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PALEOECOLOGY AND SEDIMENTOLOGY OF LATE SILURIAN
BIOGENIC STRUCTURES IN THE DOURO AND DEVON ISLAND
FORMATIONS ON WESTERN DEVON AND SOUTHWESTERN
ELLESMERE ISLANDS, ARCTIC CANADA

by

Natalie L. Sweet

A thesis submitted to the School of Graduate Studies in partial
fulfillment of the requirements for the degree of
Master of Science in Earth Sciences

Ottawa-Carleton Geoscience Centre

and

Department of Geology

University of Ottawa

Ottawa, Canada, 1995

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'The shore is an ancient world, for as long as there has been an earth and sea there has been a place of the meeting of the land and water... The intricate fabric of life by which one creature is linked with another, and each with its surroundings... has appeared, evolved and sometimes died out. The elusiveness of meaning haunts us, sends us again and again into the natural world where the key to the riddle is hidden. It sends us back to the edge of the sea, where the drama of life played its first scene on Earth...'

revised from Rachel Carson (1907-1964)

ABSTRACT

Carbonate buildups of late-Ludlow-Pridoli age occur within an extensive Silurian reef 'belt' in the Canadian Arctic Islands. Two phases of mound development were documented. The buildups include mudmounds in the uppermost Douro Formation on western Devon Island, and skeletal mounds in the Devon Island Formation on southwestern Ellesmere, North Kent, and Seal islands and Colin Archer Peninsula on Devon Island.

The mudmounds average 50m in diameter and 15m in height, and are composed predominantly of sparsely fossiliferous lime mudstone containing sponge spicules and micrite fabrics of probable microbial origin. Solitary and colonial rugose corals, tabulate corals, brachiopods, crinoidal debris, calcareous algae, and trilobites characterize proximal wackestones of the flanking facies; stromatoporoids and lithistid sponges occur rarely. Diagenetic features include recrystallized micrite, shallow marine fibrous calcite, deeper marine blocky calcite, and deep burial coarse ferroan dolomite cements.

In a few small (~3m diameter x 0.5m high) mudmounds, abundant, well-preserved lithistid sponges and distinct microbial fabrics represent an intimate association of encrusting, binding, baffling and sediment-producing constructors. Relict spicular and microbial fabrics in the

more diagenetically altered buildups suggest that this microbe-sponge association was widely responsible for construction of the larger mudmounds and the substantial dolomitized mudstone core facies of the skeletal mounds.

Coral skeletal mounds, averaging 100m in diameter and 35m in height, have stromatoid-rich mudstone cores and grade upwards from mudstone into fasciculate coral-floatstone and crinoidal wackestone. No exposed flanking facies were observed.

Coral/stromatoporoid skeletal mounds averaging 500m in diameter and 100m in height show various facies successions. A large skeletal mound at Hell Gate indicates overall upward shallowing, with a basal stromatoid-rich mudstone core facies, overlain in succession by flanking crinoidal/coral, coral/stromatoporoid and capping crinoidal facies. Lamellar colonial rugosans, tabulate corals (most commonly favositids and heliolitids), tabular stromatoporoids, solitary rugosans, calcareous algae, and brachiopods characterize the wackestones of the flanking facies. In contrast, in a skeletal mound core on North Kent Island, a floatstone facies characterized by fasciculate rugose and tabulate corals, and large tabular stromatoporoids, is overlain by a mudstone core facies. Although the skeletal mounds have been completely altered to a fine-grained dolomite, relict fabrics are

preserved and suggest a diagenetic sequence similar to that for the mudmounds.

Extensive stromatactoid structures in the more diagenetically altered mudmounds and skeletal mound cores vary from sparse, isolated forms, to classic 'stromatactis', to laterally continuous forms. The primary alternation of spicular sponge networks and dense microbial encrusting layers was a possible control on fluid migration, selective dissolution to form cavities, and eventual cement precipitation, in generating the stromatactoid structures.

The mudmounds grew during a period of substantial platform drowning, apparently related to tectonic movement on the Boothia Uplift. This resulted in an episode of sediment starvation following Douro ramp sedimentation, apparent expansion of the oxygen-minimum zone, extensive hardground generation in dysaerobic areas, termination of mound growth, and deposition of clean, crinoidal capping facies on better-oxygenated tops of some mudmounds. Basinal shales of the Devon Island Formation subsequently widely overlapped the sediments beneath this hiatus. Farther north, growth of the skeletal mounds began on favourable highs of the drowned carbonate ramp, and continued as basinal siliciclastic muds accumulated. The event represented by the hardground and associated physical features can be correlated with related features in buildups farther south where the

Douro ramp instead evolved into a carbonate shelf, represented by the Barlow Inlet Formation.

RÉSUMÉ

Des accumulations carbonatées d'âge Ludlow-Pridoli tardif se retrouvent à l'intérieur d'une province de récifs de Silurienne dans les îles arctiques canadiennes. Les monticules furent développés en deux phases. Les accumulations sont composées de *mudmounds* au sommet de la Formation de Dcuro, et de monticules squelettiques dans la Formation de Devon, au sud-ouest de l'île d'Ellesmere, sur les îles North Kent et Seal, ainsi que sur la péninsule Colin Archer.

La taille moyenne des *mudmounds* est de 50m de diamètre sur 15m de haut. Ceux-ci sont principalement composés de *mudstones* limoneux, fossilifères par endroits, contenant des spicules et ayant une fabrique micritique d'origine microbienne. Tétracoralliaires solitaires et coloniaux, tabulés, brachiopodes, débris de crinoïdes et trilobites caractérisent les faciès latéraux; stromatoporoïdes et éponges lithistidés sont rarement présents.

Des monticules coralliens squelettiques, mesurant en moyenne 100m de diamètre sur 35m de haut, ayant des noyaux de *mudstone* riches en stromatoporoïdes, se changeant graduellement en coraux branchus et wackestones crinoïdiens. Aucun affleurement des faciès latéraux ne fut observé. Des successions variées de faciès sont visibles sur des

monticules squelettiques de corailéstromatoporoïdes mesurant en moyenne 500m de diamètre sur 100m de haut. À Hell Gate, un monticule squelettique de grande taille indique une tendance de 'shallowing' vers le haut, ayant à sa base un faciès de mudstone riche en stromatoporoïdes, recouvert par une succession de faciès de crinoïdes-coraux; coraux-stromatoporoïdes et mort terrain composé de crinoïdes. Tétracoralliaires rugueux coloniaux, coraux tabulés (majoriairement favositidés et héliolitidés), stromatoporoïdes tabulés, tétracoralliaires solitaires, algues calcaies, et brachiopodes caractérisent les faciès latéraux. Par contre, dans le noyau d'un monticule squelettique sur l'île de North Kent, un faciès de mudstone caractérisé par des coraux rugueux branchus et tabulés, et par de gros stromatoporoïdes tabulés, est recouvert d'un faciès ayant un noyau de mudstone.

Quelques petits mudmounds (environ 3m de diamètre sur 50cm de haut) comptent de nombreuses éponges lithistidés bien préservées et des fabriques microbiennes distinctes, lesquelles représentent une association intime de constructeurs liants et producteurs de sédiments. Sur les monticules les plus diagénétiquement altérés, des reliques de fabriques spiculaires et microbiennes suggèrent que cette association microbe-éponge fût largement responsable de la construction des plus

gros monticules, et pour les faciès à noyaux de mudstones dolomités des monticules squelettiques.

Dans les mudmounds les plus diagénetiquement altérés et dans les noyaux de monticules squelettiques, l'on retrouve d'importantes structures de stromatactoïdes, variant de formes éparses et isolées, à des formes de stromatactis classique, à des formes latéralement continues. Lors de la formation de stromatactoïdes, l'altération primaire des réseaux d'éponges spiculaires et des couches dense de microbes encrustants a possiblement contrôlé le mouvement de fluides, la dissolution sélective formant des cavités, et éventuellement la précipitation de ciment.

Les monticules se sont développés au cours d'une période de submergence substantiel de la plateforme, en apparence reliée au soulèvement tectonique de Boothia. Un épisode de faible remplissage sédimentaire résultal suivant la sédimentation du talus de Douro en l'expansion de la zone d'oxygène minimum, la génération d'un hardground important dans les zones dysaérobiques, la fin de la croissance de monticules, et la déposition d'un faciès de couverture à crinoïdes aux sommets les mieux oxygénés de certains mudmounds. Par la suite, les shales du bassin sédimentaires de la formation de l'île de

Devon ont chevauché les sédiments situés sous cette lacune stratigraphique. Plus au nord, la croissance de monticules squelettiques débuta sur les régions favorablement élevées du talus carbonaté submergé, et s'est poursuivie pendant l'accumulation de boues siliciclastiques dans le bassin sédimentaire. Cet événement, représenté par le hardground et les traits physiques y étant associés, peut être corrélé avec des caractéristiques similaires trouvées dans des accumulations sédimentaires plus au sud, là où le talus de la formation de Douro évolua plutôt en une plateforme ceinturée représentée par la formation du Barlow Inlet.

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1.0 INTRODUCTION

1.1 GENERAL STATEMENT

Silurian carbonate buildups are known to occur widely in the Canadian Arctic Islands. Detailed work has been done on Silurian buildups of carbonate ramp and platform margin settings, near the Boothia Uplift (Jones *et al.*, 1979; Narbonne, 1981; Narbonne and Dixon, 1984; 1988; Dixon and Graf, 1992; Graf, 1988). Carbonate buildups in platform margin and basinal settings on southern Ellesmere Island and western Devon Island, however, are less well known as only reconnaissance studies have been done (Thorsteinsson and Mayr, 1987; de Freitas, 1991; de Freitas *et al.*, 1993). Other buildups in this area have been reported but remain virtually unstudied.

This project focussed on largely unstudied buildups on southwestern Ellesmere and western Devon islands (Fig. 1). These buildups formed during upward change from a carbonate ramp setting, represented by the Douro Formation into either the basinal setting of the Devon Island Formation or the platform margin setting of the Barlow Inlet Formation (Thorsteinsson and Mayr, 1987). This part of the stratigraphic sequence represents a time of significant change in paleogeographic and tectonic development during the Late Silurian.

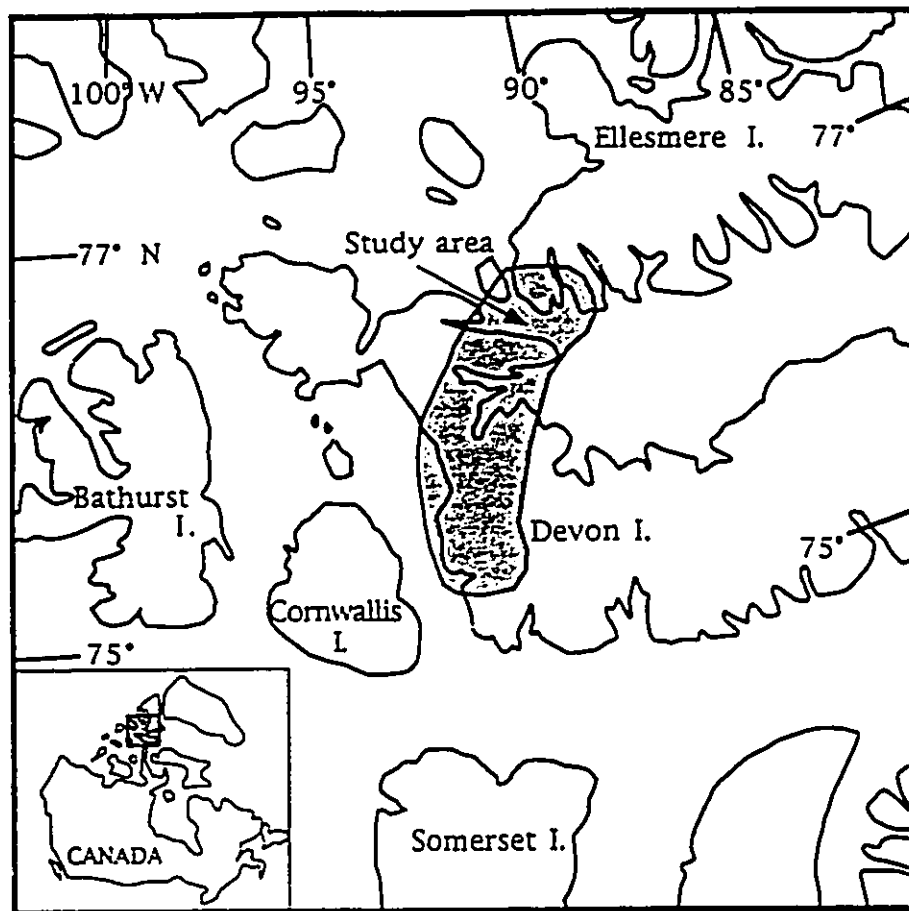


Figure 1. Location of the study area. The study area is represented in more detail on figure 3.

This project represents the first detailed study of these buildups and revealed that the buildups are more numerous than recognized during previous reconnaissance, and that several distinct types are recognized. The Arctic is now known to be an important Silurian 'reef' province and much of it is still largely unstudied. The buildups in the Arctic show significant differences from well-known Silurian 'reefs' elsewhere, making them important for comparisons and for providing more complete paleoecological information about Silurian buildups.

1.2 LOCATION AND ACCESS

The study area extends from southwestern Ellesmere Island through to western Devon Island in the Canadian Arctic Islands (Fig. 1). The area is accessible by fixed wing aircraft and by helicopter from Resolute Bay, Cornwallis Island. Access to localities on western Devon Island is more feasible by helicopter, unless all-terrain vehicles are available.

1.3 SCOPE AND OBJECTIVES

The project is a sedimentological and paleoecological study of Upper Silurian buildups near the boundary of the Douro Formation and the overlying Devon Island and Barlow Inlet formations on southwestern Ellesmere and western Devon islands. The two main objectives are:

1) to document in detail the morphology, fossil content, and lithofacies content of the buildups and the immediately surrounding rocks, and

2) to interpret the depositional environments in terms of the effects of sea-level change on paleogeography and sequence of carbonate buildup development.

1.4 METHODS

Detailed field work was carried out during two field seasons -- six weeks in 1992 and two weeks in 1993. Field work consisted of mapping the occurrence of buildups and their spatial relationships to enclosing facies, measuring stratigraphic sections, recording detailed descriptions and obtaining representative rock and fossil samples. The samples shipped back to Ottawa were slabbed, polished and stained. Forty thin sections were made from the slabs and were then analyzed petrographically.

1.5 TERMINOLOGY

Various terms have been applied to carbonate buildups in the past, making it necessary to define terms used in this study and to provide comparisons with the usages of other workers. Table 1 provides

Definitions		
This study	James and Bourque (1992)	possible equivalent terms used by other Arctic Silurian 'reef' workers
<i>Skeletal mound</i> - same as James and Bourque (1992)	<i>Skeletal mound</i> - structures built by smaller, commonly delicate and/or solitary reef building elements in tranquil settings	-reef mound (de Freitas, 1991) -reef (Brent, 1987)
<i>Mudmound</i> - buildups primarily composed of mudstone with little skeletal material in the core -does not imply inorganic origin of mud	<i>Microbial Mound</i> - structures made of stromatolites/thrombolites, calcimicrobes and carbonate mud <i>Mudmound</i> - inorganic accumulation of mud with variable amounts of fossils	-sponge reef (Narbonne, 1981) -mudmound (Graf, 1988)

Table 1. Carbonate mound terminology and definitions used in this study, and comparisons with other researchers' definitions.

comparative definitions of these terms. The term 'skeletal mound' is used here in the same sense as in James and Bourque (1992). The main difference in usage here concerns the term 'mudmound'. James and Bourque (1992) applied the term to inorganic accumulations of carbonate mud, whereas in this study the term is used in a descriptive, non-genetic sense for mounds that are composed primarily of mud-size carbonate, whether the muds can be attributed to organisms or not. Descriptive modifiers are used to classify the mudmounds further (e.g. sponge-algal mudmound). Dunham's classification is used to describe carbonate rock types.

1.6 PREVIOUS WORK

During the late 1950's and early 1960's 'Operation Franklin', a major mapping project by the Geological Survey of Canada, contributed greatly to the basic knowledge of Paleozoic stratigraphy in the Arctic Islands (Fortier *et al.*, 1963; Thorsteinsson, 1963; Kerr, 1968). The Douro and Devon Island formations were first described at that time. These strata were later mapped in detail first by Kerr (1968), and more recently by Mayr *et al.* (1994) on southern Ellesmere and North Kent islands.

Detailed lithostratigraphic and biostratigraphic work on Siluro-Devonian units in the Boothia Uplift region was presented by

Thorsteinsson and Uyeno (1980). The first comprehensive account of the regional stratigraphy of southwestern Devon Island was based on mapping by Thorsteinsson and Mayr (1987). Detailed stratigraphy of the Douro Formation was presented by Narbonne (1981; see also Narbonne and Dixon, 1982; 1984; Jones and Narbonne, 1984). Reconnaissance work by deFreitas (1991) on skeletal mounds on southwestern Ellesmere Island and Colin Archer Peninsula and detailed work by Brent (1987) on the lower part of a skeletal mound at Hell Gate, southwestern Ellesmere Island, provided some of the first information about the buildups in the study area (Fig. 3). The paleogeography and tectonic framework of the area are discussed in a variety of works since the early 1970's (Trettin, 1972; Kerr, 1977; Miall, 1986; Okulitch et al, 1986; Thorsteinsson and Uyeno, 1980; Frisch and Sandemann, 1991; de Freitas and Mayr, 1993). Trettin (1989; 1991) provided summaries of the tectonic framework of the Arctic Platform. The term Arctic Platform was first introduced by Douglas (1970) and Thorsteinsson and Tozer (1970) to refer to the Phanerozoic successions in the Arctic that have not been thrust-faulted or folded on a regional scale. deFreitas and Mayr (1993) present a detailed study of the tectonic history, sedimentology and paleogeography of the Silurian carbonate platform.

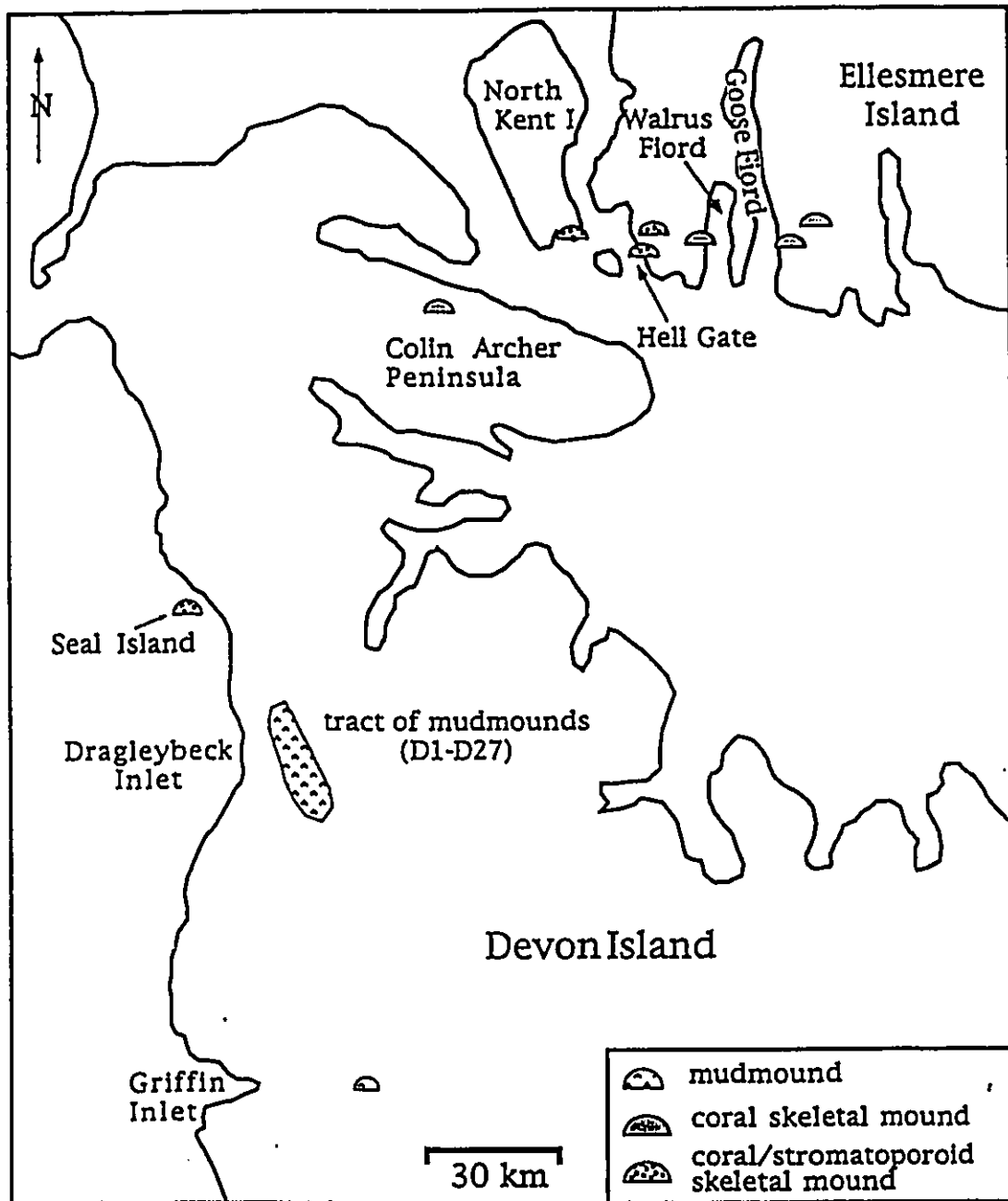


Figure 3. Distribution of carbonate buildups in the study area.

1.7 GENERAL GEOLOGY

The study area is situated within the Devon Foreland Basin which is one of five tectono-stratigraphic basins of the Arctic platform (Christie, 1972). The basin extends through western and northern Devon Island and Ellesmere Island and is confined by the eastern coastal uplift (part of the Canadian Shield), the Central Ellesmere Fold Belt to the northwest and the Boothia Uplift to the west (Fig. 4). Within this basin the Arctic platform contains a relatively undisturbed 3000m-thick succession of lower-middle Paleozoic sedimentary strata (Fig. 5). The succession is mainly of shallow marine origin although deeper water facies were deposited during a Late Silurian sea level rise (Trettin, 1991) and are present in part of the study area. The upper portion of the Silurian carbonate platform in the study area comprises shallow water carbonates of the Barlow Inlet Formation to the south (southern Devon Island) that are lateral facies equivalents of basinal calcareous shales of the Devon Island Formation to the north. The facies transition between carbonate platform and basinal deposits occurs on western Devon Island near Dragleybeck Inlet. Both of these formations conformably overlie the Douro Formation that was deposited in a carbonate ramp setting

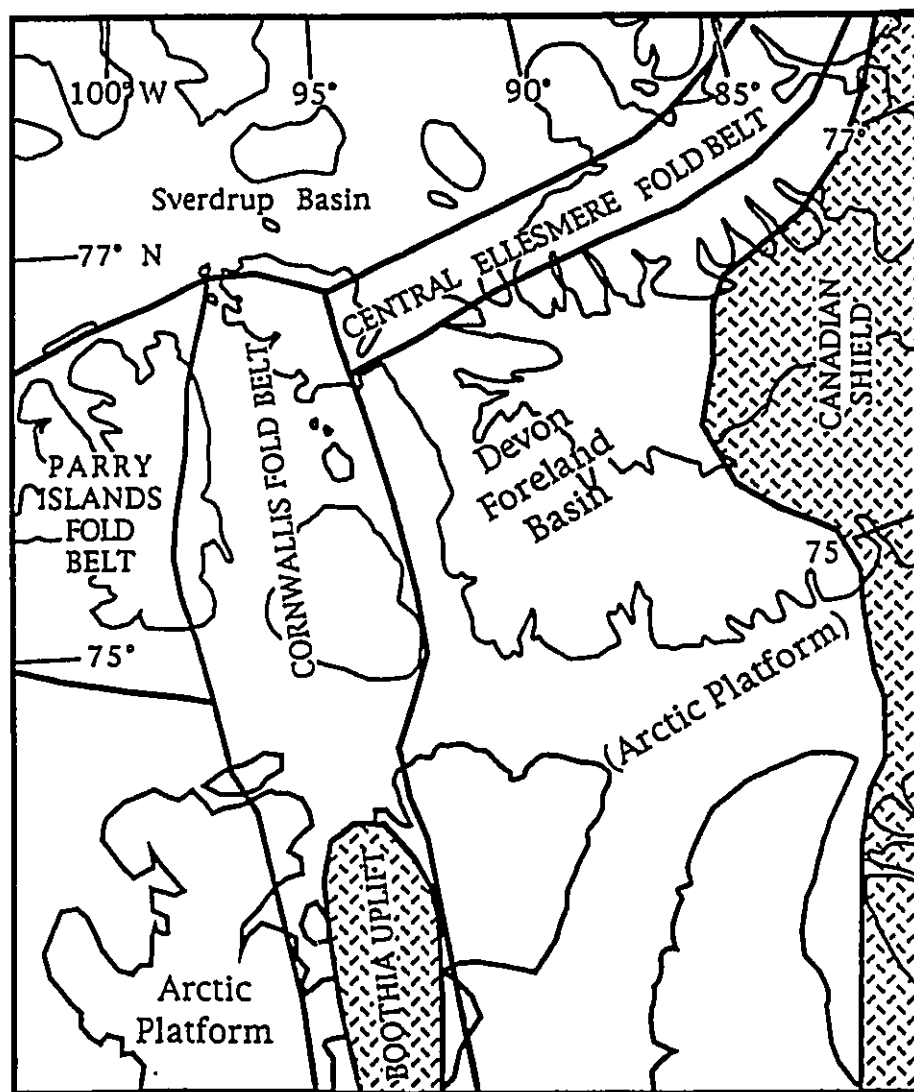


Figure 4. Tectono-stratigraphic provinces of the Canadian Arctic Islands (modified from Christie, 1972).

		southern Devon Island	western Devon Island	southern Ellesmere Island
SILURIAN	Pridoli	Barlow Inlet	Devon Island	Goose Fiord
				Devon Island
	Ludlow	Douro	Douro	Douro
		Cape Storm	Cape Storm	Cape Storm
	Wenlock			
Llandovery	Allen Bay	Allen Bay	Allen Bay	
Ordovician				

Figure 5. Silurian stratigraphy in the study area (modified from deFreitas and Mayr, 1993). The carbonate buildups studied occur in the uppermost Douro and the Devon Island formations.

(Narbonne, 1981). The Devon Foreland Basin deepened to the northwest.

Thorsteinsson (1963) described the Douro Formation as a 400m-thick sequence of argillaceous limestone with minor amounts of calcareous shale. The type section is located in the Douro Range on northwestern Devon Island. On the basis of conodont age determinations and on its stratigraphic position, the Douro Formation is of (probable) late Ludlovian age (Thorsteinsson and Uyeno, 1980) and is exposed widely on Somerset, Devon, Ellesmere, Prince of Wales, Victoria, and Cornwallis islands. The Douro Formation comprises two main lithofacies: mottled dolostone and rubbly argillaceous limestone (Narbonne, 1981). The rubbly argillaceous lithofacies is sparsely fossiliferous overall. Brachiopods, trilobites, corals, sponges and crinoidal debris occur locally and are particularly concentrated near lithistid sponge mudmounds that occur in two distinct intervals (Narbonne, 1981; Narbonne and Dixon, 1984).

The Devon Island Formation was first described by Thorsteinsson (1963) as a silty laminated shale that overlies the Douro Formation. Two broad subdivisions were later recognized, a lower, 182m-thick, medium to dark grey, graptolitic, thin-bedded siliciclastic mudstone succession, and an upper, 48m-thick, grey, argillaceous limestone

succession (Thorsteinsson and Uyeno, 1980; Thorsteinsson and Mayr, 1987).

Mayr *et al.* (1994) describe three members in the Devon Island Formation on southern Ellesmere and North Kent islands. Two of the members, corresponding to the broad subdivisions described above, are regional and mappable units, and the third is a reefal lithofacies. The lower shale member is described as recessive calcareous mudrock and lime-marl lithofacies. The overlying upper carbonate member is relatively resistant and less argillaceous than the lower shale member. The reefal member of the Devon Island Formation consists of isolated build-ups that interfinger with either or both members (Mayr *et al.*, 1994). The skeletal mounds described in this study belong to this reefal member.

The lower contact of the Devon Island Formation with the Douro Formation is abrupt but conformable on southern Ellesmere Island, but on western Devon Island, the boundary is disconformable. The presence of phosphatized hardgrounds at this disconformity indicates that this was a time of non-deposition, or that sedimentation rates were slow, during the time of platform drowning (de Freitas and Mayr, 1993). The base of the Devon Island Formation is dated to be in the late Ludlow *Pedavis latialata* (Walliser) conodont zone (Thorsteinsson and Uyeno, 1980).

The Barlow Inlet Formation is the platform carbonate facies equivalent of the Devon Island Formation, and conformably overlies the Douro Formation. This Upper Silurian-Lower Devonian carbonate succession is exposed on Devon, Cornwallis, Griffith, and Lowther islands. It is 1400m-thick on Cornwallis Island but is estimated to be only 750m-thick on Devon Island (Thorsteinsson and Mayr, 1987). The distinctive 50m-thick basal unit of calcareous and quartzose shale on Cornwallis Island is not present on Devon Island. On Devon Island the boundary between the Douro Formation and the Barlow Inlet Formation was placed at the base of a conspicuous crinoidal grainstone/rudstone (Thorsteinsson and Mayr, 1987) in a sequence transitional between the two formations. This transition contains mudmounds developed in the uppermost Douro Formation and the basal part of the Barlow Inlet Formation on southwestern Devon Island (Graf, 1988).

1.8 LOCAL STRATIGRAPHIC SETTING

The mudmounds examined in this study occur entirely within the topmost beds of the Douro Formation on western Devon Island. The formation in this area is composed of rubbly argillaceous limestone that is sparsely fossiliferous except near the mudmounds where fossil abundance and diversity are higher. The ramp carbonates of the Douro Formation in part of this area are disconformably overlain by basinal

shales of the Devon Island Formation, with the boundary defined by a major hardground. The duration of this depositional hiatus is not known. One mudmound, exposed inland from Griffin Inlet on western Devon Island, 50km SSE of the mudmound tract (Fig. 6), occurs within the uppermost Douro Formation where it is conformably overlain by platform carbonates of the Barlow Inlet Formation. A lateral facies transition between the basinal shales of the Devon Island Formation and the Barlow Inlet Formation occurs near Dragleybeck Inlet just west and south of the mudmound tract (Fig. 6).

The skeletal mounds began growth at the end of Douro Formation deposition and continued growth during deposition of the Devon Island Formation (reefal member of Mayr *et al.*, 1994). In this area ramp carbonates of the Douro Formation are abruptly but conformably overlain by siltstones and mudstones of the Devon Island Formation. The Devon Island Formation in this area consists of a lower shale member, and an upper carbonate member (Mayr *et al.*, 1994). The Hell Gate skeletal mound (HG1) extends through both members (Mayr *et al.*, 1994). The basal and lateral contacts of the other skeletal mounds in the area are not exposed and therefore their exact stratigraphic extent is uncertain.

Two main types of skeletal mounds occur in the study area: i) coral skeletal, and ii) coral/stromatoporoid skeletal. Two coral skeletal

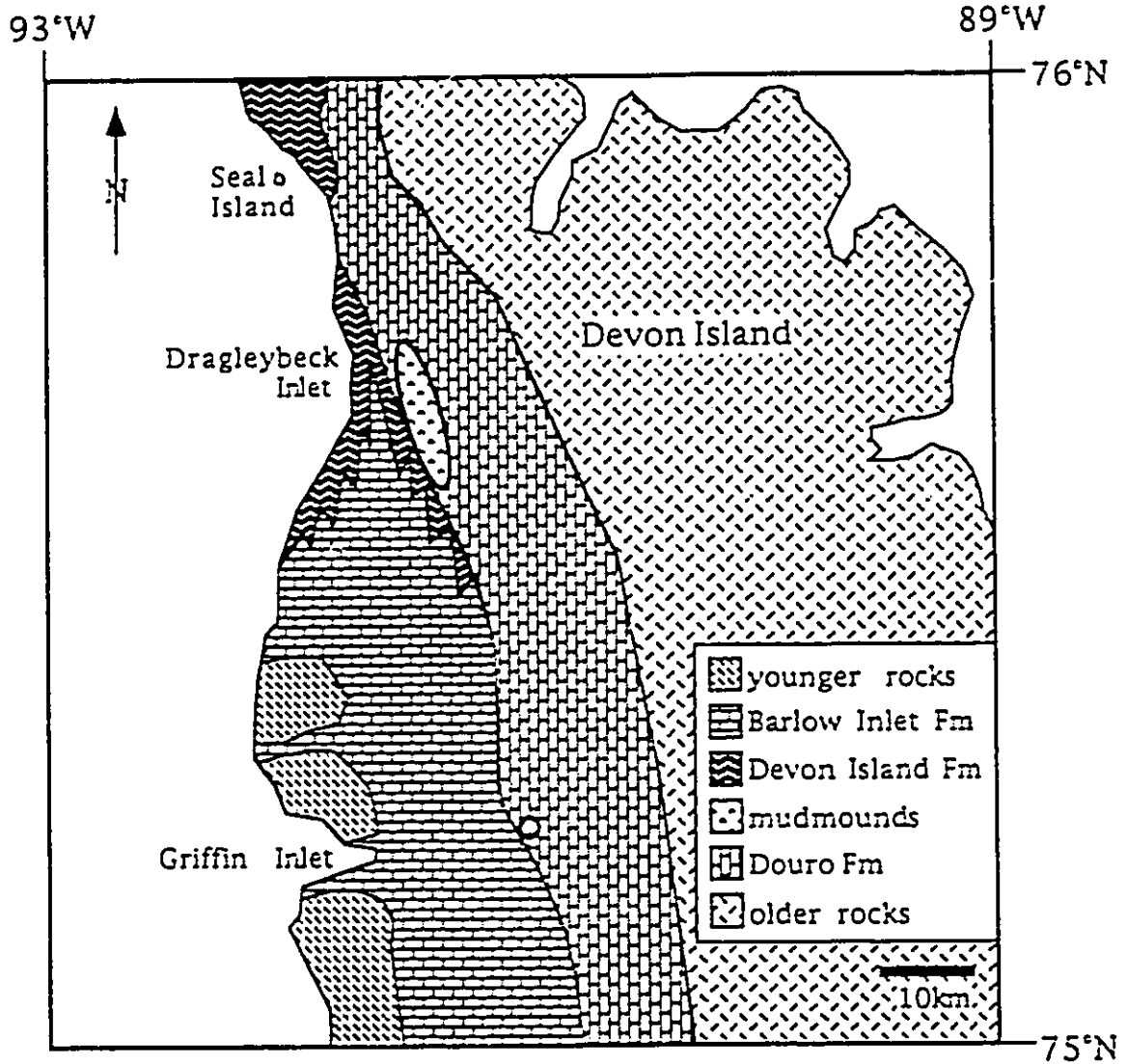


Figure 6. Location of mudmounds and generalized representation of extent and stratigraphic relationships of Upper Silurian rocks on southwestern Devon Island (after Thorsteinsson and Mayr, 1987).

mounds are exposed near Goose Fiord (GF1, GF2), one near Walrus Fiord and one on Colin Archer Peninsula (Fig. 3). A coral/stromatoporoid skeletal mound is exposed on Seal Island, another on southern North Kent Island and two near Hell Gate (HG1, HG2) on southwestern Ellesmere Island. The Goose Fiord and Hell Gate skeletal mounds were studied in detail and the others examined briefly in reconnaissance of the area.

2.0 CARBONATE BUILDUPS

2.1 MUDMOUND TRACT

A large NNW-SSE-trending tract of mudmounds is exposed on western Devon Island inland from Dragleybeck Inlet (Fig. 6). Twenty seven mudmounds have been recognized (Figs. 7A,B). Many form conspicuous, buff-coloured, resistant, topographic highs that contrast with the surrounding, generally grey-weathering, recessive terrain over shales of the Devon Island Formation (Fig. 8). Future, more extensive, field surveys would undoubtedly reveal other mudmounds in this area.

2.1.1 Morphology of mudmounds

Many of the mudmounds have only their uppermost facies exposed, so their actual height is unknown. If their present topographic relief is close to their stratigraphic height, individual mounds may range from 5-20m in height. Their diameters range from 20-200m. The larger mudmounds have discrete mound cores, flank beds and capping facies, whereas the smaller mudmounds do not have discrete flank beds but do have enclosing facies with a fauna similar to that in the flank beds of the larger mounds.



Figure 7A. Location of mudmounds (D1-16) in the northern part of the tract of mudmounds inland from Dragleybeck Inlet, western Devon Island (see also Fig. 7B). D16, marked by a star, is the 'rivermound' locality. Dashed line shows the Douro (SD) - Devon Island (SDDI) formation boundary. Scale bar = 1km. Air photo A16747-81

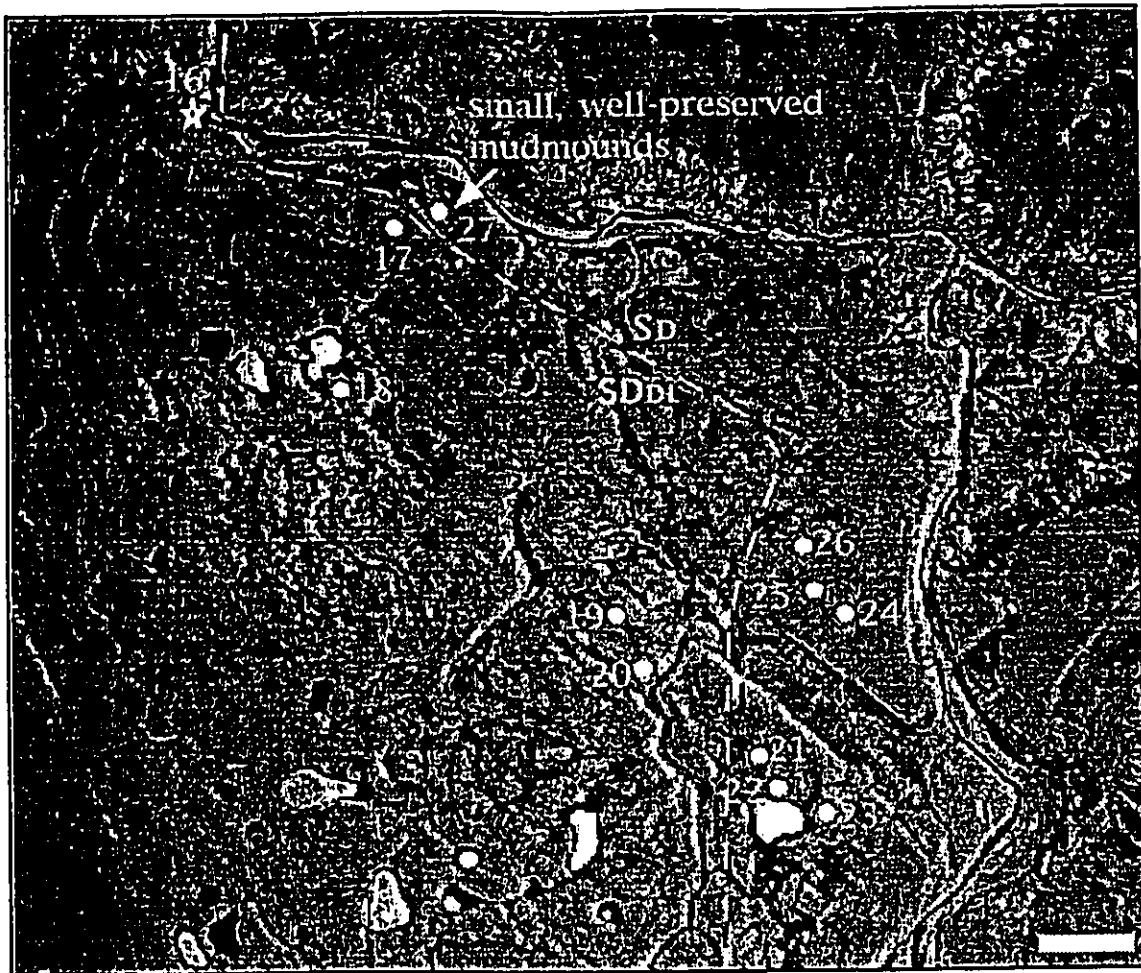


Figure 7B. Location of mudmounds (D16-D27) in the southern portion of the tract of mudmounds inland from Dragleybeck Inlet, western Devon Island (see also Fig. 7A). The dashed line marks the approximate position of the Douro (SD)- Devon Island (SDDI) formation boundary. D16, marked by the star is the 'rivermound' locality. Scale bar=1km. Air photo A 16747-83

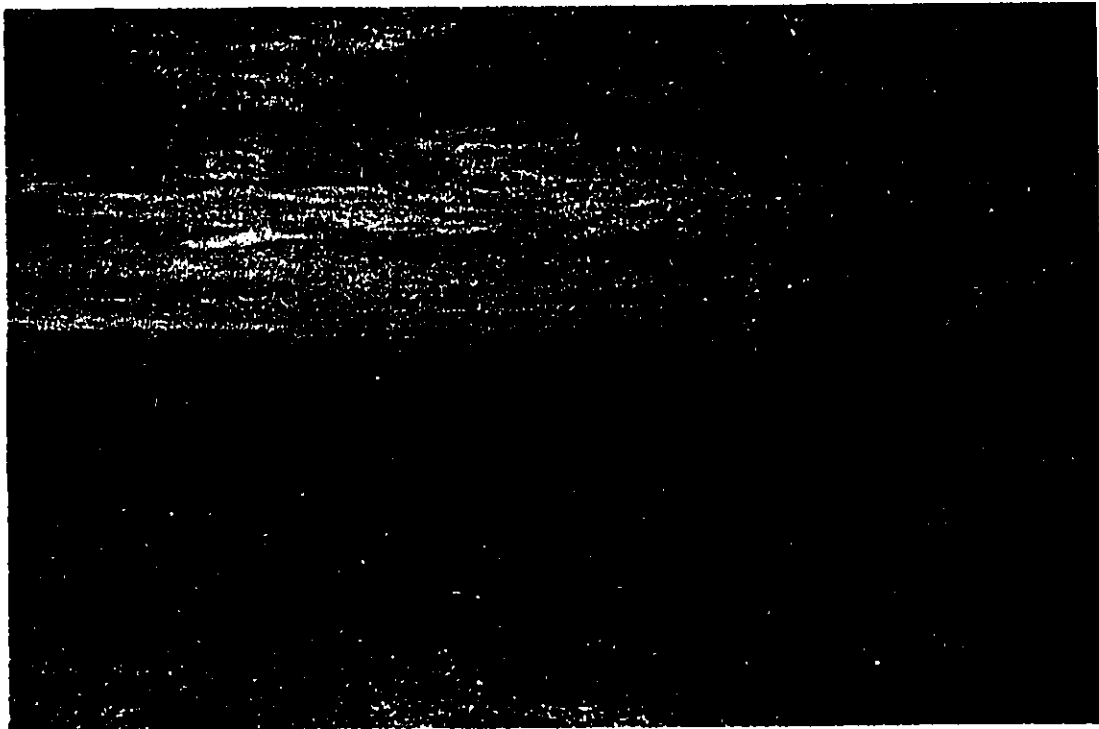


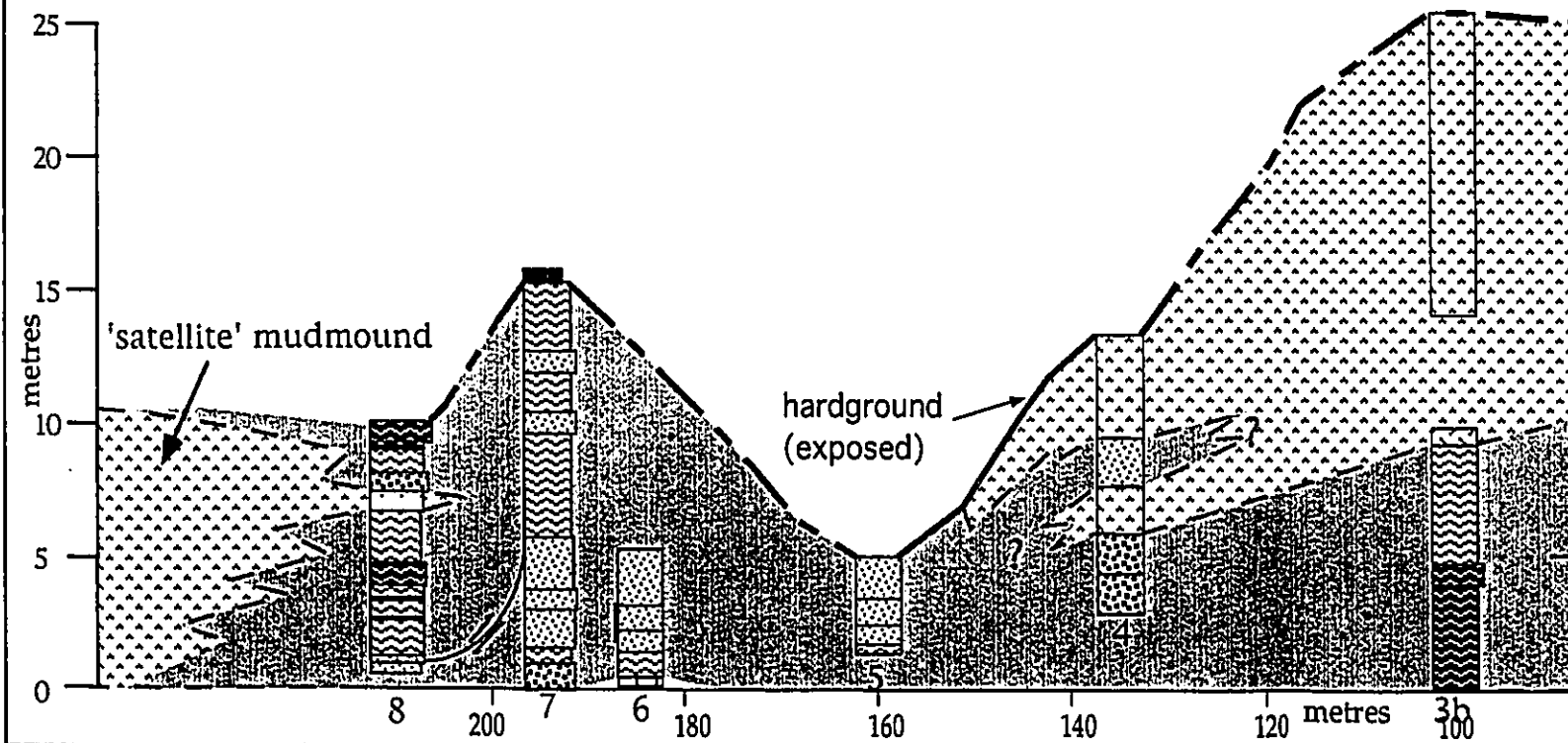
Figure 8. Topographic expression of mudmounds inland from Dragleybeck Inlet. Photograph taken from mudmound D9 looking NW. Mudmounds are buff-coloured resistant highs (arrows). Crinoidal grainstone-filled dykes of D9 are in the foreground (CF).

The mound core facies is intercalated with the flank beds and shows a change from massive mudstone into wackestone with more fossils and debris. The underlying sediments are downwarped beneath the mudmound cores. Immediately adjacent beds of the Douro Formation are more fossiliferous than is typical of the Douro Formation. The upper parts of the mudmounds are enclosed by younger shales of the Devon Island Formation, but these are recessive and only locally exposed.

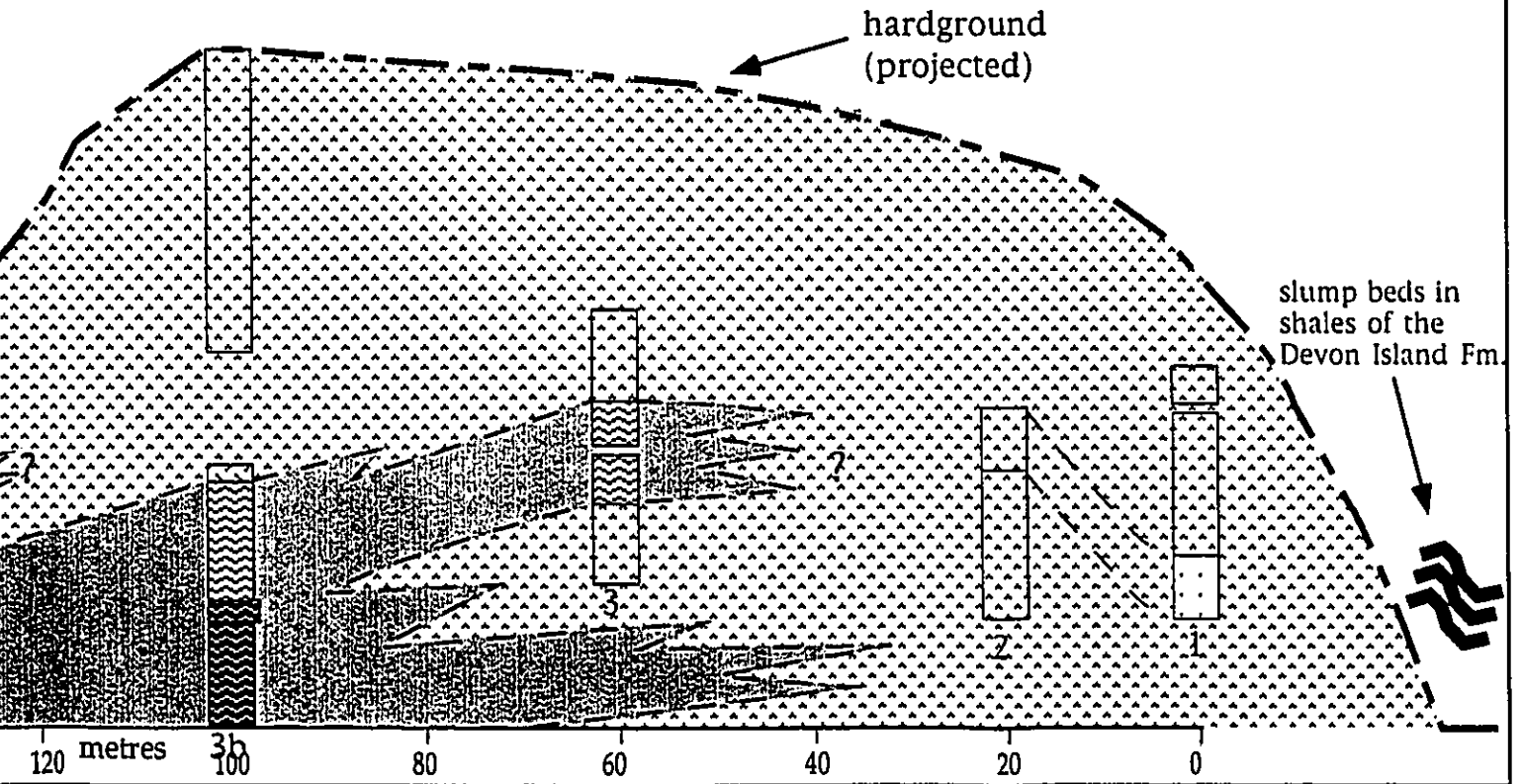
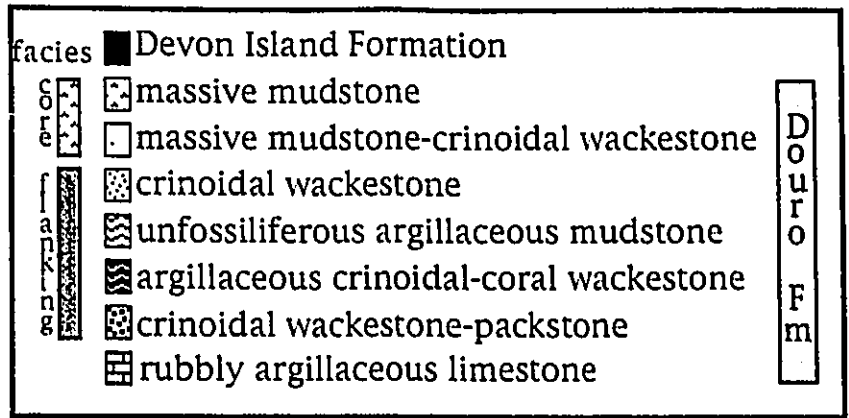
The measured stratigraphic sections (Fig. 9) of the largest and best exposed mudmound ('rivermound', D16, fig. 10) show the relationships of different facies and some aspects of mudmound geometry. Figure 11 is a schematic plan view of this mudmound showing other aspects of mudmound geometry, and the location of the measured sections. At one side of this mudmound the shales of the Devon Island Formation are folded resulting from penecontemporaneous slumping (Fig. 12).

Figure 9 represents a transect through available exposure of the rivermound (locality D16). As this was the only mudmound exposed in cross section, much of the information obtained has been taken as representative of the other mudmounds in the area. This transect does not cut through the centre of the mudmound but is off-centre. Figure 13 shows an interpretive through-centre transect, based on a NW-SE

Figure 9. Measured stratigraphic sections of the 'rivermound' (D16) with interpretations of the core and flanking facies. The fault, between section 7 and 8 represents tectonic displacement. Datum is river level. Bedding dips generally toward the viewer at angles of 15° - 5° (sections 4 to 8), 25° - 30° (sections 3 and 3b), or steeply toward the right (sections 1 and 2). The 'satellite' mound is possibly connected to the main mound behind the flanking facies of sections 4 to 8. The 'trough' defined by the hardground at section 5 is only apparent; it results from bedding dipping toward the viewer on the cliff face. For map distributions of sections, see figure 11 .



Interpretations of the tectonic displacement. of 15°-5° (sections and 2). The 'satellite' of sections 4 to 8. Results from bedding plans, see figure 11 .



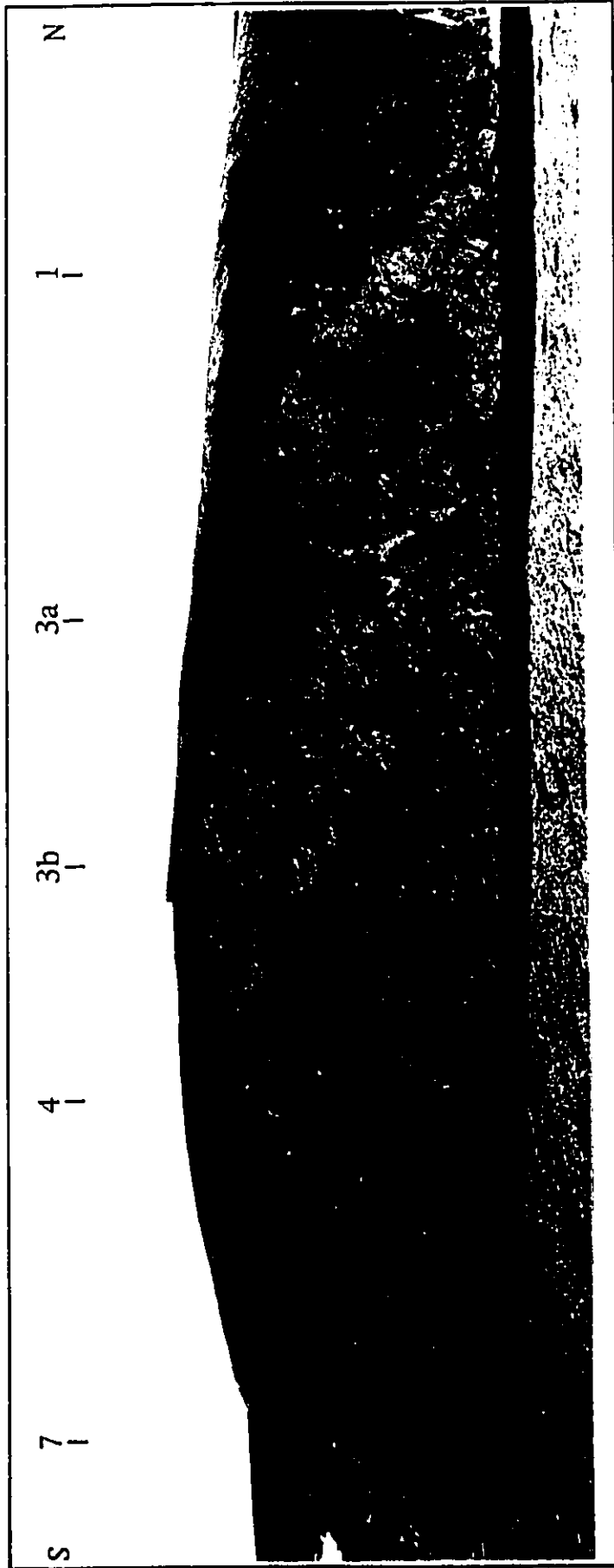


Figure 10. Panoramic photo of the 'rivermound' (D16). Numbers mark the approximate locations of some of the measured stratigraphic sections. The north end of the exposure shows massively bedded core mudstone that dips steeply into the river. The south end exposes well-bedded flanking facies with progressively shallower dips to the south. The hilltop is ~25m above river level.

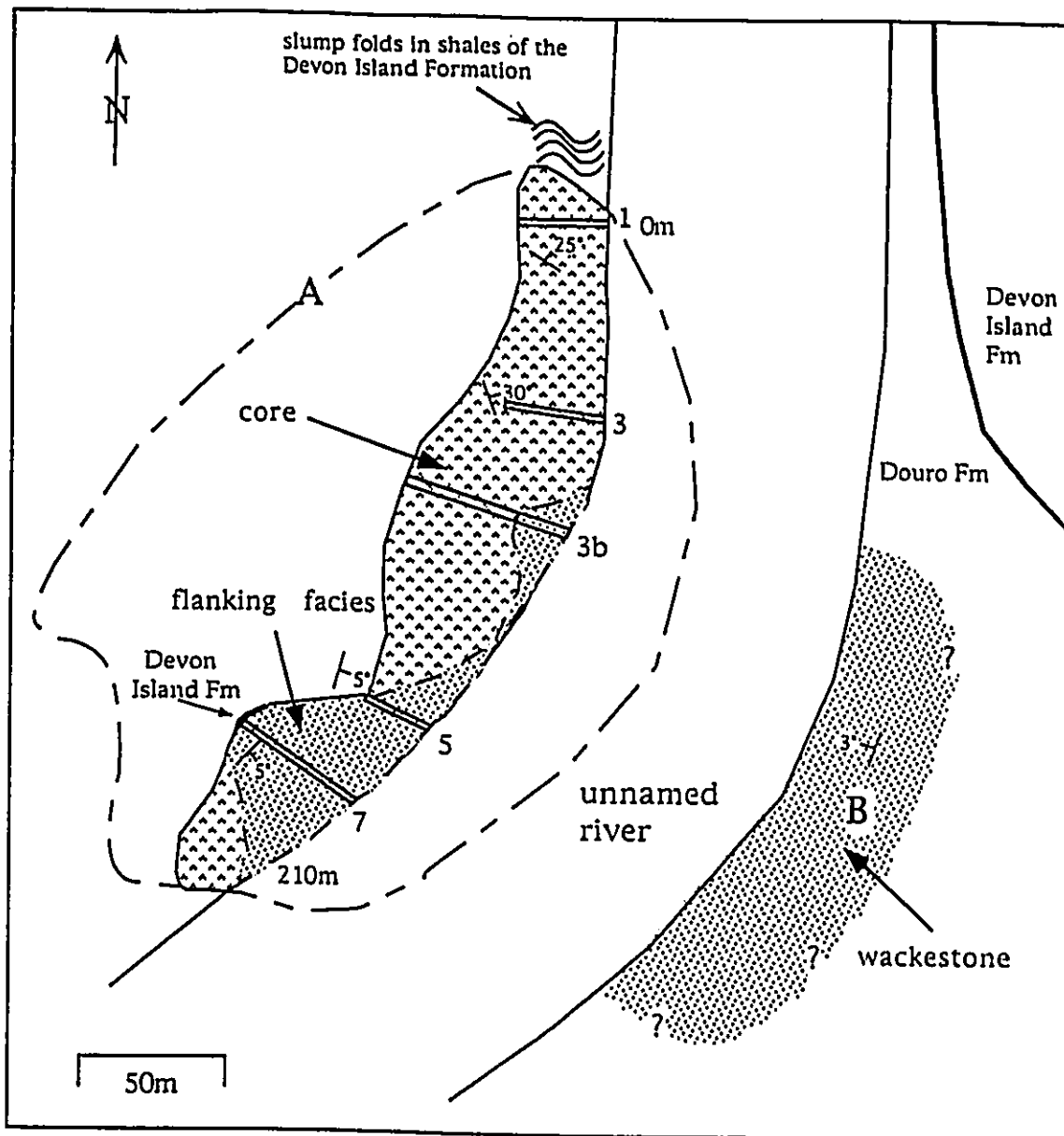


Figure 11. Map of 'rivermound' (D16) locality showing positions of some measured sections (numbered), structural attitudes, the areas of exposed core and flank facies, and exposed wackestone of the Douro Formation, apparently immediately adjacent to the basal facies of the mudmound. Dashed line (— — —) shows approximate mudmound shape and size, and A and B mark the transect represented in figure 13.



Figure 12. Slump folds in mudstone and shale of the Devon Island Formation. Core facies of the 'rivermound' are exposed 1-2m to the left of this exposure (hammer for scale).

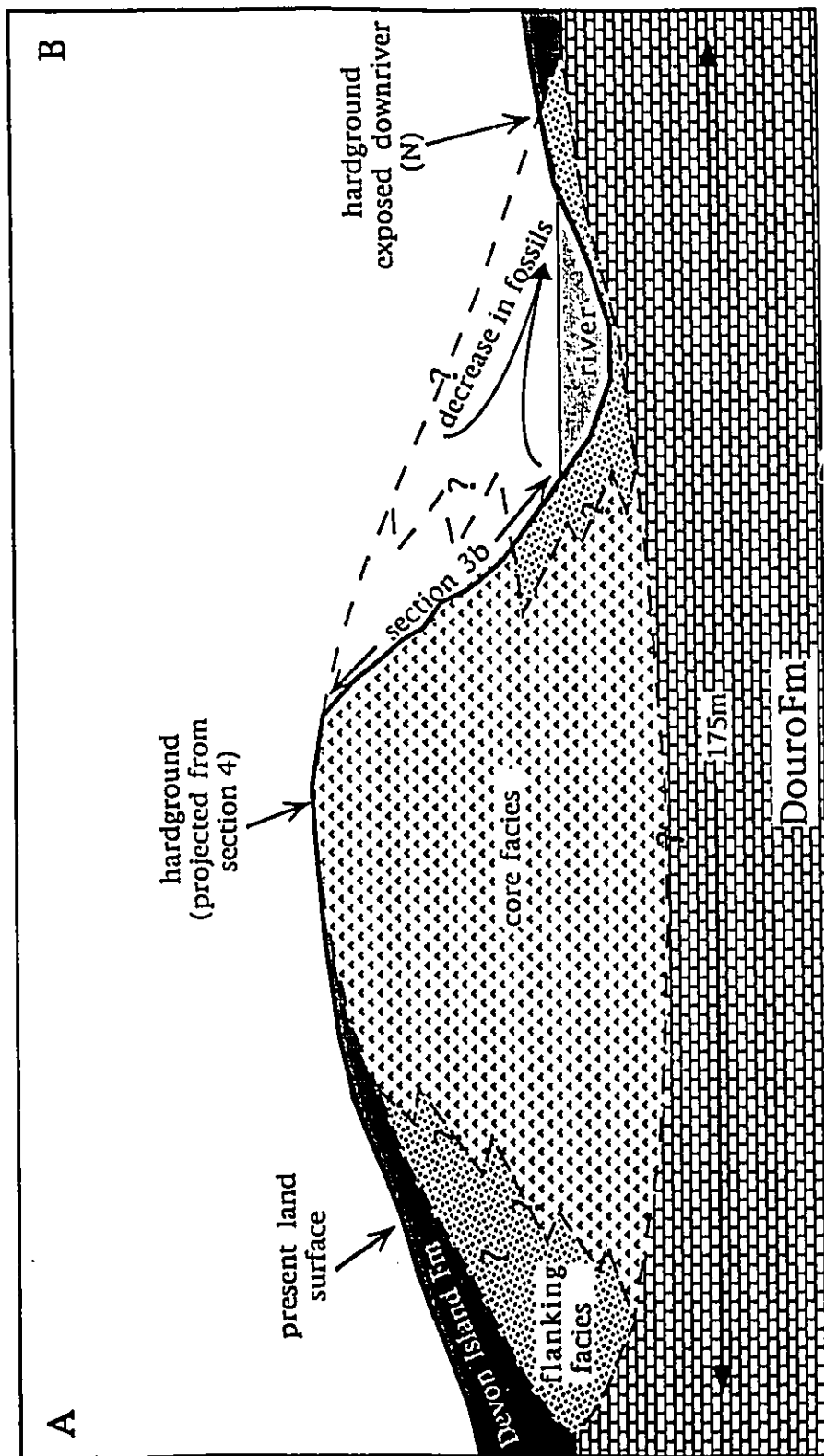


Figure 13. Interpretive through-centre cross-section of the 'rivermound'. This section is projected from NW to SE (A to B on figure 1) through section 3b. The downward basal contact with the Douro Formation and the flanking facies relationship have been interpreted based on outcrop evidence, structural attitudes and topography. There is no vertical exaggeration.

profile through section 3b (figure 9). This cross-section provides information on the relationship of the mudmound core and the flanking facies, as well as estimated size and shape.

2.1.2 Mudmound and associated facies

Core facies

The main core facies of the mudmounds is sparsely fossiliferous, massive grey to greenish-grey mudstone with local lenses of crinoidal wackestone (Fig. 14 A, B). Although these lenses occur throughout this facies they are more common in the basal portion. Also associated with the basal portion, and in proximity to the flanking facies, is a more rubbly, argillaceous, greenish-grey mudstone that occurs in horizontally discontinuous layers. The dips of the exposed beds in this facies vary from 10° to 38°.

Laterally continuous stromatactoid structures are locally common in this facies. In acetate peels and thin sections, abundant articulated and disarticulated sponge spicules and relict clotted and crinkly laminated microbial fabrics can be seen. Corals, crinoid holdfasts, crinoidal debris, trilobites and calcareous algae occur throughout but are not common and do not appear to occur in certain intervals.

Figure 14. Mudstone of the core facies of the 'rivermound' (D16).

A. Polished hand sample of stromatactoid mudstone in cross-section view. Generally unfossiliferous, the core facies in this sample contains favositid (F) and heliolitid (H) corals, crinoidal debris (Cr), crinoid holdfast (R), trilobite debris (T), and spicular micrite (Sp). Laterally continuous stromatactoid structures occur locally in the mudmound (St). Ruler with 1mm divisions.

B. Field exposure of massively bedded mudstone. The beds dip steeply towards the right.



Flanking facies

Flank beds of the mudmounds are wackestones containing a more abundant and diverse assemblage of corals, crinoidal debris, calcareous algae, bryozoans, trilobites, brachiopods and stromatoporoids than the mudmound cores. The flank beds thin, from ~50cm to ~10cm in thickness, away from the mudmound core, and dips decrease to horizontal from a maximum of 15° near the core.

The flank bed wackestones grade outward into progressively less fossiliferous wackestone and at a distance of 75-100m from the mound core become argillaceous, sparsely fossiliferous wackestone and mudstone typical of the Douro Formation.

Capping facies

Many of the mudmounds are capped by grainstone composed almost exclusively of crinoid stems and plates. In places small (5mm) atrypoid brachiopods are abundant (Fig. 15A). This grainstone also fills neptunian dykes that occur in many places in the mudmounds. Several of the dykes are up to 50cm wide and completely filled with crinoid material. The capping beds are roughly stratified, averaging 20cm in thickness and consisting of relatively unsorted crinoidal debris 3mm to 1cm in diameter. Because no upper limits are exposed, the maximum

Figure 15. Crinoidal-brachiopod grainstone associated with mudmound D7.

A. Field photograph of grainstone-filled neptunian dyke consisting largely of crinoidal debris (Cr) and atrypoid brachiopods (B). Lens cap is 5cm in diameter.

B. Unit of grainstone capping mudstone and dipping 10° NW (toward left). Block labelled 'Cr' is ~0.3m high.



thickness of these units is unknown, although exposed thicknesses range from 1-2m. This facies drapes over the mounds preferentially on the NW sides at dips of $\sim 10^\circ$ (Fig. 15B). Mudmounds D1-D15 have this capping facies while mudmounds D16-D27 have a hardground surface at the top instead.

Table 2 provides a summary of the lithofacies and associated fossil assemblages.

2.1.3 Fossils

Few body fossils are preserved in the mudmound core facies although skeletal fossils are abundant and diverse in the flank beds. The best evidence of original fossil content within the cores can be seen in small well-preserved mudmounds exposed near the base of a larger mound in the tract (Fig. 16A). Whole fossils (sponges and dasycladaceans) constitute up to 50% of these small mounds. The main components are microbial structures ($\sim 40-50\%$), lithistid sponges (30-40%), and dasycladacean algae (10%) (Fig. 16B). These show intimate growth associations representing encrusting, binding, and baffling organisms. The original occurrence of these organisms can be inferred in the more diagenetically altered larger mudmounds, from the occurrence of isolated sponge spicules, spicular micrite and micrites

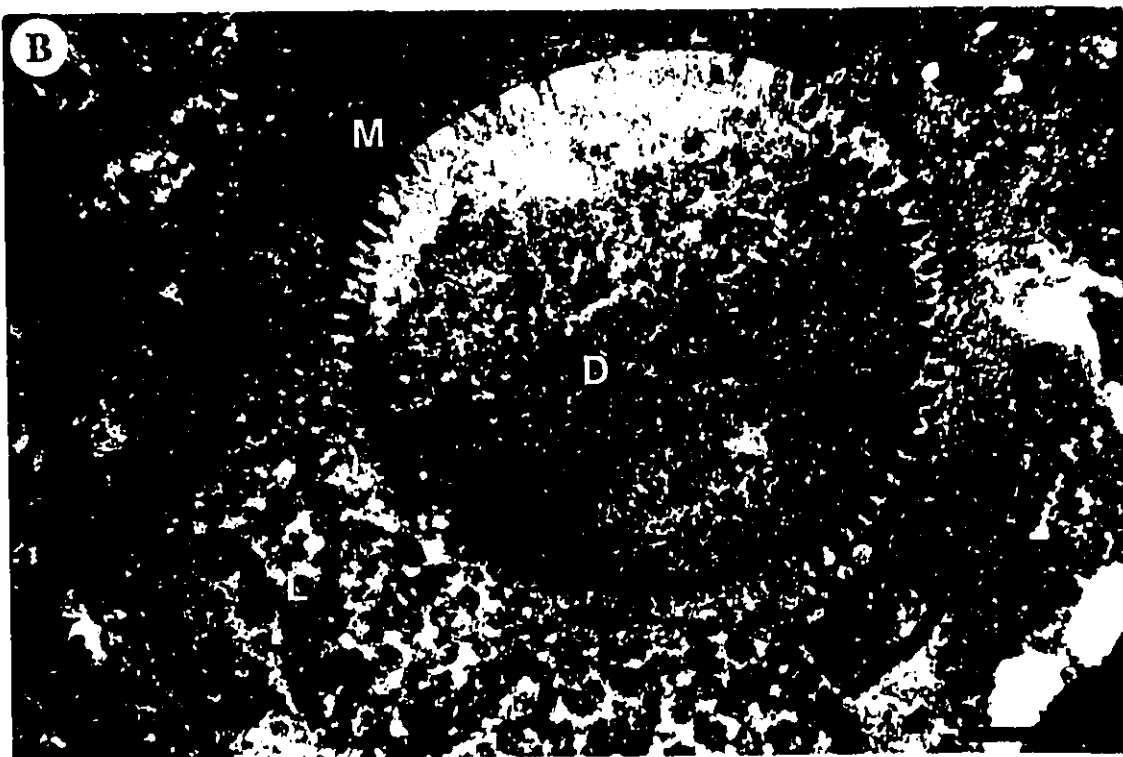
<i>lithofacies</i>	<i>description</i>	<i>fossils</i>	<i>petrographic observations</i>
core	stromatolite-rich, massive, grey mudstone with lenses of crinoidal wackestone, few skeletal fossils	heliolitid, favositid, and alveolitid corals, crinoid debris, trilobites and calcareous algae	sponge spicules and microbial fabrics are common
flanking	grey-green argillaceous wackestone, decreasing in fossil content away from mound core	as above and also solitary rugosans, bryozoans, brachiopods, stromatoporoids, lithistid sponges,	more argillaceous and fossil debris-rich than core facies

Table 2. Descriptions of mudmound facies and fossil content.

Figure 16. Field exposure of, and thin section from, a small well-preserved mudmound at D27.

A. Mudmound (Mn) surrounded by argillaceous limestone of the Douro Formation. Hammer for scale.

B. Photomicrograph of mudstone showing microbial encrustations (M) on lithistid sponges (L) and the dasycladacean algae *Vermiporella* (D) in cross-section view. Scale bar=1mm.



with faint lamination of probable microbial origin. In the fossil groups described below the generally poor preservation limited a detailed taxonomic assessment.

Microbes

Although microbes were not preserved, their presence originally can be inferred from microbial fabrics occurring abundantly in the small mudmounds. These laminar fabrics surround or drape over lithistid sponges, dasycladacean algae, and mound debris composed of bivalve and crinoid fragments (Fig. 17A). In places the microbial fabric is clotted or shows crinkly lamination (Fig. 17A, B). Small, finger-like stromatolites, 1-2cm in width and 5-6cm in height, are present in one of the small mudmounds (Fig. 18A, B).

Sponges

Lithistid sponges are common fossil elements in the small well-preserved mudmounds, and their spicules are common in the larger mudmounds. Two main types of lithistids are present, one with a loosely organized spicular meshwork, and the other with a more organized spicular meshwork (Fig. 19A). In the small mudmounds, *in*

Figure 17. Thin sections from a mudmound at D27.

- A. Thin section photograph of crinkly lamination of microbial origin (Mi) in cross-section view. D=the dasycladacean algae *Vermiporella*. The bottom of the thin section, below a shale seam (arrow) is solenoporid-bryozoan wackestone. Scale bar=5mm.
- B. Photomicrograph of clotted microbial fabric (Mi) in mudstone in cross-section view. Scale bar=1mm.

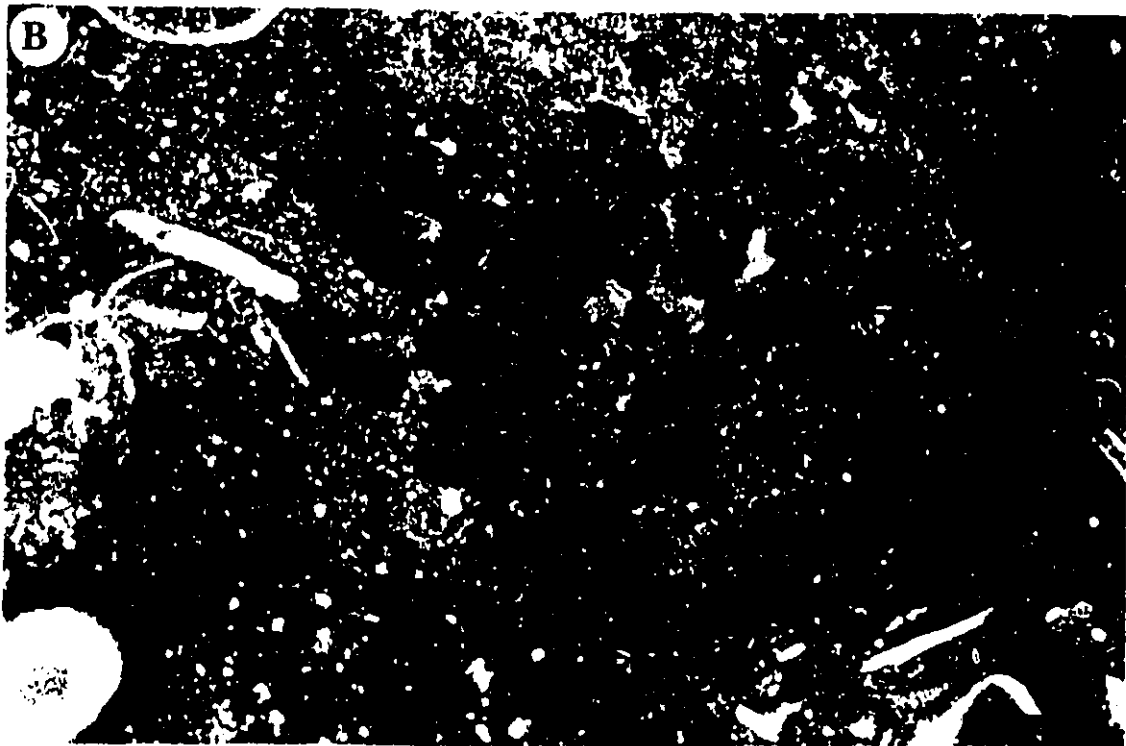


Figure 18. Stromatolites in a small well-preserved mudmound at D27.

- A. Field photograph of stromatolites (St) resting on microbial-lithistid sponge mudstone in cross-section view. Arrows mark the bottom and top of the layer of stromatolites. Scale bar=2cm.
- B. Thin section photograph of the stromatolites shown in A in cross-section view. Arrow shows the 'way-up'. In between the 'fingers' of the stromatolites (St) is debris-rich wackestone (D) composed mostly of bivalves and crinoids. Scale bar=5mm.

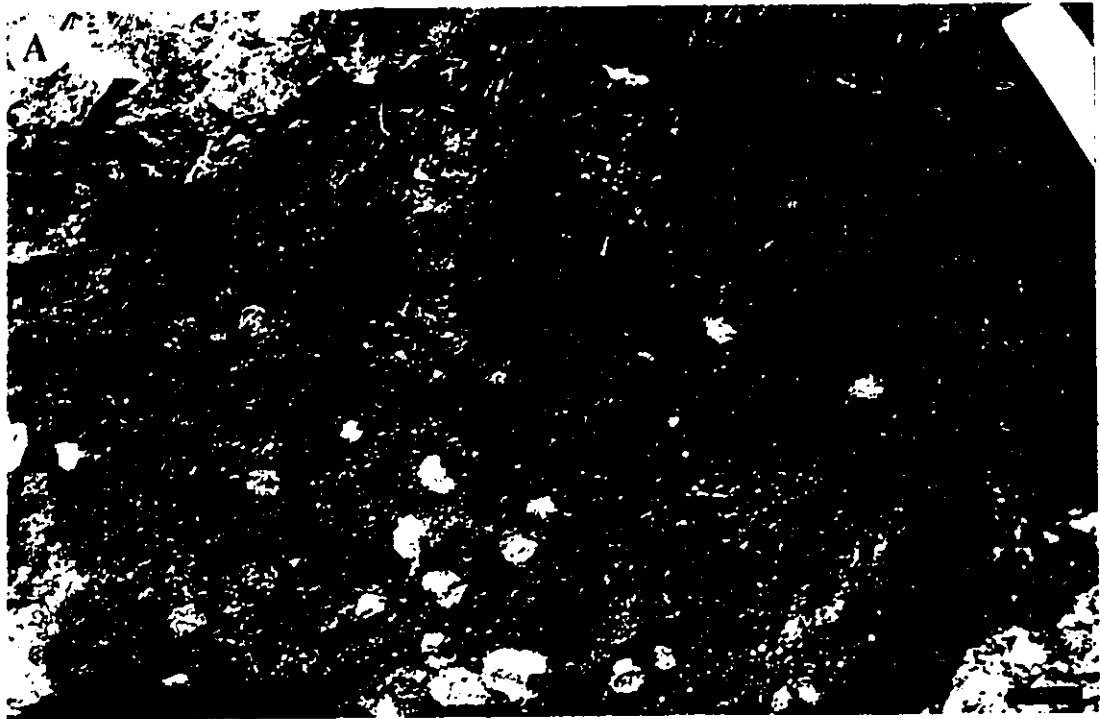
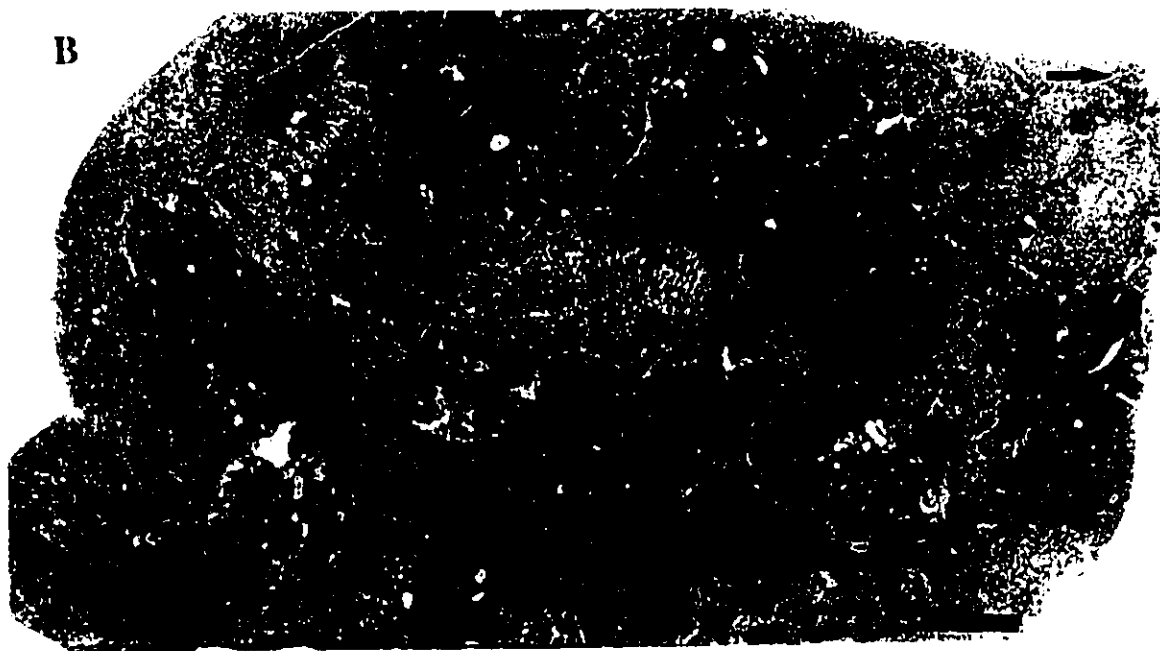


Figure 19. Thin section photographs from a mudmound at D27

- A. Branching? lithistid sponge-rich mudstone. Some of the sponges (L) are encrusted by finely laminated dark microbial micrite (Mi). Scale bar=5mm.

- B. Branching? and hemispherical lithistid sponges (L) comprising up to 60% of the thin section. Stratigraphic top to the right (arrow). Mi=microbial micrite. Scale bar=5mm.



situ lithistid sponges commonly constitute 30-40% of the mound lithology and in some slabs up to 60% (Fig. 19B).

Cylindrical and hemispherical growth forms averaging 1-2 cm in diameter are most common, although lamellar encrusting forms and branching forms are also present. Although sponges are common within the small mudmounds, none were recognized in the surrounding sediments of the Douro Formation.

Calcareous algae

Red and green calcareous algae constitute up to 10% of mound lithology of the small mudmounds. Hemispherical and bulbous solenoporids occur in rudstone at the bases of the small mudmounds (Fig. 20A,B). Lamellar solenoporids encrust tabular corals in the larger mudmounds. The dasycladacean green alga *Vermiporella* is concentrated locally and constitutes up to 10% of the small mudmounds. It occurs *in situ* as thin-walled, anastomosing tubes, 2mm in diameter (Fig. 21A,B).

Corals

Corals are abundant in the beds flanking the mudmounds but typically constitute less than 5% of mudmound core material. Within

Figure 20. Basal lithology of a mudmound at D27.

A. Thin section photograph showing a lower crinoidal-solenoporid packstone with mud intraclasts. The upper portion is composed of dasycladacean algal-bivalve wackestone. So=solenoporid alga; G=gastropod; Cr=crinoid; D=dasycladacean alga; Bi=bivalve; Do=fine-grained sucrosic ferroan dolomite. Arrow points to the area enlarged in B. Scale bar=1cm.

B. Photomicrograph enlargement of area marked in A. The lower half of the photo is crinoidal-solenoporid rudstone and the upper half is the dasycladacean-bivalve wackestone. D=dasycladacean alga (*Vermiporella*); Do=ferroan dolomite. Scale bar=0.5mm.

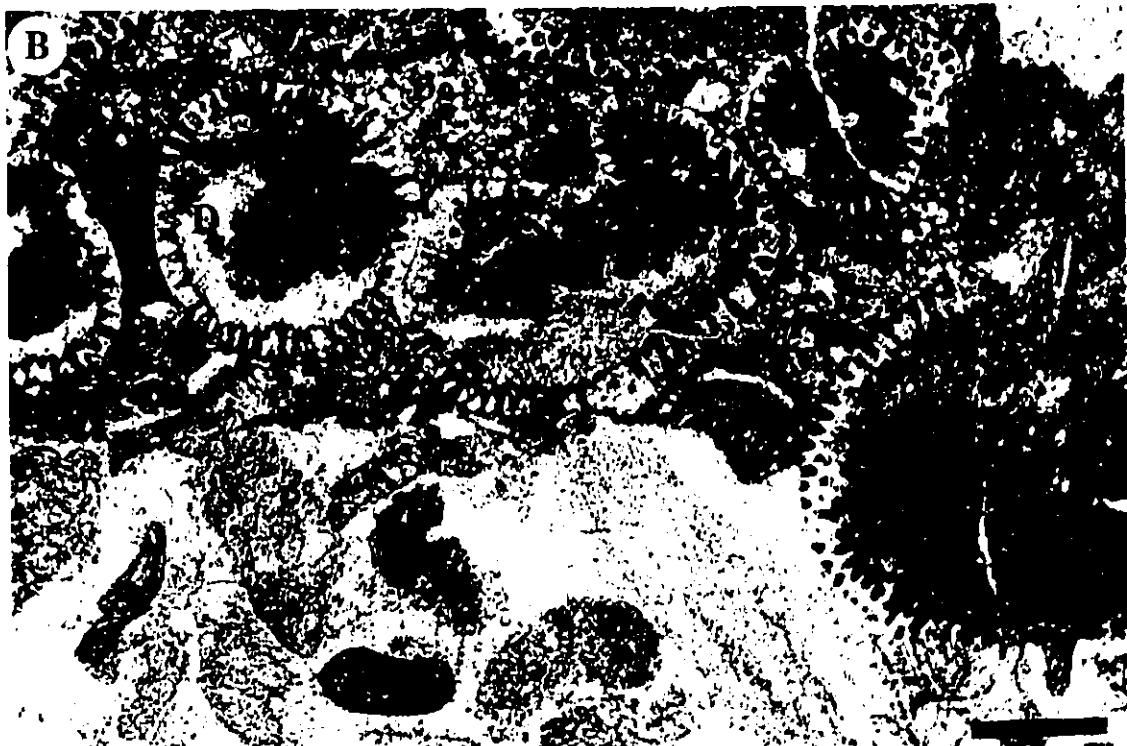
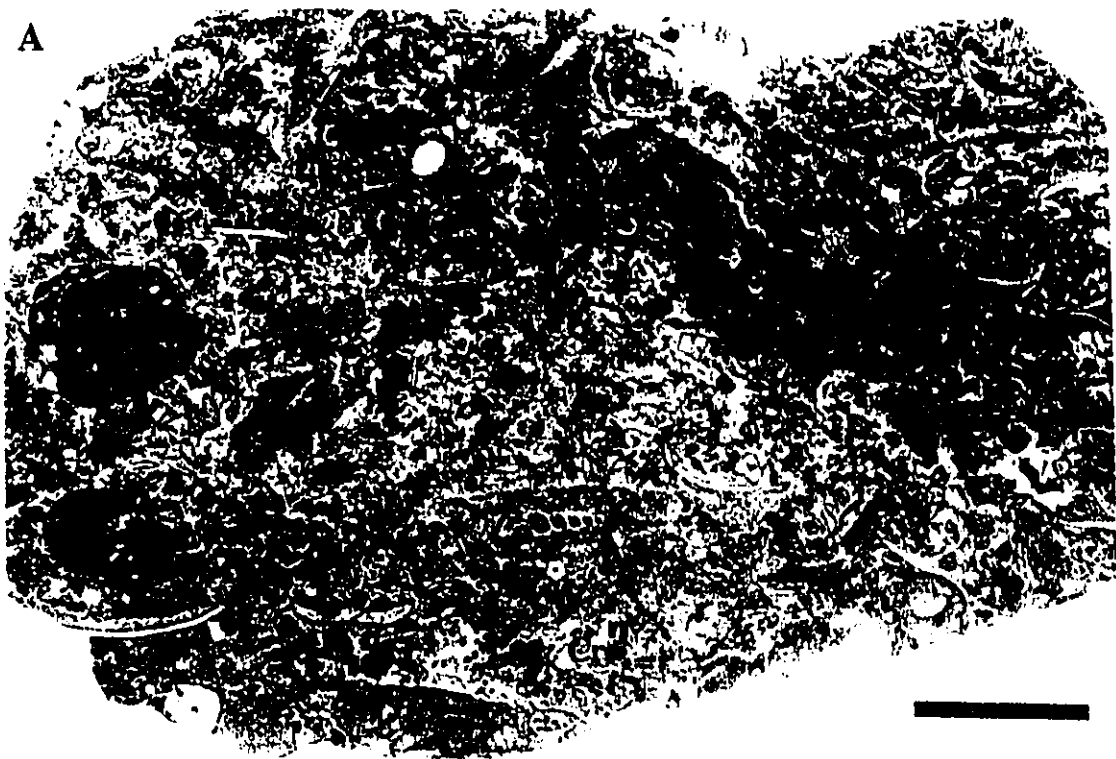
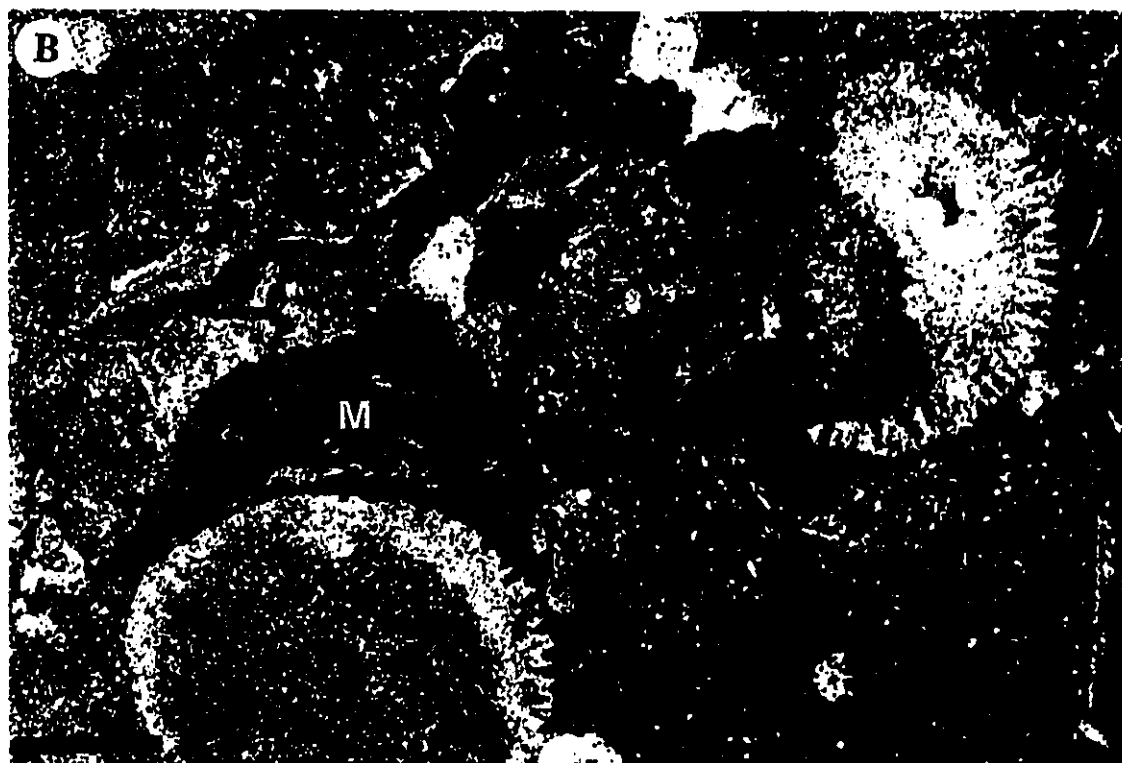


Figure 21. Photomicrographs algal mudstone from a small mudmound at D27. Scale bars=5mm.

- A Cross section and partial longitudinal section through *Vermiporella*. Note the early fascicular calcite cement and the micritized edges of the algae.
- B Microbial encrustations (M) on *Vermiporella* (D). Note the encrustation on the half-preserved *Vermiporella*; its weakly calcified skeleton may have started to dissolve, or was broken early in the evolution of the mudmound.



the core, tabular forms of *Heliolites*, *Favosites*, and *Alveolites* are present, as well as branching fasciculate rugosan colonies. Specimens of *Alveolites* are more common in more argillaceous beds of the mound core and flank beds. Heliolitids are generally more common in the flank beds and inter-mound deposits of mudmounds than in the mudmound cores (Dixon, pers. comm.).

In the flank beds corals are more abundant and diverse than in the core facies and constitute up to 25% of the flanking facies. The coral fauna includes mucophyllids and other solitary rugose corals, tabulates including heliolitids, favositids, syringoporids, and *Alveolites*, and the compound rugosans *Rhizocorallium*, and *Rhizophylloides*.

Stromatoporoids

Although common in other build-ups of this age in the Arctic Islands, stromatoporoids occur rarely in these mudmounds. They are generally found only in the flank beds of the mudmounds, are hemispherical to bulbous and typically poorly preserved.

Crinoids

Whole crinoids are not present but their stem plates are very common, range in diameter from 4mm to 1cm, and are unsorted.

Cirriferous holdfasts are present in the core facies and some are intergrown. The crinoidal material is most commonly localized in core facies and more abundant in the flanking facies.

Other associated fossils

Bryozoans, trilobites, brachiopods (*Atrypa* and other atrypoids and strophomenids), orthoconic cephalopods, bivalves and ostracods all occur as subordinate fossil components in the mudmounds and flank beds.

2.1.4 Lateral zonation

Although no vertical or lateral zonation is apparent within the mudmounds, lateral zonation is very obvious from the marked differences in diversity and abundance of fossils between the mudmound core and the flank beds. The flank bed fauna consists of solitary and colonial corals (most commonly heliolitids, favositids, and alveolitids), trilobites, brachiopods, sponges, ostracods, and crinoidal debris. Although the abundance and diversity are initially higher in flank beds immediately adjacent to the mudmound core, both decrease over short distances away from the mudmounds.

2.1.5 Roles of mudmound organisms

The small mudmounds (microbial-sponge mounds) show that there was an intimate association of binding, encrusting, and baffling organisms during mound construction. Dasycladacean algae acted as bafflers, trapping carbonate mud and keeping it on the mounds. Lithistid sponges encrusted the dasycladaceans but were mostly mound dwellers, bafflers and, where abundant, mound constructors. Perhaps most important in the construction of the mudmounds were microbes which encrusted the sponges, adding to their stability, and also encrusted the dasycladacean algae and fossil debris. The microbes also bound sediment together and therefore acted as binders.

Perhaps an even more important role than binding sediment was the role of microbes in carbonate mud production. Microbial mud constitutes ~40-50% of the carbonate mud and depositional mud constitutes 50-60%. The lack of siliciclastic material in the mudmounds suggests that the carbonate mud was produced in situ. Calcified microbes producing mud-sized sediment, is the most reasonable explanation of mud genesis.

The corals in the mudmounds were primarily mound dwellers and secondarily sediment bafflers. Although some of the tabulate coral colonies were quite large (10cm x 40cm) the fact that they were isolated and uncommon suggests that in this environment they could not have acted as framebuilders.

Crinoids played an important role in mound construction, as they acted as sediment producers, stabilizers and bafflers. The production of sand-sized and coarser sediment was important for the growth of corals, stromatoporoids, and brachiopods that required stable substrates for larval attachment. The intergrown cirriferous holdfasts would have stabilized the mud on the mound, and where crinoids were abundant and crowded they could have acted as bafflers. The greater abundance of corals and other fossils in the flank beds is likely related to the greater availability of hard substrates that crinoidal debris would have provided for larval attachment.

2.1.6 Hardground and biota

A phosphatized hardground marks the boundary between the Douro and Devon Island formations in the study area. The hardground is a 2-4mm thick dark grey resistant phosphatic layer that coats fossils and grains, and infills cracks in the mudmound, indicating early seafloor

cementation. At the 'rivermound' locality (D16) a hardground that forms the top of the mudmound core and flank beds (Fig. 22A), apparently represents the major hardground that regionally defines the top of the Douro Formation.

The hardground is marked by a distinctive fossil biota of orthoconic cephalopods (1-2cm in diameter), brachiopods (atrypoids, rhynchonellids), and bivalves (Fig. 22B). Spherical to ovoid coated grains averaging 1mm in diameter are commonly associated with the hardground (Fig. 22C).

2.1.7 Depositional environment and mudmound growth

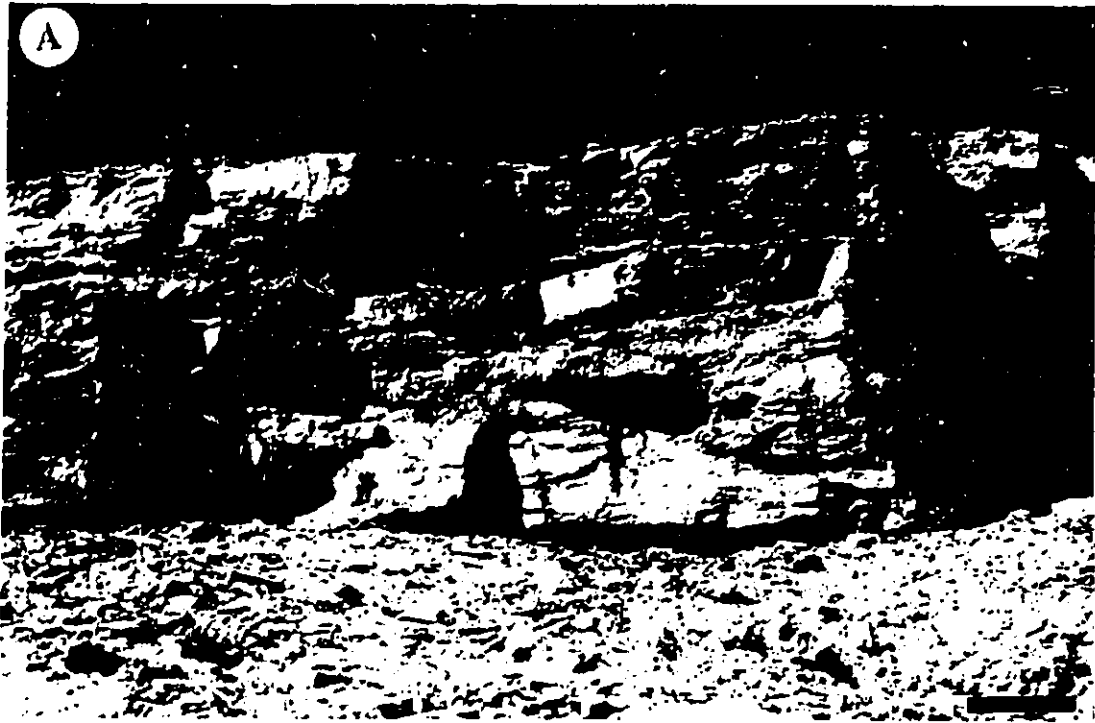
The microbial-lithistid sponge mudmounds developed during the final stage of Douro sedimentation. Narbonne (1981; Narbonne and Dixon, 1988) interpreted the Douro Formation as representing deposition on a carbonate ramp. Within the study area, the mudmounds formed in this ramp setting at a time of regional transgression that eventually led to widespread onlap of basinal shales of the Devon Island Formation over the Douro ramp. The rubbly argillaceous limestones of the Douro Formation were deposited in a subtidal environment below fair-weather wave-base (Packard, 1985). The predominantly fine grain size

Figure 22. Hardground features in the mudmound tract.

A. Field photograph of hardground (arrow) and associated rusty weathering at the top of section 4 of the 'rivermound'. Scale bar=50cm.

B. Hand specimen of hardground, in bedding plane view, near mudmound D7 showing 'large' bivalves (Bi) and orthoconic cephalopods (Ce). Scale bar=1cm.

C. Surface of hardground near mudmound D7 showing common associated fossils. Cr=crinoid debris; B=brachiopods; G=coated grains. Ruler with mm divisions



of the sediments and fragile nature of the mound constructors are consistent with deposition in a quiet-water environment within the photic zone.

Downwarping of beds of the underlying Douro Formation suggests that the mudmounds initially developed on a relatively soft substrate. Termination of mudmound growth coincided with the termination of carbonate production of the Douro Formation during relative sea-level rise. The phosphatized hardground at the top of the Douro Formation and at the corresponding tops of many of the mudmounds represents a hiatus in deposition of uncertain duration.

The slight NW-SE elongation of the mounds, probably parallels current directions at the time of deposition. Although some of this elongation could have been caused by or emphasized by Quaternary ice flow, the presence of capping crinoidal grainstone preferentially on the northwestern sides of the mounds implies an asymmetry that would be consistent with currents having a NW/SE azimuth. The clean, unsorted nature of the crinoidal-brachiopod capping grainstone, and the fact that it infills neptunian dykes in different parts of the mounds, suggest that this material was transported minimally.

That the crinoids and brachiopods were growing locally on the tops of the mounds during the period of non-deposition is implied by the absence of detrital mud matrix in the grainstone. After death their skeletal material would have accumulated on the adjacent slopes of the mounds and would tend to be unsorted. The dips in these beds may represent original dips in the material transported by grainflow and possibly slumping off the tops of the mounds on to the margins. Large quantities of this material could have been produced in situ if the hiatus in detrital sedimentation was sufficiently long.

Original synoptic relief of the mudmounds can be interpreted from the following: 1) downwarping of the underlying Douro Formation, 2) neptunian dykes, 3) the configuration of the hardground at the top of the 'rivermound', and 4) penecontemporaneous slump folds in the adjacent Devon Island Formation. Downwarping of underlying sediments and the presence of neptunian dykes implies differential loading and settling, therefore suggesting that the mounds had topographic relief. The hardground is exposed in the sediments surrounding the 'rivermound' and can be traced from discontinuous exposures up and over the mound. The slump structures in the Devon Island Formation, on the NE side of the 'rivermound', suggest that the

shales were deposited on a sloping flank of the mudmound. Based on these observations, the original synoptic relief of the 'rivermound' may have been 25m.

The presence of abundant in situ dasycladacean (green) algae limits the depth of occurrence of the mudmounds to within the photic zone. The abundance of lithistid sponges suggests that water energy was quite low because many lacked larger robust skeletons and could not have withstood high wave turbulence. Corals were present on the mudmounds but were not major mound constructors in this area. The scarcity of hard substrates, low light intensity and probably slow water circulation over the mounds could have been factors that limited coral growth. The greater abundance and diversity of corals in the flank beds could reflect the greater availability of skeletal debris as substrates.

2.2 GRIFFIN INLET MUDMOUND

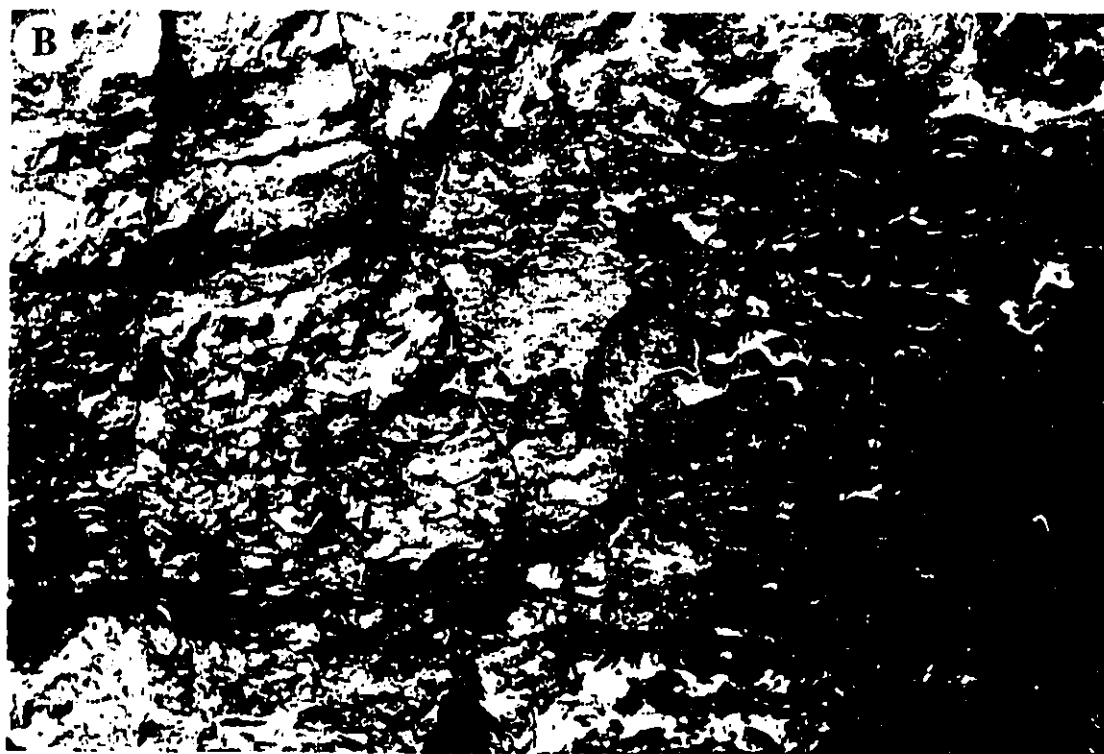
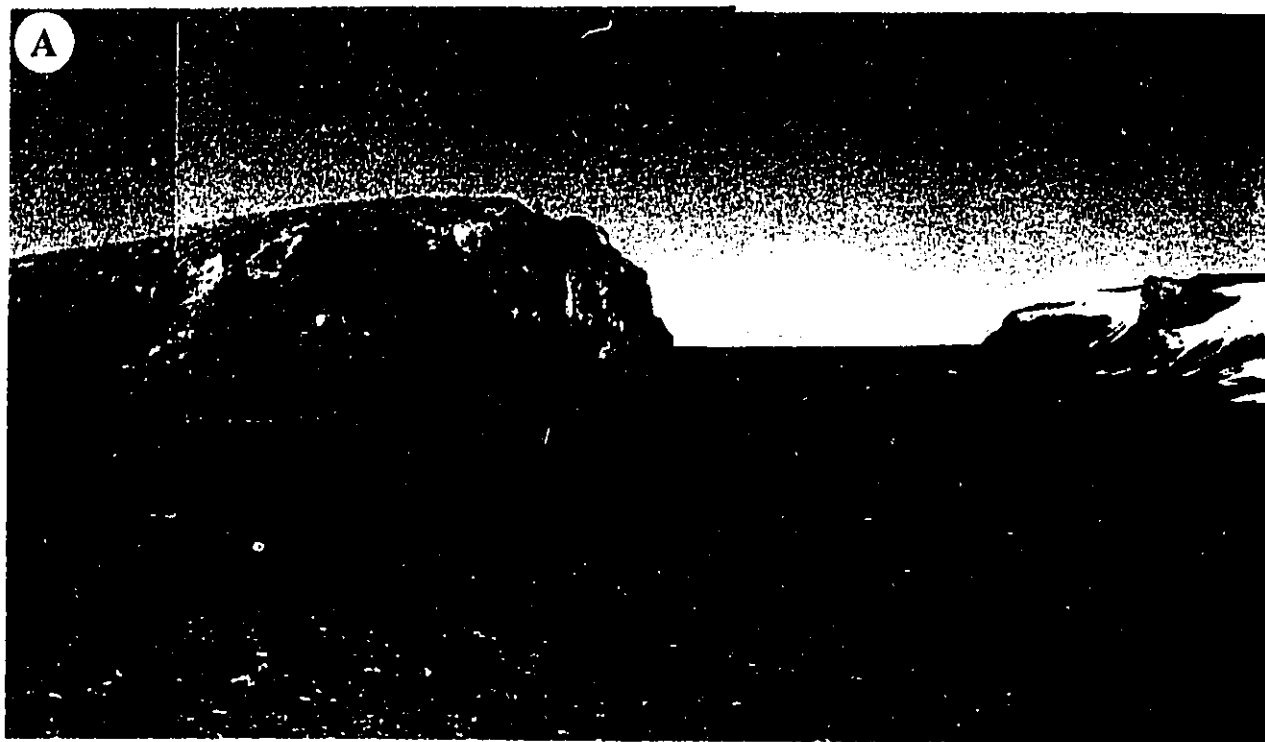
2.2.1 *Morphology and lithofacies*

The mudmound is 25m in height and 150m in diameter, with a developed 'foremound' and 'backmound' (Fig. 23A). These terms are used to describe the asymmetry present within the mudmound, the steeply dipping beds representing the 'foremound' and the gently dipping beds the 'backmound'. Although the core facies (Fig. 23B) that is present in this mound is similar to that in the mudmounds further north, the associated organisms are different. Large fasciculate rugosans and tabular *Favosites* are relatively abundant at two intervals in the mudmound (Fig. 24A, B). Large (.3m x 1m) tabular stromatoporoids are common in the upper interval of the mudmound.

Stromatactoid structures are the most conspicuous element of the mudmound, although they are not as clearly defined, as large or as abundant as those in the mudstone cores of the skeletal mounds further north (discussed later in this chapter). The structures average 5-10cm in length and 1-2cm in height and are commonly not interconnected. These structures are not present where corals and stromatoporoids are present, but occur in intervals above and below them. A thin

Figure 23. Griffin Inlet mudmound.

- A. Profile of the mudmound, viewed toward the east. The stream valley cuts directly through the middle of the mudmound, exposing the 'foremound' on the right and the 'backmound' on the left of the photo. Height of the mound is 27m.
- B. Field exposure of typical stromatolite-rich mudstone facies in cross-section view. Hammer for scale.



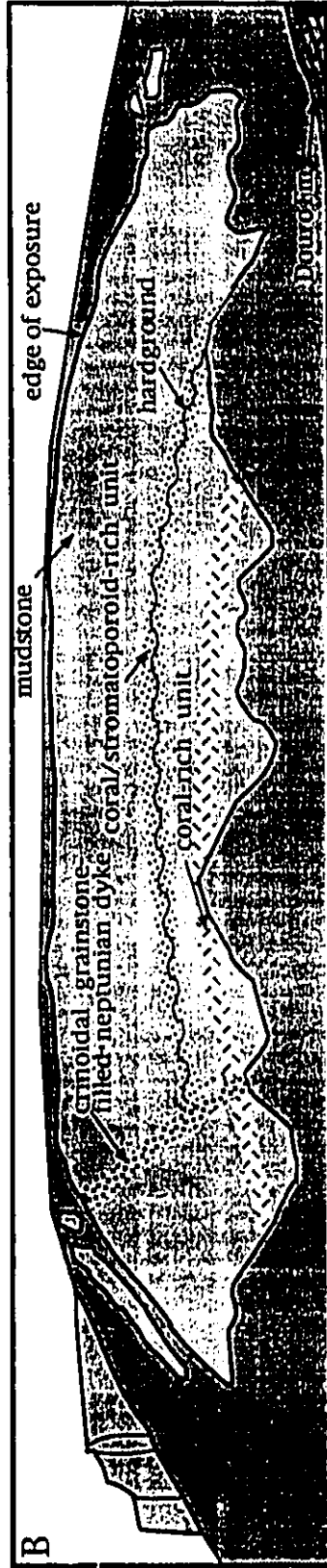


Figure 24. Griffin Inlet mudmound.

A. Oblique view of mudmound, looking northward. Cliff height is 33m.

B. Sketch of A showing the generalized mound succession. The wavy line represents a 'hardground' within the mudmound. The dyke shown is the largest of many that occur throughout the mudmound. Note the downwarp of the underlying Douro Fm.

phosphatized hardground is present in the middle of the mudmound and is undulose ('wavy') and extends through the entire exposed cross section of the mound.

2.2.2 Fossils

Corals

Within the mudmound core, large (40cm x 15cm) tabular *Favosites*, tabular *Stelliporella* and large (up to 1m in diameter) fasciculate rugosans are abundant in two main intervals and occur sparsely within the rest of the mudmound core. Cerioid rugose corals, mucophyllids, heliolitids, favositids, *Mazaphyllum*, small solitary rugosans, and gregarious rugosans are present in the flank beds of the mudmound.

Stromatoporoids

Large (100cm x 30cm), tabular stromatoporoids are common in the coral/stromatoporoid-rich unit. The stromatoporoids are silicified, which makes them conspicuous in the mudmound as they weather whitish-grey and are more resistant than the surrounding mudstone. Stromatoporoids occur rarely in the rest of the mudmound core and flank beds.

Other associated fossils

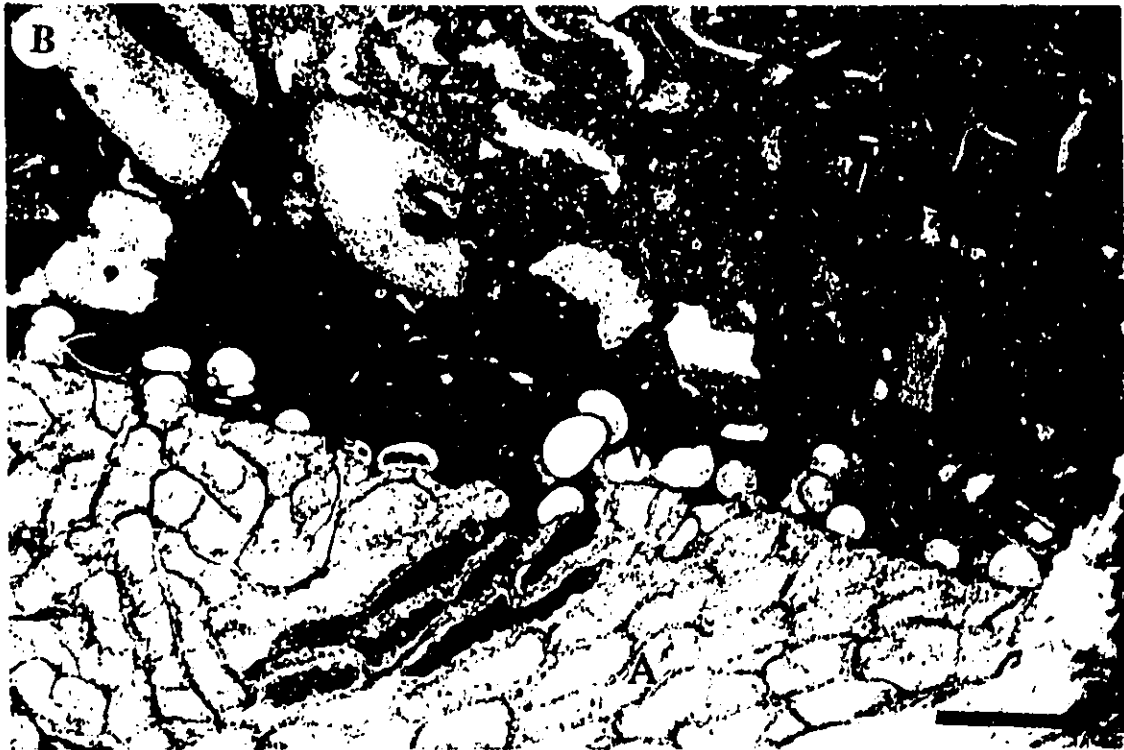
Most of the associated organisms occur in the flank beds of the build-up and only rarely in the mudmound core. Trilobites (*Encrinuris* sp.), brachiopods (atrypoids), ostracods, calcareous algae, and crinoidal debris are abundant in the flank beds. Calcareous algae present in the mudmound core and flank beds include *Solenopora* (Fig. 25A), *Wetheredella* (Fig. 25B), *Sphaerocodium*, *Receptaculites*, and *Rhapdoporella*.

2.2.3 Depositional environment and mudmound growth

The faunal characteristics and stratigraphic relationships indicate that the Griffin Inlet mudmound was deposited in an environment somewhat different from the other mudmounds further north. Deposition in shallower water is suggested by the presence of platform carbonates of the Barlow Inlet Formation overlying the mound. Another indication of shallower water depth is the presence of stromatoporoids, as they are much more characteristic of relatively shallow environments.

Figure 25. Photomicrographs of wackestone from Griffin Inlet mudmound. Scale bars=1mm.

- A. Sequence of encrustation and growth: 1) heliolitid coral (H), 2) solenoporid alga (S), and 3) alveolitid coral (A). Other bioclasts are crinoidal debris (Cr), ostracods (O) and sponge spicules (Sp).
- B. *Wetheredella* (W) encrusting an abraded alveolitid coral (A). R= recrystallized wackestone matrix, showing lighter colour and larger crystals.



The lower coral-rich interval and the upper coral/stromatoporoid-rich interval within the mound indicate that at different times of mound growth the environment became more favourable for these organisms. The wavy hardground (Fig. 26) within the upper interval indicates that there was a change in depositional environment, possibly a short-term deepening, resulting in a depositional hiatus and development of a thin phosphatized hardground. The crinoidal grainstone that infills the neptunian dykes provides evidence that a capping crinoidal facies followed mound development but is no longer preserved. The change in fossil composition, from almost unfossiliferous in the underlying and laterally equivalent beds of the Douro Formation to higher diversity and abundance in the flank beds, also suggests that mudmound relief improved the environment immediately around the mound.



Figure 26 Hardground within the Griffin Inlet mudmound succession. The surface of the hardground (arrow) is wavy but there are no apparent karst features, borings, or obvious mineralization surfaces. Hammer for scale.

2.3 DIAGENETIC FEATURES IN MUDMOUNDS

2.3.1 *Neptunian dykes*

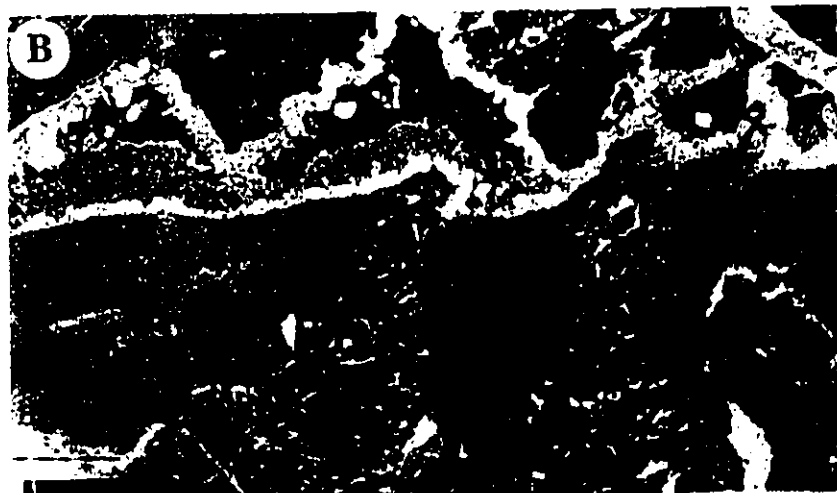
Neptunian dykes are common features in the mudmounds and result from early lithification of carbonate mud and differential loading causing fissures and cracks. These tend to be perpendicular to the top of the mound and range from a few centimetres up to a metre in width. The large dykes are filled by crinoidal grainstone (truncated capping facies) while the smaller ones are filled by fibrous calcite cement. The dykes are common in the mudmounds north of the 'rivermound' and in the Griffin Inlet mudmound but are uncommon in the mudmounds immediately south of the 'rivermound' (D17-D27).

2.3.2 *Cements*

Evidence of three main stages of calcite cementation and one stage of dolomitization has been recognized (Fig. 27A). The first two stages of cementation are represented by non-ferroan radial fibrous calcite that occurs in the cavities of the mudmounds. The first stage lined the cavities and the second grew subsequently into the remaining voids. Shelter cavities were also filled by this type of cement or, in places, the cavities were filled with diagenetic or depositional micrite. The

Figure 27. Diagenetic features in thin sections of core facies of the Griffin Inlet mudmound. Scale bars=5mm.

- A. Thin section photograph of cement generations (numbered) in a cavity filling in cross-section view:
- 1- non-ferroan radiaxial fibrous calcite.
 - 2- micrite partly infilling shelter cavities. This diagenetic micrite is laminated, is a lighter colour and more obviously crystalline than the original micrite.
 - 3- non-ferroan radiaxial fibrous calcite.
 - 4- zoned (iron-rich/iron-poor) blocky calcite.
 - 5- silt-sized micrite.
- B. Thin section photograph showing spicular micrite (Sp) with diagenetically altered micrite of probable microbial origin (M). The irregular (not smooth) nature of the micrite/spicular micrite boundary may represent a diagenetic front. Sucrosic medium-grained ferroan dolomite is the latest stage of cementation (6).



diagenetic micrite is lighter coloured and more obviously crystalline than the original micrite of the mounds (Fig. 27B). The third stage of cementation produced blocky calcite that largely filled much of the remaining void space. Zoning in the calcite is caused by alternating iron-containing and iron-free calcite. Another stage of infilling by a laminated silt-size carbonate postdated this stage of cementation. The final stage of cementation is represented by sucrosic ferroan dolomite that infilled fractures, cavities and also appears to have invaded the surrounding matrix. The radial fibrous calcite and micrite recrystallization likely occurred in a shallow marine environment soon after deposition. A deeper environment is suggested by the blocky zoned calcite that had alternating iron-rich and iron-poor water passing through the mudmound. Dolomitization was the final and deepest stage of diagenesis.

Stromatactoid structures are common features in the mudstone cores of the larger mudmounds. These are discussed in detail in the next section.

2.4 CORAL SKELETAL MOUNDS

Coral skeletal mounds (Fig. 28) are characterized by similar core facies, and fossil content, and by the lack of obvious flanking facies. Descriptions are based mostly on the eastern Goose Fiord mound (GF1), as this mound was studied in most detail. GF2 was studied in some detail but discontinuous exposures made it difficult to measure sections. Exposures at Walrus Fiord and Colin Archer Peninsula were looked at briefly during reconnaissance of the area.

2.4.1 Morphology and lithofacies

The coral skeletal mounds vary in size. The eastern Goose Fiord mound (GF1) is 30m in height and approximately 100m in diameter, and the other coral skeletal mounds range from 25-50m in height and 75-200m in diameter. They have stromatactoid-rich mudstone cores, and an upper coral-rich floatstone facies and crinoidal wackestone facies. The mudstone cores grade upwards into the coral-rich facies, which grades laterally and upwards into crinoidal wackestone. No flanking facies are exposed at any of the localities, and therefore it is unknown whether they were originally present.

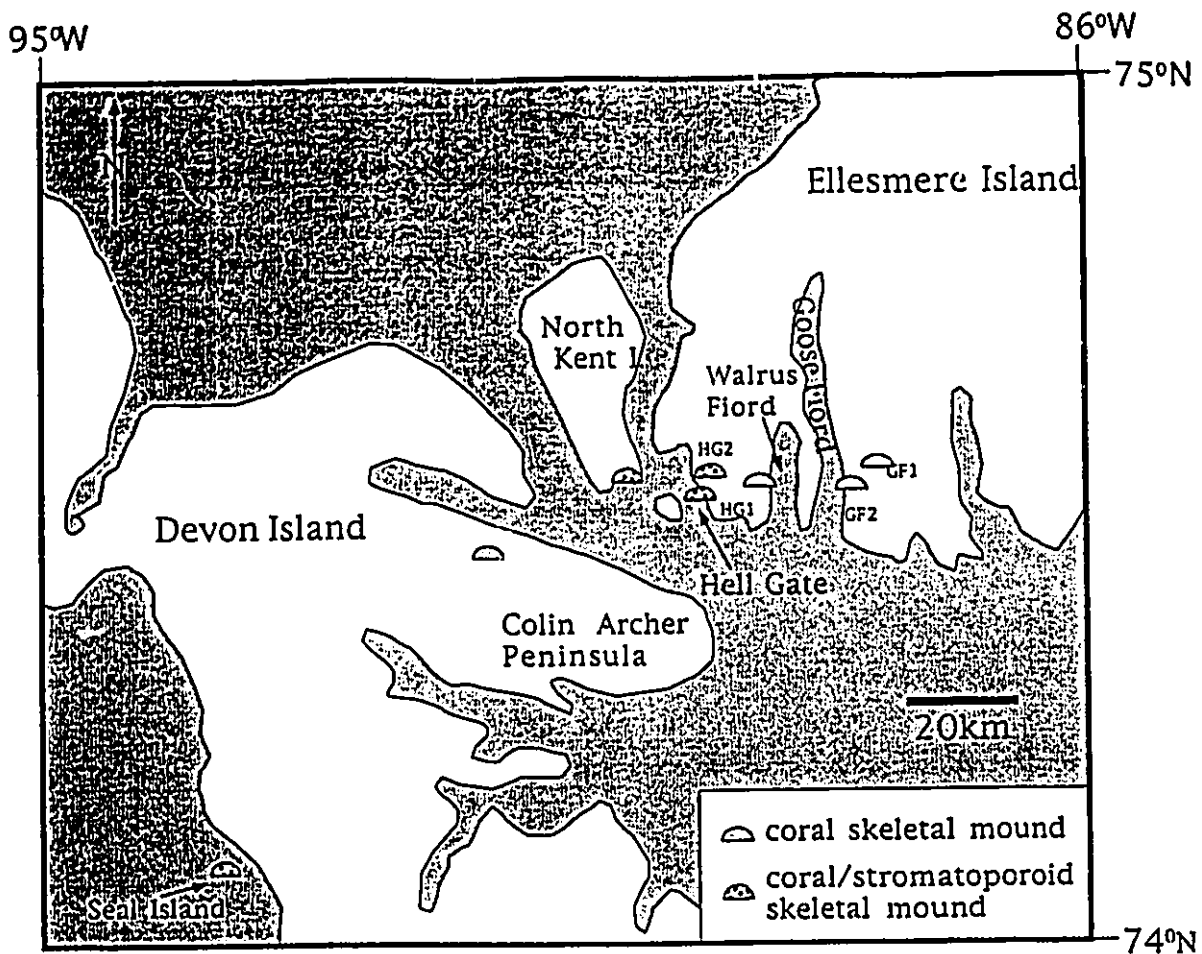


Figure 28. Location of Upper Silurian skeletal mounds in the study area. The distribution and stratigraphic relationships of relevant formations are difficult to represent clearly at this scale, because of structural complexity. Maps representing the geology of the region can be found in Thorsteinsson and Mayr (1987, Map1614A) and Mayr *et al.* (1994, Map1840A).

No contacts between the mounds and the Douro Formation were recognized at any of the localities. The base of the GF1 mound was ice covered in 1992, but was exposed in 1981 (Dixon, pers. comm.). At that time the mudstone core facies was seen to rest directly on buff/orange-weathering dolosiltite, closely resembling a distinctive resistant unit of dolosiltite several metres thick that occurs at the Douro/Devon Island formational boundary in the vicinity of both Goose Fiord skeletal mounds. The position of nearby outcrops of the Douro Formation suggests that the bases of the mounds are at the Douro/Devon Island formational boundary.

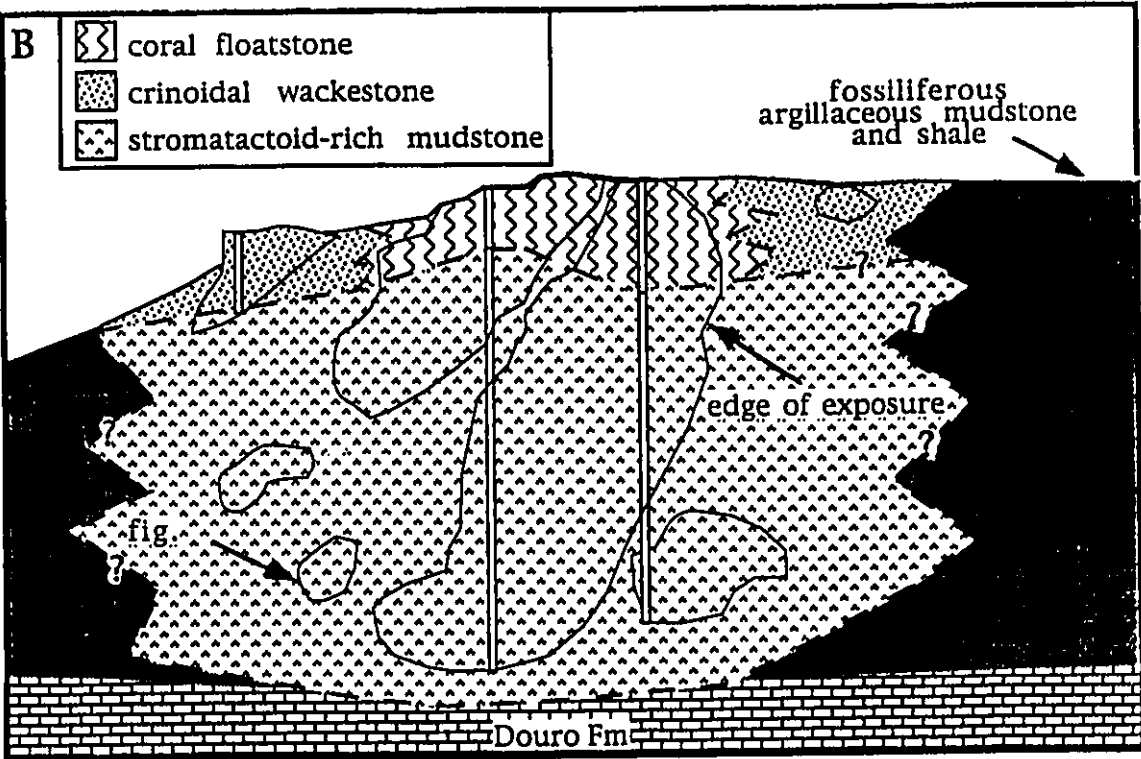
Although the Devon Island Formation weathers recessively, the presence of rubble from it near the mound margins, suggests that the coral skeletal mounds, now exposed, were once surrounded by shales of the Devon Island Formation. These sediments near the GF1 skeletal mound, are more diversely fossiliferous than the typically graptolitic shales of the lower member of the Devon Island Formation and may represent the upper carbonate member of the Devon Island Formation.

The main rock types of the GF1 coral skeletal mound are massive carbonate mudstone, coral floatstone and crinoidal wackestone (Fig. 29A,B). The massive mudstone composes the basal core and although it

Figure 29. Goose Fiord coral skeletal mound (GF1).

- A. Field photograph of mound, viewed to the west. Height of exposure at centre about 33m.
- B. Sketch of A showing generalized mound succession. Arrow pointing from 'fig' shows location of the amalgamated mudmounds (3m in height) of figure 33. Vertical bars represent measured stratigraphic sections.

A



is relatively unfossiliferous there are abundant stromactactoid structures in the otherwise monotonous facies. Smaller mounds appear to have amalgamated together forming a larger mudmound. The stromatactoid structures follow the dip of the smaller mounds. 'Classic' stromatactis, as defined by Bathurst (1959), is present but variations of this structure are more common and are called stromatactoid structures. These are discussed in detail in the section on diagenesis. These structures vary in size (0.5cm-5cm in height and 1-15cm in length), shape (flat or more vertically extended) and extent of interconnection with other stromatactoid structures (isolated or very interconnected) (Fig. 30A,B,C). The basal portion of the mudstone at GF1 has small isolated structures, while near the top of the mudstone the stromatactoids are larger and laterally continuous. These two types of stromatactoids can be seen as end members; various intermediate types are present in the mudstone facies. Although present at GF1, the best example observed of laterally continuous stromatactoids is exposed at GF2 (Fig. 31A,B).

Figure 30. Stromatactoid structures in Goose Fiord (GF1) skeletal mound in cross-section view. The field photographs show different types of structures within the mudstone cores facies. Hammer for scale for all three photos (photos OAD).

- A. Sparse stromatactoid structures (arrow)
- B. Intermediate stromatactoid structures (classic 'stromatactis').
- C. Laterally continuous stromatactoid structures.

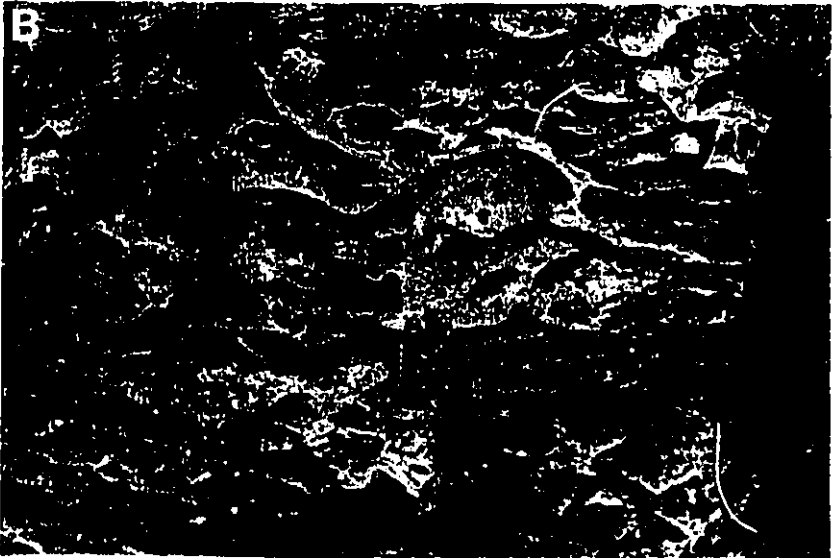
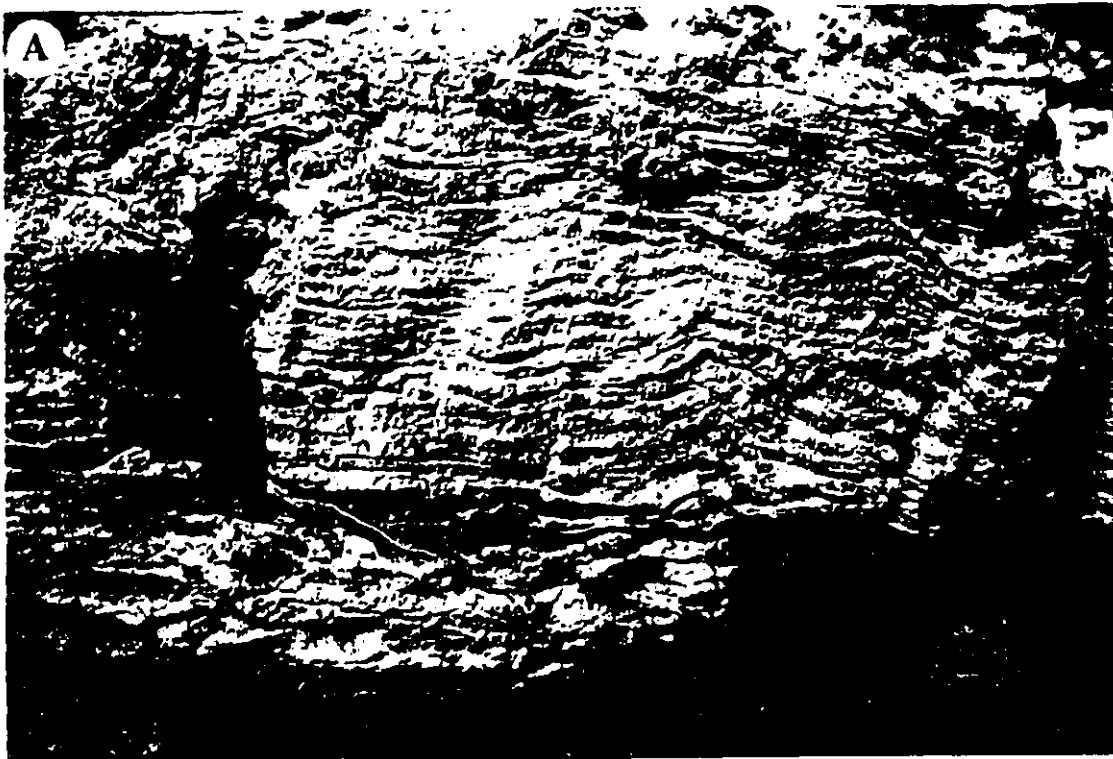


Figure 31. Stromatactoid structures in Goose Fiord (GF2) skeletal mound.

- A. Field photograph of laterally continuous stromatactoid structures in the mudstone facies in cross-section view. Lens cap is 5cm in diameter.
- B. Thin section photograph of mudstone from the outcrop in A. The mudstone and stromatactoid structures have been completely replaced by fine-grained non-ferroan dolomite. Relict spicular micrite (S) and the isopachous nature of the originally calcite cement are still preserved. The white areas in the middle of the stromatactoid structures are medium-crystalline ferroan dolomite. Scale bar=1cm.



2.4.2 Fossils

Corals

The coral-dominated facies contains four main coral types although preservation was too poor to permit identification of all of the different genera. Branching growth forms are most common, with fewer tabular and solitary forms present. The GF1 skeletal mound contains the following corals, in decreasing order of abundance:

1) fasciculate rugosans with corallite diameters of 5mm, 2)

Rhizophylloides, 3) fasciculate Tabulata with flat tabulae, reduced septa

and corallite diameters of 3mm, and 4) syringoporids with funnel-

shaped tabulae and corallite diameters of 3mm. Other corals that are

present but not abundant are tabular *Favosites*, solitary *Mucophyllum*,

Cystiphyllodes and fasciculate rugosans with corallite diameters of

2mm, 4mm, 6mm, and 10mm each representing a different species.

Heliolitids and solitary rugose corals are most common in the sediments surrounding the coral skeletal mounds.

The same types of corals are present in the Walrus Fiord coral skeletal mound, but on Colin Archer Peninsula this coral facies is represented by a 3m thick stylopleurid-coral floatstone.

Crinoids

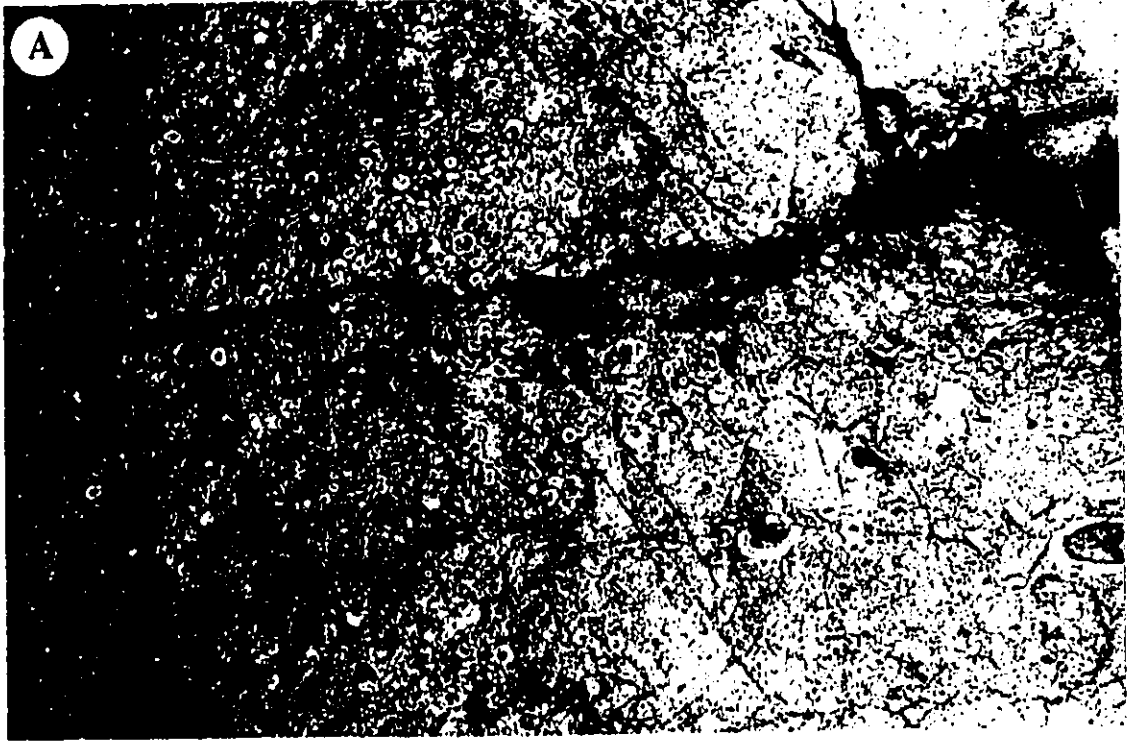
Crinoidal debris is present throughout the GF1 skeletal mound, occurring in local patches of wackestone in the mudstone core, and as a 4-5m thick wackestone on the margins of the mound. The crinoidal material is unsorted and crudely cross-bedded, with stem plates varying from 4mm to 1.5cm in diameter (Fig. 32A).

Other associated fossils

The skeletal mounds (GF1, GF2) do not host a large or diverse fossil assemblage. Brachiopods, trilobites, gastropods and orthoconic cephalopods are present but not common. The surrounding sediments of the Devon Island Formation, at GF1, contain a more diverse fossil assemblage including *Heliolites*, *Favosites*, solitary rugose corals, bryozoans, brachiopods (atrypoids), lithistid sponges, crinoidal debris and calcareous algae. Further away from the mound (GF1) the fossils are very small with little size variation within the different fossil types (Fig. 32B). This biota occurs episodically and is associated with hardbands. These hardbands are later diagenetic features and are not hardgrounds.

Figure 32. Crinoidal wackestone in the Goose Fiord skeletal mound (GF1) and fossiliferous hardband of the Devon Island Formation.

- A. Field photograph of unsorted crinoidal wackestone in the crinoidal wackestone facies in cross-section view. Hammer for scale.
- B. Hand specimen of fossiliferous surface from mudstone near the GF1 mound in bedding plane view. The fossils are small with little diversity. B=atrypoid brachiopod; S=sponge; C=calcareous alga; Cr=crinoidal debris. Slab is 16 cm in length.



2.4.3 Lateral and vertical zonation

The coral skeletal mounds exhibit an overall vertical zonation from a basal mudstone facies into either a coral-rich facies or a crinoidal wackestone facies. The upper portion of the GF1 coral skeletal mound exhibits a simple lateral zonation. The coral floatstone facies changes laterally into a 'dense' crinoidal wackestone away from the skeletal mound core. Beyond the crinoidal wackestone, the surrounding sediments are orange-weathering calcareous shale and wackestone of the Devon Island Formation, although no contact is exposed.

2.4.4 Depositional environment and mound growth

Coral skeletal mounds are carbonate build-ups with a stromatactoid-rich mudstone core overlain by coral-rich floatstone and capping crinoidal wackestone. There is evidence that the amalgamation of smaller mudmounds was a significant factor in enlargement of the mudstone cores (Fig. 33).

The mudstone facies contains little fossil material except for local corals and crinoidal debris. The most conspicuous components are the



Figure 33. Amalgamated mudmounds (Mm) in the Goose Fiord (GF1) skeletal mound. The dashed line marks the boundary between two small mudmounds in the core facies.

abundant stromatactoid structures that dominate the core facies. As growth continued upward apparently into more shallow water the corals increasingly colonized and eventually dominated mound surfaces.

Although no crinoidal material like that exposed on the mound margins presently caps the mounds, this is likely an effect of present-day exposure. The unsorted nature of the material and crude cross-beds are consistent with the material being transported only very short distances from the tops of the mounds to their margins. Crinoidal wackestone is inferred to have been the final deposit associated with the coral skeletal mounds before the termination of mound growth. The latter was likely caused by deepening and onlap of muds during early deposition of the Devon Island Formation.

The unusually fossiliferous and calcareous nature of the Devon Island Formation in proximity to the coral skeletal mounds may reflect the influence of the mounds on the local environment. Increased water circulation locally could have promoted organic activity and the generation of carbonate sediments. The presence of apparently dwarfed fossil assemblages in the remaining formation suggests that this environment was less than ideal, possibly with lowered oxygen levels and increased rates of mud deposition. The episodic occurrence

of the fossil biota may reflect fluctuating aerobic and anaerobic conditions.

2.5 CORAL/STROMATOPOROID SKELETAL MOUNDS

Coral/stromatoporoid skeletal mounds (Fig. 28, see p. 75) have distinct core and flanking facies that are different in lithology, fossil content and inferred depositional environments. Because these facies are presently known largely from separate exposures, they are discussed separately below. The descriptions of mound cores are based on skeletal mounds exposed on Seal and North Kent islands, and in an unnamed stream near Hell Gate (HG2). Descriptions of flanking facies are based on the mound SE of Hell Gate (HG1) where they are exposed in an extensive cliff transect. Table 3 provides a summary of the core and flanking facies and fossil content.

2.5.1 Morphology

The incompleteness of the various exposures makes it difficult to determine the sizes of the complete coral/stromatoporoid skeletal mounds (Fig. 34). The Seal Island skeletal mound has very little vertical exposure with only ~12m of stratigraphic thickness exposed. The skeletal mound at HG2 has a diameter of over 580m and an exposed stratigraphic thickness of 64m. The sea cliff on the east shore

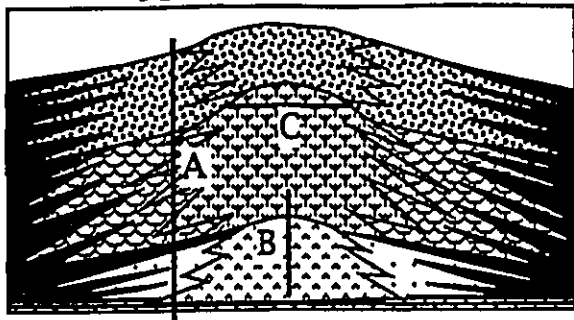
<i>lithofacies</i>	<i>description</i>	<i>fossils</i>	<i>petrographic observations</i>
core	<ul style="list-style-type: none"> - stromatolite-rich, massive, grey mudstone with lenses of crinoidal wackestone, few skeletal fossils - coral/stromatoporoid floatstone 	large fasciculate rugosans, lamellar favositids, tabular stromatoporoids, crinoidal debris, bryozoans, trilobites and calcareous algae	extensively dolomitized, relict spicular and microbial micrite
flanking	steeply dipping, fossil debris-rich wackestone-packstone, with shale interbeds	lamellar favositids, fasciculate rugosans, solitary rugosans, heliolitids, lamellar and domal stromatoporoids, crinoidal debris, bryozoans, and brachiopods	extensively dolomitized, more argillaceous and debris-rich than core facies

Table 3. Descriptions of coral/stromatoporoid skeletal mound facies and fossil content.

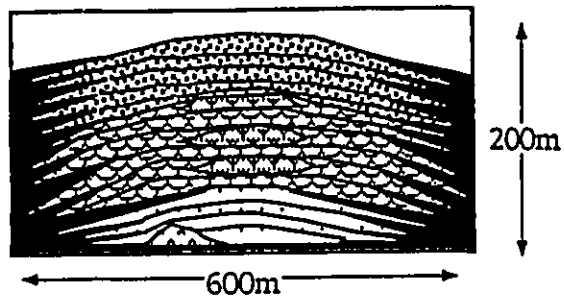
Figure 34. Reconstructed cross sections (1-based on A,B,C and 2-based on D) through coral/stromatoporoid skeletal mounds. Bold lines with letters A to D show the interpreted positions of various studied exposures:

- A. Hell Gate cliff (HG1) - a vertical cross section near the flank of a skeletal mound.
- B. Hell Gate stream (HG2) - a vertical cross section with no flank beds or basal contacts exposed.
- C. Seal Island - entire island consists of laterally extensive, gently dipping core facies, with a cumulative stratigraphic thickness of 10-12m.
- D. North Kent Island - represented as a profile of cliff exposure of a skeletal mound. At least 400m of the lower facies is exposed along shore.

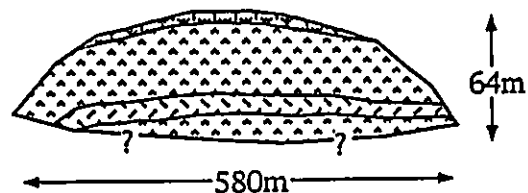
#1 Hypothetical cross section



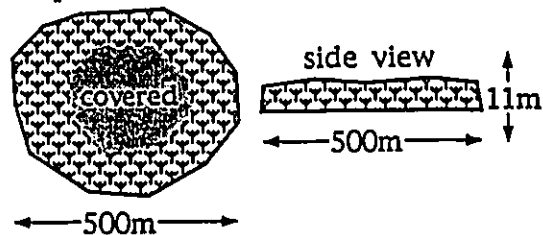
A Hell Gate cliff (HG1)



B Hell Gate stream (HG2) cross section

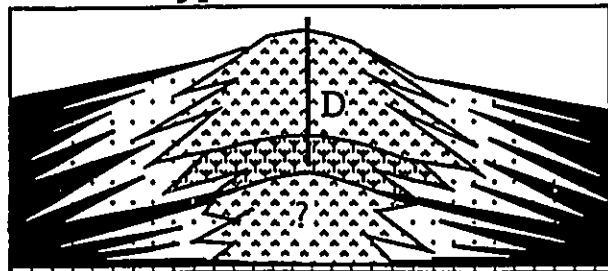


C Seal Island skeletal mound plan view



- calcareous shale and mudstone
 - ▨ crinoidal wackestone-packstone
 - ▨ coral/stromatoporoid/crinoidal wackestone
 - coral/crinoidal wackestone
 - ▨ crinoidal wackestone-packstone
 - ▨ coral/stromatoporoid floatstone
 - ▨ bryozoan wackestone
 - ▨ stromatactoid-rich mudstone
 - ▨ argillaceous limestone
- Flank
- Core

#2 Hypothetical cross section



D North Kent Island

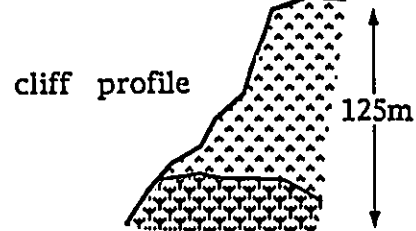


Figure 34

at Hell Gate exposes a transect through the flank beds of apparently the largest skeletal mound (HG1, Fig. 35). These flank beds are over 200m in stratigraphic thickness and extend at least 600m laterally. Dips range from near horizontal in distal flank beds to as high as 45° in beds nearest the core. The structural attitudes and position of facies at HG1 suggest that most of the mound core was once seaward of the cliff but has been largely removed by erosion.

2.5.2 Core lithofacies

The lower parts of the coral/stromatoporoid skeletal mound cores are generally massive and less fossiliferous than the flank beds. Upper facies, except at North Kent Island, are coral/stromatoporoid-rich, and consist of coral or stromatoporoid floatstone with a markedly higher fossil abundance but lower diversity than in the flanking facies.

The lower core facies is composed of massive mudstone with relatively thin units containing low diversity skeletal fossil assemblages. These are represented at HG2 by a 10m thick bryozoan wackestone unit, and two units of stylopleurid floatstone: the lower unit with gregarious stylopleurids and the upper with colonial stylopleurids (Fig. 36A,B). Within these units one species is generally abundant. At HG2, a facies transition occurs between the bryozoan wackestone and



Figure 35. Coral/stromatoporoid skeletal mound at Hell Gate (HG1).
Photograph represents an oblique view of the sea cliff exposure
looking towards SE and showing flank beds of the skeletal mound
dipping 15° to 45° into the cliff.

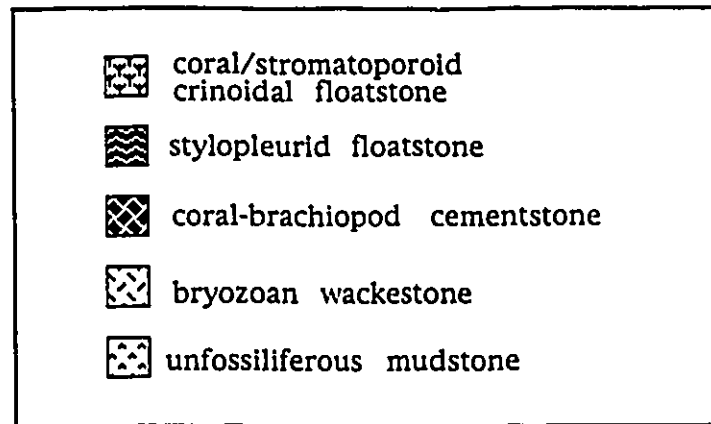
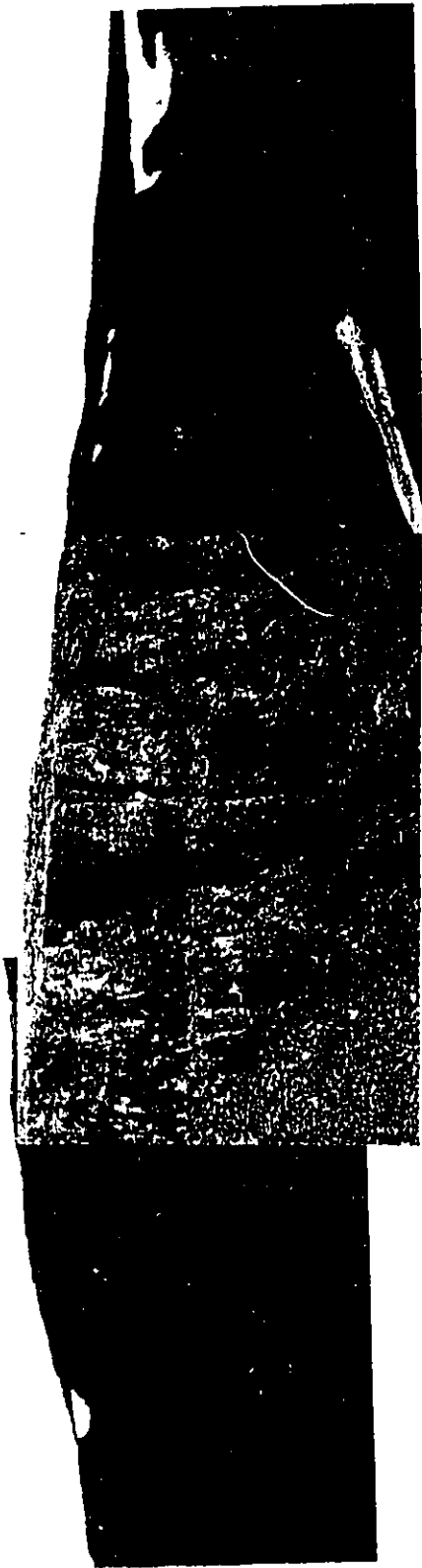


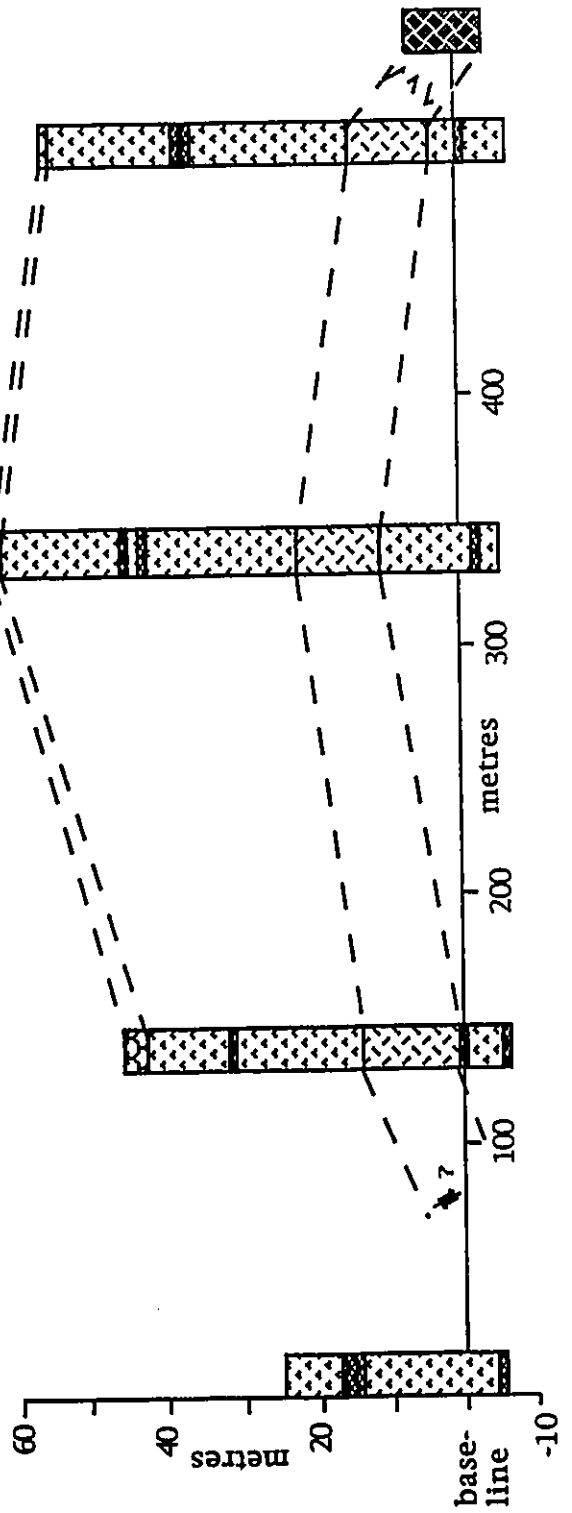
Figure 36. Coral/stromatoporoid skeletal mound (HG2) near Hell Gate.

- A. Panoramic view of the north side of the stream canyon exposure.
- B. Measured stratigraphic sections from the south side of the stream canyon. The fault shown towards the left is a later tectonic feature. The base line is a levelled line.

EAST



WEST



coral/brachiopod cementstone, likely representing the transition between the core and flanking facies.

Most of the mounds show an upwards zonation from a mudstone facies into the coral or coral/stromatoporoid facies. The mound at North Kent Island differs in that the lowest exposed portion of the mound is 5-10m of coral/stromatoporoid floatstone, and is overlain by approximately 110m of mudstone with two thin units of coral/stromatoporoid boundstone. A suggested interpretation of this succession is represented in figure 34.

Stromatactoid structures are a common and conspicuous feature of the mudstone facies and are similar to those present in the coral skeletal mounds. These are described in detail in the following diagenesis section.

2.5.3 Core fossils

Corals

Within the lower portion of the HG2 mound core the most common corals are gregarious and colonial stylopleurids. Their corallites range from 1-4cm in corallite diameter and 5-8cm in length with colonies

averaging 0.5m in height and 1.5m in width (Fig. 37A). Mucophyllids (solitary rugosans) are also present within the lower mound core and have basket shapes that are 4cm across at the widest part. Lamellar forms of *Favosites* (cerioid tabulate) are next in order of abundance and average 5cm in height and 15cm across.

In the upper portions of the HG2 core, fasciculate rugosans are the most abundant corals in the coral floatstone. Different taxa with different corallite diameters (from 5-8mm), tend to occur separately and in thickets with colony sizes averaging 30cm x 30cm (Fig. 37B). Lamellar specimens of *Favosites* are common within this facies and colonies vary from 2-8cm in height and 8-40cm in diameter.

Stromatoporoids

Stromatoporoids in the core facies are typically dolomitized and are beige-weathering with a massive texture and little or no preserved microstructure. Lamellar growth forms are common and locally abundant in the mound core exposure on Seal Island (Fig. 38A,B) and in the lowest exposed portion on North Kent Island (coral/stromatoporoid facies). The stromatoporoids vary from 3-30cm in height and 10-75cm in diameter.

Figure 37. Field photographs of large coral colonies in coral/stromatoporoid skeletal mounds.

- A. Cross-section view of *in situ* stylopleurid coral colony in the upper stylopleurid coral-rich unit in the HG2 skeletal mound near Hell Gate. Jacob's staff is 50cm long.

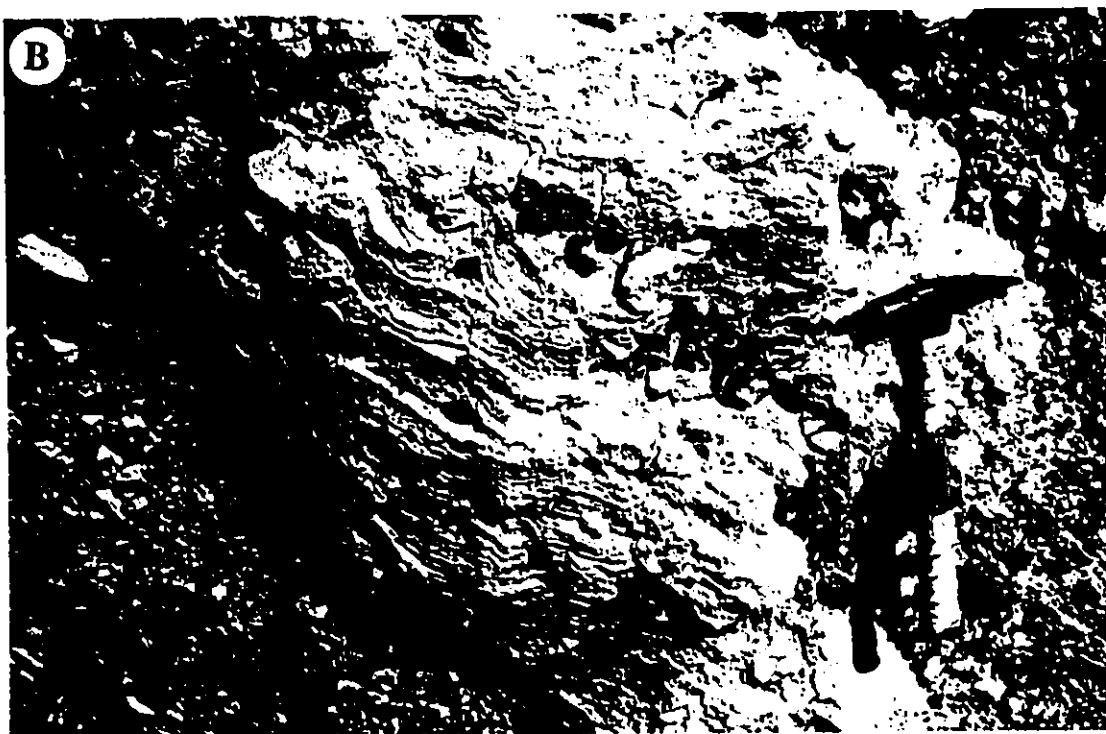
- B. Bedding plane view of *in situ* fasciculate rugosan colony in the lowermost exposure of the North Kent Island skeletal mound. Individual colonies averaged 30cm x 30cm, with corallite diameters of 4mm. Hammer for scale.



Figure 38. Field photographs of stromatoporoids in coral/stromatoporoid skeletal mounds.

- A. Stromatoporoid-rich unit in the Seal Island skeletal mound in cross-section view. Many of the stromatoporoids are overturned or on their sides. Hammer for scale.

- B. Dolomitized stromatoporoid in North Kent Island skeletal mound. Hammer for scale.



Bryozoans

Stick forms of trepostomate bryozoans are abundant in one interval in the HG2 mound core, and occur locally in exposures near sea-level in the mound on North Kent Island; otherwise they are rare in the mudstone of the core facies. Bryozoan wackestone forms a 10m-thick unit that extends through the core near the bottom of the HG2 stream exposure, and is intercalated with flank beds of coral/brachiopod wackestone.

Crinoids

Unsorted crinoidal stem plates are common in the core facies and vary from 4mm to 1.5cm in diameter. Large portions of stems, up to 15cm in length and 1.5cm in diameter, are present locally.

Other associated core fossils

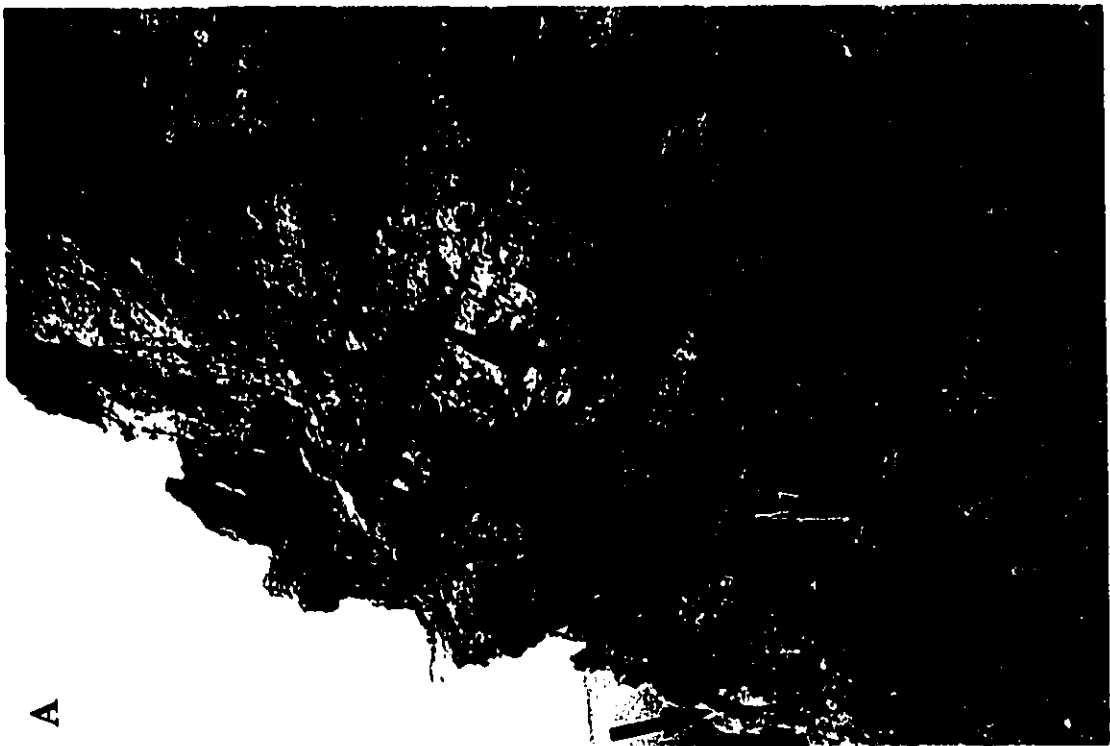
Brachiopods (atrypoids), gastropods (high-spired) and orthoconic cephalopods are locally abundant.

2.5.4 Flanking lithofacies

Steeply dipping, well-bedded wackestones are the predominant flank beds at HG1 (Fig. 39A). Shale interbeds are common in the lower

Figure 39. Flank beds of the coral/stromatoporoid skeletal mound (HG1) SE of Hell Gate.

- A. Steeply dipping (25-39° into the cliff) coral/stromatoporoid/crinoidal wackestone beds. The top of the massive bed (arrow) is at 60m in section 1 (Fig. 42). The beds above become thicker upwards and have progressively fewer shale interbeds.
- B. Thin resistant flank beds of coral/stromatoporoid/crinoidal debris on the southeast side at HG1. Shale interbeds are much thicker than in A.



portion of the flank bed sequence, while in the upper portion the wackestone beds are thicker with less interbedded shale. The most distal flank beds (Fig. 39B) have shale interbeds over 6m in thickness; these thin to ~0.5m between the most proximal flank beds.

The proximal flank beds dip at angles up to 45° (into the cliff) and dips decrease distally. Large olistoliths of brecciated core material up to 10m x 25m are present at two levels in the flanking sequence. The blocks of core material consists of mudstone clasts (<1cm to ~20cm) and local fossil debris at the lower level, and of broken coral/stromatoporoid floatstone at the upper level. This core material was brecciated, cemented and later transported downslope as large blocks. The brecciated material was extensively dolomitized to coarse and fine-grained dolomite, but is cemented by coarse calcite, giving the blocks a different weathering character than the surrounding beds. The beds below these yellow-weathering blocks are downwarped while the beds above drape over them (Fig. 40).

: The steepness of the Hell Gate cliff exposure prevented investigation of much of the upper portion of the flank bed sequence. One of the stratigraphic sections documented spans the complete flank bed sequence exposed on the cliff on the northeastern side of the skeletal

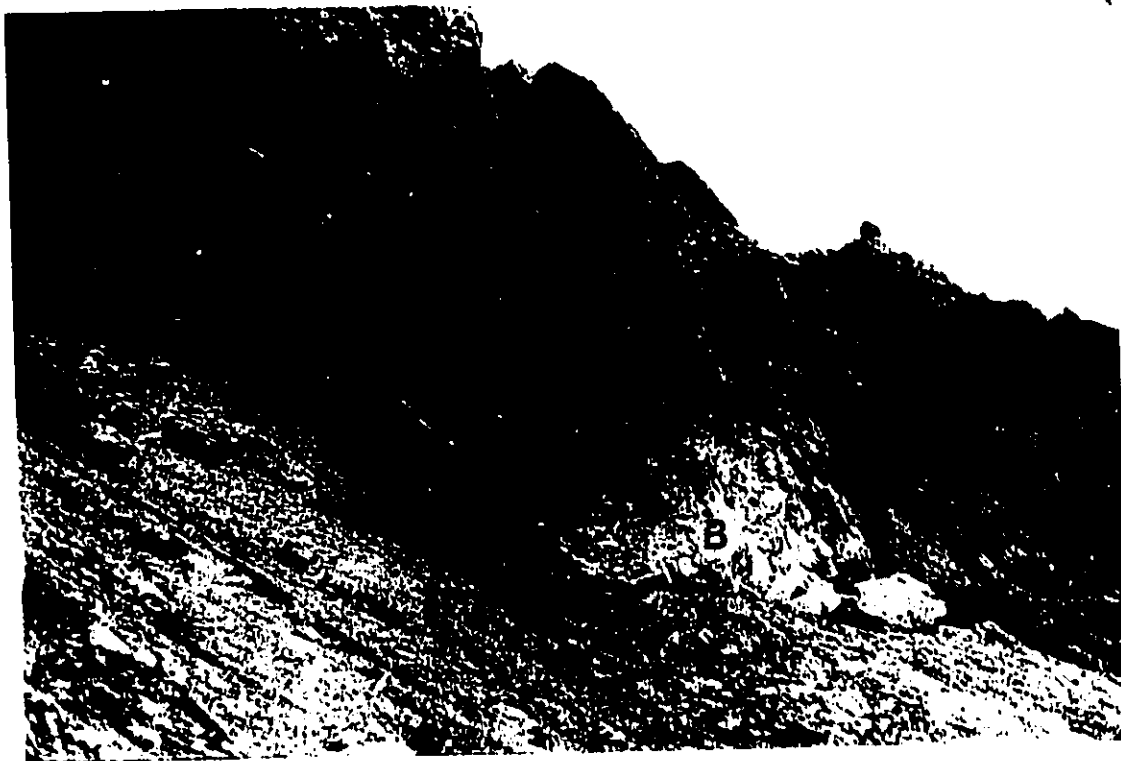


Figure 40. Block of brecciated core mudstone in flank beds of the coral/stromatoporoid skeletal mound (HG1) SE of Hell Gate. The light yellow-beige weathering contrasts with the grey-weathering flank beds. Beds below the block are downwarped; those above drape over the block. Block (B) is 3m high.

mound (Fig. 41A,B; Fig. 42). The lower part of this sequence consists of medium- to thick-bedded (averaging 40cm) crinoidal/coral wackestones with thin shale interbeds. Thicker shale interbeds (generally 25-50cm thick) occur at 9m and from 26-31m, and a 6m shale unit begins at 33m.

The lower portion of the flank bed sequence was more accessible and several stratigraphic sections were documented across the cliff exposure (Fig. 43). This was the portion studied by Brent (1987) as the 'lower Hell Gate Reef'. A distinctive facies in this lower area is stromatactoid-rich mudstone that represents the basal facies of the skeletal mound and the only exposed part of the core facies (Fig. 44A, B). This exposure is presumed to represent an off-centre portion of the skeletal mound core.

2.5.5 Flank bed fossils

Corals

Lamellar and fasciculate corals are the most common forms in the flank beds. Lamellar *Favosites* are very abundant and vary from 2-50cm in height and 4-100cm in diameter. Some smaller specimens of

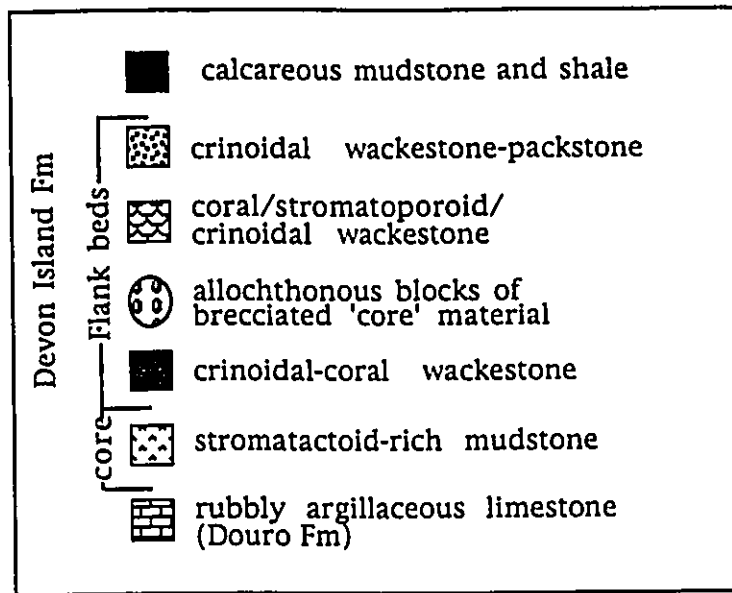
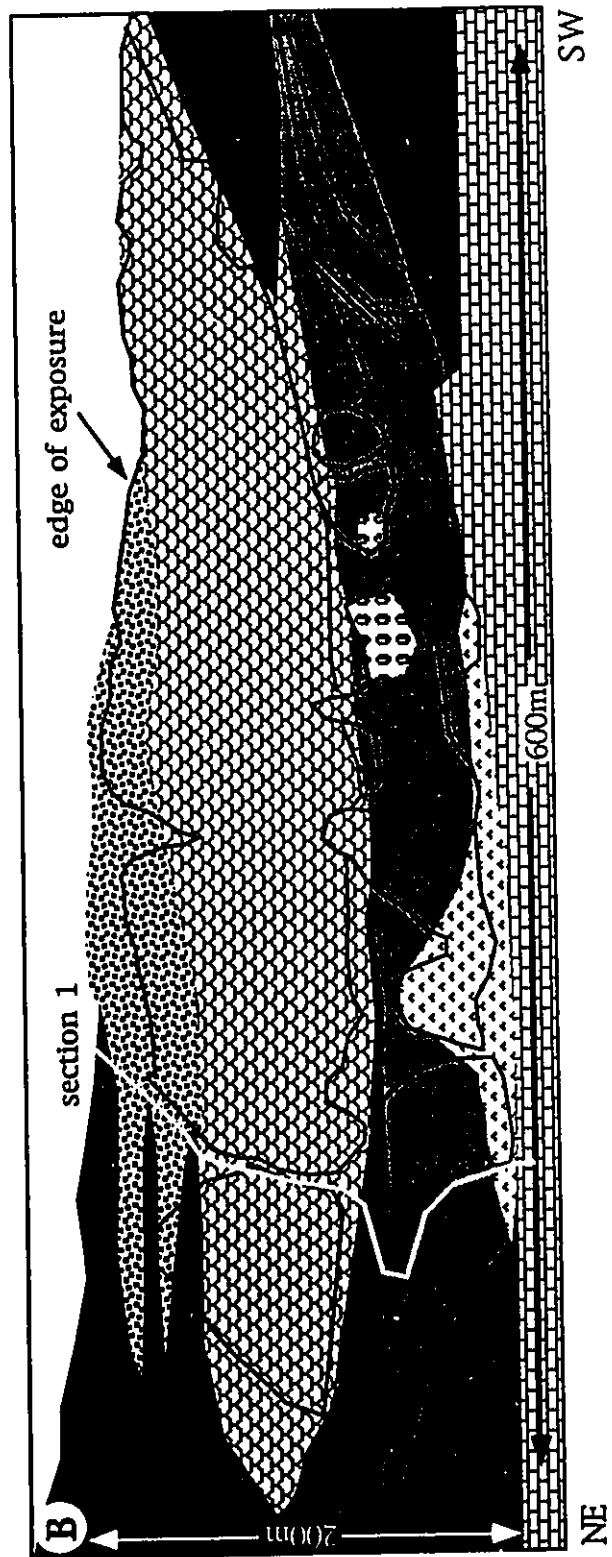


Figure 41. Coral/stromatoporoid skeletal mound (HG1) SE of Hell Gate.

A. Panoramic view (eastward) of the sea cliff exposure.

B. Sketch of A showing generalized succession of facies. The fault shown on the right is a younger tectonic structure.



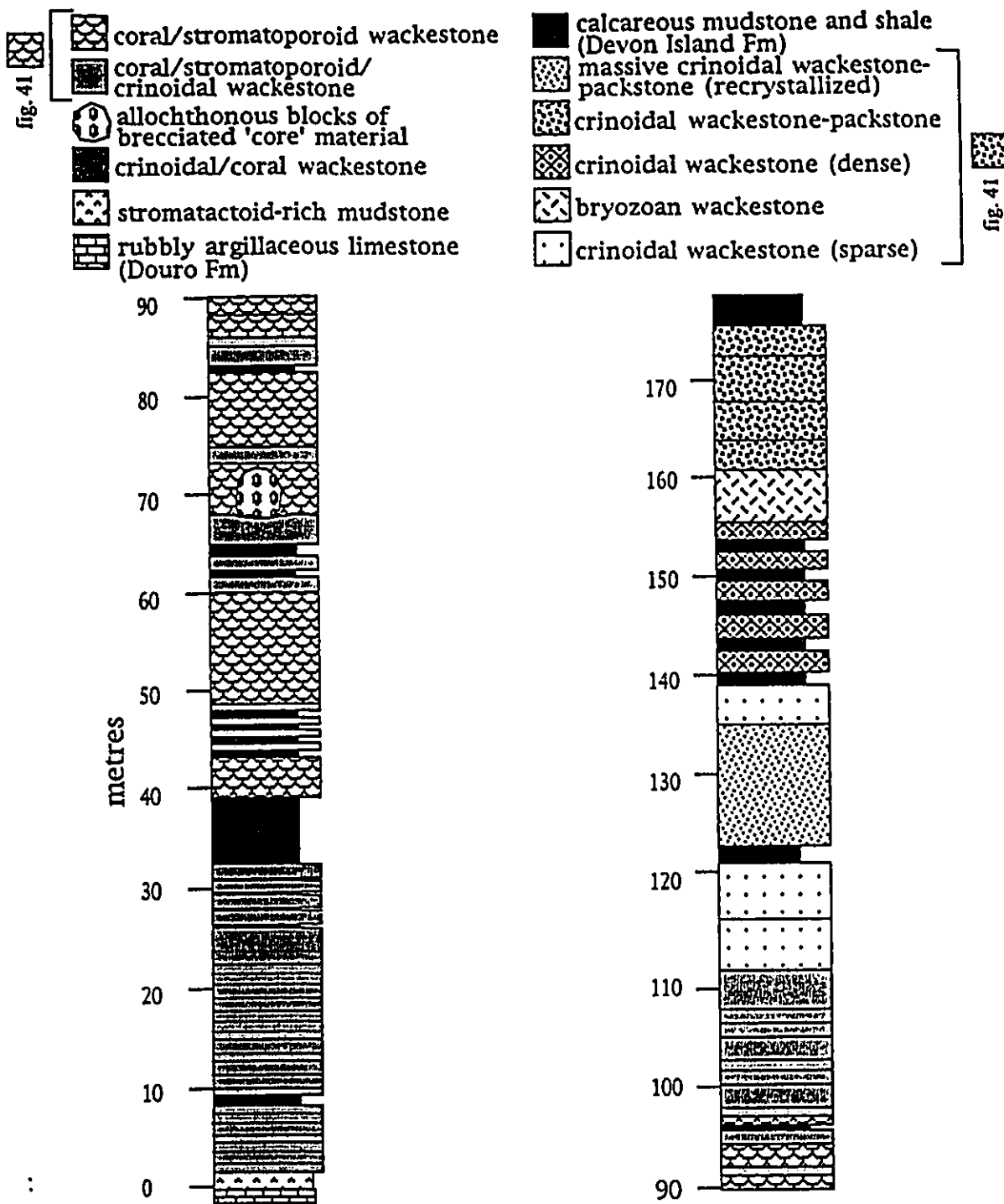


Figure 42. Stratigraphic section (section 1 in Fig. 41) largely representing facies flanking the coral/stromatoporoid skeletal mound (HG1) on sea cliff SE of Hell Gate. The flanking facies rest on mudstone of the mound core, and are intercalated with black shale of the surrounding Devon Island Formation. The blocks consist of brecciated coral/stromatoporoid material that appears to have been derived from the core facies. Some of the units are grouped together in figure 41 due to scale differences.

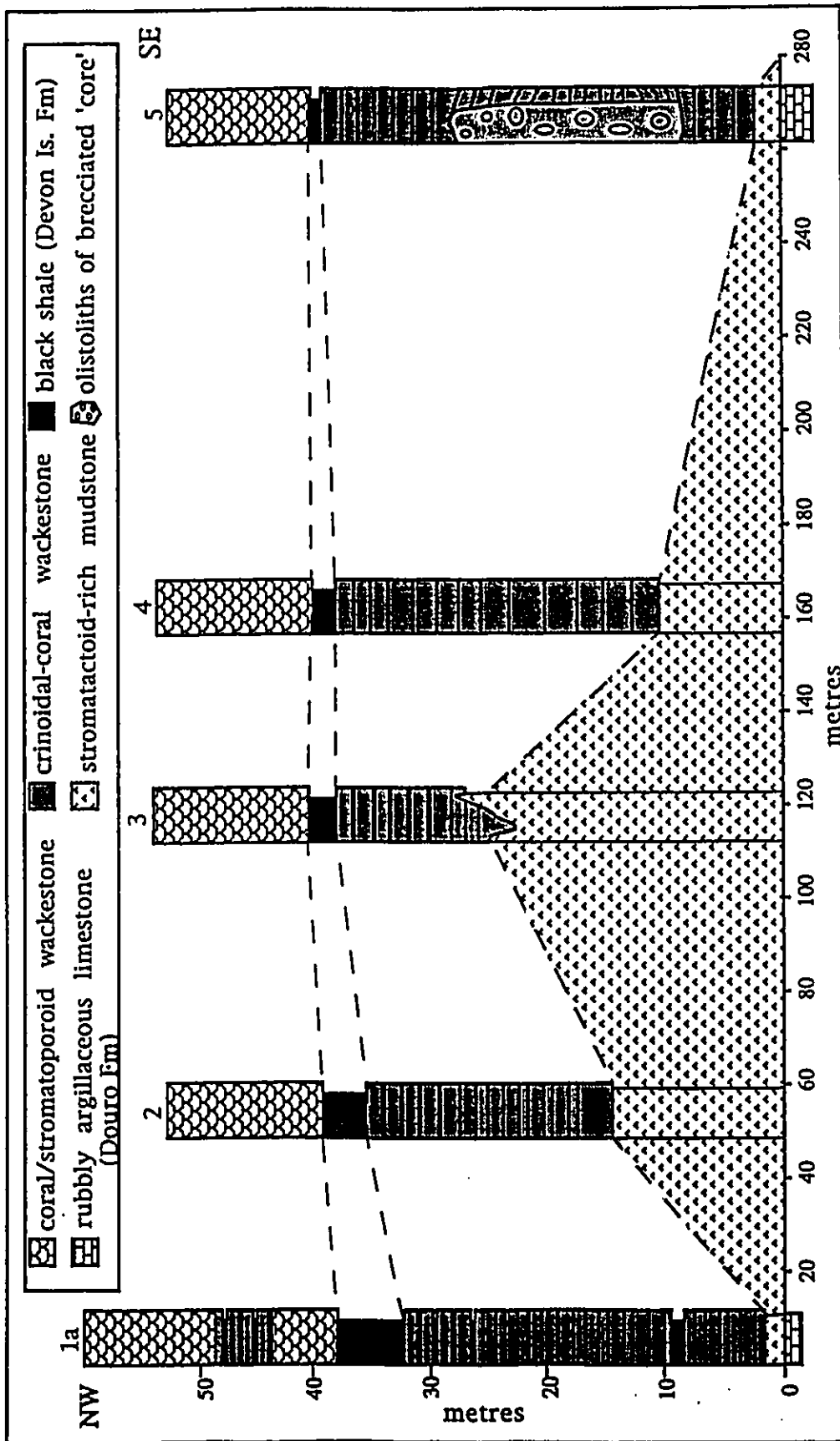
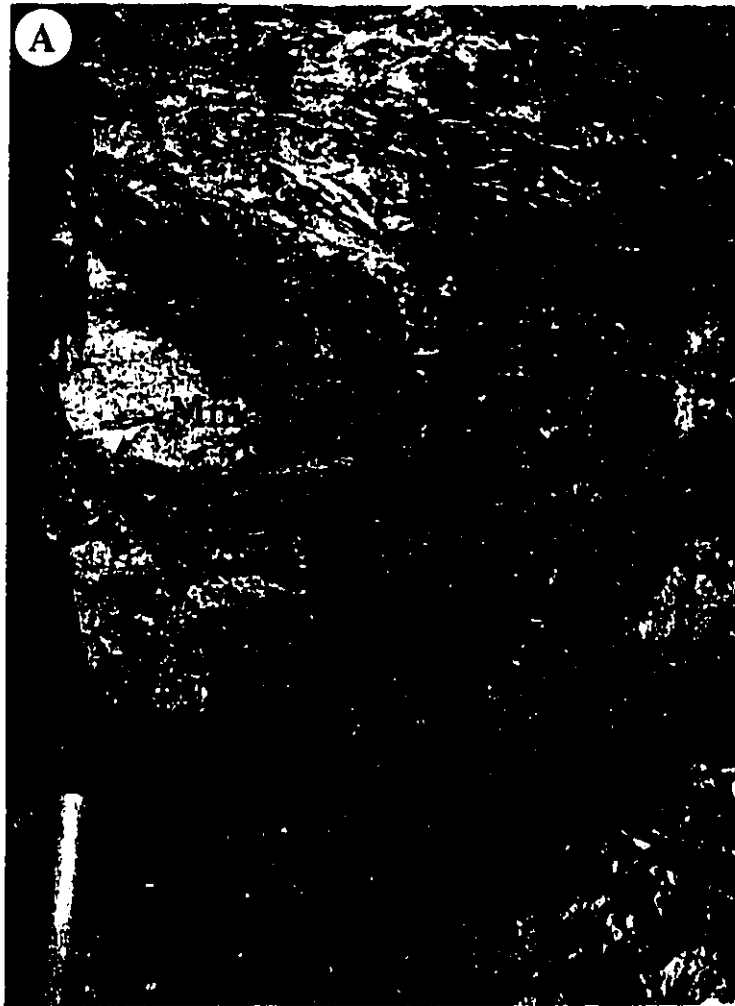


Figure 43. Measured stratigraphic sections through the lower portion of the HG1 skeletal mound and associated flanking facies on seaciffs SE of Hell Gate. The stromatactoid-rich mudstone unit at the base of all the sections is the initial facies of the skeletal mound. Section 1a is the basal part of the section shown in figure 42.

Figure 44. Field photographs of stromatoid-rich mudstone in basal core of the coral/stromatoporoid skeletal mound (HG1) SE of Hell Gate.

- A. Stromatoid-rich mudstone resting on rubbly argillaceous limestone of the Douro Formation (Do) in cross-section view. The arrow marks the base of the mudmound (Mm). Hammer for scale.
- B. Bedding plane view of dark organic-rich mudstone filling stromatoid structures in the mudstone facies. Scale bar=2cm.



Favosites are fragments but most are whole. Fasciculate rugosans are next in order of abundance and colonies vary from 5cm to 30cm in diameter. Mucophyllids and other solitary rugosans are common and while some are overturned many appear to be *in situ*. These corals vary from 1-2.5cm in diameter and 2-5cm in height.

Heliolitids are more common in the shale-rich most distal flank beds. Closer to the mound core lamellar *Favosites*, fasciculate rugosans, and fasciculate tabulates are more common.

Stromatoporoids

Stromatoporoids in the flank beds are not as well-preserved as the corals, are recrystallized to a massive texture, and weather beige. Lamellar growth forms are most common and vary from 2-10cm in height and 5-35cm in length. Domal stromatoporoids averaging 3-5cm in diameter and 2-4cm in height are less abundant.

Bryozoans

Stick forms of trepostomate bryozoans, 3mm in diameter and 2-3cm in length, occur in a 5m-thick wackestone near the top of the flanking facies at HG1. This unit is similar in lithology and fossil content to the bryozoan unit in the skeletal mound core facies of HG2.

Crinoids

Unsorted crinoidal stem plates are common and range from 2mm to 1.5cm in diameter and 3-4cm in length, although some stem portions are up to 8cm long. Some of the crinoidal wackestones, in the basal portion of the HG1 flank bed sequence, show low-angle cross-bedding. The amount of crinoidal material increases in the more distal portions of the flank beds. More dense crinoidal wackestone-packstone is present in the upper 15m of the flank bed sequence.

Other associated flank bed fossils

Orthoconic cephalopods, trilobites, gastropods (high-spired) and calcareous algae (solenoporids) are locally common in the flank beds, and brachiopods locally common or abundant.

2.5.6 Lateral and vertical zonation

The flank beds in HG1 show distinct lateral changes in flank bed thickness and fossil content. The most proximal beds (near the centre of the cliff exposure) are up to 5m thick, contain larger and more *in situ* corals and stromatoporoids, and have few, thin shale interbeds. The most distal flank bed wackestone units are 5-30cm thick, with shale

interbeds 5-100cm thick. The amount of crinoidal material increases distally and heliolitid corals are more common.

No distinct lateral zonation was observed in the core facies. The different corals and stromatoporoids occurred in thickets on the mound surfaces. At the eastern end of the HG2 exposure bryozoan wackestone is transitional laterally into coral-brachiopod cementstone, dipping up to 25° eastward. This change likely represents a transition from core to flanking facies.

Vertical zonation is apparent in the core facies of the coral/stromatoporoid skeletal mounds but is not consistent at all the localities. In the mudstone core at HG2, thick units of unfossiliferous mudstone alternate with thin units of mudstone containing abundant fossils, but of very low diversity. The uppermost exposure of this mound is a coral-floatstone, with a more diverse fauna. In contrast, on North Kent Island, the lowest exposed facies is floatstone and boundstone with a diverse coral-stromatoporoid fauna, and is overlain by mudstone core facies containing two thin units of coral-stromatoporoid boundstone.

At HG1 the general vertical zonation comprises in ascending order a basal core facies of stromatoid-rich mudstone, a flanking facies

dominated by crinoidal-coral wackestone, a coral/stromatoporoid wackestone, then coral/stromatoporoid/ crinoidal wackestone, and finally a predominantly crinoidal facies changing upward from sparse wackestone to dense wackestone to packstone. A 5m-thick bryozoan wackestone unit occurs within this upper facies.

2.5.7 Depositional environment and mound growth

Growth of the coral/stromatoporoid skeletal mounds was initiated at the end of Douro Formation sedimentation during a time of regional transgression. Mound growth continued, and was eventually terminated, during deposition of the Devon Island Formation. The stromatactoid-rich mudstone cores represent the initial phase of mound building. Information from well-preserved mounds further south and the relict spicular and micritic fabrics preserved in the mudstone cores, suggests that mudmounds and mudstone cores were constructed by the same organisms, namely microbes and sponges.

Skeletal mounds HG1 and HG2 were colonized by corals and stromatoporoids, and represent general upwards shallowing. The bryozoan unit and the thin stylopleurid coral units at HG2 indicate brief changes in the mound environment that allowed these organisms to

replace the sponges and microbes temporarily as dominant mound constructors. Although the causes of these brief changes are not known, they could represent changes in water circulation and increased nutrients, for example. These more fossiliferous units show very low diversity, indicating that the environment remained stressful. The thick unfossiliferous mudstone units between these thin units are an indication of return to conditions favouring the growth of microbes and sponges, which appear to have dominated mound growth overall.

The sequence of facies in the skeletal mound on North Kent Island suggests a sequence of environmental change different from that in HG1. The basal coral/stromatoporoid floatstone indicates growth in a relatively shallow, well-oxygenated and illuminated environment. The overlying mudstone containing only two thin units of coral/stromatoporoid boundstone, indicates that subsequent mound growth was mainly in deeper water in conditions favouring the microbe-sponge biota.

The facies sequence in the HG1 skeletal mound represents overall upward shallowing. The coral and coral/stromatoporoid wackestones in the middle of the sequence represent a time of optimal growth for the mound. The steeply dipping flank beds, large allochthonous blocks, and

fewer shale interbeds suggest that the mound itself, had substantial relief and exceeded relative sea-level rise. The upper crinoidal wackestone-packstone indicates progressive domination by crinoids, and probably represents growth into more shallow water with higher energy conditions, excluding growth of the corals and stromatoporoids. This facies sequence is discussed in greater detail in the next chapter.

2.6 DIAGENETIC FEATURES IN SKELETAL MOUNDS

2.6.1 *Neptunian dykes*

Neptunian dykes occur in the mudstone cores of most of the skeletal mounds. Dykes are infilled by bladed cements (originally calcitic), clasts of darker mudstone similar to the Devon Island Formation, blocks of skeletal mound lithology, crinoidal debris and bitumen. Dykes range in width from 2cm to 20cm. The crinoidal debris-filled dykes occur most abundantly in the GF2 coral skeletal mound and less commonly in other exposures. In general, the dykes appear to be oriented perpendicular to bedding and are more common towards the periphery of the skeletal mound.

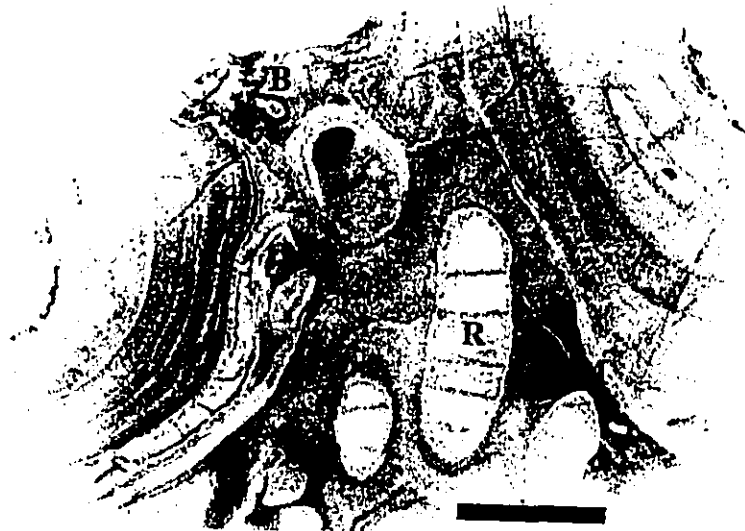
2.6.2 *Cements*

The skeletal mounds were pervasively dolomitized by a fine-grained non-ferroan dolomite. Original cement fabrics are preserved and appear to have been radiaxial fibrous calcite cements (Fig. 45A). The most distal beds of the HG1 flanking facies where the shale interbeds are much thicker, have not been as extensively dolomitized and still retain small amounts of originally calcitic cement. A late-stage, coarser grained, ferroan-dolomite fills fractures and voids in the mounds. Molds

Figure 45. Thin section photographs of diagenetic features in core facies of skeletal mounds. Scale bars=1cm.

- A. Coral cementstone from HG2 showing multiple generations of isopachous cement in cross-section view. The cements were likely originally early marine calcite but were later replaced by fine-grained dolomite.
R=rugose coral; B=bitumen.
- B. Stromatactoid-rich mudstone from GF1 in cross-section view. The mudstone has been replaced by fine-grained dolomite.
S=stromatactoid structure; Sp=spicular dolomicrite; Do= coarse grained ferroan dolomite; 1,2=generations of isopachous cements.

A



B



of gypsum laths are common (the laths are rarely preserved) and postdate all of the cements.

In the HG2 skeletal mound exposures and on North Kent Island very coarse grained frothy white calcite fills large fractures in the mudstone and voids in fossils. This calcite is likely related to a much younger tectonic event as it cross-cuts and postdates all other mound features.

Stromatactoid structures are cement-filled voids, of unknown origin. Relict cement textures suggest the presence originally of at least two generations of isopachous calcite cement (Fig. 45B). At HG1, some of the stromatactoid structures are lined by a thin cement and largely filled with dark carbonaceous mudstone instead of typical isopachous cements.

Stromatactis was originally described by Dupont (1881, 1883) but the 'type' definition from Lecompte (1937, p. 5) is as follows:

'...mass of sparry calcite having a flat to undulose smooth lower surface, and digitate upper surface, made up of one or several isopachous crusts of centripetal cement, with or without sediment infillings, and commonly embedded in lime mudstone or wackestone.'

Bathurst (1959, 1980) further described stromatactis as masses of sparry calcite embedded in a lithified carbonate mud with a digitate upper surface and a smooth undulose lower surface, extending subhorizontally, and connecting with other masses in a reticulate pattern. Many of the structures seen in this study area do not completely fit this definition, and therefore the more encompassing term 'stromatactoid structures' is used generally instead of 'stromatactis'. The stromatactoid structures differ from 'classic' stromatactis in that they can be sparse and isolated, laterally continuous or intermediate between the two. The intermediate type would best fit the definition of 'stromatactis'.

3.0 DISCUSSION

3.1 MOUND DEVELOPMENT

Two episodes of mound development during the late Ludlow and Pridoli are recorded in the study area. The first episode was the development of mudmounds on the Douro ramp during the mid-late Ludlow. These are represented by a tract of at least 27 mudmounds on western Devon Island. The second episode was the development of isolated skeletal mounds during deposition of the Devon Island Formation during the late Ludlow-Pridoli. These skeletal mounds are exposed further north, from northern Devon to southwestern Ellesmere islands.

The occurrence of these mounds reflects an overall northward displacement of carbonate build-up development in the Canadian Arctic during the Late Silurian. The development and depositional environments of the two phases of mound development are discussed separately below.

3.1.1 *Mudmounds*

Mudmounds (D1-D27) were initiated and grew on relatively soft argillaceous carbonates of the Douro Formation. These are interpreted above as representing a normal marine setting on a carbonate ramp, below fair-weather wave-base and within the photic zone. Tectonic movement in the Boothia Uplift area during late Ludlow time (deFreitas and Mayr, 1993) caused abrupt deepening on the Douro ramp, ending carbonate mud production, shutting off the source of detrital material, and resulting in a hiatus in sedimentation. Relative sea-level rise could have caused the expansion of the oxygen minimum zone (OMZ), or the creation of an OMZ due to nutrient upwelling (Pedersen and Calvert, 1990), and combined with the period of starved sedimentation, resulted in formation of a phosphatic hardground (Fig. 46). Although the duration of the hiatus is unknown, it was sufficiently long enough for a few metres of clean crinoidal capping grainstone to be deposited locally and for the formation of successive phosphatized hardgrounds. The succession of hardgrounds and phosphate-coated fossil material indicates that this OMZ fluctuated in level, and this

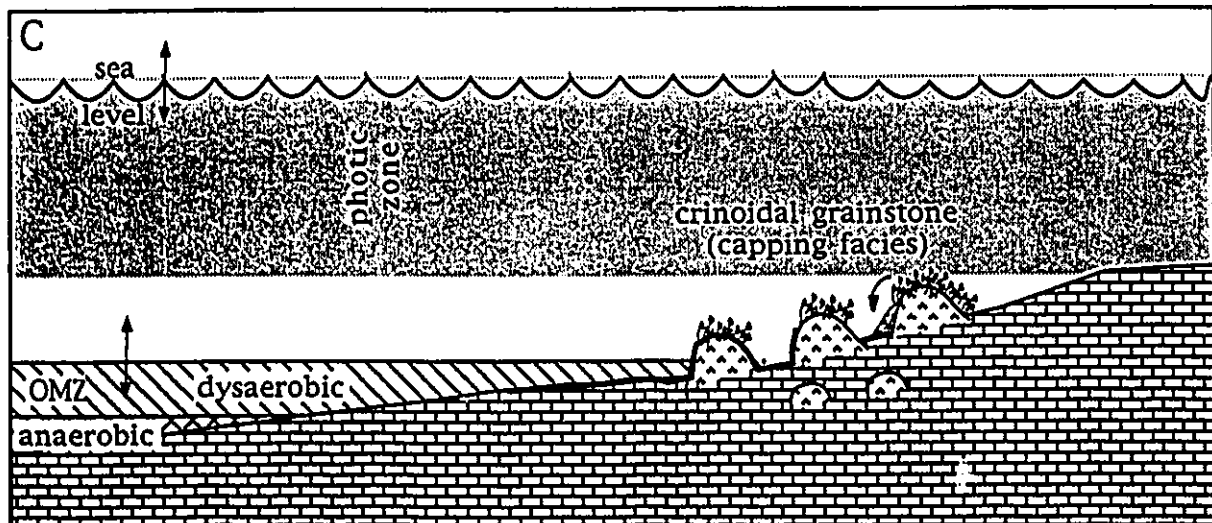
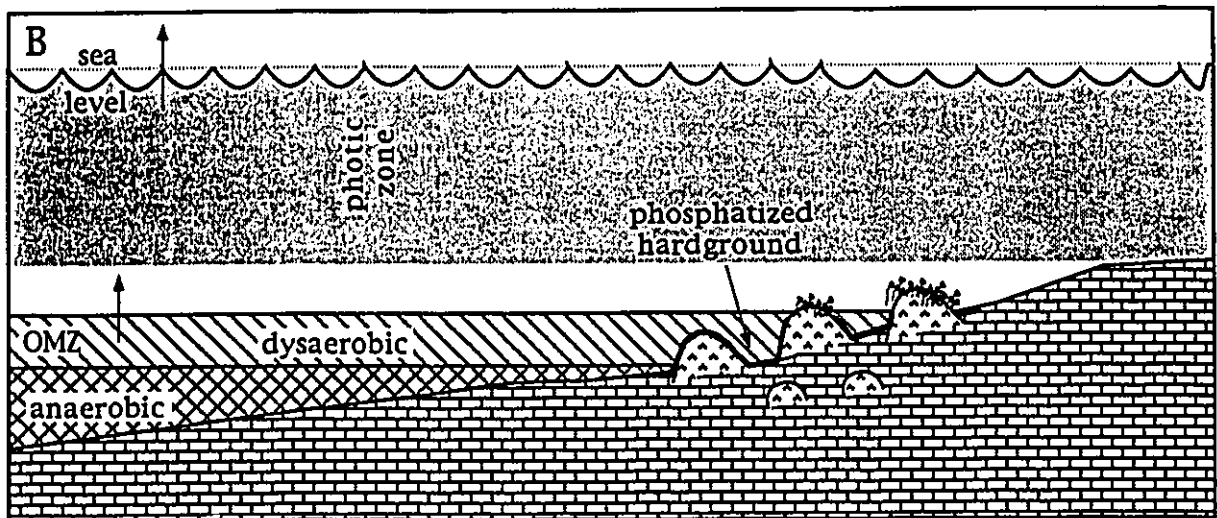
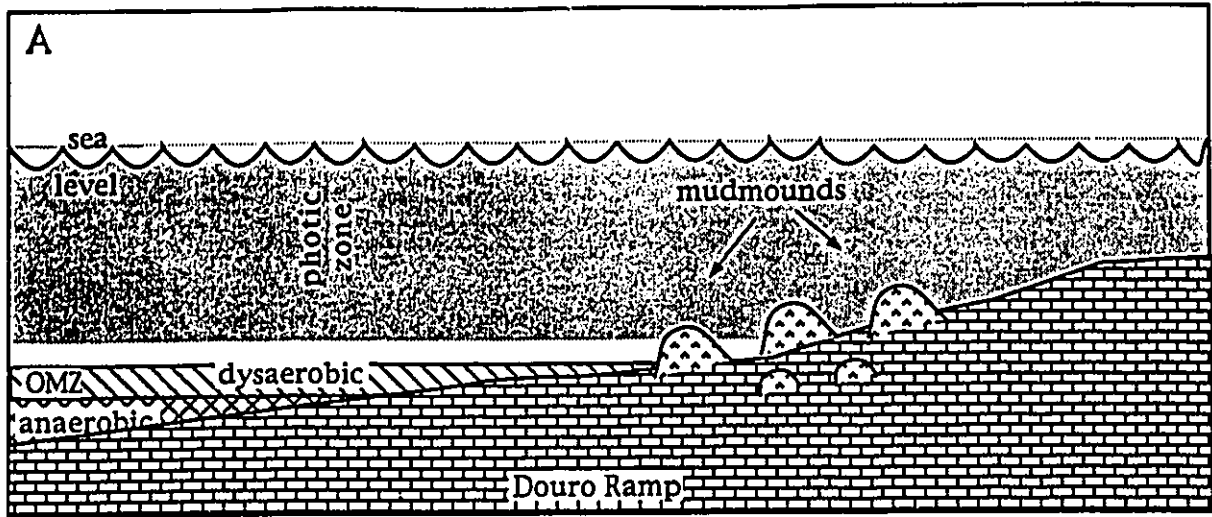
presumably stressful environmental variability is substantiated in the relatively small size of benthic fossil components.

Figure 46 represents schematically how sea-level and paleogeographic changes could have resulted in OMZ fluctuations and affected mudmound development. When bottom water was more oxygenated, organisms would have colonized hardground surfaces. During times of dysaerobia, phosphate mineralization would have occurred at the sediment/water interface. Certain bivalves are known to be more tolerant of stressed environments. Those associated with the hardground do not appear to be dwarfed and possibly survived on the hardgrounds even during times of dysaerobia. The cephalopods present were nektonic and their presence on the hardground indicates that this area was still open to normal marine circulation.

Mudmounds that had greater topographic relief or that grew slightly higher on the ramp would have had areas that were still in more oxygenated waters, allowing for colonization by crinoids. After death, crinoidal material that accumulated on the mounds could have been transported downslope by slumping or grainflow, resulting in the clean, unsorted, roughly stratified capping facies that drapes

Figure 46. Diagrammatic interpretation relating mudmound termination, crinoidal capping facies and hardground development to sea-level fluctuations.

- A-Initiation and growth of mudmounds below fairweather-wave base and at, or below storm wave-base in well-oxygenated waters. Frequent or prolonged turbidity is suggested by the strongly argillaceous content of the Douro ramp sediments.
- B-With relative sea-level rise, input of siliciclastic mud was effectively terminated, and the mudmounds placed below the photic zone, terminating carbonate mud production and mudmound growth. Corresponding migration of the oxygen minimum zone (OMZ) placed areas of the ramp and the mudmounds in a dysaerobic zone, and with sediment starvation resulted in development of a phosphatized hardground. Mudmounds above this dysaerobic zone were still in oxygenated waters now largely free of turbidity, allowing crinoids to colonize the tops of the mounds.
- C-Slight sea-level fluctuations and/or fluctuations in the level of the OMZ caused alternation between hardground development, hardground colonization by shelly benthos and dense crinoid growth. The crinoid growth and the limited biota on the hardground were associated with more oxygenated waters. These fluctuations are indicated by successive layers of coated fossils. During this time crinoidal material was transported by gravity off the mounds and onto the mound margins.



some mounds. No capping facies or crinoidal grainstone-filled neptunian dykes were recognized in association with mudmounds D17-26. However, phosphatized hardgrounds are present at the tops of these mudmounds, and they were likely situated deeper on the ramp and below the OMZ where crinoids could not grow.

3.1.2 Small well-preserved mudmounds

Diagenesis of the mudmounds and mudstone cores of skeletal mounds has greatly obscured information about their genesis and original biotic composition. This is commonly the case for Paleozoic mudmounds. The presence of small mudmounds (D27) that are much better preserved, near the base of a larger mudmound in the mudmound tract, provides key information about the other more diagenetically altered mudmounds in the study area and perhaps about other mudmounds as well.

These small mudmounds contain well-preserved lithistid sponges and microbial structures and strongly suggest that these organisms were essential to the construction of the larger mudmounds.

Lithistid sponges acted as dwellers, bafflers and where abundant as builders, while microbes were encrusters, builders and carbonate mud producers. This microbe-sponge association occurs throughout

the Paleozoic and is discussed in detail in a recent paper by Brunton and Dixon (1994). The presence of this biota in an environment similar to that interpreted for the mudmounds and mudstone cores, strongly suggests that the larger buildups, too, were constructed by this microbe-sponge association.

Although many of the larger mounds were extensively altered through diagenesis, there remain some clues that indicate the original presence of sponges and microbes. Abundant calcified sponge spicules and faintly laminated micrite are preserved locally within the mudmounds, and relict examples of these fabrics are seen in the dolomitized mudstone cores of the skeletal mounds. As the preservation potential of the microbes and sponges is low, it is uncommon to see examples of this biotic association. However, the examples provided in this study show that it is possible to interpret their presence even in extensively diagenetically altered mounds.

3.1.3 *Skeletal mounds*

The skeletal mounds initiated growth on local favourable sites on the drowned Douro ramp at a time of regional transgression. At these sites, farther from the Boothia Uplift, platform geometry was

not changed as drastically from Douro to Devon Island formation time, compared to areas on southwestern Devon Island much closer to the uplift. Packard (1985) suggested that there may have been a change from a shallow ramp setting during Douro sedimentation to a distally steepened ramp setting at this time on Cornwallis Island.

The lower member of the Devon Island Formation was deposited in an anoxic-sulphidic environment (Mayr *et al.*, 1994), perhaps brought about by upwelling of nutrients from deeper water (Pedersen and Calvert, 1990) or from expansion of an oxygen-minimum zone. A foreslope setting has been interpreted for the upper member of the Devon Island Formation in this area, based on breccias and debris flows (Mayr *et al.*, 1994). Alternatively, the discontinuous occurrences of the debris beds and large olistoliths could reflect more local slopes related to isolated carbonate build-ups rather than reflecting a regional carbonate slope.

The cliff exposure at Hell Gate (HG1) provides a complete section through marginal facies of a skeletal mound, including a basal contact with the Douro Formation. As this exposure represents the flanking facies of the mound, the relationship with the nonreefal sediments of the Devon Island Formation could be documented, providing a useful

combination of information about depositional conditions. Figure 47 is an interpretive cross-section of HG1 showing three general stages of mound growth related to paleoenvironmental changes. The HG1 skeletal mound exhibits an overall zonation reflecting upward-shallowing. Stage A is the initial constructional stage, represented by a sponge-microbe mudmound (stromatactoid-rich mudstone core) with its flanking facies. During this stage the mound developed substantial relief as indicated by the presence of large blocks of brecciated core material and extensive flank beds. A substantial rise in relative sea-level at the end of stage A resulted in onlap of calcareous mudstone and black shale that covered the flank beds and nearly ended mound growth. Stage B represents the most substantial mound-related growth. The environment favoured colonization by corals and stromatoporoids, and mound growth kept pace with and surpassed the relative sea-level rise resulting from basinal subsidence. Intertonguing of mudstone and shale with the flank beds reflects fluctuating energy levels, probably related to sea-level fluctuation. Higher energy levels are reflected in the larger and more robust forms of the corals and stromatoporoids in the stage B. Colonization of the mound by crinoids represents the final stage of

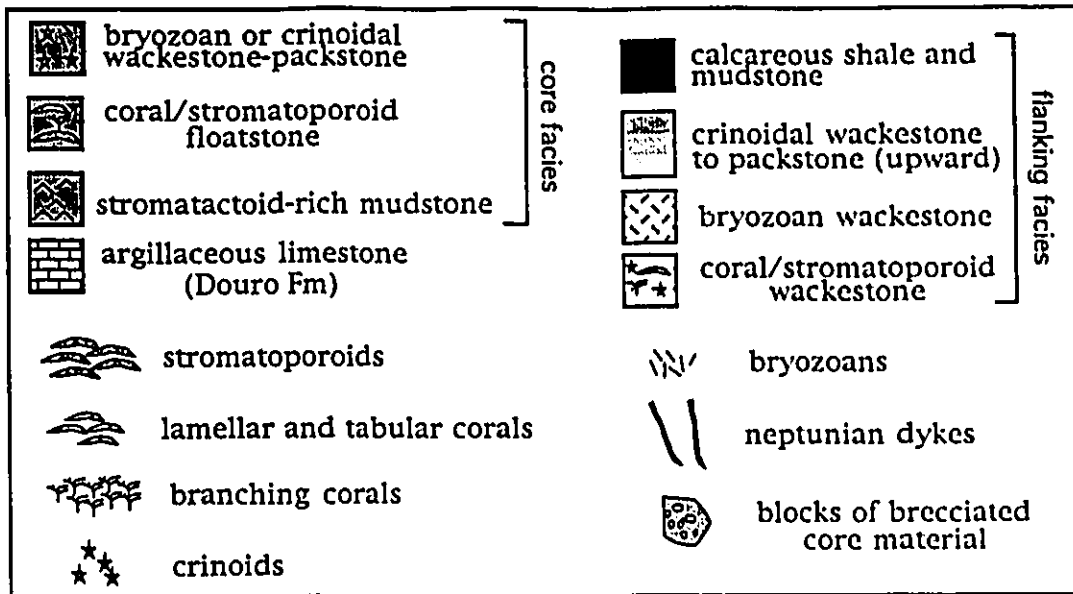


Figure 47. Interpretative cross-section of HG1 skeletal mound, based on available exposure of the flanking facies, basal core facies and information about core facies from other coral/stromatoporoid skeletal mounds in the study area. A, B, and C represent successive stages of mound growth.

- A Initial mound-building stage represented by stromatactoid-rich mudstone resting on the top of the Douro Formation. The presence of allochthonous blocks of brecciated core material indicates that there was substantial relief at the time. Abrupt sea-level rise resulted in deposition of a thick unit of calcareous shale on the flank beds and proximal to the mound core, nearly covering the mound.
- B Initial relative sea-level fall during this stage allowed corals and stromatoporoids to colonize the mound. The environment was favourable for mound growth, *i.e.* well-oxygenated waters within the euphotic zone, and mound growth kept up with and eventually surpassed an overall relative sea-level rise. Intertonguing of shale and siliciclastic mudstone with the flank beds suggests that there were sea-level fluctuations throughout this stage.
- C Increasing amounts of crinoidal debris upwards from sparse wackestone to packstone in the flank beds suggest that crinoids increasingly dominated the skeletal mound as a result of growth into higher-energy conditions. The bryozoan unit in this stage may suggest that the environment was nutrient-rich or that there was an increased amount of detrital material in the water, and was not favourable for the growth of other organisms.

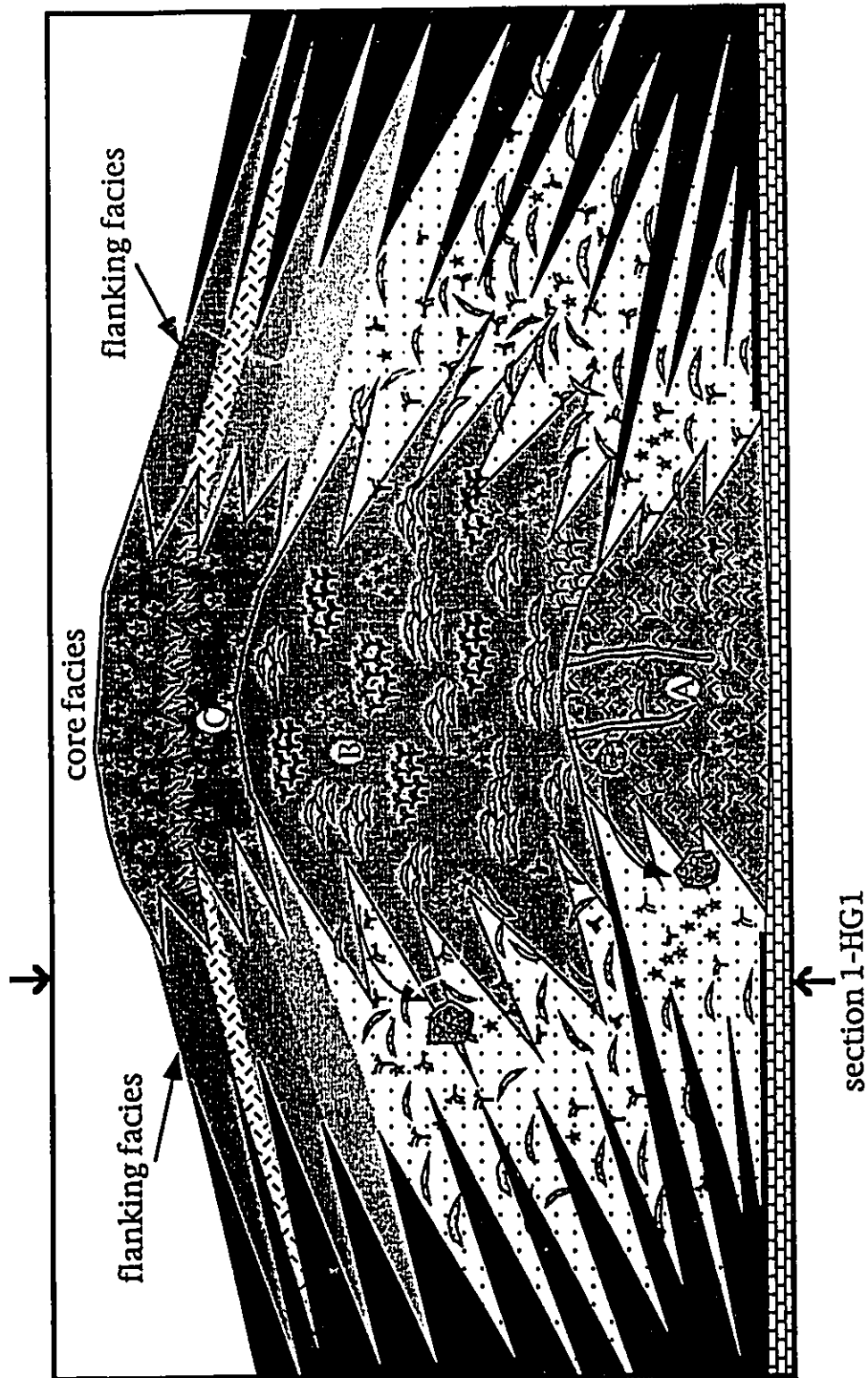


Figure 47

mound-related growth (stage C). The environment at this time was more energetic and not favourable for the growth of corals and stromatoporoids, but more favourable for crinoids. The change from crinoidal wackestone to packstone, with decrease in mud, suggests that there was an increase in water energy in the final stage of mound growth.

Other skeletal mounds studied were not as well constrained stratigraphically as HG1, as their basal and/or upper contacts were not exposed. From the positions of nearby exposures of the contacts of the Douro and Devon Island formations, all of the skeletal mounds appear to have initiated growth at this boundary. The coral skeletal mounds are likely equivalent to stage A of figure 47 and possibly the initial part of stage B, but were terminated by the substantial overall sea-level rise represented in stage B. The coral skeletal mounds may have initiated growth in slightly deeper water and were unable to sustain growth in response to rapid deepening.

The North Kent Island skeletal mound shows a vertical zonation markedly different from that interpreted from HG1. The lowest exposed facies of the North Kent Island skeletal mound is a coral/stromatoporoid floatstone and is overlain by mudstone. The

two thin units of coral/stromatoporoid boundstone within the mudstone indicate that the environment changed briefly during these intervals. James and Bourque (1992) present a model to describe facies changes in deeper water mounds in response to sea-level changes. The skeletal mounds in this study area fit this model well. Figure 47 represents the three stages (A, B, and C) interpreted for the HG1 skeletal mound as keeping up to, and surpassing sea-level rise. The skeletal mound on North Kent Island shows a stage B to stage A succession, that was presumably also preceded by stage A. This ABA succession represents changes in sea-level, and unlike the HG1 mound, this mound could not keep up and reverted to growth characteristic of deeper water instead of the shallower water conditions indicated by stages B and C.

These differences in the general zonation of the skeletal mounds indicate that the mounds were influenced by local as well as regional factors. The fact that skeletal mounds occupied different positions on the distally steepened ramp could have accounted for the different vertical zonations. Mounds that were higher up on the slope would have had a better chance of keeping up with rising sea-level, and

therefore maintaining growth in an optimal environment -- more light, oxygen, higher energy, and less detrital material in the water.

3.2 COMPARISONS

3.2.1 Other Arctic carbonate buildups

Silurian carbonate buildups are numerous, diverse, and occur in a variety of settings in the Canadian Arctic. These include, for example, large microbial buildups in the Wenlock-early Ludlow Allen Bay Formation on Ellesmere Island (de Freitas, 1991); small intertidal algal mudmounds in the lower Ludlow Cape Storm Formation on Somerset Island (Stewart, 1987); large fore-slope mudmounds in the Wenlock of the Cape Phillips Formation (de Freitas, 1991; de Freitas *et al.*, 1993); mid-Ludlow deeper water lithistid sponge 'reefs' in the Douro Formation on Somerset Island (Narbonne, 1981; Narbonne and Dixon, 1984, 1988); late Ludlow-Pridoli proximal foreslope microbe-lithistid 'reef' mounds and shelf-margin stromatoporoid/coral build-ups in the Barlow Inlet Formation on eastern Cornwallis Island (Packard, 1985; Brunton and Dixon, 1994; Brunton, pers. comm.); and shallow water 'reef mounds' of

Ludlow age in the transitional sequence between the Douro and Barlow Inlet formations on southwestern Devon Island (Graf, 1988; Dixon and Graf, 1992). Locations of many of these are represented in figure 48.

The mudmounds of this study have most in common with the mid-Ludlow lithistid sponge 'reefs', and late Ludlow-Pridoli microbe-lithistid 'reef' mounds, and occur at the same stratigraphic level as the microbe-sponge-coral 'reef mounds' in the Douro-Barlow Inlet transition. These are discussed in more detail below and their stratigraphic occurrence is represented in figure 49.

The microbe-sponge mounds of the uppermost Douro Formation on western Devon Island are very similar to slightly older lithistid sponge 'reefs' of the mid- and mid-upper Douro Formation on Somerset Island (Narbonne, 1981; Narbonne and Dixon, 1984). These mounds occur within two distinct intervals of the Douro Formation, each representing deepening over the carbonate ramp. A general vertical zonation was documented in these mounds and consists of a basal crinoid-bryozoan-solenoporid pioneering stage, followed by a mound-building microbe and lithistid sponge (*Haplistion* and *Somersetella*) stage, and finally a thin capping coral-rich stage. The

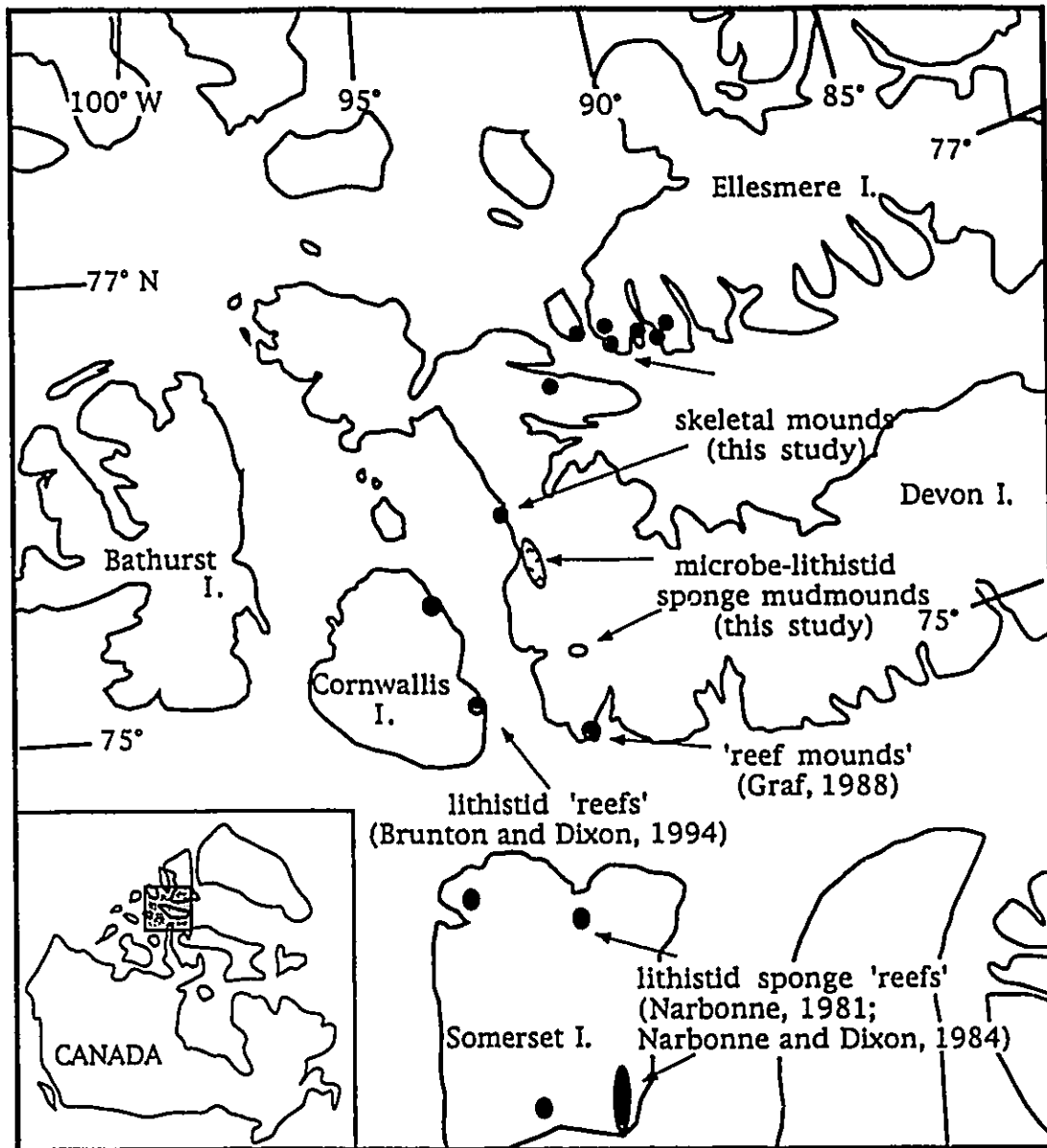


Figure 48. Distribution of Upper Silurian carbonate buildups in the Central Arctic Islands. The Somerset Island occurrences are the oldest (mid-Ludlow) and the skeletal mounds in the north are the youngest buildups in the area (Pridolian). During the Silurian the northward displacement of mound growth was related to the northward progression of disturbance in the Boothia Uplift area (Brunton and Dixon, 1994). See figure 49 for stratigraphic occurrence.

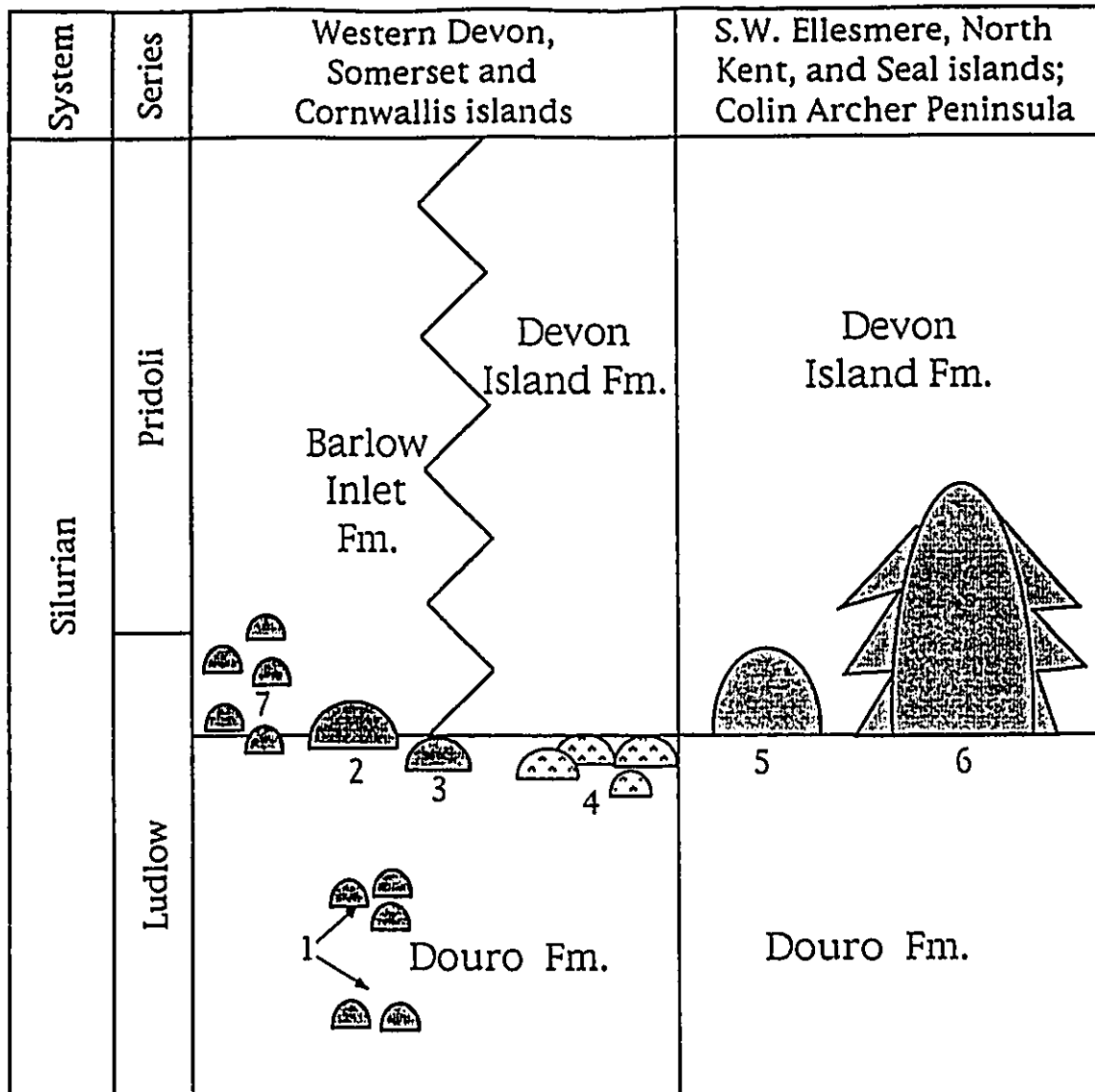


Figure 49. Stratigraphic occurrence of upper Silurian carbonate buildups in Central Arctic Islands. 1-lithistid sponge 'reefs' on Somerset Island (Narbonne, 1981; Narbonne and Dixon, 1984); 2-'reef mounds' on southwestern Devon Island (Graf, 1988; Dixon and Graf, 1992); 3-microbe-lithistid sponge mudmound near Griffin Inlet, Devon Island (this study); 4-microbe-lithistid sponge mudmounds, western Devon Island (this study); 5-coral-skeletal mounds at Goose Fiord (GF1,2), Walrus Fiord, and Colin Archer Peninsula (this study); 6-coral/stromatoporoid-skeletal mounds, with extensive flank facies at Hell Gate (HG1,2), and North Kent and Seal islands (this study); 7-lithistid 'reefs' on Cornwallis Island (Brunton and Dixon, 1994; Packard, 1985). See figure 48 for geographical distributions.

first two growth stages can be recognized in mudmounds on western Devon Island, but there is no capping coral-rich facies. The basal stage is present in the small well-preserved mudmounds, although it is represented by crinoid-solenopodid rudstone with few bryozoans. The absence of the coral-rich facies possibly indicates that the mudmounds did not grow into conditions shallow enough for corals to colonize the mounds.

In the Douro sponge 'reefs' on Somerset Island shallowing upward trends are indicated by the predominance of corals in the uppermost phases of mound growth at both stratigraphic levels. Narbonne and Dixon (1988) suggested that the main difference between the two intervals was a greater amount of terrigenous sediment introduced at the lower level, and that this had an influence on the faunal composition of the mounds.

Build-ups on southeastern Cornwallis Island occurred at a time of paleogeographical change from a ramp to carbonate shelf. The *microbe-lithistid* sponge reef mounds grew in a deeper water setting, similar to that interpreted for the mudmounds of this study, on a proximal foreslope (Brunton, pers. comm.)

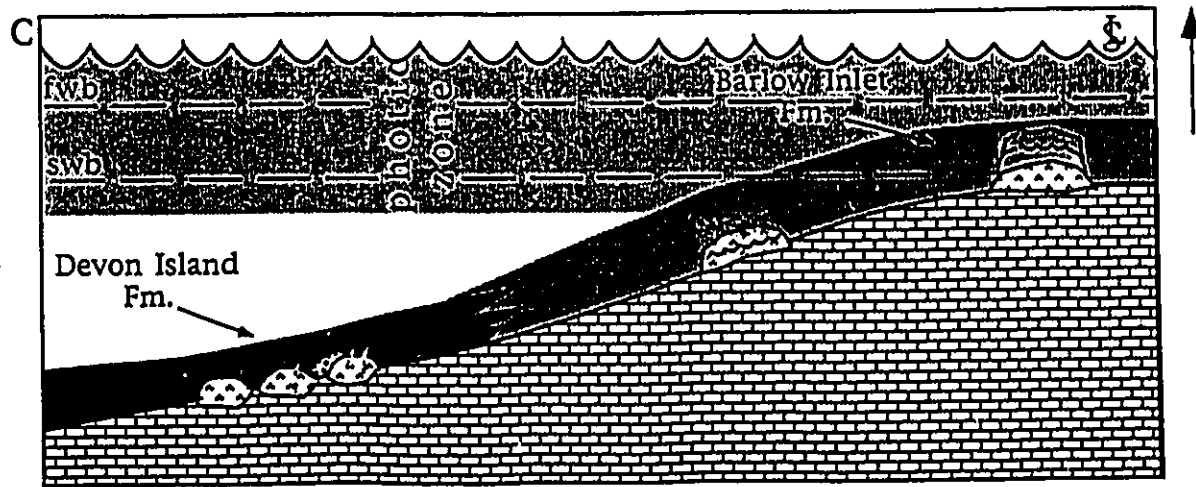
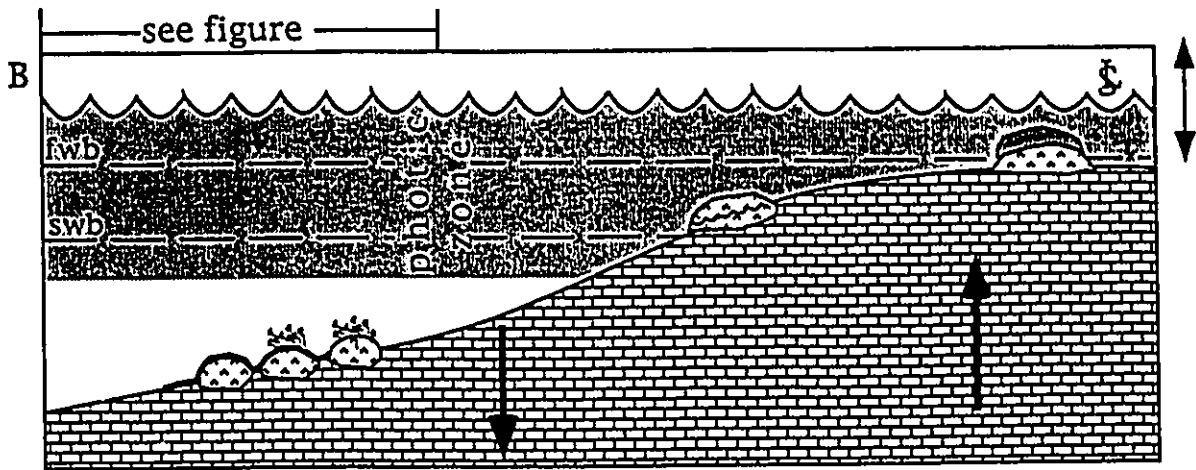
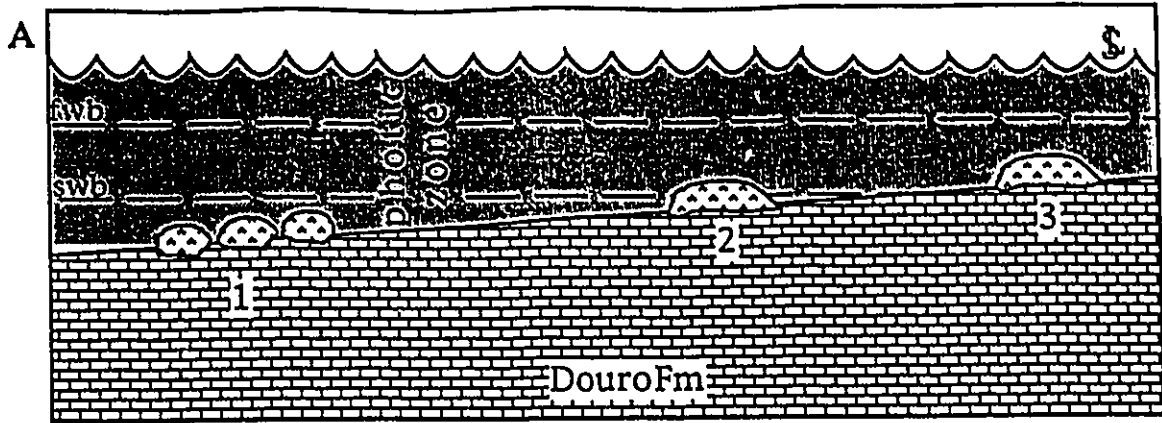
'Reef mounds' in the top-most Douro Formation and the lowermost Barlow Inlet Formation on southwestern Devon Island grew at a time of overall shallowing, representing change from the ramp setting of the Douro Formation to the platform setting of the Barlow Inlet Formation (Dixon and Graf, 1992). These 'reef' mounds show three main stages of growth. The basal facies, within the Douro Formation, is mudstone containing lithistid sponges and is overlain by a middle coral-crinoidal mudstone facies that represents growth into more shallow water. The boundary between the Douro and Barlow Inlet formations has been placed locally at the first appearance of crinoidal grainstone in the inter'reef' facies and corresponds to the boundary between the lower and middle 'reef' stages (Thorsteinsson and Uyeno, 1980). A hardground marks the boundary between the middle and upper facies. Dixon and Graf (1992) suggested that the upper facies dominated by stromatoporoids and crinoids was considerably stressed by increased sediment input. This facies is overlain by argillaceous limestone, suggesting deepening.

Biostratigraphic work in the area is not yet sufficient to correlate events of mound construction confidently from Gascoyne Inlet to Griffin Inlet and the mudmound tract further north. A correlation

can be postulated, however, using physical features that represent events that are logically related to major sea-level and paleogeographic changes. An obvious physical feature is a single hardground exposed at several of the localities, possibly signifying sediment starvation of regional extent. A major hardground has been recognized at Gascoyne Inlet within the 'reef mounds' (Dixon and Graf, 1992). A hardground also occurs within the mudmound at Griffin Inlet. A major hardground caps many of the mudmounds near Dragleybeck Inlet, most notably at the 'rivermound', and is continuous with that defining the Douro-Devon Island formational boundary in that area. One possible interpretation for the presence of these hardgrounds is that they are part of a regionally extensive hardground that developed due to sediment starvation related to sea-level rise. This 'event' could also represent the end of mound growth and initiation of the local crinoidal capping facies on other mudmounds in the Dragleybeck Inlet area. This capping facies likely corresponds with the continued growth of the Griffin Inlet and Gascoyne Inlet mounds. A schematic representation of suggested sea-level and paleogeographical changes related to mound development in the different areas is shown in figure 50. Figure 51

Figure 50. Diagrammatic interpretation of probable effects of paleogeography and sea-level changes on mudmound development during the late Ludlow on southwestern and western Devon Island. fwb=fairweather wave-base; swb=storm wave-base.

- A. Initiation of mudmounds across the Douro ramp. 1-mudmound tract (D1-D27); 2-Griffin Inlet; 3-Gascoyne Inlet, lower facies of Dixon and Graf (1992)
- B. Tectonism related to the Boothia Uplift apparently changed platform geometry from ramp to rimmed shelf. This change would have resulted in deepening on the slope and shallowing on the shelf (subsidence and uplift respectively). On mudmounds below the photic zone, carbonate mud production would have ended. This interval of inferred sea-level fluctuation is considered to have resulted in: deposition of the middle mound facies at Gascoyne Inlet; hardground formation on Griffin Inlet mudmound and continuation of mound growth; local deposition of the crinoidal capping facies on mudmounds and hardground formation in the mudmound tract.
- C. Abrupt deepening could have resulted in: onlap of shales of the Devon Island Formation on the slope; termination of Griffin Inlet mound and deposition of crinoidal capping facies (below photic zone); hardground development at top of middle mound facies at Gascoyne Inlet. Local shallowing on the platform margin possibly allowed for subsequent deposition of the upper mound facies at Gascoyne Inlet.



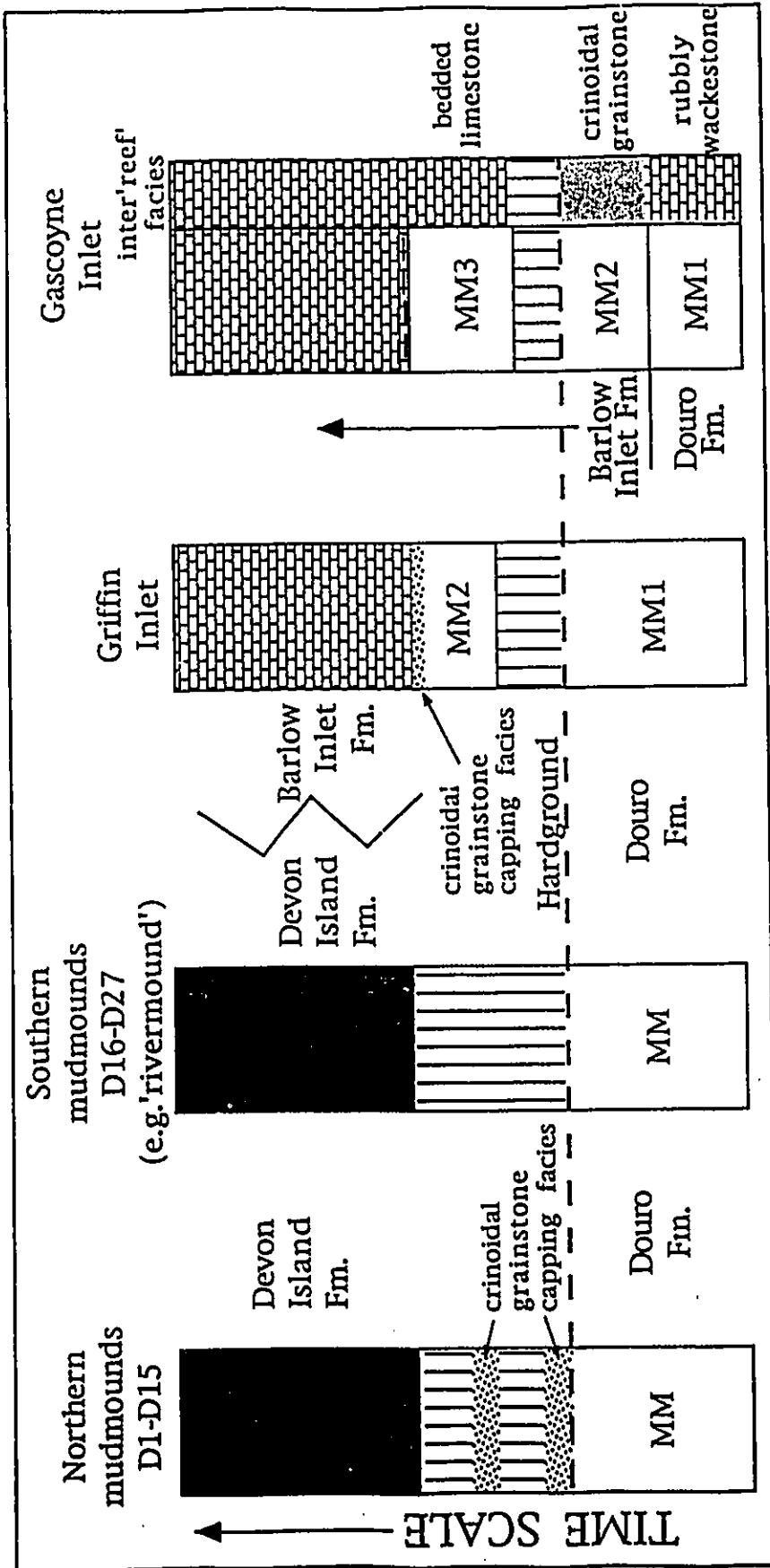


Figure 51. Proposed event correlation for Upper Silurian rocks on western Devon Island. Mound growth stage (MM1,2,3), a depositional hiatus (vertical ruling) and a single regionally extensive hardground are correlated in a framework of relative time. No stratigraphic thicknesses are implied and the time scale is relative. The Douro-Barlow Inlet formational boundary in the Gascoyne Inlet area is placed at the base of a crinoidal grainstone unit flanking the mounds (Thorsteinsson and Uyeno, 1980). See text for a more detailed discussion of event correlations.

relates the events to a relative time scale. The depositional hiatus likely varied in duration in different areas: shorter in the shallower water environment at Gascoyne Inlet, and longer in the deeper water environment at Dragleybeck Inlet. Another regional 'event' is indicated by the beginning of deposition of the siliciclastic sediments of the Devon Island Formation in the Dragleybeck Inlet area. This regional, tectonically-related event would probably have been expressed differently in the carbonate shelf setting further south. In the Gascoyne Inlet area argillaceous limestones cap the mounds, and at Griffin Inlet the capping crinoidal grainstone is overlain by bedded limestones (Fig. 51). In all three areas, the change may be attributed to an abrupt deepening event. The development of the mounds and associated features fit the model of James and Bourque (1992) to describe facies changes in deeper water mounds in response to sea-level changes. The physical features present in the mounds (e.g. hardground, capping facies, continued mound growth) would depend on the position of the different mounds.

This new paleoenvironmental interpretation differs from the one of De Freitas *et al.* (1993) who referred to the skeletal mounds of this study area as 'pinnacle reefs' and 'mudmounds', terms generally

corresponding to the coral/stromatoporoid skeletal mounds and the coral skeletal mounds of this study, respectively. The Walrus Fiord coral skeletal mound was referred to as a pinnacle reef even though it is nearly identical in size and facies relationships to the Goose Fiord mound (GF1).

Conspicuous faunal differences between the mudmounds of the Douro Formation and the mudstone cores of the skeletal mounds of the Devon Island Formation were considered by de Freitas *et al.* (1993). They considered the unusual distribution of lithistid sponges in the Canadian Arctic, namely the abundance of sponges in the mudmounds and their apparent absence from the mudstone cores of the skeletal mounds. However this study suggests that the present occurrence of obvious sponge material is only an apparent distribution that reflects differential preservation of the sponges in different settings. The mudstone cores were pervasively dolomitized, obliterating most features except relict fabrics of the original mudmound. The recognition of faintly spicular dolomicrite in this study suggests that sponges were once present. Even without precise identifications of lithistid sponges, there is evidence to suggest that lithistid sponges and microbes were responsible for

construction of the mudstone cores, considering the similarity in appearance and interpreted paleoenvironment of the mudmounds and mudstone cores.

3.2.2 Ludlow-Pridoli reefs worldwide

A brief summary of Ludlow-Pridoli carbonate build-ups is provided; for more comprehensive information about Silurian reefs see Copper and Brunton (1991, and references within). Globally, Ludlow-Pridoli mounds have a wider geographic distribution than earlier Silurian reefs, but tend to be smaller (Copper and Brunton, 1991). During the late Silurian global climatic warming resulted, in many areas, in basin shrinkage and evaporite sedimentation; most notable is the desert belt of the Michigan basin (Shaver, 1977). Towards the end of the Ludlow, major regression is recorded in many areas worldwide, but this period in the Canadian Arctic is marked by regional transgression over the Douro ramp in response to tectonism in the Boothia Uplift area.

Sears and Lucia (1979) described Silurian pinnacle reefs in the Michigan Basin. They interpreted these reefs with stromatactis-rich mudmound cores and overlying coral/stromatoporoid facies as

having been initiated in a relatively deep water setting (below fairweather wave-base) on a subsiding carbonate ramp. These build-ups are similar to the skeletal mounds of this study except that the Michigan Basin build-ups are enclosed by evaporites instead of basinal shales.

Biohermal complexes of mid-Ludlow to late Pridoli age in eastern Canada, have been described by Bourque and Amyot (1988) and Bourque and Raymond (1988) on the Gaspé Peninsula, and by Noble (1985; 1988) in northern New Brunswick. These complexes are thought to be part of a large, 1000km-long reef tract (Bourque, 1988). Stromatactis mudmounds of a lower reef complex in the Gros Morbe Member of the West Point Formation (Bourque and Raymond, 1988; Bourque and Gignac, 1983) are similar to mudmounds of this study as they had substantial paleorelief and flank beds contain spicular micrite and stromatactoid structures, and represent a relatively deep water setting. An upper reef complex comprises stromatoporoid/coral reefs that grew in a subtidal-intertidal setting (Bourque and Amyot, 1988).

Mid-Ludlow-age microbe-calcareous sponge reef mounds in SE Alaska, were interpreted to have formed at a shelf-edge in an island

arc setting (Soja, 1991; 1993; Soja and Riding, 1993; Riding and Soja, 1993). Clough and Blodgett (1988) documented a Pridoli subtidal to intertidal algal reef mound complex that formed on a carbonate ramp or distally steepened ramp.

A large belt of late Llandovery-early Wenlock reefs occurs in North Greenland (Hurst, 1980; Sonderholm and Harland, 1989) and extends westward into Ellesmere Island (Trettin, 1991). These reefs grew on a carbonate shelf-to-slope profile ranging from deep subtidal to supratidal environments. Although most reef growth was terminated by platform drowning during the Wenlock, build-ups occurred in the Ludlow on the tops of some of the older reefs (Sonderholm and Harland, 1989). Many of these build-ups have 'stromatactis' mudstone cores and corals and stromatoporoids that colonized the tops and steep flanks.

In the past, Silurian build-ups were considered to have been dominated by skeletal components, and less importance was placed on non-skeletal mound builders. Non-skeletal organisms may not have built mounds as large as those formed by corals and stromatoporoids, but they occupied a wide range of environments and commonly were the initial mound builders. 'Stromatactis'-rich

mudstone cores have now been documented by many researchers, and were most likely built by weakly skeletonized or non-skeletal components such as sponges and microbes.

3.3 STROMATACTOID STRUCTURES

The origin of stromatolites has been a topic of research for many years, and is still somewhat of an enigma in Paleozoic carbonate sedimentology. Many possible origins for stromatolite structures have been suggested, but no single explanation has been found to be completely satisfactory. A common element of the different theories is that stromatolite structures formed by the early marine cementation and infilling of cavity systems, although the origin of the cavities and the construction of mudmounds containing these structures are the source of much debate (e.g. Pratt, 1986; Bourque and Gignac, 1983).

Bathurst (1980, 1982) suggested that the cavities formed beneath submarine cemented crusts by excavation of underlying sediment. Pratt (1982) supported the idea of sediment removal from beneath a crust, but considered the crust to have been microbially bound sediment and the removed sediment to have been unbound or non-

microbial mud. Other hypotheses involving physical and diagenetic processes include enlargement of pre-existing cavities in unconsolidated lime mud and redeposition of this sediment on the cavity floors (Wallace, 1987), and diagenetic CaCO_3 replacement of large 'microbial' accretions (Tsien, 1985).

Decay of sponge material and consequent early cementation of the resulting porous network and/or collapse of decaying sponge tissue creating cavities is a theory supported by some researchers (Bourque and Boulvain, 1993; Davies and Nassichuk, 1990; Bourque and Raymond, 1988). Other researchers have postulated that the cavities formed by decay of microbial mats (Flajs and Hüssner, 1993) or bryozoans (Textoris and Carozzi, 1964). Bourque and Gignac (1983), and Lees (1988) believed that there are multiple origins for the creation of cavities and stromatoloid structures but that there is an organic control. Pratt (in press) and Tsien (1985) discuss many of the different theories and Tsien provided a table summarizing different studies.

Pratt (in press) discusses the occurrence and origin of 'zebra' stromatolites, *i.e.* stromatolites that forms horizontally continuous sheets. He theorized that syn-sedimentary tectonism, forcing apart

variably lithified (microbially bound) layers of sediment, caused these structures.

The stromatactoid structures in the mudstone cores and mudmounds of this study area include classic 'stromatactis' and 'zebra' stromatactoid structures, as well as very sparse stromatactoid structures. The sparse and laterally continuous ('zebra') stromatactoid structures appear to be end members that are intergradational with the intermediate classic 'stromatactis. Because of this, it is apparent that various forms of stromatactoid structures should not be interpreted in isolation but have common or related origins. Sparse or horizontally continuous stromatactoid structures could represent differential expansion (more extensive in the 'zebra' form) of cavities in lime mud, or may represent the original abundance of sponge material. Different combinations of physical, biological, and diagenetic processes may be the causes of differences in cavity form or cementation shown by stromatactoid structures.

: No previous studies have considered the possibility that sponges and microbes in combination could have been controls on creation of intrasediment cavity systems. Evidence from the well-preserved mudmounds in this study shows that the mudmounds were

constructed essentially by sponges and microbes in an intricate binding, baffling, and constructing relationship. An explanation for the origin of stromatactoid structures in the related larger mudmounds and mudstone cores in skeletal mounds may come from examining this microbe-sponge association more closely. Lithistid sponges were originally porous and had a spicule network that was susceptible to dissolution. Binding and encrusting by microbes creates compact carbonate sediment with little permeability. The result could have been formation of diagenetic pathways within the sponge material, confined above by microbially-bound sediment encrusting the sides and tops of the sponges.

The sparseness or the degree of interconnectedness of the stromatactoid structures could reflect in part the relative abundance of the sponges in the mudmounds as well as the amount, and duration, of water passage that could have further opened the pore system. The irregular digitate tops on many stromatactoid structures may simply reflect the irregularity of sponge surfaces encrusted by microbes. Impermeability of microbial encrustations would have promoted lateral rather than vertical circulation of pore waters through the mudmounds.

4.0 CONCLUSIONS

The following conclusions can be made from this study of Upper Silurian carbonate build-ups on western Devon, and southwestern Ellesmere islands and vicinity:

1) Two phases of carbonate build-up development can be recognized in the late Ludlow-Pridoli of the study area. The first phase is represented by a large tract of at least 27 mudmounds in the uppermost Douro Formation on western Devon Island. The second is represented by isolated skeletal mounds in the basal Devon Island Formation on southwestern Ellesmere, southern North Kent, and Seal islands, and on Colin Archer Peninsula.

2) Most of the mudmounds are similar in size, shape, lithology and faunal composition. They averaged 50m in diameter and 15m in height, are composed of stromatactoid mudstone containing little recognizable skeletal fossil material, and are flanked predominantly by coral-crinoidal wackestone.

3) Mudmound growth was terminated by abrupt sea-level rise apparently related to tectonism in the nearby Boothia Uplift region. A hiatus in deposition on western Devon Island resulted in the formation of a phosphatized hardground in dysaerobic areas and local crinoidal grainstone capping mounds in aerobic areas. The hardground at the top

of the 'rivermound' is continuous with the hardground that marks the boundary between the Douro and Devon Island formations in that area.

4) The mudmound at Griffin Inlet grew in somewhat shallower water than those farther north, as suggested by the presence of large stromatoporoids and corals within the mudmound. The hardground present within the mound succession indicates an abrupt deepening followed by shallowing and continued growth of the mudmound.

5) The single conspicuous hardground in the mudmound tract and that in the Griffin Inlet mudmound are tentatively correlated with a hardground in 'reef mounds' at Gascoyne Inlet, suggesting that the major deepening event was expressed regionally. This event probably was associated with a change from ramp to carbonate shelf geometry at the time.

6) There are two main types of skeletal mounds: coral skeletal and coral/stromatoporoid skeletal mounds. They formed on isolated favourable sites on a drowned carbonate ramp, and continued growth during basin subsidence on a distally steepened ramp during the deposition of the Devon Island Formation.

7) Relative sea-level change is reflected differently in the different skeletal mounds. Sea-level changes can be inferred from changing proportions of shale and mound-associated deposits in the skeletal mound flank bed sequence southeast of Hell Gate (HG1). This sequence

comprises a basal stromatactoid-rich mudstone facies overlain in turn by, crinoidal-coral, coral-stromatoporoid-crinoidal, and finally a crinoidal capping facies, and reflects shallowing upward, overall. The mound on North Kent Island in contrast shows a coral-stromatoporoid facies overlain by a substantial mudstone facies, suggesting that the mound could not keep up with sea-level rise but reverted to mound construction characteristic of deeper water.

8) Well-preserved lithistid sponges and microbial fabrics in some small mudmounds, and relict fabrics in the other more diagenetically altered buildups, indicate that these organisms were the primary constructors of the larger mudmounds and the mudstone cores of skeletal mounds.

9) The presence of the microbe-sponge association in the well-preserved mudmounds and the greater proportion of stromatactoid structures in more diagenetically altered mudmounds and mudstone cores, possibly indicates that the sponges and microbes had a role in development of cavities in mudmounds. These cavities could have resulted from dissolution or decay of porous, easily dissolved opaline spicular networks, encrusted by more dense impermeable microbial layers. The original presence of layers of different permeability may help to explain the development of stromatactoid structures in these mounds and in Paleozoic mudmounds in general.

REFERENCES

- Bathurst, R. G. C. 1959. The cavernous structure of some Mississippian Stromatactis reefs in Lancashire, England. *Journal of Geology*, 67: 506-521.
- Bathurst, R. G. C. 1980. Stromatactis — Origin related to submarine-cemented crusts in Paleozoic mud mounds. *Geology*, 8: 131-134.
- Bathurst, R. G. C. 1982. Genesis of stromatactis cavities between submarine crusts in Paleozoic carbonate mud buildups. *Journal of the Geological Society of London*, 139: 165-181.
- Bourque, P.-A. 1988. Silurian reefs. *In* Reefs, Canada and Adjacent Areas. *Edited by* H. H. J. Geldsetzer, N. P. James and G. E. Tebbutt. Canadian Society of Petroleum Geologists Memoir 13: 245-250.
- Bourque, P.-A., and Amyot, G. 1988. Stromatoporoid-coral reefs of the upper West Point reef complex, Late Silurian, Gaspé Peninsula, Québec. *In* Reefs, Canada and Adjacent Areas. *Edited by* H. H. J. Geldsetzer, N. P. James and G. E. Tebbutt. Canadian Society of Petroleum Geologists Memoir 13: 251-257.
- Bourque, P.-A., and Boulvain, F. 1993. A model for the origin and petrogenesis of the red stromatactis limestone of Paleozoic carbonate mounds. *Journal of Sedimentary Petrology*, 63: 607-619.
- Bourque, P.-A., and Gignac, H. 1983. Sponge-constructed stromatactis mud mounds, Silurian of Gaspé, Québec. *Journal of Sedimentary Petrology*, 53: 521-532.
- Bourque, P.-A., and Raymond, L. 1988. Non-skeletal bioherms of the lower reef complex of the West Point Formation, Late Silurian, Gaspé Peninsula, Québec. *In* Reefs, Canada and Adjacent Areas. *Edited by* H. H. J. Geldsetzer, N. P. James and G. E. Tebbutt. Canadian Society of Petroleum Geologists Memoir 13: 258-262.
- Brent, D. 1987. The Upper Silurian lower Hell Gate reef, southern Ellesmere Island, Arctic Canada. Unpublished B.Sc. thesis, McGill University. 47 pp.

- Brunton, F. R., and Dixon, O. A. 1994. Siliceous sponge-microbe biotic associations and their recurrence through the Phanerozoic as reef mound constructors. *Palaios*, 9: 370-387.
- Christie, R. L. 1972. Central stable region. *In* The Canadian Arctic Islands and the Mackenzie region: *Edited by* R. L. Christie, D. G. Cook, W. W. Nassichuk, H. P. Trettin, and C. J. Yorath. 24th International Geological Congress Field Excursion A66. pp. 40-87.
- Clough, J. G., and Blodgett, R. B. 1988. Silurian-Devonian algal reef mound complex of southwest Alaska. *In* Reefs, Canada and Adjacent Areas. *Edited by* H. H. J. Geldsetzer, N. P. James and G. E. Tebbutt. Canadian Society of Petroleum Geologists Memoir 13: 404-407.
- Copper, P., and Brunton, F. R. 1991. A global review of Silurian reefs. *In* The Murchison Symposium: Proceedings of an International Conference on the Silurian System. *Edited by* M. G. Basset, P. D. Lane and D. Edwards. Palaeontological Association of London, Special Paper in Palaeontology No. 44: 225-259.
- Davies, G. R., and Nassichuk, W. W. 1990. Submarine cements and fabrics in Carboniferous to Lower Permian, reefal, shelf margin and slope carbonates, northwestern Ellesmere Island, Canadian Arctic Archipelago. Geological Survey of Canada, Bulletin 399: 77pp.
- de Freitas, T. 1991. Stratigraphy, mud buildups, and carbonate platform development of the Upper Ordovician to Lower Devonian sequence, Ellesmere, Hans, and Devon islands, Arctic Canada. PhD, University of Ottawa. 441pp.
- de Freitas, T. A., Dixon, O. A., and Mayr, U. 1993. Silurian pinnacle reefs of the Canadian Arctic. *Palaios*, 8: 172-182.
- de Freitas, T., and Mayr, U. 1993. Middle Paleozoic tear faulting, basin development, and basement uplift, central Canadian Arctic. *Canadian Journal of Earth Sciences*, 30: 603-620.
- Dixon, O. A., and Graf, G. C. 1992. Upper Silurian reef mounds on a shallowing carbonate ramp, Devon Island, Arctic Canada. *Bulletin of Canadian Petroleum Geology*, 40: 1-23.

- Douglas, J.W. 1970. Geology of the Arctic Archipelago, *In* Geology and Economic minerals of Canada. Edited by R. J. W. Douglas. Geological Survey of Canada Economic Geology Report, 1, 5th edition: 2-8.
- Dupont, E. 1881. Sur l'origine des calcaires Dévoniens de la Belgique. Académie Royale des Sciences Belgique, Bulletin, 3rd series, 2: 264-280.
- Dupont, E. 1883. Sur l'origine des calcaires Carbonifère de la Belgique. Académie Royale des Sciences Belgique, Bulletin, 3rd series, 5: 211-229.
- Flajs, G., and Hüssner, H. 1993. A microbial model for the Lower Devonian stromatolite mud mounds of the Montagne Noire (France). *Facies*, 29: 179-194.
- Fortier, Y. O., Blackadar, R. G., Glenister, B. F., Greiner, R. H., McLaren, D. J., McMillan, N. J., Norris, A. W., Roots, E. F., Souther, J. G., Thorsteinsson, R., and Tozer, E. T. 1963. Geology of the north-central part of the Arctic Archipelago, Northwest Territories (Operation Franklin). Geological Survey of Canada, Bulletin 320, 671p.
- Frisch, T., and Sandemann, H. A. I. 1991. Reconnaissance geology of the Precambrian Shield of the Boothia Uplift, northwestern Somerset Island and eastern Prince of Wales Island, District of Franklin. Geological Survey of Canada, Paper 91-1C.
- Graf, G. 1988. Carbonate mudmounds complexes of the Upper Silurian Douro and Barlow Inlet formations at Gascoyne Inlet, Devon Island, Arctic Canada. Unpublished M.Sc. thesis, University of Ottawa. 152pp.
- Hurst, J. M. 1980. Palaeogeographic and stratigraphic differentiation of Silurian carbonate buildups and biostromes of North Greenland. *American Association of Petroleum Geologists Bulletin*, 64: 527-548.
- James, N. P. 1984. Reefs. *In* Facies Models. Edited by R. G. Walker. Geoscience Canada: 229-244.
- James, N. P., and Bourque, P.-A. 1992. Reefs and mounds. *In* Facies models, response to sea-level change. Edited by R. Walker and N. P. James. Geological Association of Canada: 323-348.

- Jones, B., and Narbonne, G. M. 1984. Environmental controls on the distribution of *Atrypa* species in Upper Silurian strata of Arctic Canada. *Canadian Journal of Earth Sciences*, 21: 131-144.
- Jones, B., Oldershaw, A. E., and Narbonne, G. M. 1979. The nature and origin of rubbly limestone in the Upper Silurian Read Bay Formation of Arctic Canada. *Sedimentary Geology*, 24: 227-252.
- Kerr, J. W. 1968. Southwestern Ellesmere Island. Geological Survey of Canada, Map 10-1968.
- Kerr, J. W. 1977. Cornwallis Fold Belt and the mechanism of basement uplift. *Canadian Journal of Earth Sciences*, 14: 1374-1401.
- Lecompte, M. 1937. Contribution à la connaissance des récifs du Dévonien de l'Ardenne. Sur la présence de structures conservées dans des efflorescences cristallines du type "Stromatactis". *Bulletin du Muséum Royale d'Histoire Naturelle de la Belgique*, 13: 1-14.
- Lees, A. 1988. Waulsortian "reefs": the history of the concept. *Mémoires de l'Institut Géologique de la Université de Louvain*, 34: 43-55.
- Mayr, U., Packard, J. J., Goodbody, Q. H., Okulitch, A. V., Rice, R. J., Goodarzi, F., and Stewart, K. R. 1994. The Phanerozoic geology of southern Ellesmere and North Kent islands, Canadian Arctic Archipelago. Geological Survey of Canada, Bulletin 470: 298pp.
- Miall, A. D. 1986. Effects of Caladonian tectonism in Arctic Canada. *Geology*, 14: 904-907.
- Morrow, D. W., and Kerr, J. W. 1977. Stratigraphy and sedimentology of Lower Paleozoic formations near Prince Alfred Bay, Devon Island. Geological Survey of Canada Bulletin, 254: 122pp.
- Narbonne, G. M. 1981. Stratigraphy, reef development and trace fossils of the Upper Silurian Douro Formation in the southeastern Canadian Arctic Islands. Unpublished PhD thesis, University of Ottawa. 259pp.
- Narbonne, G. M., and Dixon, O. A. 1982. Physical correlation and depositional environments of Upper Silurian rubbly limestone facies in the Canadian Arctic Islands. *In Arctic Geology and Geophysics. Edited by A. F. Embry and H. R. Balkwill. Canadian Society of Petroleum Geologists, Memoir 8. pp. 135-146.*

- Narbonne, G. M., and Dixon, O. A. 1984. Upper Silurian lithistid sponge reefs on Somerset Island, Arctic Canada. *Sedimentology*, 31: 25-50.
- Narbonne, G. M., and Dixon, O. A. 1988. Sponge-dominated reef mounds in the Douro Formation (Upper Silurian) of Somerset Island, N. W. T. *In* Reefs, Canada and Adjacent Areas. *Edited by* H. H. J. Geldsetzer, N. P. James and G. E. Tebbutt. Canadian Society of Petroleum Geologists Memoir 13: 339-343.
- Noble, J. P. A. 1985. Occurrence and significance of Late Silurian reefs in New Brunswick. *Canadian Journal of Earth Sciences*, 22: 1518-1529.
- Noble, J. P. A. 1988. The Late Silurian Laplante reefs of northern New Brunswick, Canada. *In* Reefs, Canada and Adjacent Areas. *Edited by* H. H. J. Geldsetzer, N. P. James and G. E. Tebbutt. Canadian Society of Petroleum Geologists Memoir 13: 344-349.
- Okulitch, A. V., Packard, J. J., and Zolnai, A. I. 1986. Evolution of the Boothia Uplift, Arctic Canada. *Canadian Journal of Earth Sciences*, 23: 350-358.
- Packard, J. J. 1985. The Upper Silurian Barlow Inlet Formation, Cornwallis Island, Arctic Canada. Unpublished PhD thesis, University of Ottawa. 791pp.
- Pedersen, T. F., and Calvert, S. E. 1990. Anoxia vs. productivity: what controls the formation of organic carbon-rich sediments and sedimentary rocks. *American Association of Petroleum Geologists Bulletin*, 74: 454-466.
- Pratt, B. R. 1982. Stromatolitic framework of carbonate mud mounds. *Journal of Sedimentary Petrology*, 52: 1203-1227.
- Pratt, B. R. 1986. Sponge-constructed stromatactis mud mounds, Silurian of Gaspé, Québec - Discussion. *Journal of Sedimentary Petrology*, 56: 459-460.
- Pratt, B. in press. The origin, biota and evolution of deep-water mud-mounds. *In* Carbonate mudmounds: their origin and evolution. *Edited by* C. L. V. Monty, D. Bosence, P. H. Bridges, and B. R. Pratt. International Association of Sedimentologists, Special Publication 25.

- Riding, R., and Soja, C. M. 1993. Silurian calcareous algae, cyanobacteria, and microproblematica from the Alexander Terrane, Alaska. *Journal of Paleontology*, 67: 710-728.
- Sears, S. O., and Lucia, F. J. 1979. Reef-growth model for Silurian pinnacle reefs, northern Michigan reef trend. *Geology*, 7: 299-302.
- Shaver, R. H. 1977. Silurian reef geometry — new dimensions to explore. *Journal of Sedimentary Petrology*, 47: 1409-1424.
- Shaver, R. H., and Sunderman, J. A. 1989. Silurian seascapes: water depth, clinothems, reef geometry, and other motifs — a critical review of the Silurian reef model. *Geological Society of America Bulletin*, 101: 939-951.
- Soja, C. M. 1991. Origin of Silurian reefs in the Alexander Terrane of southeastern Alaska. *Palaios*, 6: 111-125.
- Soja, C. M. 1993. Carbonate platform evolution in a Silurian oceanic island: a case study from Alaska's Alexander Terrane. *Journal of Sedimentary Petrology*, 63: 1078-1088.
- Soja, C. M., and Riding, R. 1993. Silurian microbial associations from the Alexander Terrane, Alaska. *Journal of Paleontology*, 67: 728-738.
- Sønderholm, M., and Harland, T. L. 1988. Uppermost Ordovician - lowermost Silurian carbonate mounds, western North Greenland. *In* *Reefs, Canada and Adjacent Areas. Edited by H. H. J. Geldsetzer, N. P. James and G. E. Tebbutt. Canadian Society of Petroleum Geologists Memoir 13: 241-244.*
- Sønderholm, M., and Harland, T. L. 1988. Franklinian reef belt, Silurian, North Greenland. *In* *Reefs, Canada and Adjacent Areas. Edited by H. H. J. Geldsetzer, N. P. James and G. E. Tebbutt. Canadian Society of Petroleum Geologists Memoir 13: 356-366.*
- Stewart, A. 1987. Late Proterozoic to Early Tertiary stratigraphy of Somerset Island and northern Boothia Peninsula, District of Franklin, N. W. T. Geological Survey of Canada, Paper 83-26.
- Textoris, D. A., and Carozzi, A. V. 1964. Petrography and evolution of Niagaran (Silurian) reefs, Indiana. *American Association of Petroleum Geologists Bulletin*, 48: 397-426.

- Thorsteinsson, R. 1963. Prince Alfred Bay. *In* Operation Franklin. *Edited by* Y. O. Fortier *et al* Geological Survey of Canada, Bulletin 320; pp. 221-232.
- Thorsteinsson, R., and Mayr, U. 1987. Sedimentary rocks of Devon Island, Canadian Arctic Archipelago. Geological Survey of Canada, Bulletin 411, 182pp.
- Thorsteinsson, R., and Tozer, E. T. 1970. Geology of the Arctic Archipelago, *In* Geology and Economic minerals of Canada. *Edited by* R. J. W. Douglas. Geological Survey of Canada Economic Geology Report, 1, 5th edition: 547-590.
- Thorsteinsson, R., and Uyeno, T. 1980. Stratigraphy and conodonts of Upper Silurian and Lower Devonian rocks of the environs of Boothia Uplift, Canadian arctic Archipelago. Geological Survey of Canada, Bulletin 292, 75pp.
- Trettin, H. P. 1987. Pearya: a composite terrane with Caladonian affinities in northern Ellesmere Island. Canadian Journal of Earth Sciences, 24: 224-245.
- Trettin, H. P. 1989. The Arctic Islands. *In* The Geology of North America - an overview. *Edited by* A. W. Bally and A. R. Palmer. Geological Society of America, pp. 349-370.
- Trettin, H. P. 1991. Tectonic framework. *In* Geology of the Innuitian Orogen and Arctic Platform of Canada and Greenland. *Edited by* H. P. Trettin. Geological Survey of Canada, Geology of Canada, no. 3, pp. 59-66.
- Tsien, H. H. 1985. Origin of Stromatactis — a replacement of colonial microbial accretions. *In* Paleoalgology: Contemporary Research and Applications. *Edited by* D. F. Toomey and M. H. Nitecki. Springer-Verlag, pp. 274-289.
- Wallace, M. W. 1987. The role of internal erosion and sedimentation in the formation of stromatactis mudstones and associated lithologies. Journal of Sedimentary Petrology, 57: 695-700.