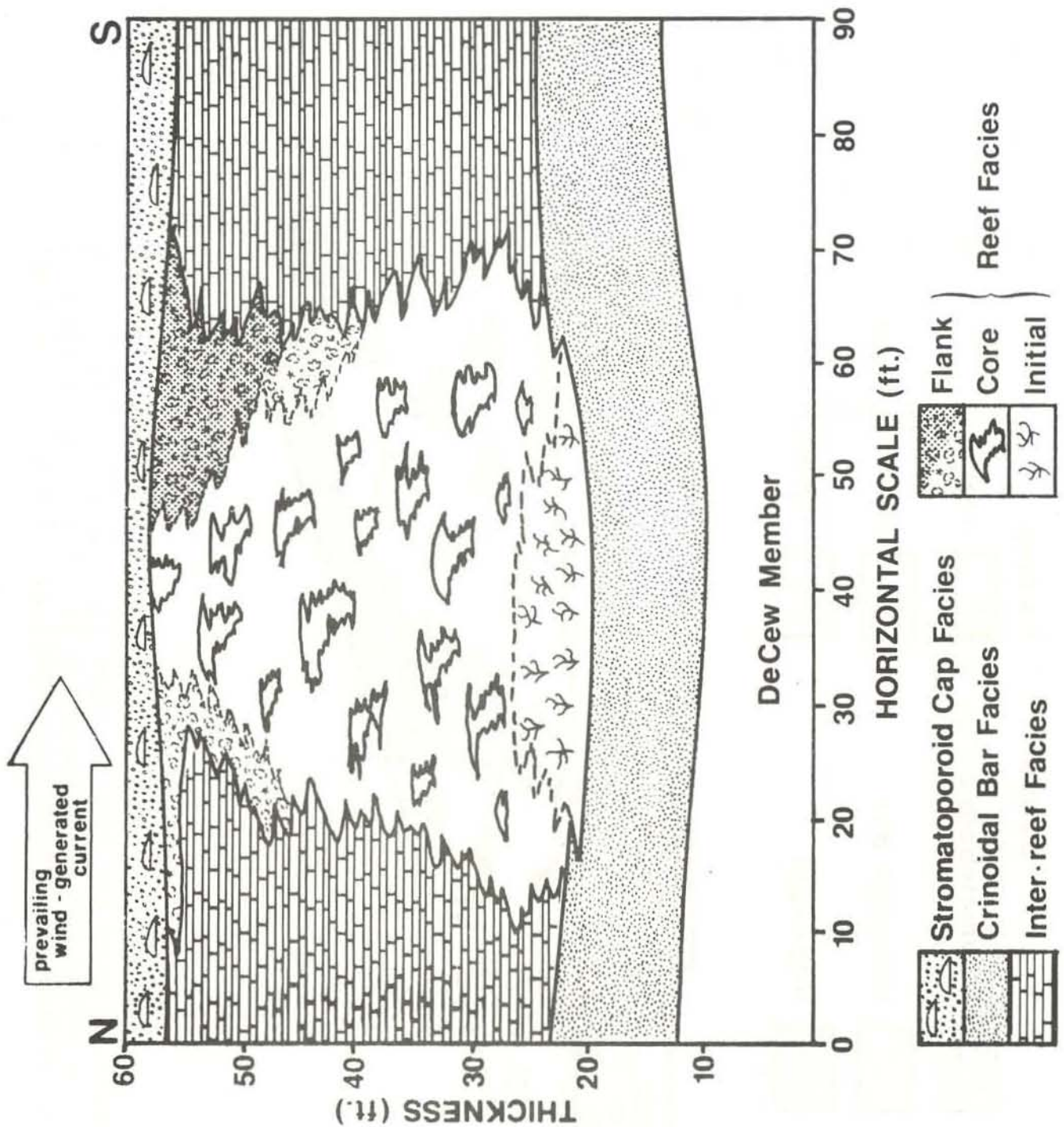
Fig. 3 - Diagrammatic illustration of Gasport facies and reef
subfacies. Shaded part of flank subfacies represents
detritus in dark dolomitic matrix. Stromatoporoids
are shown developed asymmetrically into prevailing
wind-generated current from north. Vertical and
horizontal scales are for average Gasport reef.
From Crowley (1973).

A-7

Gasport   Facies

Stromatoporoid Cap   Flank ⎱
                                 ⎰
Crinoidal Bar   Core   ⎱ Reef
                                 ⎰
Inter·reef   Initial ⎭

South   North

Goat Island Member

bridge
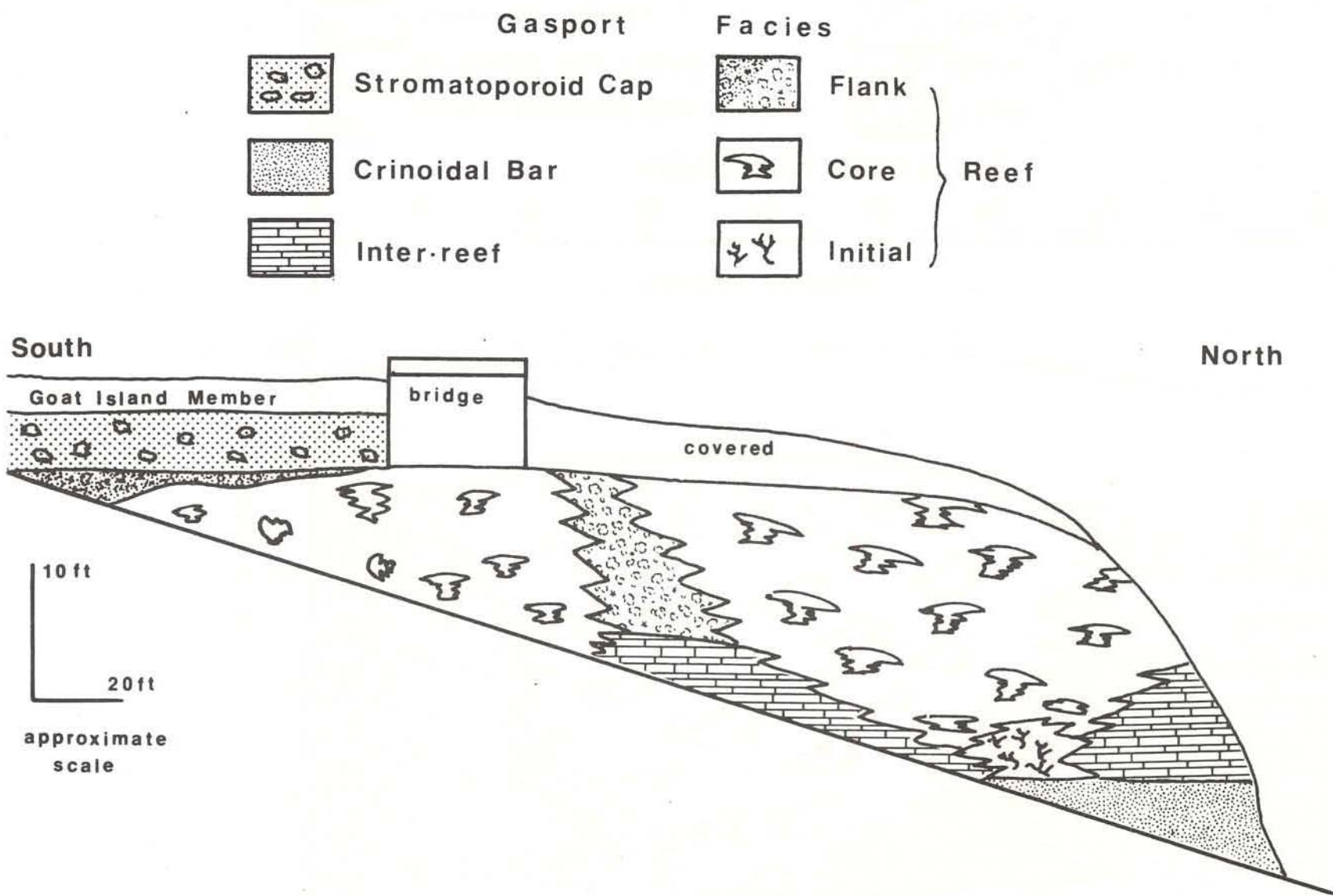
covered

A-8

10 ft

20 ft

approximate
scale

Fig. 4 - Diagrammatic view of two Gasport reefs exposed in road cut at Pekin, New York.
Symbols for corals and stromatoporoids are like those in Figure 3. Scale is
distorted because of vertical exaggeration. STOP #1 of field trip.

skeletal debris from the breakdown of these organisms also accumulated. The various encrusting forms of corals (Alveolites fibrosus), bryozoans (Hallopora) and girvanellid algae partially bound the mixed interstitial material in place.

Parallel pioneer reef communities are found in the Ordovician of Texas (Toomey, 1970) and Lake Champlain region (Pitcher, 1964); in the Silurian of the Michigan Basin (Lowenstam, 1950); and Devonian of New York (Poore, 1969), Western Canada (Embry and Klovan, 1970), and Belgium (Lecompte, 1959). In each case the actual biota is different, but there is similarity of form and function. Delicate, branching colonies trapped the mud and contributed skeletal material, while mud and debris were stabilized by other forms with an encrusting or tabular growth habit. In all these examples just cited, as well as in the Gasport, the result was the establishment of an organic mound that stood above the surrounding sea floor and was self-perpetuating as it grew upward into shallower water where increased wave and current action necessitated assemblage and form modifications if growth was to continue.

Reef-core subfacies - The initial-reef subfacies grades vertically upward into more massive- and irregularly-bedded, lighter-gray rock in which stromatoporoids are the dominant fossils (Fig. 3). The first stromatoporoids upwards in the reefs are small colonies (4 to 6 inches in diameter), of irregular shape, with latilaminae separated by thin layers of fine-grained dolomite. Within 3 or 4 ft. above the initial reef facies the stromatoporoid colonies reach heights of 2 to 3 ft. They become more columnar and somewhat umbrella-shaped. At irregular intervals the latilaminae spread laterally and encrust the surrounding dolomite. Asymmetrical growth toward the north occurs in one of the reefs at Peking, N.Y. (Loc. Z-14). Broadhurst (1966), describing Silurian reefs of southern Norway, postulates that such asymmetry faced into the prevailing current. A second reef just 25 ft. south of the one at Pekin (Fig. 4) contains stromatoporoid colonies that show much less asymmetrical growth.   STOP #1 of Field Trip

Two genera of stromatoporoids have been identified as Stromatopora and Clathrodictyon, but further identification to species is not possible because of poor preservation. So far, no correlation between growth form and genus has been detected in the stromatoporoids. Ecologic control of growth form, however, has been pointed out by Broadhurst (1966), Galloway (1957), Harper (1970), Fischbush (1969) and Lowenstam (1950).

A few domal-shaped favositid colonies occur along with the stromatoporoids and some have latilaminae similar to those described in Silurian reefs of Iowa by Philcox (1971). The favositid colonies in the Gasport are, however, not the major reef framework builders in the Gasport reefs. Branching tabulate and rugose corals, branching bryozoans, crinoids, and brachiopods, are also present within the reef core, usually as fragments mixed with the fine-grained, interstitial sediment that surrounds the stromatoporoids. The distribution and quantity of these fragments is

irregular, both within one reef and between reefs. These fragments represent essentially the same fauna as that of the initial-reef subfacies, with the exception that Girvanella is rare within the reef core.

The interstitial sediment of the reef core is burrow-mottled, fine-grained dolomite like that previously described in the initial-reef subfacies. As in the initial-reef subfacies, it appears to have been plastically deformed and squeezed into almost every void of the stromatoporoid framework. Point counts from photographs of large blocks and exposures of the core in place show that this interstitial dolomite makes up 52 percent to 75 percent of the reef volume. Estimates of framework corals of Pleistocene reefs, arrived at by similar methods, show that they comprise approximately 30 percent of the reefs leaving 70 percent interstitial sediment of which 40 percent is calcilutite and 60 percent is skeletal sand or voids (Stanley, 1966). Roy (1970) described coral thickets growing in the muddy water of Fanning Island in the South Pacific Ocean. There the carbonate mud probably makes up most of the interstitial sediment in the coral framework, as is typical in the Gasport reefs.

Reef flank subfacies - The flanks of the Gasport reefs (Fig. 3) are neither as detrital-rich nor as steeply-dipping as the flanks of the Niagaran reefs in the Michigan Basin (Lowenstam, 1950; Textoris and Carozzi, 1964). Maximum dips are 15°, but most are less than 10°. Part of this dip results from the inter-reef sediments compacting more than the reef. Some indication of the height of the reef core above the surrounding flank and inter-reef deposits is given by the 3 to 4 ft. of thinning of the stromatoporoid cap facies over the tops of the reefs. The 3 to 4 ft. should be considered a minimum height, however, because the tops of some of the reefs were eroded before being covered by the cap facies.

Fragments of stromatoporoids, tabulate corals and other reef-derived detritus are found in dark gray to black dolomitized micrite extending a few feet or tens of feet out from the edge of the core. These fragments are commonly replaced by anhydrite or dolomite, but enough structure remains for general identification. Most reefs do not have extensive detrital fringes. An exception to this is in two closely-spaced reefs at Pekin, N.Y. (Loc. Z-14) which are separated by a zone of detritus 25 ft. wide (Fig. 4). This zone is a light yellow-brown, coarsely-crystalline dolomite that contains numerous crystal-filled, or partially-filled, vugs representing skeletal fragments. The initial porosity of this zone apparently allowed increased water movement resulting in more solution and replacement by coarsely-crystalline dolomite.

Flank deposits are thicker and more extensive near the tops of the reefs just beneath the stromatoporoid cap facies. These were produced by erosion of the tops of the reefs before they

were covered by the stromatoporoid cap facies. In addition to reef-derived rubble, these uppermost flank deposits also contain fragments of more robust tabulate coral species than those corals within the reefs. These robust tabulate corals were either indigenous to the flank zone or were a transitional fauna adapted to the increasing higher-energy conditions which partially produced the overlying stromatoporoid cap facies.

Lenses of nearly black, fine-grained dolomite enclosing fragments of reef fauna are found at several localities. The dark color is due to the presence of microcrystalline pyrite possibly indicating small areas sheltered from oxygen-bearing water where organic-rich muds accumulated without oxidation. At the Pekin reefs (Loc. Z-14), these dark lenses are on the flank of a reef opposite the direction of preferred growth of the stromatoporoids. Perhaps deflection of the currents by the reef produced local pockets of poorly-oxygenated water and sediment on the lee side of the reef. Reef detritus accumulated in these organic-rich carbonate muds which subsequently became pyrite rich. This further supports the hypothesis that the dominant current direction was from the north.

Inter-reef Facies. Inter-reef lithology is found only between the reefs, above the crinoidal bar facies and below the level of the stromatoporoid cap facies. The inter-reef facies pinches out east of locality Z-63 and to the west in Ontario where there are no reefs (Fig. 2), thus leaving the Goat Island Member directly overlying the crinoidal bar facies.

The crinoidal bar facies grades upward into the finer grained inter-reef facies through a transition zone one to two feet thick. The upper contact of the inter-reef facies with the stromatoporoid cap facies is abrupt. The well-bedded, inter-reef lithology grades laterally into the massive reef facies.

The inter-reef facies is a dark-gray, dolomitized micrite and biomicrite. Replacement by dolomite is almost complete with only a few calcite fossil fragments remaining. The 4 to 8 in. thick beds are separated by black, shaly partings on bedding-plane surfaces. Most of the fine-grained dolomite has been partially homogenized by burrowing organisms but some internal stratification is still present. Intraclasts, with poorly-defined shapes, are common in these fine-grained rocks. Where beds are composed of alternating thin layers of crinoidal biomicrite and dark micrite, burrowing is absent.

The very reduced fauna of this facies consists of pelmatozoans along with a few brachiopods, small solitary rugose corals and burrowing organisms. All fossil debris has either been recrystallized to coarse-grained calcite or replaced by dolomite making more specific identification impossible.

Since the relief of the reefs was no more than a few feet, current and wave action over the reefs would have been about the same as between the reefs. Within the reefs, however, water movement near the sediment-water interface was slowed by the upward growth of the reef's organisms, which acted as baffles, allowing fine-grained sediment to accumulate. Lateral growth of the stromatoporoids then bound the sediment in place. In contrast, the currents between the reefs were unrestricted and thus could shift the sediment and produce stratification. The layers of crinoidal sand within the micrite probably represent storm lag deposits within the normally-muddy, inter-reef sediment.

Submarine consolidation of carbonate mud probably accounts for the intraclasts since no other evidence supporting subaerial dessication has been found. Partially-consolidated carbonate sediments have been reported in shallow, sub-tidal sediments of Florida (Jindrick, 1969) and the Bahamas (Ball, 1967)

Burrowing is confined to the fine-grained sediments which probably were deposited slowly. The coarse-grained layers were deposited rapidly and were reworked by currents and, hence, burrows are absent.

Stromatoporoid Cap Facies. The stromatoporoid cap facies of this study corresponds to the lower part of what Zenger (1965) calls the Goat Island Member and describes as "saccharoidal dolomite containing stromatoporoids" (p. 61). He suggests, however, that "...there is probably at least a slight facies relationship between the uppermost Gasport and the lowermost Goat Island" (p. 51). Lithologic continuity at the lower boundary of the cap facies with the Gasport and the erosional discontinuity at the upper boundary, however, makes it logical to include it with the Gasport facies.

The stromatoporoid cap facies forms a 4 to 6 ft. layer that caps both the reef and the inter-reef deposits and pinches out both to the east and west where reefs are not developed (Fig. 2). Although the lower contact with the reef and inter-reef facies is conformable in most places, the tops of some reefs have probably been eroded before being covered by the stromatoporoid cap sediments. Erosion is indicated by the presence of increased flank detritus immediately beneath the cap facies of some of the reefs. However, dolomitization has obliterated any direct evidence of an erosional surface on the tops of the reefs. Dark-gray, well-bedded, cherty Goat Island dolomite overlies an erosional upper surface of the stromatoporoid cap facies. This erosional surface truncates fossil fragments which must have been firmly cemented in place.

Lithologically, this facies is a light-colored, fossiliferous, vuggy dolomite which was originally a biosparudite and biomicrudite. Fragments of stromatoporoids and favositid corals along with other

fossil debris have been leached out and the voids filled or partially filled with crystals of dolomite, gypsum, galena, and sphalerite. The light-colored, vuggy nature of this facies makes it easy to see from some distance and should make a recognizable marker in the subsurface.

At most localities the fossils of this facies are fragmented and the debris well-bedded. At Gasport, N.Y. (Loc. Z-37), however, stromatoporoids and coral colonies have been preserved in growth position. Exposure of a bedding-plane surface made possible an analysis of their size, density, and distribution. Most of the fossils found in place are dome-shaped or massive stromatoporoid heads ranging from a few inches to 4 ft. in diameter. Most of these heads show a preferred growth towards the NNW which nearly coincides with the northward-preferred growth of the stromatoporoids in the reefs. Some heads continued to grow after they were overturned while others formed larger masses by the coalescing of a clump of several small heads. Branching tabulate colonies of Cladopora ordinata (Davis, 1887) are also in growth position at this same locality and also have a preferred growth toward the north-northwest. Together, the stromatoporoids make up 14 percent of the surface area with colonies spaced close enough together so that it would be possible to jump from one to another. A similar study of a Devonian biostrome (Kissling and Lineback, 1967) showed that coral and stromatoporoid colonies also covered 14 percent of the surface area, but stromatoporoids make up only 26 percent of the colonies in contrast to nearly 100 percent in this study. The stromatoporoid colonies in the Gasport are surrounded by a well-bedded, carbonate sand composed of crinoids, Cladopora and stromatoporoid fragments. Some fine-grained dolomite matrix is present, but is not as abundant as in the reef and inter-reef facies.

Massive, dome-shaped stromatoporoids, coarse, organic rubble, well-bedded coral-crinoidal sand, and little fine-grained carbonate matrix all suggest a higher energy environment than the reef and inter-reef environments. The vuggy texture along with erosional surfaces within and on top of the unit suggest subaerial exposure of part of the unit resulting in lithification, solution and wave erosion.

One of the best Recent and Late Pleistocene analogs of this facies is found in Shark Bay, Australia described by Logan and Cebulski (1970) and Logan, et al. (1970). Part of the Late Pleistocene Bibra Formation of Shark Bay is a 1 to 3 ft. thick coral biostrome with coral heads ranging from 1 to 4 ft. in diameter surrounded by a pelecypod coquina. Lithoclasts are found on the weathered, upper surface of this formation indicating that is has been wave beveled previous to burial beneath tidal-flat deposits. (Logan, et al., op. cit.). Logan and Cebulski (op. cit., p. 35 report sheets of lithified sediments forming today in the upper intertidal zone of Shark Bay. Logan, et al. (op. cit., p. 79) report that the environment in which the Bibra Formation was formed was similar to that found on the rocky intertidal platforms in northern Shark Bay today.

The portion of the stromatoporoid cap facies of the Gasport where stromatoporoids and coral heads are in place and surrounded by coral-crinoidal sand is analogous to the sediments of Shark Bay forming in shallow subtidal channels and pools. As in Shark Bay, this portion of the Gasport was bordered by intertidal flats covered by stromatoporoid, coral and crinoidal rubble carried above the low tide level by currents and storms. Once exposed to air and rain water, this rubble was lithified, leached, and subsequently eroded. Dominant current direction (probably wind generated) was from the north-northwest as indicated by the preferred-growth orientation of the stromatoporoids and coral colonies.

Gasport Facies and Reef Development

A model that explains the deposition of Gasport facies involves a combination of lateral and vertical facies development on a discontinuously-subsiding, shallow marine platform. Lateral facies progression during the transgression, such as that proposed by Irwin (1965) and illustrated by Laporte (1967, 1969) in the Devonian Helderberg Group, accounts for the general development of the Gasport reef zone on the transgressing crinoidal sand bar complex. Vertical facies development of reefs into shallower more agitated water, such as has been well documented by Lowenstam (1950) and Textoris and Carozzi (1964), accounts for the vertical changes noted in Gasport reefs, including the stromatoporoid-cap biostrome. Variation in regional subsidence and consequent changes in basin circulation, however, are required to more fully explain the initiation and termination of Gasport deposits.

The following summary of Gasport facies development should be read with reference to the series of diagrams shown in Figure 5 illustrating the various developmental phases.

DeCew-Gasport Transition. DeCew carbonate mud was deposited on the northern flank of the Allegheny Basin which was at that time receiving mostly clastics from the east (Zenger, 1965, p. 143). The fine-grained, well-bedded character of the DeCew, along with the general lack of fossils indicates a restricted, low-energy environment sheltered behind the Wiarton crinoidal bank complex with which it interfingers near Hamilton, Ontario (Sanford, 1969, p. 12). The Wiarton bank complex, which coincides with the Algonquin Axis, was in existence throughout the deposition of the lower-half of the Lockport (Sanford, op. cit., p. 12). The Wiarton bank complex, which coincides with the Algonquin Axis, was in existence throughout the deposition of the lower-half of the Lockport (Sanford, op. cit., p. 12).
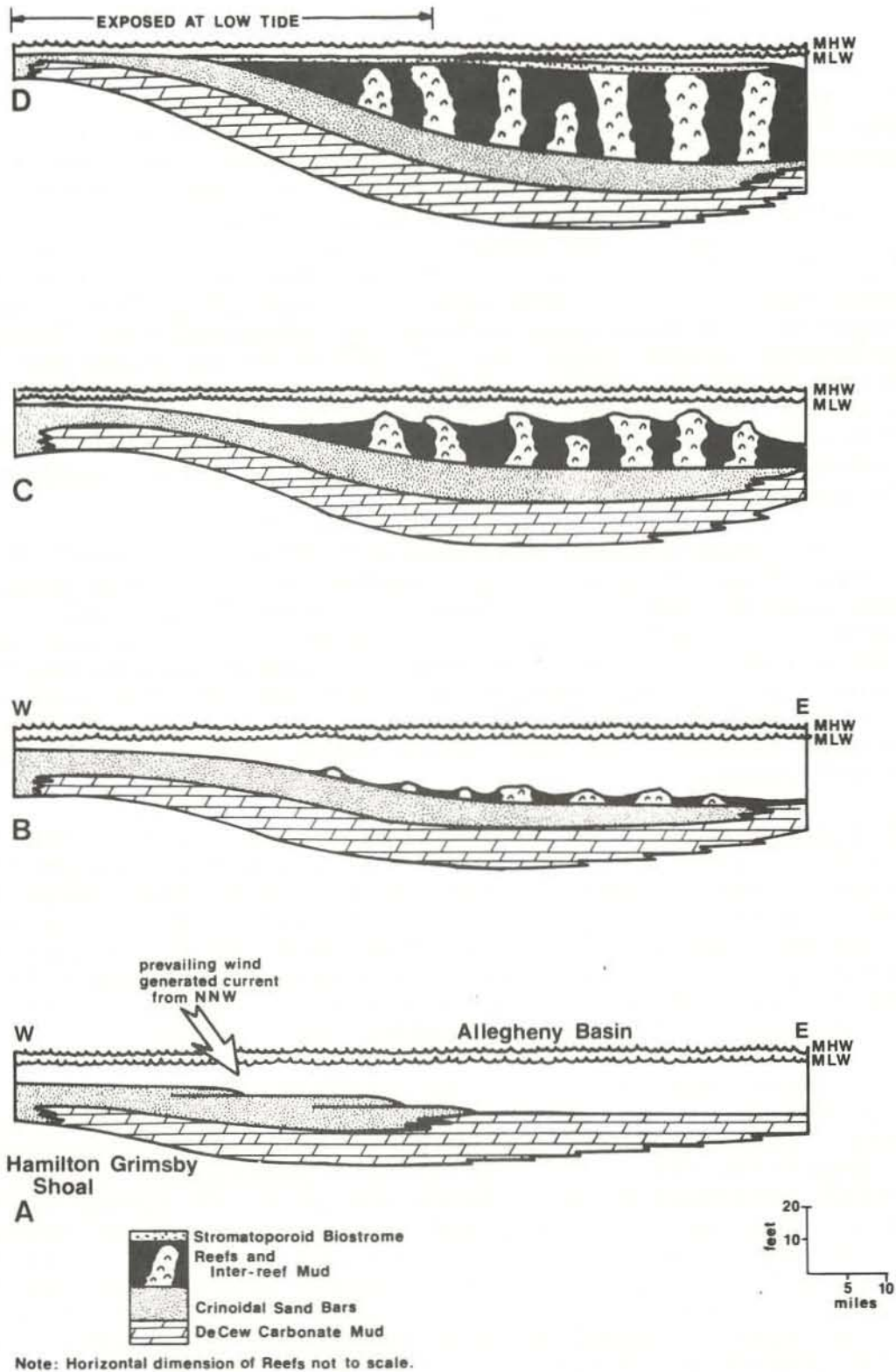
EXPOSED AT LOW TIDE

MHW
MLW

D

MHW
MLW

C

W   E
MHW
MLW

B

prevailing wind
generated current
from NNW

W   Allegheny Basin   E
MHW
MLW

Hamilton Grimsby
Shoal

A

Stromatoporoid Biostrome
Reefs and
  Inter-reef Mud
Crinoidal Sand Bars
DeCew Carbonate Mud

Note: Horizontal dimension of Reefs not to scale.

20
feet 10

5   10
miles

Fig. 5.   Series of diagrams illustrating Gasport facies
          development. Sections parallel east-west out-
          crop belt of study area. Arrow indicates
          prevailing wind-generated currents from north and
          north-northwest throughout deposition of Gasport.
          Horizontal dimensions of reef are not to scale.
          From Crowley (1973).

A-15

Encroachment of the crinoidal bank complex southeastward into the area of DeCew deposition apparently was in response to increased regional subsidence allowing more open circulation from the north across the Wiarton bank. Increased current and wave activity caused submarine, crinoid sand bars to migrate into the once-quiet, muddy environment much as the oolite bars are migrating over the top of carbonate mud on the Bahama Platform today (Ball, 1967). The upper few feet of the DeCew mud were eroded and carried away before the crinoidal sand covered the remaining layers (Fig. 5A). Intraclasts of DeCew mud found in the lower few inches of the sand remain as evidence of this erosion. Interbedded sand and mud at the eastern end of the crinoidal bar facies represents the intermediate condition of contemporaneous sand and mud deposition at the leading edge of the encroaching sand bar.

The area between Hamilton and Grimsby, Ontario (Loc. B-23 to B-9, Fig. 2) apparently subsided less than the Allegheny Basin resulting in the sands thickening to the east. The area around Hamilton, Ontario acted as the hinge axis during the subsidence that allowed the sand to sweep into the Allegheny Basin from the Wiarton bank to the northwest. The Gasport crinoidal sands thicken eastward from the shoal area in response to increased current activity and subsidence while little sand accumulated on the shoal.

Reef Development. As the southeastern portion of the Gasport crinoidal platform subsided, small patch reefs began to grow in slightly deeper areas in the lee of the Wiarton-Gasport shoal near Hamilton, Ontario. The first reefs began to grow while crinoidal sand was actively being produced by crinoid meadows fluorishing on the submarine sand bars. Although a few of these reefs have been preserved, most were destroyed and the debris incorporated into the surrounding skeletal sand.

There seems to have been a threshold period when reefs gained a permanent foothold on the southeastern part of the area. This threshold was probably reached when carbonate sand accumulation failed to keep up with subsidence causing the depositional interface to move below the level of strong current agitation. Less agitation allowed the reefs to become firmly established and develop close together which further constricted water circulation. The result was a sudden vertical change from crinoidal sand, deposited in a highly agitated environment, to reefs growing on the sand in muddy, relatively quieter water (Fig. 5B). The reefs probably did not all appear at once, but lateral spreading of the patch reefs was rapid enough so that there was very little intermixing of the two facies.

Vertical development of the reefs from quiet-water, pioneer clumps of delicate, branching corals and bryozoans upward to massive, stromatoporoid-dominated patch reefs indicates that they were

either growing into shallower water or the environment was becoming more rigorous (Figs. 3 and 5 C). Increased flank detritus and the capping stromatoporoid biostrome would favor the first interpretation. At any one time the reefs did not stand more than 3 to 4 ft above the surrounding muddy bottom. As they continued to build upward, mud filled in all voids within the reefs and continued to accumulate around them. Oriented growth of the stromatoporoid heads indicates that the prevailing current, probably wind generated, was from the north across the Wiarton-Gasport shoal.

During the period of reef building, no sediment was accumulating on the Wiarton-Gasport shoal. In fact, the crinoidal facies thins down to 3 ft. just east of Hamilton, Ontario where the top contact is leached, stained with limonite and a shaly parting separates it from the overlying Goat Island cherty dolomite. This probably is evidence for subaerial weathering, possibly occurring after deposition of the stromatoporoid cap facies to the east. It is also possible that the Wiarton-Gasport shoal was exposed during the period of reef building, thus inhibiting strong currents from the northwest and allowing acceleration of patch reef growth.

Stromatoporoid Biostrome. The vertical change from reef-associated facies to stromatoporoid cap facies is abrupt throughout the 60 mile wide reef zone (Fig. 5 D). This could be attributable to a change in energy as the reefs built upward into the wave-agitated subtidal and intertidal zones. There are, however, several features that argue for a slight drop in sea level placing most of the reef area in very shallow water at about the same time: (a) The transition from muddy reef and inter-reef sediments to coarse biosparrudites is abrupt although it appears to be conformable in most places; (b) The tops of some of the reefs have been eroded before being covered by the cap facies; (c) The unit maintains a uniform thickness of 4 to 6 ft. over a 60 mile wide area; (d) The adjacent crinoidal shoal to the northwest and portions of the cap facies show evidence of subaerial weathering and erosion.

Any one of these features would not be sufficient evidence for a drop in sea level. Together, however, they indicate that a lower stand of sea level left the Wiarton-Gasport crinoidal shoal to the northwest out of the water causing such an abrupt change in conditions in the reef zone that reef growth ended. The reef zone, now in the wave-agitated zone was covered by an assemblage of isolated, domal stromatoporoids, branching tabulate coral colonies, and crinoids. Skeletal debris from these animals accumulated above low tide where exposure to air and rainwater caused cementation and weathering. Both subtidal areas with colonies still in growth position and intertidal areas where skeletal rubble accumulated are found within the stromatoporoid cap facies.

The top of this facies is an erosional surface as is the
top of the adjacent crinoidal shoal in Ontario. Immediately over-
lying this erosional contact is the dark, well-bedded, cherty
dolomite of the Goat Island Member. Although the Goat Island
has not been studied in detail, fossils found mainly in the chert
nodules (Zenger, 1965) indicate that the area was again submerged,
but that the sea was more restricted than during Gasport time.

ONONDAGA REEF

Introduction

This study is based on a Master's thesis submitted by
Richard Poore to the Department of Geological Sciences at
Brown University in 1969.

The Onondaga Limestone (Middle Devonian) of New York State
crops out almost continuously from Buffalo east to Albany, and
then south and southwest to Port Jervis (Fig. 6). Along most of
this outcrop belt, the lowest member of the Onondaga Fromation
is a light-gray, coarsely-crystalline, crinoidal and coralline
limestone. This unit has been named the Edgecliff Member of the
Onondaga Limestone (Oliver, 1954).

The Edgecliff Member contains more than thirty irregularly-
distributed, small bioherms that provide an excellent opportunity
for paleoecological studies. This study concerns one of these
bioherms, the Leroy Bioherm which is located in an abandoned quarry
approximately two miles northwest of the Town of Leroy, New York
(STOP #4 of Field Trip).

Fig. 6 - Outcrop belt of Edgecliff Member of Onondaga
         Limestone, and location of the Leroy bioherm.
         Modified from Oliver (1956).

Stratigraphy

The Onondaga Formation in western New York rests uncon-
formably upon the Bois Blanc Formation (upper Lower Devonian,
Emsian) or Upper Silurian dolomite (Oliver, 1966). There is
a gradational contact between the Onondaga Formation and the
overlying Oatka Creek Shale Member of the Marcellus Formation
(Rickard, 1964).

Oliver (1954) divided the Onondaga Formation into four
members, these being, in ascending order, the Edgecliff, Nedrow,
Moorehouse and Seneca. Ozol (1964) renamed the Nedrow Member
in western New York, the Clarence Member, on the basis of its
high chert content. Lindholm re-studied the Onondaga Limestone
in 1967 and, along with Oliver, showed that bioherms occur in
the Edgecliff Member (Fig. 7).

As an incidental part of the
study of the stratigraphy of the
Onondaga Limestone in New York,
Oliver (1954) listed the fauna
of the Williamsville Bioherm in
western New York, and the Thomp-
son Lake Bioherm in eastern New
York. Later, Oliver (1956b)
listed the location of over twenty
bioherms in eastern New York.
Oliver (1966) provides a short
discussion of the Edgecliff
bioherms and gives a generalized
diagram of the relationship of the
core and flank facies of these
bioherms to the surrounding non-
biohermal rocks.

Mecarini (1964) and Bamford
(1966) provide the only detailed
studies that have been done on
Edgecliff bioherms. Mecarini
studied the Mt. Tom Bioherm and
Bamford worked on the Albrights
Reef, both in eastern New York.
These workers found that the
bioherms were best described
as patch reefs, and that they
displayed a remarkably similar,
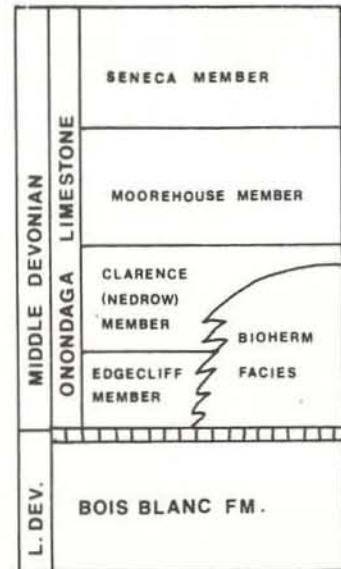but not identical, vertical
sequence of ecological
succession.

Fig. 7 - Stratigraphy of
the Onondaga Lime-
stone showing
subdivision into
Members and
stratigraphic
equivalents of
the Leroy bio-
herm. Modified
from Oliver (1966).

Bioherm Facies

Detailed analysis has resulted in the division of the Leroy Bioherm into nine facies. These are in order of discussion: the Acinophyllum facies, the Core facies, which includes the Inner Core subfacies and the Outer Core subfacies, the Transitional facies, the Heliophyllum facies, the Near Reef Edgecliff facies, the Flank facies, the Protocap facies, the Flank-Cap facies and the Modified Flank-Cap facies. These facies can be seen on two sides of the reef exposure and are illustrated in a cross section of the south side (Fig. 8). Table 1 is a summary of point count data for several of the facies and Table 2 contrasts the coral fauna of the biohermal units.

Both Oliver (1954), (1956a) and Lindholm (1967) agree that the deepest part of the Onondaga basin was in central New York. Lindholm (1967) suggests that the axis of the basin ran from Syracuse roughly southwest into Pennsylvania. The authors have adopted this viewpoint, and in the following discussion the western side of the bioherm is toward the platform and the eastern side of the bioherm is toward the basin.

Coelenterate classification follows Stumm (1964), except in the case of Synaptophyllum where McLaren (1959) is followed.

Acinophyllum Facies. This facies is a biomicrudite which crops out very discontinuously at the east end of the south side of the bioherm (Fig. 8) and at the base, near the center of the north side. The lower contact of this facies was not observed, and the maximum thickness observed was 2 ft.

This facies is characterized by a large number of Acino-phyllum in a dark matrix of micrite and fine-grained fossil hash. Point count analysis of thin sections shows that Acino-phyllum comprises from 31 to 60 percent of the rock volume. Most of these corals are strongly oriented in an east-west direction.

Crinoids, auloporids, ostracods and gastropods are present in meager amounts. With the exception of the ostracods, these accessory organisms occur as broken fragments.

Spar is present in most skeletal voids and in secondary voids such as fractures. Occasional patches of pseudospar can be found in the micrite, fossil hash matrix.

This facies is interpreted as a basal platform or substrate on which the core of the bioherm was built. Acinophyllum acts as a pioneer population which colonizes the area and traps mud*

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*In the remainder of this paper, mud refers to everything less than 20 microns which includes both micrite and silt-sized particles.

BIOHERM

HELIOPHYLLUM

Transitional

Inner Core

Outer Core

ACINOPHYLLUM

FACIES

Modified Flank-Cap

Flank-Cap

Flank

Protocap

Near Reef Edgecliff

LEROY QUARRY

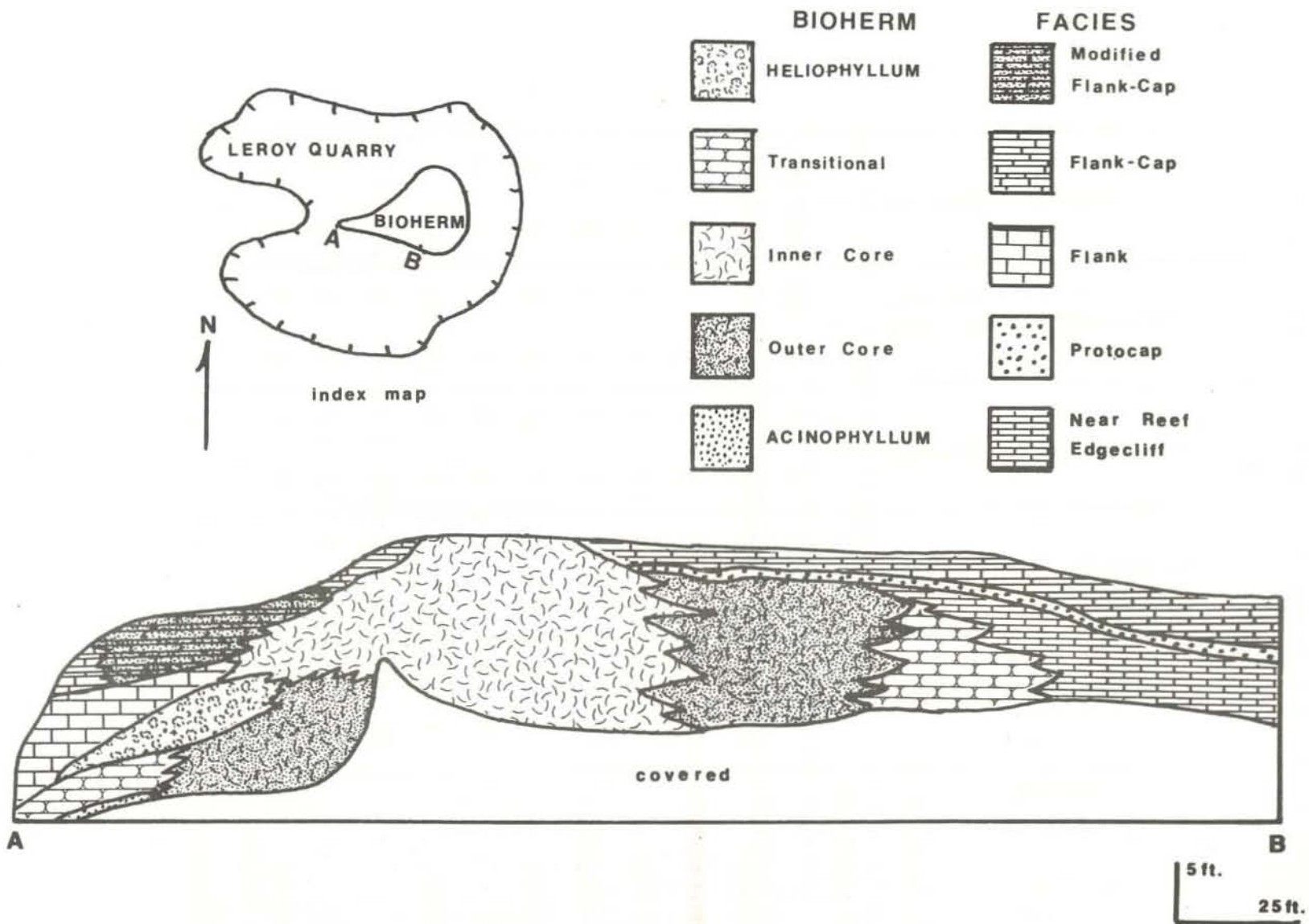BIOHERM

A

B

N

index map

A

covered

B

5 ft.

25 ft.

Fig. 8 - Cross section of Leroy bioherm showing facies. Cross section is along the south side of the core of the bioherm which is exposed in the middle of the Leroy quarry (see index map).

Table 1: Summary of point count data for selected biohermal facies and subfacies. A average; SD standard deviation; x not seen in facies; - too minor to be counted

Facies	Inner Core subfacies		Outer Core subfacies		Transitional facies		Near Reef Edgecliff facies		Protocap facies	
Number of samples	9		14		4		5		5	
Percent	A	SD	A	SD	A	SD	A	SD	A	SD
"cladoporids"	14	7	20	8	9	3	2	1	6	5
other tabulates	3	4	2	3	3	2	8	6	2	2
Acinophyllum	1	-	2	3	12	4	-	-	26	8
Synaptophyllum	x	x	-	-	2	3	-	-	8	12
other rugose	1	-	1	3	7	10	4	8	2	2
ectoproct	4	3	2	2	5	4	1	1	2	1
pelmatozoan	13	7	13	7	8	4	56	13	15	13
mud	34	11	35	9	28	10	6	6	21	12
spar	21	8	17	9	13	12	4	6	8	3
unidentified skeletal debris	6	4	5	3	8	5	9	8	9	4
other	5	3	2	2	3	1	1	1	1	1

Table 2: Relative abundance of tabulate and rugose coral genera in Leroy Bioherm facies and subfacies. A abundant - crowded in rock; C common - easily found; P present - can be found; R rare - rarely found; x not seen; ? questionable identification

Facies	Acinophyllum	Outer Core	Inner Core	Transitional	Heliophyllum	Near Reef Edgecliff	Protocap	Flank	Flank-cap	Modified Flank-cap
Heliolitidae										
PROPORA (?)	X	X	P	X	X	X	X	X	X	P
Favositidae										
FAVOSITES	X	P	C	C	X	C	P	C	A	A
EMMONSIA	X	C	C	X	X	X	X	P	R	X
THAMNOPORA	X	A	A	C	P	C	C	?	C	C
CLADOPORA	X	A	A	A	C	C	A	C	C	C
COENITES	X	P	X	C	X	X	?	X	X	X
Auloporidae										
ROMNIGERIA	R	C	P	P	R	P	X	X	P	X
AULOCYSTIS	R	C	C	C	C	C	C	P	C	C
Streptelasmatidae										
HETEROPHRENTIS	X	X	X	X	X	X	?	P	P	X
SIPHONOPHRENTIS	X	P	P	X	X	?	X	C	?	?
Zaphrentidae										
HELIOPHYLLUM	X	R	X	C	A	C	R	C	A	A
BETHANYPHYLLUM	X	R	X	?	X	C	R	C	C	?
Stauriidae										
SYNAPTOPHYLLUM	X	R	X	C	C	X	A	X	P	P
Phillipsastraeidae										
CYLINDROPHYLLUM	X	X	X	?	?	X	P	X	P	X
ACINOPHYLLUM	A	P	P	A	A	P	A	?	A	P
Digonophyllidae										
CYSTIPHYLLOIDES	X	A	A	X	X	C	R	C	C	X
EDAPHOPHYLLUM	X	R	X	X	X	?	X	R	R	X

and other organic debris between its elongate cylindrical coralites, resulting in a compact or firm substrate.

This platform building stage took place in low energy conditions where the mud and other organic debris was able to filter down between the Acinophyllum corallites. Acinophyllum with its elongate, cylindrical and laterally-connected corallites is better adapted to a turbid environment than massive sheet-like or head-like favositid corals would be. In addition to this, the compound, interconnected Acinophyllum provides an excellent framework, which, once packed with mud and other debris, becomes a suitable foundation for the bioherm-building organisms.

The Acinophyllum facies is analogous to the initial-reef subfacies of the Gasport reefs. The biota of the Gasport is different but the effect was the same, that of providing the framework in which sediment accumulated. The resulting mound then acted as the base on which other organisms grew.

Core Facies. A casual examination of this facies in outcrop would probably not result in further subdivision. However, detailed examination of lithology and faunal abundance, summarized in Table 3, has resulted in identification of two subfacies.

Inner Core Subfacies - The Inner Core subfacies (Fig. 8) is a cladoporid-crinoid sparse biocalcisiltite to a poorly-washed biosparudite. The maximum thickness observed for this unit is 20 ft. The Inner Core subfacies is characterized by its dark-gray color, vuggy weathering appearance, and complete lack of bedding.

The tabulate corals present fall into two natural groups. The first is composed of members of the genera Favosites, Emmonsia, Thamnopora, (larger species than counted in cladoporids) and Propora (?) with reptant and phaceloid growth forms. The second group is composed of cladoporids and auloporids. The latter are much smaller and their growth form is predominantly ramose. These cladoporids commonly grow in thickly-entwined, anastomosing clusters and make up 14 percent of the rock volume.

Cystiphylloides americanum is the most abundant large rugose coral. Two other types of rugose corals, one of the subfamily Acrophyllinae and the other resembling Placophyllum (?) (Fagerstrom, 1961) are present in this subfacies.

Platyceratid gastropods are fairly common, and one portlockiellid gastropod was seen in this unit. Cyclostome ectoprocts are found encrusting cladoporids and matrix. Other organisms present are molluscs, trilobites, ostracods, brachiopods, fenestrate cryptostome ectoprocts, and other rugose corals.

The matrix is composed of 34 percent lime mud, which includes micrite as well as silt-sized grains less than 20 microns in diameter, and other larger skeletal debris (Table 1).

Outer Core Subfacies - The Outer Core subfacies is a cladoporid-crinoid packed biocalcisiltite to a poorly-washed biosparudite. It, in part, underlies and laterally interfingers with the Inner Core subfacies.

On outcrop this unit is dark gray, does not exhibit a well-developed, vuggy-weathering surface, and has highly-irregular, discontinuous bedding.

The same two natural grouping of tabulate corals mentioned for the Inner Core subfacies are present, but with modifications (Table 3). Propora (?) is not present, and Emmonsia is more abundant, especially on the outer and upper edges of the unit. These larger tabulates are, as a whole, more abundant than in the Inner Core subfacies. There are three noticeable changes in the second group. Individuals of the genera Coenites are found in the Outer Core subfacies, but not in the Inner Core subfacies, and the cladoporids do not form as many anastomosing clusters in the Outer Core subfacies. In addition to this, Romingeria is more abundant.

Cystiphylloides americanum is still the dominant rugose coral, but Edaphophyllum, Heliophyllum and Bethanyphyllum are also present.

These two subfacies are interpreted as being the major topographic building unit of the bioherm with the Inner Core subfacies acting as the main growth center. The thickly-entwined cladoporids provided a framework or upward-reaching sieve, which trapped organic debris and mud. Larger favositid corals helped to buttress the cladoporid framework, and in conjunction with encrusting ectoprocts, helped stabilize the skeletal debris.

Away from the main growth center (Outer Core subfacies), the larger tabulates increased in abundance and played more of a major role in upward building. The cladoporids in this subfacies are more evenly distributed and form fewer clusters. Thus it seems that deposition was slightly slower in this subfacies, allowing more of the cladoporids to be broken and mixed in with the other organic detritus. This is in contrast to the Inner Core subfacies, where most of the cladoporids were incased in organic detritus while still in growth position.

Squires (1964) describes a coral thicket of Upper Miocene age in New Zealand, in which the framework-building organism is Lophelia parvisepta, a deep-water scleractinian coral with a highly-reticulate growth pattern. The writers do not wish to suggest that the Leroy Bioherm is a deep-water structure, but rather that Squires' (1964) thicket, coppice, and early bank stages are probably analogous to the first stages of the Core facies development.

Table 3: Basis for subdividing Core Facies

Inner Core subfacies	Outer Core subfacies
weathers very vuggy	weathers slightly vuggy
massive	irregular and discontinuous bedding
low abundance of Emmonsia trace amounts of Acinophyllum	higher abundance of Emmonsia more Acinophyllum
Synaptophyllum not present	Synaptophyllum present
presence of Placophyllum (?) and member of subfamily Acrophyllinae	Placophyllum (?) and member of subfamily Acrophyllinae not present
Cystiphylloides dominant almost to exclusion of other large rugose corals	Cystiphylloides dominant, but Edaphophyllum, Heliophyllum and Bethanyphullum present

The spar content of the core facies is considerably greater than that of the underlying Acinophyllum facies thus suggesting better circulation and a higher energy environment for the Core facies. This facies, then, represents the semi-rough water stage of development.

Although "stick" or "finger" tabulate corals are commonly known to build mounds and biohermal structures during Devonian time (Stumm, 1969, Dumestre and Illing, 1967), they usually do so in concert with stromatoporoids. Only two stromatoporoids were seen during this study.

Transitional Facies. This facies in part overlies the Acinophyllum facies and interfingers laterally with the Outer Core subfacies and the Near Reef Edgecliff facies. On the western or platform side of the bioherm, it has a gradational contact with the overlying Heliophyllum facies (Fig. 8).

This unit is a packed, cladoporid-Acinophyllum biocalcisiltite. On outcrop this facies is light-gray, non-vuggy, and exhibits moderately well-developed bedding. Large tabulate and rugose corals are not very abundant in this unit. On fresh exposures this unit has a speckled appearance caused by the color contrast between the matrix and the lighter colored Acinophyllum, Synaptophyllum and cladoporids.

In thin section this unit is characterized by the Acino-phyllum, Synaptophyllum and cladoporid association. Mud content is still high averaging 28 percent. Associated organisms in order of decreasing abundance are brachiopods, gastropods, trilobites and ostracods. Many of the organisms present in this facies are either broken, or are not in growth position.

This facies represents the narrow band that separated the Outer Core subfacies from the Near Reef Edgecliff facies and is composed of the detritus that was, in part, transported from the Outer Core subfacies. The area was not a prolific growth area for the cladoporid group, except perhaps for Coenites, and because of this Acinophyllum was not crowded out as it was in the Core facies.

Heliophyllum Facies. This facies is developed only on the western (platform) side of the bioherm. It interfingers laterally with the Outer Core subfacies and the Flank facies. It has a gradational contact with the underlying Transitional facies and the overlying Modified Flank-Cap facies (Fig. 8).

On outcrop this unit is very distinctive and is dominated by Heliophyllum and Acinophyllum horizons in a black, dense matrix. The Heliophyllum display a weakly-aggregated growth habit. West-ward dips ranging from 8 to 12 degrees were recorded for this unit.

In thin section this unit is best described as a sparse to packed Heliophyllum-Acinophyllum biomicrudite. Synaptophyllum occurs irregularly within the Acinophyllum-rich horizons, and an occasional Cladopora-rich zone was encountered.

The matrix is a mixture of fine fossil hash and micrite. Occasionally, pockets of crinoid ossicles and spar can be found, but on the whole, both of these components are minor. Ectoprocts, ostracods, brachiopods, gastropods, trilobites and auloporids are also found in this facies.

This unit is thought to represent an "energy shadow" deposit accumulated on the platform side of the bioherm as it built up into the semi-rough water environment.

The Heliophyllum-rich zones are well-defined and continuous. The weakly-aggregated individuals are most often found lying on their sides forming, in places, a white band of rock that closely parallels the dip of the unit. Another feature of the occurrence of these corals is that very few broken or abraded individuals were found. These observations indicate that these corals have not been transported to any significant degree and, in addition, are probably very near their original growth position with only a minor amount of compaction.

The zonation seen in this unit is probably due to turbidity changes. During times of high turbidity Acinophyllum was better adapted for this quiet, muddy environment. During times of reduced turbidity and concomitant, slower deposition of fines, Heliophyllum was able to dominate over Acinophyllum.

Near Reef Edgecliff Facies. This facies interfingers laterally with the Transitional facies and is overlain by the Protocap facies or the Flank-Cap facies. It is exposed on the east and northeast side of the bioherm (Fig. 8). On the western side of the bioherm it has been quarried out.

On outcrop this unit is a light- to dark-gray, medium-crystalline crinoid sand. It is fairly well-bedded, with individual beds ranging from 2 - 6 in. in thickness. Favositid and solitary rugose corals are common in this unit. The growth forms of the favositids are usually reptant or sheetlike and they appear to be in life position. Occasional hemispherical (2-4 in. diam.) Favosites were seen. Heliophyllym, Bethanyphyllum and Cystphylloides are common. The latter are sometimes concentrated on the lowermost bedding planes of this unit.

In thin section this unit is a crinoid biosparudite. Mud content is low, averaging only 6 percent and virtually no micrite was seen. The crinoid content averages 56 percent. Brachiopods and platyceratid gastropods are found throughout this unit. Fragmented Acinophyllum, Synaptophyllum and ectoprocts are minor components of this facies.

The Near Reef Edgecliff facies is very much like that of the normal Edgecliff and represents only a slight modification of normal Edgecliff conditions. The most obvious difference between the two is that the Near Reef Edgecliff facies does not contain the black chert beds and nodules that are present in the normal Edgecliff. The normal Edgecliff also has less spar, and more large spherical to hemispherical Favosites than the Near Reef Edgecliff.

Flank Facies. This is present on the western or platform side of the bioherm. It is a wedge-shaped unit that overlies the Transitional facies and, in part, the Heliophyllum facies. It is in turn overlain by the Modified Flank-Cap or the Flank-Cap facies. It laterally interfingers with the Heliophyllum facies (Fig. 8).

On outcrop this unit is a light-gray to pink, medium crinoid sand which is massive- to poorly-bedded. Large and small Favosites are present as are large solitary rugose corals. Most of the Favosites are reptant or in a semi-sheet growth form, however, some larger head or semi-hemispherical forms were seen. Rugose corals include Compressiphyllum, Edaphophyllum, Siphonophrentis, Heliophyllum, Bethanyphyllum and Cystiphylloides.

In thin section this unit is a crinoid biosparudite. Cladopora is the only cladoporid found in this unit and auloporids are relatively lacking. With the exception of the larger rugose and the reptant or sheet-like favositids, most of the organisms present in this facies show some degree of breakage or abrasion. The mud content of this facies (9 percent) is higher than that of the Flank-Cap facies, and some micrite is present in this category.

There is a prominent and continuous bedding plane on the north side of the bioherm that separates this facies from the overlying Flank-Cap facies and the Modified Flank-Cap facies. On the south side of the bioherm, where this area of the outcrop is more severely weathered and partially overgrown, this relationship is not as well developed. It is possible that this facies should be considered as part of the Modified Flank-Cap facies rather than as a separate unit, however, the "Flank-Cap" designation is used to imply that a unit both flanks and overrides the core facies.

This unit is thought to have been deposited during the initial stages of the formation of the "crinoid garden," which later draped the area and formed the Flank-Cap facies. As this crinoid garden was forming, the individuals would be initially widely-spaced, perhaps in patches, and therefore susceptible to being broken up. They then could be washed over and around the bioherm and deposited in the slight energy shadow on its platform

side. The larger rugose corals and sheet-like or reptant
favositids probably were growing in this area along with some
crinoids and their associated platyceratid gastropods. The
larger Favosites were washed into the area along with other
crinoid and skeletal debris during times of storm activity.

Protocap Facies. This facies is found only on the eastern or
basin-side of the bioherm. It overlies the Core facies, the
Transitional facies and the Near Reef Edgecliff facies. It is,
in turn, overlain by the Flank-Cap facies (Fig. 8). The thickness
of this unit varies from 4 to 6 in. This unit is best developed
on the south side of the bioherm and was seen at one point on
the north side. The lower contact of this unit is sharp, but the
upper contact is gradational into the Flank-Cap facies.

On outcrop this facies is dominated by Acinophyllum oriented
parallel to the lower contact. Shaley partings are more obvious
in this facies than in any other biohermal unit.

The Protocap facies is thought to represent the very begin-
ning of the wave-resistant or rough water stage in the development
of the bioherm. It would seem that this unit was developed just
below or right at the lower limit of normal wave base.

Flank-Cap Facies. This facies overlies the Protocap facies, the
Near Reef Edgecliff facies, the Core facies and, in part, the
Flank facies. It also interfingers with the Modified Flank-Cap
facies.

On outcrop this unit is a whitish-gray to pink, extremely-
coarse, crinoid sand. As is indicated by its name, it both flanks
and caps the core of the bioherm. The unit has a bedded appear-
ance which is caused by zones or horizons of concentrations of
rugose and tabulate corals. The larger, tabulate corals present
are head-shaped and semi-hemispherical Favosites, and heavy
ramose Thamnopora. Some of the Favosites are several feet in
diameter and 6 to 8 in. thick.

The rugose coral zones are composed of Acinophyllum or
Heliophyllum. Cladopora is usually present in the Acinophyllum
zones, and in some cases Cladopora and auloporids make up a coral
horizon. Bethanyphyllum and Cystiphylloides are common in this
unit, but they do not form coral horizons or zones.

The rock between coral zones is an extremely-coarse, pink
and white crinoid sand with abundant crinoid columnals up to an
inch in diameter. Brachiopods and gastropods are associated
with these crinoid sand layers. The unit dips away from the
core of the bioherm at angles up to 15 degrees.

In thin section this unit is a crinoid biosparudite. Point count data are strongly affected by the location of the sample in relation to the coral-rich horizons, therefore no attempt was made to obtain average amounts of the various components. Skeletal debris is abundant in this facies and mud is usually minor, occurring in significant amounts only in the coral horizons.

The Flank-Cap facies is interpreted as being the culminating stage in the development of the Leroy Bioherm. The crinoids equipped with holdfasts and flexible stems, are well-suited to living in a near-surface, high-energy environment. There organisms formed a crinoid garden, that draped the bioherm and the surrounding area. The lower flanking portions of this unit formed during the early period of the wave-resistant stage, probably contemporaneously with the higher portions of the core. As the core built up into the zone of normal wave action, the crinoid garden migrated up and over the core, and finally capped the structure.

The coral horizons represent times of relatively low-energy conditions, when corals were able to grow in great profusion in and around the crinoid stalks. During times of relatively high-energy conditions, these coral beds were buried by crinoid and other skeletal debris. In his dicussion of Niagaran reefs, Lowenstam (1957) describes typical reef-flank sections in the following manner:

> "...Reef-flank sections denoting an early stage of
> the wave-resistant phase commonly show cyclical
> interlayering of frame-building organisms and bio-
> clastics reflecting periodic storm-induced burial
> by reef-derived fragments and hence temporary re-
> traction of the building sphere..."

The Flank-Cap facies seems to represent a similar situation to that seen in some large Niagaran reefs; however, it is not similar to the flank subfacies of the Gasport reefs.

Modified Flank-Cap Facies. This facies is found on the western side of the bioherm. It overlies the Flank facies and the Heliophyllum facies, and interfingers laterally with the Flank-Cap facies (Fig. 8).

On outcrop this unit varies from a rugose coral-rich, dark, dense rock to a light-gray, coarse crinoid sand. Favositid corals are irregularly present and are of the same assemblage as that of the Inner Core subfacies. Mud content is generally quite high (average 33 percent) and the facies contains many entwined Heliophyllum and subordinate Acinophyllum.

In thin section this facies varies from a rugose coral, sparse-to-packed biocalcisiltite to a crinoid biosparudite. The matrix trapped by the Heliophyllum contains micrite and silt-sized skeletal debris. Associated organisms include ectoprocts, trilobites, ostracods, gastropods, and brachiopods.

The facies is thought to represent a combination of a second generation energy-shadow deposit and a shifting of the core out of the high-energy zone. Even after the bioherm was built up into the rough water zone, and was overgrown by the crinoid garden, it initially had enough relief to provide a slight energy-shadow on its platformward side. Heliophyllum became established in the area, along with corals characteristic of the Inner Core subfacies. The Heliophyllum, in this case, acted as the major framework building organism, and was able to trap fines.

As the Flank-Cap unit began to reduce the relief of the area the Modified Foank-Cap facies was soon smothered by the encroaching crinoid garden.

Surrounding Rocks

The stratigraphic succession exposed in the quarry walls surrounding the Leroy Bioherm can be divided into four units. These units can be traced around the entire quarry and show little variation from place to place.

1. The lowest unit exposed is a vaguely-bedded to massive, medium-grained, dark, crystalline crinoid limestone. There are a few solitary rugose corals in this unit along with brachiopods and occasional gastropods and cladoporids. The maximum thickness seen for this unit was 3 ft. The upper contact is sharp and is overlain by a 2 in., dark chert bed at the base of the overlying unit. The lower contact with the Lower Devonian, Bois Blanc Formation was not observed.

2. This unit is a well-bedded, medium-to-coarse, dark-gray crinoid sand. The individual beds which are 2 to 8 in. thick commonly exhibit considerable lateral variations in thickness. The total thickness of the unit is about 7.5 ft. The unit is very fossiliferous, containing abundant rugose and tabulate corals, brachiopods and some gastropods. The favositid colonies are up to a foot in diameter and are either head-shaped or reptant. Cladoporids and auloporids are found scattered throughout, along with the dominant rugose corals, Heliophyllum and Bethanyphyllum.

Chert is very abundant in the lower portion of this unit, occurring in 1 to 3 inch discontinuous beds, or as nodular horizons. Towards the top of the unit, chert content decreases and no chert beds are present. The upper contact with the overlying unit is gradational. Chert content for the unit as a whole is approximately 30 percent.

3. This unit is a well-bedded, light-to-gray, coarse crinoid
sand. Individual beds are 1 to 8 in. in thickness, and often
a thick bed will split laterally into two thinner ones. The
total thickness is 9 ft.

This unit is extremely fossiliferous, containing two species
of Heliophyllum along with Bethanyphyllum, Cystiphylloides,
Acinophyllum, Siphonophrentis and Edaphophyllum. Tabulate corals
are represented by several species of Favosites, auloporids and
the cladoporids. Brachiopods are abundant in this unit with
spiriferids, pentamerids and several species of Atrypa being
common. Gastropods are also abundant in this unit.

Coral beds of Acinophyllum and Heliophyllum are present as
are auloporid and favositid-rich zones. The coarse crinoid sand
between these coral horizons is packed iwth the other solitary
rugose corals, brachiopods and gastropods.

Beds of Favosites measuring 2 ft. in diameter are not
uncommon in this unit. Reptant and smaller hemispherical Favo-
sites are also present. Chert content of this unit is less than
5 percent.

The lower limit of this unit is set at a marked ledge on
the southern quarry wall and the upper limit is set at the first
occurrence of a continuous chert bed at the bottom of the over-
lying unit.

4. The topmost unit is well-bedded, dark gray, medium crinoid
sand. The bedding is very similar to that in the underlying unit.
The maximum observed thickness is 6 ft.

This unit is also very fossiliferous, but differs from the
underlying unit in that rugose corals are less abundant,
Heliophyllum still forms coral beds. Again, two species of
Heliophyllum are present, one forms the coral beds and the other
is irregularly distributed. Acinophyllum does not occur in beds,
but rather in circular clumps. Large head-shaped Favosites are
not as common and small spherical favositids are more abundant.

The most notable faunal change from the underlying unit is
in gastropod abundance and diversity. Two species of euomphalids,
several platyceratid, and many large unidentified gastropods are
found in this unit. These gastropods are often found in association
with the chert beds. Brachiopods are still common. Chert in this
unit is approximately 45 percent and occurs as irregular 2 to 4 in.
beds, or as chert nodule horizons. Rock debris looking very much
like this unit was found on top of the bioherm. It seems reasonable
to assume that this unit once overlay the Flank-Cap facies at the
bioherm.

Units 2 and 3 compare favorably with description of the Edgecliff Member by Oliver (1954, 1966) and Lindholm (1967) although unit 3 is influenced considerably by the proximity of the flank-cap facies of the reef. Unit 4 is probably equivalent to the Clarence Member (Nedrow of central New York). However, its fossil content indicates that the nearby reef was still an active influence during the initial phases of Clarence sediments.

Reef Development Model

There is a marked vertical community succession or seral succession (as used by Nicol, 1962) exhibited by the Leroy Bioherm. The main communities are, in ascending order, the Acinophyllum community, the cladoporid community, and the crinoid garden community.

The Acinophyllum community is characterized by low taxonomic diversity and is dominated numerically by one species, Acinophyllum baculoideum. This community forms a pioneer community, and the controlling factors in its development are water energy and turbidity. This community represents the quiet-water stage of the bioherm.

The cladoporid community is characterized by a high taxonomic diversity and, as far as could be determined, no one species is numerically dominant. This community is the major topographic building unit of the bioherm. The cladoporids and subordinate larger favositids (except perhaps in the upper portions where Emmonsia and other Favosites may have become more important) constructed a framework which provided many niches for other organisms and provided a trap which retained debris created in and around this growth center, thereby facilitating its upward growth. The controlling factor is again water energy. This community represents the semi-rough water and, in part, the rough water stage of the bioherm.

The crinoid garden community is characterized by a moderate-to-high taxonomic diversity and is possibly numerically dominated by crinoids. When it is seen directly over the core of the bioherm, it does not contain the diverse fauna that it shows away from the core. This is to be expected as the point over the core was, for a time, the topographically highest position of the crinoid garden and, therefore, in the area of highest energy. It is reasonable to expect a slight reduction of diversity in a stress environment.

The controlling factor is once more water energy. The initiation of the crinoid garden was caused by the bioherm penetrating up into the surf zone, where the cladoporid community could not survive. The crinoid garden community was then able to take over the area. This stage of the bioherm was not very important in upward building of the structure. The growth of the bioherm during this stage was mainly in a horizontal direction and was soon able to level the relief of the area. The crinoid garden community is considered to be the rough water stage of the bioherm.

Organisms acting as sediment binders within the bioherm are cyclostome ectoprocts, crinoids, sheet-like and reptant favositids. The framework builders are the cladoporids, Acinophyllum, auloporids, and larger favositid corals. The sediment-producing organisms are crinoids, cryptostome ectoprocts, gastropods, brachiopods, trilobites, ostracods, and to some degree all of the coral present in these rocks.

In an effort to construct a general model for Edgecliff biohermal development, the detailed facies of the Leroy reef can be grouped into four basic units (Fig. 9). The first unit is the platform-building or Acinophyllum facies. The matrix of this unit is mainly micrite. The lower extent of the Acinophyllum facies and its relationship to underlying rocks is now known.

Overlying the Acinophyllum facies is the Core facies which is the main relief-building unit of the bioherm. The framework builders are delicate "finger" corals and to a lesser degree other larger favositids. The matrix of this unit is a mixture of micrite and silt-sized organic debris. The top of this unit may or may not be channeled. On the platformward side of the core, the energy-shadow facies is developed. This unit has more micrite in its matrix than the Core facies, but less than the Acinophyllum facies. Organisms with a high tolerance for mud are found living in this area. Fluctuations of turbidity experienced by this environment are indicated by a zonation of organisms, which are interpreted as having different levels of tolerance to turbidity.

The last basic unit is the Flank-Cap unit which both flanks and overrides the structure bringing its upward growth to a half. The change from the upward-building, core facies to the lateral-building, Flank-cap facies is brought about by the penetration of the bioherm into the wave zone. As a result, the Flank-Cap facies is extremely coarse and virtually mud free.

Reconnaissance field work in 1969 indicated that most of the bioherms exposed in eastern New York fit the model suggested in Fig. 9. Observations made during this time support the interpretation that "finger corals" are important in the framework of the main relief building facies of these bioherms.
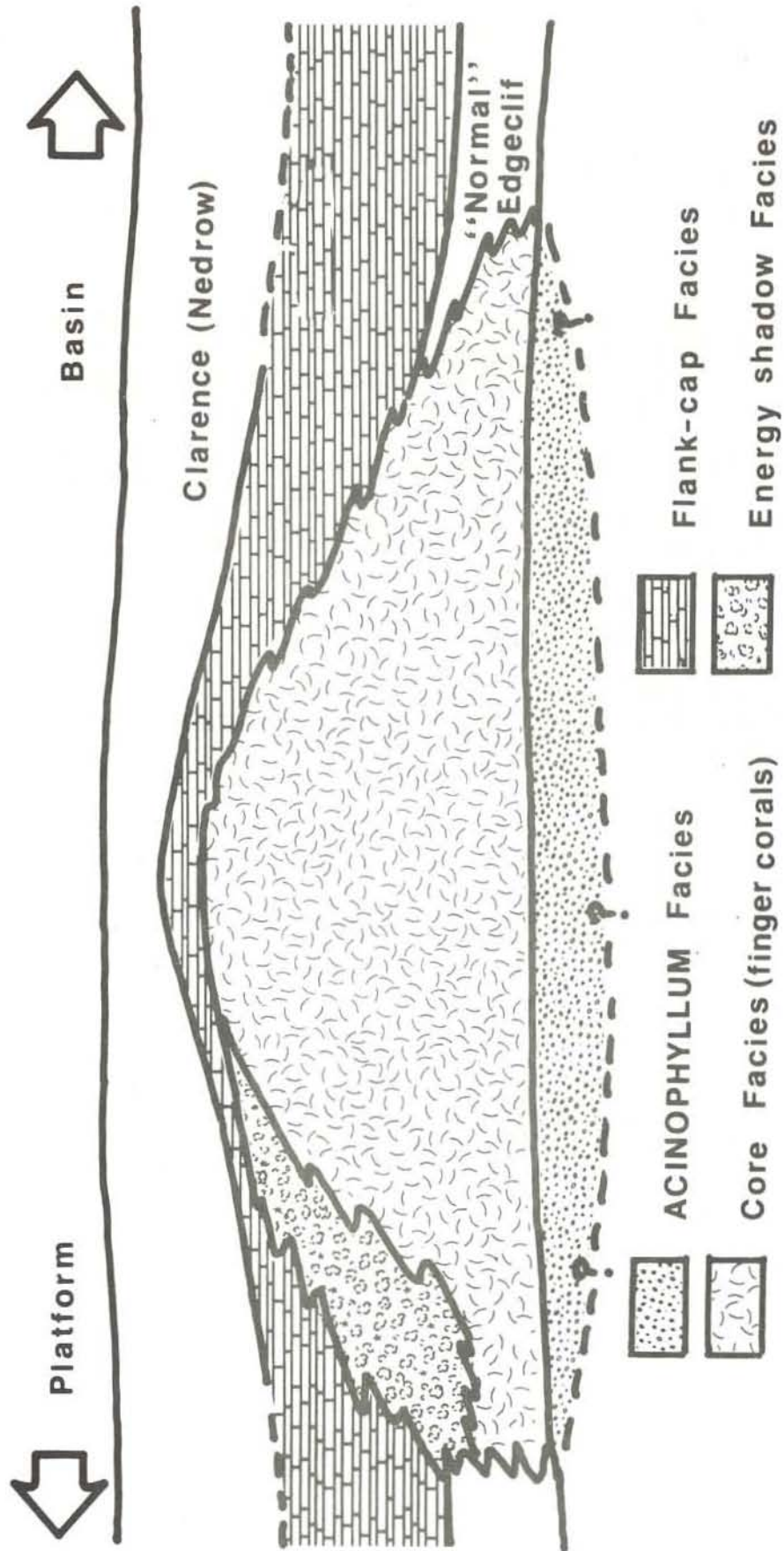
Fig. 9 - Diagrammatic cross section of a "typical" Edgecliff bioherm. See text for discussion of facies.

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TRIP A - LOCKPORT (MIDDLE SILURIAN) AND ONONDAGA (MIDDLE
        DEVONIAN) PATCH REEFS IN WESTERN NEW YORK

        Donald J. Crowley (Field Trip Leader) and
        Richard Z. Poore

                        Location of Stops

STOP 1.
        Road cut on escarpment in the village of Pekin, 1.8 miles
        north on route 429 from intersection with route 31.
        Ransomville 7½' quad.
                Two patch reefs in the Gasport Member (Lockport Fm)
                are exposed on the west side of the road cut (See Fig. 4
                in report). Lower few feet of the overlying chert-
                bearing Goat Island Member are also exposed.

STOP 2.
        Railroad cut on the east side of "The Gulf", 1.3 miles
        east on route 31 from intersection with route 78 in Lock-
        port. Lockport 7½' quad.
                DeCew Member and the crinoidal bar facies of the
                Gasport (Lockport Fm.) are exposed. This is the
                most fossiliferous exposure of the Gasport and preser-
                vation of fossils is also good. Coral thickets form
                lenses in the crinoidal bar facies.

STOP 3.
        Frontier Stone Products quarry, 1.4 miles southwest of
        intersection of routes 31 and 78 in Lockport. Lockport
        7½' quad.
                All Gasport facies (Lockport Fm.) are exposed including
                several patch reefs. Stromatoporoid cap facies forms
                light band near the top of the quarry walls. A few
                feet of the Goat Island Member is exposed above the
                light band and the floor of the quarry is the top of
                the DeCew Member.

STOP 4.
        Abandoned quarry ("LeRoy quarry"). From the intersection of
        routes 5 and 237 in the village of Stafford (Stafford 7½'
        quad.) go north 2.2 miles on route 237, turn right and go
        2.6 miles to the east end of Britt Road (to the point where
        the road turns south and crosses the Leigh Valley Railroad
        tracks). Turn north into entrance road to quarry. Byron
        7½' quad.
                Patch reef in Onondaga Limestone exposed in the middle
                of the quarry. Edgecliff and the lower part of the
                Clarence member exposed around the outside quarry wall.
                (See Fig. 8 in report for cross section of reef).

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