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BIOHERM DEVELOPMENT IN THE EDGECLIFF MEMBER OF THE ONONDAGA FORMATION, PORT COLBORNE, ONTARIO

BIOHERM DEVELOPMENT IN THE EDGECLIFF MEMBER OF THE ONONDAGA FORMATION, PORT COLBORNE, ONTARIO

By

Craig Thomas Johnston

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ABSTRACT

Bioherm growth within the Edgecliff Member of the Onondaga Formation in the vicinity of Port Colborne, Ontario is represented by a broad low-lying coralliferous mound, trending approximately north-south. The mound displays a progressive pattern of faunal and lithologic succession which can be broken down into four stages. The Basal and Coral-Rich Basal Facies represents deposition in a shallow to deep shelf lagoon, below fair weather wave base and above storm wave base. Stage I of mound development is initiated in response to a slight regression near the top of these facies, corresponding to the deposition of the Transitional Facies, a shoaling upwards sequence reaching above the surrounding substrate. Stage II is represented by the colonization and stabilization of the mound by solitary and colonial corals within fair weather wave base. Stage III results in the diversification of the mound upwards into a high energy zone, corresponding to the deposition of the Core Facies. At this time, sea-level remains stable and intermound areas are filled in by the Biostrome, Flank, and Flank/Cap Facies. The final stage, Stage IV represents the termination of mound growth by deposition of a crinoidal cap due to, either a fall in sea-level, or growth of the mound into the surf zone.

The inferred paleocurrent direction from facies relationships, and a measured coral orientation, suggest currents direction from the southeast to northwest.

Thus, the Edgecliff Member of the Onondaga Formation in the vicinity of Port Colborne, Ontario represents deposition in a shallow shelf lagoon, and displays evidence for two possible sea-level fluctuations; one near the top of the Basal and Coral-Rich Basal Facies, and the second corresponding the Flank/Cap and Cap Facies, terminating mound development.

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CHAPTER I

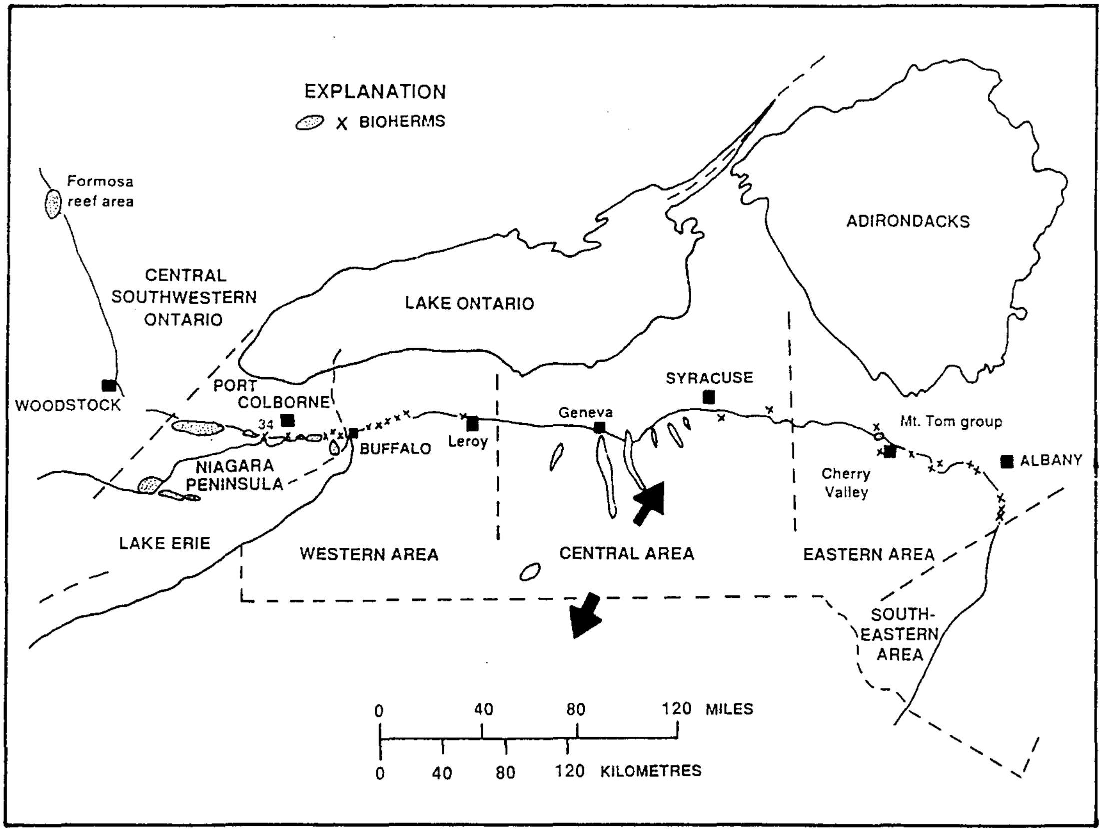
INTRODUCTION

At the beginning of Devonian time, the highlands of eastern North America, uplifted by the Taconic orogeny, were covered by an epeiric sea. Sea-level fluctuated throughout the Lower Devonian, ending with a period of widespread emergence of the Craton (Cincinnati Arch) to the west and the geosyncline to the east, creating an unconformity at the base of the Middle Devonian (Eifelian) Onondaga Formation (Oliver, 1966). The Onondaga Formation was deposited by a transgressing epeiric sea, as the Appalachian basinal axis shifted from eastern New York west into central New York (Mesolella, 1978). A return to well-aerated shelf sea conditions is exemplified by the rich coral fauna of the Edgecliff Member, the lowermost member of the Onondaga Formation.

The Edgecliff Member is the "great coral bearing limestone" of Hall (1879), forming more than thirty biohermal structures throughout New York State and southern Ontario (Figure 1a). The majority of Edgecliff bioherms are restricted to eastern New York, western New York and the Niagara Peninsula of Ontario where they generally occur as clusters of two or more build-ups. Detailed studies of

Figure 1a. Outcrop belt of the Onondaga Formation in New York State and southern Ontario with the location of the identified Edgecliff bioherms and study area (Bioherm 34). (modified from Oliver, 1976)

Figure 1b. Map of the Niagara Peninsula in the vicinity of Port Colborne, Ontario with the location of the study area.


EXPLANATION
X BIOHERMS
Formosa
reef area
CENTRAL
SOUTHWESTERN
ONTARIO
LAKE ONTARIO
ADIRONDACKS
WOODSTOCK
PORT
COLBORNE
34
BUFFALO
Leroy
Geneva
SYRACUSE
Mt. Tom group
ALBANY
NIAGARA
PENINSULA
Cherry
Valley
LAKE ERIE
WESTERN AREA
CENTRAL AREA
EASTERN AREA
SOUTH-
EASTERN
AREA
0 40 80 120 MILES
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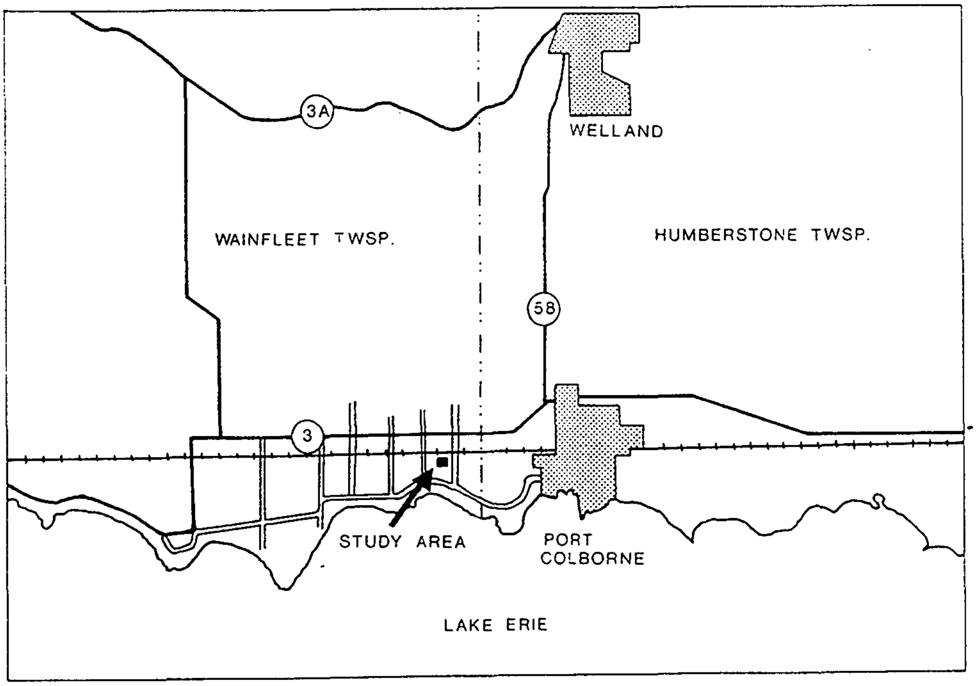

3A
WELLAND
WAINFLEET TWSP.
HUMBERSTONE TWSP.
58
3
STUDY AREA
PORT
COLBORNE
LAKE ERIE

bioherm development have contributed to the depositional history of the Edgecliff Member in both eastern and western New York. Studies of bioherm development are rare in the Niagara Peninsula of Ontario. Therefore, it is the objective of this study to conduct a detailed facies examination of bioherm growth in the vicinity of Port Colborne, Ontario in an attempt to define better the depositional environment of the Edgecliff Member of the Onondaga Formation.

STRATIGRAPHY:

The Onondaga Formation crops out in a narrow band extending from eastern New York west into southern Ontario, thickening both east and west of the basinal axis (Figure 1a). Sanford (1967) concluded that the Onondaga Formation passes laterally into the Detroit River Group (Amherstburg and Lucas Formations and Columbus Limestone) and the Dundee Formation beneath central Lake Erie and New York State. In Ontario and western New York, the Onondaga Formation rests unconformably on the Bois Blanc Formation and occasionally on the Upper Silurian Bertie-Akron Formation (Oliver, 1966). In eastern New York, a complete sequence from the Upper Silurian to the base of the Middle Devonian is present, with the Onondaga Formation unconformably overlying the Schoharie Limestone. Correlations of the various formations in southern Ontario and New York State are given in Figure 2.

Oliver (1954, 1966) divided the Onondaga Formation into four members. These are, from bottom to top, the: Edgecliff; Nedrow/Clarence; Moorehouse; and Seneca. The Edgecliff is the basal Member of the Onondaga Formation thickening from 5 m in western New York to 11 m in eastern New York (Lindemann, 1979). The Edgecliff appears as a light-gray, coarse-grained, fossiliferous limestone and is characterized by an abundance of rugose and tabulate corals, with brachiopods, bryozoans, gastropods, stromatoporoids and trilobites also present. Oliver (1954) identified three faunal zones in the Edgecliff Member. Zone A is a basal brachiopod dominated unit with scattered quartz sand and silt. Zone B is a discontinuous, coral dominated limestone which exist only in western New York and Ontario. Zone C is the typical and predominant Edgecliff faunal zone, dominated by rugose and tabulate corals. This unit can be traced from the Niagara Peninsula, Ontario, eastward for some 490 km (Lindemann, 1979).

The Edgecliff Member is conformably overlain by the Clarence Member in western New York and Ontario and the Nedrow Member in central and eastern New York. The Clarence Member consists of 40-75% chert and is medium to dark-gray, non-argillaceous, fine-grained limestone. Fossils are scarce to absent with the basal layers occasionally bearing

Figure 2. Correlation chart of Upper Silurian to Middle Devonian stratigraphic units in southern Ontario and New York State. (modified from Oliver, 1966)

LONDON-WOODSTOCK AREA, ONTARIO	BUFFALO AREA ONTARIO-NEW YORK	CENTRAL NEW YORK	HELDERBERG AREA EASTERN NEW YORK	SERIES OR STAGE		
HAMILTON GR.	HAMILTON GR.	HAMILTON GR.	HAMILTON GR.	CAZENOVIA		MIDDLE DEVONIAN
DUNDEE FM.	ONONDAGA FM: SENECA MEM.	ONONDAGA FM.: SENECA MEM.		ONESQUETHAW	EIFELIAN	
D R G: COLUMBUS LST.	MOOREHOUSE MEM.	MOOREHOUSE MEM.	ONONDAGA FM.: MOOREHOUSE MEM.			
LUCAS FM.	CLARENCE MEM.	NEDROW MEM.	NEDROW MEM.			
AMHERSTBURG FM.	EDGECLIFF MEM.	EDGECLIFF MEM.	EDGECLIFF MEM.			
BOIS BLANC FM.	BOIS BLANC FM.	BOIS BLANC	SCHOHARIE LST.		EMSIAN	LOWER DEVONIAN
			CARLISLE CENTER FM. ESOPUS FM.		SIEGENIAN	
		ORISKANY SST.	ORISKANY SST.	DEER PARK		
			HELDERBERG GR.	HELDERBERG	GEDINNIAN	
BERTIE-AKRON FM.	BERTIE-AKRON FM.	BERTIE-AKRON FM.	RONDOUT FM. COBLESKILL LST.	CAYUGA	LUDLOVIAN	UPPER SILURIAN

a fauna similar to the underlying Edgecliff. The Nedrow Member is a thin-bedded, very fine-grained, argillaceous limestone. Variation of fauna occurs with the basal beds dominated by platyceratid gastropods, brachiopods and a few rugose corals. The upper beds are generally less argillaceous and contain a low diversity, high density brachiopod fauna (Oliver, 1954).

The Moorehouse is gradational with the underlying Clarence and Nedrow Members. It consists of a medium-grey, very fine-grained limestone with numerous shale partings and chert throughout. The fauna is the most diverse of all the Members and suggests a return to an Edgecliff type environment (Oliver, 1966).

The Seneca Member represents the uppermost Member of the Onondaga Formation and is separated from the Lower Moorehouse by the Tioga Bentonite. The Seneca grades from Moorehouse-like lithology, becoming a darker, less fossiliferous, shaly fine-grained limestone. To the east the Seneca Member thins and is laterally equivalent to the Marcellus Shale.

The Marcellus Shale conformably overlies the Onondaga Formation and marks the end of the Eifelian Stage. The shale represents a westward transgression of clastic sedimentation in response to the beginning of the Acadian orogeny on the east coast of North America (Stearn et al., 1979).

PREVIOUS WORK - Edgecliff Bioherms

Hall in 1859 was the first to identify the presence of "coral reefs" in the Edgecliff Member of the Onondaga Formation and in 1879 referred to the Edgecliff as "the great coral bearing limestone". Later Grabau in 1903 and 1906 identified "reefs" in western and eastern New York, but did not describe them in detail. Oliver (1954, 1956b) made important contributions to the understanding of Edgecliff reefs, reporting on the fauna, dimensions and locations of more than 20 bioherms. Since then, detailed studies of individual bioherms have been conducted in both eastern and western New York. Studies of eastern New York bioherms by Williams (1980) and Wolosz (1985) suggest that these were shallow water reefs whose growth ceased upon entrance into the high energy surf zone. Crowley and Poore (1974) and Lindemann (1989) examined the LeRoy bioherm in western New York and agreed that this Edgecliff reef grew in shallow water with growth being terminated by entrance into the surf zone. Lindemann (1989) also concluded based on burial and regrowth of coral, that sedimentation was episodic, possibly due to the influence of storms. The only detailed study of bioherm development in central New York is from subsurface data and suggests a deep water origin for many of the

Edgecliff reefs, due to the lack of well developed stromatoporoids and algae (Kissling, 1981).

In Ontario, Cassa (1979) studied a bioherm in the vicinity of Port Colborne. She concluded that it was not a typical Edgecliff bioherm, but rather a shallow lagoonal bank which ceased growing as transgressing seas deepened and component fauna could not keep pace.

LOCATION AND ACCESS

The study area is an abandoned quarry located 2.7 km west of Port Colborne, Ontario, 0.2 km north of Lake Erie on the west side of Quarry Road (lot 6, con. I, Wainfleet T.) (Figure 1b). The quarry contains bioherm 34 of Figure 1a and is location C10 of Oliver (1976); not the old Canada Cement Company quarry as suggested by Navickas (1979) and Ripley (1980). The quarry was pumped dry in the early nineteen seventies by the Conservation Authority (Risk, pers. comm.) revealing 3-3.5 m of the basal section. The lower 1.2 m was thought to be Bois Blanc in age based on the fauna (Oliver, 1976), but pumping activities were abandoned and the quarry flooded before further work could be done. The study area is confined to the quarry on the west side of the road due to better exposure and is herein referred to as the Port Colborne Quarry. Access to the northern portion of the quarry is from a dirt road in the northeast corner. The southern portion of the quarry is flooded, but exposures can be examined along the south and southeast walls.

PURPOSE AND SCOPE:

The Port Colborne Quarry exhibits both vertical and horizontal variation with respect to lithology and fauna content. The quarry consist of biostromal beds with evidence of bioherm development in the north and south-east walls. Navickas (1979) conducted a petrographic and biostratigraphic study concentrating on the east wall of the Port Colborne Quarry and was able to define four major and three minor carbonate facies. Ripley, in 1980, examined the distribution and abundance of fauna on the floor of the Port Colborne Quarry defining the depositional environment and paleocurrents of the Edgecliff Member of the Onondaga Formation. Both these studies neglected the horizontal and vertical variations in the quarry and lack descriptions of bioherm development.

The purpose of this study is to correlate the horizontal and vertical facies variation in the Port Colborne Quarry with stages of bioherm growth. Detailed stratigraphic sections were measured throughout the quarry. Petrographic, stratigraphic and paleoecologic information was used to correlate the various facies in an attempt to define the successional stages of bioherm growth and identify the depositional environment of the Edgecliff Member of the Onondaga Formation.

METHOD OF STUDY:

Field work was conducted in late August and early September of 1989. The quarry was examined for both lateral and horizontal variation, and six stratigraphic sections were measured. Lithology, type of bedding, sedimentary structure (where present), upper and lower contacts, and faunal associations of each unit were recorded and over 90 representative samples collected. The six stratigraphic sections were surveyed using an automatic level and correlated with respect to horizontal.

In the laboratory, samples were cut and polished with number 8 abrasive powder to help verify the field descriptions. From the polished slabs, twenty-one samples were chosen and thin sections prepared. The thin sections were stained with a combination of Alizarin Red-S and Potassium Ferricyanide to help in mineral identification. Thin sections were analyzed in two separate traverses for modal composition by a point counting method. The first traverse identified the major petrographic constituents (allochems, matrix and cements) with a minimum of 600 counts per thin section. In the second traverse the allochems were identified and separated taxonomically as far as possible.

Over 60 samples from the six stratigraphic sections were chosen for dissolution. The samples were first cut and washed in order to remove any weathered surfaces and then crushed to a coarse gravel and dried in an oven for twelve hours at 50-60 degrees celsius. Dried samples were weighed on a balance and placed in beakers with 20% HCl. Upon dissolution the samples were filtered through pre-weighed millipore filters and allowed to dry for 12 hours. The dried samples were then re-weighed and the percent carbonate and percent insoluble residue calculated.

CHAPTER II

FACIES DESCRIPTIONS

From the six stratigraphic sections measured in the Port Colborne Quarry, eight facies (A, A-I, B, C, D, E, F, and G) can be differentiated on the basis of lithologic, petrographic, and paleontologic evidence.

Petrographic Methods

Petrographic data from modal analyses of six of the eight characteristic facies are displayed in appendix I. Modal analysis of the major petrographic divisions were made by ten traverses of approximately 60 points each recognizing eight variables: spar cement; calcisiltite matrix; saddle dolomite; dolomite (rhombs); opaques; detrital silica; replacement silica, and allochems (Appendix IA). "Calcisiltite" was first proposed for the fine grained carbonate in the Onondaga Formation by Lindholm (1969). In this study, "calcisiltite" is adopted in place of "micrite" which was originally defined as finer than 4 microns (Folk, 1965) and "microspar" which results from neomorphism of micrite (Folk, 1965). Three random thin sections were recounted at three separate intervals within a period of 8 weeks. Percent abundance of the eight major petrographic divisions can be reproduced to within 20% (Appendix IB). The allochems were further differentiated in a second traverse of over 300 points, separating the components into their major taxonomic groups: corals; brachiopods; ostracods; bryozoa; echinoderms; trilobites; gastropods; stromatoporoids, and unidentified particles (Appendix IC). Identification of skeletal material is based on internal structure and overall morphology discussed in Horowitz and Potter (1971), Flugel (1982), and Scholle (1978). Pellets were identified in some of the thin sections and separated from the skeletal material. Error in point counting was calculated in the same manner for the allochems as for the major constituents and is reproducible to within 15% (Appendix ID).

Dissolution data:

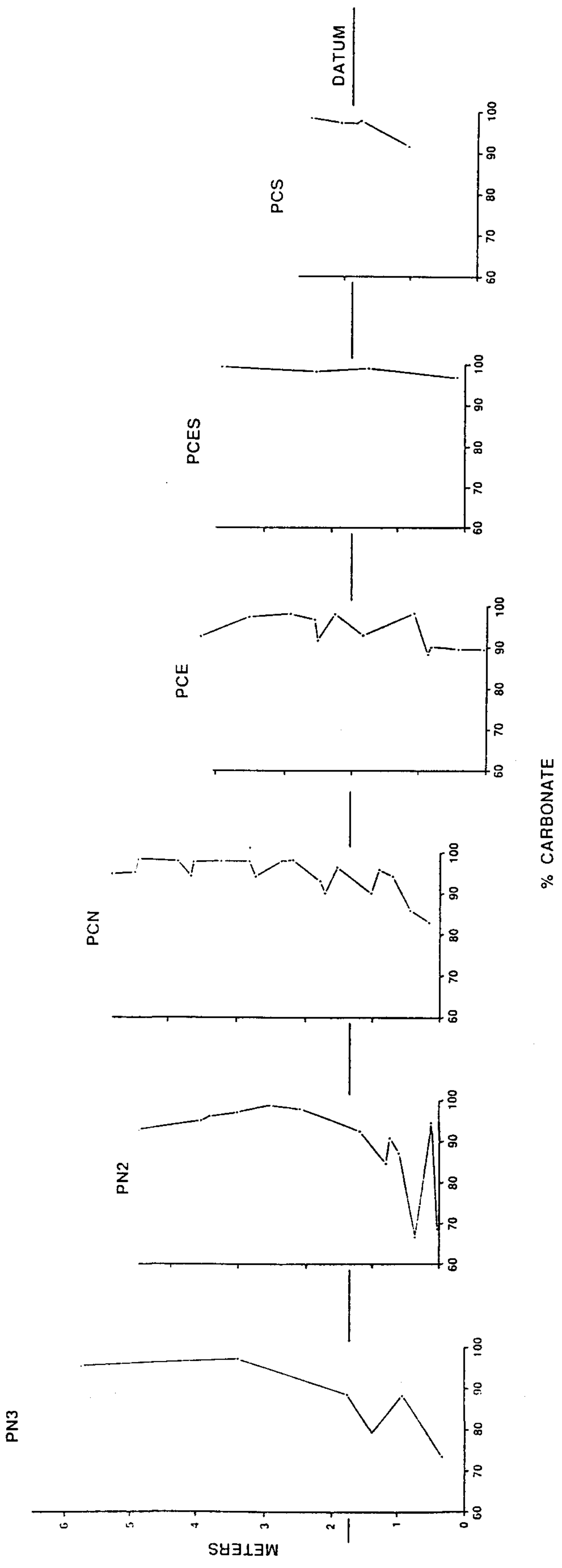
Dissolution data for over 60 samples are displayed in both chart (Appendix IIA) and graphical form (Appendix IIB and Figure 3). The insoluble residue is mainly siliciclastic material, with varied amounts of silica from replacement of skeletal material. The main sources of error are the loss of material during filtering, and errors in weighing the samples. A sample was reweighed 35 times over the period of one week and a standard deviation of 0.005% was obtained. This suggests that errors in weighing are negligible and the major source of error is due to the loss of material.

Percent insoluble residue is graphed against percent calcisiltite and percent calcisiltite plus opaques and silica (both detrital and replacement) calculated from modal analysis (Appendix IIB). The graph of percent insoluble residue to percent calcisiltite, opaques, and silica reveals the best linear relationship with a regression coefficient of 0.70. This relationship suggests that the amount of siliciclastic material is a good predictor of the amount of calcisiltite in the rock and thus, useful in determining arbitrary cut-offs for the various rock types. The combination of thin section descriptions and detailed descriptions of dissolved samples allow arbitrary division between: mudstone-wackestone; wackestone-packstone; and, packstone-grainstone at; 94, and 96.4 percent carbonate respectively (Figure 3).

FACIES A: BASAL FACIES

This facies comprises the lower 1 to 2 meters of the quarry, changing both vertically and horizontally throughout the quarry (Figure 20, 21). It is characterised by dark gray to brown, moderately bedded, wackestone to packstone

Figure 3. Changes in carbonate content, both vertically and horizontally within the Port Colborne Quarry. Datum is same as measured for stratigraphic sections.


DATUM
PCS
PCES
PCE
PCN
PN2
PN3
% CARBONATE
METERS
60
70
80
90
100
0
1
2
3
4
5
6

beds with 10 to 15 cm shale interbeds.

To the west, Facies A appears as a dark gray to brown, fine grained mudstone with intercalated shales (Figure 4). Bedding becomes more prominent upwards in the facies, ranging from 10 to 25 cm thick. Individual beds consist of several (2-3) coarsening upwards sequences grading from a mudstone to a crinoidal wackestone, often terminated by thin (0.5 to 2.0 cm) encrusting corals or stromatoporoids. Small (less than 1 mm) black conical microfossils cf. Styliolina are more abundant in the less fissile mudstones. Dissolution data reveal a low percent carbonate, increasing upwards to a maximum of 88.6% (Figure 3, Appendix IIA). At PN3, faunal content is low within Facies A, with encrusting corals and stromatoporoids, rugose corals and small solitary tabulate corals draped by muddy shales present in low abundances.

East of PN3 percent carbonate increases (Figure 3), faunal abundance increases and bedding becomes clearly defined (Figure 20, 21). Fissile shale beds thicken from 5-15 cm just east of PN3, at PN2, to 15-20 cm at PCE in the east (Figure 5). The lithology changes from dominantly mudstones and wackestones in the west to wackestones and packstones in the east. This may be a result of to either increased winnowing of fine carbonate muds in a higher energy environment or the absence of mud in the initial

Figure 4. Basal Facies (Facies A) at PN3. Note the lack of bedding and skeletal organisms. Hammer marks contact of Facies A with overlying Facies D.

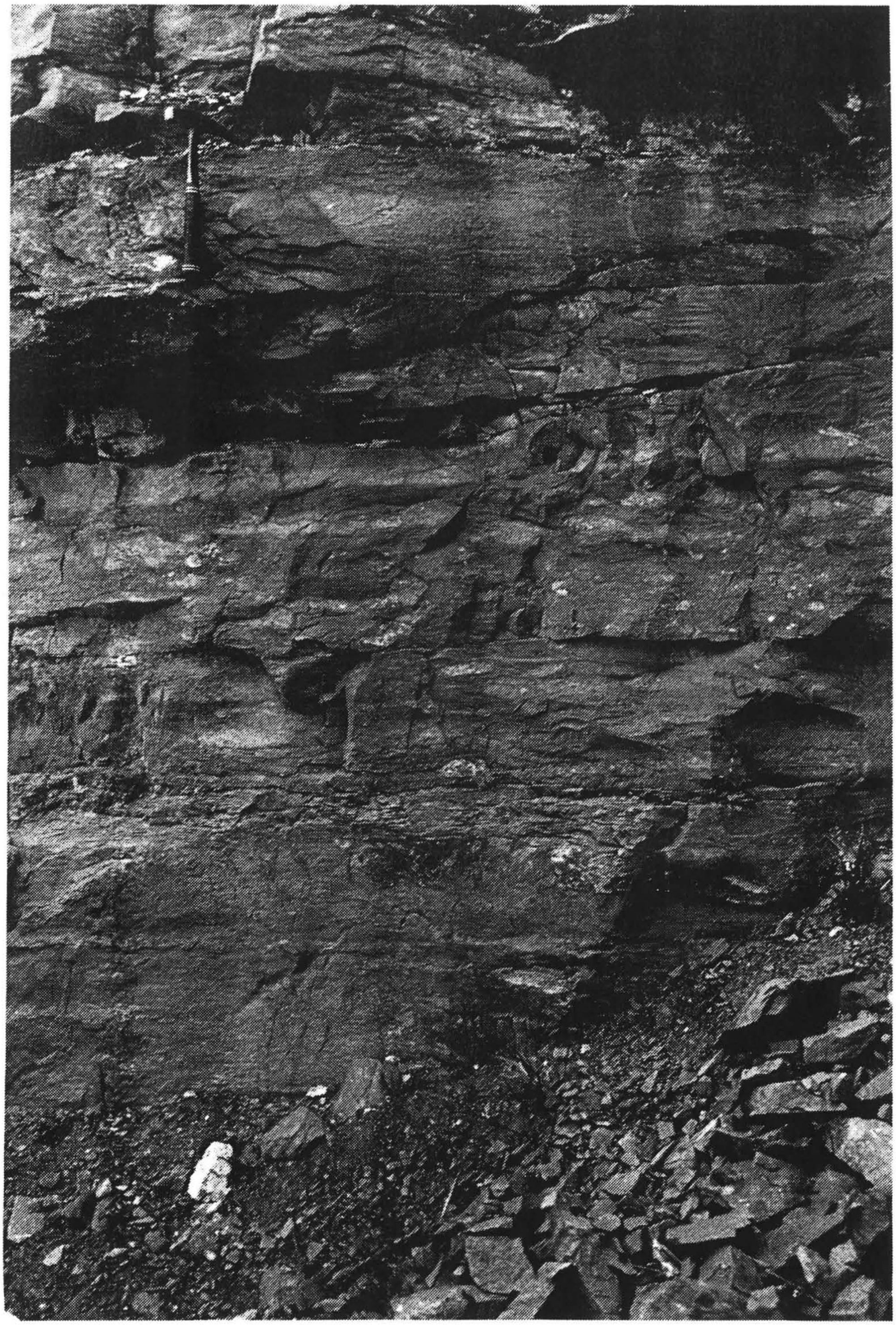


Figure 5. Basal and Coral-rich Basal Facies (Facies A and A-I respectively). Hammer marks the contact of Facies A with Facies A-I. Note well developed bedding, fissile shale interbeds.

sediment (Folk, 1962). Individual beds are highly variable, both coarsening and fining upwards with varying degrees of bioturbation. Coarsening upwards sequences exhibit gradational lower contacts and sharp to erosional upper contacts, capped by thin (1 cm), tabular stromatoporoids. The upper contacts of fissile beds are commonly colonized by encrusting corals, stromatoporoids and brachiopods, sharply overlain by crinoidal packstone beds that fine upwards into fossiliferous wackestones.

Petrography

Detailed petrographic examinations of Facies A and A-I were not performed due to the extreme variability of these facies within the study area. Navickas (1979) conducted detailed petrographic examinations of Facies A and A-I at PCE to which interested readers are referred.

Three thin sections were chosen from Facies A which represented similar lithofacies characterized by bioturbated wackestones overlain by crinoidal packstones in an attempt to distinguish if firm ground development existed (Figure 6). The wackestones are composed mainly of allochems 40%, calcisiltite 19.8-38.1%, and dolomite 17.1-35.4%. Spar comprises 3-5% with opaques and silica (detrital and replacement) also present in trace amounts. Packstones show greater abundances of allochems (55.6-61.9%) and spar (12.7-

16.9%), than the wackestones with also less calcisiltite and dolomite (16.0-21.9% and 4.3-7.5%, respectively).

The matrix is intensely bioturbated with skeletal grains found infilling burrows, oriented in circular patterns around burrows (Figure 7) and concentrated in clusters giving a mottled appearance. Dolomite is present as 40-60 micron euhedral crystals in the matrix and appears to be concentrated in areas of intense bioturbation, possibly indicating a detrital origin. The suspected firmground is bioturbated and appears to have been soft, unlithified sediment when the packstone cap was deposited Thus, the absence of firm ground development may be attributed to the intense bioturbation and rapid deposition of the packstone cap. Skeletal grains composed mainly of echinoderm bioclasts (29.2 to 45.2%) form the bulk of the allochems. Corals, brachiopods, ostracods, bryozoans, and gastropods are common in both the wackestones and packstones. Trilobite bioclasts and _Styliolina_ were also found but in greater numbers within the bioturbated wackestones. Trilobites and possibly _Styliolina_ may have been important bioturbating organisms in the lower basal facies (Figure 6). Pellets were observed within the bioturbated wackestones and are thought to be under-estimated in modal analysis.

Figure 6. Bioturbated fossiliferous wackestone overlain by a crinoidal packstone (Facies A). Note (a) Styliolina and (b) large trilobite fragment.

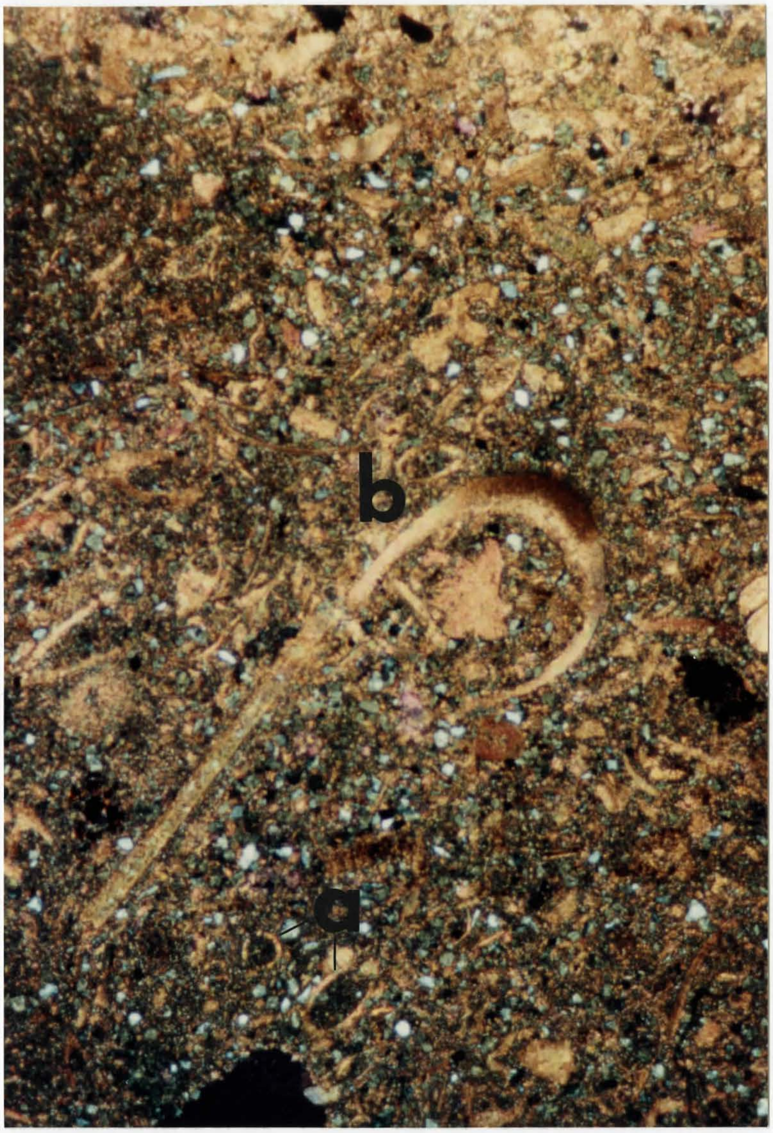
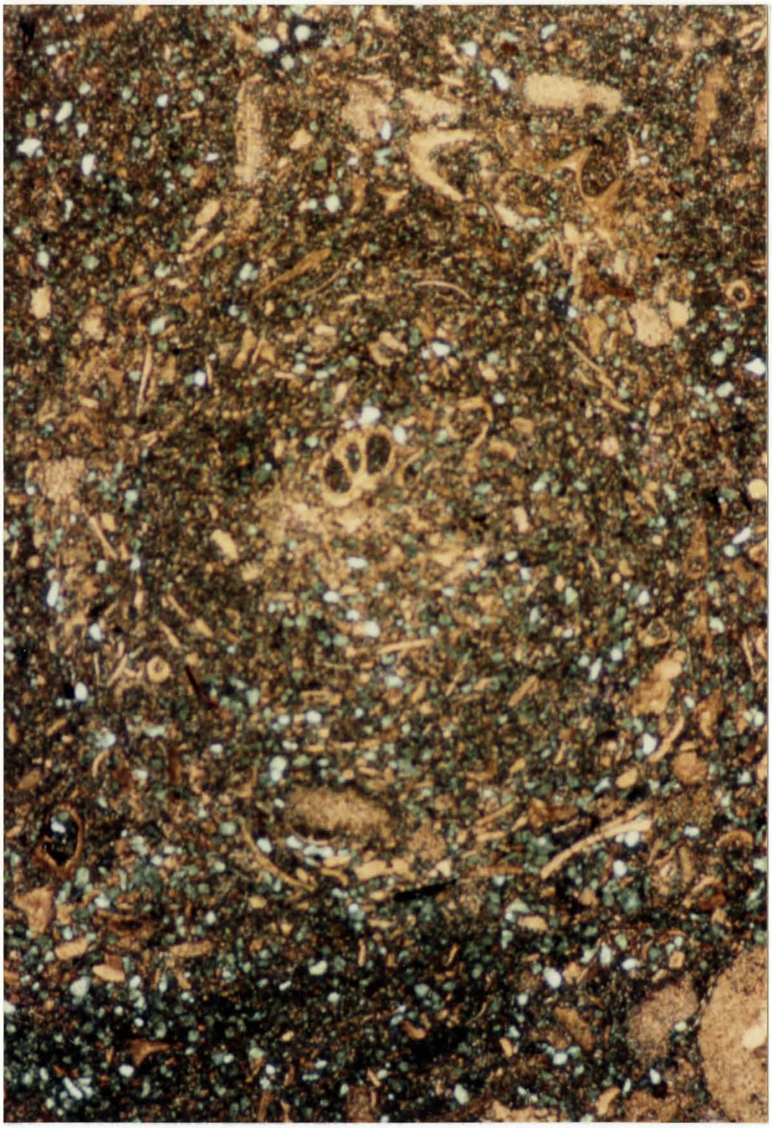

b
a

Figure 7. Bioturbated wackestone (Facies A). Note circular alignment of skeletal bioclasts due to burrowing organisms.



FACIES A-I: CORAL-RICH BASAL FACIES

Facies A-I is characterized by well bedded, light gray to blue, coral-rich, crinoidal packstones with distinct coral-rich fissile shale interbeds (Figure 5). The densely packed corals belong to the genus Cyanthophyllum sp. and Cystiphyllum sp., ranging in size from 3 to 5 cm in diameter and comprise 40 to 50 percent of the beds by volume. The corals show no preference to lithology and are geniculated often one or more times, however, the epitheca is only slightly abraded. The basal section contains thick crinoidal packstone to grainstone beds with sharp upper and lower contacts. Stromotoporoids are common in these beds as well as rugose and tabulate corals. Upwards in the facies, beds become thinner, composed of wackestone to packstone lithologies and have gradational contacts. Within the shale beds, lenses of crinoidal packstones are common as well as fine (less than 1 mm) skeletal debris. Facies A-I is similar to Facies A but is primarily distinguished by a much denser rugose coral fauna.

FACIES B: TRANSITIONAL FACIES

This facies is observed at PCN and PCES gradationally overlying Facies A (Figure 20, 21). It consists of light gray to blue, well bedded, dominantly coarsening upwards sequences, separated by thin shaley partings. Bedding thickness ranges from 10 to 25 cm, decreasing upwards in the facies. The coarsening upwards sequences commence with a moderate to poorly sorted crinoidal wackestone-packstone grading into a well sorted, crinoidal packstone-grainstone. Each sequence is capped by a thin slightly fissile shale. Individual beds are sharp-based, with the thicker beds generally containing several (2 to 3), 5 to 7 cm coarsening upwards sequences, often terminated by a thin (0.5 to 2.0 cm), elongate (15 to 60 cm) in situ encrusting coral or stromatoporoid, which itself marks the beginning of the next sequence. Fining upwards beds are defined within the facies and are restricted to the lower, thicker beds. Dissolution data reveals a increase in percent carbonate within individual beds ranging from 94.1% at the base to 98.3% at the top (Figure 3, Appendix IIA). Brachiopods are commonly found on top of the fissile shale partings, but are also found disarticulated within the wackestone-packstone beds. Tabulate corals of the genus Favosites sp. are found both in situ and overturned within the facies. The in situ corals appear to nucleate on coarse crinoidal packstones and grainstones, becoming more abundant towards the top of the facies. Cystiphyllum and Heliophyllum are present but rare.

Petrography

Allochems, spar, and calcisiltite are the main carbonate components of the facies, comprising 46 to 61%, 24.1 to 32.4%, and 9.1 to 9.3% respectively. Dolomite as 40-60 micron euhedral crystals represents 4.9 to 11.0% of the rock. Opaques, saddle dolomite and silica are present in trace amounts.

The matrix appears nonhomogeneous, composed dominantly of calcisiltite with intermixed dolomite crystals infilling skeletal voids and intragranular pores.

Allochems are mainly composed of skeletal bioclasts displaying varying degrees of fragmentation. Coral fragments appear to dominate in the upper portion of the facies increasing in abundance towards the Core Facies (Facies E) comprising 25.1 to 42.9% (Figure 8). In the lower facies, echinoderm bioclasts are the main constituent, representing 63.6% of the skeletal grains (Figure 9). Other observed fauna includes bioclasts of brachiopods, ostracods, bryozoans, trilobites, and gastropods all in minor amounts. Brachiopods are more abundant at PCN than at PCES and are found disarticulated and articulated within the facies.

Texturally, Facies B appears as a grain supported, well to moderately packed, fossiliferous packstone to grainstone with wackestone beds associated with fissile shale partings. The grains begin to display a slight imbrication in the

Figure 8. Coral-rich packstone-grainstone of the Upper Transitional Facies (Facies B).

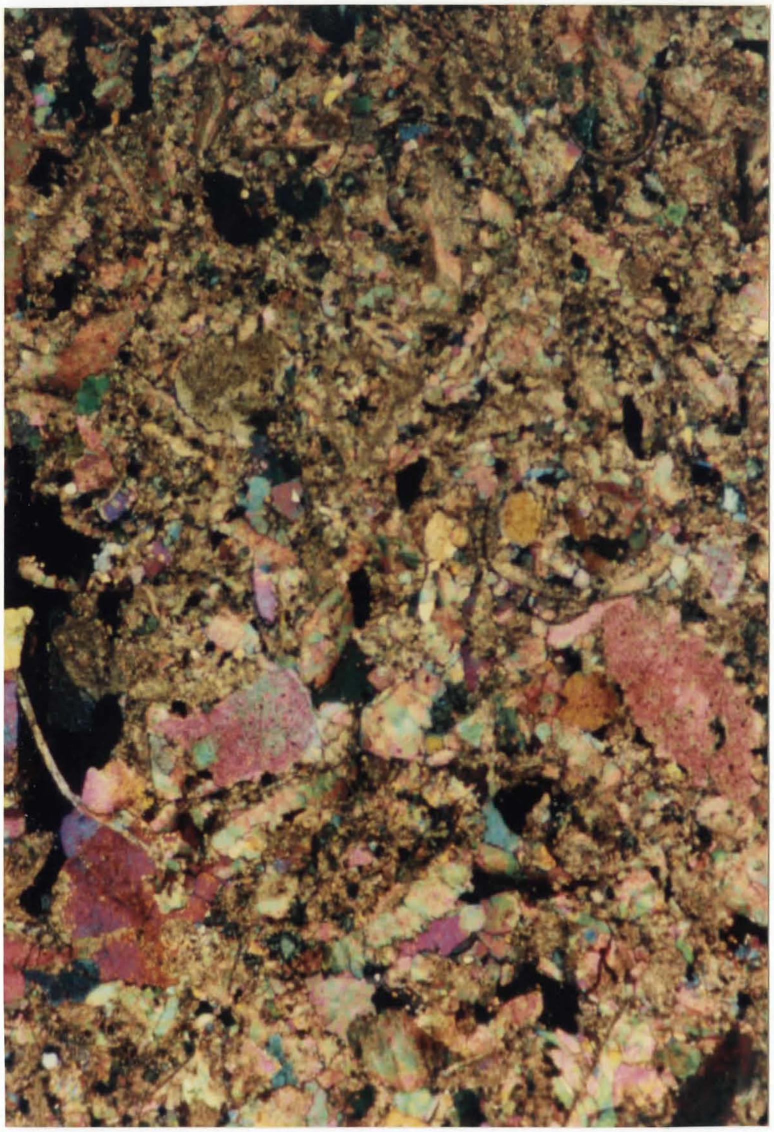
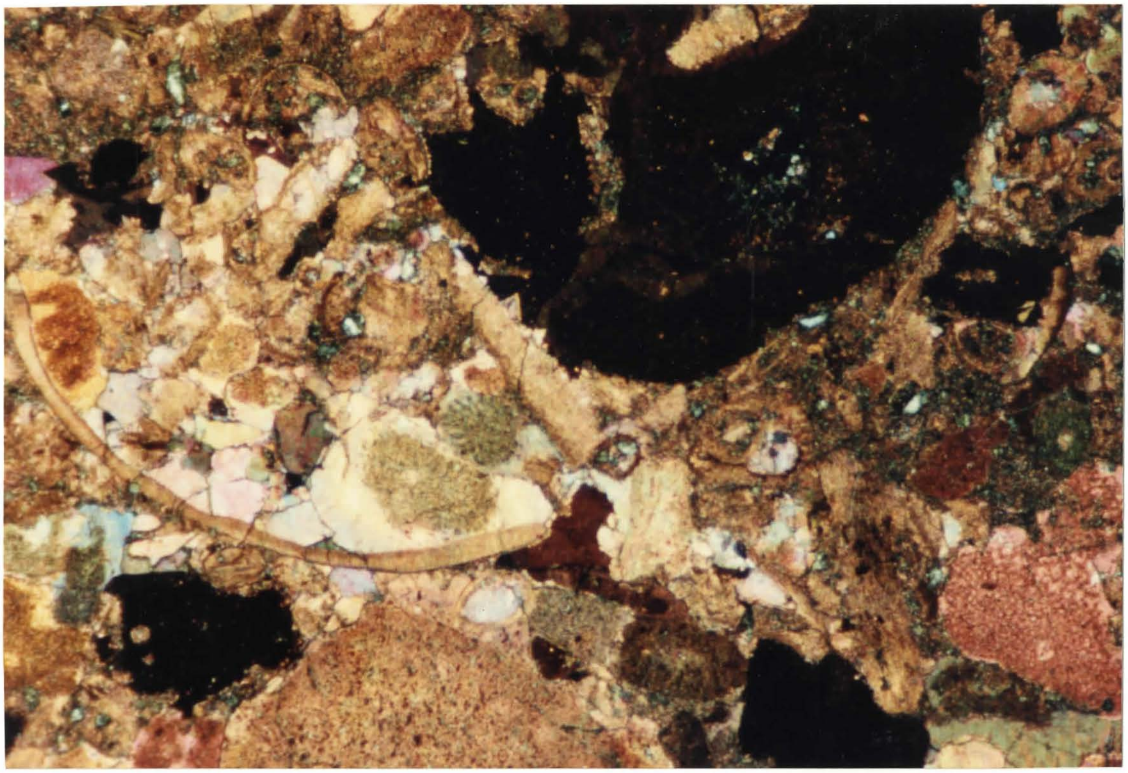


Figure 9. Echinodermal packstone-grainstone of the Lower Transitional Facies (Facies B).



packstone-grainstone facies near the top of each bed. Facies B is interpreted as being deposited in a moderate to high energy environment and represents a shoaling upwards sequence.

FACIES C: FLANK FACIES

Facies C is only observed between PCN and PN2 (Figure 20, 21), composed of skeletal material dominated by crinoids, rugose corals and the branching tabulate coral Acinophyllum sp.. The lithology varies, from a coarse grained, light gray to blue, poorly bedded, crinoidal grainstone near the base to a dark gray to brown, moderately bedded, crinoidal wackestone to packstone near the top of the facies. Dissolution data support this observation, with percent carbonate increasing from 97.8% to 95.0% upwards in the facies (Figure 3, Appendix IIA). Two rugose coral horizons are present in Facies C composed of both Cystiphyllum and Heliophyllum corals; one at the base, 0.5 meters thick and a second, 1.0 meter up the section, 0.3 meters thick. Other observed fauna includes overturned Favosites heads, stromatoporoid and encrusting corals, and disarticulated brachiopod valves. Branching coral fragments are rare in the lower unit, but mark the change from Facies

C to Facies F, 1.4 meters up the unit. Here, the corals are highly fragmented and intermixed with a crinoidal packstone matrix.

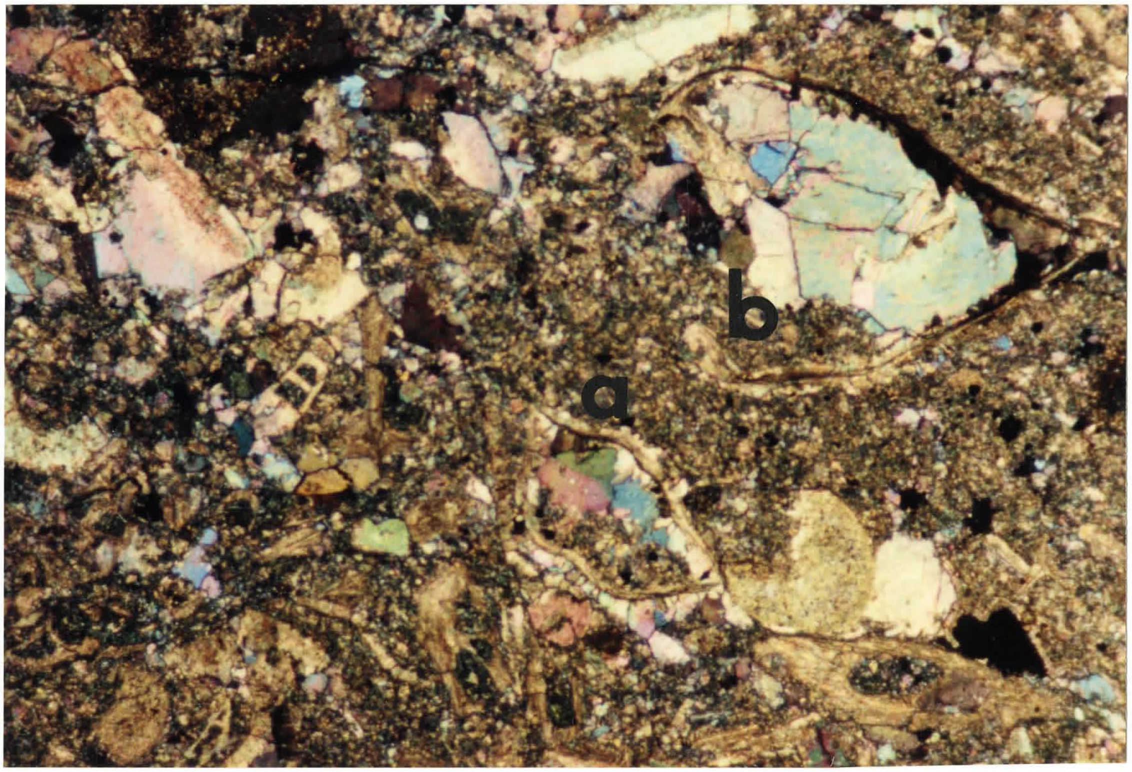
Petrography:

Mineralogically, Facies C shows a distinct variation in sparry cement and calcisiltite matrix. The spar to matrix ratio decreases upwards in the facies as the calcisiltite matrix increases and spar decreases (Appendix IA). Allochems form the most abundant constituent, remaining relatively constant throughout the facies. Dolomite, opaques, and silica are also present, generally comprising less than 5% of the rock by volume. In the lower, spar-rich portion of the facies, three forms of cement can be identified: fibrous crusts lining skeletal pores; blocky ferroan crystals filling skeletal and intragranular pore spaces, and syntaxial overgrowths on crinoid ossicles. Of these three cements, blocky ferroan crystals are the most abundant, commonly filling intragranular pores, indicating a well washed sediment at time of deposition (Figure 10).

The calcisiltite-rich matrix in the upper portion of the facies is intensely bioturbated. Pellets are common in the calcisiltite matrix and are underestimated by modal analysis, calculated as less than 2% of the rock by volume. Individual grains display micrite rims and evidence of

Figure 10. Crinoidal grainstone of the Lower Flank Facies (Facies C). Note the high amount of spar cements.

Figure 11. Fossiliferous wackestone-packstone of the Upper Flank Facies (Facies C). Note (a) articulated Brachiopod and (b) disarticulated Brachiopod.


a
b

bioerosion.

Allochems are the most abundant constituent, comprising 58.8 to 66% of the rock by volume. Pellets are rare in the lower section of Facies C (1.6 to 1.8%) with the majority of allochems exclusively composed of skeletal grains. Faunal content does not vary between the upper and lower part of the facies. The skeletal grains appear as sand to gravel sized bioclasts, dominated by crinoids (52%) and corals (16.4 to 20.3%). The crinoids show signs of slight imbrication near the top of the first rugose coral horizon (approximately 1.0 meters up Facies C). Other observed skeletal bioclasts includes: disarticulated and articulated brachiopod valves (Figure 11); ostracod valves; trilobites; and, gastropods.

Texturally, Facies C can be separated into two members; a lower grain supported, well sorted, crinoidal grainstone displaying slight current derived imbrication (Figure 10), and a upper grain supported, bioturbated, fossiliferous wackestone (Figure 11).

FACIES D: BIOSTROME FACIES

Facies D is observed at PN3 and PCS (Figure 20, 21), forming biostromal beds characterized by unfragmented, in situ colonial tabulate corals. The type of coral and associated fauna varies depending on the location; however, gastropods, Cystiphylloid corals and large crinoid stems (2 to 3 cm in diameter) are common to both PN3 and PCS.

At PN3, the dominant coral is the colonial tabulate Synaptophyllum sp.. The lower portion of the facies is characterized by in situ corals baffling a fine grained, gray to dark brown mudstone. Upwards in the facies, the coral colonies become fragmented, with individual corallites mixed in a coarse, light gray crinoidal packstone.

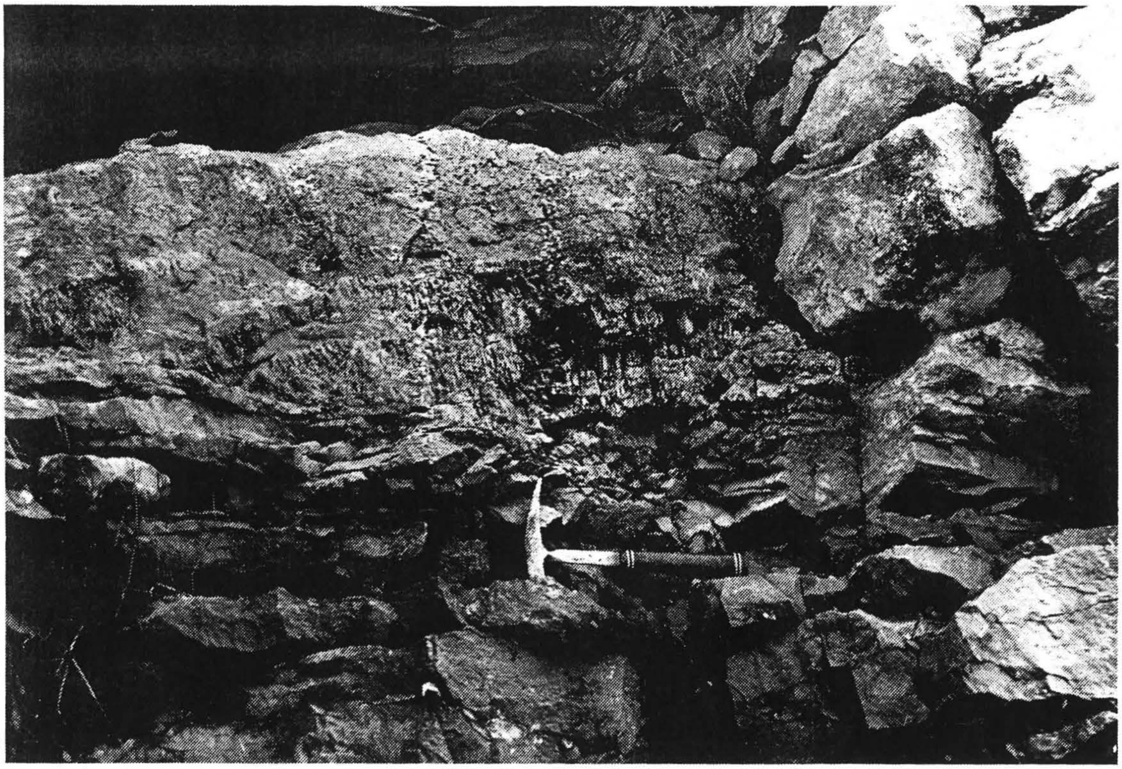
A more varied coral fauna is found at PCS, with Synaptophyllum sp. and Erindophyllum sp. all occurring in growth position, dominating the upper portion of the facies. Colonies vary in size, appearing in thin 20 to 30 cm beds and rarely as large mounds 2 meters in width, extending vertically 1 meter above the surrounding substrate. The corals baffle a coarse grained, light gray to blue, crinoidal packstone. Stromatoporoids are common in the lower portion of Facies D, binding the coarse grained crinoidal sediment. A distinct layer of broad encrusting sheet form Favosite sp. corals (1.0 to 1.5 meters wide and 20 to 30 cm thick) are common in the middle of PCS. The corals display irregular tops, migrating back and forth during growth as coarse crinoidal debris is deposited on top. This growth form is interpreted by Philcox (1971) to occur only during periods of "negligible sedimentation", with episodic sedimentation causing the coral to change its growth direction.

FACIES E: CORE FACIES

Facies E is restricted to PCN and PCES (Figure 20, 21), forming broad low-lying, light gray, massively bedded, coral rich mounds (Facies E). The dominant coral is the colonial tabulate Acinophyllum sp. occurring as broken colonies with individual corallites floating in a crinoidal packstone to wackestone matrix (Figure 12). The facies is characterized by a higher percent carbonate than the surrounding sediments, reaching a maximum of 97.9%. The matrix between individual corallites changes vertically within the facies, grading from a fine grained skeletal wackestone to a coarser grained crinoidal packstone. The high percent carbonate and the coarsening upwards matrix are features that can be attributed to deposition above the surrounding substrate in high energy conditions causing winnowing of the sediments. Large hemispherical Favosites sp. heads (0.5 to 2.0 meters in diameter) are characteristic of the lower portion of the facies, nucleating on coarse crinoidal packstones of Facies B (Figure 13). Other observed but rare fauna include: rugose corals; brachiopods; and, stromatoporoids.

Figure 12. <u>Acinophyllum</u> <u>sp</u>. rudstone to bafflestone in a crinoidal wackestone-packstone matrix, Core Facies (Facies E).

Figure 13. Large (2.0 meter diameter) <u>Favosites</u> <u>sp</u>. coral nucleating on coarse crinoidal packstones of the Transitional Facies (Facies B).



Petrography:

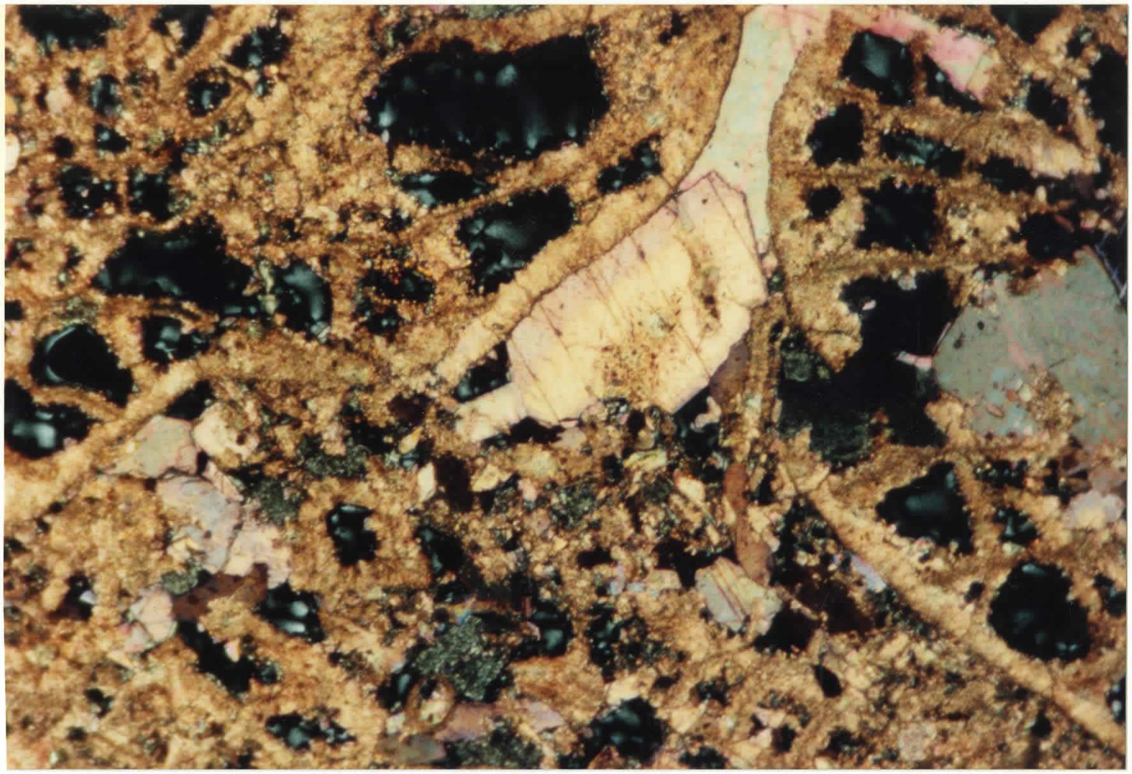
Facies E is composed of approximately 97% carbonate (Appendix IIA) in the form of sparry cements, calcisiltite matrix and skeletal material. Sparry cements decrease upwards in the facies from 23.4 to 16.4%, occurring as syntaxial overgrowths, pore lining fibrous cements, and blocky subhedral crystals. The fibrous cements occur at 90 degrees to grain boundaries, radiating inward towards skeletal voids, often covered by a later ferroan, blocky subhedral cement (Figure 14). The fibrous pore lining crusts are similar to those reported by James et al. (1976) from shallow Belize reefs and interpreted as submarine syndepositional cements. The matrix is composed mainly of coral fragments with minor amounts of calcisiltite (5.8 to 6.1%) and dolomite (Figure 14). Stained thin sections reveal two distinct forms of dolomite; rhombohedral crystals 40-60 microns in size and pore filling saddle dolomite. The rhombohedral dolomite crystals contain cloudy centers and are restricted to the calcisiltite matrix, increasing upwards in the facies from 5.1 to 8.9%. Saddle dolomite occurs as a late diagenetic event, infilling skeletal voids and pore spaces between skeletal grains. Saddle dolomite increases upwards in the facies with decreasing spar from 2.2 to 4.5%. Silica and opaques are associated as pore filling along solutional seams and are present in trace amounts.

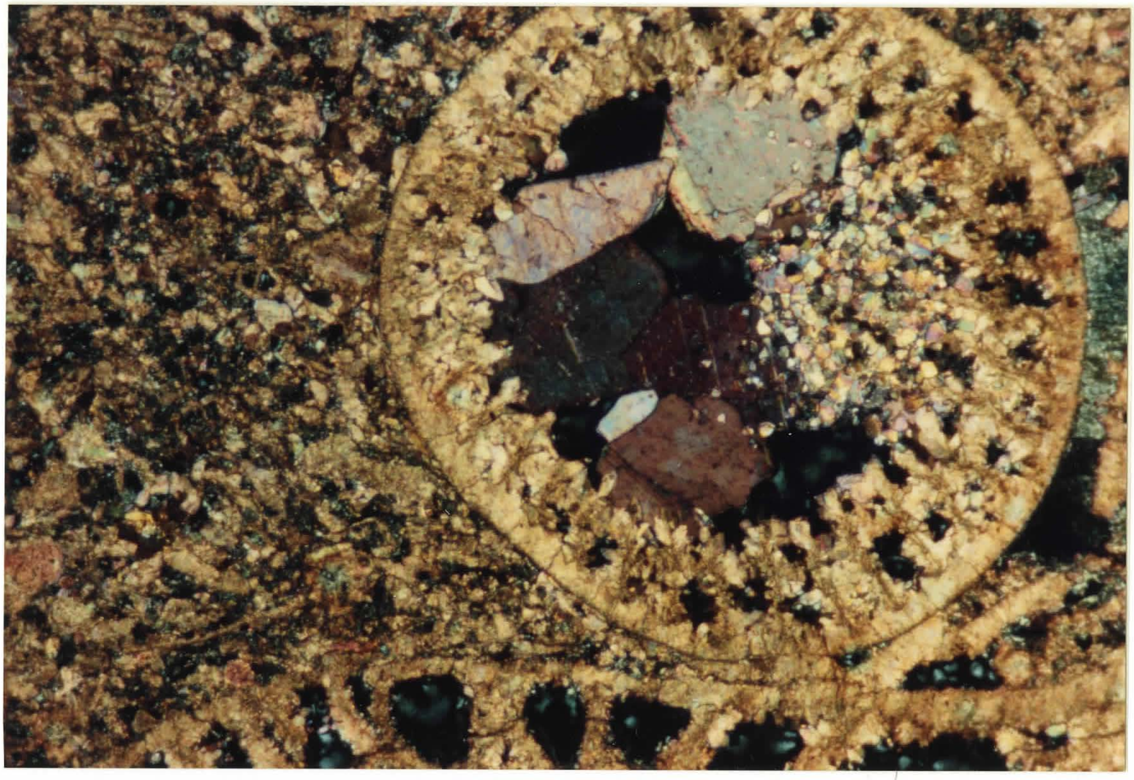
Allochems in the form of skeletal grains are the most abundant petrographic constituent, comprising 62.1 to 63.8% of the rock by volume. Coral bioclasts represent over half (51.8%) of the allochems in the middle of the facies decreasing upwards to 20.5%. The corals appear in the matrix as sand size bioclasts (septa and tabulae) and as relatively well preserved corallites (2.0 to 3.0 mm in diameter) (Figure 15). In the upper portion of the facies, coral bioclasts are rare with crinoid grains becoming the dominant skeletal component (43.4%). The increase in crinoid grains in the upper portion of the facies is interpreted as allochthonous deposition under higher energy conditions. The crinoid grains range in size from medium sand to gravel sized bioclasts with the large gravel sized ossicles showing a higher degree of abrasion. Disarticulated brachiopod valves, bryozoan, gastropods and stromatoporoid or encrusting coral bioclasts are also present, generally representing less than 10% of the skeletal constituents.

Facies E is classified as a poorly sorted Acinophyllum sp. bafflestone to rudstone (Dunham, 1962 and Embry and Klovan, 1971). This facies is interpreted as a coralliferous mound, initially deposited in a moderate energy environment with growth being terminated by entrance

Figure 14. *Acinophyllum sp.* rudstone of the Core Facies (Facies E). Note fibrous pore lining crusts covered by blocky ferroan spar and matrix of coral bioclasts.

Figure 15. Well preserved *Acinophyllum sp.* corallite of the Core Facies (Facies E).





into the high energy surf zone. Supporting evidence for interpretation:

i) change in matrix from coral dominated to crinoid dominated, suggesting the transport of allochthonous skeletal material;

ii) low percentage of calcisiltite within skeletal pores;

iii) the lack of any well preserved coral colonies.

FACIES F: FLANK/CAP FACIES

This facies is found in the upper portion of the quarry at all locations, except PCS (Figure 20, 21). Facies F is characterised by a light gray to blue, massively bedded, well sorted, crinoidal packstone to grainstone. Individual beds are difficult to identify, becoming more prominent in the upper section, separated by thin fissile shale partings and occasionally by thin (0.5 to 2.0 cm), tabular (greater than 15 cm), in situ stromatoporoids. The facies fines upwards from a well sorted crinoidal grainstone to a moderately sorted crinoidal packstone. Dissolution data support this trend with percent carbonate decreasing upwards from 98.02% to 97.28% (Figure 3, Appendix IIA).

The fauna is dominantly composed of in situ stromatoporoids and large crinoid stems 1.0 to 2.0 cm in diameter and 10 to 15 cm in length (no calyxes were observed). Rugose and tabulate corals are also present, rarely found in life position.

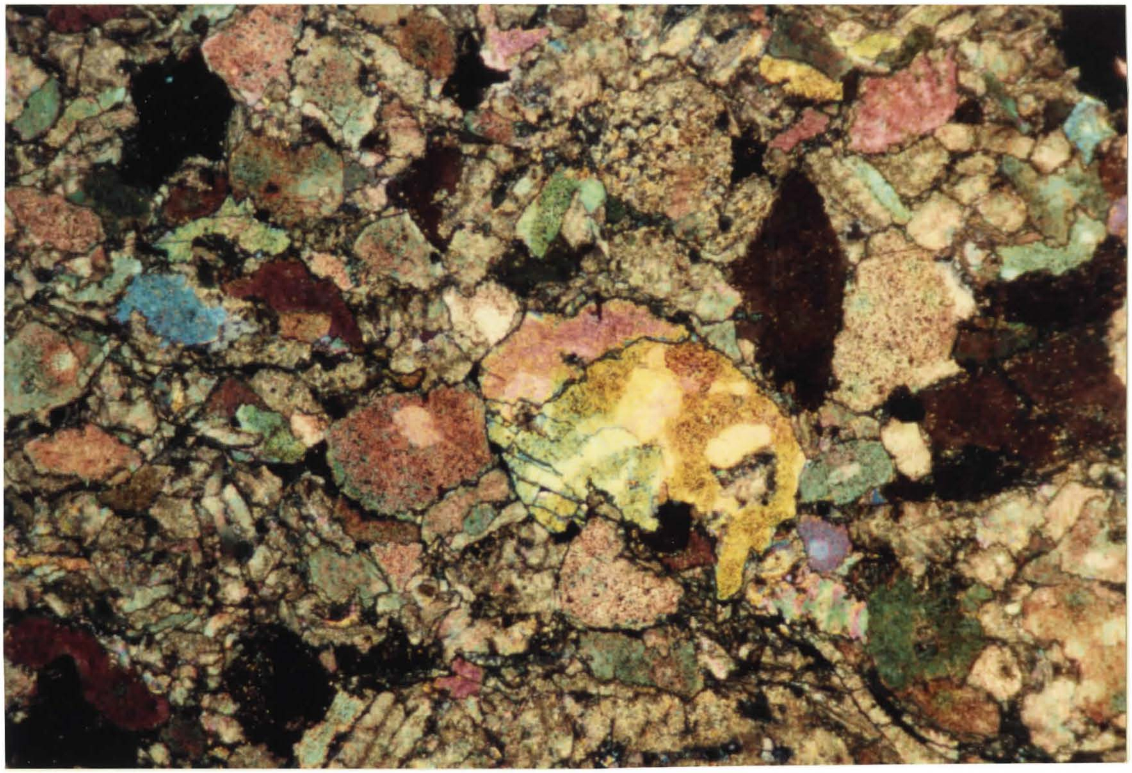
Petrography:

Facies F is composed mainly of sand sized skeletal fragments and sparry cements. Sparry cements (17.7 to 21.8%) occur as blocky subhedral crystals, infilling skeletal pore spaces and as syntaxial overgrowths on skeletal grains. Calcisiltite is a minor component (6.4 to 13.0%), and is generally of greater abundance at the top of the facies. Dolomite is rare (1.7 to 4.4%), found mainly as euhedral crystals 40-60 microns in size, replacing skeletal grains and within the calcisiltite matrix. Opaques, saddle dolomite, and authigenic silica are present in trace amounts.

The calcisiltite matrix is mainly found as rims around densely packed skeletal grains with sutured contacts (Figure 16) and rarely as intragranular pore infilling. In this facies, the calcisiltite is likely a result of neomorphism and therefore better termed microspar in accordance with Folk (1965).

Skeletal bioclasts, which are the sole allochems, comprise from 62.4 to 68.1% of the thin sections. Echinoderm fragments, especially crinoid ossicles, account

Figure 16. Crinoidal grainstone of the Flank/Cap Facies (Facies F). Note the heavily sutured grain contacts.



for 51.1 to 66.8% of the skeletal grains. Corals, bryozoan, and brachiopod bioclasts are the next most abundant skeletal grains comprising 5.8 to 17.8%, 1.4 to 2.9% and 2.5 to 8.6% respectively. Coral fragments appear to be dominant directly above and to the west of the Core Facies (Facies E). East of the Core Facies, coral bioclasts are rare (5.8%) with echinoderm and brachiopod bioclasts comprising approximately 75% of the skeletal grains. Ostracod, gastropod, and trilobite bioclasts are minor to absent in most of the thin sections.

Texturally, Facies F is characterized by densely packed, grain supported, elongate to poorly rounded, bioclasts of echinodermal debris (Figure 16), thus classified as a well sorted crinoidal packstone-grainstone. Grain contacts are tangential to heavily sutured, indicating compaction of the original sediments (Figure 16). Skeletal grains appear to be oriented parallel to bedding, inferring a possible current dependant imbrication.

Facies F is interpreted as having been deposited under high to very high energy conditions, with currents moving in a dominantly western direction. Reasons for this interpretation are:

(i) well sorted, coarse grained, subrounded and highly fragmented crinoidal debris;

(ii) the fining upwards nature, possibly indicating transportation;

(iii) sharp increase in coral debris in the vicinity of the Core Facies and gradual decline to the west;

(iv) the abundance of in situ stromatoporoids, a wave resistant colonial organism best suited to a high energy environment.

FACIES G: CAP FACIES

Facies G is characterized by a light gray to blue, moderate to poorly sorted, massively bedded, wackestone to packstone, with scattered chert nodules. It is traceable throughout the quarry (PN3, PN2, PCN, and PCE) and identified from Facies F by a sharp, fairly regular lower contact (Figure 20, 21). The facies fines upwards from a moderately sorted, crinoidal packstone at the base, to a poorly sorted fossiliferous wackestone. Dissolution data reveal a slight decrease in percent carbonate upwards from 95.2 to 92.7%, supporting the field and petrographic observations of a fining upwards sequence (Figure 3, Appendix IIA). Silica commonly appears as nodules and as replacement of skeletal debris (Figure 17).

Large crinoid stalks (1.0 to 2.0 cm in diameter and up to 30 cm long) are common in the lower, coarser grained

Figure 17. Characteristic weathered appearance of the Cap Facies (Facies G) with silicified corals (a) and chert nodules (b).

packstones, becoming smaller and decreasing in abundance upwards in the facies. Geniculate rugose corals and bryozoans are the dominant fauna, appearing slightly fragmented while Favosites sp. and stromatoporoids are both found in life position, nucleating on coarse crinoidal debris. Stromatoporoids are generally rare in this facies, differing considerably in abundance from Facies F.

Petrography:

Mineralogically, Facies G is composed of greater than 95% carbonate, dominated by allochems and calcisiltite matrix. Sparry cements are generally rare in Facies G (9.3 to 10.7%), found mainly in skeletal voids as geopetal structures. Calcisiltite is the second most abundant component next to the allochems, increasing upwards in the facies from 18.7 to 21.2%. Dolomite occurs as euhedral crystals mixed within the calcisiltite matrix composing 2.8 to 3.3% of the rock. Silica appears in trace amounts in thin section (underestimated according to both field and hand specimen observations).

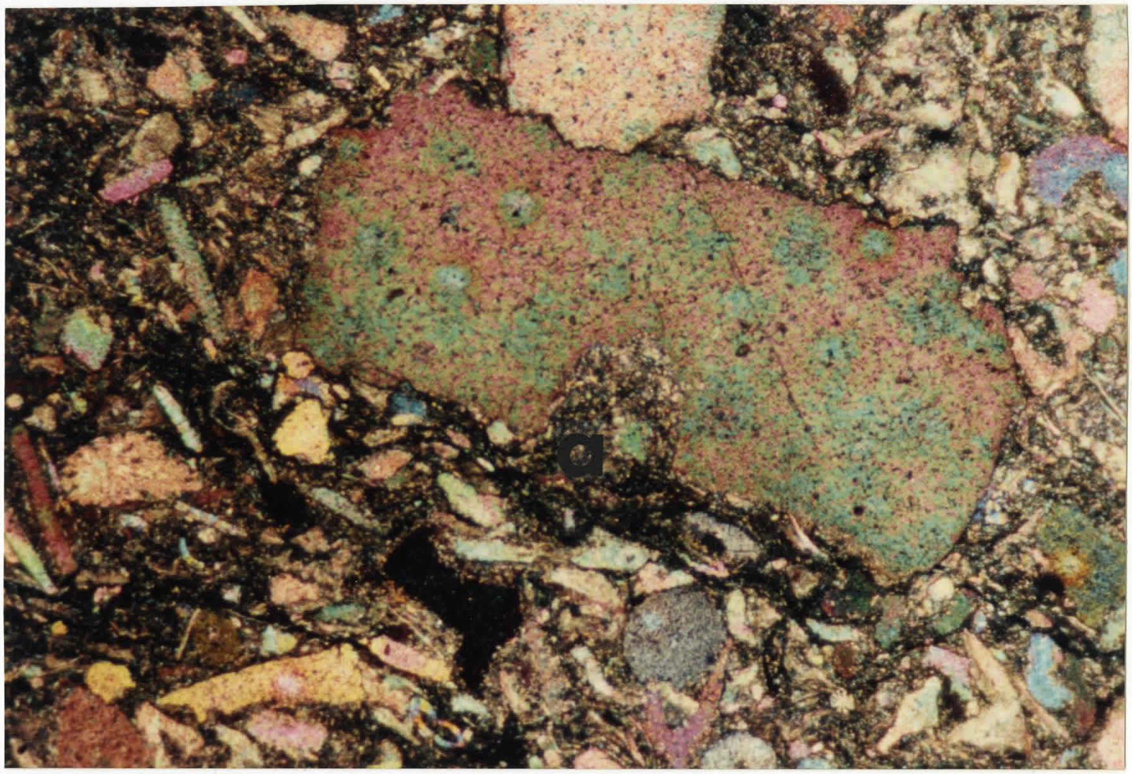
The calcisiltite matrix appears nonhomogeneous, with distinct zones of bioturbation. Burrows are characterized by concentrations of much darker fine grained carbonate (Figure 18) and collapsed burrows that have later been infilled by blocky ferroan cements.

Allochems are the primary petrographic constituent, composing 56.2 to 65.9% of the rock by volume and are almost exclusively skeletal material. The skeletal grains occur as bioclasts, in a mottled calcisiltite matrix often with well developed micrite envelopes. The most abundant skeletal constituents are echinoderm fragments, comprising 56.2 to 65.9%. Corals, brachiopods, ostracods, and bryozoan debris are also present, generally comprising less than 8% of the skeletal material. Pellets less than 0.5 mm in diameter are rare (0.6 to 1.5%), found mainly in areas of high calcisiltite.

Both mud and grain supported particles are present in Facies G. The skeletal grains lack any apparent orientation, appearing mottled within a calcisiltite matrix (Figure 18). The lower portion of Facies G is classified as a moderate to well sorted crinoidal packstone (Dunham, 1962; Embry and Klovan, 1971). The upper portion of the facies begins to show evidence of mud supported clasts and is termed a moderately sorted wackestone to packstone. Facies G is interpreted to have been deposited in a moderate energy environment in which wave activity has subsided, possibly due to a slight rise in sea level, or due the to development of some offshore barrier. Supporting evidence is:

i) poorly washed sediment with increasing abundance of calcisiltite;

Figure 18. Bioturbated wackestone-packstone of the Cap Facies (Facies G). Note truncated crinoid ossicle with darker carbonate infilling (a).


a

ii) the presence of in situ corals and large crinoid stems

CHAPTER III

STRATIGRAPHY OF THE PORT COLBORNE QUARRY

In the Niagara Peninsula of southern Ontario, the Edgecliff Member of the Onondaga Formation thickens from 14.9 meters in the east to 29.2 meters in the west (Cass, 1975). The lower portion of the Edgecliff Member is exposed within the Port Colborne Quarry, ranging in thickness from 6.5 meters in the west wall to 2.8 meters in the south wall. The quarry is divided into eight units based on lithology, fauna, and relationship to bioherm development. Each unit corresponds to a particular facies and will be referred to by the facies nomenclature in order to simplify terminology. Six stratigraphic sections were measured in the quarry and correlated in two cross-sections. These sections are: 1) A-A′ which extends from west to east along the north wall and includes sections: PN3; PN2; PCN, and PCE (Figure 20), and 2) B-B′ which extends from the middle of the north wall, south-east to the south wall and includes sections: PCN; PCE; PCES, and PCS (Figure 21). See Figure 19 for cross-section legend.

Figure 19. Legend for cross-sections A-A' and B-B' (Figures 20, 21) and summary diagram (Figure 32).

LEGEND

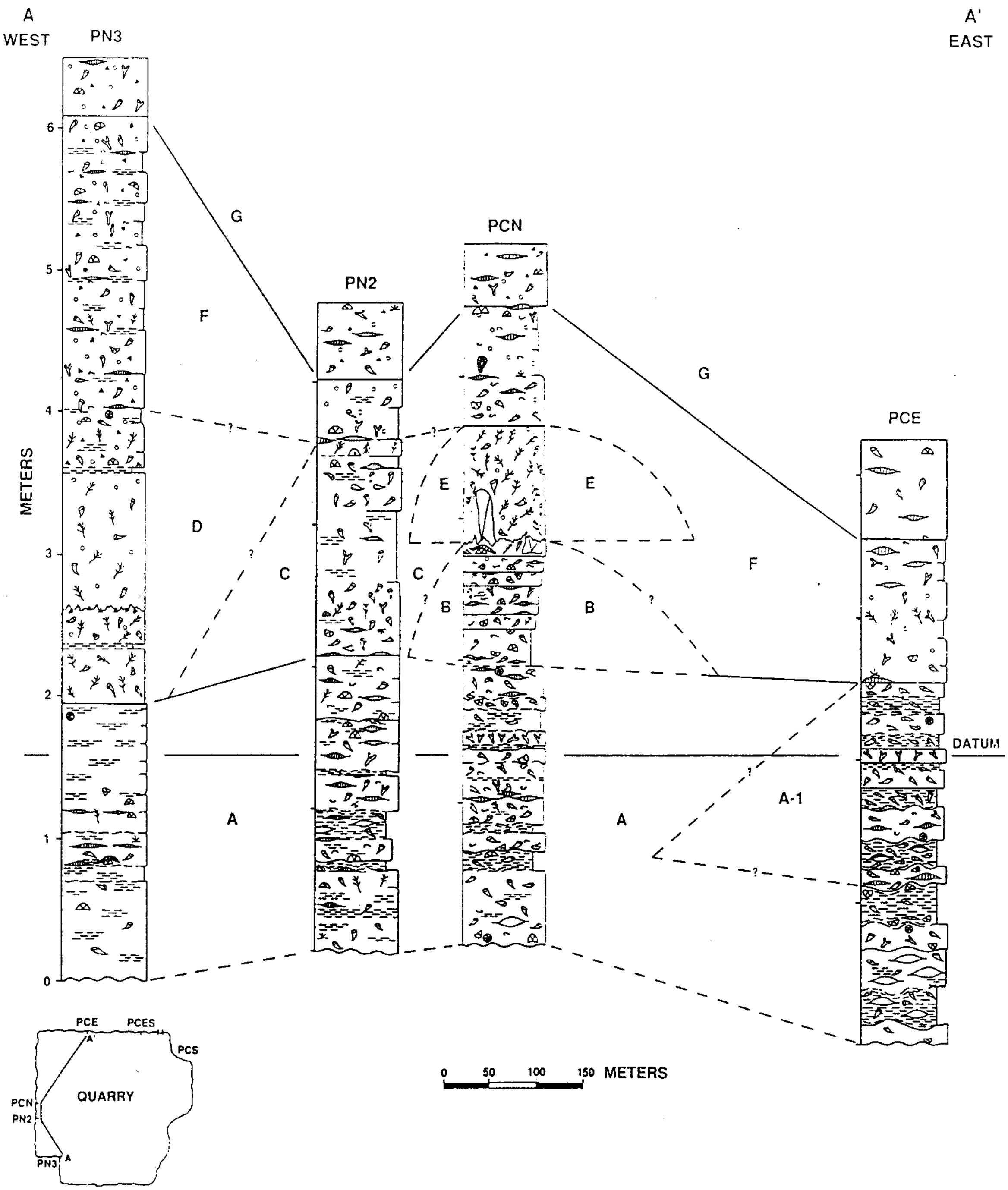
LITHOLOGY

- Fissile Shale
- Chert
- Lenticular Bedding
- Sharp Contact
- Gradational Contact

FAUNA

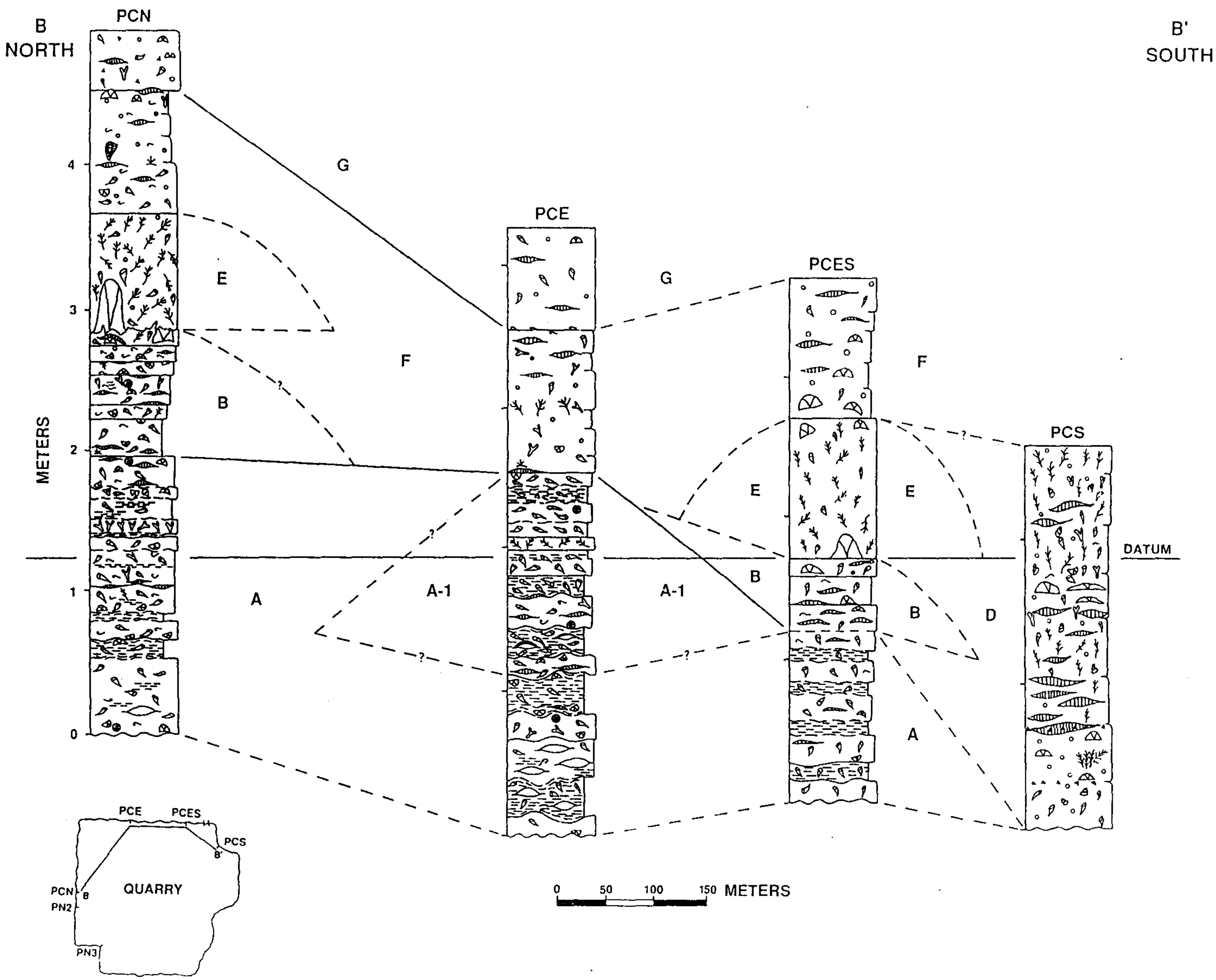
- Stromatoporoid
- Bryozoan
- Brachiopod
- Crinoids
- Rugose Corals
- Circumrotary Corals
- <u>Favosites</u> Corals
- Branching Corals

Figure 20. Cross-section A-A', Port Colborne Quarry. Datum is surveyed with respect to the top of Facies A and A-I.



A
WEST
PN3
A'
EAST
METERS
0
1
2
3
4
5
6
PN2
PCN
PCE
G
F
D
C
E
B
A
A-1
DATUM
0 50 100 150 METERS
QUARRY
PCE
PCES
PCS
PCN
PN2
PN3

Figure 21. Cross-section B-B′, Port Colborne Quarry. Datum is same as in cross-section A-A′.


B
NORTH
B'
SOUTH
PCN
PCE
PCES
PCS
METERS
0
1
2
3
4
G
E
F
B
A
A-1
D
?
DATUM
0 50 100 150 METERS
QUARRY
PCN
PN2
PN3
B
B'

FACIES A:

Facies A represents the Basal Facies and is observed at: PN3; PN2; PCN; PCE, and PCES, ranging in thickness from approximately 2.0 meters in the western end of the quarry to 1.1 meters in the east (Figure 20 and 21). The facies displays both vertical and lateral variations, generally characterized by mudstone to bioturbated wackestone-packstone beds with fissile shale interbeds. Percent carbonate increases vertically at each section and horizontally at all intervals from west to east throughout the quarry (Figure 3, Appendix IIA).

In the western portion of the quarry at PN3, Facies A is characterized by poorly bedded, unfossiliferous dark gray to brown, bioturbated mudstones and wackestones with intercalated shales. The bedding becomes more pronounced upwards in the facies with individual beds grading upwards from a mudstone to wackestone. At PN3 the top contact is sharp to erosional with a thin fissile shale separating Facies A from Facies D (Figure 22). Towards the east, fissile shale beds thicken from 5-15 cm at PN2 to 10-25 cm at PCE. Faunal content and percent carbonate (Figure 3, Appendix IIA) also increase eastward as the lithology changes from dominantly wackestones to dominantly packstones. The top contact of Facies A with Facies C is sharp at PN2, marked by a discontinuous stromatoporoid

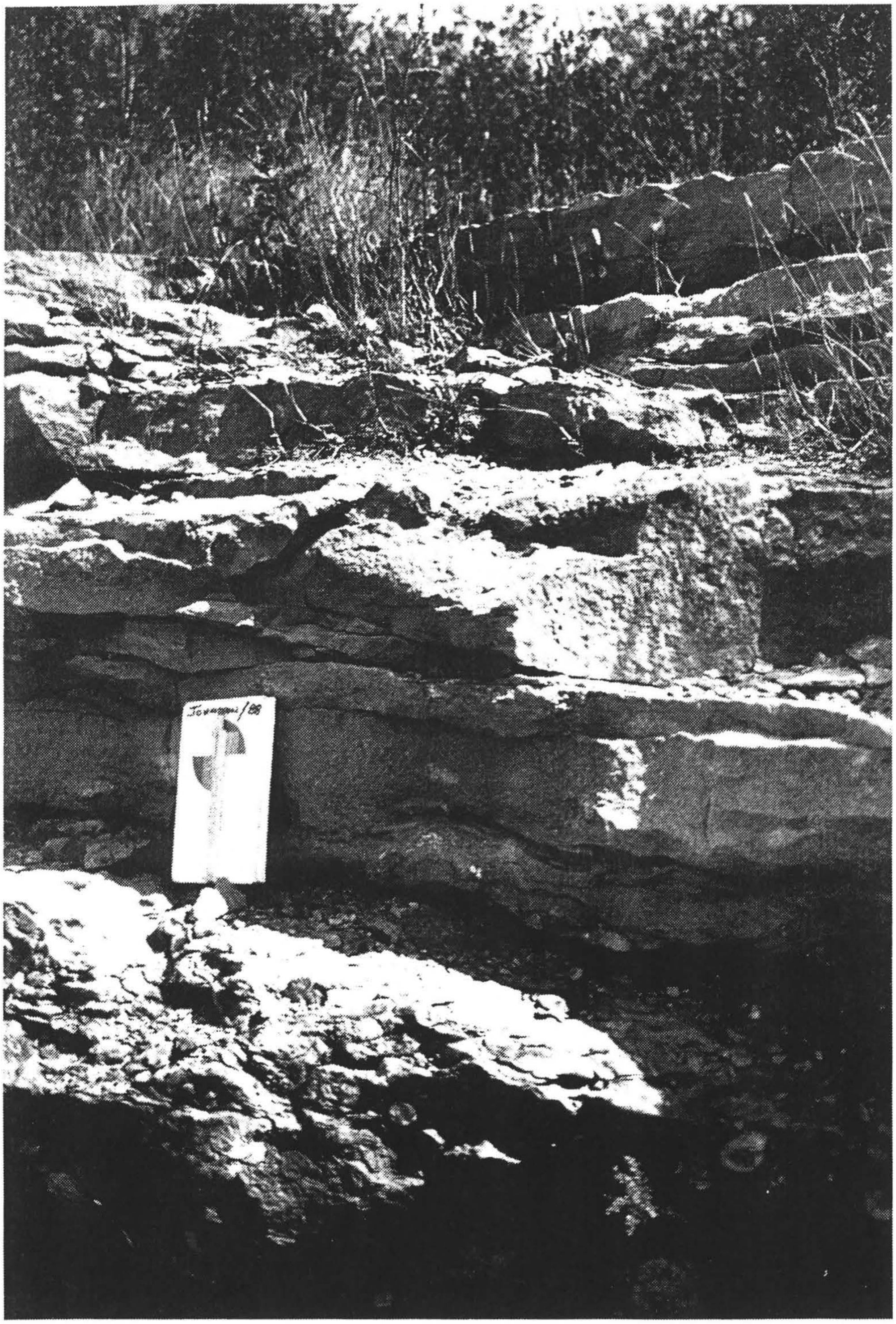
Figure 22. Contact between Facies A and D at PN3. Contact is in the middle of the hammer.

horizon suggesting a slight hiatus in deposition. At PCN, Facies A is gradationally overlain by Facies B, distinguished by a rapid decrease in shale, better defined bedding and higher percent carbonate represented by packstone to grainstone type lithologies. In the east wall, fissile shale beds obtain a maximum thickness, displaying sharp to erosional lower contacts and gradational upper contacts. The limestone beds are dominantly bioturbated wackestones to packstones ranging in thickness from 10 to 15 cm. In the very southern portion of the quarry at PCES, Facies A dips 3-4 degrees to the southeast, disappearing beneath the water line.

Facies A-I:

Facies A-I is very similar to Facies A, distinguished by a higher percentage of Cystiphylloid rugose corals (approximately 40-50% of the rock by volume) and a change in lithology from bioturbated wackestone-packstone beds to coarser grained, crinoidal packstone-grainstone beds. This facies is only observed in the northern portion of the quarry along the east wall (Figure 20, 21). At PCE, Facies A-I extends 1.56 meters above Facies A and is sharply overlain by Facies F (Figure 23) with stromatoporoid development common at the contact. To the north of PCE, beds dip to the northeast 3-5 degrees changing south of PCE,

Figure 23. Contact of Facies A-I with Facies F at PCE. Note contact is mark by note book.



dipping southeast.

Facies B:

Facies B is the Transitional Facies, found only at PCN and PCES upon which the Core Facies (Facies E) is deposited. The facies reaches a maximum thickness of 0.85 meters at PCN and is characterized by a series of slightly coarsening upwards crinoidal packstone beds (10-25 cm thick) separated by thin (less than 1 cm) shale partings. Facies B passes westward into Facies C and Facies D, corresponding to the Flank and Biostrome Facies and east into the Flank/Cap Facies, Facies F (Figure 20, 21). The upper contact is partially stylolitized at both locations with large hemispherical Favosites sp. heads extending from Facies B up into Facies E. At PCES, Facies B appears to be dipping southeast at 3-5 degrees, draping over Facies A-I of PCE. Facies B is interpreted to be correlatable between PCN and PCES forming an oval mound.

Facies C:

The Transitional Facies and Core Facies, Facies B and E of PCN pass westward into the flanking beds of Facies C at PN2 (Figure 20, 21). Here, Facies C rests on a slightly unconformable contact with Facies A and is characterized by poorly bedded, crinoidal wackestones to packstone-grainstones. The upper contact of Facies C with Facies F at PN2 is placed at the top of an Acinophyllum sp. rudstone bed. This bed parallels the top of Facies E at PCN and is composed of skeletal debris similar to that of Facies E. Further west, Facies C grades laterally into a Biostrome Facies (Facies D) at PN3.

Facies D:

Facies D corresponds to the Biostrome Facies observed at PN3 and PCS (Figure 20, 21). At PN3, Facies D overlies Facies A and is characterized by 2.0 meters of coral bafflestone to rudstone. The upper contact is gradational, merging into a crinoidal wackestone to packstone lithology characteristic of the Flank/Cap Facies (Facies F). At PCS, Facies D appears stratigraphically higher than Facies A and B of PCES and is gradational with Facies E and F. Here, Facies D dips southeast 3-5 degrees (Figure 24) and is characterized by a coralliferous stromatoporoid bindstone to coral bafflestone-rudstone.

Facies E:

Facies E is only observed at PCN and PCES forming broad (30-60 meter), low-lying (0.8-1.0 meter) Acinophyllum sp. rudstone to bafflestone mounds (Figure 25) and represents the Core Facies (Figure 20, 21). The lower contacts are

Figure 24. Outcrop photo of Facies D at PCS with beds dipping south-east at 3-5 degrees.

Figure 25. Outcrop photo of PCN. Note lighter coloured Core Facies (Facies E) forming a broad mound (20-30 meters).

partially stylolitized at both locations. Upper contacts are sharp to gradational with a crinoidal packstone-grainstone of Facies F. Facies E can be correlated between PCN and PCES and is interpreted to have formed an oval mound trending north-south, in the eastern portion of the quarry.

Facies F:

Facies F corresponds to the Flank/Cap Facies and is found at all locations except PCS, possibly due to glaciation or non-deposition (Figure 20, 21). At PCN, PCE, PCES, and PN2, Facies F is represented by a crinoidal grainstone which passes laterally into a crinoidal wackestone-packstone at PN3. The facies thins from 1.2 meters at PN3 to 0.4 meters at PN2, thickening slightly to 0.9 meters over the Core Facies at PCN and to 1.0 meters (minimum thickness) at PCE (Figure 20). The contact between Facies F and Facies G is sharp and easily distinguished at all observable locations throughout the quarry.

Facies G:

Facies G is characterized by a crinoidal wackestone to packstone with a high amount of silica both as skeletal replacement and small 3-4 cm. nodules. The high silica content gives this facies a distinct weathered appearance providing easy identification from Facies F. In portions of the quarry Facies G has been removed or partially removed by glacial processes. This facies corresponds to the Cap Facies and is present at: PN3; PN2; PCN, and PCE.

CHAPTER IV

PALEONTOLOGY AND PALEOECOLOGY

The fauna of the Port Colborne Quarry is well preserved both as recrystallized calcite and replacement silica. Corals were the most predominant fauna and thus identified to a generic level or further using Case (1982), Bayer et al. (1956), Oliver (1976), and Shimer and Shrock (1944) as the major taxonomic references. In addition, stromatoporoids, tubinate and platyceratid gastropods, echinoderms, bryozoans, and brachiopods were also present, but not differentiated any further.

Identified solitary rugose corals include: Cynathophyllum robustum; Heliophyllum halli; Cystiphyllum vesiculosum; Bloththrophyllum decorticatum, and Zaphrentis sp.. These corals are most abundant in the fissile shales and to a lesser extent within the calcarenite beds. Corals are observed to exhibit broken bases, singly or doubly geniculate corallums and well preserved epithecas. In situ corals are rare, but figure 26 reveals a rugose coral cemented in the upper portion of the Core Facies that has been broken at the base. This coral supports a southeast to northwest current direction with breakage caused by a sharp increase in energy, likely the result of a violent storm.

Figure 26. In situ geniculated rugose coral growing within the Core Facies (Facies E). Note coral trends SE -NW.

Figure 27. In situ _Favosites_ _basalticus_ coral draped by fissile shales of the Basal Facies (Facies A).

In general, solitary rugose corals show signs of:

i) disturbance by periodic, very high energy events as evident by the broken bases

ii) minimal transport as evident by the well preserved epitheca

iii) regeneration after disturbances as evident by the singly and doubly geniculate corallums.

The highest concentration of these corals is observed at PCE in Facies A-I, where 40-50% of the beds by volume are composed of the rugose corals, Cyanthophyllum robustum and Cystiphyllum vesiculosum.

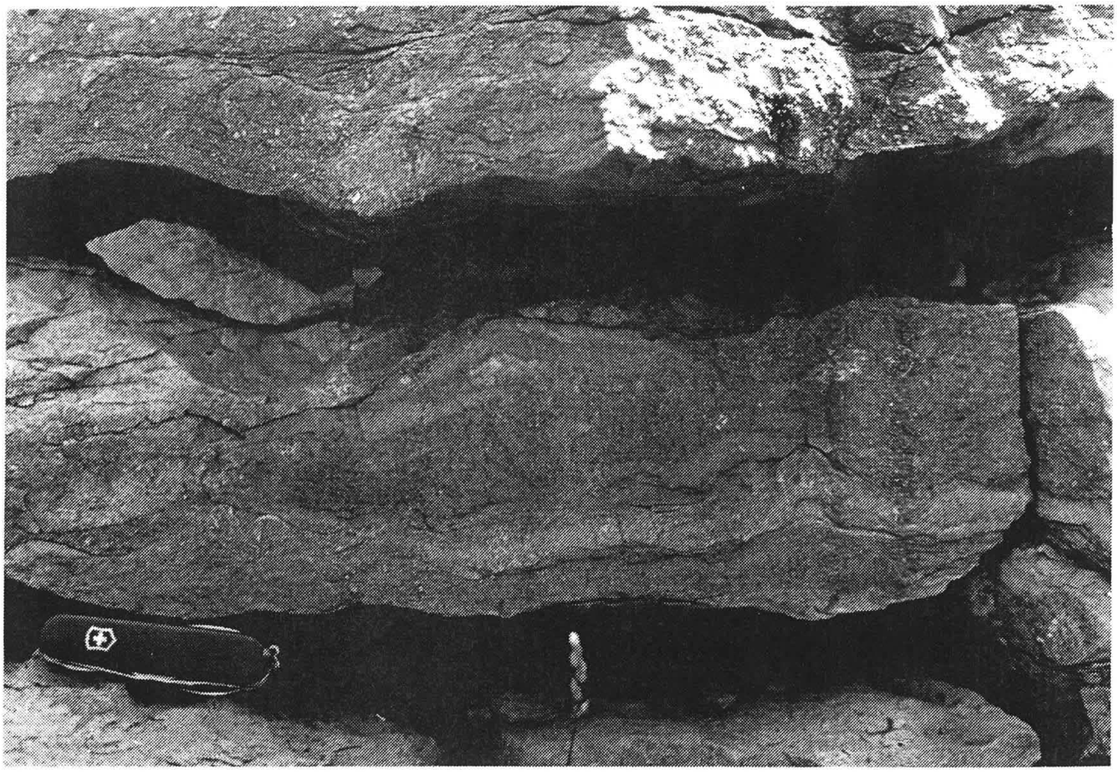
Solitary Tabulate corals identified are dominantly from the genus Favosites sp. including: Favosites emmonsia; Favosites canadensis, and Favosites basalticus as well as Pleurodictym sp.. Favosites canadensis is a broad flat encrusting coral found dominantly in Facies A, and A-I growing on the upper surface of packstone beds and also colonizing the upper surfaces of fissile shales. Favosites basalticus occurs as radial hemisperical heads in all facies throught the quarry. This coral is found both in situ and over turned in Facies A and A-I, often draped by overlying shales (Figure 27) with muds present within corallites and preserved in thin, regularly spaced layers in the coral skeleton, suggesting growth in a periodically disturbed turbide environment. Favosites basalticus is important in

Facies B, colonizing the upper surface upon which mound development is initiated. "Sheet forms" of this coral are common in Facies D at PCS in the south east portion of the quarry, suggesting low sedimentation rates (Philcox, 1971). _Favosites_ _emmonsia_ is mainly found in Facies A, A-I, and B as an unattached, spherodal coral with radially disposed corallites resulting from growth outward in all direction. Kissling (1973) terms this growth form "circumrotary" based on modern and Silurian examples from sloping flanks of small bioherm or ancient mudbanks whose crests at time of deposition were elevated above the surrounding seafloor and inhabited by rooted crinoids.

Colonial corals identified include both rugose and tabulate varieties: _Snaptophyllum_ _simcoense_; _Syringopora_ _sp_.; _Acinophyllum_ _sp_., and _Erindophyllum_ _colligatum_. _Acinophyllum_ _sp_. is the dominant mound forming coral restricted to Facies E. _Syringopora_ _sp_. is mainly found in Facies A and A-I where it is associated with a very muddy sediment. The rest of the colonial corals dominate the Biostrome Facies (Facies D). _Erindophyllum_ _colligatum_ is only observed at PSC, associated in the upper portion of the biostrome with _Synaptophyllum_ _simocense_ corallites. Here in situ coral colonies obtain widths of 2.0 meters and heights of 1.0 meters. The corallites of corals from the Biostrome Facies are generally larger in diameter (1.0-1.5 cm) as

Figure 28. Stromatoporoids development in the Flank/Cap Facies (Facies F) at PCE.

Figure 29. Stromatoporoid capping fissile shale pulse in the Basal Facies (Facies A).



opposed to the smaller diameter corallites of _Acinophyllum sp_. corals (0.5 cm) in the Core Facies. Corallite size has been shown to reflect sedimentation rates in modern environments, with larger corallites better suited to high sedimentation rates by Scott and Cope, 1989.

Stromatoporoids are characterized by thin tabular growth forms, rarely exceeding 5 cm in width. They are found in most facies throughout the quarry but reach the highest abundances in Facies D and F in the east wall of the quarry (Figure 28). In Facies A and A-I they are found encrusting the tops of both shale and calcarenites beds and terminating coarsening upwards sequences in Facies B (Figure 29). In these facies the stromatoporoids are generally thin (1-2 cm), suggesting a highly fluctuating environment characterized by episodic sedimentation. Within each section, stromatoporoids increase in thickness and abundance upwards, reflecting the change to a higher energy, less muddy environment (James, 1983).

Brachiopods and Gastropods are found throughout the quarry, dominating the lower portion of the quarry corresponding to Facies A and A-I. Bryozoans are dominantly ramose in form occurring in descrete beds, such as at PCN and mixed amongst other fossil debris at all locations within the quarry (Figure 30). Echinoderms, dominantly crinoids, occur as individual ossicles composing the bulk of

Figure 30. Bedding plane exposure of ramose bryozoans and large geniculate rugose corals.

Figure 31. Bedding plane exposure of large crinoid stems in the Biostrome Facies (Facies D) at PCS. Note crinoids approximately 1.5 to 3.0 cm in diameter and up to 1.0 meters in length.

limestone beds and as large crinoid stems, 1.5 to 3.0 cm in diameter and often up to 60.0 to 100.0 cm in length (Figure 31). The large crinoid stems are common in the Biostrome Facies at PCS where they are exposed on bedding planes and to a lesser extent at PN3.

CHAPTER V

INTERPRETATION AND DISCUSSION

Fossil reefs have been referred to as reefs, mounds, and banks by various workers; lacking many of the characteristics we ascribe to reefs, yet composed of skeletal organisms growing above the surrounding substrate. Detailed reviews of this problem are given by Nelson et al. (1962) and Heckel (1974).

The term "carbonate build-up" has been used by Heckel (1974) and Wilson (1975) to describe a body of locally formed (laterally restricted) carbonate sediment which posses topographic relief. This term carries no inference to the internal composition or shape of the structure, thus it is strictly used as a general term to describe carbonate deposits. In this study, the structure in question is best termed a "coral mound" based on its composition and shape according to Heckel (1974).

Reef mounds and carbonate banks are typically formed in a quiet water environment, either well below wave base or in water so shallow that wave action does not exist (Wilson, 1975). Preferred geographic locations for these deposits are: in the deeper basin; downslope along shelf margins, and in shelf lagoons or shallow basinal areas. For this study, mound development is believed to have initiated in a shallow water shelf lagoon, as all sedimentary textures and faunal assemblages closely concur with those discussed by Wilson (1975).

The lower beds of the Port Colborne Quarry represented by the Basal and Coral-Rich Basal Facies are interpreted to have been deposited in a shallow to deep shelf lagoon below fair weather wave base and within storm wave base. In the eastern portion of the quarry, evidence of storm processes are clearly present and have been described in detail by Navickas (1979). Some characteristics of storm deposits are:

i) graded-bedding, sharply truncated bases and transitional tops (Seilacher, 1982 and Kelling and Mullins, 1975).

ii) storms are usually preserved in "one event" beds, often coquinas forming winnowed lags (Kreisa and Bambach, 1982; Aigner, 1982; Brenner and Davis, 1973; Specht and Brenner, 1979, and Miller et al., 1988).

iii) commonly contain escape burrows.

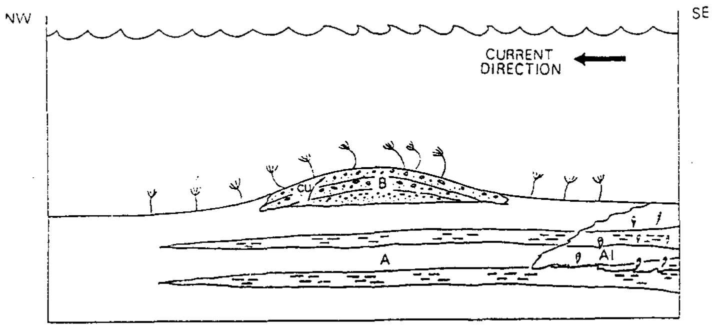
If storm processes are responsible for the deposition of the Basal Facies in the Port Colborne Quarry, these processes would be expected to operate at a regional scale, thus traceable throughout the quarry and the Niagara Peninsula. This is not the case in the quarry. Storm deposits are most pronounced in the east wall of the quarry, gradually dissipating westward over a distance of 600 meters where they are absent in the west wall of the quarry. It therefore appears that storm processes are variable in the Port Colborne Quarry and further study is suggested to ascertain if storm processes are identifiable elsewhere in the Edgecliff of the Niagara Peninsula.

Mound development in the Port Colborne Quarry is initiated in response to a slight regression near the top of the Basal Facies, corresponding to the deposition of the Transitional Facies in a shallow shelf lagoon, close to fairweather wave base. The Transitional Facies represents Stage I of mound development depositing a series of shoaling upwards beds forming an oval, low lying mound which extends above the surrounding substrate (Figure 32). At the end of Stage I a slight hiatus in deposition occurs as evidenced by: the sharp to erosional contact traceable throughout the quarry; development of stromatoporoid horizons at various locations on this contact, and the initiation of coral growth on the topographic high produced by the Transitional Facies.

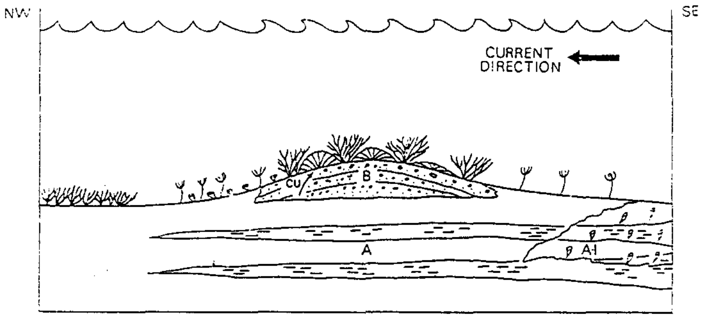
Stage II of mound development corresponds to the "Stabilization and Colonization Stage" of Isaacson and Curran (1981) and Walker and Alberstadt (1975) or the "Pioneering Stage" of Copper (1988). Large hemispherical

Figure 32. Summary diagram of reef stages.

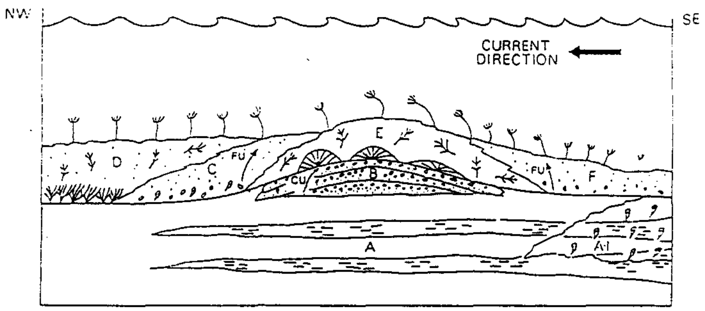
STAGE I



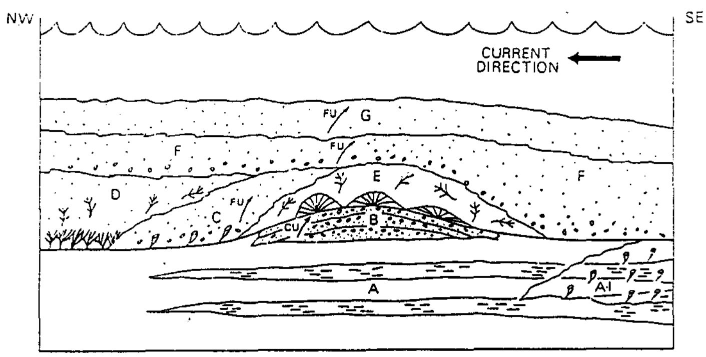
STAGE II



STAGE III



STAGE IV



tabulate corals of the genus _Favosites basalticus_ as well as the colonial rugose _Acinophyllum sp_. begin to grow and stabilize the crinoidal grainstones of the Transitional Facies (Figure 32). To the west of the shoal, _Synaptophyllum_ colonies and echinoderms are abundant, stabilizing and baffling slightly muddier sediments. The _Synaptophyllum_ corallites are larger in diameter than corals from the Core Facies, a feature indicative of siltation stress (Scott and Cope, 1989). The higher percentage of siliciclastic material and wackestone-packstone lithology is characteristic of poorly winnowed sediments and higher sedimentation rates (James, 1983) suggesting a slightly lower energy environment created by the dampening of any wave activity by the shoal itself. To the east of the shoal, sheet and hemispherical forms of the tabulate coral _Favosites basalticus_ are more abundant, associated with crinoidal grainstones and a lower percentage of siliciclastic material. This indicates a moderate energy, well winnowed sediment and low sedimentation rates (Philcox, 1971 and James, 1983). Stage II represents growth in a moderate energy environment, likely within fair weather wave base with zonation suggesting water movement from east to west across the mound.

Stage III corresponds to the "diversification stage" of Walker and Alberstadt (1975) and "growth to mean wave base" of Isaacson and Curran (1981) resulting in the expansion of Acinophyllum colonies into wave base causing colonies to become highly fragmented and the remaining sediment to be well winnowed (Figure 32). The sediment produced from the fragmentation of the coral colonies is transported westward from the mound producing the Flank Facies. Further to the west, Synaptophyllum colonies of the Biostrome Facies appear fragmented and mixed with poorly winnowed crinoidal debris. To the east of the mound, crinoidal packstones and grainstones of the Flank/Cap Facies are deposited with stromatoporoids becoming common. Stage III represents the filling of intermound areas by the Biostrome, Flank and Flank/Cap Facies during a period of stable sea level. Deposition of the Flank Facies composed of mound derived debris is further evidence supporting westward currents. This is substantiated by the paleocurrent findings of Ripley (1980), suggesting two directions of wave action; one SE-NW and the other NNE-SSW.

Stage IV corresponds the "diversification stage" of Isaacson and Curran (1981). Mound development never reaches the "domination stage" of Walker and Alberstadt (1975) with growth being terminated by the deposition of the Flank/Cap and Cap Facies, characterized by coarse crinoidal grainstones showing current imbrication and increased stromatoporoid growth, both features of a high energy environment (Figure 32). This final stage of mound succession is evident in many Edgecliff reefs (Williams, 1980; Lindemann, 1989; Wolosz, 1985, and Wolosz and Lindemann, 1986) and is interpreted to be a response to lowering of sea-level. A similar relative sea-level fall is proposed for the deposition of the Cap Facies in the Port Colborne Quarry, however, it should be noted that a fall in sea-level and growth of the mound into the surf zone would produce similar effects. In addition, this interpretation is consistent with the conclusion of Lindemann (1989), that the overlying siliceous calcisiltites of the Clarence Member were deposited in a semirestricted lagoon and not in an offshore environment. Cassa (1969) looked at a similar lagoonal bank in the vicinity of Port Colborne, Ontario and suggested termination of reef growth was due to "drowning" as corals could not keep up with the rising sea-level. This is clearly not the case in the Port Colborne Quarry where the proposed sea-level drop can be demonstrated and is the cause of mound termination.

CHAPTER VI

CONCLUSIONS

The Edgecliff Member of the Onondaga Formation within the Port Colborne Quarry exhibits eight facies which defined bioherm development:

1) Basal Facies (Facies A)
2) Coral-Rich Basal Facies (Facies A-I)
3) Transitional Facies (Facies B)
4) Flank Facies (Facies C)
5) Biostrome Facies (Facies D)
6) Core Facies (Facies E)
7) Flank/Cap Facies (Facies F)
8) Cap Facies (Facies G)

The Basal Facies represents deposition in a shallow to deep shelf lagoon environment, below fair weather wave base and within storm wave base. Mound development is initiated in response to a slight regression with four stages evident:

Stage I represents the deposition of a shoaling upwards sequence above the surrounding substrate in a moderate to high energy environment near fair weather wave base, corresponding to the Transitional Facies.

Stage II represents stabilization and colonization of the shoal by solitary and colonial corals in a moderate energy environment within fair weather wave base.

Stage III represents diversification of the mound upwards into the high energy zone corresponding to the deposition of the Core Facies. During this stage, sea-level is stable causing intermound areas to be filled in by the Flank, Biostrome, and Flank/Cap Facies.

Stage IV represents termination of mound growth by deposition of a crinoidal cap (Flank/Cap and Cap Facies), either due to a fall in sea-level or growth of the mound into the surf zone.

The dominant current direction is southeast to northwest as evident by:

i) Increased coral debris within the Flank Facies to the west of the mound

ii) Higher energy corals and stromatoporoids in well winnowed, high percent carbonate sediments to the east as opposed to poorly winnowed, low percent carbonate sediments with sparse coral and stromatoporoid fauna to the west, indicative of a lower energy environment.

iii) In situ rugose coral broken at the base in the Core Facies trending 330 degrees.

In summary, this study has indicated that Edgecliff

Member of the Onondaga Formation in the vicinity of Port Colborne, Ontario represents deposition in a shallow, muddy shelf lagoon. Bioherm development is in the form of a broad, low-lying, coral-rich mound that grew into wave base with growth being terminated by deposition of a crinoidal cap as a result of a sea-level drop or possibly emergence into the surf zone.

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APPENDIX

I(A) Petrographic Modal Analysis

I(B) Error Calculations for Major Petrographic Divisions

I(C) Skeletal Modal Analysis

I(D) Error Calculations for Major Taxonomic Groups

II(A) Dissolution Data

II(B) Graph of Dissolution Data

APPENDIX I(A) - PETROGRAPHIC MODAL ANALYSIS

THIN SECTION	SPAR	MICRITE	SADDLE DOLOMITE	DOLOMITE	OPAQUES	ALLOCHEMS	DETRITAL SILCA	SILICA REPLACE	TOTAL COUNT
FACIES A									
89-PCN-11	8.0	20.8		22.6	.6	46.9	.9	.3	665.0
89-PCN-7	11.1	26.9		10.6	.6	50.8			640.0
89-PCE-4	2.5	20.2		20.2	.2	53.4	.5	3.0	672.0
FACIES B									
89-PCN-22	32.4	9.3	.3	11.0	.3	46.0		.6	633.0
89-PCN-17	26.5	9.1	.2	5.2	.2	58.2		.7	596.0
89-PCES-2	24.1	9.8	.2	4.9	.2	61.0		.3	636.0
FACIES C									
89-PN2-12	8.0	26.5		3.0	.3	61.1		1.0	597.0
89-PN2-15	14.7	25.3		4.1	1.2	54.3		.5	641.0
89-PN2-16	16.9	8.6		5.2	.5	67.6		1.1	649.0
89-PN2-17	33.1	3.0	1.8	3.3		58.8			568.0
89-PN2-18	25.6	4.5		3.8		66.0		.2	664.0
FACIES E									
89-PCN-24	16.4	5.8	4.5	8.9	.5	63.8			639.0
89-PCN-23	23.4	6.1	2.2	5.1	.2	62.1		.5	604.0
FACIES F									
89-PCES-4	14.4	9.8	1.3	8.6		65.6		.3	604.0
89-PCE-12	27.1	3.6		6.4		61.6		1.4	661.0
89-PCN-28	10.7	18.7		2.8	3.3	64.3		.3	610.0
89-PCN-27	17.5	5.7		1.0	2.2	72.3		1.3	628.0
89-PCN-26	21.4	6.4	.3	2.2	.2	68.1		1.4	639.0
89-PCN-25	13.8	15.4	1.0	11.3		53.0	.2	5.6	661.0
FACIES G									
89-PCN-29	10.0	21.2		3.1	.3	65.0		.3	609.0
89-PN2-19	9.3	20.4		3.3	1.2	65.1		.7	676.0

APPENDIX I(B) - ERROR CALCULATIONS FOR MAJOR PETROGRAPHIC DIVISIONS

THIN SECTION	SPAR	MICRITE	SADDLE DOLOMITE	DOLOMITE	OPAQUES	ALLOCHEMS	DETRITAL SILICA	SILICA REPLACE	TOTAL
89-PCN-27	17.5	5.7		1.0	2.2	72.3		1.3	628.0
89-PCN-27	23.1	7.8		1.2	2.7	64.2		1.0	681.0
89-PCN-27	21.3	6.3		.8	1.9	68.5		1.2	635.0
AVERAGE	20.6	6.6		1.0	2.3	68.3		1.2	
MAX DEVIATION	3.1	1.2		.2	.4	4.1		.2	
% ERROR	15.0	18.2		20.0	17.6	6.0		17.4	
89-PCN-23	23.4	6.1	2.2	5.1	.2	62.1		.5	604.0
89-PCN-23	30.6	8.7	2.9	3.7	.9	52.9		.3	699.0
89-PCN-23	25.8	6.8	2.6	4.8	1.3	58.3		.4	673.0
AVERAGE	26.6	7.2	2.6	4.5	.8	57.8		.4	
MAX DEVIATION	4.0	1.5	.4	.8	.3	4.9		.1	
% ERROR	15.0	20.8	15.6	17.6	38.1	8.5		25.0	
89-PCN-29	10.0	21.2		3.1	.3	65.0		.3	609.0
89-PCN-29	7.2	30.1		2.1	.5	59.7		.3	610.0
89-PCN-29	8.4	26.6		2.5	.4	62.0		.2	626.0
AVERAGE	8.5	26.0		2.6	.4	62.2		.3	
MAX DEVIATION	1.5	4.1		.5	.1	2.8		.1	
% ERROR	17.6	15.8		19.5	17.0	4.5		37.5	

APPENDIX I(C) - PETROGRAPHIC MODAL ANALYSIS

THIN SECTION	CORALS	BRACHS	OSTR	BRYO	STROMS	ECHINO	PELLETS	TRILOBITE	GASTRO	STYLIO	UNID	TOTAL
FACIES A												
89-PCN-11	4.6	5.4	.8	3.1		29.2				2.3	54.6	375.0
89-PCN-7	6.8	6.3	1.1	1.6		33.2	2.6	.5	1.6	6.3	40.0	345.0
89-PCE-4	8.9	3.3	.3	2.8		45.2		.3	.3	2.8	36.3	361.0
FACIES B												
89-PCN-22	25.1	9.6	2.3	2.7	.2	27.9		.6			30.8	513.0
89-PCN-17	3.1	8.0	.7	2.6		63.6	.6	1.1	.6	.2	19.7	549.0
89-PCES-2	42.9	.9	.2	.9		42.2		.4	.2		12.3	552.0
FACIES C												
89-PN2-12	9.5	7.6	.3	4.7	1.3	56.8	.9	1.3	.3		17.4	317.0
89-PN2-15	14.8	8.2	.6	5.0	1.3	53.5	.3	.3	.6		15.4	318.0
89-PN2-16	11.5	5.3	.2	4.3		54.5	.7	.2			23.4	418.0
89-PN2-17	16.4	6.7	.8	7.8		51.2	1.6	.8			14.7	373.0
89-PN2-18	20.3	2.9	.3	2.6		52.0	1.8	.8	.5		18.5	379.0
FACIES E												
89-PCN-24	20.5	9.8		1.1		43.4	.2		.7		24.1	551.0
89-PCN-23	51.8	2.6		.2	2.5	25.8					17.1	604.0
FACIES F												
89-PCES-4	12.0	1.6	.8	19.4		47.1	1.3				17.8	376.0
89-PCE-12	5.8	8.6	.7	2.6		66.8		.2	.4		14.9	570.0
89-PCN-28	6.9	2.5	7.5		1.1	64.9	.6				16.6	362.0
89-PCN-27	17.8	2.6		2.9		54.8	1.2	.3			20.7	347.0
89-PCN-26	12.5	2.5	.6	1.4	10.0	51.1	1.1				20.9	359.0
89-PCN-25	25.5	7.1	1.5	2.4	3.3	38.6	2.1	1.2	.3		18.1	337.0
FACIES G												
89-PCN-29	3.4	5.6	.6	15.5		56.2	2.5				16.1	322.0
89-PN2-19	4.4	2.3	.6	7.8		65.9	1.5				17.5	343.0

APPENDIX I(D) - ERROR CALCULATIONS FOR MAJOR TAXONOMIC GROUPS

THIN SECTION	CORALS	BRACHS	OSTR	BRYO	STROMS	ECHINO	PELLETS	TRILOBITE	GASTRO	STYLIO	UNID	TOTAL
89-PCES-2	42.9	.9	.2	.9		42.2		.4	.2		12.3	552.0
89-PCES-2	41.7	.7	.1	1.3		42.5		.3	.1		13.8	489.0
89-PCES-2	38.6	.7	.2	1.0		46.5		.4	.1		12.7	521.0
AVERAGE	41.1	.8	.2	1.1		43.7		.4	.1		12.9	
MAX DEVIATION	2.5	.1	.1	.2		2.8		.1	.1		.9	
% ERROR	6.1	12.3	60.0	15.9		6.4		27.3	75.0		7.0	
89-PCN-24	20.5	9.8		1.1		43.4	.2		.7		24.1	551.0
89-PCN-24	22.1	8.9		.9		43.7			.7		23.9	423.0
89-PCN-24	22.9	9.1		1.0		44.8	.1		.6		21.5	485.0
AVERAGE	21.8	9.3		1.0		44.0	.2		.7		23.2	
MAX DEVIATION	1.3	.5		.1		.8	.1		.1		1.7	
% ERROR	6.0	5.1		10.0		1.8	47.1		8.7		7.3	
89-PCES-4	12.0	1.6	.8	19.4		47.1	1.9				17.8	376.0
89-PCES-4	11.2	1.5	.6	18.6		49.2	2.0				16.9	425.0
89-PCES-4	13.1	1.3	.8	17.3		46.5	2.1				19.0	465.0
AVERAGE	12.1	1.5	.7	18.4		47.6	2.0				17.9	
STDS	1.0	.2	.1	1.1		1.6	.1				1.1	
% ERROR	8.3	10.4	15.7	5.7		3.4	5.0				5.9	

APPENDIX IIA - DISSOLUTION DATA

SAMPLE	PRE-WEIGHT	POST-WEIGHT	% INSOL	% CARB
89-PCN-29	33.4594	1.7250	5.2	94.8
89-PCN-28	27.2025	1.3097	4.8	95.2
89-PCN-27	14.0912	.3839	2.7	97.3
89-PCN-26	31.3951	.6202	2.0	98.0
89-PCN-25	46.4685	2.6767	5.8	94.2
89-PCN-24	17.3389	.2740	1.6	98.4
89-PCN-23	16.5462	.2096	1.3	98.7
89-PCN-22	28.4680	.6053	2.1	97.9
89-PCN-21	5.5731	.3299	5.9	94.1
89-PCN-18	6.4097	.1325	2.1	97.9
89-PCN-17	10.5967	.3474	3.3	96.7
89-PCN-15	6.2683	.1097	1.8	98.2
89-PCN-12A	9.6578	.7019	7.3	92.7
89-PCN-10	8.0560	.7976	9.9	90.1
89-PCN-11	5.6886	.2054	3.6	96.4
89-PCN-8	5.7043	.5663	9.9	90.1
89-PCN-7	6.9176	.2888	4.2	95.8
89-PCN-6	7.8615	.4157	5.3	94.7
89-PCN-5	6.9448	1.0052	14.5	85.5
89-PCN-4	8.5442	1.4698	17.2	82.8
89-PCE-15	7.0349	.0641	.9	99.1
89-PCE-14	5.8486	.1089	1.9	98.1
89-PCE-13	4.6970	.1283	2.7	97.3
89-PCE-12	7.04	.2351	3.3	96.7
89-PCE-11	5.8492	.4893	8.4	91.6
89-PCE-10	5.7700	.1141	2.0	98.0
89-PCE-9	5.1424	.3660	7.1	92.9
89-PCE-7	5.5128	.1039	1.9	98.1
89-PCE-5	5.5264	.6561	11.9	88.1
89-PCE-4	7.5391	.7479	9.9	90.1
89-PCE-2	5.2929	.5645	10.7	89.3
89-PCE-1	4.6450	.4990	10.7	89.3
89-PN2-19	6.8436	.4997	7.3	92.7
89-PN2-12	7.2726	.3675	5.1	94.9
89-PN2-15	7.6555	.2937	3.8	96.2
89-PN2-16	7.8313	.2282	2.9	97.1
89-PN2-17	5.42	.0722	1.3	98.7
89-PN2-18	7.5816	.17	2.2	97.8
89-PN2-10	11.6035	.8825	7.6	92.4
89-PN2-8	8.8421	1.3555	15.3	84.7
89-PN2-9	11.9841	1.1145	9.3	90.7
89-PN2-7	12.6493	1.6246	12.8	87.2
89-PN2-3	15.1944	5.0790	33.4	66.6
89-PN2-2	13.8379	.7829	5.7	94.3
89-PN2-1	12.1163	3.8072	31.4	68.6
89-PN3-18	6.0733	.2848	4.7	95.3
89-PN3-15	4.6407	.1256	2.7	97.3
89-PN3-4	13.3087	1.5124	11.4	88.6
89-PN3-5	23.0141	4.7306	20.6	79.4
89-PN3-2	20.0485	2.3334	11.6	88.4
89-PN3-1	22.3154	5.9139	26.5	73.5

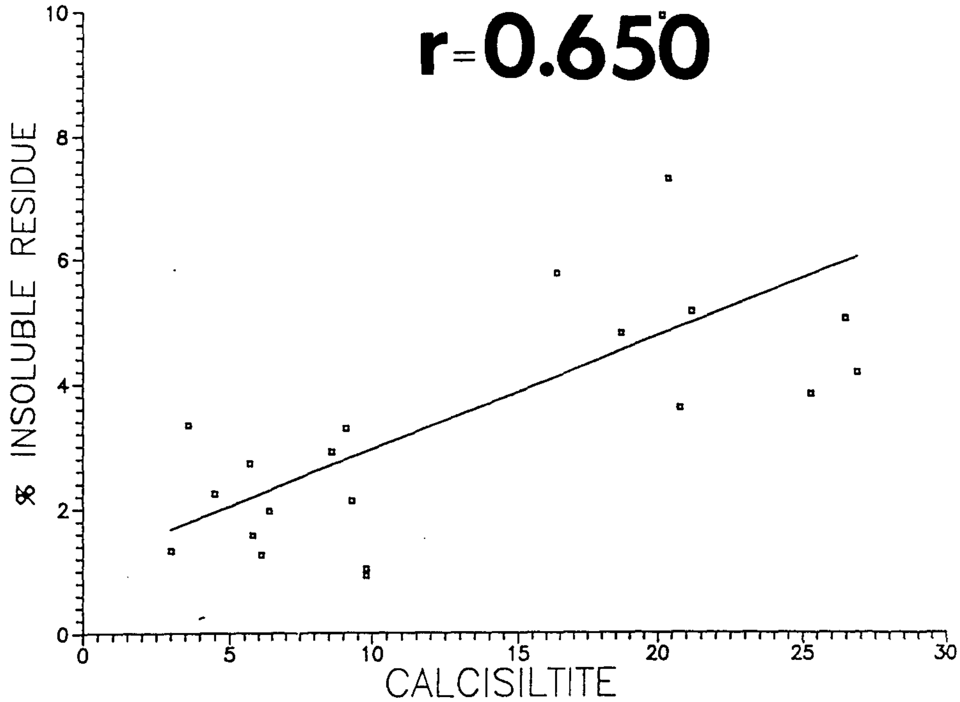
APPENDIX IIA - DISSOLUTION DATA

SAMPLE	PRE-WEIGHT	POST-WEIGHT	% INSOL	% CARB
89-PCS-5	6.5675	.1064	1.6	98.4
89-PCS-4	7.2997	.2087	2.9	97.1
89-PCS-3	4.8111	.1460	3.0	97.0
89-PCS-2	5.6900	.1381	2.4	97.6
89-PCS-1	3.8424	.3269	8.5	91.5
89-PCES-4	4.5899	.0429	.9	99.1
89-PCES-3	5.8693	.1108	1.9	98.1
89-PCES-2	6.6081	.0687	1.0	99.0
89-PCES-1	5.8561	.1997	3.4	96.6

(A) Graph of % calcisiltite obtained from thin section data versus % insoluble residue obtained from dissolution data.

(B) Graph of % calcisiltite + % opaques + % silica obtained from thin section data versus % insoluble residue obtained from dissolution data.

A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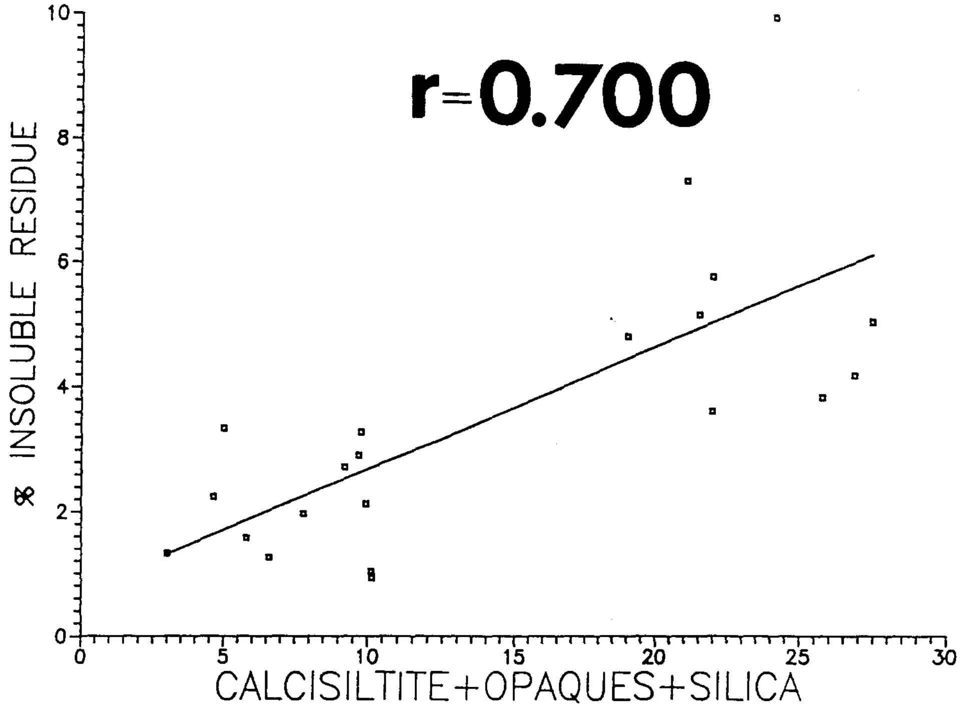
% INSOLUBLE RESIDUE
CALCISILTITE
0
2
4
6
8
10
0
5
10
15
20
25
30

B


r=0.700
% INSOLUBLE RESIDUE
CALCISILTITE+OPAQUES+SILICA
0
2
4
6
8
10
0
5
10
15
20
25
30