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UPPER ORDOVICIAN MOUNDS OF ANTICOSTI ISLAND, QUEBEC

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Sedimentology and Paleoecology of Upper Ordovician Mounds
of Anticosti Island, Quebec.

by

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Abstract

Organic buildups within the Ellis Bay Formation (Upper Ordovician) developed in the shallow subtidal marine shallowing upwards sequence of the Anticosti Basin. The sedimentation, fossil distribution, and diagenesis were studied in two separate buildups; on the Salmon River (Member 6) and Vaureal River (Member 4, Ellis Bay Formation; Bolton, 1971).

The Salmon River mud mound is bound by calcareous algae, stromatoporoids, and coral and consists of a micritic bafflestone core capped by a crinoidal grainstone. Early marine cementation is abundant and fills nearly all of the primary porosity. Cathodo-luminescence indicates at least five stages of cementation throughout the mound. Mound development was terminated by progressively shallowing, agitated marine environments (crinoidal grainstones).

A small coral (ecological) reef is exposed on Vaureal River. Primary porosity is infilled by early cements and filtering of fine sediments.

The small size of buildups, early marine cements and the lack of overlying impervious cap rock indicates that they are unsuitable for hydrocarbon reservoirs.

Resume

Les edifices organiques de la formation d'Ellis Bay de l'ordovicien superieur, se retrouvent a l'interieur d'une sequence stratigraphique du Bassin d'Anticosti. Cette sequence represente un environnement marin peu profond et situe au dessous de l'action des marées. Il est a noter que plus l'on monte le long de la sequence, plus l'environnement enasin se situe a faible profondeur. La sedimentation, la distribution des fossiles et la diagenese ont ete etudie pour deux edifices differents; l'un a la riviere Salmon (membre 6) et l'autre a la riviere Vaureal (membre 4), (formation d'Ellis Bay; Bolton; 1971).

La butte de boue a la riviere Salmon est bordeée d'algues calcaireuses, de stromatoporoides de coraux et consiste en un centre de "Bafflestone" micritique coiffe par une "grainstone" a crinoides. Une cimentation marine precoce est abondante et remplit a peu pres toute la porosite primaire. Des analyses par cathodo-luminescence relevent au moins 5 periodes de cimentation a travers la butte. Les derniers developpements de la butte se sont termines par une succession d'environnements marine, a profondeurs de plus en plus faibles, et agites ("grainstone" a crinoides).

Un petit recif corallien (ecologique) est expose a la riviere Vaureal. Un ciment precoce et une infiltration de sediments fins ont completement obstrue la porosite primaire.

La petitesse des edifices organiques, la presence d'une cimentation marine precoce, et l'un manque d'une coiffure rocheuse impermeable indiquent que ces deux localites n'ont aucun potentiel comme reservoir d'hydrocarbures.

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CHAPTER 1 - INTRODUCTION

The study of organic buildups developed within ancient epeiric seas has received considerable attention, due to their potential as reservoirs for petroleum accumulation. In addition, the origin of some mud mounds have puzzled geologists for a number of years.

This research involves the study of two separate mounds of Richmondian (Upper Ordovician) age on Anticosti Island, Quebec ($61^{\circ}45'$ - $64^{\circ}35'$ longitude / $49^{\circ}03'$ - $49^{\circ}55'$ latitude). Mound origins, sedimentary history including stages of diagenesis and the environment of formation are studied.

Field work was carried out during 1975 near the conclusion of the regular field season, while employed by the Government of Quebec, Ministry of Natural Resources during a stratigraphic mapping project of Anticosti Island under the direction of Dr. Allen Petryk. Use was also made of other information collected earlier in the summer.

Regional Geology

Anticosti Island is unique in eastern North America in exposing a complete Upper Ordovician section. The island forms part of a broad tectonically undeformed Ordovician and Silurian carbonate shelf. A total of 2820 feet (860 meters) of section is exposed on the island (Bolton, 1972). North of Anticosti Island, Precambrian Grenville structural province rocks are exposed on the Cote Nord. The Anticosti Basin rocks outcrop on the Mingan Islands, the western margin of Newfoundland and the Straits of Belle Isle. A belt of

thrusting bounded by Logan's Line separates Anticosti Island and the equivalent section within the St. Lawrence lowlands from the Appalachian fold belt of the Gaspé Peninsula. The regional strike of the island varies between N.70°W. and N.85°W., dips ranging from one-half to two degrees (Bolton, 1972). The area affords one of the best exposed continuous Upper Ordovician - Lower Silurian sequences in North America, especially along the many rivers which drain the island.

Previous Work

The first geological survey of Anticosti Island was undertaken in 1857 by J. Richardson, who named and divided the various formations. Schuchert and Twenhofel (1910) carried out a regional geological survey, followed by Twenhofel (1921, 1926). In 1928 Twenhofel published his monumental "Geology of Anticosti Island". Bolton (1961, 1965, 1972, 1975) has contributed to the stratigraphic and paleontological knowledge of the region.

Many of the rocks on the island are fossiliferous. Paleontological studies have been done by Billings (1857, 1866), Shaler (1865), Lambe (1900, 1901), Cox (1936), and Strachan (1954) and Barrass (1953, 1954). More recently, Ross (1960, 1961) revised the bryozoa fauna of the island. Boucot and Johnson (1966, 1967), Gaure and Boucot (1968), Sinclair and Bolton (1965) have carried out more detailed studies of the fossils, especially the brachiopods and corals. Riva (1969) outlined the graptolite zonation of the island. Dixon (1974) studied corals; Nitecki (1970), algae; and Rigby and Nitecki

(1974), sponges of the island.

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Method of Study

The lithofacies, sedimentology, paleontology, and diagenesis of the mounds were studied. Emphasis was placed on detailed lithofacies and biofacies relationships through mapping at a scale of one centimeter equals 200 centimeters and thin section and insoluble residue studies.

The study involved the study of coral mounds at two localities. The first area is located immediately below Ten Mile Lodge on the Salmon River (fig.1). The mound occurs at

the base of Member 6, Ellis Bay Formation (Bolton, 1975, Pers. Comm.) and is composed of three separate exposures along the Salmon River (fig.1). Most of the field work was carried out at this locality because of good exposures.

The second area is located south of the Vaureal River bridge, on the Vaureal River (fig.2). The reef is part of Member 4, Ellis Bay Formation (Bolton, 1975, p.519). Outcrop is limited to a single horizontal river bed surface.

The limited exposures, as with most ancient reefs, prevent a three dimensional reconstruction to be made. Facies were mapped in detail within and around the mounds at the two localities, and plotted on a series of maps and cross-sections (figs. 4,11,12, A&B). These diagrams provide a slightly diagrammatic representation of the relationships observed and serve as a framework for outlining depositional history.

The Ellis Bay Formation has been subdivided into six members by Bolton (1972), the type-section being exposed near the village of Port-Menier. The contacts between members are recognized on sedimentological and paleontological grounds.

Stratigraphic Column of Anticosti Island, (Thickness of Formations and Rock Descriptions, after Bolton, 1972).

Age	Formation	Rock Types
SILURIAN	Chicotte 75-100'	Massive to thick bedded crinoidal limestone
	Jupiter 475'	Dense, fossiliferous limestone and alternating shale
	Gun River 450'	Thin-bedded, highly fossiliferous limestone with intraformational conglomerate. Thin- to thick-bedded limestone with intraformational conglomerate. Thin, evenly bedded dense to semi-lithographic limestone.
	Becscie 265'	Thick- to thin- bedded dense to granular limestone.
UPPER	Ellis Bay 175-315'	Shale with interbeds of argillaceous limestone and local reef development.
	Vaureal 1000-1200+	Intraformational conglomerate, shale with fine-grained to dense limestone and intraformational conglomerate.
ORDOVICIAN		

CHAPTER 2- SALMON RIVER MOUND

The Salmon River mound is located immediately below Ten Mile Lodge on the Salmon River (fig.1). The mound is composed of three separate exposures along the banks of the river; the exposures on the north and south shores being termed the northwest reef, northeast reef and south reef for ease of reference.

Nowhere is a complete section of the mound exposed. As a result, only minimum dimensions are known. The mound has a minimum height of eight meters and an east-west width of more than 283 meters, and over 105 meters in the north-south direction. The one and one-half degree southerly regional dip of the strata and the nature of the topography of the area exposes the lower portion of the mound on the north shore of the river (northwest and northeast reefs, fig. 1). A complete stratigraphic section of the mound is reconstructed by placing the upper portion (south reef and adjacent outcrop) on top of the lower portion (north outcrops, fig.3), resulting in the composite section illustrated in Figure 4. The facies subdivision of the mound, based on lithological and paleontological criteria, are also illustrated in Figure 4.

The term "mound" describes the buildup on Salmon River better than "reef" because it lacks a supporting organic framework. Rather, it is a carbonate mud mound which contains a wide variety of fossils, mostly algae, corals, bryozoa and stromatoporoids.

The Salmon River mound occurs at the contact between member 5 and 6 of the Ellis Bay Formation (Bolton, 1975, Pers. Comm.).

Figure 1, Salmon River Mound. Arrows indicate area of study.

Current direction as indicated
by preferential orientation
of colonial coral

Vertical Joints

Figure 2, Location Map of Vaureal River Reef Locality.
Arrow indicates area of study.

Figure 3, Cross-section of the Salmon River locality showing stratigraphic relationship of the northeast and south reefs. The lower portion of the mound is exposed on the north shore and the upper portion on the south shore due to the southeast regional dip. A complete stratigraphic section of the mound may be obtained by superimposing the south on top of the northeast reef.

Figure 4, Composite diagram of the Salmon River Mound cross-section.
Numbers refer to sample localities.

Lithofacies, Salmon River Mound

The mound and associated facies is subdivided into the following six facies, in descending order:

Off-Mound	}	Member 6, Ellis Bay Formation
Crinoid Blanket		
Upper Mound		
Lower Mound		
Platform		
Member 5, Ellis Bay Formation		

These facies are described and discussed in ascending order.

Member 5, Ellis Bay Formation

The uppermost two and a half meters of Member 5, Ellis Bay Formation is exposed on the north shore of the Salmon River (fig.4). The sequence consists of alternating thin-bedded gray carbonate mudstone predominating over shale by a ratio of 15:1. The carbonate mudstone beds are laminated and vary from 2 to 8 cm. in thickness. The beds are somewhat undulating, occasionally rippled although they remain uniform in thickness and are extensively laterally (plate 1a). The mudstone beds are burrowed primarily in a horizontal direction, especially the topmost bed. The burrows average 2 mm. in width, are coated with brown micritic mud, and are elliptical in cross-section due to compaction. The shale is gray, fissile, soft and averages $\frac{1}{2}$ cm. in thickness.

A 5 cm. thick laminated wackestone bed composed of silt- and clay-size skeletal carbonate grains occurs 85 cm. below the top of the sequence. This bed contains brachiopod and ostracod fragments, scolecodonts and silt-size rounded quartz grains. A large, conically-shaped vertical burrow (fig. 5)

disrupts the laminations. Several 1-cm. vertical micrite-filled fractures are found within this disrupted interval.

The amount of insoluble residue from this stratigraphic interval averages about 12.5% by weight and consists of mature terrigenous medium silt- to clay-size quartz, feldspar, and illite.

Figure 5, Member 5, Ellis Bay Formation. Disruption of a laminated wackestone bed by burrowing. Vertical fractures are filled with micrite. Locality 35.

Fossils are locally preserved within ripple troughs, including delicate aligned crinoid stems (up to 8 cm. in length), complete Herbertella maria (Billings) and trilobite fragments (plate 1c). Pyritized worm burrows are found on some exposed bedding planes. These weather out in irregular patterns and average 2.5 mm. in diameter (plate 2a). Several mudstone beds, especially the uppermost, show extensive bioturbation of unknown origin on upper bedding

surfaces.

Depositional Environment

The environment of deposition of this facies is interpreted as tranquil, subtidal marine for the following reasons. 1) The predominance of fine-grained sediments; carbonate mudstone, shale and laminated wackestone, and their great lateral extent indicate a tranquil environment (Laporte, 1967; Walker, 1973; Wilson, 1974; Mazzullo and Friedman, 1975). The laminated wackestone of member 5, Ellis Bay Formation may have been deposited by similar low-energy currents: 2) The preservation of burrows as bedding surface features further suggests tranquil current conditions. 3)

An abundance of delicate, complete crinoid stems, about 5 cm. long, and brachiopods within some ripple troughs also indicates tranquil, subtidal marine conditions. Upon death, the organic coating on crinoids quickly disintegrates and the columnals are susceptible to fragmentation by currents. Similarly, the hinge lines of early brachiopods were not sufficiently articulated to withstand strong agitation after death and disintegration of the muscles (Ziegler, et al., 1968).

Since brachiopods are and where sessile benthic organisms attached to the substratum (Rudwick, 1965, p.199), it is possible that perfectly preserved brachiopods could result from rapid sedimentation and burial since they were incapable of locomotion (Purdy, 1964).

Unfortunately, Ziegler's (1968) suggested depth environments based on the distribution of Silurian brachiopod species

is not noted on Anticosti Island. Lack of significant water depth variation in the rocks of Anticosti Island suggests that brachiopod distribution is related to sediment type in this instance (Bolton, point raised at Eastern Canada Paleontology and Biostratigraphy Seminar, Toronto).

Member 6, Ellis Bay Formation
Mound Platform Facies

The Mound Platform facies forms the basal unit of member 6, Ellis Bay Formation. It is a uniformly thick, one meter marker bed of grainstone and wackestone (plate 2b) which can be correlated across the entire island (Bolton, 1975, pers. comm.). The upper and lower bedding surfaces are planar and parallel, except beneath the mound, where the upper bedding surface is irregular and bed thickness varies from 60-135 cm. Allochems include crinoid stems, bryozoa, brachiopod shells, gastropods, abraded rugose coral and Catenipora sp. fragments, rounded masses of Wetheredella silurica, trilobite fragments, and oncolites. The skeletal grains are well sorted, well rounded, have thick micrite envelopes (particularly the bryozoa) and are cemented by sparry calcite (plate 2d). The middle third of the bed is a fossiliferous grainstone, containing medium pebble-size, discrete, concentrically-arranged spheroidal oncolites (plate 2e).

A break in sedimentation two-thirds of the way up the bed is marked by large, rounded 2-5 cm. intraclasts and overturned solitary corals (plate 2c). The low degree of oncolite and solitary coral abrasion at this horizon in-

icates a nearby growth position and lack of transport. Above this break, the rock is a wackestone with zones of laminated micrite (plate 3a).

A large mass of Wetheredella silurica at the top of the bed contains a 2.6 X 4.0 mm. elliptical boring (plate 3c, loc. 38). The edge of the boring is very sharp.

Depositional Environment

The environment of deposition of the Platform facies is shown to be strongly agitated, shallow, subtidal marine for the following reasons. The skeletal grains are well rounded and well sorted, indicating a significant amount of agitation. There is a general absence of carbonate mud except within the wackestone of the upper third of the bed. Furthermore, the occurrence of discrete, spheroidal oncolites is also indicative of shallow, agitated, subtidal shoal waters (Logan, et al. 1964).

Lower Mound facies

The Lower Mound facies is a vaguely bedded, fossiliferous, carbonate mudstone and wackestone containing abundant brachiopod shells (including Leptaena sp.), and in situ corals (primarily Paleofavosites sp., Catenipora sp., and Protroscitholithus sp.), as well as Wetheredella silurica, other algae, solitary corals, and rare bryozoa fragments, crinoid plates, sponges, trilobites and stromatoporoids (Ecclimadictyon sp.). These skeletal grains are poorly sorted and rounded and often appear in growth position. The fine details of brachiopod shells, crinoid stems, bryozoa

Figure 6, Plot of facies stratigraphy versus percent insoluble residue for the Salmon River locality. Note that there is no regular pattern of insoluble residue content throughout the mound. However, the off-mound equivalent values are consistently higher than the mound facies. Numbers beside plots represent sample localities.

Sedimentary Facies

Sediment Types

Allochems

Depositional Environment

Crinoid Blanket

Bedded Grainstone
and PackstoneCrinoid Stems, Gas-
tropods, Brachiopods,
and Solenopora algae

Intertidal

Off-Mound

Thin Bedded Mudstone
Grainstone-Shale,
laterally extensiveTrilobites, Crinoid
Stems, Leptaena sp.
Brachiopods, Solita-
ry Corals

Subtidal to Intertidal

Upper Mound

Calcareous Mudstone,
Hemispherical Growth
FormsBryozoa, Wetheredella
silurica, Brachiopods
Crinoid Stems, Protr-
oscitholithus, Caten-
ipora, Paleophyllum
Trilobites, Ecclimad-
ictyon, Solitary cor-
als, Gastropods

Shallow Subtidal

Lower Mound

Mudstone-Wackestone,
Massive, UnbeddedBrachiopods, Paleofa-
vosites, Catenipora,
Protroscitholithus,
Wetheredella siluri-
ca, Solitary Corals,
Bryozoa, Crinoids,
Sponges, Trilobites
Crinoid Stems, Bryo-
zoa, Brachiopods,
Gastropods, Rugose
Corals, Algae, Tril-
obites, Oncolites

Shallow Subtidal

Platform

Grainstone-Wackestone
Thick BedBrachiopods, Ostra-
cods, Scolecodonts

Subtidal

Member 5

Thin-Bedded, Later-
ally Extensive, Mud-
stone-Shale-Grainst-
one

Subtidal

fragments and gastropods are excellently preserved.

The Off-Mound facies is in very sharp contact with the Lower Mound facies (see fig. 4). A mature assemblage of well-rounded, medium silt size quartz, feldspar and illite occur in consistently greater amounts (up to two times) in the Off-Mound over the Mound facies (fig. 6). This suggests dilution within the mounds by the carbonates and more rapid carbonate accumulation. This is also supported by relief of the mounds relative to the surrounding Off-Mound facies.

The northwest reef is separated into two parts; fossiliferous packstone to the east and calcareous mudstone on the western side (fig. A). The skeletal constituents are predominantly bryozoa, brachiopods, gastropods, Wetheredella silurica and Catenipora sp. Bedding is characterized by crude, thin, discontinuous units which pinch and swell. A large, irregularly shaped zone filled with a crinoidal grainstone is found near locality 44 (8 meters west on grid, plate 4c) and likely represents an irregular depression formed within the mound.

The northeast reef is partly capped with an 8 cm. bed of bryozoa wackestone containing delicate Pachydicta crassa and Hallopora elegantula prolifica bryozoa, fragmented crinoid stems, a few small (1 cm.) solitary corals and several half centimeter gray shale layers.

The Paleofavosites sp. and Catenipora sp. are dispersed throughout the mound rather than limited to certain horizons or sectors. The Catenipora sp. largely stand upright within the mud, although a few broken ones occur at the top, and

several are in an overturned position on the northwest reef, Protroscitholithus sp. (plate 6d) and Ecclimadictyon sp. are rare in the Lower Mound facies. Catenipora sp. are often coated in part with Wetheredella silurica.

Some sponges were noted at locality 42 on the northeast reef (plates 4e, 4f, 5a). These spherical structures measure to 40 cm. diameter and immediately overlie the Platform facies. The exterior morphology is distinctively irregular, demonstrating many small randomly distributed surface bumps. The interior contains several 5 mm.-wide, crudely radiating structures which diverge from the centre and are infilled with light coloured micrite (plate 4f). Several monaxon sponge spicules occur in thin section (plate 5a), the largest of which measures 1500 X 15 μ .

Nearly everywhere, a thin, encrusting, locally abundant stromatoporoid is preserved in all parts of the reef as successive horizontal bands with interconnecting tubes (plates 4b, 5f). They are too poorly preserved for specific identification. Often this stromatoporoid is encrusted on the upper surface by Wetheredella silurica.

Depositional Environment

The Lower Mound facies developed in a quiet, shallow subtidal marine environment for the following reasons. The excellent preservation of many fossils, often in growth position within a crudely bedded sequence of calcareous mudstones and wackestones suggests deposition under weakly agitated conditions.

Figure 7, Relative content of various fossils throughout the Mound facies, Salmon River. Values derived from thin section data, see appendix for original data.

Number of Samples

10

16

7

6

Echinoderms
(Crinoid Columnal
Plates)

Bryozoa

Brachiopods

Gastropods

Wetheredella
silurica

Solenopora sp.

Solitary Corals
Paleofavosites sp.

Paleophyllum sp.Catenipora sp.Protrosciolithus sp.

Trilobites

Ecclimadictyon sp.

100
90
80
70
60
50
40
30
20
10
0

PERCENT

Crinoid Blanket
Facies

Upper Mound
Facies

Lower Mound
Facies

Platform
Facies

The abrupt contact between the Lower- and Off-Mound facies demonstrates that relief occurred between the two during mound growth; little or no relief might be exemplified by interfingering of the two facies. The difference in height between the Lower- and Off-Mound facies during mound development is further supported by the amount of insoluble residues present. The increasing upwards insoluble residue trend (fig. 6) within the Lower Mound facies suggests that the difference in height between the two facies increases with time.

The crinoid-filled dilational fissures of the northwest reef (plate 4c) formed by post-depositional tension within the well consolidated mud bank. Lithification of the bank sediment must have occurred prior to fissure formation in order to prevent infilling by slumping.

The algae Wetheredella silurica and the laminar encrusting stromatoporoid (fig. 2d) were important sediment trapping organisms during mound growth, although their relative abundance is low. They are found encrusting large skeletal grains in packstone as well as encrusting carbonate mudstone exclusively.

Catenipora sp. occurs in both vertical and horizontal growth forms. In the Lower Mound facies it occurs in a vertical form, which may be attributed to agitation, depth of water, or alternately to variation of species type with depth. This contrasts with a horizontal or tabular growth forms within the Middle Ordovician of the Gaspé (P.A. Bourke, 1975, Pers. Comm.), which may be attributed to higher ag-

itation or shallower water.

The Catenipora sp. are colonized by microfossils (<2 mm.) attached to the outer epitheca (plate 4d). These microfossils have been considered to be of bryozoa, gastropod, rotifer, tunicate, acorn barnicle, reproductive coral stages, algae, foraminifera, bivalved shells, worm tubes and graptolite affinities by Flower (1961) and have been classified according to morphology.

Upper Mound facies

The Upper Mound facies is essentially a continuation of the Lower Mound lithologies, increasing mound relief to some extent. The Upper Mound facies is composed of a series of unbedded hemispheroidal randomly distributed calcareous mudstone mounds with vertical topographical relief to 2.5 meters. The skeletal grains include bryozoa, Wetheredella silurica, brachiopods, crinoid columnal plates, Protroscitholithus sp., Catenipora sp., Paleophyllum sp., trilobites, Ecclimadictyon sp., solitary corals and gastropods (relative abundances shown in figure 7). The fossils are well preserved and are generally less abraded than those in the Lower Mound facies. They are randomly distributed throughout the mounds and often occur in an upright growth position.

Two regular-bedded 10 cm.-thick grainstone-packstone beds are exposed at the base of the eastern portion of the Upper Mound facies (97-120 meters, south reef, fig. A). These beds contain abundant partly rounded bryozoa and Wetheredella silurica fragments. The matrix is distinctly bed-

ded with alternating sparry calcite and micrite, although the percentage of skeletal grains remains constant.

Locally, the Upper Mound facies contains laminated micrite (plate 5e), in part overlain by Wetheredella silurica.

The hemispheroidal mounds are not erosional features, but represent a growth morphology, proven by the absence of reef rubble within the intermound depressions, lack of truncated features within the mounds, lack of solution features, encrustations, bored surfaces, etc. They often overlie and overlap one another, and grow on top of one another (see fig. A, east end of section C).

The Upper Mound facies contains more insoluble residues than the Lower Mound. Many of the mounds locally contain laminar encrusting stromatoporoids, which are poorly preserved and recrystallized, making identification difficult. At locality 8, (40 meters, fig. A), several lateral growths of the stromatoporoid form hook shapes which are oriented in the same direction, possibly from current direction (fig. 8). Wetheredella silurica encrusts this stromatoporoid. Hence some surfaces of the mound and the skeletal elements were encrusted and stabilized by both stromatoporoids and algae. Paleophyllum sp. is the predominant coral found dispersed throughout the Upper Mound facies, followed by minor amounts of Catenipora sp. and Protroscitholithus sp. The stromatoporoid Ecclimadictyon sp. was noted in small quantities within mudstone near the top of the mound (plate 5e).

Depositional Environment

Figure 8, Outline of laminar stromatoporoid (gray) encrusting micrite. Note the hook forms oriented in the same direction (arrows).

For the following reasons, the Upper Mound facies represents a shallowing upwards, subtidal, marine sequence with corresponding increasing agitation. Two discontinuous regular bedded crinoidal grainstone-packstone beds at the base of the south reef section (97-120 meters, south reef, fig.A), were derived from an off-mound source. Their great lateral extent and uniformity of thickness and composition suggests the mound had low relief in order for the foreign sediment to be transported and evenly distributed on the mound.

The lack of flanking accumulations of coarse reef-derived bioclastic debris or solution features, borings, cal-

careous crusts, etc., is evidence for absence of marine erosion or subaerial exposure of the mound.

Locally abundant laminated micrites were formed by encrusting non-coralline algae which succeeded in trapping and binding the material (plate 5e), Wetheredella silurica and the laminar encrusting stromatoporoid played a similar role.

Paleophyllum sp. is the dominant coral in the Upper Mound facies, and apparently because of the very shallow waters, grew horizontally. The presence of the stromatop-
oroid Ecclimadictyon sp. near the top of the mound may also be the result of the shallower more agitated conditions.

Crinoid Blanket facies

The Crinoid Blanket facies is composed of bedded grainstone and packstone with slightly rounded crinoid stems, gastropods, brachiopods and Solenopora spongioides grains. The portions infilling the voids between the mound hemispheroidal growth forms pinch out and were deposited contemporaneously with the mounds. The beds which continuously blanket the mounds and depressions are post-mound deposition. The latter beds are uniformly 10-15 cm. thick and dip off the mounds at angles up to 28° (plate 6b). This in turn is overlain by a bryozoa mudstone bed containing excellently preserved nautiloid cephalopods, crinoid calyx, and Leptaena sp. brachiopods. The dip of bedding represents a minimum value since compression of the mud mound was greater than in the less compressible overlying grainstone and

packstone material. Time lines of laterally contemporaneous grainstone within depressions suggests that up to 30 cm. of relief existed at the end of mound growth.

The two localities within the intermound depressions, the bedded crinoidal grainstone interfingers or grades, from east to west, into mudstone of the same depression (at 48 and 102 meters, south reef, fig. A).

Within the lower grainstone beds, many of the skeletal grains, particularly bryozoa, have thick micrite envelopes. Large Paleophyllum sp. are found both overturned and in upright position within the grainstone (plate 6c).

At locality 3, within the bryozoa mudstone of the upper portion of the Crinoid Blanket facies, an inclined solitary coral shows abrasion of the epitheca (plate 6e). A five-millimeter-thick band of Wetheredella silurica completely encrusts the upper surface of the bed.

Depositional Environment

The Crinoid Blanket facies formed in a shallow subtidal environment with variably high and low agitation conditions for the following reasons. Within the crinoidal grainstone, the removal of micrite size fraction and sorting of ossicles indicates considerable agitation. Large Paleophyllum sp. are found both overturned and in the upright position, (plate 6c), indicating transport and agitated conditions. The thick micrite envelopes on skeletal grains is sometimes considered to indicate shallow subtidal origin (Bathurst, 1967; Mazzulo and Friedman, 1975).

At locality 3, a solitary coral has an abraded epitheca

(plate 6e) and is partly coated with Wetheredella silurica. The algae completely encrusts the coral and has since been partly abraded. Wetheredella silurica completely encrusts the upper bedding surface at this locality.

The lack of sufficient outcrops at this stratigraphic level makes it impossible to determine the source of the crinoid material. The Blanket facies is composed of the same skeletal material as the grainstone and packstone transported and deposited contemporaneously with the termination of mound growth. The source of the skeletal grains within these beds is generally considered to be a local crinoidal bank. At two localities within the intermound depressions, from east to west, the bedded crinoidal grainstone grades laterally into mudstone (at 48 and 102 meters, south reef, fig. A). This lateral grain gradation possibly resulted from a reduction of the capacity of the current to transport material. The angle of repose, as indicated by the dip of the overlying crinoidal blanket beds off the hemispheroidal mounds (at least 28° , not including compaction effects, 100 meters, south reef), suggests that the mounds attained at least 30 cm. of relief above adjacent depressions at the termination of mound development. The original dip was probably less if lime mud compaction is considered.

The Crinoid Blanket facies is overlain by a bryozoa mudstone. The bryozoa are well preserved and little abraded, suggesting that the fossils are in situ. The bryozoa may have played an active role in trapping and baffling

(stabilizing) carbonate mud (Thomsen, 1976).

The immediate superposition of bryozoa mudstone on crinoidal grainstone-packstone beds suggests that a wide variation in depositional conditions occurred side by side. The ecological importance of ancient bryozoans as environmental indicators is not fully understood. Modern ectoproct bryozoa are directly affected in their growth forms by a large number of factors such as rate of sedimentation, turbulence, substratum, salinity and possibly wave energy and currents (Schopf, 1969). Agitated waters with low turbidity are generally considered to be requirements for growth of bryozoa (Beerbower, 1960, p.276).

Off-Mound facies

The Off-Mound facies is composed of sparsely fossiliferous, laterally extensive thin, regular-bedded mudstone, grainstone and shale with a few thin-pebble conglomerate lenses near the top of the section. The Crinoid Blanket facies pinches out near the margin of the mound and is not found within the Off-Mound facies. A description of a portion (115 cm.) of typical Off-Mound facies sequence is shown in figure 8, located 800 meters west of the south reef on Salmon River (fig.1). No obvious sedimentary cycles were observed. Here, current ripples are consistently oriented at N.E. - S.W. (40° azimuth), with several cephalopods oriented normal to this direction.

The mudstone beds are commonly 2-5 cm. thick, gray massive, nodular, thin and well bedded, containing a few tril-

Figure 9, Section of Off-Mound strata measured 800 meters west-south-west of the mound on the south shore of Salmon River.

Gastropods, trilobite heads, rugose corals, scolecodonts, and *Leptaena* brachiopods found within grainstones.

obites, crinoid stems, Leptaena sp. brachiopods and solitary corals. A few beds show bioturbated bedding surfaces.

A typical grainstone of the Off-Mound facies (plate 8d) is composed of dark gray 5 cm. unlaminated regular-bedded, laterally continuous fossiliferous beds. The allochems include fine peloids, brachiopod fragments and some scolecodonts, showing both rippled and planar bedding plane features (fig. 9). Insoluble residues of the grainstones contain 13.2% well-rounded, medium silt size quartz grains with subordinate quantities of feldspar and illite.

Stratigraphically well above the mound, beds of thin-pebble conglomerate are generally 8 cm. thick and pinch out laterally. Pebbles are oriented flat in relation to the bedding plane, are poorly rounded, are not imbricated in a preferred direction, and measure up to 0.6 X 5 cm. (plate 8e). The pebbles are composed of abundant ostracod and brachiopod minute fragments oriented parallel to bedding, with a lime mud matrix.

The Ellis Bay - Becscie Formation (Ordovician - Silurian) boundary is exposed 2.4 miles to the west of the Salmon River section (Bolton, 1975, p.520).

Depositional Environment

The Off-Mound facies developed in shallow subtidal to intertidal marine conditions for the following reasons. The thin-bedded, laterally extensive, sparsely fossiliferous beds are indicative of intertidal to protected subtidal origin (Laporte, 1967; Walker, 1973; Lucia, 1974). This

is produced by reworking and transport of sediment with continuing fossil abrasion. The irregularly repetitive nature of interbedded mudstone, grainstone and shale with superimposed large-scale oscillation ripple marks of constant current direction also suggests shallow conditions. Preferred orientation of current direction is achieved by frictional contact with the bottom in shallow waters.

In terms of the environment of flat-pebble conglomerates, recent examples are usually interpreted as forming within the intertidal zone (Laporte, 1967, p.99).

The overlying Becscie Formation is interpreted as representing intertidal conditions (Dixon, 1970), based on deposits of crinoidal detritus, current-style ripples, abundance of nautiloids and the erosional summit of a local bioherm within the underlying Ellis Bay Formation at Point Laframboise. Available information suggests that stratigraphically upwards, the depositional environments gradually shallowed in Upper Ellis Bay and Becscie Formations.

MOUND ORIGIN

The mound appears to have undergone early submarine cementation and lithification on the basis of intraclasts, borings and fracture fillings. Intraclasts within the Mound Platform facies indicate significant early lithification. The tubular boring within Wetheredella silurica at the top of this bed (plate 3c) possibly attributed to sipunchulid or polychaete worms (Bromley, 1970) and infilling of an oncolite internal fracture (plate 2d) by marine skeletal

debris also suggests early lithification. The grains within the fracture are not self-supporting, but have settled under gravity after partial cementation. Within the Lower Mound facies, tension fractures formed within sediments lithified earlier in mound history (plate 4c).

During mound development, growth of algal laminated mudstone, Wetheredella silurica and the laminar encrusting stromatoporoids, even though small volumetrically, must have played an important role in encrusting and binding the mound.

CHAPTER 3 - DIAGENESIS OF SALMON RIVER MOUNDS

Diagenetic processes are especially important in mound development and can often be used to indicate whether the earliest stages of cementation were submarine or subaerial. In addition, diagenesis provides clues about the burial history and processes undergone prior to later subsurface processes and more recent telogenetic surface exposures.

Original Porosity Types

The variation in primary or fabric selective porosity within the various facies of the Salmon River Mound are illustrated in figure 9. All primary porosity is now filled with cement. Original porosity was calculated by the two dimensional point counting of thin sections, using the Nikon projector field microscope. No adjustments were made for compaction effects, which are not considered significant in these rocks. In general, original primary porosity increases upwards stratigraphically. The filling of voids by fine sediment and cements has destroyed the original primary porosity of the mound. Volumetrically, interparticle was by far the most important type of porosity present throughout the mound, due to predominance of wackestone over boundstone content. Intraparticle, moldic and shelter porosity was volumetrically insignificant. Considerable primary porosity was filled by micrite. Interparticle porosity, and to a lesser degree, moldic porosity are abundant in the crinoid blanket facies (plates 7a and 7d). These types of porosity are rare within the lower facies of the mound, except the Platform facies (plate 2d). Shelter porosity occurs beneath

Figure 10, Estimates of porosity, rounding and sorting within the various facies, Salmon River Mound, based on point counts of thin sections. See Appendix A for data.

brachiopod shells, etc., throughout the Mound and Off-Mound facies (plates 2d and 8d). Examples of moldic porosity are limited to the crinoid blanket facies (plate 7d). Intraparticle or growth framework porosity was not volumetrically important throughout the mound, being limited to corallites of Paleofavosites sp., Catenipora sp., Paleophyllum sp., and solitary corals. Cement infills the spaces not occupied by calcareous muds (plates 2d, 3c, 3f, 4a, 6e, 7a). Fenestral porosity is formed locally within algal laminated muds (plate 5e). Well-formed geopetals are found extensively throughout the mound, forming within brachiopod shells, corallites and algal borings (plates 3c, 6e).

The preservation of remnant primary porosity is limited to some Paleofavosites sp. corallites within the Lower Mound facies (plate 4a). Non-fabric selective or late stage solution porosity is limited to a few irregular fractures infilled with sparry calcite throughout the mound.

Cements

Cement-types throughout the mound include fine drusy calcite lining surfaces of cavities and grains, followed by coarse-grained, inclusion-rich sparry calcite (plates 2d, 3f, 4a, 7a). Five stages of cementation are recognized throughout the mound, using cathodo-luminescence techniques (fig. 12, plates 5b, 7e,f, 8a,b). a) earliest stage; non-luminescing manganese- and iron-poor cement. The earliest cement is dark, non-luminescing, and appears as a thin discontinuous band which often lines only portions of some

Figure 11, Stages of cementation observed by luminescence throughout the Mound and Crinoid Blanket facies. (a) Five stages of cement from Lower Mound facies. Cement infills Paleophyllum sp. corallite (loc.42). (b) Same five stages of cementation observed within Crinoid Blanket facies. Cement is a syntaxial overgrowth on crinoid columnal plate (c). Stages 1 and 2 are poorly developed here.

cavities (plates 5b, 7f, 8b), As in the modern and Pleistocene, certain skeletal constituents such as echinoids are the preferred surfaces upon which cements grow, in optical continuity with the grain. Local examples of the non-luminescing dark cement show euhedral crystal outlines, while most show irregular outlines. This cement is found throughout the mound, coating both upper and lower surfaces of skeletal grains and cavities. Thin sections cut at various angles to bedding show no preferred direction of cement growth

or control of growth by gravity, as in stalactitic cements.

b) second stage yellow-luminescing cement. The second stage of cement is a thin, bright yellow-luminescing band restricted to coating the outer surface of the first cement. It is 500 μ thick, non-corroded and is restricted to coating the first dark non-luminescing stage. Freeman (1971) and Meyers (1974) suggest that cements often luminesce a bright yellow due to high manganese content. The first two stages are best developed in the lower portions of the mound, (c,d) The third and fourth stages are a repetition of the first two. (e) The final stage of cementation is a broad, dull-luminescing iron and/or manganese poor, inclusion-rich blocky spar. A slight variation of cement chemistry within this stage is indicated by subtle luminescence shades (plate 7f). The absence of a sharp contact between these shades suggests this cement belongs to the same stage; the variation caused by changes in solution chemistry. Many authors (Freeman, 1971; Kendall and Tucker, 1973; Friedman, 1973; Meyers, 1974) note that cements formed within the marine environment are commonly non-luminescing due to low Fe^{++} , Mg^{++} , or Mn^{++} contents; whereas non-marine cements are usually rich in one or more of these elements and therefore luminesce. Shallow meteoric ground water and surface meteoric water is more likely to precipitate strongly luminescing calcites than deep subsurface waters. Absence of thin bands of alternating luminescing and non-luminescing cements indicates they were probably not formed under the influence of fresh water, in response to repeated solution chemistry changes over

short periods.

Age of Cements

Cementation probably occurred early in the history of Salmon River mound development. Evidence supporting this includes 1) preservation of mound morphology with little evidence of erosion, 2) maintenance of fissures within the Lower Mound facies for sufficient time to allow infilling by grainstone, 3) boring in calcareous algae at the base of the Lower Mound facies indicating early cementation, 4) development of a hardground and large intraclasts indicating early lithification within the Mound Platform facies, 5) lack of compaction and pressure solution features throughout the mound, necessitating an early cementation history, 6) cathodo-luminescence suggests an early marine stage of cementation, and 7) the high angle of repose of sediments preserved within the Crinoid Blanket facies.

Collectively, the above mound features indicate an early submarine cementation history contemporaneous or nearly so with mound development. The growth of a thin, brightly luminescing cement combined with later development of a thin-pebble conglomerate suggests brief subaerial exposure of the sequence before repeated marine submergence.

Neomorphism of material throughout the Salmon River mound is minimal. Most rocks studied show little evidence of neomorphism. Rare examples show preferential neomorphism of fossil skeletal parts over surrounding matrix material. Examples of aggrading neomorphism in brachiopods,

Catenipora sp., and laminar encrusting stromatoporoids were noted (plates 3b, 4d, 5f).

The micritization of skeletal grains occurs throughout the mound, and is especially marked in bryozoa fragments within the Mound Platform and Crinoid Blanket facies (plate 7a). The early cementation of lime mud is observed in plates 7b and 7d, resulting in the maintenance of a now cement-filled void space, surrounding the algae and alternately the micrite within the geopetal.

The micritization of skeletal grains by endolithic algae occurs subaerially as well as in the submarine environment (Bathurst, 1971). However, micritization is most common within the shallow subtidal setting (Laporte, 1967; Bathurst, 1967; Walker, 1973; and Mazzullo and Friedman, 1975). The micritization of coralline algal material may provide an important source of lime mud production infilling pore spaces.

Dolomite forms less than two percent of the mound rocks. The crystals are small; idiomorphic (euhedral), equigranular, and regularly distributed throughout the rock, formed by post-depositional aqueous replacement of calcite. The larger size of these ancient dolomites compared to modern dolomites suggests a very slow growth of crystals (Zenger, 1972a; Folk and Land, 1975).

Pseudomorphs of calcite after gypsum are found infilling a cavity at the Upper Mound - Crinoid Blanket facies interface. The gypsum crystals grew within an irregular elliptical pore spaces surrounded by micrite and partially protected by a brachiopod shell. The crystals consist of eu-

hedral laths which cross each other in a random fashion.

Silica within the mound is restricted to terrigenous clays and silts dispersed throughout the limestone (fig. 6).

Authigenic pyrite was found to infill worm burrows within member 5, Ellis Bay Formation beneath the mound, and within some oncolites of the Mound Platform facies (plates 2a and 2d). The pyrite is early because it precedes infilling by sediment, cement, or partial replacement of earlier void-filling material.

Stylolites were only found at four sample localities on Salmon River (Loc. 8, 26, 30, 39; fig.A). Stylolites are located at the summit of a hemispheroidal mound form, Upper Mound facies (loc. 8), and immediately above the Platform facies, within the Lower- and Off-Mound facies (loc. 26, 30, 39). In terms of the history of burial of a carbonate sequence, their presence is often considered to be evidence of intermediate vs. late cementation (Bathurst, 1958; Beales, 1971; Park and Schot, 1968). Dissolution associated with stylolitization has generally been suggested as an important source of cement. However, the small quantity of stylolitization throughout the mound precludes this process as being the main source of primary early burial cementing solutions.

Sedimentary compaction features are rare. Adjacent to the mound, within member 5, Ellis Bay Formation are slightly compacted horizontal worm burrows in mudstone. The general absence of pressure solution features throughout the mound is suggestive of early marine cementation and/or shallow

burial of the units. Solution phenomena and fracture filling within the mound is minimal.

CHAPTER 4 - COMPARISON WITH OTHER MUD MOUNDS

The Salmon River mound does not represent an "ecological reef" with necessary organic boundstone framework according to the definition of Lowenstam (1950), but rather is composed largely of lime mud with interspersed non-framework building organisms.

A model outlining the development of an idealized mud mound accumulating within a quiet water environment has been formulated by Wilson (1975, p.367). This model is applicable to both ancient and modern examples, since many mounds show similar vertical and lateral sequences of textural and organic facies. Within shallow basinal areas, the mound shape results from the accumulation of locally produced carbonate sediment up to wave base under conditions of stable or rising sea level (Wilson, 1975, p.364). Mounds commonly begin growth below wave base and build up into it, remaining there for sufficient time to develop crestal boundstone, flanking beds, talus and perhaps a capping bed (fig. 12).

Fig XII-5 Ideal carbonate mound with seven commonly developed facies. See also Fig IV-9 and VI-25. The sequence of facies develops when the accumulation grows into wave base and is controlled by varying rates of sediment production, rates of subsidence, and hydrographic factors

Figure 12, Diagram of idealized mud mound, after Wilson, (1975, p.367).

The following are the stages of development outlined by Wilson (1975) for the idealized mound illustrated in figure 12. 1) Basal bioclastic wackestone pile, 2) Micritic bafflement core, 3) Crestal boundstone, 4) Organic veneer, 5) Flanking beds, 6) Talus, and 7) Capping grainstone.

The mound developed under shallow subtidal to intertidal marine conditions that gradually became shallower upwards, in contrast to mound development in a rising sea. Development at the Salmon River locality progressed into the area of wave base, which is common for mounds growing within shallow basinal environments.

The Lower Mound facies of the Salmon River is similar to the Basal bioclastic wackestone pile (1) of Wilson (1975). It contains much micritic sediment with overturned corals, bryozoa, brachiopods as well as abundant in situ coralline algae development. Salmon River mound initially grew on an irregular bedding plane at the base of the Lower Mound facies. In contrast, according to Wilson, (1975), many mounds developed upon piles of shell debris, presumably accumulated by current action. The thickest part of the mound generally consists of a micritic matrix containing organisms capable of trapping and baffling fine lime mud, and presumably represents the Micritic bafflement core (2) of Wilson (1975). Each geological age has its predominant organism(s) which filled this role. The predominant binding and sediment trapping organisms within the Salmon River mound (in decreasing order of abundance) are: 1) Wetheredella

silurica (algae), 2) laminar encrusting stromatoporoids, 3) Treptosoma bryozoa, and 4) Corals; Catenipora sp., Paleofavosites sp., Paleophyllum sp., and Protroscitholithus sp.

The Upper and Lower Mound facies of the Salmon River buildup are assigned to Wilson's (1975) Micritic baffle-stone core (2). The stratigraphic variation in quantity and types of organisms upwards in the mound is likely a function of changes in circulation and depth of water.

The Salmon River Mound varies from the Wilson (1975) model by not developing a Crestal boundstone (3) at the summit of the mound. No significant increase in the quantity of boundstone development is noted within the final stages of mound growth. However, significant algal and stromatoporoid growth was responsible for binding the sediments into the hemispheroidal growth forms of the Upper Mound facies.

No Organic veneer (4) of encrusting organisms and associated fissure filling terminates mound development. The only fissure filling in the Salmon River mound occurs near the base of the Lower Mound facies (plate 4c).

Development of Flanking beds (5), corresponding to the Off-Mound facies, occurs around the margins of the mound. Very few mound organisms have been transported from the mound to the flanking beds. The few fossils within the flanking beds are preserved in situ or overturned in place. Hence, flanking beds are poorly developed in Salmon River mound; lapping onto but not burying the mound (fig. A).

Minor coarse detritus in the form of locally transported

Paleophyllum sp. and solitary corals are found within depressions between the hemispheroidal growth forms at the top of the mound. The absence of talus indicates low agitation conditions or possibly an absence of boring organisms.

A capping grainstone sequence of crinoid - Solenopora sp. grainstones is well developed over the Salmon River mound; the skeletal grains originating within the Off-Mound environment. This development, similar to Wilson (1975), is attributed to stabilization of sea level and subsequent development of a shelf with little relief.

Summary

The Salmon River mound illustrates the Micritic baffle-stone core (2), and Capping grainstone (7) of Wilson's (1975) ideal carbonate mound facies.

Mound Development

The stages of mound development at the Salmon River locality are outlined (fig. 1³), based on data summarized in figure 4. The Mound Platform facies serves as the only reliable datum plane for correlation of the Mound and Off-Mound facies. There is no other datum above this level save the Crinoid Blanket facies, which interfingers with the Off-Mound facies.

Underlying Platform

Initially the Platform facies was deposited under shallow subtidal conditions over an extensive area. An angular

bedding surface (restricted to the area beneath the mound) developed on the upper bedding surface of the Platform facies. The elevation afforded by the irregular surface provided relief for organisms from being buried by sediments, as well as providing a hard substratum on which to colonize. The organisms, by growing and proliferating more rapidly than adjacent carbonate sediments, were able to maintain the morphology of the mound.

Stage 2

The mound grew and maintained its differential height over the surrounding Off-Mound facies, presumably as a result of relatively rapid sediment accumulation on the mound, the proliferation of encrusting algae, and early marine cementation. The crudely bedded Lower Mound facies gives way to the hemispheroidal growth forms in the Upper Mound facies as a response to increasing wave agitation resulting from upward growth of the mound and/or lowering of sea level.

Stage 3

The last stage (3, fig.13) records the termination of mound development through gradual burial by sediments derived from an off-mound source (the Crinoid Blanket facies). These crinoidal grainstones resulted from gradually shallowing subtidal conditions, followed later by intertidal sedimentation and the deposition of sparse thin-pebble conglomerates.

Within the mound, a change occurs from predominantly Paleofavosites sp. in the Lower Mound facies to Paleophyl-

lum sp. and Catenipora sp. in the Upper Mound facies. This may be attributed to the relative stability and tolerance of these corals to shallower, more agitated conditions, similar to changes in growth forms in modern Caribbean reefs.

Ladd (1957) suggests that Ordovician corals had not developed a means of substrate attachment, inferring that this may explain the paucity of Upper Ordovician barrier reefs. He adds that few corals were able to flourish successfully within the zone of wave action. They relied upon sinking into the substrata and exceeding the sedimentation rate in order to maintain their upright position. The limited amount of boring by organisms within the Salmon River mound may account for the absence of talus breccia and preservation of the hemispheroidal growth forms in the Upper Mound facies.

In modern reefs, removal of skeletal debris by current action prevents the reef from choking in its own detritus (Goreau and Land, 1974, p.85), in contrast to mud mounds, where accumulation adds to the buildup.

Lime Mud Production

Lime mud production on reef platforms has been studied by many geologists. The means of production includes inorganic precipitation (whittings), post-mortem disintegration of algae, skeletal debris particle size reduction by abrasion, and micritization. Micrite accumulation on a mound may be accounted for by bottom load transport from a foreign source, as is much of the terrigenous material included in most mounds (Neumann, 1972). The rapid acc-

Figure 13, Stages of Mound Development, Salmon River

Stage 1: Deposition of Platyform facies on the shallow Upper Ordovician shelf of the Anticosti Basin. The local irregular upper bedding surface providing a suitable substrate for mound development.

Stage 2: Mound Buildup. Accumulation and submarine cementation of material by post-mortem in situ breakdown plus trapping of allochthonous sedimentary material by calcareous organisms.

Stage 3: Burial of the Mound facies by the Crinoid Blanket facies. Mound development was stopped by shallowing waters and subsequent widespread intertidal conditions.

STAGE I

2
0 m 20

STAGE 2

2
0 m 20

STAGE 3

2
0 m 20

About 5X Vertical Exaggeration

umulation of carbonate mud on the mound suggests the importance of organisms in providing both the supply and the trapping mechanism for sediment accumulation.

Many authors have suggested the importance of the baffle effect which bryozoa, sponges, algae and corals play in the trapping of sediment.

Marshall and Orr (1931) and Stoddart (1969) have shown that fine sediment accumulation around the lower portions of corals is more lethal to organism survival than is the rain of sediment from suspension. Perhaps the rapid accumulation of lime mud was not beneficial to all reef organism.

Mud mounds from many localities and periods have been described and interpreted as to mode of formation. Mud mounds occur within deep restricted basins; on the foreslope of carbonate banks; and within the shallow protected waters of the back-reef environment. The size, basinal position, abundance, ecological framework and mode of preservation of the mounds varies with the individual localities. Examples of mud mounds interpreted as forming on the foreslope of the carbonate platform have been described by; Cotter (1965), Toomey and Ham (1966), Ham and Toomey (1967), Toomey and Riding (1972), Heckel and Cocke (1969), Achauer (1969), Mountjoy and Jull (1975), Mountjoy and Riding (in press).

Growth of mounds is controlled primarily by water circulation patterns and the mechanical accumulation of sediment, the remaining criteria being secondary. Trapping

Figure 14, Distribution of Upper Ordovician carbonate strata in North America (after Flower, 1967, p.124) and position of Ordovician equator and climatic zones (Strakhov, 1967), after Cumming, 1975, figure 2.

of sediment, the stabilization of the mound by organisms and the slow cementation of calcareous mud leads to mound preservation.

CHAPTER 5 - VAUREAL RIVER REEF, MEMBER 4, ELLIS BAY FORMATION.

This reef is located 800 meters south of the bridge on the Vaureal River (fig. 2). The reef is exposed on a horizontal surface displaying negligible relief (plate 9a). It occurs within member 4 of the Ellis Bay Formation (Bolton, 1975, Pers. Comm.). This outcrop gives no clue to the initial vertical relief of the reef.

The Vaureal River Reef is discussed using the distribution of facies (fig. 16) and the interpreted cross-section (fig. 15). Five facies are recognized in this reef outcrop:

Coral-Algal Rubble facies,
Detrital Packstone facies,
Clay-rich carbonate wackestone reef depressions,
In situ Paleophyllum and Paleofavosites (reef mound) facies,
Paleophyllum and Paleofavosites mudstones and wackestones
(reef flat) facies.

Lithology, Vaureal River Reef

(a) In situ Paleophyllum and Paleofavosites (reef mound facies)

This facies consists of several exposures of colonial coral growth trapping fossiliferous carbonate mud, interpreted to be coral mounds. The skeletal grains include poorly rounded and sorted bryozoa, crinoid columnal plates and gastropods. The two primary mound-forming corals, Paleophyllum sp. and Paleofavosites sp. grow horizontally and are successively stratified one above the other throughout. Locally, Catenipora sp. and small stromatolites are found in situ (loc. 51, fig. B).

Depositional Environment

The horizontal growth of corals may represent a response

to slow sedimentation rates or extremely shallow waters rather than agitated conditions. (Philcox, 1971). Rapid sedimentation rates would presumably require coral growth to achieve vertical forms in order to avoid burial and subsequent death. The Paleophyllum sp. growth form on Anticosti Island is believed to serve as a sediment baffle, similar to Tetradium cellulatum in the mid-Ordovician of New York State (Walker, 1973).

(b) Paleophyllum - Paleofavosites Mudstones and Wackestones
(Reef Flat) facies

This facies is distinguished from the in situ reef mound facies by containing a greater proportion of skeletal sediments, sparse coral growth framework and lower topographic relief. This facies consists of abundant upright and overturned Paleophyllum sp. and Paleofavosites sp. enclosed by fossiliferous mudstone and wackestone. The skeletal grains include poorly rounded and sorted crinoid columnal plates, bryozoa and gastropods. This facies is bedded in part and grades into the reef mounds proper. Throughout the facies, Paleofavosites sp. horizontally overgrows the margins of ceroid-shaped Paleophyllum sp. colonies. Columnar cigar-shaped stromatoporoids which grew in an upright position are found overturned within this facies (plate 9b). Where exposed, the lower bedding plane of this facies is slightly undulating.

Depositional Environment

The horizontal growth of Paleophyllum sp. and Paleo-

Figure 16, Diagrammatic cross-section of the reef on Vaureal River. Location of section is noted on Figure 16.

Figure 16, Schematic diagram of Member 4, Reef, Ellis Bay Formation, Vaureal River locality.

Figure 17, Outline of horseshoe-shaped Paleofavosites sp. growths around reef depressions. The depressions are infilled with an anomalous amount of terrigenous clays,

favosites sp. may have been a response to shallow water conditions and high turbidity rather than to strong agitation. The packstone matrix demonstrates good preservation of fine skeletal material, suggesting minimal agitation.

(c) Clay-rich Carbonate Wackestone Reef Depression facies

Within the southern portion of the outcrop are two horseshoe-shaped, three meter long depressions, the margins of which are outlined by a continuous growth of Paleofavosites sp. (fig. 17). The Paleofavosites sp. exists as an 8-cm. thick horizontal growth upon a carbonate mud base. These depressions compose the Clay-rich Carbonate Wackestone Reef Depression facies. The depressions open to the west and contain an abundance of fossiliferous gray terrigenous clays (20%) plus carbonate mud.

Skeletal grains within the depressions include medium rounded, well sorted, crinoid columnal plates, bryozoa, brachiopods, trilobites and skeletal grains. A large ceroid-shaped Paleofavosites sp. occurs in growth position in the easterly depression (fig. 17).

Depositional Environment

These depressions are surrounded on three sides by Paleofavosites sp., open to the west, and contain a substantial amount of terrigenous clays. These ceroid-shaped Paleofavosites sp. are in growth position. Possibly the depressions afforded them local protection. The depressions later served as traps for an anomalous quantity of terrigenous clays.

(d) Detrital Packestone facies

This limited facies consists of packestone, occurring on the eastern margin of the outcrop (fig. 16). It contains fragments of transported corals, a few overturned cigar-shaped columnar stromatoporoids, and abundant bryozoa and brachiopods in a yellow lime mud matrix. The exact stratigraphic position of this facies with respect to the Coral-Algal Rubble facies is undetermined due to lack of exposure.

(e) Coral-Algal-Rubble Facies

This facies consists of a fossiliferous packestone assemblage containing abundant well rounded, poorly sorted crinoid columnal plates, bryozoa, brachiopod fragments, ellipsoidal Solenopora spongioides (red calcareous algae) to 5 cm., Protroscitholithus sp., and solitary corals (plate 9e). The Solenopora spongioides show excellent preservation of internal structure. The skeletal elements are randomly oriented, occur within a matrix of carbonate mud and grey terrigenous clays, showing poor sorting and no bedding features. The coral-algal rubble dips at 10° to the west in both areas of exposure. (fig. B).

Throughout the Ordovician, various species of calcareous algae are found in many environments and hence do not constitute good environmental indicators.

Interpretation

The Vaureal River Reef is composed of a framework of

abundant corals and is therefore considered to represent a true "ecological reef" (Lowenstam, 1950). By analogy with Recent coral reefs, the structure probably developed within an agitated shallow subtidal environment. Laminar coral, stromatoporoids and stromatolites suggests very shallow agitated subtidal marine conditions. The shallow water, horizontal low relief growth of corals provided a minimal amount of resistance to wave energy, preventing coral abrasion and destruction. The Coral-Algal Reef Rubble on the upper surface of the reef is believed to be transported from the off-reef environment because of the high degree of abrasion which the exotic Protroscitholithus sp., crinoid columnal plates and Solenopora spongioides have undergone.

Diagenesis of Vaureal River Reef

Because of the limited outcrop exposure of the Vaureal River reef, a thorough investigation of diagenesis was not possible. The reef is well indurated and lithified, and contains no voids attributable to primary porosity. Both interparticle and intraparticle porosity is largely infilled by carbonate mud throughout the reef (plates 9c and 9d), leaving little space for development of later cements. Sparry calcite cement infills some of the intraparticle porosity within Catenipora sp. and Paleophyllum sp. There is very little preservation of primary porosity within the mudstones - wackestones - packstones of the reef, possibly as a result of fine lime mud filtering into these voids.

The coarse sparry cements luminesce a very dull orange

colour, suggesting that cementation occurred under early shallow marine conditions. Non-fabric selective cements are present in the form of fracture fillings.

Throughout most of the reef, early stages of aggrading neomorphism are noted. Advanced stages of neomorphism appear to be limited to Catenipora sp. structure within the in situ Paleophyllum and Paleofavosites (reef mound) facies (plate 9c).

Dolomitization of the reef is very sparse. The dolomite is anhedral, equigranular, small and randomly dispersed throughout both the fossils and matrix. Stylolites and compaction features are uncommon. Late fracture filling by sparry calcite and some terrigenous clays is quite common throughout the reef, usually not exceeding several millimeters in width. No distinct pattern of fracturing was noted.

Interpretation

By analogy with Recent coral reefs, the structure probably developed within a slightly agitated shallow subtidal environment. Laminar corals and stromatolites having a predominantly fossififerous lime mud matrix suggests very shallow slightly agitated submarine conditions. The horizontal growth forms of corals and stromatolites provided a minimum of resistance to agitation.

CHAPTER 6, SUMMARY AND CONCLUSIONS

The following table briefly contrasts the pertinent sedimentological, diagenetic, lithological and paleontologic features of the Anticosti Island buildups studied. The two buildups are distinctly different in response to their environment of formation.

Summary and Comparison of Salmon and Vaureal River Mounds.

	<u>Salmon River Mound</u>	<u>Vaureal River Reef</u>
Age	Richmondian (Upper Ordovician), Member 6, Ellis Bay Formation.	Richmondian (Upper Ordovician), Member 4, Ellis Bay Formation.
Development	Organically-bound mud mound.	Ecologic Reef.
Depositional Environment	Shallowing-upwards Conditions.	Shallowing-upwards Conditions.
Depth of Water	Shallow Subtidal	Subtidal
Size (LxWxH)	?X283X8 meters	22X11X2+meters
Sediment types	mudstone-wackestone-packstone-grainstone	mudstone-wackestone-packstone-grainstone-boundstone
Facies Recognized	Off-Mound Facies Crinoid Blanket facies Upper Mound facies Lower Mound facies Mound Platform facies Member 5, Ellis Bay Formation	Coral-Algal Rubble facies Detrital Packstone facies Clay-rich carbonate wackestone reef depressions In situ <u>Paleophyllum</u> and <u>Paleofavosites</u> (reef mound facies) <u>Paleophyllum</u> and <u>Paleofavosites</u> mudstones and wackestones (reef flat) facies
Organic Framework/ Organisms Binding Sediments	<u>Wetheredella silurica</u> , laminar stromatoporoids, <u>Catenipora</u> sp., <u>Paleofavosites</u> sp., <u>Paleophyllum</u> sp., <u>Ecclimadictyon</u> sp.	<u>Paleophyllum</u> sp., <u>Paleofavosites</u> , <u>Stromatolites</u> , <u>Catenipora</u> sp.

	<u>Salmon River Mound</u>	<u>Vaureal River Reef</u>
Skeletal Grains	Echinoderms (Crinoid Columnal Plates), Bryozoa, Brachiopods, Trilobites, Gastropods, Solitary Corals, <u>Solenopora spongioides</u>	Echinoderms (Crinoid columnal Plates), Bryozoa, Brachiopods, Trilobites, Solitary Corals, <u>Solenopora spongioides</u> , <u>Protroscitholithus</u>
Terrigenous Minerals	Quartz, Feldspar, Illite	Quartz, Feldspar, Illite
Coral Distribution and Growth Forms	Upper Mound facies predominated by <u>Catenipora</u> sp. and <u>Paleophyllum</u> sp. Lower Mound facies predominated by <u>Catenipora</u> sp. and <u>Paleofavosites</u> sp. All forms grow in a vertical manner	Vertical alternation of <u>Paleophyllum</u> sp. and <u>Paleofavosites</u> sp., growth within the in situ <u>Paleophyllum</u> and <u>Paleofavosites</u> (reef mound) facies. All forms grow laterally
Diagenesis: Porosity	Primarily intergranular with minor intragranular, moldic, shelter and fenestral. Non-fabric selective porosity not well represented	Predominated by fracture-filling, non-fabric selective porosity, with most fabric selective porosity infilled by carbonate muds
Neomorphism	Minor- most textures well preserved	Minor- most textures well preserved
Authigenic Minerals	Pyrite in worm burrows and oncolites at base of mound. Not highly dolomitized	Not highly dolomitized
Stylolites and Compaction Features	Minor	Minor
Source of Sediments	Abrasion of carbonate secreting organisms, micritization, bed load transport, whittings(?)	Abrasion of carbonate secreting organisms, micritization, bed load transport, whittings(?)
Reason for Development and Preservation	Ideal water depth, circulation patterns, irregular initial bottom surface (Mound Platform facies), binding of sediment by calcareous algae and stromatoporoids, combined with early submarine cementation.	Insufficient data to access initial reef development. Preservation resulting primarily from binding strength of the coral framework against agitation Top of mound bound by coral framework.

Conclusions

There are considerable differences between the Vaureal River reef and the Salmon River mound. Both buildups developed in the regressive shallow subtidal epeiric Anticosti Basin during Upper Ordovician times. The Salmon River mound development was initiated on an irregular bedding surface and grew from a crudely bedded mudstone and packstone sequence into an upper portion exhibiting distinctive hemispheroidal mudstone growth forms. Mound growth began upon the irregular, lithified substrate of the Platform facies. The highest elevations of the Platform facies irregular upper bedding surface provided protection for organisms from burial by flanking sediments. Variation in coral species occurs throughout the mound, possibly from a response to increased agitation and shallowing upward conditions. Paleofavosites sp. and Catenipora sp. in the lower portion of the mound were succeeded by Paleophyllum sp. and Catenipora sp. in the upper portion.

The mound was overwhelmed by an influx of crinoidal grainstone as a result of shallowing conditions and increased agitation. Subsequent intertidal sedimentation conditions continued into the overlying Becscie Formation. Lack of mound erosion, maintenance of fissures, boring in calcareous algae, development of intraclasts, rarity of compaction features, as well as the presence of early cemented micrite and initial non-luminescing marine cements suggests that early marine cementation occurred throughout the mound.

The Vaureal River reef is composed of a rigid Paleophyllum sp. and Paleofavosites sp. coral framework. Subsequently, crinoid and Solenoporaceae wackestone was deposited onto the reef as reef rubble. Growth of the reef is interpreted to have occurred under shallow subtidal conditions. The Vaureal River reef is a true "ecological" reef in the sense of Lowenstam (1950).

The source of lime muds incorporated into the buildups is not known but appears to be from the destruction of coralline algae, abrasion of skeletal grains, micritization, or inorganic precipitation. Bottom transport of sediments onto the mound from nearby or distant sources is not likely if they stood higher than their surroundings. A sufficient volume of encrusting algae, treptosoma bryozoa and corals greatly assisted in stabilizing the buildups. The Salmon River mound exhibits the micritic bafflestone core and capping grainstone of Wilson's (1975) ideal carbonate mound facies.

Economic Significance

Initial fabric selective porosity throughout the Salmon and Vaureal River buildups was abundant, save within the mudstones and wackestones. Early cementation and infilling of porosity by both carbonate mud and mainly marine cements, however, preceeded any hydrocarbons into the buildups.

The units immediately overlying the buildups are too porous and coarse-grained to act as good impermeable horizons. Predicting the location of similar buildups within

the subsurface is hampered by ignorance of their lateral distribution. Buildups within the same stratigraphic horizon are distributed across the entire island, with notable examples exposed at Point Laframboise and East Point (Bolton, 1971). Those exposed, however are too small to be significant reservoirs. Regional paleo-environmental evidence suggests that larger buildups would be located further basinward. Surficial expressions of buildups within the subsurface are not immediately obvious.

If diagenesis and cementation conditions similar to those studied here occur in adjacent Ordovician strata, then most of the porosity in prospective reservoir rocks has largely been filled with sediment and early submarine cements. In the rocks studied, there is little or no apparent evidence of subaerial exposure and it has had little influence on creating porosity.

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PLATES

Plate 1

Salmon River Mound, North Shore

- A. Panoramic View of the northeast reef, north shore of the Salmon River.

Member 5, Ellis Bay Formation

- B. Thin, interbedded mudstone, shale and grainstone beneath the mound on the north shore of the Salmon River. Note the small-scale ripples on many bedding surfaces.
- C. Oriented crinoid stems and complete Herbertella maria brachiopods on mudstone bedding plane. The assemblage is preserved within a ripple trough. Wave agitation must have been low to preserve these delicate fossils.

Plate 2

Member 5, Ellis Bay Formation, (con't)

- A. Pyritized worm burrow (black in relief on the grainstone bedding plane).

Platform facies, Salmon River North Shore

- B. (A) Member 6, Ellis Bay Formation (Off-Mound facies);
(B) Platform facies, Member 6, Ellis Bay Formation;
(C) Member 5, Ellis Bay Formation. The Platform facies continues laterally across the entire island and is uniform in thickness. Note the break in sedimentation (in B) two-thirds of the way up the Platform facies. Section is located immediately east of the mound.
- C. Abrupt contact marking the hiatus or break in sedimentation two-thirds of the way up the Platform facies (Plate 2b). The lower grainstone containing structureless grains, broken brachiopod shells, crinoid stems, oncolites and minor Catenipora sp. and Wetheredella silurica fragments is overlain by intraclasts, solitary corals and wackestone.
- D. Fractured oncolite partially infilled by gravitational settling of grains. The brachiopod has protected the cavity from further infilling. The complete oncolite measures 12 x 17 mm. and contains some pyrite (loc. 28).
- E. Vertical exposure of grainstone within lower portion of Platform facies. Rock contains broken brachiopod shells, crinoid stems, oncolites, few Catenipora sp, and Wetheredella silurica fragments and solitary corals. The allochems are well sorted and well rounded.

Plate 3

Platform facies, Salmon River North Shore (con't)

- A. Photograph of brachiopod, gastropod, peletal mud pack-stone containing rounded fragments and complete skeletal grains of bryozoa, rugose corals, brachiopods, trilobites gastropods and crinoid stems in a peletal mud matrix (loc 24).
- B. Photomicrograph of preferential neomorphism of a brachiopod shell (B). Compare the lower degree of neomorphism of the micrite infilling the brachiopod (on the right) to that of the shell (B). (loc.24).
- C. Geopetal formed within bored Wetheredella silurica. Photomicrograph of thin section from the Platform facies-Lower Mound facies contact. Note the low degree of micritization around the margin of the boring.(loc.38).
- D. Photomicrograph of transported Wetheredella silurica within the Platform facies (loc.28).
- E. Photomicrograph of Vermiporella sp. calcareous algae within the Platform facies (loc.29).

Lower Mound Facies, Salmon River North Shore

- F. Photomicrograph of horizontally sectioned Paleofavosites sp. Note that the mural pores are at the angles rather than centre of the walls, distinguishing it from Favosites sp. Note the degree of micritization of the septa and two stages of cement (Growth Framework Porosity). (loc.30).

Plate 4

Lower Mound facies, North Shore Salmon River

- A. Photomicrograph of Paleofavosites sp. (as above) sectioned horizontally, showing detail of porosity. Note the growth of drusy calcite cement crystals (Growth Framework Porosity). (loc.30).
- B. Photograph of horizontally bedded encrusting stromatoporoid in vertical cross-section, Northwest Reef.
- C. Photograph of irregularly shaped zone infilled with a coarser crinoid grainstone than surrounding rock. Note the irregular nature of the bedding planes. This feature is interpreted as infilling of a tension fissure in semi-lithified sediment, Northwest Reef.
- D. Photomicrograph of early cemented micrite within gastropod, as noted by irregular geopetal-cement surface. The gastropod is trapped in mud between overturned Catenipora sp.(C). The Catenipora sp. shows a high degree of recrystallization in comparison to the lime mud matrix. The microfossil (U) attached to the Catenipora sp. (top centre of photo) is of unknown affinity (Flower, 1961) (loc.44)
- E. Sponges (S) resting directly on top of the Platform facies. The sponges are large, spherical objects with a distinct exterior morphology. Note the bedded nature of the Lower Mound facies immediately above the sponges. (loc.42).
- F. Photograph of sponge interior morphology, infilled with calcareous yellow mud and several bryozoa. The light zones form a radiating pattern of diverging paths from the centre of the sponge (left) to the exterior (right of photo) (loc.42).

Plate 5

Lower Mound facies, Salmon River North Shore (con't)

- A. Photomicrograph of monaxon sponge spicules found within the darker zones of the sponge (plate 4F). The largest observed spicule measured $1500\mu \times 50\mu$ (loc.42).
- B. Cathodo-luminescence effect of cements (C) within Paleophyllum sp. corallite. Note the presence of a bladed crystal non-luminescing early stage (black) coated with a brightly luminescing second stage. The stages are repeated and finally coated with a dull luminescing non-banded stage (loc.40).

Upper Mound facies, Salmon River South Shore

- C. Photomicrograph of Ecclimadictyon sp. stromatoporoid found in growth position at the mound summit (loc.4).
- D. Photomicrograph of Wetheredella silurica (W) overgrowth on horizontally encrusting stromatoporoid (S) near the top of the mound (loc.8).
- E. Laminated carbonate mud showing an arching shape, indicating algal encrustation during sedimentation (loc.11).
- F. Photomicrograph of laminar encrusting stromatoporoid showing parallel banding, and high degree of recrystallization (loc.8).

Plate 6

Upper Mound facies, Salmon River South Shore (con't)

- A. Photograph of a portion of the Upper Mound facies, south shore of Salmon River.
- B. Photograph of the Blanket facies (B) overlying the top of a hemispheroidal mound (M), south shore, Salmon River.

Crinoid Blanket facies, South Shore, Salmon River

- C. Photograph of Paleophyllum sp. (P) corals at the top of a bed within the Crinoid Blanket facies. Note that the Paleophyllum sp. are both upright and overturned.
- D. Photomicrograph of Protroscitholithus sp., a Heliolitid found locally within the Crinoid Blanket facies, but primarily within the Upper and Lower Mound facies.
- E. Photomicrograph of a portion of an overturned rugose coral resting in calcareous mud. The inter-tabular areas are infilled with calcareous mud plus clear sparry cement (Growth Framework Porosity). The epitheca (E) has been considerably abraded. Some micritization of the septa has occurred (loc.3).
- F. Photomicrograph of Cricoconarid sp., a Tentaculites from the Upper Mound facies-Crinoid Blanket facies contact (loc.9).

Plate 7

Crinoid Blanket facies, Salmon River South Shore (con't)

- A. Photomicrograph of grainstone containing micritized crinoid stems, bryozoa (B), brachiopods and intraclasts in a sparry calcite cement (loc.2).
- B. Photomicrograph of Rhabdoporella sp., a calcareous Dasyclidian algae found throughout the Crinoid Blanket facies (loc.16).
- C. Photomicrograph of Rhabdoporella sp. lateral cross-section from above locality (loc.16).
- D. Photomicrograph of packstone containing crinoid stems, bryozoa, brachiopods, Solenopora spongioides, and gastropods in a spar plus micrite matrix. Note the moldic porosity within brachiopod shell, central portion of photo (loc.16).
- E. Photomicrograph of grainstone containing rounded crinoid columnals with syntaxial overgrowth of blocky spar cement (loc.16).
- F. Cathodo-luminescence of adjacent (plate 7E) thin section illustrating five stages of cementation. The first cement is black and discontinuous, followed by a thin bright yellow-luminescing band. The first two stages are again repeated. The final cement is dull luminescing (loc. 16).

Plate 8

Crinoid Blanket facies, Salmon River South Shore (con't)

- A. Photomicrograph of a rounded crinoid columnal (gray portion in centre of photo) surrounded by sparry calcite cement (loc.16).
- B. Cathodo-luminescence photomicrograph of same portion of adjacent (plate 8A) thin section. Note the discontinuous early black, followed by thin, bright yellow-luminescing band. The first two stages are again repeated. The final cement (central white portion) is non-banded and dull luminescing. Early cements do not line the entire pore space (loc.16).

Off-Reef facies, Member 6, Ellis Bay Formation

- C. Photograph of section west of reef on south shore of Salmon River illustrating typical off-reef sequence.
- D. Photomicrograph of well sorted and rounded grainstone composed of structureless brachiopod shells and bryozoa with microspar infilling interparticle porosity. Shelter porosity has developed beneath the large brachiopod shell in lower right corner of photo. Sample taken 15 cm. above the base of measured section (fig.3). The grains are oriented with long axes parallel to the bedding plane.
- E. Intraformational conglomerate representative of examples stratigraphically above the Salmon River mound. Conglomerate clasts are flat and tabular and contain abundant ostracod and brachiopod fragments.
- F. Photograph of well preserved bryozoa, crinoid, brachiopod wackestone marginal to the Lower Mound facies. Lack of rounding, a mud matrix and good preservation indicates little transport (loc.26).

Plate 9

Vaureal River Reef

- A. Photograph of Vaureal River Reef locality, Member 4, Ellis Bay Formation. Location of man denotes extent of continuous reef exposure. The view is to the north. Note the lack of vertical expression of the reef.
- B. Paleophyllum and Paleofavosites Mudstone and Wackestone (reef flat) facies. Note columnar stromatoporoid (S) and Paleofavosites sp. (P) coral, as well as abundance of crinoid stems within blue calcareous and terrigenous mud matrix.
- C. In situ Paleophyllum and Paleofavosites (reef mound) facies. Prograding neomorphism within Catenipora sp. (C) coral (loc.51).
- D. Clay-rich Carbonate Wackestone Reef Depressions. Wackestone containing crinoid stems (C), trilobites (TR), bryozoa (B), tentaculites (TE), and brachiopods in a partly neomorphosed lime mud matrix (loc.50).
- E. Coral-Algal Rubble Facies. Contains ellipsoidal shaped Solenopora spongioides, crinoid plates, Protroscitholithus sp., and brachiopod fragments in a gray calcareous and terrigenous mud matrix (loc.51).
- F. Coral-Algal Rubble facies. Photomicrograph of Solenopora spongioides showing excellent preservation of detail (loc. 57).

APPENDIXInsoluble Residue Analysis

Sample Locality	Percent Insoluble Residue (by wt.)
2	2.0
4	8.8
5	8.8
8	3.5
11	6.1
13	3.7
14	3.0
16	5.6
17	10.5
22	6.4
26	14.9
28	0.8
29	35.8
31	5.0
32	8.7
33	13.8
35	12.0
36	11.8
38	14.7
39	5.1
40	5.9
43	1.4
59	11.9

All samples were subjected to two consecutive 24 hour periods of digestion in 300 cc. of 3.0% HCl. The samples were then rinsed in distilled water, air dried and reweighed within the beakers. The weight of beakers was noted before and after the dissolution process in order to reduce the inaccuracy of weighting.

Insoluble residue samples at localities 2, 17, 25, and 36 were analyzed by x-ray diffraction in order to determine the mineral composition. The oriented slide air dried method of mounting the grains was used in order to facilitate clay mineral identification. A Siemens Kristalloflex 2 using CuK α radiation, 30Kv and 20mA, issuing 4×10^4 counts per minute/f.s. was used. 2 θ was measured between

2° and 30° at a rate of 2°/min. and the d-spacings for clay minerals were interpreted using Brown (1961).

Under the binocular microscope, the insoluble residues were found to fall in the clay to fine-silt size ranges.

Crinoid Blanket Facies, Salmon River Mound

Sample Locality	1	1	2	3	5	15	16	16
Crinoid Columnal Plates	-	11	20	1	-	15	25	30
Bryozoa	1	10	15	2	1	10	2	5
Brachiopods	1	10	1	-	3	1	2	2
Gastropods	-	-	-	-	-	-	1	-
<u>Wetheredella sil.</u>	10	-	-	20	1	-	-	-
<u>Solenopora spong.</u>	-	-	-	-	-	1	1	1
Solitary Coral	1	-	-	1	-	1	-	-
<u>Paleofavosites sp.</u>	-	-	-	-	-	-	-	-
<u>Paleophyllum sp.</u>	-	-	-	-	10	1	-	-
<u>Catenipora sp.</u>	5	1	-	-	-	-	-	-
<u>Protroscitholithus</u>	-	-	-	-	-	-	-	-
Trilobites	-	-	-	5	-	3	-	-
<u>Ecclimadictyon sp.</u>	-	-	-	-	-	-	-	-
Micrite Matrix	76	74	10	69	75	46	13	22
Porosity:								
Interparticle	37.5	66.6	100	100	100	100	90	92.6
Intraparticle	-	-	-	-	-	-	-	-
Moldic	-	-	-	-	-	-	1.5	2
Shelter	6.25	33.3	-	-	-	-	1.5	7.4
Rounding	H	-	L	L	L	M	H	L
Sorting	P	P	P	P	P	P	P	P

All data derived from point counting of thin sections, using micrometers and cross-hairs on Nikon projector microscope. Point counting was deemed unfeasable because of the nature, size and distribution of skeletal grains and matrix.

Upper Mound facies, Salmon River Mound

Sample Locality	2	4	6	7	9	9	9	8	11	12	20	22	23
Crinoid Columnal Plates	5	-	-	1	1	-	2	1	1	20	-	20	-
Bryozoa	15	1	5	2	30	2	1	1	15	20	-	1	-
Brachiopods	10	1	1	-	1	-	5	2	1	-	-	10	2
Gastropods	-	1	-	-	-	-	-	-	-	-	-	-	-
<u>Wetheredella sil.</u>	-	35	10	15	35	2	2	15	1	1	-	1	15
<u>Solenopora spong.</u>	-	-	-	-	-	-	-	-	-	-	-	-	-
Solitary Corals	-	-	-	1	1	-	-	-	20	-	-	-	-
<u>Paleofavosites s.</u>	-	-	-	-	-	-	-	-	-	-	-	-	-
<u>Paleophyllum sp.</u>	-	-	-	-	-	-	-	-	-	-	95	-	-
<u>Catenipora sp.</u>	-	-	2	-	25	-	15	-	-	-	-	-	-
<u>Protroscitholith</u>	-	-	-	-	-	-	-	-	-	-	-	-	80
Trilobites	-	-	-	-	-	2	2	-	-	10	-	-	-
<u>Ecclimadictyon sp.</u>	-	20	-	-	-	-	-	-	-	-	-	-	-
Micrite Matrix	10	37	73	73	4	84	63	73	58	20	2	6	3
Porosity:													
Interparticle	100	100	62.	90	45	71	100	40	66	100	20	100	75
Intraparticle	-	-	-	-	45	-	-	-	-	-	80	-	-
Moldic	-	-	-	-	-	-	-	-	-	-	-	-	-
Shelter	-	-	38	10	10	29	-	60	34	-	-	-	25
Rounding	L	L	L	L	L	L	L	-	L	L	-	H	L
Sorting	L	-	L	L	L	-	-	-	-	M	-	H	-

Lower Mound facies, Salmon River Mound

Sample Locality	26	30	30	39	44
Crinoid Columnal Plates	10	--	--	-	-
Bryozoa	30	-	-	5	1
Brachiopods	2	-	-	.1	1
Gastropods	-	-	-	-	1
<u>Wetheredella sil.</u>	-	-	-	3	1
<u>Solenopora spong.</u>	-	-	-	-	25
Solitary Coral	-	-	-	-	-
<u>Paleofavosites</u> sp.	-	100	100	-	-
<u>Paleophyllum</u> sp.	-	-	-	-	-
<u>Catenipora</u> sp.	-	-	-	-	-
<u>Protroscitholithus</u>	-	-	-	1	10
Trilobites	-	-	-	5	-
<u>Ecclimadictyon</u> sp.	-	-	-	-	-
Micrite Matrix	5	3	3	75	46
Porosity:					
Interparticle	75	100	100	10	90
Intraparticle	-	-	-	-	-
Moldic	25	-	-	-	10
Shelter	-	-	-	-	-
Rounding	L	-	-	L	L
Sorting	L	-	-	L	L

Mound Platform facies, Salmon River Mound

Sample Locality	25	28	29	38
Crinoid Columnal Plates	-	5	5	-
Bryozoa	3	3	-	1
Brachiopods	1	5	5	1
Gastropods	-	-	-	-
<u>Wetheredella sil.</u>	1	1	-	10
<u>Solenopora spong.</u>	-	-	-	-
Solitary Coral	-	-	-	-
<u>Paleofavosites sp.</u>	-	-	-	-
<u>Paleophyllum sp.</u>	-	-	-	-
<u>Catenipora sp.</u>	-	1	1	15
<u>Protroscitholithus</u>	-	-	-	-
Trilobites	1	-	-	1
<u>Ecclimadictyon sp.</u>	-	-	-	-
Micrite Matrix	93	3	84	77
Porosity:				
Interparticle	84	86	100	82
Intraparticle	8	14	-	12
Moldic	-	-	-	-
Shelter	8	-	-	6
Rounding	H	H	H	-
Sorting	H	H	H	-

Examples of Mud Mounds Described in the Literature

The following examples of mud mounds are interpreted to occur within shallow submarine conditions; Hadding, (1950); Schwarzacher (1961); Lees (1961); Pitcher (1964); Rigby (1966); Ross et al (1971); Roberts (1968); Walker and Ferrigno (1971); Bathurst (1971); Kapp (1971); Jamieson (1971); and Turmel and Swanson (1976).

Deep basinal marine mud mounds have been described by Thompson (1976); and Mathur (1976).

Development of mud mounds on the foreslope environment of carbonate platforms has recieved considerable attention. Cotter (1965) suggested that Waulsortian-type mounds of the Mississippian of central Montana were preserved by early lithification of hardgrounds. In the Upper Pennsylvanian of the North American mid-Continent, phylloid algae supplied sediment and stabilized mound development on the foreslope (Heckel and Cocke, 1969). According to Wilson, (1974), most mud mounds developed on the foreslope derive their sediment from shallower source areas. Holocene mounds on the foreslope of the Florida Straits (in deep water) (Neumann, 1972), grew by traction transport of sediments, submarine lithification of hardgrounds, bioerosion, attachment and production of sediments by organisms.

Development of mud mounds in present day environments within shallow-marine waters has similarly recieved much attention. Development of mud mounds on the Tavernier and Rodruiguez Banks, Florida, was initiated by Thalassia grass acting as baffles, followed by colonization and stabili-

zation by black and red mangrove (Bathurst, 1971; Turmel and Swanson, 1976). Production of calcareous algae upon the surface of Thalassia grass as a source of sediment, combined with shallow, protected waters, accounts for mound accumulation.

102

WEST

LOWER MOUND FACIES

PLATFORM FACIES

30

5X VERTICAL EXAGGEI

T

EAST

13 of

DATUM PLANE

10
eters)

NO VERTICAL EXAGGERATION

CAL EXAGGERATION

NO

ST

TUM PLANE

NORTHWEST REEF A

LOWER M

PLATFO

MEM
ELL
FORM

WEST

LOWER MOUND FACIES

PLATFORM FACIES

MEMBER 5,
ELLIS BAY
FORMATION

0

10

20

30

5X VERTICAL EXAGGERATION

NO VERTICAL EXAGGERATION

EAST

NORTHEAST REEF B

AST

DATUM PLANE

EAST

CRINOID BLANKET FACIES

UPPER MOUND FACIES

5X VER

12 of

$\frac{100^\circ}{85^\circ S.}$

5X VERTICAL EXAGGERATION

NO VERTICAL EXAGGERATION

WEST

S
VE

WEST

SOUTH REEF

C

SALMON RIVER MOUND VERTICAL CROSS-SECTIONS

A) Northwest Reef

B) Northeast Reef

C) South Reef

FIGURE A

F- Paleofavosites

P- Paleophyllum

C- Catenipora

•• Grainstone

Mudstone and Packstone

••••• Oncolite Grainstone and Packstone

⑮ SAMPLE LOCALITY

PALEOPHYLLUM
(55) AND
PALEOFAVOSIT

18

14

107

PALEOFAVOSITES

18 MUDSTONE

(54)
BRECCIA

MOUND,
PRIMARILY

CE
PAL

24

MUDSTONE
WITH A FEW
PALEOFAVOSITES

57

RUBBLE
ABUNDANT
DAL SOLENOPORA

10%

58

MUDSTONE
MOUND
WITH A FEW
PALEOFAVOSITES

PALEOFAVOSITES
MOUND 56

13 of

PALEOFAVOSITES
AND
PALEOPHYLLUM

PACKSTONE

PALEOPHYLLUM
MOUND

PALEOPHYLLUM
WITH PACKSTONE
MATRIX

187

MUDSTONE

C
PAI

54
BRECCIA

MOUND,
PRIMARILY
PALEOPHYLLUM

PALEOFAVOSITES

53 DEPRESSION

52
PALEOFAVOSITES

PALEOFAVOSITES
AND
PALEOPHYLLUM

107

PALEOFAVOSITES

TONE

CENTRE OF
PALEOPHYLLUM
MOUND

MOUND,
PRIMARILY
PALEOPHYLLUM

PALEOPHYLLUM
MOUND

25 PALEO-
PHYLLUM

AREA OF
PRIMARILY
PALEOFAVOSITES

~~PALEOFAVORITES~~

53 DEPRESSION

PALEOFAVORITES

PALEOFAVOSITES AND PALEOPHYLLUM

PALEOFAVOSITES

DEPRESSION

AREA OF EXTENSIVE
CORAL GROWTH

PALEOFAVOSITES
MOUND

REEF RUBBLE

WITH ABUNDANT
ELLIPSOIDAL
SOLENOPORA

PALEOPHYLLUM

10

10

49