UPPER SILURIAN CARBONATES

OF

LAKE MEMPHREMAGOG AND LIME RIDGE AREAS, QUEBEC

by

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Thesis submitted in partial fullfilment of
the degree Master of Science,
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For my wife, Wendy

SOMMAIRE

Dans la région des Cantons de l'est du Québec, deux ceintures de carbonates d'âge Silurien se trouvent en contact discordant sur les roches Cambro-Ordoviciennes de l'orogène Taconique. La ceinture sud-ouest, le long des rives du Lac Memphrémagog, consiste en ordre ascendant, du Conglomérat de Peasley Pond (d'âge Wenlockien ou plus vieux), de la Formation de Glenbrooke (d'âge Wenlockien-Ludlovien inférieur) et du Calcaire de Sargent Bay (Ludlovien moyen). Une quatrième unité (Ludlovien Supérieur), reposant sur le calcaire de Sargent Bay dans des affleurements le long de ruisseaux dans la partie est du Lac Memphrémagog, a été indentifiée. La principale unité de calcaire (Ludlovien-Pridolien) de la Formation du Lac Aylmer a été examinée dans la ceinture nord-est, dans la région de Lime Ridge-Marbleton.

L'analyse de faciès de ces roches indique une plateforme carbonatée constituée de monticules récifaux et, possiblement, d'une série de récifs à la bordure du talus, développée à partir d'un talus de roches silicicIastiques et carbonatées dans les deux régions, Lime Ridge-Marbleton et Lac Memphrémagog. Au Lac Memphrémagog, le faciès sédimentaire profond se retrouve présentement entre le craton, à l'ouest, et le talus et le faciès continental à l'est. Cette configuration est l'inverse de celle proposée pour les régions de Lime Ridge-Marbleton et Lac Aylmer.

Plusieurs modèles tectoniques ont été proposés pour expliquer l'inversion du talus. Ceux-ci incluent (1) formation de failles de decrochement pré-Acadiennes avec bassins d'extension dans le Synclinorium de Connecticut Valley-Gaspé, (2) extension du soie Taconique au Silurien supérieur, et (3) au Paléozoique supérieur, formation de failles de décrochement dextres post-Acadiennes.

ABSTRACT

Two Silurian carbonate belts lie unconformably on Cambrian-Ordovician rock of the Taconic Orogen within the Eastern Townships of Quebec. The southwest belt along the shores of Lake Memphremagog consists, in ascending order, of the Peasley Pond Conglomerate (Wenlockian or older), the Glenbrooke Formation (Wenlockian-Early Ludlovian), and the Sargent Bay Limestone (Middle-Ludlovian). A fourth unit (Late Ludlovian) was discovered overlying the Sargent Bay Limestone in creek exposures along the eastern side of Lake Memphremagog. The main limestone unit (Ludlovian-Pridolian) of the Lake Aylmer Formation was examined in the northeast belt in the Lime Ridge-Marbleton areas.

Facies analysis of these rocks indicate that a carbonate shelf-platform consisting of patch-reefs, and possibly, a reef tract-margin, developed from a siliciclastic and carbonate ramp in both the Lake Memphremagog and Lime Ridge-Marbleton areas. At Lake Memphremagog the basin facies presently lies between the craton in the west and the slope and shelf facies in the east. This configuration is the reverse of that proposed for the Lime Ridge-Marbleton and Lake Aylmer areas. Several tectonic models are proposed to explain the slope reversal. These include (1) pre-Acadian strike-slip faulting in the Connecticut Valley-Gaspe Synclinorium with pull-apart basins, (2) Late Silurian extension of the Taconic basement, and (3) Late Paleozoic, post-Acadian, dextral, strike-slip faulting.

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CHAPTER ONE - INTRODUCTION

Carbonate rocks exposed around the shores of Lake Memphremagog and in quarries and natural exposures in the Lime Ridge-Marbleton area of Quebec (Fig. 1) allow the reefal facies of the Upper Silurian rocks of the southern Gaspe peninsula to be traced southwestward along strike into the Eastern Townships. The Acadian Orogeny (Middle Devonian) has deformed rocks in both areas into folds with vertical limbs. At Lake Memphremagog the Silurian beds are folded into two complex, north-south trending synclines informally called the Sargent Bay Syncline and the Lake Memphremagog Syncline (Fig. 2). In the Dudswell area the beds are folded into synclines and anticlines that have been cut by thrust faults (Fig. 3). The calcareous siltstones and shales are prominently cleaved and bedding is obscure, while the limestones are clearly bedded. Despite the degree of deformation the fossils of stromatoporoids and corals may be well preserved particularly in the Dudswell area where deformation is not as intense.

Location

Lake Memphremagog is located within the Eastern Townships of the Province of Quebec between latitudes 45° 00' to 45° 20'N and longitudes 72° 05, to 72° 20' E (Fig. 1). The area is easily accessible, from Montreal by Autoroute 10. The Dudswell map area encompassing the towns of Lime-Ridge, Saint Adolphe-de Dudswell and Marbleton lies 80 km to the northeast.

Figure 1: Location map showing study area on a regional scale and Silurian belts in the Lake Memphremagog and Lake Aylmer areas. C-O = Cambro-Ordovician strata, S = Silurian strata, D = Devonian strata.

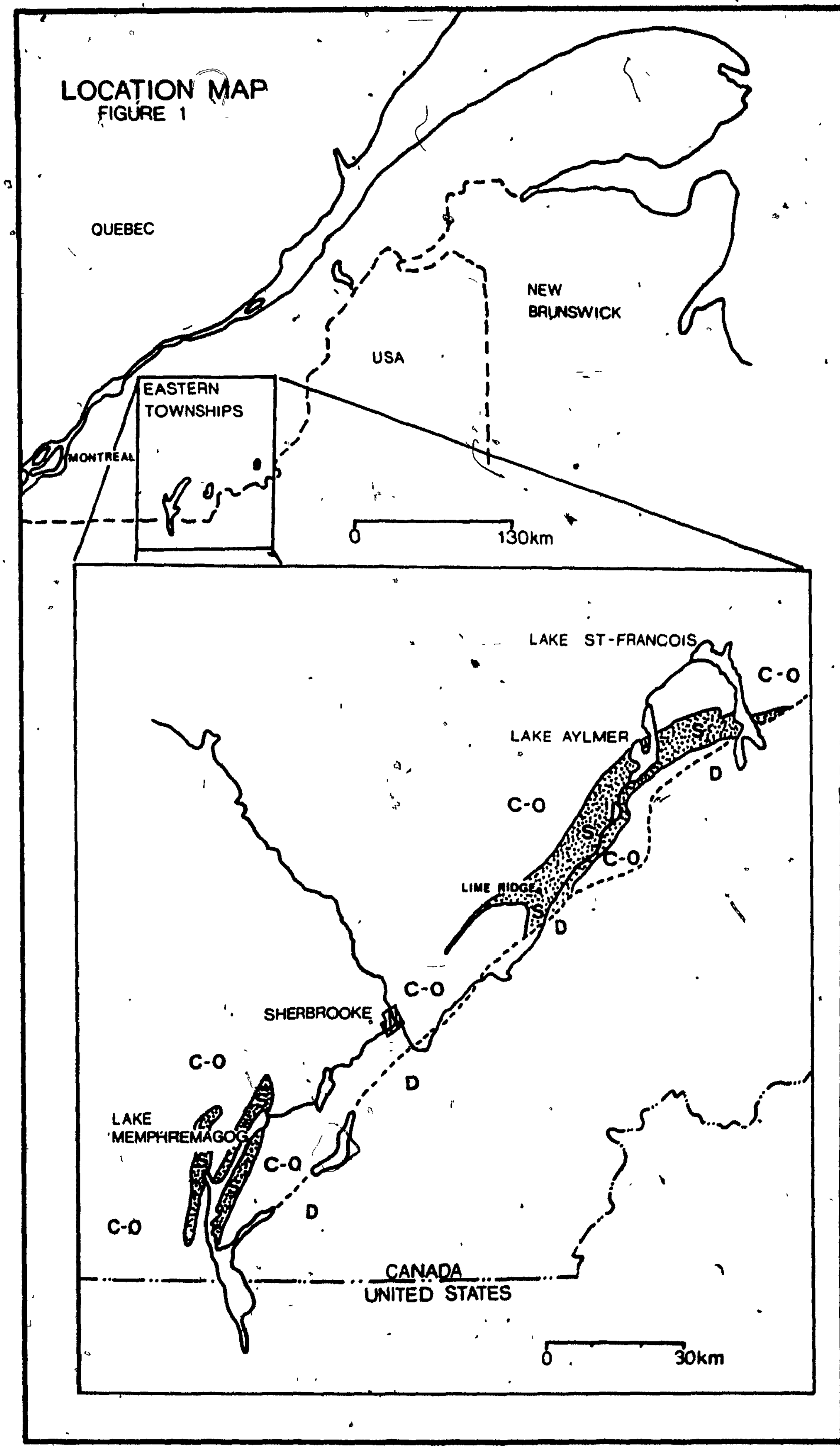

LOCATION MAP
FIGURE 1
QUEBEC
NEW BRUNSWICK
USA
EASTERN TOWNSHIPS
MONTREAL
0
130km
LAKE ST-FRANCOIS
C-O
LAKE AYLMER
S
D
C-O
S
C-O
LIME RIDGE
D
C-O
SHERBROOKE
C-O
D
LAKE MEMPHREMAGOG
C-O
D
C-O
CANADA
UNITED STATES
0
30km

FIGURE 2.

LEGEND

UCS - Upper Calcareous Siltstone.

SBL - Sargent Bay Limestone.

GF - Glenbrooke Formation.

PPC - Peasley Pond Conglomerate.

▬▬ Fault

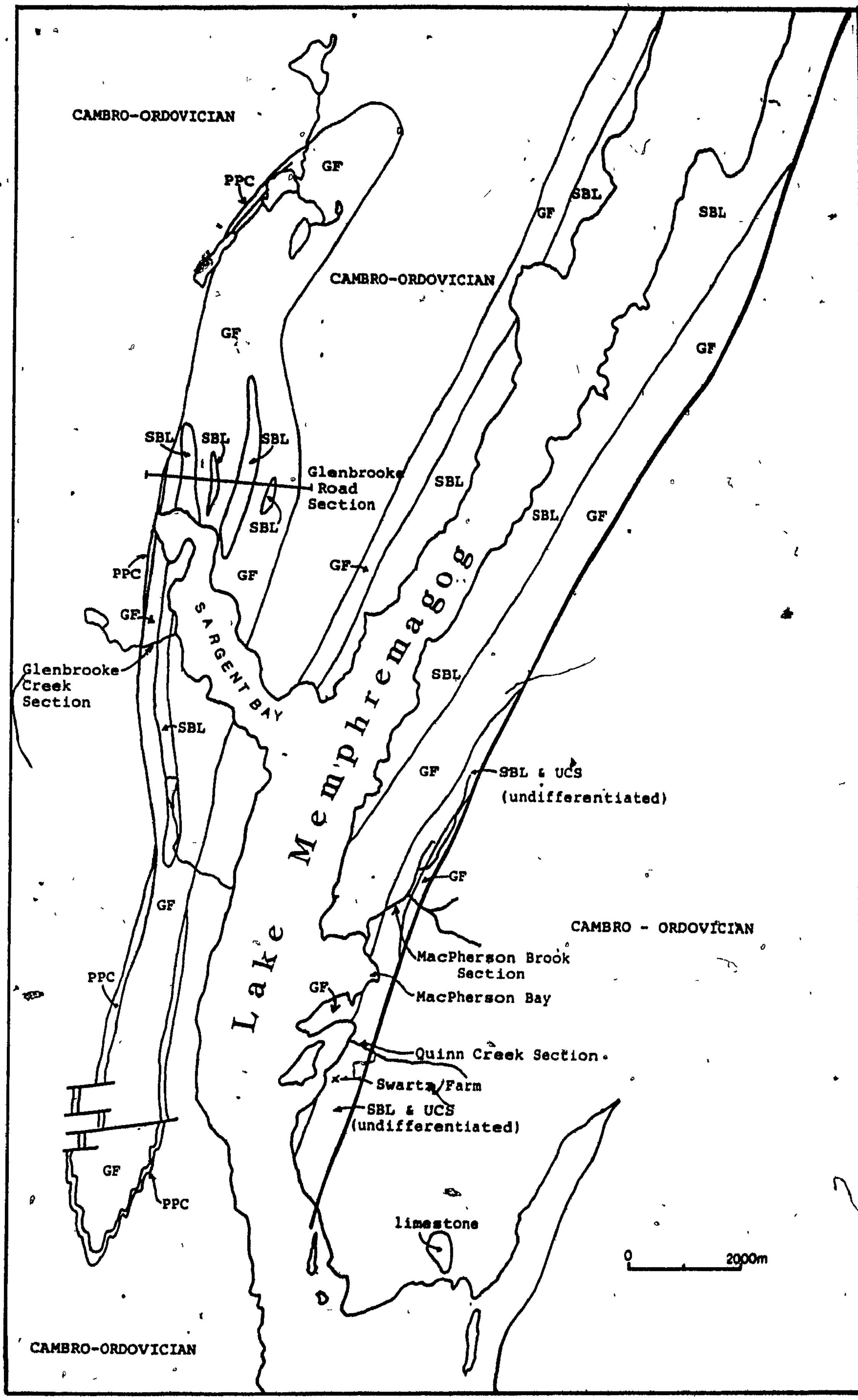

CAMBRO-ORDOVICIAN
GF
PPC
SBL
GF
SBL
CAMBRO-ORDOVICIAN
GF
GF
SBL
SBL
SBL
Glenbrooke
Road
Section
SBL
SBL
SBL
GF
PPC
GF
GF
GF
SARGENT BAY
Glenbrooke
Creek
Section
SBL
Lake Memphremagog
SBL
GF
SBL & UCS
(undifferentiated)
GF
GF
CAMBRO - ORDOVICIAN
MacPherson Brook
Section
GF
MacPherson Bay
PPC
Quinn Creek Section
Swartz Farm
SBL & UCS
(undifferentiated)
GF
PPC
limestone
0
2000m
CAMBRO-ORDOVICIAN

FIGURE 3, LIME RIDGE

LEGEND

AYER'S CLIFF FORMATION (DEVONIAN)

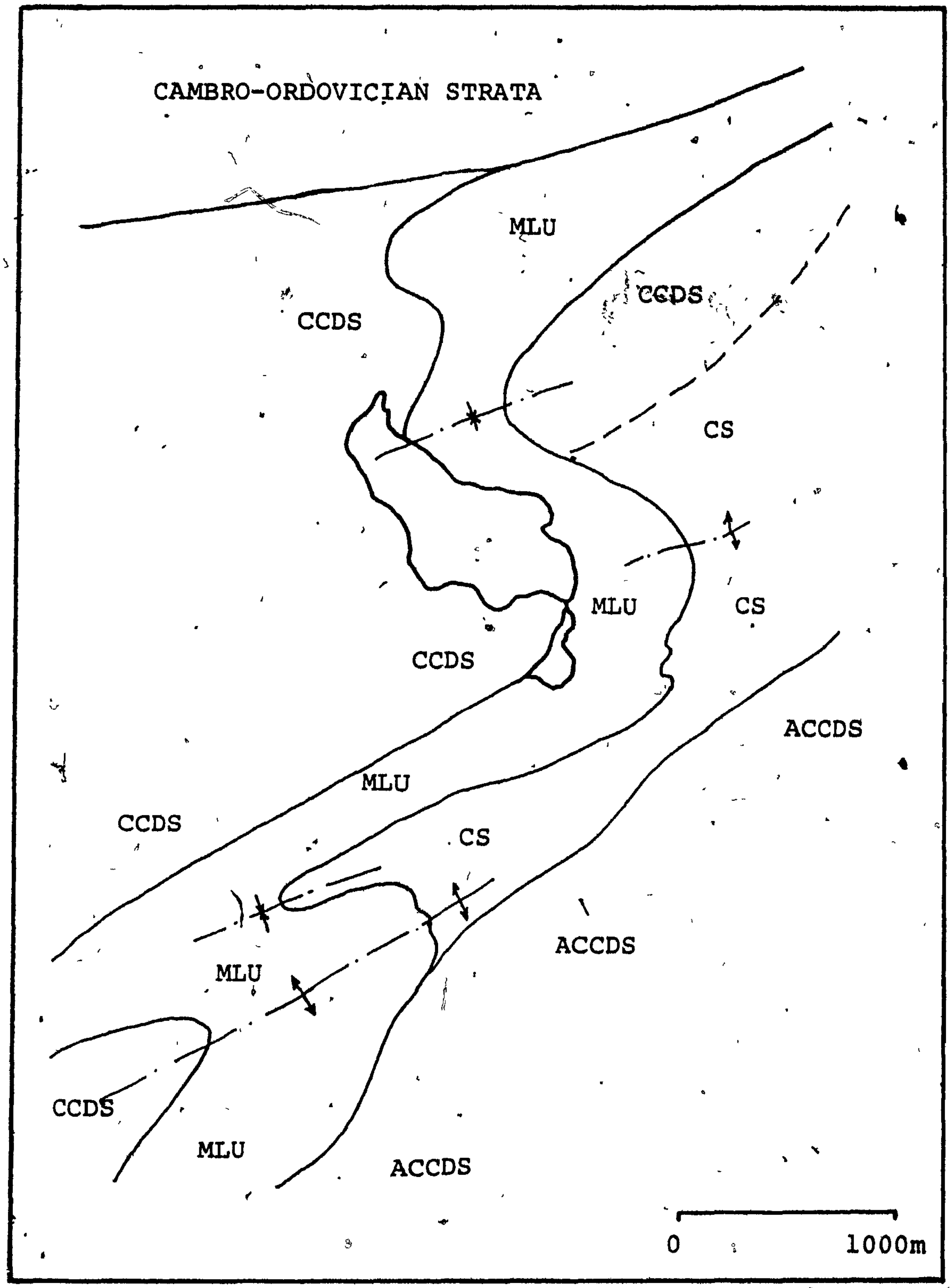
ACCDS - Calcareous and dolomitic siltstone.

LAKE AYLMER FORMATION (UPPER SILURIAN)

CS - Calcareous siltstone.

MLU - Main limestone unit.

CCDS - Conglomerate and calcareous and dolomitic siltstone (undifferentiated).



Original geology by Petryk, 1985
(unpub. map), and de Romer, 1985.

There is considerable relief within the Lake Memphremagog map area. The maximum elevations of 828 m and 953 m are for the summits Owl's Head and Mont Orford respectively. The lake straddles the Sutton and Stoke ranges of the southern Quebec Appalachians. The Sutton Range parallels the western shore of Lake Memphremagog. The Stoke Range enters the Province at Owl's Head on the southwestern side of the lake and continues on the eastern side as far as Dudswell Township.

Purpose of Study

Published studies by Clark (1936), Cooke (1950), Boucot and Drapeau (1968), Lamothe (1981a, 1981b, and 1979), de Romer (1980, and 1985) and unpublished work by Petryk (1985), and Lavoie (1985) have provided the stratigraphic framework within which detailed lithofacies and corresponding biofacies can be defined. The following research is based on stratigraphy, fossil content, and lithofacies of the Lake Memphremagog and Dudswell areas.

The purpose of this paper is to:

(1) examine and describe lithofacies relationships and corresponding fossil types within the limestones and calcareous siltstones of both the Lake Memphremagog and Dudswell areas, and to correlate them.

(2) construct a depositional facies model for these limestones.

(3) To put the Dudswell and Lake Memphremagog areas into a "depositional model" of Late Silurian time.

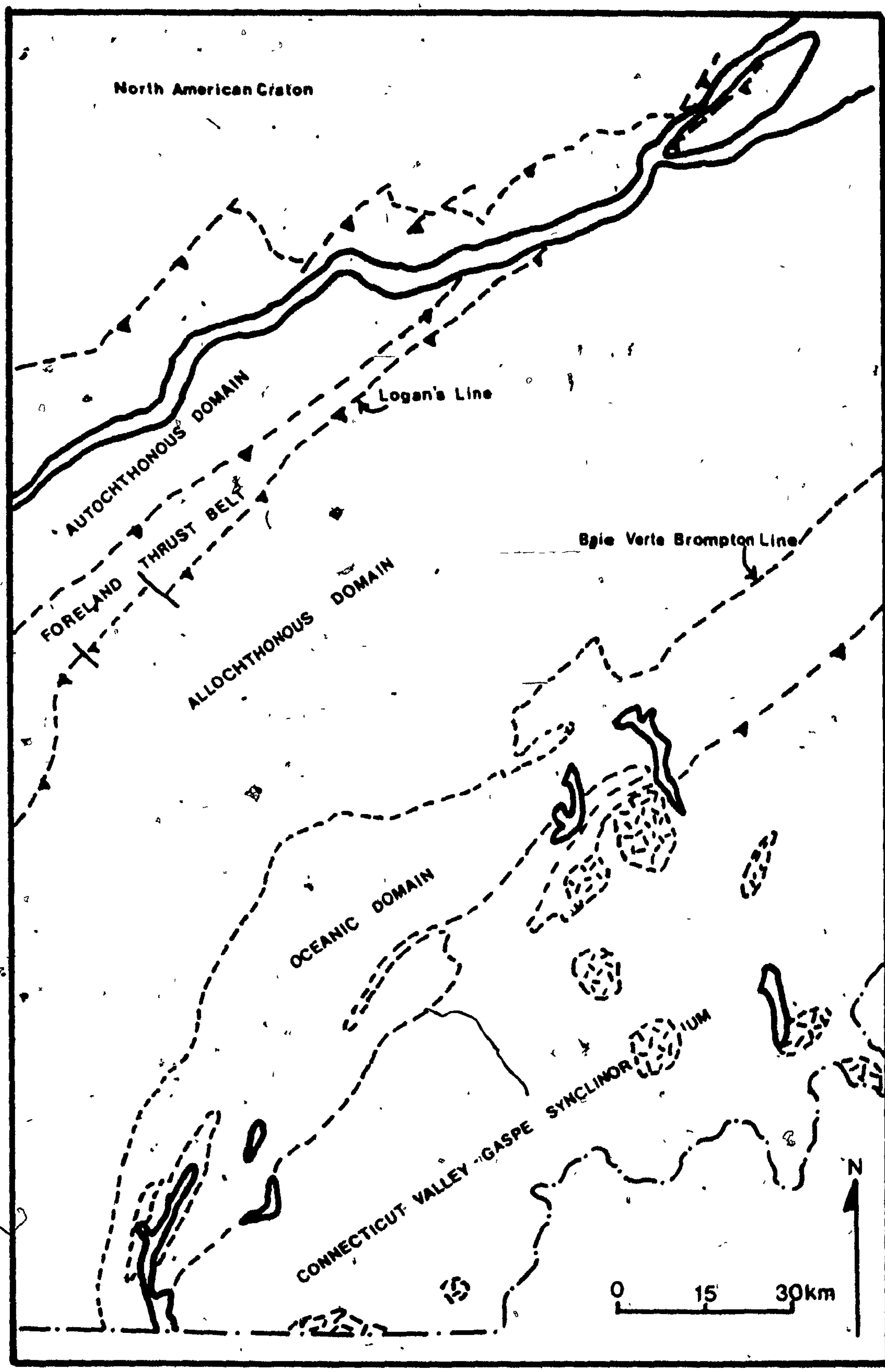
1.2. REGIONAL GEOLOGY

Introduction

The sedimentary rocks of the Eastern Townships have been divided by St-Julien and Hubert (1975) into 5 structural-stratigraphic domains (Fig. 4): autochthonous domain, foreland thrust domain, allochthonous domain, oceanic domain, and the Connecticut Valley-Gaspe Synclinorium. Sediments within the first four domains were deposited in Cambrian to Middle Ordovician time, those in the last domain were deposited in Silurian and Devonian time. The sediments of "Cambrian-Ordovician" and "Silurian-Devonian" age form two temporal belts. These belts together form the southwestern portion of the Quebec Appalachians.

The oceanic sequence of the Cambro-Ordovician belt is characterized by a basal red and green argillite and conglomerate overlain by the enigmatic St-Daniel shale-olistostrome. Overlying the St-Daniel are pelagic-hemipelagic sediments and turbidite sequences of the Middle Ordovician, Magog Group. The St-Daniel olistostrome is contemporaneous with the first orogenic movement of allochthonous terranes. The Magog Group represents sedimentation in a foreland basin undergoing rapid subsidence and narrowing due to viscoelastic relaxation of the lithosphere (Quinlan and Beaumont, 1984). The Magog Group forms the basement upon which the Silurian sequence was deposited.

Figure 4: Structural domains from St-Julien and Hubert (1975). From west to east, they are: Autochthonous Domain, Foreland Thrust Belt, Allochthonous Domain, Oceanic Domain, and the Connecticut Valley-Gaspe Synclinorium.


North American Craton
AUTOCHTHONOUS DOMAIN
Logan's Line
FORELAND THRUST BELT
ALLOCHTHONOUS DOMAIN
Baie Verte Brompton Line
OCEANIC DOMAIN
CONNECTICUT VALLEY GASPE SYNCLINORIUM
N
0 15 30km

The second belt represents a deep water package of a "monotonous turbidite sequence of alternating grey and black shale and fine grained laminated sandstone" (St-Julien et. al., 1983, p. 107). These authors maintain that the Acadian Orogeny thrust Silurian-Devonian sedimentary rock westward upon Cambrian-Ordovician strata.

Paleotectonic Setting

The Silurian rocks of the Lake Memphremagog and Lake Aylmer synclines lie unconformably on Taconic deformed, Cambrian-Ordovician strata, adjacent to the Connecticut Valley-Gaspe Synclinorium (Fig. 4). This large synclinorium has been interpreted as a Late Silurian trough by Naylor and Boucot (1965), Boucot (1968), Rodgers (1970), Poole (1976), Roy (1980), and Bradley (1983). Additionally, other Silurian paleotopographic features have been recognized. These include, from west to east: (1) North American Craton; (2) Foreland Basin or Sandstone Belt; (3) Appalachia or Taconia; (4) Connecticut Valley - Gaspe Trough; (5) Piscataquis Volcanic Belt; (6) Aroostook - Matapedia Trough; (7) Miramichi Trough; (8) Merrimack Trough; (9) Fredericton Trough; (10) Coastal Volcanic Belt; and (11) Avalonia (Fig. 5). The Lake Memphremagog and Lake Aylmer synclines are considered here as remnants of the western margin of the Connecticut Valley - Gaspe Trough that onlapped the Taconic land mass in Late Silurian Time.

Models describing the formation of these Late Silurian, Ludlow-Pridolian, paleotectonic elements are complex and

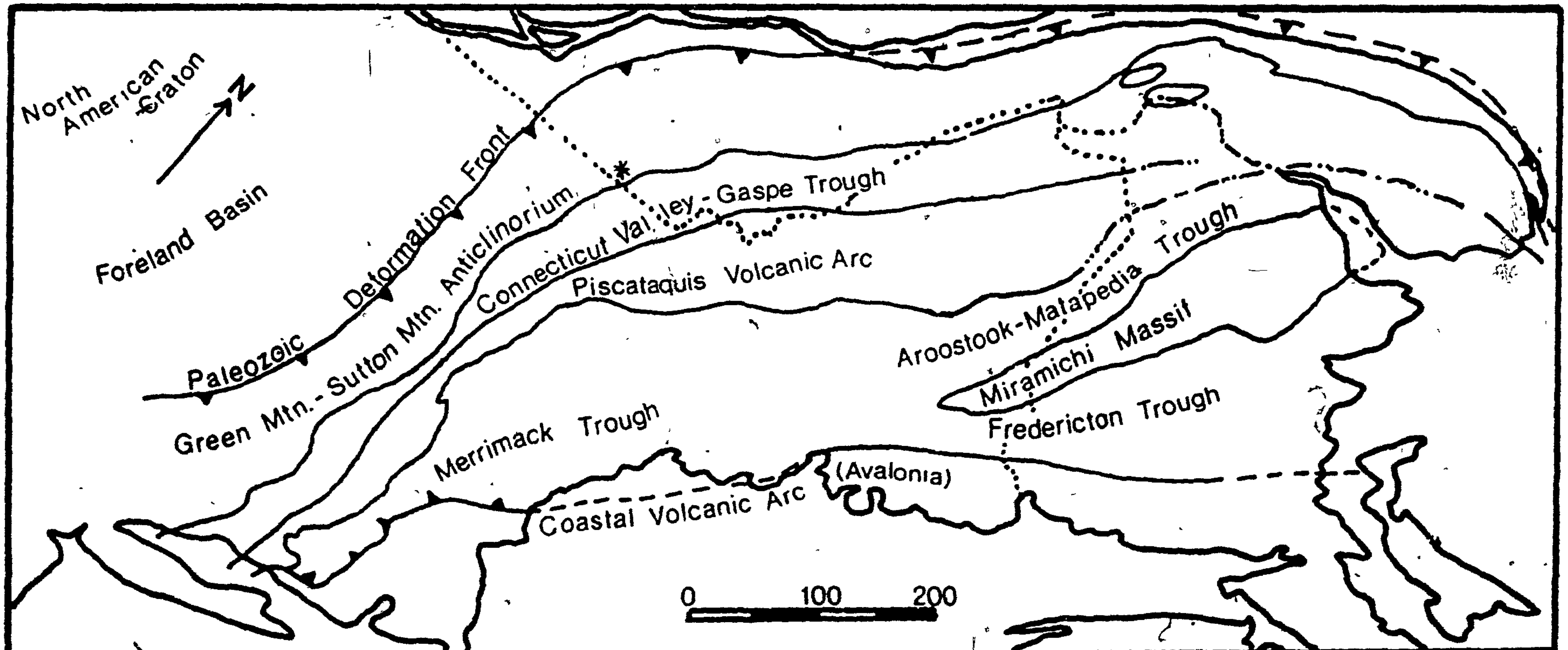


Figure 5: Paleotopographic features of Silurian time (modified after Bradley, 1983). These include, from west to east: North American Craton, Foreland Basin, Taconia, Connecticut Valley-Gaspe Trough, Piscataquis Volcanic Belt, Aroostook-Matapedia Trough, Fredericton Trough, Coastal Volcanic Belt, and Avalonia.

controversial. The controversy arises in the interpretation of the Piscataquis volcanics, a Silurian-Devonian volcanic belt that borders the eastern margin of the Connecticut Valley - Gaspe Trough. These volcanics, many of which were erupted subaerially, have been identified as a varied suite of basalts, andesites, dacites and rhyolites (Rankin, 1968; McKerrow and Zeigler, 1971; and Bradley, 1983). Additionally, plutons thought to be comagmatic with these volcanics show calc-alkaline differentiated trends and REE patterns characteristic of subduction derived magmas (Bradley, 1983). In contrast, other workers (Hepburne, 1981; Bedard, 1985) have interpreted the volcanics to be of tholeiitic to alkaline affinity. Bedard (1985), working on pre-Acadian magmatic suites of the Chaleurs Bay area (and included within the Piscataquis Volcanic Belt, Bradley, 1983), has concluded that the apparent calc-alkaline trend interpreted by other workers can be attributed to felsic contamination. Hepburne (1981) has interpreted the possibly correlative Standing Pond Volcanics located within the eastern part of the Connecticut Valley-Gaspe Trough as LREE-depleted tholeiites.

The interpretation of the Piscataquis volcanics as showing either calc-alkaline or tholeiitic-alkaline affinities invariably leads to two very different tectonic models. Bradley (1983, 1982b) has proposed a "Mollucca-Type, arc-arc collision", in which northwestward subduction in a bilateral subduction model (McKerrow and Ziegler, 1971) is responsible for an island arc (Piscataquis Volcanic Belt) and a back-arc trough (Connecticut Valley - Gaspe Trough). The back-arc setting is regarded by Bradley (1983) as a zone of oblique, dextral strike-slip movement in which the Mistigougueche and Lac des Baies subbasins of Roy (1980), and Lajoie et. al. (1968) respectively, originated as pull aparts. Subsidence within these basins was localized and rapid.

In the second model Ruitenberg et. al. (1977) and Poole (1976) postulated a single subduction zone lying much further to the southeast. Subduction dipped northwest under Avalonia producing the Coastal Volcanic Belt. The Piscataquis volcanics would then have been generated, as suggested by Bedard (1985) for the Chaleurs Bay area, by major strike-slip faults with localized tensional environments within a foreland to an orogenic belt. Along this belt Avalonia probably collided with North America.

Whether the subduction zone is placed along the western margin of the Fredericton-Merrimack Trough, or along the eastern border of Avalonia, the Connecticut Valley-Gaspe Trough and the Piscataquis Volcanic Belt must have been areas of major transcurrent motion. Pull-apart basins like the Lac des Baies subbasin (Lajoie et. al., 1968) were a product of major strike-slip movement (Mitchell and Reading, 1980; Aydin and Nur, 1982).

Upper Silurian Depositional History

Silurian sedimentary rocks of the Eastern Townships comprise the Lake Aylmer Formation, and Glenbrooke, and St. Francis groups. The Lake Lambton Formation, the only formation of Silurian age, belonging to the St. Francis Group, consists of a basal conglomerate, shale and siltstone, and calcareous and dolomitic siltstone assemblage. The Lake Aylmer Group was reduced to formation status by Lavoie (1985). The Upper Silurian, Lake Aylmer Formation consists of three members Ay1, Ay2, and Ay3 (St-Julien, 1970b). These three members are respectively, a basal conglomerate alternating with sandstone and shale, alternating siltstone and shale, and blue-grey limestone. The Glenbrooke Group is comprised of a basal conglomerate, an overlying slate, siltstone and calcareous siltstone, and an uppermost limestone (Clark, 1936; Boucot and Drapeau, 1968).

Lavoie (1985) has divided the Lake Lambton Formation into eight lithologic members (see Table I). Lavoie's classification of these members as "A" through "H" is an adaptation of Duquette's (1961) original recognition of members A, B, C, D, and E. Correlation between the Lake Aylmer Formation and the Lower St. Francis Group, Lake Lambton Formation was first proposed by Duquette (1961) and confirmed by Lavoie (1985, p. 105).

The following depositional history for the Lake Aylmer and Lake Lambton Formations is a summary of that presented by Lavoie (1985). Both formations rest unconformably on

TABLE I (Lavoie, 1985)

LAKE AYLMER FORMATION	LITHOLOGY	DEPOSITIONAL ENVIRONMENT
Ay3 - Member	calcareous siltstone/ silty limestone	deep marine & shallow marine (limestone)
Ay2 - Member	siltstone	subaerial
Ay1 - Member	conglomerate, siltstone,	subaerial

LAKE LAMBTON FORMATION	LITHOLOGY	DEPOSITIONAL ENVIRONMENT
H - Member	dark green shale	deep marine
G - Member	alternating dolomnitic siltstone and shale	deep marine
F - Member	Silty dolomite, crinoids brachiopods and corals	shallow marine
E - Member	Shale and silty limestones	deep marine
D - Member	sandstones and conglomerates brachiopods, corals	shallow marine
C - Member	shale with silty dolomite and limestone - rare crinoids	deep marine
B - Member	limestone and silty dolostone	shallow marine
A - Member	conglomerate and orthoquartzite locally argillaceous	subaerial

Cambrian and Ordovician strata. The two formations are presumed by Lavoie (1985) to have been deposited concurrently in the same basin and to have shared the same source.

The denudation of Taconic highlands in the northwest portion of the basin resulted in the deposition of Ay1 and Ay2 members under fluviatile conditions. Members A, B, and C of the Lake Lambton Formation suggest deposition under transgressive marine conditions that were concurrent with Ay1 and Ay2 deposition. The marine regression inferred from the deposition of member D at Lake Lambton had little effect on the Lake Aylmer area as conglomerates, siltstones, and shales continued to be deposited under fluviatile conditions. A marine transgression inundated both Lake Aylmer and Lake Lambton areas depositing Ay3 calcareous siltstones and silty limestones and E-member shales and calcareous siltstones respectively. Ay3 and F-members indicate Early Pridolian regression, and Ay3 and G-H members indicate Late Pridolian transgression.

Doolan and others (1983, p. 106) have correlated the lower two formations of the Memphremagog Group by lithic similarity with the Shaw Mountain Conglomerate and the Northfield Slate of northern Vermont. The Sargent Bay Limestone was correlated with the St. Francis Group in southeastern Quebec and the Ayers Cliff Member (not to be confused with the Ayer's Cliff Formation of the Saint Francis Group) of the Waits River Formation in northern Vermont. However, their correlation of the Lake Memphremagog Group with the eastern Quebec, St. Francis Group is not clear (Fig. [illegible] p. 106). The upper two formations of the St. Francis Group have been assigned a Devonian age (St-Julien, 1970).

Rocks of the Silurian-Devonian, Connecticut Valley-Gaspe Synclinorium of northern Vermont and southeastern Quebec have been intruded by many Devonian plutons. These dioritic, quartz dioritic and granodioritic plutons have been interpreted as Acadian orogenic intrusives.

Acadian Orogeny

The Silurian-Devonian cover, along with the Cambro-Ordovician basement was deformed during the Acadian Orogeny. Acadian deformation began in the Lake Memphremagog area as early as Eifelian time (Boucot, 1968), Emsian in Maine (Donohoe and Pajari, 1973), and Siegenian at Chaleurs Bay (Donohoe and Pajari, 1973). The Acadian Orogeny was characterized by a west-directed over-thrust of either an accretionary wedge (Bradley, 1983) or by the allochthonous Avalonian terrane (Ruitenburg at. al., 1977; Poole, 1976, and Osberg, 1978). Loading of the crust resulted in crustal downwarping and rapid subsidence in the Connecticut Valley-Gaspe Trough (Bradley, 1983). Erosion of the uplifted highlands to the east and of the peripheral bulge to the west (Quinlan and Beaumont, 1984) provided sediment for turbiditic deposition in the Ayers Cliff, Compton, Seboomook, Temiscouata, Gile Mountain and Fortin formations in Devonian time.

In latest Devonian time dextral strike-slip faulting dominated regional tectonics on the Avalonian side of the Acadian Orogen (Bradley, 1983, 1982b) while thrust faulting dominated the area closer to the craton (St-Julien et. al., 1983). The Connecticut Valley-Gaspe Trough was folded and extensively faulted into a broad synclinorium (St-Julien and Hubert, 1975; St-Julien et. al., 1983). The allochthonous Lake Lambton Formation has been thrust against the autochthonous Lake Aylmer Formation. The interpretation of the Guadaloupe fault, however, along the St. Victor and Connecticut Valley-Gaspe synclines as a zone in which younger, Devonian strata was thrust westward over older, Cambro-Ordovician strata is controversial. This sequence of faulting is opposite of the typical, old thrust over young sequence (Dahlstrom, 1972). Strike-slip motion along north-east trending high-angle faults has been recognized by Bradley (1983) in southeastern Maine, and the Fredericton, Aroostook-Matapedia troughs. Although most movement is Carboniferous in age some occurred as early as Middle Devonian.

1.3. PREVIOUS WORK

Logan first described the rocks of the Lake Memphremagog area in a series of reports (1849, and 1863). In these reports he assigned the limestone exposures along the shores of Lake Memphremagog to a Late Silurian age. Ells (1887, 1888, and 1896) confirmed the Siluro-Devonian age of these rocks. Clark (1936) in a brief article proposed the Lake

Memphremagog succession be called the Glenbrooke Group. Cooke (1950) suggested a Devonian age for the limestones of Lake Memphremagog based on poorly preserved fossils collected by Kerr in 1923 and described by E. M. Kindle. Boucot and Drapeau (1968), have reviewed the evidence for the Late Silurian age of the Glenbrooke Group. Preliminary maps of the Lake Memphremagog area have been published by Lamothe (1981a, 1981b, and 1979) and de Romer (1980).

A Devonian age was assigned to the Lake Aylmer Group within the Dudswell area by Cooke (1950). Cooke's conclusion was based entirely on fossils classified by Clark (1942) as Helderberg (Lower Devonian) in age. Boucot and Drapeau (1968) and St-Julian (1970) proposed a Ludlovian-Pridolian age for the Lake Aylmer Group within the Dudswell area. Petryk (1985) in an unpublished map shows the distribution of limestones of the Dudswell area and assigns them a Late Silurian age. Lavoie (1985) and de Romer (1985) have described the stratigraphy of the Late Silurian limestones of the Lake St. Francois and Lake Aylmer areas.

Local Stratigraphy

In the Lake Memphremagog area the Silurian rocks have been called the Glenbrooke Group but the term is inappropriate as it has also been used for one of the formations within the group. The author suggests this term be dropped and replaced with the term "Memphremagog Group". The Memphremagog Group would then include the Sargent Bay

Limestone, Glenbrooke Formation, and Peasley Pond Conglomerate.

An angular unconformity separates the Silurian succession from the underlying Ordovician slates. The Peasley Pond Conglomerate overlies this unconformity along the west side of Lake Memphremagog. In the type section for the Peasley Pond Conglomerate, along the north shore of Peasley Pond, Clark (1936) described 63.3 m of alternating, polymictic quartz and chert conglomerates and sandstones. Boucot and Drapeau (1968, p. 5) state that "the conglomerates are polymictic, and the pebbles, few of which exceed one inch in diameter, are composed of quartzite and chert with smaller pebbles of slate and metavolcanic rock set in a matrix of sand-sized grains of quartz with some feldspar." Recrystallization, these authors contend, has masked the original cement, but they believe that it may have been siliceous and calcareous. The sandstones are described by Clark (1936) as grey to light tan in colour with subangular to subrounded grains of quartz similar to the grains found in the conglomerate. These rocks are now classified as quartzites (Boucot and Drapeau, 1968).

The lower, non-calcareous slate and upper calcareous siltstone that overlie the Peasley Pond Formation constitutes the Glenbrooke Formation. Clark (1936) first described this unit calling it the Glenbrooke shale. The type section for this unit is in Glenbrooke Creek. Cooke (1950) simply termed this unit "Argillite", but Boucot and Drapeau (1968), in keeping with Clark's (1936) nomenclature, have called it the Glenbrooke Formation. The lower, blue-grey shales weather rusty. The upper, greenish-grey siltstones weather to a pitted surface.

The contact of the Glenbrooke Formation with the overlying Sargent Bay Limestone is locally abrupt at the Glenbrooke Creek section. Boucot and Drapeau (1968, p. 7) described this limestone as "greyish-blue, fine grained limestone that may be shaly at the base". The Sargent Bay Limestone in Glenbrooke Creek consists of thin, massive rhythmic beds separated by shale partings. The boundary of the Sargent Bay limestone is arbitrarily placed at the top of the highest calcareous siltstone bed retaining the gradational succession in the Glenbrooke Formation. No body fossils and only a few trace fossils were collected from the calcareous siltstone member (A1) but Ells (1896), Cooke (1950) and Boucot and Drapeau (1968) report a variety of fossils including trilobites, brachiopods and cephalopods.

On the east side of Lake Memphremagog at MacPherson and Quinn Brooks (Fig. 2) the upper 35 to 50 m of the Glenbrooke Formation consists of fossiliferous, nodular calcareous siltstones. Cooke (1950, p. 69) described the rock as a "badly sheared nodular material, with nodules of hard calcareous material in a slaty, somewhat calcareous matrix". Cooke concludes that the nodules appear to be partly silicified fossils in an accumulation of calcite that separate free as the matrix weathers to an earthy dust. Fossils include crinoidal debris, tabulate and rugose corals and stromatoporoids.

A similar sequence of basal conglomerates, overlain by slates and a less argillaceous upper limestone is described in the Lake Aylmer Formation (Cooke, 1950; Boucot and Drapeau, 1968; and Lavoie, 1985). Cooke (1950) described the conglomerates as composed of rhyolite, grey granite, quartzite or greywacke, and slate pebbles up to a foot or more in diameter that are crowded together in a matrix of quartz, chert and rhyolitic grit. The matrix is sandy to slaty in places. The Lake Aylmer dark blue-grey slates, Cooke (1950) maintains, do not occupy a specific position within the group and two bands of them exist northeast of Dudswell where the units appear to be interbedded with limestones. Similarly, Lavoie (1985) has described the Lake Aylmer Formation as consisting of a basal conglomerate alternating with sandstones, siltstones and shales, and a regular alternation of limestones and calcareous siltstones. Adopting St-Julien's (1970) classification of Ay1, Ay2, and Ay3 for the Lake Aylmer Formation, Lavoie (1985) shows the upper Ay3 thickening towards Lime Ridge, where he describes limestone rich in stromatoporoids, corals and brachiopods. The Ay3 in other areas of the Eastern Townships consists of grey-blue limestone beds up to 8m thick with rare fossils.

CHAPTER TWO - LAKE MEMPHREMAGOG

2.1. STRATIGRAPHIC SECTIONS

Introduction

Three schematic stratigraphic sections (figs. 6) (1) Sargent Bay Syncline, (2) Lake Memphremagog Syncline, and (3) eastern limb of the Lake Memphremagog Syncline were constructed from data collected along Glenbrooke Creek, Glenbrooke Road, the shoreline of Lake Memphremagog, MacPherson Brook, Macpherson Bay, and Quinn Creek. Geologic maps of the creeks are presented along with structural profiles (figs. 7,8,9, and 10). Field and petrographic observations summarized in these sections and maps were used in the identification of lithofacies for the Sargent Bay Limestone and the structure in the Lake Memphremagog area. Detailed descriptions of Glenbrooke Creek, Glenbrooke Road, MacPherson Brook and Quinn Creek are presented in Appendix A.

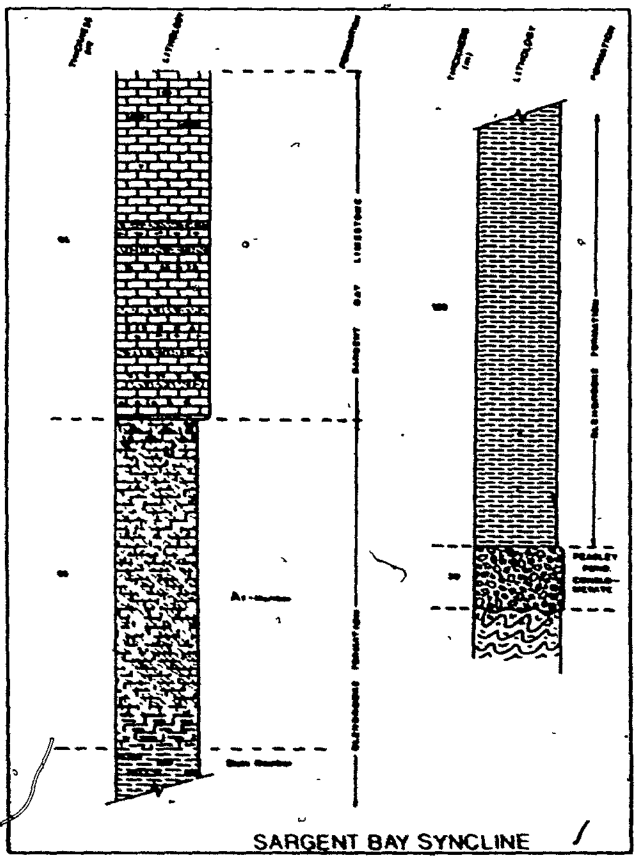
Glenbrooke Creek

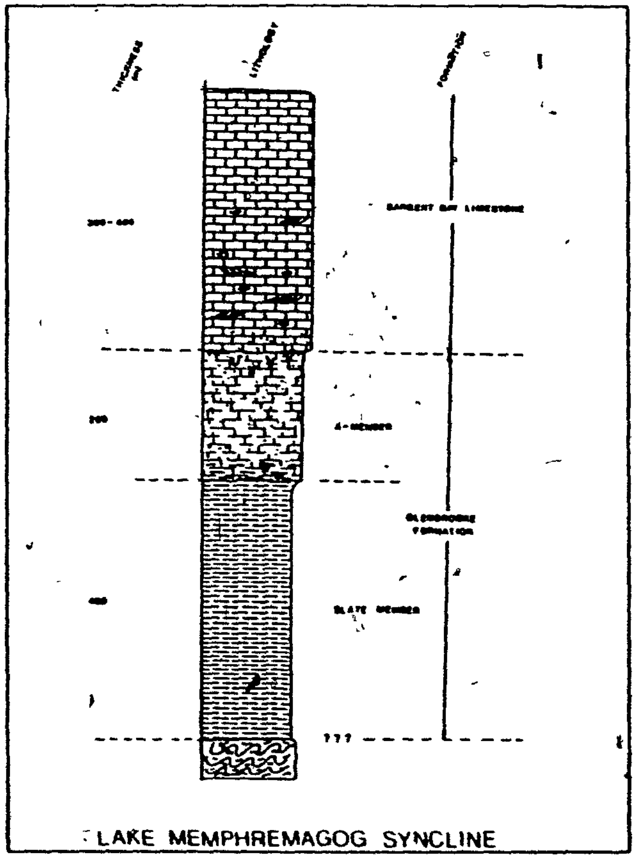
The Glenbrooke Creek section consists of approximately 20m of Peasley Pond Conglomerate, 180m of Glenbrooke Formation, and 65m of Sargent Bay Limestone. The lower portion of the Glenbrooke Formation, lying abruptly on the Peasley Pond Conglomerate, consists of 120m of non-calcareous to moderately calcareous, unfossiliferous slate. The contact between the basal Slate member and the overlying A member is gradational, as is the contact with the overlying Sargent Bay Limestone.

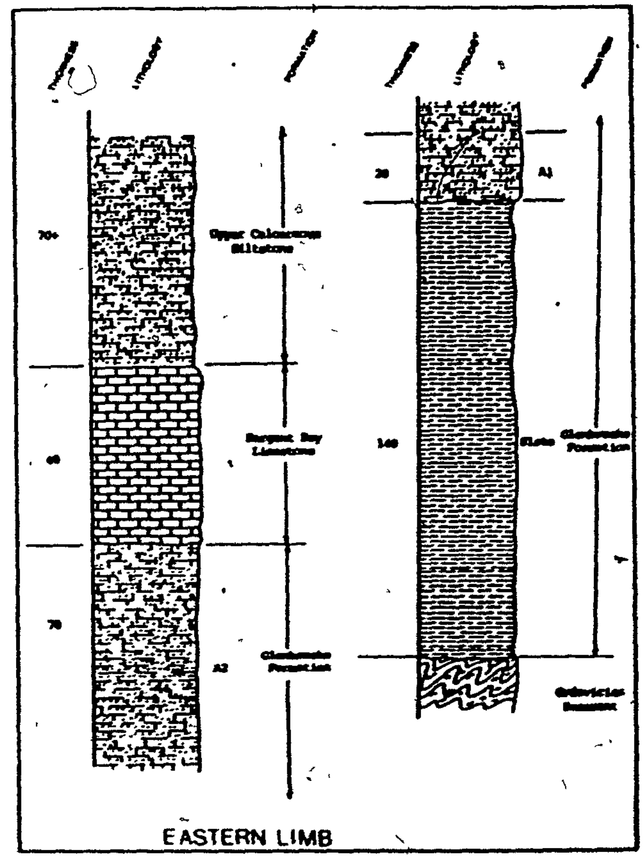
Figure 6: Schematic stratigraphic sections for Sargent Bay Syncline, Lake Memphremagog, and Eastern Limb.

LEGEND FOR FIGURES 6 TO 10

- limestone
- Calcareous Siltstone
- Slate
- Conglomerate
- Cambro-Ordovician Strata
- pseudonodules
- Siltstone boudins
- allodapic limestone
- Cross lamination
- Cross bedding
- burrows
- cleavage
- inferred thrust fault
- confirmed thrust fault


SARGENT BAY SYNCLINE


LAKE MEMPHREMAGOG SYNCLINE


EASTERN LIMB

GLENBROOKE CREEK SECTION - MAP

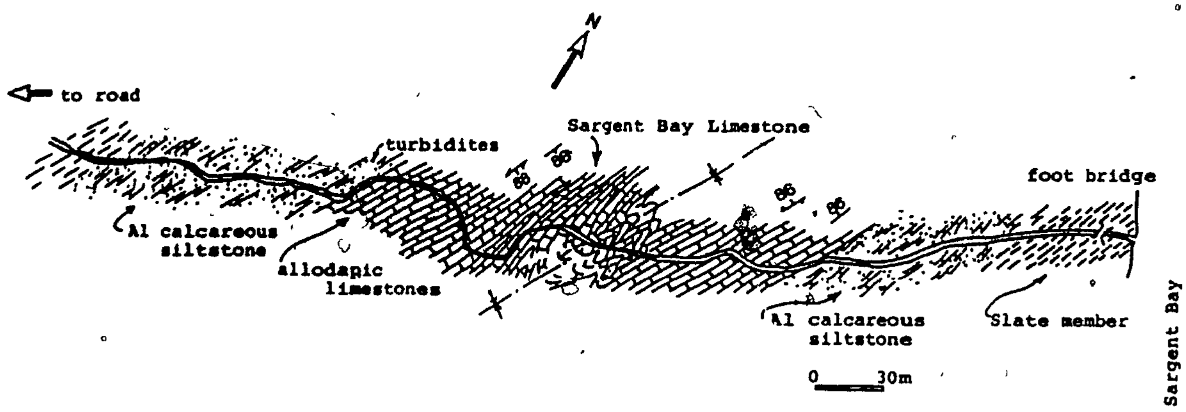


Figure 7: Geology of the Glenbrooke Creek Section.

GLENBROOKE ROAD SECTION - STRUCTURAL PROFILE

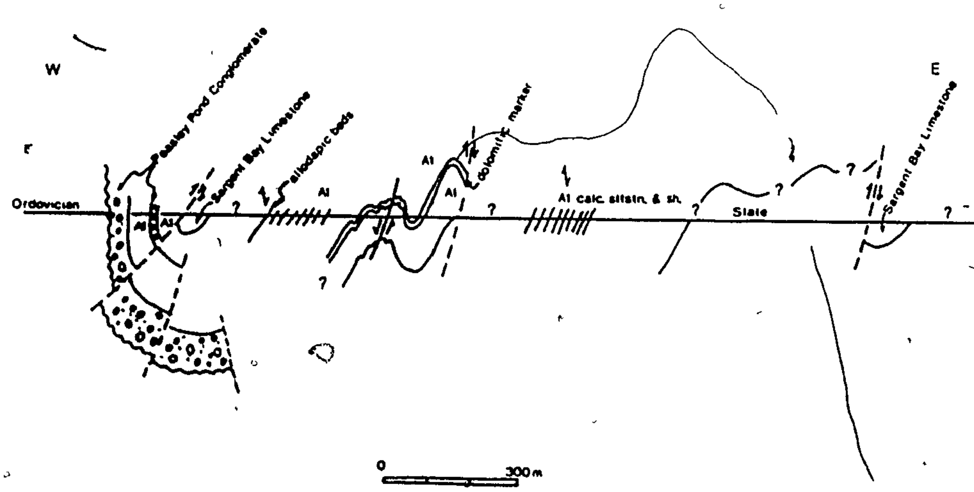
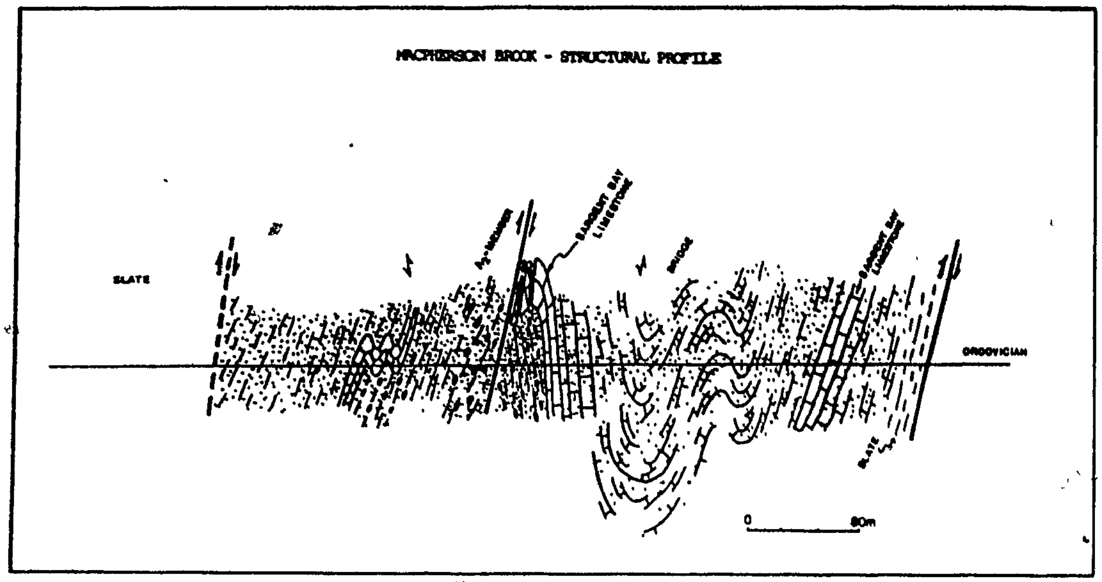


Figure 8: Structural profile of the Glenbrooke Road Section.



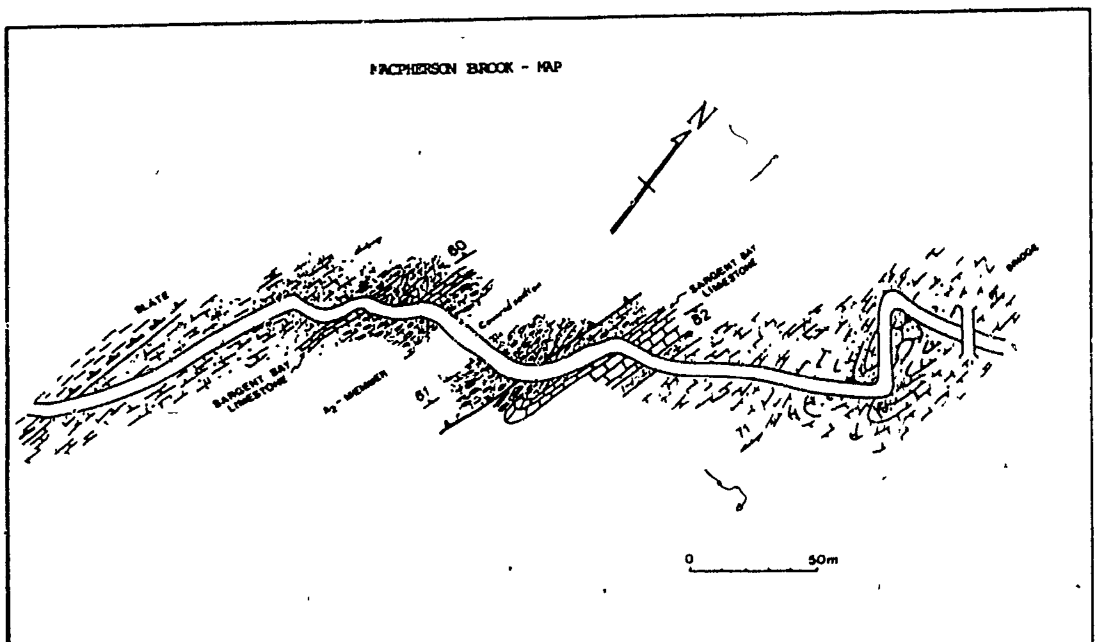
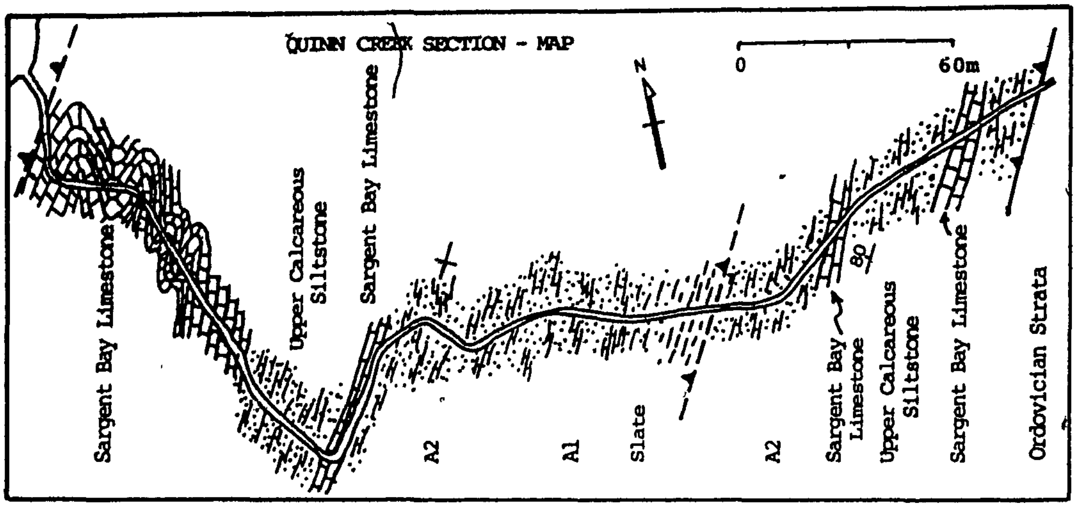


Figure 9: Structural profile and geology map for MacPherson Brook.



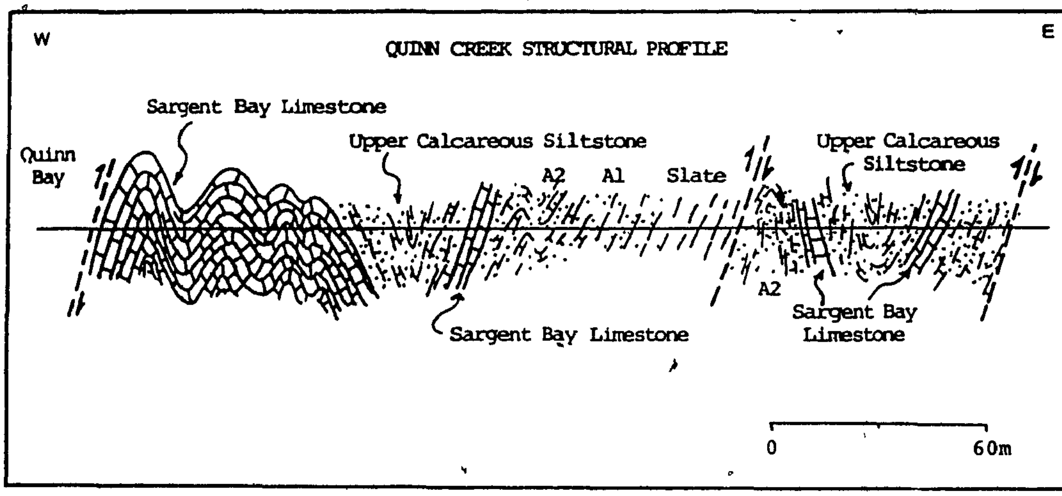


Figure 10: Structural profile and geology map for Quinn Creek.

Glenbrooke Road Section

The Glenbrooke road section (Pl. I; figs. A-B) has approximately 22m of Peasley Pond Conglomerate (sandstone), 110m of Glenbrooke Formation, and almost 100m of Sargent Bay Limestone. A 2m thick bed of green sandstone, similar to the Peasley Pond Conglomerate was observed in the Glenbrooke Formation. The contact between the sandstone and the overlying slates is abrupt. Gradational contacts, however, exist between all other units within the Silurian section.

Lake Memphremagog Shoreline

The shoreline of Lake Memphremagog showed 400m of non-calcareous slate, 200m of unfossiliferous, calcareous siltstone, and 300-400m of Sargent Bay Limestone. The Slate member consists of a thick monotonous sequence of slates. The nature of the contact between the Slate member and the Ordovician basement is not clear. Small pockets of conglomerate similar to the Peasley Pond conglomerate were found as weathered regolith near the road to Belmere Point. The conglomerates are presumed to lie close to, or at the contact between the Slate member and the Ordovician basement. Although actual beds were not observed, St-Julien, in Boucot and Drapeau (1968), found a small patch of conglomerate, the precise location of which is not known, except that it is on the southeastern side of the lake. Pockets of conglomerate outcrop locally on the western side of the lake where, in the Lake Memphremagog Syncline, it can be found overlying the Ordovician basement. The contact between the Slate member and the A member is gradational, as is the contact between the A member and the overlying Sargent Bay Limestone.

MacPherson Brook, MacPherson Bay, and Quinn Creek Section

The rocks within MacPherson and Quinn creeks and in MacPherson Bay are fossiliferous. The Glenbrooke Formation is represented by 140m of slate overlain by 20m of unfossiliferous, calcareous siltstone of the A member. The A member consists of a basal, unfossiliferous, and a fossiliferous calcareous siltstone. The Sargent Bay Limestone in MacPherson Brook consists of 15m of 4 texturally distinct limestones. These limestones in Quinn Creek are overlain by 25m of rhythmically bedded, argillaceous lime mudstones separated by shale partings. A previously unidentified unit consisting of fossiliferous fine silt and lime mud overlies the Sargent Bay Limestone.

2.2. GLENBROOKE FORMATION

Introduction

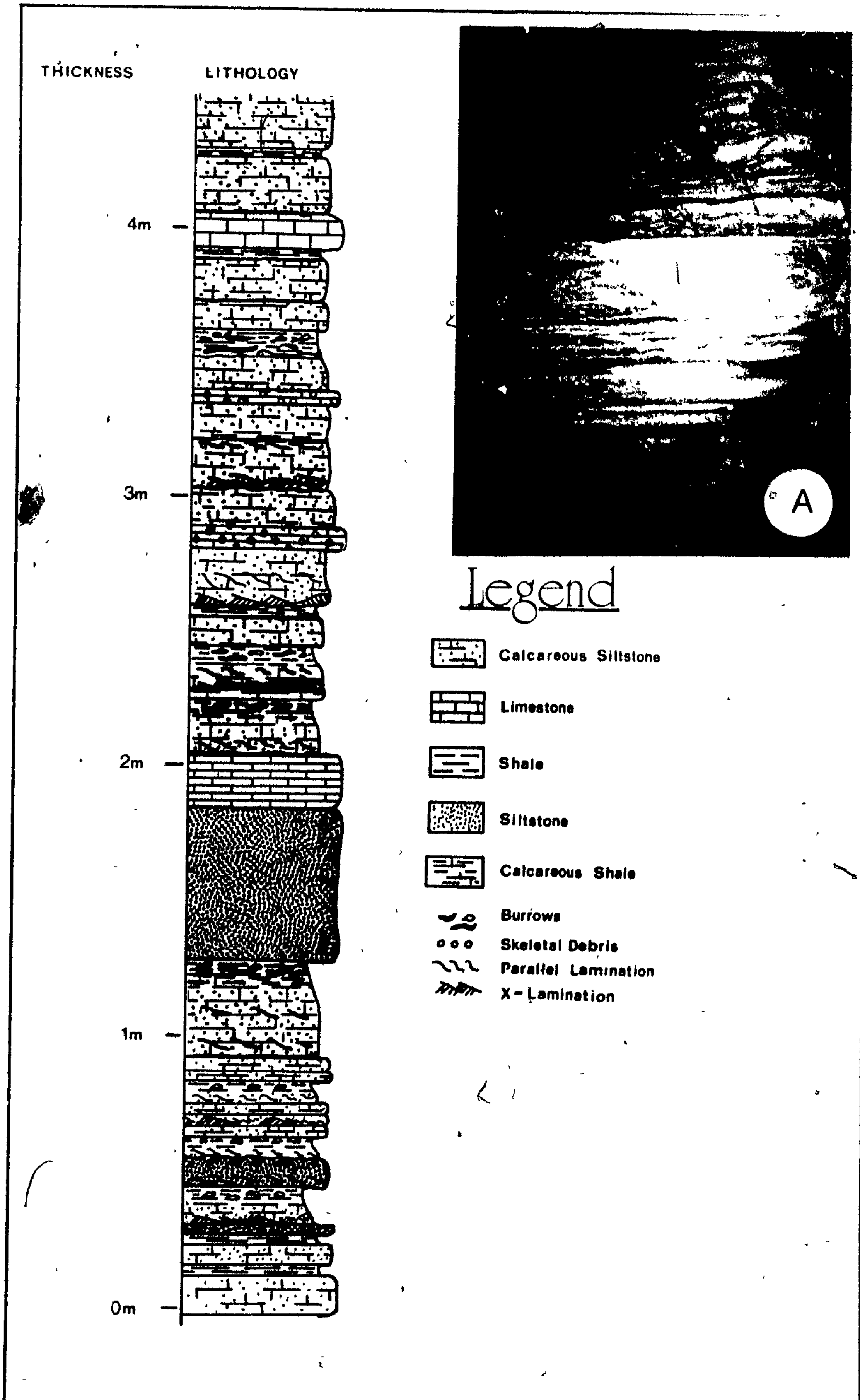
The Glenbrooke Formation is divided into 3 members: (1) a basal sequence of slates overlain by (2) unfossiliferous and (3) fossiliferous calcareous siltstones. Only the lower two members are present in the Glenbrooke sections. On the eastern side of the lake all three are present within exposures along natural drainage ditches, shoreline and roadside outcrops. All members represent deposition under similar conditions with a gradual increase in carbonate content upward. All formations and members grade into one another.

Description and Depositional Environment

The Slate member consists of a thick sequence of dark grey slates that have been severely sheared, effectively destroying primary sedimentary structures. The calcareous siltstone members in contrast, commonly show primary sedimentary structures such as burrows, cross and parallel laminations, and possible "ball and pillow structures". Thin beds and pseudonodules of siliceous dolomitic siltstone are found in the upper portion of the Slate member. They represent either (1) carbonate remobilized into concretions and along bedding planes, (2) original carbonate beds that have undergone deformation forming tectonic boudins, or (3) soft sediment load structures. Evidence for any one of these interpretations is inconclusive. The pseudonodules range in length of a few centimetres to discontinuous lenses up to a metre or more in length. The tabular pseudonodules have a mean thickness of 6cm.

The A1 member consists of bedded calcareous siltstones and turbidite beds. Boucot and Drapeau (1968) recorded body fossils from this member, however, none was collected in this study. The turbidites are interpreted as evidence suggestive of a distal depositional environment. Most turbidite sequences identified in the A1 member (Fig. 11) of

Figure 11: Stratigraphic section showing turbidite sequence in the A member, Glenbrooke Creek.



THICKNESS
LITHOLOGY
4m
3m
2m
1m
0m
A
Legend
Calcareous Siltstone
Limestone
Shale
Siltstone
Calcareous Shale
Burrows
Skeletal Debris
Parallel Lamination
X-Lamination

the Glenbrooke Creek section represent the C, D, and E divisions of the Bouma cycle. A typical turbidite sequence within this member consists of a C-division, cross-laminated calcareous siltstone that grades upward into a D-division of parallel-laminated calcareous siltstone and shale, all of which are overlain by a burrowed, dark calcareous shale of an E-division. Some beds within the section, such as the massive dolomitic siltstone bed located a third of the way up the section, may represent lower divisions. However, as these beds do not grade into higher divisions they may have been deposited from grain or mass flows.

The burrows are manifest as small elliptical blebs to discontinuous and irregular "stringers" subparallel to bedding. Movement of the organism through the sediment, although dominantly horizontal was also vertical as sediment from the overlying bed infills the burrows. The burrows must have had structural rigidity produced by a lining or other wall structure that allowed the network of tunnels to remain vacant until the deposition of the overlying bed. The sediment infill is now dolomitic. The cross-section of the burrows is like that of Planolites and Chondrites. Both are considered to have a wide range of environmental habitats, from shallow water, below wave base to deep marine.

A turbidite sequence is commonly overlain by thin bioclastic packstone-grainstone beds. These beds locally are graded but are, for the most part, massive. The allochemical constituents consist of echinoids (60%), brachiopods (20%), quartz sand (10%), unidentified shell fragments (8%), tabulate corals (2%). The beds are similar to those beds found in the lower portion of the overlying Sargent Bay Limestone and may represent deposition from either turbidite flows or from grain flows.

This study has divided the A member into two submembers A2 and A1 on the presence or absence of body fossils and turbidites. The A1 member contains turbidites and, although fossils were not found in this member in this study, a number of collections have been made by past workers (Ells, 1896; Cooke, 1950; and Boucot and Drapeau, 1968). A list of specimens collected by these workers is given in Table II. In contrast to A1, the A2 member contains abundant fragments of crinoids and fossil corals, mainly Favosites sp. Concretions are scattered throughout the A2 member and were probably formed by remobilized calcite but many contain a core of silicified fossil coral. Body fossils found in the A2 member suggest deposition under shallower marine conditions than for the turbiditic A1 member. Fossils collected from the A1 member in Glenbrooke Creek by past workers are presumed to have been transported to deeper areas of the basin in mass flows. The A1 and A2 members are therefore interpreted as contemporaneous deposits under different water depths within the same basin.

Age of the Glenbrooke Formation

The coral Favosites suggests an Early Silurian to Early Devonian age for the A2 member. Consequently, the A1 and Slate members are at least this age or older. The trilobites collected by previous workers (Table II) are of Silurian age. The coral <u>Favosites gothlandicus</u> found by Boucot and Drapeau (1968) implies a Wenlockian-Ludlovian age for both the A2 and A1 members.

2.3. SARGENT BAY LIMESTONE

Introduction

The type section located in Glenbrooke Creek (Clark, 1936), represents a portion (1/6) of the lithofacies identified in exposures for the whole of Sargent Bay Limestone on both sides of the lake. A low diversity fauna of crinoids and brachiopods occurs here in thin allodapic beds comprised largely of bioclastic debris. The lowermost beds contain allodapic limestones, and the upper beds are lime-mudstones. Outcrops along the east shoreline of Lake Memphremagog contain skeletal fragments similar to those found in the allodapic limestones of the Glenbrooke Creek Section. The only significant additions to the fauna come from MacPherson and Quinn creeks where body fossils of corals, stromatoporoids and brachiopods were collected from argillaceous, lime-mudstones.

Description and Depositional Environment

Six lithofacies have been identified in the Sargent Bay Limestone. The relative abundance of these lithofacies is not considered to reflect on the original abundance, owing

TABLE II: List of specimen types collected in various studies done on the A1 lithofacies of the Sargent Bay Syncline. Modified after Boucot and Drapeau (1968).

Fossils	Ells 1896	Cooke 1950	Boucot & D. 1968
Spirophyton sp.	x	-	-
Psilophyton sp.	x	-	-
Buthotrephis sp.	x	-	-
Favosites gothlandica	-	-	x
Dalmanites lunatus	-	x	x
Dalmanites sp. ind.	-	x	-
Bronteus pompilius	-	x	-
Calymene sp.	-	-	x
Cheirurus sp.	-	-	x
Ceratocephala geniata	-	x	-
Chonetes sp.	-	x	-
Encrinurus sp.	-	x	-
Orthoceratites sp.	-	x	-
Leptaena sp.	-	x	-
? Wilsonia sp.	-	x	-
Atrypa nodostriata	-	x	-
Coelidium sp.	-	x	-

to the intense deformation and erosional loss. Consequently they are described below in the order of appearance from west to east.

Lithofacies I

(Pl. 2; figs. A-D)

Lithofacies I consists of rhythmically bedded, shaly lime-mudstones, calcareous shale partings and laminated, argillaceous lime-siltstones with graded- and non-graded-calcarenites of allochthonous origin. Grading and non-grading of the calcarenites suggest deposition by two mechanisms. Thin beds of calcareous siltstone commonly overlie the calcarenites. The calcarenites and siltstones dominate the lower portion of this facies. Small lenticular and tabular beds of calcarenites are comprised of packstones and grainstones that lie abruptly on the underlying, rippled, calcareous, dark grey shale and fine, light grey siltstone.

Argillaceous lime-mudstones separated by shale partings into beds of relatively even thickness dominate the upper portion of this facies. Buff-coloured pseudonodules, ranging in length from a few centimetres to 15 centimetres, are common in the rhythmically bedded shaly limestones. A thin-section of these pseudonodules shows distorted internal laminations within a light coloured, carbonate (dolomite) siltstone. Necks or lobes of carbonate siltstone extend outward from the main pseudonodule into the surrounding shale lime matrix rich in skeletal debris (20%). Pettijohn, Potter and Siever (1972) have described these pseudonodules as ball and pillow features. These structures form whenever two adjacent layers are unstable. Instability will result when the upper layer, in this case carbonate silt, has a larger specific weight than the lower shaly lime mud and silt (Fig. 12). "Differences in specific weights may result from (1) original differences in packing (porosity), (2) degree of saturation, and (3) expansion of clays producing swelling" (Pettijohn et. al., 1972, p. 370).

This lithofacies is typical of that in deep marine basins and slope environments (Wilson, 1975). The graded-calcarenites are interpreted as allodapic limestones deposited from turbidity currents (Meischner, 1964). The non-graded calcarenites may have been deposited from grain flows (Lowe, 1976). The horizontally laminated, lime-mudstones, and calcareous, argillaceous siltstones may represent the C and D divisions of a turbidite sequence. The calcareous shales are commonly bioturbated and are interpreted as hemipelagic, probably the E division of the Bouma cycle.

Lithofacies II

(Pl. III; figs. F and G)

This facies is composed of bedded limestone consisting of skeletal wackestone and grainstone. Rip up clasts and trough cross beds are common. The grainstones are well sorted and rounded crinoid, brachiopod, and coral (Cladopora) skeletal fragments. The mean grain-size varies

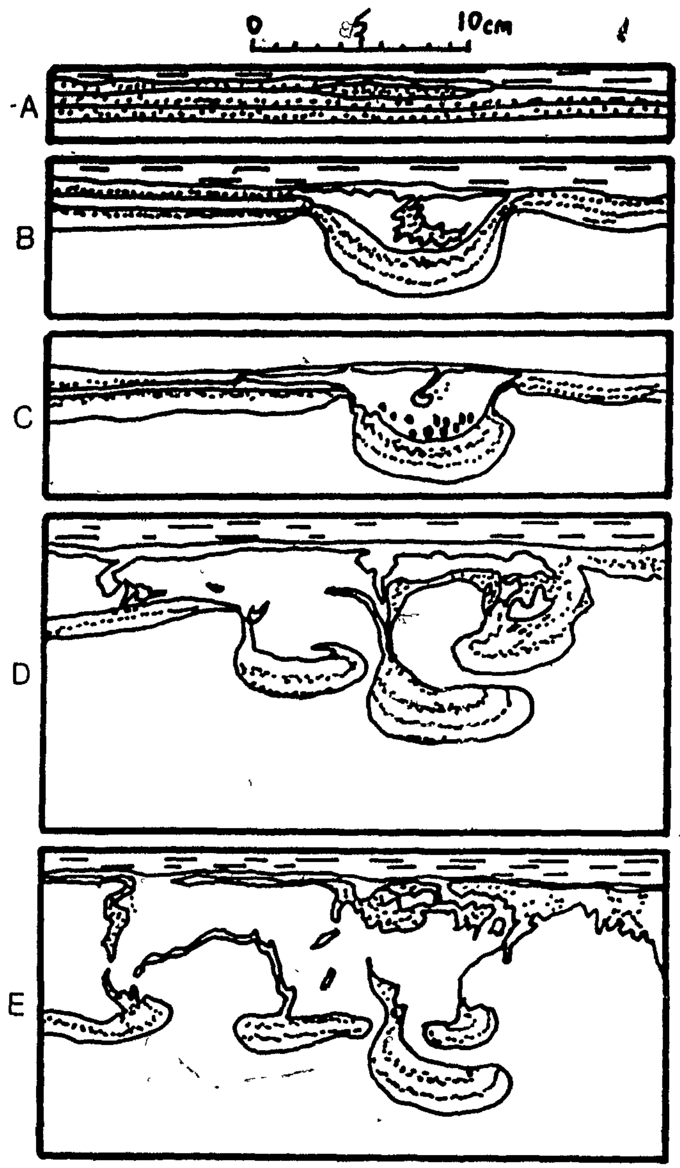


Figure 12: Diagram from Pettijohn et.al. (1972) showing the development of ball and pillow structures. See text for description.

from bed to bed, the smallest is 0.12mm, and the largest, 0.52mm. The skeletal fragments are well-cemented with syntaxial calcite overgrowths. Well-rounded quartz sand grains with silica overgrowths represent 10% of the allochemical component. Other beds show an even distribution of allochemical components within moderately - sorted, silty, calcareous packstone and wackestones. These alternating beds of well and moderately sorted calcarenites are interpreted to have been deposited in a moderate to high energy environment, where storm and wave action produced winnowed and well sorted calcarenites (Heckel, 1972). The conditions were open marine on a shelf or near a shelf break.

Lithofacies III

(Pl. III; Fig. H)

The facies consists of blue-grey packstone-wackestone composed dominantly of crinoids and minor amounts of brachiopod fragments, in beds up to 5m in thickness. The moderately sorted, angular to sub-angular allochems within what is now an argillaceous, pseudospar matrix suggest that transport distances were not significant. Deposition was in an open marine environment under low to moderate energy conditions below wave base.

Lithofacies IV

(Pl. III; Fig. E)

This facies is comprised of bioclastic debris within a floatstone-rudstone. Fossils consist of crinoid fragments and body fossils of brachiopods, stromatoporoids, and corals. The stromatoporoid fragments exhibit both digitate and hemispherical growth forms. The solitary rugose coral, Tryplasma sp., and the tabulate coral Syringopora are locally overgrown by hemispherical stromatoporoids. Cavities in specimens of the brachiopod Kirkidium often show calcite spar and geopetal structures. The unit is poorly sorted with 50% consisting of an argillaceous lime mud matrix that has been replaced by calcite pseudospar. The angularity of the body fossils suggests that these organisms had undergone little transport before they were deposited. The fact that this facies occurs in lenticular beds (5 X 10m) may indicate it was deposited as small patch communities under low to moderate energy, shallow open marine conditions.

Lithofacies V

Lithofacies V consists of a thick sequence of argillaceous, lime-mudstone, and digitate stromatoporoid (Ecclimadictyon stylotum) bafflestone with locally, Favosites and rugose corals. Large hemispherical concretions are scattered in the Quinn Creek section. The stromatoporoids probably trapped lime mud forming a bafflestone. Internal structure of the stromatoporoids have been largely masked by replacing calcite microspar. Kerogen has fortunately highlighted the growth form and some minor peripheral structure. Kerogen highlighting of the fossils indicates that the muds were once rich in residual organic matter. Using the classification scheme of McIlreath and James (1984) the digitate and bulbous growth forms of the stromatoporoid and Favosites respectively, suggest growth under moderate energy and high to moderate sedimentation rates. However, the regularly bedded argillaceous lime-mudstone are indicative of environments of lower energy and sedimentation rates.

Many workers have completed paleoenvironmental studies on the assumption that environment controls the growth form of modern reef-building corals. Comparative studies between modern reef zonation and Paleozoic coral and stromatoporoid reefs have been made. Stearn (1982) concluded that (1) no general pattern of shape-zonation on modern reefs is applicable to all reefs, and (2) variations in shape are the result of the interaction of many environmental factors with the genetically dictated growth pattern of the coral (modern and ancient) and stromatoporoids (ancient). Pope (1986) concluded that paleoenvironmental analyses based on stromatoporoid morphologies alone are invalid.

Lithofacies VI

This facies constitutes the upper portion of the Sargent Bay Limestone. It is composed of thin (10cm) rhythmically bedded, argillaceous lime- mudstone separated by shale partings. Abundant Favosites sp. occur throughout this facies, which is classified texturally as a mudstone. Lenticular and spherical concretions were observed near the top of the facies. These concretions are lime green patches in a dark grey, lime-mudstone. The mud appears laminated, and these laminations exist within the nodules. Deposition under low to moderate energy below wave base under moderate sedimentation rates is suggested for the lower portion of this facies. The dark laminated lime-mudstones in the upper portion of this facies indicate deposition under quiescence and lower sedimentation rates possibly verging on restricted marine conditions.

2.4. UPPER CALCAREOUS SILTSTONE

Introduction

A previously undefined unit was discovered in the creek sections on the eastern side of Lake Memphremagog. This unit consists of at least 70m of fine silt and lime-mudstone. A variety of tabulate corals and a single rugose coral were collected from this unit. Most fossils are located at the head of MacPherson Bay. The unit is moderately to well sheared making bedding difficult to detect in the limbs. Weathering to a pitted rust colour, the unit resembles both the A2-member and portions of the main carbonate unit at Lime Ridge and Marbleton. The Upper Calcareous Siltstone grades into the underlying Sargent Bay Limestone within a relatively short interval that may be as little as 1 metre.

Description and Depositional Environment

Two lithofacies were identified in this unit, one located only at the head of MacPherson Bay, the other in both MacPherson Brook and Quinn Creek. Poor outcrop has made it next to impossible to map the original distribution and relative abundance of these two lithofacies. The inability to observe lateral relationships along strike make the observation of lateral facies relationships between these two lithofacies purely speculative.

Lithofacies VII

(Pl. IV; figs. A-D; Pl. V; figs. I and J)

This facies occurs in both MacPherson and Quinn creeks where it consists of a crinoidal wackestone. Silicified coral fragments were found in parts of the section. This unit shows a slight increase over the previous units in coral diversity with Alveolites, Heliolites, Halysites catenularia, Cladopora, several species of Favosites and a colonial rugose coral ?Entelophyllum. A large angular block of ?Entelophyllum was found in the nose of a fold within MacPherson Brook. The fold forms a small cataract just west of the bridge. A stereo plot (Fig. 13) of bedding and corallite attitudes revealed that this coral was in fact a fragment inclined to the original bedding plane at an angle of 49 degrees. Furthermore, the matrix between the corallites contained less silt than the wackestone. The upper portion of this facies consists of interbedded dolomitic siltstone and skeletal packstone-calcarenites. The

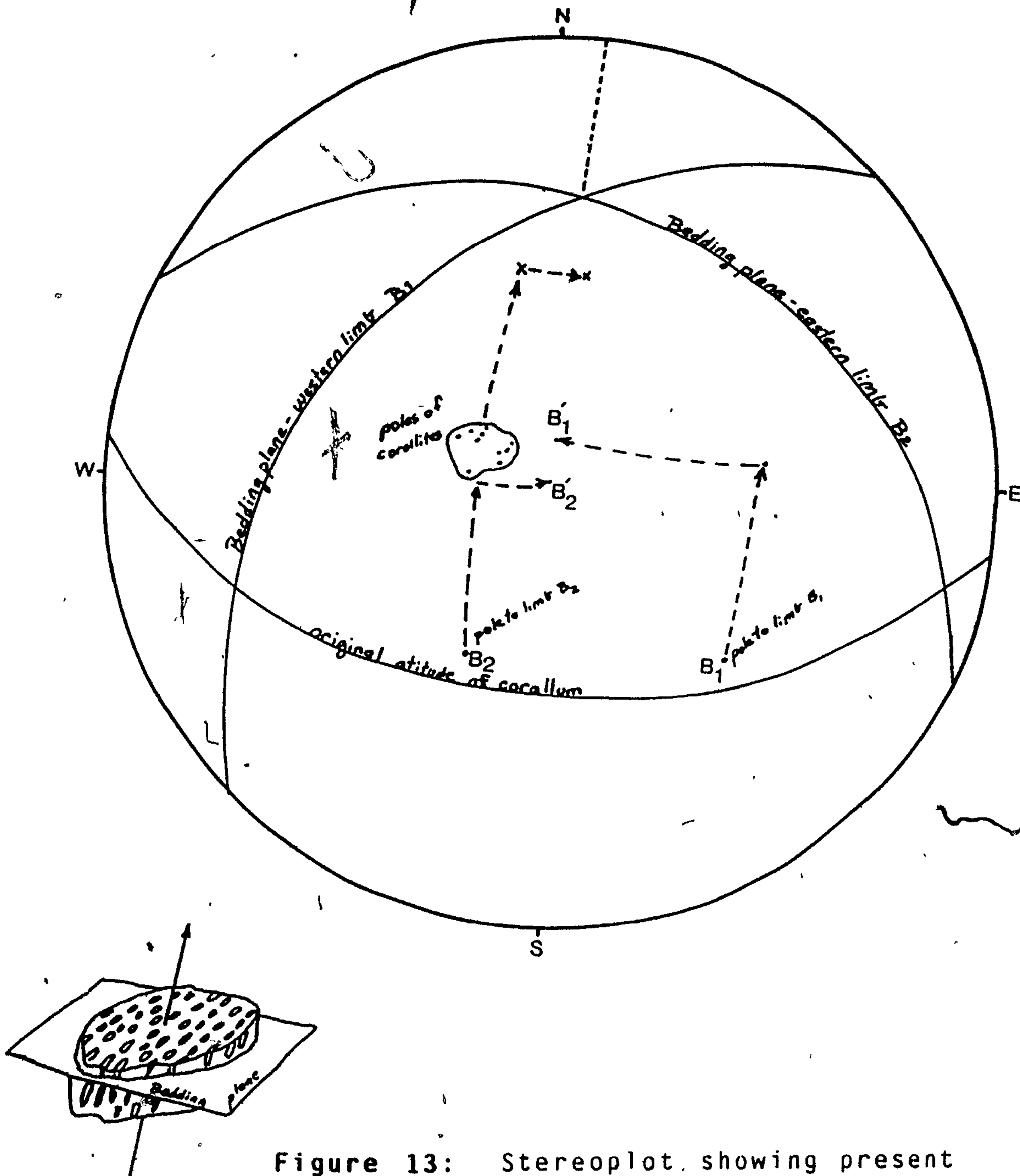


Figure 13: Stereoplot showing present and original attitudes of bedding and corallites of the colonial rugose coral, Entelophyllum sp.

packstones often form nodules that may occasionally contain the brachiopod Kirkidium. The corals and brachiopods in calcarenite beds are believed to be allochthonous deposits below wave base.

Lithofacies VIII
(Pl. V; Fig. K)

At the head of MacPherson Bay a densely fossiliferous unit consisting of brachiopods, crinoids and a variety of corals in a nodular calcareous siltstone occurs in a small weathered outcrop. The tabulate coral Cladopora is by far the most abundant specimen. Cladopora, Favosites, and Syringopora are located within a very siliceous matrix that contains a red "iron-rich" carbonate. Kerogen has not only highlighted the corals, but also occurs in concentric bands throughout the fossils. This type of kerogen is also found in fossils at Lime Ridge. Angular fragments of Favosites coralla are rarely encrusted with a laminar silty lime mud that is compositionally similar to the matrix. The nodules consist of blue-grey, crinoidal wackestone- and packstone-calcarenite. Fossil fragments include brachiopods, crinoids, stick corals, and a few pelecypod fragments. The boundaries between the nodules and matrix are abrupt with fossils lying across the nodule and matrix interface. Small fragments of wackestone float along with fossils in a dolomitic siltstone matrix adjacent to larger calcarenite nodules as do many fossils. This lithofacies was deposited as a debris flow of partially lithified and unlithified material.

Age of Sargent Bay Limestone and Upper Calcareous Siltstone

A Late Silurian, Ludlovian age is suggested for the Sargent Bay Limestone and the overlying unnamed unit. The diagnostic fossils for this age assignment include the brachiopod, Kirkidium sp., and the stromatoporoid, Ecclimadictyon stylotum. Another fossil that may be considered diagnostic is the coral Heliolites sp. cf. H. lavieillensis.

2.5. STRUCTURAL GEOLOGY OF THE LAKE MEMPHREMAGOG AREA

The Silurian rocks of the Lake Memphremagog area are sheared and isoclinally folded within two decoupled north-south trending synclines, formally named by Ambrose (1942) as the Sargent Bay and Lake Memphremagog synclines. Boucot and Drapeau (1968) interpret the structure of the Sargent Bay Syncline as three minor synclines. Lamothe (1981a,b), in contrast, had proposed two minor synclines. Cleavage is axial plane, usually lying within 10 degrees of vertical. The same cleavage overprints the Ordovician basement where it is classified as S3 cleavage. The repetition of stratigraphy on either side of a fold axis in Glenbrooke Creek and, in a section exposed along strike to the north in the Glenbrooke Road rock cut, confirmed the interpretation of structure as a single syncline. Cleavage refraction (Plate I) at the Glenbrooke Road section shows that beds of calcareous shales and siltstones dip steeply to the west. Furthermore, both bedding and cleavage attitudes along the Glenbrooke Road rock cut, from Austin towards the west, appear to indicate a single syncline axis lying to the west and adjacent to the Ordovician basement (Fig. 9). The fold axis plunges to the south. Boucot and Drapeau's (1968) and Lamothe's (1981a,b) proposals of several synclines for the Sargent Bay Syncline are therefore in doubt.

The stratigraphic thickness of the Memphremagog Group in the western limb of the Sargent Bay Syncline is much thinner than in the eastern limb. There are, however, two solutions to this problem. (1) Sediments within the western limb were deposited on a series of step faults. This would explain why only 20m to 30m of Peasley Pond Conglomerate was measured in the Glenbrooke Road section and yet along strike, to the north and up plunge, Clark (1936) measured 63m of the conglomerate. (2) The eastern limb has been folded and faulted into a series of climbing folds and small thrust faults with east vergence that repeat the stratigraphy several times within the eastern limb of the syncline (Fig. 9). In addition, the western limb had been thrust eastwards along a fault that truncated the axial plane near the fold axis (Pl. I; Fig. A), thereby reducing the thickness of the Memphremagog Group through erosion of the hanging wall.

Beds in the western limb of the Lake Memphremagog Syncline dip at or near the vertical. Along the eastern shoreline of Lake Memphremagog beds within the Sargent Bay Limestone dip westward at angles as low as 45 degrees. Beds along both sides of Route 247, just north of Georgeville, indicate a small antiformal structure. A small roadside rock cut north of Georgeville where Route 247 joins the road to Fitch Bay shows beds that dip east at 31 degrees. Exposures on the eastern limb of the Lake Memphremagog Syncline therefore show beds with dips between 45 to 75 degrees. These measurements are less than those measured by Boucot and Drapeau (1968). Structure for the Lake Memphremagog Syncline is that of a large syncline overturned to the east.

Cooke (1950), Boucot and Drapeau (1968), and de Romer (1981) have all noted the large fault bounding the eastern limb of the Lake Memphremagog Syncline. Direction of movement along this fault was not specified by Cooke or de Romer, but Boucot and Drapeau (1968, p. 12) suggested that "movement, westside downward, is approximately equal to, or somewhat greater than, the thickness of the Glenbrooke Formation". This direction of movement, is opposite to that suggested by structure within the MacPherson Brook and Quinn Creek sections adjacent to the east bounding fault. Faults and folds within MacPherson and Quinn creeks all show east verging structures with direction of movement along these faults as west side up. The direction of movement is similar to Acadian faults in the Ordovician basement described by Lamothe (1981b) on the western side of the lake in an area from Owl's Head to Sargent Bay. Sections exposed within the creeks show convergent fan cleavage with axial planes that dip steeply to the west. In summary, the structure within the MacPherson and Quinn creeks is complex with steep dipping faults and folds. The Sargent Bay Limestone provides a good marker unit that shows these structures well. The author suggests that structure within the creeks on the eastern side of the lake, and adjacent to the Ordovician basement represents a zone of intense deformation. This zone is to be called the "MacPherson Fault Zone".

CHAPTER 3 - LIME RIDGE & ST-ADOLPHE-DE-DUDSWELL

3.1. LAKE AYLMER FORMATION - Introduction

The Lake Aylmer Formation crops out in the Lime Ridge and St-Adolphe-de-Dudswell area in small, patchy exposures and in quarries. In ascending order, this formation consists of: (1) a basal unit comprised of polymictic conglomerates and intraformational breccias alternating with quartzites, siltstones and shales; (2) reefal limestones and calcareous siltstones and silty limestones; (3) an overlying unit of calcareous siltstones and silty limestones; and (4) an overlying unit of calcareous siltstones interbedded with sandstones and silty limestones (Petryk, unpublished map, 1985; de Romer, 1985). The first unit corresponds to the Ay1 and Ay2 members of Lavoie (1985) and St-Julien (1970). The last three units lie wholly within the Ay3 member. The boundaries between all units and members are gradational, and siliciclastics dominate throughout the entire section. Only the main limestone unit was studied in detail. Furthermore, these units have been described in detail for other areas by Lavoie (1985), St-Julien (1970), Duquette (1961), and Burton (1931).

3.2. LIMESTONE UNIT AT LIME RIDGE AND DUDSWELL

The Lake Aylmer "main" limestone unit displays a variety of textures and lithologies. In the Lime Ridge and Dudswell area Petryk (1985) has identified grainstones, rudstones, packstones, calcilutite and coral and stromatoporoid boundstones. In addition to massive limestones, fossiliferous breccias and reefal limestones. De Romer (1985) described interbedded calcareous siltstones and dolostones. The stratigraphic section (Fig. 14) for the main limestone unit can be divided into three divisions: (1) a basal nodular calcareous siltstone; (2) a middle floatstone, rudstone, and sedimentary breccia; and (3) an upper blue-grey lime mudstone, stromatoporoid and coral breccia and stromatoporoid framestone.

Fossils found at Lake Memphremagog were also found in greater numbers at Lime Ridge and Dudswell. Faunal diversity was also higher in the Lime Ridge and Dudswell area. In addition to the greater abundance and diversity of fauna in the Lime Ridge area, framebuilders were found in both organically constructed and detrital facies. Only the latter was observed in the Sargent Bay Limestone at Lake Memphremagog.

The limestones and their associated faunas were assigned to five mappable lithofacies. Petryk (pers. comm., 1987) has also suggested a five-fold lithofacies model for the main limestone unit at Lime Ridge. However, his facies model is not presented here. The paucity of good exposures has made the areal distribution of the facies at Lime Ridge difficult to decipher. Thus, exact relationships between facies is uncertain.

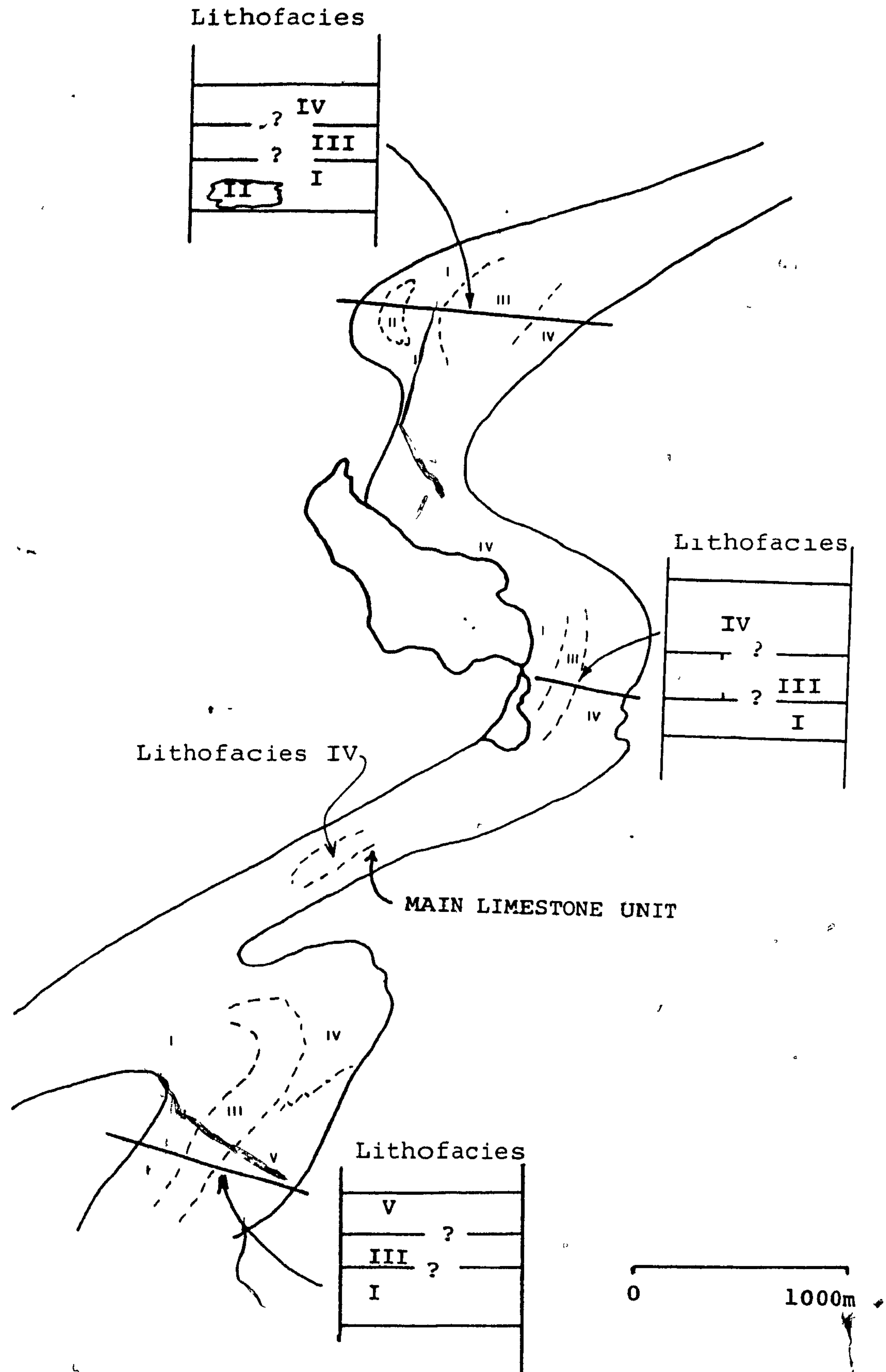


Figure 14: The main limestone unit in the Lime Ridge-Marbleton area showing stratigraphic sections at various locations along the unit.

Description and Depositional Environment

Sampling in the area could not be systematic and consequently relative facies abundance is not known. Any attempt at determining the relative, present and original abundances is hampered by the paucity of outcrop and complexity of structure. The descriptions of various lithofacies for the Lime Ridge and Dudswell area are presented beginning at the base of the main limestone unit.

Lithofacies I

This facies is a nodular, well sheared, crinoidal wackestone. The shearing has occurred along anastomosing shale partings giving the rock a nodular appearance. The nodules consist of remobilized carbonate and commonly have a fossil core. The facies weathers to a pitted rust surface which contrasts with the dark blue-grey colour of a fresh surface. Stromatoporoids and _Favosites_ sp. are found sporadically throughout the facies and exist as fragments that are probably detrital. This lithofacies is ubiquitous in the Lime Ridge and Dudswell area, and forms a basal unit within the main limestone unit. Thin beds of calcareous siltstone are interbedded with crinoidal packstone-calcarenite that forms rhythmic beds near the top of the facies. Specimens of the coral _Heliolites_, very similar to _Heliolites lavieillensis_ (Pers. comm. Dixon, 1987) were found in these beds. In areas where deformation is intense the packstones are commonly segmented and separated by siltstone from underlying and overlying beds, similar to the

Upper Calcareous siltstone (Pl. IV). These structures are interpreted as pinch and swell features (Hobbs, Means, and Williams, 1976). The siltstones are commonly cemented with dolomite (de Romer, 1985). Tabular stromatoporoids occur with dendritic and branching forms of Favosites sp. These growth forms are indicative of moderate to high wave energy under low sedimentation rates. Only fragments of stromatoporoids and corals are found in this facies, and they are probably allochthonous.

Lithofacies II

This facies is composed of bedded limestone consisting of a brachiopod rudstone and an overlying floatstone-packstone. The only example of this facies is located in a small drainage ditch, due north of Saint-Adolphe-de-Dudswell (Pl. VIII, figs. G and H; and Pl. IX, figs. I-L). It consists of the pentameran brachiopod, Kirkidium sp., first identified in the area by Petryk (1985, p.56; 1986, p.5) and confirmed as Kirkidium by Boucot (1985, pers. comm. to A. Petryk). These large brachiopods, with an average length of 50mm, lie within a fine grey lime silt. Most are disarticulated, and show a preferred orientation that is probably depositional (see Appendix B). In addition to the large brachiopods, numerous small, angular fragments of favositid corals, Heliolites, brachiopods, and crinoids occur together in the rudstone forming a packstone matrix. The rudstone-packstone is interbedded with thin bedded dolomitic siltstones. A floatstone containing Kirkidium sp. and a dendritic Favosites sp. in a skeletal packstone-wackestone matrix overlies the rudstone. The facies is interpreted as a storm deposit below wave base. A kerogen-like material is commonly visible as a thin film on fossil skeletons, and has penetrated into the skeleton via fracture systems.

Lithofacies III

(Pl. VI, figs. M-Q; Pl. VII, figs. A-D; Pl. VIII, figs. E-F)

This facies consists of a floatstone-packstone, sedimentary breccia, and a boundstone block. Faunal diversity for this facies is high but none of the fossils is in situ. The fauna includes several species of Favosites, the rugose coral Tryplasma, a species of Cladopora, and Heliolites. The stromatoporoids grew in globular and tabular forms and have locally grown over corals. Echinoderm debris is ubiquitous. Corals and stromatoporoids are commonly whole with only minor breakage. All fossils are randomly oriented within a rust coloured, dolomitic siltstone matrix. Small angular blocks of graded cross-laminated and laminated, siliceous calcarenite lie within the floatstone-packstone matrix at Domlim number 3 quarry. The matrix weathers preferentially leaving the fossils and allochthonous blocks standing in relief. The facies is massive, and in outcrop shows little indication of bedding attitudes.

At a small roadside outcrop, located in front of the cemetery just north of St-Adolphe-de-Dudswell and east of Silver Lake, is a coral and stromatoporoid framestone. The tabulate corals include _Cladopora_ sp., both branching and hemispherical species of _Favosites_, fragments of _Halysites_ sp., and _Syringopora_ sp. and the rugose coral _Tryplasma_ sp. Stromatoporoids show both tabular and globular growth forms and have locally grown over rugose corals and the tabulate _Syringopora_. The matrix is comprised of a fine dolomitic and calcareous bioclastic siltstone that weathers to a rusty (earth) colour. Most of the skeletal debris consists of small coral fragments, brachiopod shells and minor amounts of crinoid debris. The outcrop is 7.5 metres in length and gives no indication of the local extent of this boundstone block. A domal and tabular stromatoporoid and globular _Favosites_ coral framestone dominates the eastern portion of the outcrop. The south portion of the outcrop is dominated by a bafflestone consisting of a dendritic _Favosites_. Textural variations among the blocks within this facies suggests they are allochthonous within a mass flow deposit.

The calcarenite blocks are allochthonous and indicate transport along with organic debris in a mass flow. This would explain the randomly oriented, sediment supported bioclasts in the matrix. If this hypothesis is correct, then the boundstone may also be an allochthonous block. There is, however, little conclusive proof to show this to be true. Geopetal structures are parallel to measured bedding attitudes of the block in question. A smaller outcrop lying

45m to the west on the same side of the road shows bedding attitudes near vertical.

Lithofacies IV

Lithofacies IV is comprised of interbedded, dark blue-grey calcilutite, packstone/floatstone-rudstone, and minor grainstone beds. Ubiquitous skeletal debris contains fragments of stromatoporoids, brachiopods, <u>Alveolites</u>, <u>Halysites</u>, <u>Cladopora</u>, several species of <u>Favosites</u>, and large numbers of echinoderm ossicles. Whole stromatoporoids in growth position are common. Grainstones are rarely graded, with crinoidal debris and clasts of fine lime silt. Small rhombs of dolomite commonly float within syntaxial calcite cement. This facies also contains thin beds composed of stromatoporoid and coral reef talus. An environment of moderate to high energy and sedimentation rates are interpreted.

Lithofacies V

Small hemispherical to tabular stromatoporoids form a framestone that has trapped fine, blue-grey calcilutite. The stromatoporoids have locally grown over dendritic <u>Favosites</u>. The digitate stromatoporoid, <u>Ecclimadictyon</u> <u>stylotum</u>, rarely occurs as small lenticular globes scattered among the other stromatoporoids and corals. The stromatoporoids are <u>in-situ</u>, thus wave energy is considered to have been low to moderate with moderate to high sedimentation rates and a low siliciclastic input.

Age of the Main Limestone Unit

The diagnostic brachiopod, Kirkidium sp., and the unique stromatoporoid, Ecclimadictyon stylotum indicate a Ludlovian-Pridolian age for this unit. Heliolites sp. cf. H. lavieillenses occurs along with Kirkidium sp. within the lower beds of the main limestone unit.

3.3. STRUCTURAL GEOLOGY OF THE LIME RIDGE DUDSWELL AREA

The Lake Aylmer Formation forms a large syncline that plunges to the northeast at Bishopton, and southwest at Lake Aylmer (Fig. 15). Large faults on the northwestern and southeastern limbs, suggest that the Lake Aylmer Formation is allochthonous (de Romer, 1985). Lavoie (1985) has shown the Weedon Fault truncating the southeastern limb of the syncline. St-Julien (1970, p. 16) reports that in the Lake St. Francis area "the southeast limb of the syncline is truncated by rocks of the St. Francis Group and the Ascot Formation, which forms part of a series of allochthonous rocks thrust-faulted toward the northwest". There is, however, little agreement among workers (de Romer, 1985; Lavoie, 1985; and Petryk, 1985) as to the exact position of this fault in the southwestern part of the syncline. De Romer (1985) interprets the fault as lying within a zone parallel to route 112 east of Silver Lake in the Lime Ridge-Marbleton area. He has placed this fault between similar lithologies of the Lambton Formation (Lake Aylmer Formation)

Petryk (1985)		de Romer (1985)		Lavoie (1985)
6	St. Francis Grp.	7	Ayer's Cliff Fm.	Devonian
5	Lake Aylmer Fm.	6	Lake Lambton Fm.	Ay3
4		5		main limestone unit
3		4		Ay3
2		4		Ay1-Ay2
1	Magog Grp.	3	Magog Grp.	Cambro-Ordovician

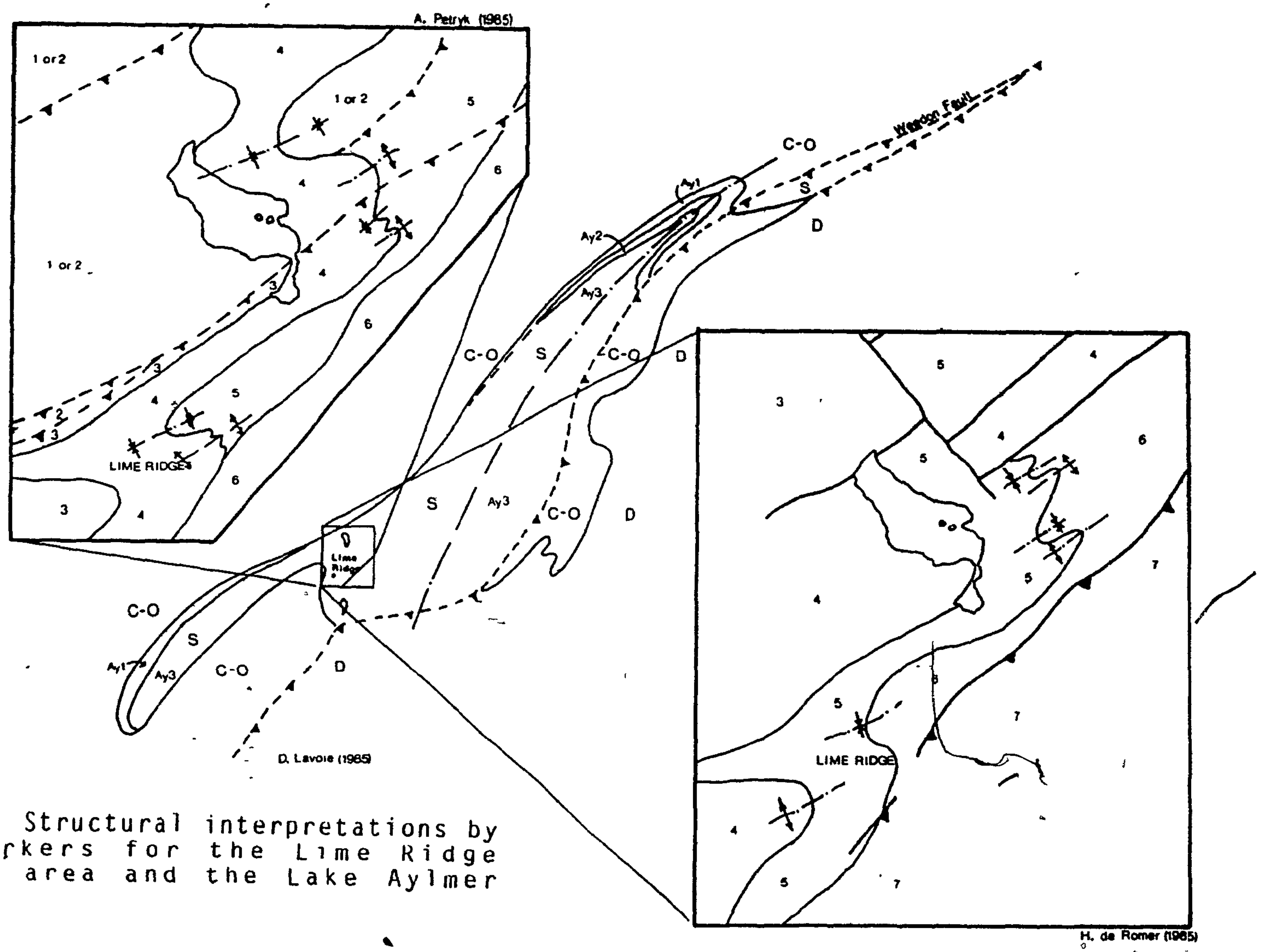


Figure 15: Structural interpretations by recent workers for the Lime Ridge Marbleton area and the Lake Aylmer Syncline.

and the Ayer's Cliff Formation. This mapping places Devonian rock further to the northwest than suggested in Lavoie's (1985) Figure 14. Petryk (1985), in contrast, has placed this fault slightly to the northwest and has it cutting across both the St. Francis Group and the Lake Aylmer Formation. Both workers have the St. Francis Group lying concordantly on the Lake Aylmer Formation. This study has seen evidence in the main limestone unit that supports both proposals. It therefore seems reasonable that the area includes many faults and that they represent splays within the Guadaloupe Fault Zone (St-Julien et. al., 1983). Direction of movement along these faults would all have been in a northwesterly direction forming a structure like that of an imbricated thrust zone.

The main limestone unit in the Lime Ridge-Marbleton area lies within the northwestern limb of the syncline, and has been folded into a series of small northeasterly plunging, S-Type, parasitic folds. Beds dip steeply (50 to 70 degrees) around the vicinity of Domlim number 2 quarry, but in other areas the dip is shallower, between 25 and 50 degrees. Cleavage is axial plane, and is slightly convergent. Deformation within the Lake Aylmer Formation has been defined by de Romer (1985) as second phase.

CHAPTER 4 - DISCUSSION

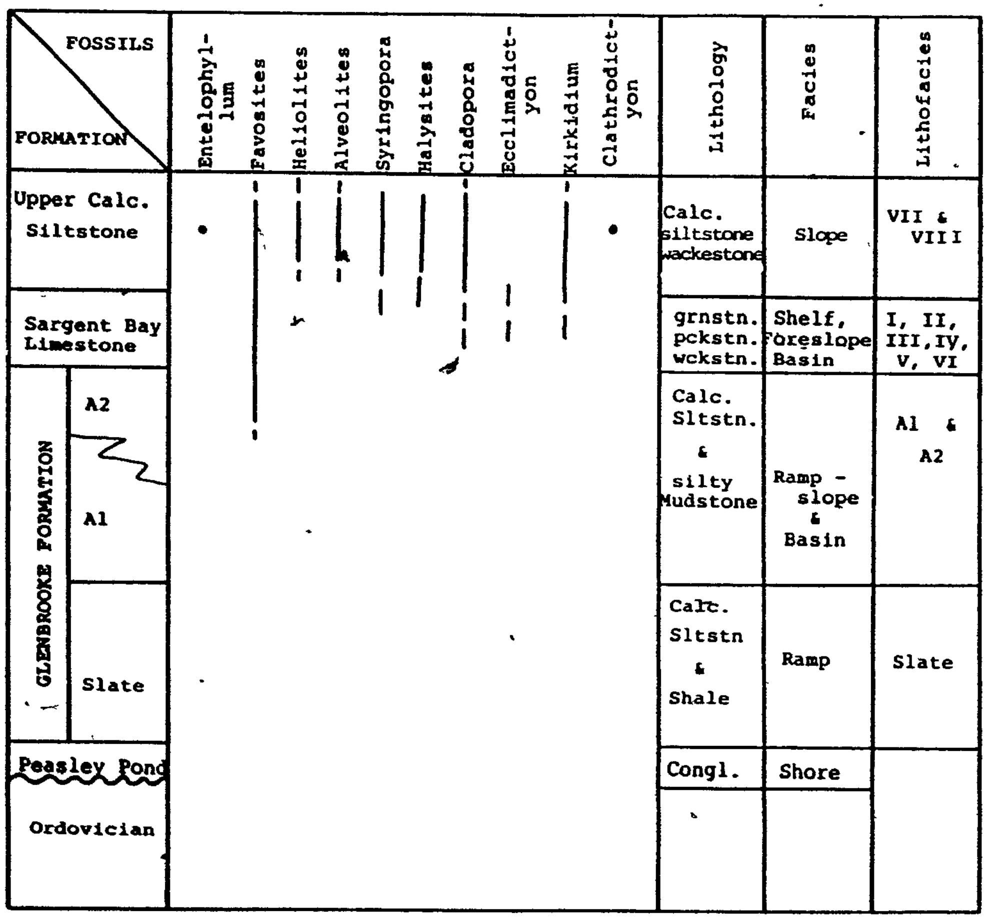
4.1. FACIES INTERPRETATION

Two facies are recognized in the A member of the Glenbrooke Formation and three facies are recognized in the Sargent Bay Limestone in the Lake Memphremagog area (Fig. 16). These include basin-ramp and ramp-slope facies for the A member, and basin-slope, shelf-margin, and shelf-platform facies for the Sargent Bay Limestone. The upper calcareous siltstone is interpreted as a second phase of slope sedimentation within the Lake Memphremagog area. One facies (slope-facies) is recognized. Three main facies, slope, reef-margin and back-reef-lagoonal facies and facies are recognized for the main limestone unit at Lime Ridge-Marbleton.

A member, Glenbrooke Formation

Basin-ramp & Ramp-slope Facies

Moderately deep marine clastic sediments dominate most of the section in the Sargent Bay Syncline (Basin-ramp Facies), the lower half of shales and siltstones and the upper half comprised essentially of calcareous siltstones. Turbidite deposits dominate the top portion of the calcareous siltstones, and persist into the overlying Sargent Bay Limestone. A similar sequence of sediments was observed in the Lake Memphremagog Syncline (Ramp-slope Facies), however, skeletal wackestones and packstones rather than turbidites dominated the upper portion of the



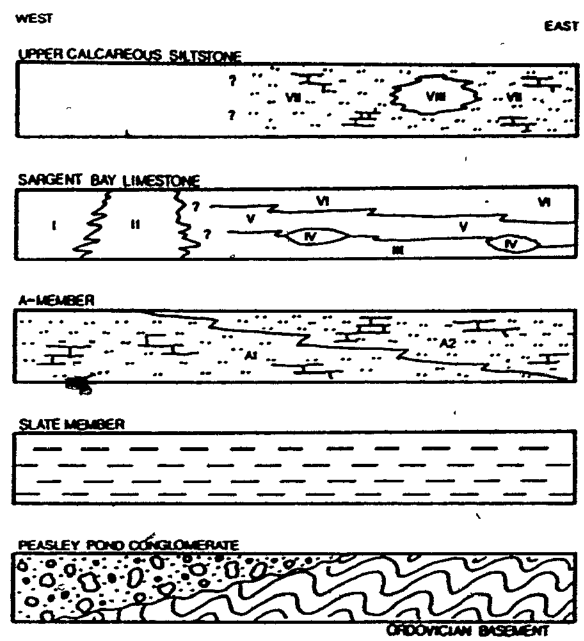


Figure 16: Chart showing fossils with corresponding facies, lithofacies and formations. The right hand side illustrates the presumed relationships of lithofacies within each formation and member.

calcareous siltstones along the eastern shoreline of Lake Memphremagog.

Read (1985) has described carbonate ramps as having gentle slopes, on the order of 1 degree or less. Nearshore, shoal-water complex of skeletal sand banks or shoals often pass downslope, without a marked break in slope, into deep water, basin lime muds and interbedded shales with rare breccias and turbidites.

Sargent Bay limestone

Basin-slope Facies

The basin-slope deposits are comprised entirely of lithofacies I overlying a basal siliciclastic ramp-slope deposit. The association consists of thin-bedded, lime-mudstones with graded and non-graded packstone- and grainstone-calcarenites. The lower portion of lithofacies I contains turbidites consisting of graded and non-graded calcarenites. Along the eastern shoreline of Lake Memphremagog, and further upslope towards the margin; limestones, calcareous shales with fine-grained turbidites, and thin beds of graded-calcarenites overlie marine, non-calcareous and calcareous clastic beds of the preceeding ramp facies.

Turbidites and allodapic limestones indicate a carbonate slope. It is unlikely that this carbonate association consists of only the one lithofacies. Further detailed examination may prove that many more lithofacies exist within the basin-slope facies. Non-graded and graded-calcarenites are well documented in the literature as allodapic limestones (Cook et. al., 1972; Conaghan et. al., 1976; and Srivastava et. al., 1972). These allochthonous deposits typically contain material derived from shoal-water carbonates. These deposits occur in thin continuous and lenticular beds that are interpreted respectively as debris sheets and channels.

Shelf-margin (shoal) Facies

The shelf-margin facies is restricted to the Georgeville area. This facies may have been more extensive than what is presently shown. The thickness of the skeletal sand shoal (lithofacies II) and the underlying calcareous and non-calcareous siliciclastic ramp margin is approximately four times that of the other facies. Siliciclastics occur in significant amounts in the lower portion of the shoal facies. The grains are well rounded and sorted.

The relatively large thickness of this facies in comparison to the basin slope and shelf-facies suggests that it must have been prograding basinward under moderate sedimentation rates and very little basin subsidence (Wilson, 1975). McIlreath and James (1984) have interpreted this sort of setting as a depositional margin with shallow water lime sand shoals bordering a gentle slope margin, where turbiditic deposition of shoal derived sands produced the allodapic limestones. Heckel (1977) interpreted well sorted and rounded crinoids, fragments of brachiopod shells, within cross-bedded calcarenites as indicative of zones of water agitation above wavebase. Furthermore, he found that accumulations may occur at a change in slope which influenced the breaking of waves.

Shelf-platform Facies

The shelf-platform facies consists of well bedded continuous and lenticular packstones and grainstones, stromatoporoid bafflestone, and rhythmically bedded lime-mudstones. Well bedded and massive skeletal packstones and grainstones form basal shelf-platform deposits that extensively cover the former calcareous siliciclastic ramp platform. Lenticular beds comprised of rudstones and floatstones form local deposits that overlie the crinoidal calcarenite beds. Rhythmically bedded lime-mudstones with a basal stromatoporoid bafflestone unit dominate the upper portion of the carbonate shelf-platform facies association. The accumulated thickness of regularly bedded mudstones is highly variable within the shelf-platform.

This facies is interpreted as deposited in a carbonate shelf-platform, moderately deep-lagoonal, type environment. Basal non-graded calcarenites are concluded to have been bottom current, reworked sediments. Deposits of this nature are similar to deeper water slope deposits reported by McIlreath and James (1984). Small patch communities of corals, stromatoporoids, and brachiopods in addition to crinoids are believed to have developed locally over the shelf platform. Later communities are concluded to have been comprised almost solely of the digitate stromatoporoid Ecclimadictyon stylotum. Deeper water deposits of thinly bedded lime-mudstone and intercalated calcareous shales in the upper portion of the facies indicate renewed subsidence on portions of the shelf.

Upper Calcareous Siltstone
Slope Facies - Second Phase

The second phase, slope facies, is dominated by well bedded calcareous siltstones and massive brecciated units. The upper portion of this facies consists of skeletal calcarenites and dolomitic siltstone interbeds. The slope facies overlies the shelf-platform facies and is not observed anywhere other than in the creek sections on the eastern side of Lake Memphremagog. The calcareous siltstones form regular beds, 20 - 40cm thick. Allochthonous fragments of Alveolites, Heliolites, Halysites, Cladopora and ?Entelophyllum have been found locally throughout the section. A brecciated unit was found only at the head of MacPherson Bay.

The facies association represents foreslope deposition on a calcareous siliciclastic ramp. The massive calcarenites were deposited as allodapic limestones. The brecciated unit containing both a reefal fauna and clasts of skeletal calcarenites is interpreted as a mass flow. Hopkins (1977) noted that if clasts are largely skeletal in composition, an organic frame or reef is generally postulated. Considering the large number of body fossils in these deposits, it appears likely that a margin shelf facies comprised of reef and skeletal sands lay to the southeast (and has now been eroded away) shedding material downslope.

Main Limestone Unit

Slope Facies

Bedded calcareous siltstones and skeletal-calcarenite interbeds, rudstones, floatstones, boundstone and calcarenite breccias form slope deposits near to the margin facies. Interbedded calcareous siltstones and calcarenites dominate the lower section of this facies. Debris flow and other mass flow deposits, and tempestites tend to occur in the upper sequences of this facies. Bed thickness among mass flow deposits are non-uniform, ranging in thickness of several centimetres to a metre or more.

The faunal diversity within these deposits is much higher than was observed at Lake Memphremagog. Furthermore, a significantly higher biomass and large boundstone blocks suggest a proximal reef source. Angular cross-laminated and graded calcarenite blocks may have been derived from lithified channel flow deposits on the foreslope or tidal channel deposits on the reef margin.

The wide range of growth forms exhibited by tabulate corals and stromatoporoids suggest deposition under a variety of environmental conditions. It is unlikely that these all grew in the same environment, and they probably represent habitats in different ecologic zones on a reef margin or platform with patch reefs. A cross section through a hypothetical, zoned, marginal reef (Figure 9 of James, 1984) shows many environment-related growth forms. (1) A bafflestone-floatstone contains globular growth forms in a back reef environment. (2) Tabular, domal, and branching organisms form a bafflestone and framestone within a reef front environment. (3) A rudstone-grainstone consist of reef talus in the fore reef environment. Bourque et. al. (1980, Fig. 8; and 1986, Fig. 35) show a paleoenvironmental profile and ecological zonation of a reef platform. In their profile of a Silurian Gaspe reef they show cladoporids and tabular stromatoporoids on the reef flat. Although the form of reef mound was not defined at Marbleton, the fauna collected from this facies indicates that reefs did exist in Silurian time in the Lime Ridge and Dudswell area.

Near Reef-margin Facies

Stromatoporoid framestones with fine-calcilutite matrix form the reef-margin facies. The facies forms the top unit of the main limestone unit of the Lake Aylmer Formation due south of Lime Ridge.

Bourque et. al. (1986, Fig. 40) and Bourque (1980, Fig. 8) have identified similar digitate stromatoporoids in the reef flat and back reef to lagoon facies of the Colline Daniel reef margin.

Back Reef-lagoonal Facies

This facies is recognized as interbedded, dark blue-grey calcilutite, packstone, floatstone-rudstone, and minor grainstone beds. Access to Quarry #2 at Lime Ridge was limited and consequently only one lithofacies has been described.

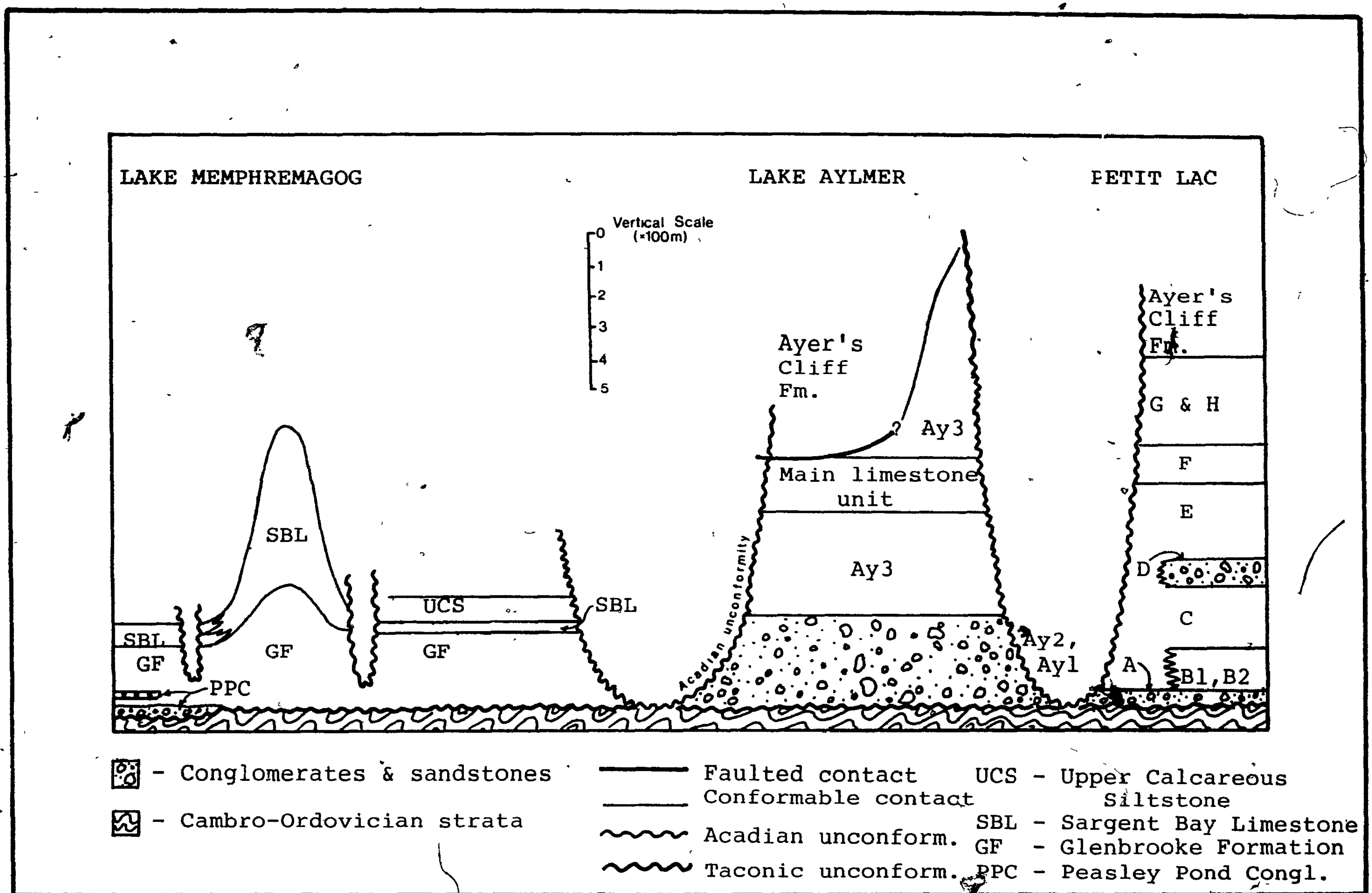
The author feels that several more lithofacies exist within this facies, but further investigation is necessary. Large number of echinoderm ossicles and in-situ stromatoporoids suggest deposition in a back reef, lagoon environment. Graded grainstones-packstones may have been deposited as tidal channel deposits near the reef.

4.2. LITHOLOGIC AND TEMPORAL CORRELATION BETWEEN LAKE MEMPHREMAGOG AND LIME RIDGE-MARBLETON

Past workers (Lavoie, 1985; Bouçot and Drapeau, 1968) have not made specific correlations between the Memphremagog Group and the Lake Aylmer Formation. Duquette (1961), proposed that the basal conglomerates of the Lake Aylmer Formation correlated with both the Peasley Pond Conglomerate of the Lake Memphremagog area and conglomerates of the St. Francis Group. This study suggests that at least parts of the Lake Aylmer Formation can be correlated with the Memphremagog Group (see Figure 17).

The Peasley Pond Conglomerate (or more properly sandstone), both in the Glenbrooke Road and in the Glenbrooke Creek sections, correlates lithologically with the sandstones and conglomerates of the Ayl member of the

Figure 17a: Chart showing stratigraphic correlation between ~~Lake~~ Lake Memphremagog, Lake Aylmer and Petit Lac (Lake St-François) areas.



Data from Lavoie, 1985 and this study.

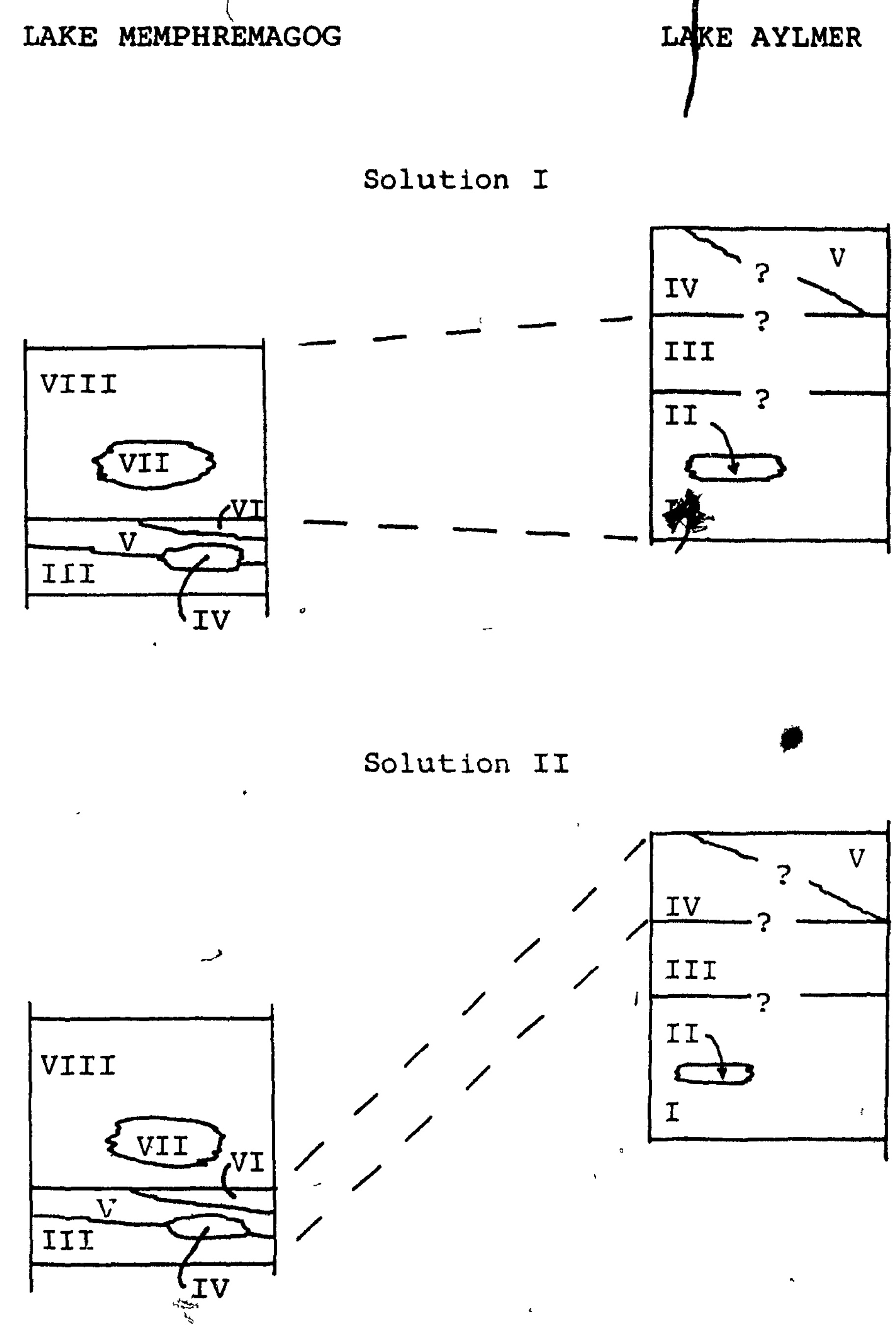


Figure 17b: Two solutions to the problem encountered when correlating the main limestone unit with the Sargent Bay Limestone. (See text for details).

Lake Aylmer Formation. There is no equivalent in the Lake Aylmer Formation of the Slate Member. There are, however, two units of shales (C and E) separated by a conglomerate unit (D) in the Lake Lambton Formation. In the Glenbrooke Road section a unit of conglomerate was observed within the Slate Member. Calcareous siltstones of the A member of the Glenbrooke Formation, can be correlated with the lower portion of the Ay3 member. However, the carbonate content in the lower Ay3 member was high enough to justify Lavoie's (1985) description of the unit in that area as a silty limestone. The stratigraphic position of the Sargent Bay Limestone lithofacies is similar to the main limestone unit of the Ay3 member. Both units, consisting of similar limestone facies, and have calcareous siltstones lying above and below.

Units within the Memphremagog Group show lithologic affinities with both the Lake Aylmer and Lake Lambton formations, but precise correlation could not be made. De Romer (1985) has mapped the Lake Aylmer as the Lake Lambton Formation. Lavoie (1985) has suggested that the Lake Aylmer and the Lake Lambton formations represent units deposited contemporaneously within the same basin, and that the two formations therefore represent broad lateral equivalents. Similar depositional environments are inferred for the eastern portion of the Upper Calcareous Siltstone and the Lake Aylmer Formation at Lime Ridge and the Lake Lambton Formations. Units within the Memphremagog Group could not be conclusively shown to have been deposited at the same time as corresponding units within the Lake Aylmer and Lake Lambton formations.

Problems develop when correlating the Memphremagog Group with the Lake Aylmer and Lake Lambton formations. The first and obvious problem is that there is no equivalent to the Glenbrooke Slate member in the Lake Aylmer Formation. The second problem is the correlation of the second phase, foreslope facies to the foreslope facies at Lime Ridge. The problem here, is that the correlative facies lies below the shelf-platform facies at Lime Ridge, whereas at Lake Memphremagog the second phase, foreslope facies lies above the shelf-platform facies. In conclusion, (1) the upper calcareous siltstone unit at Lake Memphremagog correlates, both lithologically and temporally, with the calcareous siltstone lying in the lower portion of the main limestone unit at Lime Ridge (Fig. 17b). The limestones within both areas may then represent sedimentation under similar environmental conditions, but are not correlative; or (2) the limestones are time transgressive and the similarity between the siltstones, that occur in one place above the limestone, but in the other, below, is purely coincidental. The former interpretation is favoured.

Temporal Correlation between Lake Memphremagog and lime Ridge-Marbleton Area

The Sargent Bay Limestone and the upper calcareous siltstone in the Lake Memphremagog area can be correlated with the main limestone unit of the Lake Aylmer Formation in the Lime Ridge-Marbleton area. The brachiopod Kirkidium sp. was collected from all three units and suggests that all units are of Ludlovian age. Boucot and Drapeau (1968) assigned the Lake Aylmer Formation to the Pridolian based on the more time-restricted Eccentricosta jerseyensis and Protathyris. However, it is not known from which unit in the Lake Aylmer Formation these specimens, neither of which were collected in this study, were found. Petryk (Pers. commun., 1985) has reported that conodonts collected from this unit agree with the Pridolian assignment.

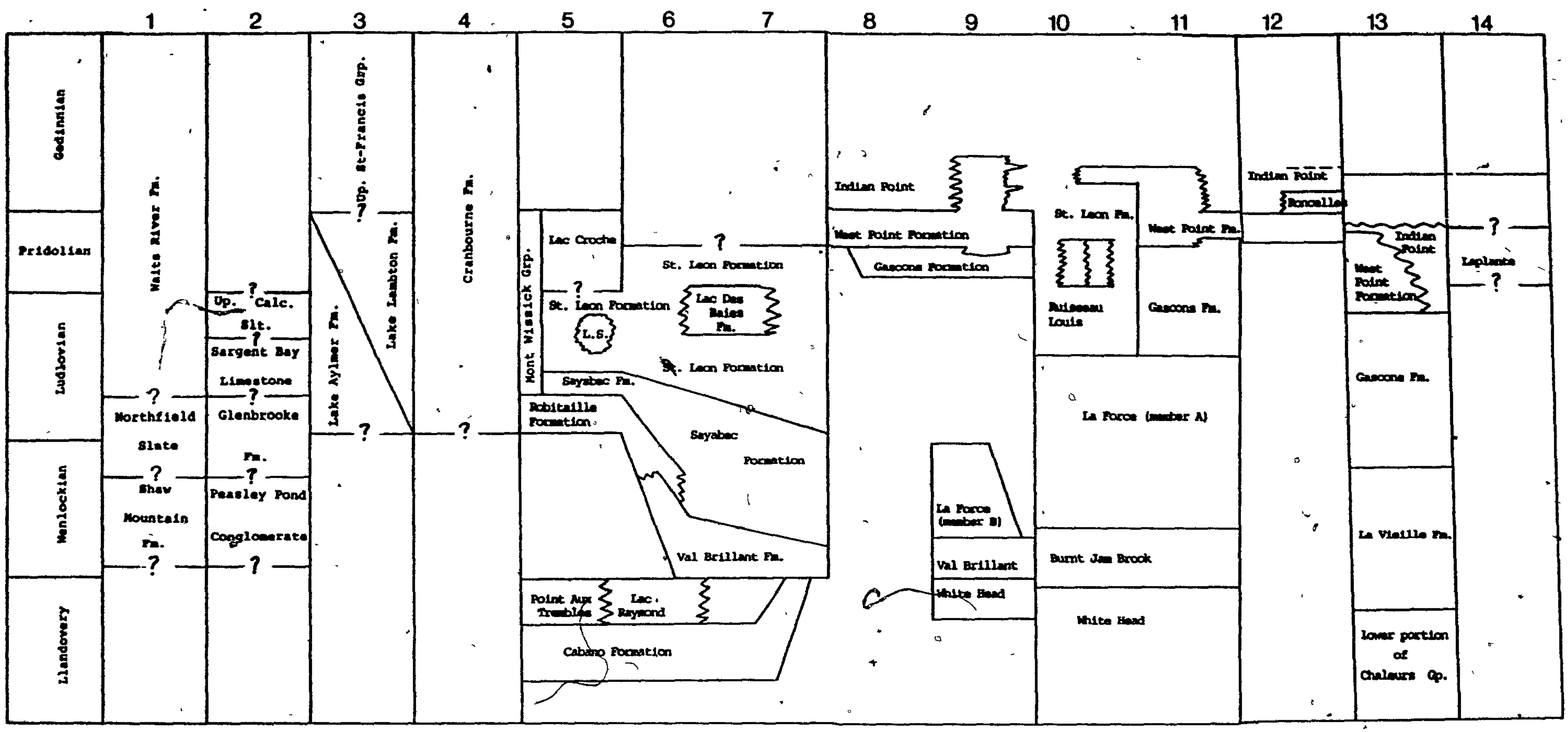
4.3. TIME CORRELATION - NORTHERN APPALACHIANS

Introduction

Rocks of Ludlovian-Pridolian age are widely distributed throughout the Appalachians including northern Vermont, northwestern Maine, Quebec Eastern Townships, Lake Temiscouata and the Matapedia River Valley, the Gaspe Peninsula, and New Brunswick (Fig. 18). A compilation of work by Boucot (1961), Boucot and Drapeau (1968), Berry and Boucot (1970), Bourque (1977), Bourque et. al. (1981), Bourque et. al. (1986), Doll (1984), Lajoie et. al. (1968), Lesperance and Greiner (1969), Noble (1985), and Pope (1985) allows a biostratigraphic correlation to be made between the Silurian in the above-mentioned areas of the Northern Appalachians.

Figure 18: Chart showing regional correlation for the Northern Appalachians.

Source of Information		Location
1.	Boucot (1961)	Northern Vermont
2.	Boucot (1961) and this study	Lake Memphremagog
3. & 4.	Boucot (1961), Lavoie (1985)	Eastern Townships
5. to 7.	Lajoie et.al. (1968)	Lake Temiscouata to Matapedia
8. to 12.	Bourque (1977)	East and west Northern Outcrop Belt, St.-Jean River Anticline and West and east Central Outcrop Belt
13.	Bourque et.at. (1986)	Chaleurs Bay Synclinorium
14.	Noble (1985)	Petit Rocher, New Brunswick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Gedinnian
Pridolian
Ludlovian
Wenlockian
Llandovery
Waite River Fm.
Northfield Slate
Shaw Mountain Fm.
Up. Calc. Slt.
Sargent Bay Limestone
Glenbrooke Fm.
Peasley Pond Conglomerate
Up. St-Francis Grp.
Lake Lambton Fm.
Lake Aylmer Fm.
Cranbourne Fm.
Mont Wissick Grp.
Lac Croche
St. Leon Formation
L.S.
Lac Des Baies Fm.
Sayabec Fm.
Robitaille Formation
Sayabec Formation
Val Brillant Fm.
Point Aux Trembles
Lac Raymond
Cabano Formation
Indian Point
West Point Formation
Gascons Formation
La Force (member B)
Val Brillant
White Head
St. Leon Fm.
Ruisseau Louis
West Point Fm.
Gascons Fm.
La Force (member A)
Burnt Jam Brook
Roncelles
La Vieille Fm.
Lower portion of Chaleurs Gp.
Laplante

The key fossils used for correlation are shown in Figure 19 along with their biostratigraphic ranges. Fossils collected in the Lake Memphremagog area clearly indicate a Ludlovian age for the Glenbrooke Formation, and the Sargent Bay Limestone, and a Ludlovian to possibly Pridolian age for the Upper Calcareous Siltstone unit. The brachiopod *Eccentricosta jerseyensis* was described by Berry and Boucot (1970) as characteristic of beds of Latest Pridolian age in New York, Pennsylvania, New Jersey, Maryland, and West Virginia, and the base of the Pridolian in the Appalachians. The genus *Kirkidium* sp. is reported by these authors to be restricted to the Late Wenlockian through Pridolian. The *Kirkidium* sp. found in the St. Leon and Gascons formations is dated as Ludlovian. *Atrypa* "*reticularis*" is considered as Llandoverian to Wenlockian in age. The unique stromatoporoid, *Ecclimadictyon stylotum* (Parks, 1933) has a time range from Ludlovian to Pridolian.

Northern Vermont

Doll (1984, p. 12), after Boucot and Drapeau (1968), has correlated the "Waits River - Barton River Formation with the upper part of the Lower St. Francis Formation". The term Formation is incorrect and should be replaced by Group. Boucot and Drapeau (1968) suggest that fossils collected from the Shaw Mountain Formation could be of Ludlovian and Pridolian or as old as Upper Llandovery (C3 or younger age). They also suggest that the Lower St. Francis Group is the southern Quebec equivalent of the Waits River,

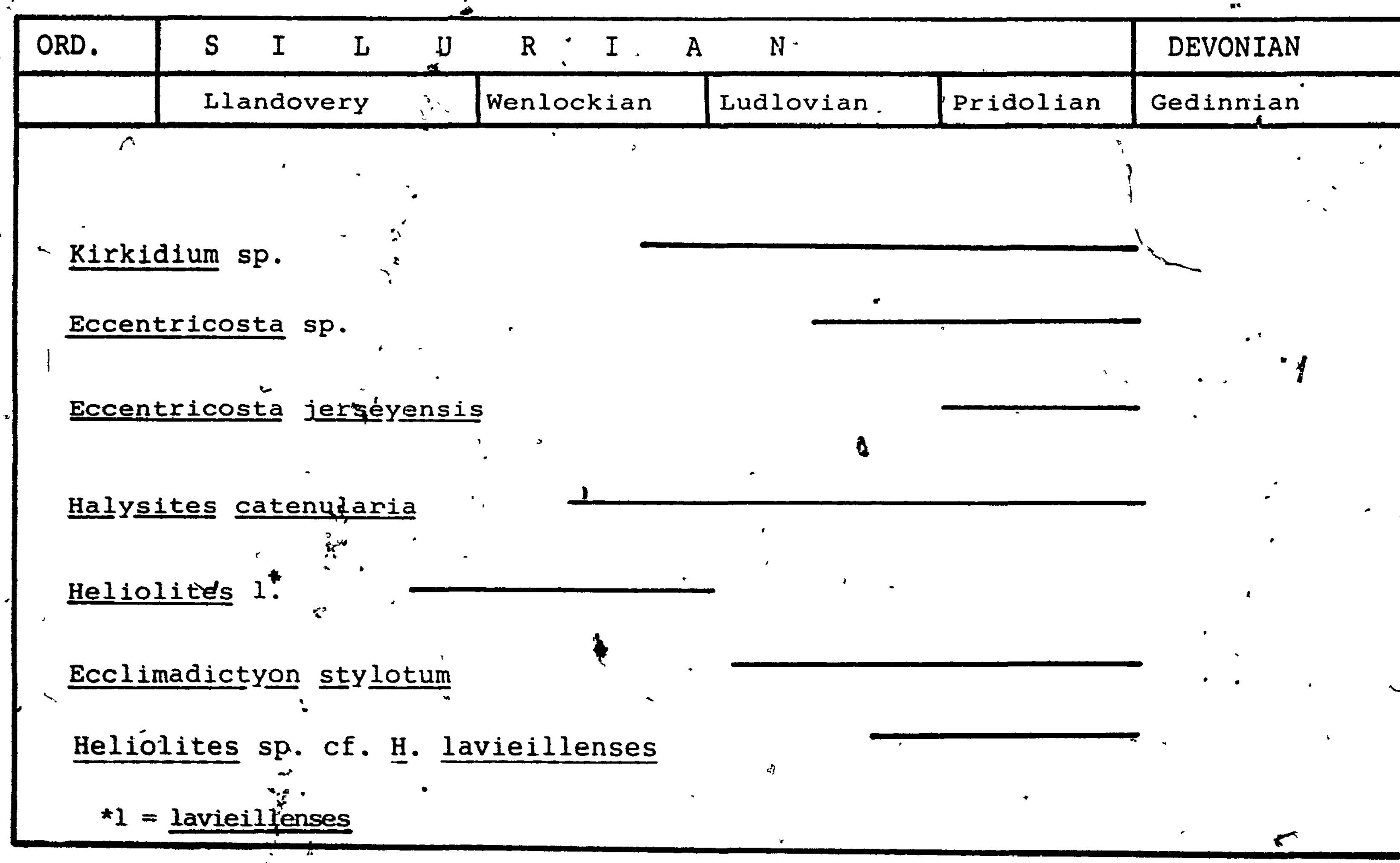

FIGURE 19. Ranges of Key Fossils

Northfield, and Shaw Mountain formations. The Ayers Cliff member of the Waits River Formation may be stratigraphically equivalent to the Sargent Bay Limestone. However, there are no diagnostic fossils that would confirm this. Doll (1984) has provided a list of the fossil genera common to both the Eastern Townships and Vermont. A partial list includes the corals Favosites, Zaphrenthis, Syringopora, and Cladopora; and the brachiopod Gypidula.

Lake Temiscouata and Matapedia Area

Boucot and Drapeau (1968, Fig. 1) imply a correlation between the Memphremagog Group and the St. Leon Formation of the Matapedia Valley Sequence. In the Lake Temiscouata area the Mont Wissick Group consists of the basal Sayabec Formation, overlain by the St. Leon Formation and the Lac Croche Formation. The Sayabec Limestone is of Ludlovian age as indicated by Columnaria? coralliferum (Lajoie et. al., 1968). The Lac Sauvagesse member of the St. Leon Formation yielded Kirkidium cf. K. knighti of Ludlovian age. The Lac Croche Formation contained Eccentricosta sp. (Lesperance and Greiner, 1969), indicating a Ludlovian to Pridolian age (Berry and Boucot, 1970). Kirkidium cf. K. knighti was also collected from the upper part of the Sayabec Formation at La Redemption indicating a Ludlovian age in that area. The Ludlovian-Pridolian age indicated by these brachiopods suggests a correlation of the Sayabec with the main limestone unit in the Lake Aylmer Formation, and the Sargent Bay Limestone.

Gaspe Peninsula

The Gascons Formation was assigned a Ludlovian to Pridolian age by Bourque (1977) in the western portion of the Central Outcrop Belt and the Saint-Jean River Anticline of the Gaspe Peninsula. Ludlovian age beds of the Gascons Formation were not observed in the Northern Outcrop Belt. The Ludlovian age assignment of this formation was based on the presence of Kirkidium sp. (Berry and Boucot, 1970). However, the Kirkidium beds of the Gascons and West Point formations were considered of Pridolian age by Bourque (1977). This age assignment was based on the occurrence of Eccentricosta sp. Berry and Boucot (1970) suggest that the appearance of Kirkidium and Halysites indicated a Ludlovian age for the West Point Formation. In the Chaleurs Bay Synclinorium the age of the West Point Formation has not been well established (Pope, 1986). Pope (1986) reported that a Ludlovian-Pridolian age applied to the entire formation. This was based on Lockovian (earliest Devonian) conodonts collected from the laterally equivalent Indian Point Formation, and the Wenlockian graptolite, Pristrograptus ludensis from the basal units of the underlying Gascons Formation. The stromatoporoid, Ecclimadictyon stylotum was observed by Pope (1986) and Bourque et. al. (1986)* in the Sandy Cove member of the West Point Formation. A Ludlovian-Pridolian age assignment suggests a correlation of this unit with the main limestone

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*Bourque et. al. (1986) have called this stromatoporoid Clathrodictyon stylotum stylotum.

unit of the Lake Aylmer Formation.

Other Regions

Work on the Late Silurian reefs in northern New Brunswick is at a preliminary stage, and correlation between this area and the Eastern Townships is speculative. Noble (1985) has described the informally named, Laplante carbonate unit within the siliciclastic, Petit Rocher Formation. Nowlan (1982) dated conodonts in this unit as Pridolian. Furthermore, Noble (1985) noted that stromatoporoids, corals, and brachiopods collected from this unit were similar to those found in the Ludlovian-Pridolian West Point Formation.

Near Little Big Wood Pond, Maine, Boucot (1961), collected Eccentricosta jerseyensis, Halysites sp., and Protathyris sp. from the Silurian, Harwood Mountain Formation. Eccentricosta indicates a Pridolian age for these rocks, and implies a correlation of the Harwood Mountain Formation with the Lake Aylmer and Lake Lambton formations in the Eastern Townships.

Discussion of Correlation

This study agrees with Boucot and Drapeau (1968, p. 23) that the Sargent Bay Limestone at Lake Memphremagog is Ludlovian, and that the limestones of the Lake Aylmer Formation and the Lake Lambton Formation contain fossils that indicate Ludlovian-Pridolian age. Lithologic correlations are possible between the Silurian-Devonian sequences within specific regions. These regions include (1) northern Vermont and the Eastern Townships; and (2) Lake Temiscouata through to the Gaspe Peninsula. Although correlations can be made between areas within each of the regions, evidence suggestive of direct lithologic correlation between them is inconclusive.

4.4. TECTONIC IMPLICATIONS OF UPPER SILURIAN SEDIMENTATION & SLOPE REVERSAL IN THE EASTERN TOWNSHIPS

The Silurian belts at Lake Memphremagog and Lake Aylmer are enclosed within folded Cambrian-Ordovician rocks of Taconic Orogen. There are no Silurian shelf sediments west of Lake Memphremagog. The spatial and temporal distribution of facies has been reconstructed by lithologic mapping, thin section analysis and identification of fossils within each facies. At present, the Lake Memphremagog area has basin facies located between the craton and foreslope and shelf-platform facies to the east (Fig. 16). This configuration is the reverse of those deduced for Ludlovian-Pridolian time in the Lake Aylmer (Lavoie, 1985), and Lac des Baies (Lajoie, et. al., 1968) areas. An understanding of carbonate basin, foreslope, shelf margin, and shelf sedimentation and Late Silurian tectonics is essential for a reconstruction of paleoenvironments of the Quebec, Eastern Townships. Three tectonic models are proposed to explain the slope reversal for the Lake Memphremagog area.

Depositional Paleoenvironments

In the Lake Memphremagog area, sandstone and conglomerate deposition over the Taconic unconformity was replaced in Ludlovian time by fine-grained siliciclastic sedimentation within a shallow epi-continental sea. Subsidence subsequent to shale deposition produced a homoclinal calcareous siltstone ramp and deep-water basin (Fig. 20a). The basin facies is identified by the presence of fine-grained, distal turbidites and the almost complete absence of body fossils. Crinoids and small brachiopods are believed to have flourished in nearshore environments just prior to the end of siliciclastic sedimentation on the ramp. Skeletal sand shoals comprised almost exclusively of crinoids and brachiopods began to form on the ramp. Some of this material was rarely shed to the northwest, downslope, within turbidity currents and other mass flow deposits forming thin beds of skeletal wackestone- and packstone-calcarenites.

By the Middle of Ludlovian time, carbonate sedimentation replaced siliciclastic sedimentation within the basin-ramp environment (Fig. 20b). The development of a large, prograding shoal complex formed a margin that separated the basin-slope and shelf facies. The basin facies is characterized in the Sargent Bay Syncline by thin, rhythmically bedded, shaly lime-mudstones alternating with calcareous shales. Allodapic limestones comprised of material derived from the shoal facies are common in the lower limestones of the Sargent Bay Syncline. Turbiditic and mass flow deposits commonly form the slope facies exposed along the western shoreline of Lake Memphremagog. If the interpretation of some of the non-graded packstones as grain flows is correct, then the slope must have been moderately steep. True grain flows require a slope of 18 to 30+ degrees to sustain movement, however, density-modified grain flows could occur over slopes of 9 to 14 degrees (Cook, 1983). The lower shelf units consist of crinoidal and brachiopod skeletal packstones and wackestones, indicating that shelf fauna was dominated by these organisms. Small patch reef communities comprised of brachiopods, digitate and hemispherical stromatoporoids, and tabulate and rugose corals were established behind the shoal within a lagoonal environment. Stromatoporoid (Ecclimadictyon stylotum) and small digitate favositid coral communities replaced these small patch communities. Rhythmically bedded lime-mudstones with calcareous shale partings exposed only within Quinn Creek suggest that either this section represents a deeper water environment farther out into the lagoon or portions of the shelf were subject to differential subsidence. Patch reef communities within the locally deeper portions of the shelf were subsequently drowned and covered with deeper water, fine grained sediments.

Fluviatile sandstone and conglomerate sedimentation proceeded in the Lake Aylmer, Lime Ridge-Marbleton areas while at Lake Memphremagog the Sargent Bay Limestone was being deposited. A thick clastic sedimentary package in the Lake Aylmer area suggests higher subsidence rates than at Lake Memphremagog. Environments of deposition at Lake Memphremagog and Lime Ridge-Marbleton were similar by the end of Ludlovian time when largely siliciclastics and carbonates were deposited (Fig. 20C). The Upper Calcareous Siltstone and the lower, main limestone unit are interpreted as foreslope deposits. Mass flow deposits are common and contain reefal bioclastic debris along with large framestone and calcarenite blocks. Although a reef margin was not observed, one is inferred for both the Lake Memphremagog and Lime Ridge-Marbleton areas at this time.

Stabilization of subsidence in the Lime Ridge-Marbleton area during Pridolian time resulted in largely carbonate sedimentation (Fig. 20d). Subsequently, the back-reef was inhabited by small hemispherical stromatoporoids and to a lesser extent, digitate stromatoporids and corals. Well bedded limestones with numerous corals, crinoid ossicles, and *in situ* stromatoporoids characterize shelf deposits within a back-reef, lagoon environment. Re-established instability and subsidence arrested carbonate sedimentation and returned the area to calcareous, siliciclastic conditions that continued on into the Devonian.

Tectonic Models

Model A

The first model envisages the Connecticut Valley-Gaspe Trough (Synclinorium) as a zone of major strike-slip faulting (cf. Bradley, 1983; and Bedard, 1985). The present facies configuration at Lake Memphremagog is similar to that of an asymmetric basin which according to this model is a pull-apart that developed in response to dextral strike-slip movement. Development of this basin would result in initial subsidence and the uplift of low lying highlands to the northwest forming a normal fault-scarp along the northwestern margin of the basin (Fig. 21a). The Peasley Pond Conglomerate (sandstone), deposited within the northern part of this basin, is similar to sandstone debris flows along a margin of a strike-slip orogenic basin on the Hercynian Cantabrian belt in Northern Spain (Reading, 1975). Calcareous siltstones and shales derived from a southeastern land source formed mass-flow deposits on the slope bordering a southeastern carbonate platform (Fig. 20A-C). The Lake Aylmer-syncline would represent the northeastern portion of the pull-apart basin.

Mitchell and Reading (1978) has described the characteristics of transform strike-slip-related basins as (1) rapid deposition giving great local thicknesses of sediments, (2) uplift and erosion leading to development of unconformities in close proximity to subsiding sedimentary basins, (3) lateral variation in facies, (4) simultaneous development of both extensional and compressional tectonics in nearby areas, and (5) sparse igneous activity. Subsidence in the Lake Aylmer basin is considered to have been more rapid than the Lake Memphremagog basin. Both basins, however, lack the thick sedimentary sequences (up to 3000m thick, Mitchell and Reading, 1978) usually described for such basins. Uplift due to compression has produced highlands on either side of the basin (Figs. 20A-C). The subsequent erosion of these highlands was responsible for shedding material into the adjacent basin. Simultaneous deposition of calcareous siltstones, turbidites, allodapic limestones, shoals, reefs within both basins shows undoubtably, the presence of lateral variations in facies. Igneous rocks are present in both Lake Memphremagog and Lake Aylmer areas, however, little work has been done on them.

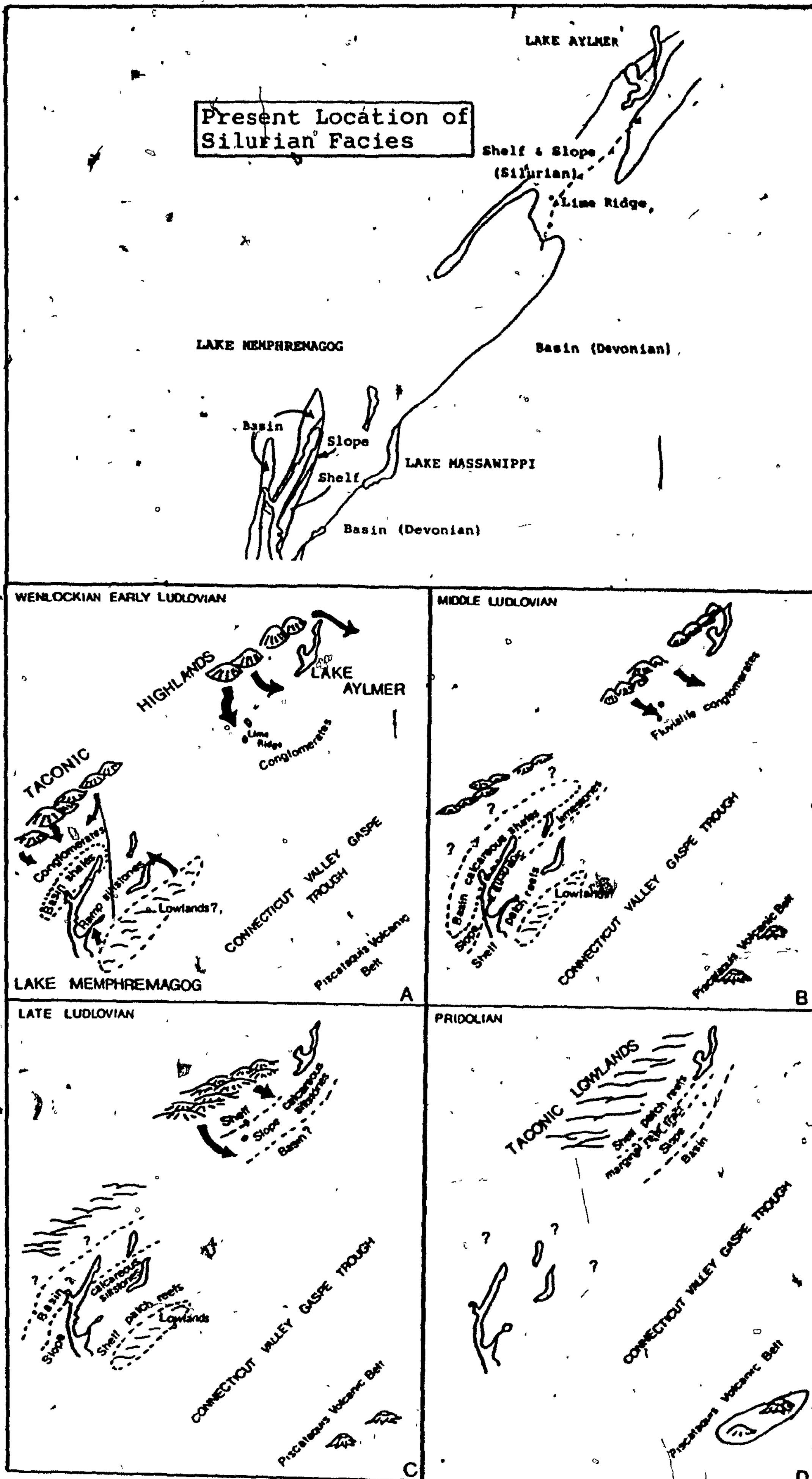
Model B

The second model invokes Upper Silurian extension of the Taconic basement which produced block faulting. A carbonate and siliciclastic ramp and shelf-platform developed on the southeastern face of a subsiding half-graben structure at Lake Memphremagog (Fig. 21b). Initial subsidence in the Wenlockian-Ludlovian would be greater in the northwest forming a basin where conglomerates, sandstones and mass flows would be shed from a steep fault scarp into the basin. Slower subsidence would occur to the southeast allowing a large prograding carbonate shoal to develop during Middle Ludlovian time. Late Ludlovian time would see the erosion of the fault scarp in the Lake Aylmer area. A calcareous, and siliciclastic ramp formed on fluvial conglomerates at Lime Ridge-Marbleton. The ramp subsequently evolved into a carbonate shelf and slope by Pridolian time, upon which patch-reefs developed (Fig. 20B-D). Bourque and Amyot (1982) and Bourque et. al. (1986) have suggested a similar tectonic setting for the Late Silurian of the Gaspe.

Model C

The third, and least likely model, attributes the present facies configuration at Lake Memphremagog to major Post-Acadian dextral, strike-slip faults (Fig. 22). The

Figure 20a-d: Cartoon showing depositional history for the Lake Memphremagog and Lake Aylmer areas. (A) Glenbrooke Formation and Ay1, (B) Sargent Bay Limestone and Ay1 conglomerates and sandstone, (C) Upper Calcareous Siltstone Ay2 and Ay3, and (D) Main limestone unit.


Present Location of Silurian Facies
LAKE AYLMER
Shelf & Slope (Silurian)
Lime Ridge
LAKE MEMPHREMAGOG
Basin (Devonian)
Basin
Slope
Shelf
LAKE MASSAWIPPI
Basin (Devonian)
WENLOCKIAN EARLY LUDLOVIAN
HIGHLANDS
LAKE AYLMER
Lime Ridge
Conglomerates
TACONIC
Conglomerates
Basin shales
Ramp siltstones
Lowlands?
CONNECTICUT VALLEY GASPE TROUGH
Piscataquis Volcanic Belt
LAKE MEMPHREMAGOG
A
MIDDLE LUDLOVIAN
Fluviatile conglomerates
Basin calcareous shales
limestones
patch reefs
Slope
Shelf
Lowlands
CONNECTICUT VALLEY GASPE TROUGH
Piscataquis Volcanic Belt
B
LATE LUDLOVIAN
Shelf
Slope
Basin?
calcareous siltstones
Basin
calcareous siltstones
Slope
Shelf
patch reefs
Lowlands
CONNECTICUT VALLEY GASPE TROUGH
Piscataquis Volcanic Belt
C
PRIDOLIAN
TACONIC LOWLANDS
Shelf patch reefs
Slope
Basin
CONNECTICUT VALLEY GASPE TROUGH
Piscataquis Volcanic Belt
D

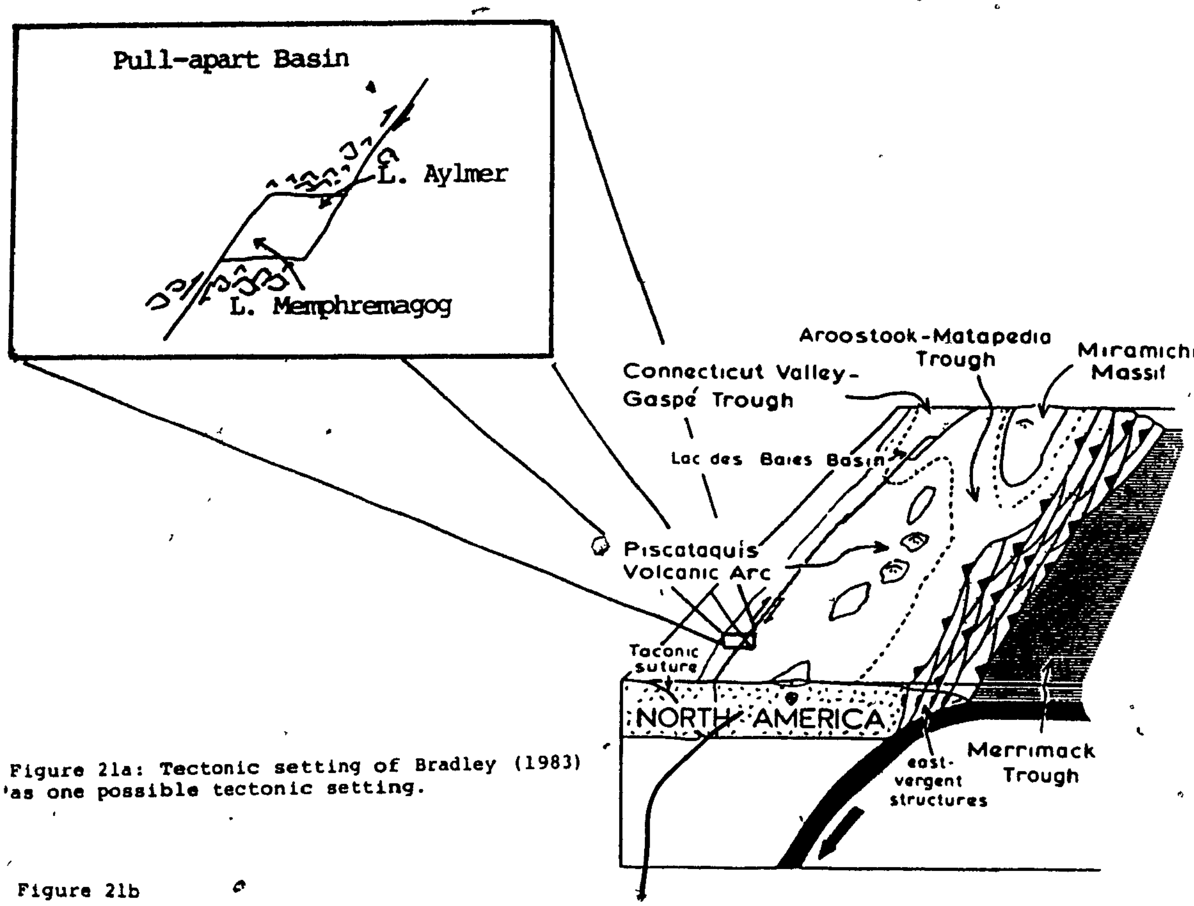
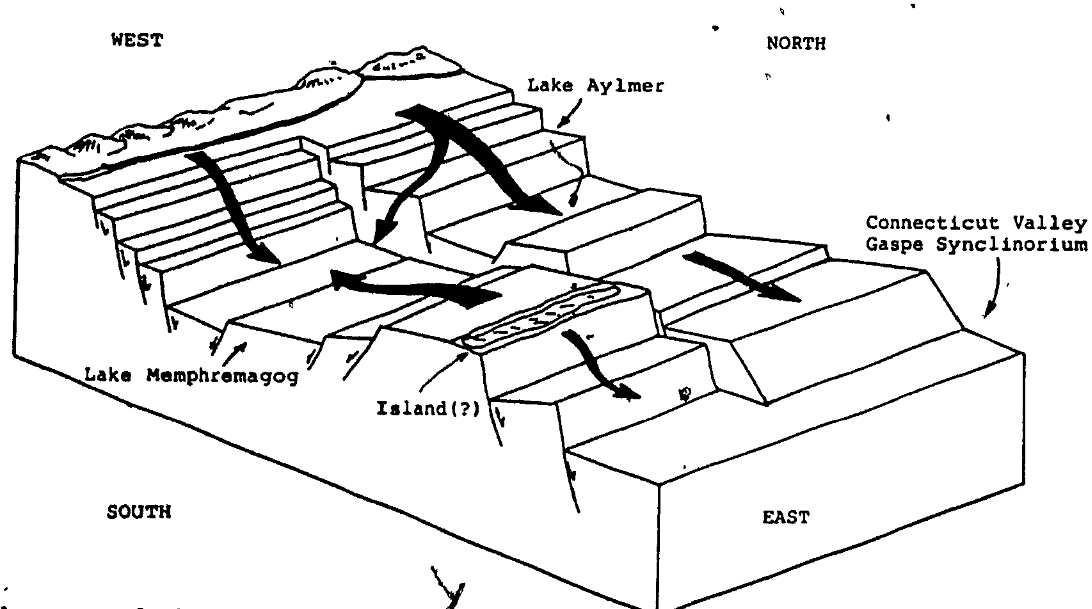


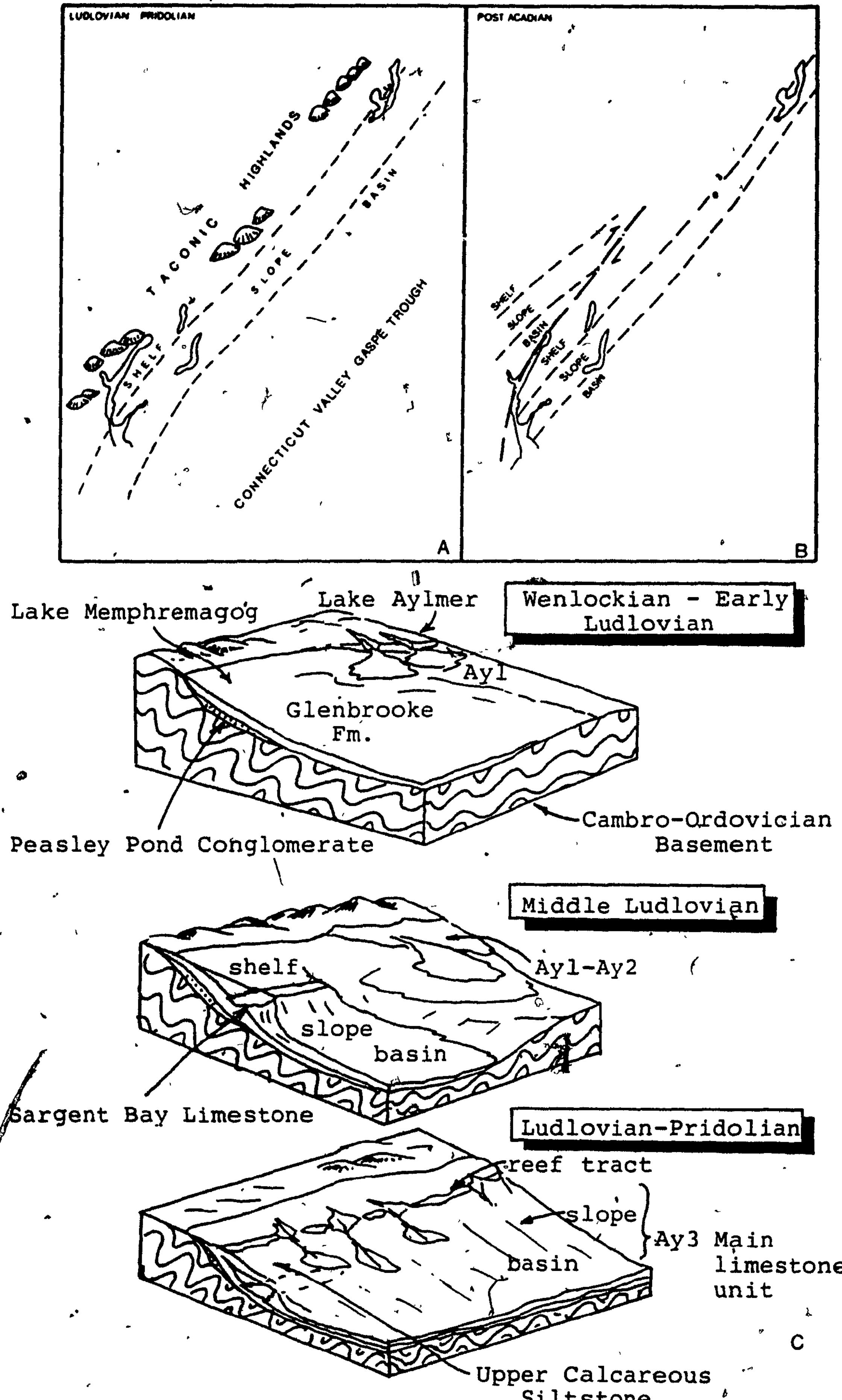
Figure 21a: Tectonic setting of Bradley (1983) as one possible tectonic setting.

Figure 21b



(b) A conceptual sketch showing horst and graben structures associated with extensional tectonics. The southside, Lake Memphremagog, would have subsided before the northern side, Lake Aylmer. The arrows suggest possible direction of sediment transport from their source areas.

Figure 22: (A) Original position of facies at time of deposition. (B) Present position of facies after Post Acadian faulting. (C) Illustration showing a possible tectonic setting that could be responsible for the original distribution, by showing a basin (Connecticut Valley-Gaspe Trough) formed as a result of lithospheric flexure in response to an advancing Acadian deformation front from the east.


LUDLOVIAN PRIDOLIAN
TACONIC HIGHLANDS
SHELF
SLOPE
BASIN
CONNECTICUT VALLEY GASPE TROUGH
A
POST ACADIAN
SHELF
SLOPE
BASIN
SHELF
SLOPE
BASIN
B
Lake Memphremagog
Lake Aylmer
Wenlockian - Early Ludlovian
Ay1
Glenbrooke Fm.
Cambro-Ordovician Basement
Peasley Pond Conglomerate
Middle Ludlovian
shelf
Ay1-Ay2
slope
basin
Sargent Bay Limestone
Ludlovian-Pridolian
reef tract
slope
basin
Ay3 Main limestone unit
C
Upper Calcareous Siltstone

fault would bring the basin facies into a position northwest of the platform facies. Sedimentation would have proceeded during the Silurian time on a southeastern facing slope bordering a foreland basin.

Evidence for Post-Acadian strike-slip movement in the Taconic basement has not been documented for the area. Furthermore, structural observations in the Silurian cover rocks at Lake Memphremagog showed only evidence of compressional tectonics. Perhaps future work by structural geologists may provide evidence for this hypothesis.

CHAPTER 5 - PALEONTOLOGY

Introduction

Fossils collected from Lake Memphremagog and Lime Ridge-Marbleton areas are described here. Although the preservation of some fossils is excellent, most range from poor to good. How well a fossil is preserved appears to depend on the fossil type. For example, most corals are moderately to well preserved, and yet the stromatoporoids collected from the same unit commonly show only ghosts of the original structure. Units within the Lake Memphremagog area are sparsely fossiliferous. Consequently, the paucity of fossils combined with selective preservation made identification of specimens beyond the generic level impossible at Lake Memphremagog. Good preservation and a greater number of fossils allowed some specimens to be identified at the species level in the main limestone unit of the Lake Aylmer Formation in the Lime Ridge-Marbleton area. For these reasons many specimens listed in the fossil list are not described here.

The systematic paleontology has been greatly simplified, in order that the presentation be kept succinct. Much of the synonymy has been left out, and the reader is referred to published synonymy lists mentioned in the text. All fossils described in the text are stored at McGill University. Sample numbers refer to thin sections. The localities and stratigraphic position are listed in Appendix A. Many thin sections contain more than one fossil specimen.

Phylum Brachiopoda Dumeril, 1806

Order Pentamerida Schuchert & Cooper, 1931

Suborder Pentameroidea Schuchert & Cooper, 1931

Superfamily Pentameracea M'Coy, 1844

Family Pentameridae M'Coy, 1844

Subfamily Pentamerinae M'Coy, 1844

Genus Kirkidium Amsden, Boucot & Johnson, 1967

Subgenus Kirkidium Boucot and Johnson, 1979

Pl. IX; figs. I-L.

Description: The shape of the shell is presumed to have been elongate, as suggested by the flattened sides of the shells shown in sketches 12 to 15 (Fig. 23); pedicle valve strongly convex (sketches 19 through 26, Fig. 23), beak of pedicle valve extends beyond the brachial valve, and is hooked (sketch 23, Fig. 23); strong radial costae; spondylium supported by a long, high median septum; brachial valve contains two parallel rods serving as brachiophores, running the length of the interior of the valve.

Discussion: Sketches 4, and 8 through 11, show a broad resemblance to Figure 5a of Conchidium sketched from the Treatise of Invertebrate Paleontology (1965), and sketch 17 and 5e. Amsden et. al. (1967) have distinguished Kirkidium from Conchidium on the basis of their brachial valve structure, and the reader is referred to Amsden et. al. (1967) and to Boucot and Johnson (1979) for a more detailed analytical description. Bourque (1977) identified two different species of the genus, Kirkidium knighti and

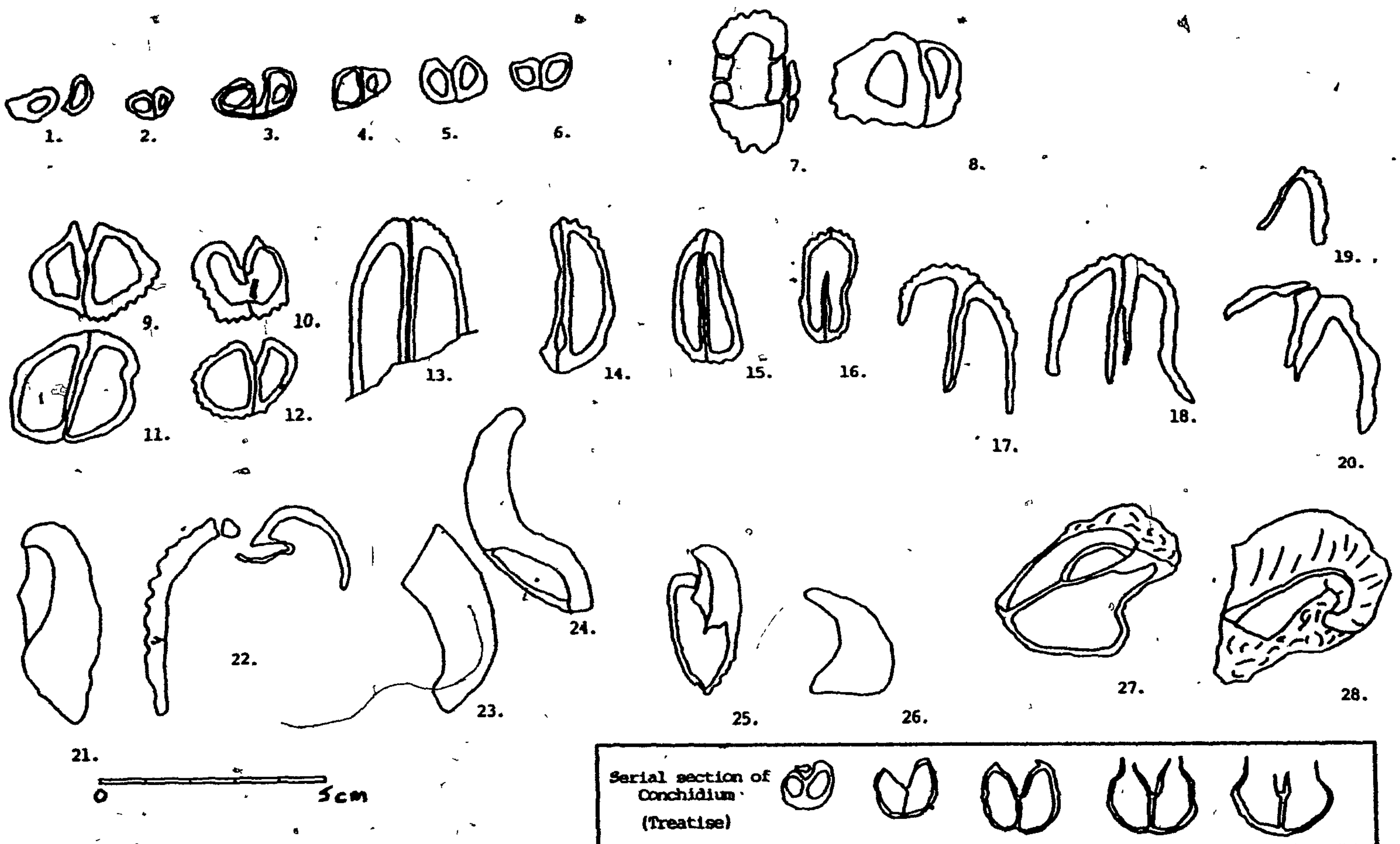
Kirkidium aff. *K. knighti* in the Pridolian of the Gaspe. *Kirkidium knighti* was found within siltstones to fine-grained sandstones, and *K.* aff. *Knighti* in calcarenites and calcirudites that have been interpreted as indicative of higher-energy environments. Sections of the brachial valves collected from the drainage ditch near Saint-Adolphe-De-Dudswell were like those illustrated in Figure 1, Plate 10 of Bourque (1977) showing *K.* aff. *knighti*. For a detailed description of the rudstone bed see Appendex A.

Material and Occurrence: Specimens were collected from a bed, lying within the lower portion of the main limestone unit near Saint-Adolphe-de-Dudswell. Few specimens were collected from the Sargent Bay Limestone and the upper calcareous siltstone in MacPherson and Quinn creeks near Lake Memphremagog. Owing to the degree of metamorphism complete extraction of specimens was not possible. Several sections were sketched and compiled in Figure 23 in order that a composite of the skeleton could be made. These brachiopods were first identified within the Lake Aylmer Formation by Petryk (1985) and confirmed by Boucot (person. commun. to Petryk) as being *Kirkidium* sp. Most of the shells are broken and disarticulated within a silty calcarenite. The surrounding sediment has the appearance of a schist.

Age: Ludlow - Pridolian.

Figure 23: Non-serial sections sketched from the block shown in Plate IX, figures I to L. Number 3 represents a section through a brachial valve, and number 25 shows a section through both valves. All others represent sections through various portions of the pedicle valve. Note the similarity between Conchidium (inset) and Kirkidium sp.

NON - SERIAL SECTIONS OF THE BRACHIOPOD KIRKIDIUM



TABULATE CORALS

FAVOSITES

Large numbers of measurements are essential to illustrate adequately a viable ecophenotypic range within a species (Polan, 1982 after Stel, 1978). Furthermore, because measurements such as corallite diameter, tabular density, wall thickness and pore size are considered as inadequate criteria to define species of Favosites, the species assignment may be suspect (Polan, 1982). The number of specimens collected within this study was very limited, and most species are represented by a single specimen. The author therefore suggests that the species presented by Boucot and Drapeau (1968) be regarded as suspect. Consequently, identification of Favosites is not taken further than the generic level. They are instead placed into groups that exhibit similarities among the parameters mentioned above.

Order Favositida Wedekind, 1937

Suborder Favositina Wedekind, 1937

Superfamily Favositacea Dana, 1846

Family Favositidae Dana, 1846

Subfamily Favositinae Dana, 1846

Genus Favosites Lamarck, 1816

Pls. X - XIV.

A. **Favosites** sp. (Plate X, figures A, B)

Description: Corallum fragment, cerioid, probably hemispherical; corallites hexagonal, diameter 1.78 mm (n=12, min.=1.58mm; max.=1.98mm); thin-walled (n=12; X=0.08mm; min.=0.06; max.=0.11mm); rare short "stubby" spines; tabulae complete, thin and parallel, spacing approximately 4 per 1mm; mural and corner pores, 1 to 3 per wall (usually 2) showing a diameter of 0.20mm (n=12; min.=0.13; max.=0.23), pore plates common. Material: one specimen collected, sample number MBS-1A,B.

B **Favosites** sp. (Plate X, figures C, D)

Description: Corallum fragment, cerioid, probably hemispherical; corallites, polygonal, with a diameter of 1.05mm (n=14; min.=0.85mm; max.=1.29mm); thin-walled containing a single mural pore, diameter 0.19mm (n=13; min.=0.13mm; max.=0.2mm); numerous spines developed in mature corallites; tabulae are complete, straight and parallel with a spacing of 2 per 1mm. Material: One specimen collected, sample number Dom 23A, B.

C **Favosities** sp. (Plate XI, figure A)

Description: Corallum hemispherical, cerioid; corallites polygonal with a diameter of 1.71mm (n=12; min.=1.31mm; max.=2.10mm); numerous spines of moderate length; single mural pore, diameter is 0.22mm (n=8; min.=.11mm; max.=0.31mm); tabulae are complete, moderate spacing, 2 per 1mm, slightly convex down.

Material: One specimen collected, sample number DQ-1A.

Discussion: This specimen was very similar to Favosites sp. group B with respect to shape of the corallites, spines, and tabulae spacing, but the corallites are much larger.

D *Favosites* sp.

Description: Corallum digitate; corallites polygonal, with diameter of 1.35mm (n=8; min.= 1.18mm; max.=1.76mm), long in sectional view, initially subparallel with corallum axis but curve gently to intersect the corallum periphery at a slightly oblique angle; spines present only in peripheral corallites; pores absent; tabulae mostly complete, subparallel, spacing is approximately 2 tabulae per 1mm.

Material: One specimen collected, sample number Dom. F2A,B.

Discussion: This specimen bears some resemblance to species C, except that pores were not observed, and the corallum is digitate.

E *Favosites* sp. (Plate XI, figures B-D; Plate XII, figures A,B)

Description: Corallum hemispherical, cerioid; corallites polygonal, long and slender with numerous mural spines, diameter 0.4mm (n=23; min.= 0.2mm; max.=0.5mm); pores rare, form a single row with diameter of 0.3mm; tabulae complete, convex down, closely spaced ranging from 1.4 to 2.7 per 1mm. **Material:** Six specimens collected, sample numbers: McB2A, B; McBH3, H1, H4; CMR 4A.

F **Favosites** sp. cf. **F. gothlandicus** (Plate XII, figures C,D; Plate XIII, figures A,B)

Description: Corallum cerioid, tabular and hemispherical; corallites hexagonal with a diameter of 2.3mm (n=70; min.=1.2mm; max.=3.1mm); short stubby mural spines; pores rarely present, commonly one per wall rarely two; tabulae complete, widely spaced, 8 per 6.4mm, and straight with slight deflection, concave down. Material: Four specimens collected, sample numbers: McB1A, QC7, QB6A, CCEMA, Swartz farm.

G **Favosites** sp. (Plate XIV, figures A, B)

Description: Corallum fragment, cerioid, tabular growth form; corallites polygonal, diameter 1.28mm (n=15; min.=0.94mm; max.=1.45mm), long, slender, straight and parallel; tabulae well spaced, 5 per 6.4mm; mural and corner pores, diameter 0.2mm. Material: One specimen collected, sample number MC4A, B. Discussion: This specimen is very similar in tangential section to those of group F, but differs, however, in corallite size.

H **Favosites** sp. (Plate XIV, figure C, D; Plate XV, figure D)

Discussion: Corallum small, round, and dendritic, cerioid verging on meandroid; corallites polygonal, diameter 0.93mm (n=29; min.=0.50mm; max.=1.2mm); corner pores, some solenia like; short mural spines; tabulae poorly preserved, appear complete and parallel, spacing 5 per 3.2mm. Material: Four specimens were examined, sample numbers CEM1, CEM4B.

Superfamily Pachyporicae Gerth, 1921

Family Pachyporidae Gerth, 1921

Genus ? Cladopora Hall, 1851

Pl. X V; figs. A & B.

? Cladopora sp.

Description: Corallum ramose, long, slender and cylindrical; corallites subrounded to rounded, most are pear shaped, initially parallel with axes, but gradually turn to intersect the periphery at an oblique angle; walls very thick at the periphery; tabulae and pores absent.

Material: MB4H; CEM 1; DQ1A, 2-3-Ab, Bb; LR 1; Dom 2-1-A.

Age: Silurian-Devonian.

Suborder Alveolitina Sokolov, 1950

Family Alveolitidae Duncan, 1872

Subfamily Alveolitinae Duncan, 1872

Genus Alveolites Lamarck, 1801

Pl. X V; figs. A & C; Pl. XVI; figs. A-D; Pl. XVII; Fig. A.

A Alveolites sp.

Description: Corallum small, round, dendritic, meandroid; corallites polygonal to subrounded, corallite diameter 0.22mm (n=33; min.=0.15mm; max.=0.35mm); tabulae complete, well spaced, 8 per 1.6mm, very thin; walls undulate slightly, some are incomplete giving appearance of spines in tangential view, spines absent in cross-sectional view.

Material: Twelve specimens examined, CEM1, MB 4A.

Age: Upper Silurian-Devonian.

B **Alveolites** sp.

Description: Corallum fragment, meandroid; corallites polygonal, subrounded to rounded, slightly crescentric in tangential section, long, slender, and parallel, bent min.=0.61mm; max.=0.97mm); corner and mural pores form single and double rows, pore plates common; spines rare in tangential view, when present they barely rise away from wall. **Material:** Three specimens, sample numbers; D2-1-A, B; D2-2-A, B; CMR 5; Marb. CA.

Age: Upper Silurian-Devonian.

C **Alveolites** sp.

Discussion: Corallum fragment, meandroid; corallites strongly crescentric, large; spines small, extend upwards from the convex side of wall; tabulae not observed. **Material:** Two specimens, sample number: MC12A; MC33.

Age: Upper Silurian-Devonian.

Suborder Halysitina Sokolov, 1947

Family Halysitidae Milne-Edwards & Haime, 1849

Subfamily Halysitinae Milne-Edwards & Haime, 1849

Genus Halysites Fischer von Waldheim, 1828

Halysites catenularia Linnaeus, 1767

Pl. XVII; Fig. B.

Description: Corallum fragment; corallites arranged in a single, anastomosing chain that join regularly at every third to fifth corallite; small rectangular mesocorallites between larger elliptical autocorallites; autocorallites long and slender, diameter of short axes 0.80mm (n=10; max.=0.94; min.=0.69mm); tabulae poorly preserved, commonly complete, spacing of 15 in 6.4mm.

Material: Only one specimen was collected (MCBL 6) from the Upper calcareous siltstone in MacPherson Brook. The enclosing sediment, including the fossil is severely sheared. A high degree of recrystallization has resulted in the masking of internal structure of the corallites. Only recrystallized fragments of single chains were collected from the Lime Ridge area, and were not included in the description. Sample number MC BL1.

Discussion: The specimen resembles Halysites labyrinthica of Goldfuss (1826), but the autocorallites of H. labyrinthica are much larger with a short diameter between 1.3 and 1.6mm, and a long diameter between 2.2 and 2.6mm (Buehler, 1955).

Age: Silurian.

Order Auloporida Sokolov, 1947

Superfamily Syringoporicae de Fromentel, 1861

Family Syringoporidae de Fromentel, 1861

Genus Syringopora Goldfuss, 1826

Syringopora sp. A

Pl. XVII; figs. C & D.

Description: Corallum fragment; corallites closely spaced and parallel, rarely joined by stolons; tabularium diameter is 0.59mm (n=15; min.=0.57mm; max.=0.62mm); walls 0.08mm thick (n=10; min.=0.0072mm; max.=0.09mm); tabulae thin, poorly preserved, complete.

Material: One specimen collected from the Upper Calcareous Siltstone in Quinn Creek. Preservation is poor, and recrystallization has masked internal structure in most corallites. Corallite spacing was not measured, because shearing and pulling apart of corallites is believed to have occurred. Sample number QC2.

Discussion: The specimen resembles _Syringopora compacta_ (Billings, 1858) described in Young and Noble (1987). Comparison was made on the basis of wall thickness, tabularium diameter, and thin complete or incomplete tabulae that irregularly surround an axial tube. Young and Noble (1987) report that _S. compacta_ and _S. reteformis_ (Billings, 1958) found in northern New Brunswick and in the Gaspe are very similar. These authors stress that measurements must be carefully made in order that individuals are not assigned to the wrong species. Accurate measurements are difficult with this specimen. Boucot and Drapeau (1968) report _S. compacta_ from the Late Silurian, Pridolian of Dudswell. Young and Noble (1987) report an age of Llandovery to Late Wenlock for _S. compacta_ and Late Llandovery to middle Wenlock, and possibly early Ludlow for _S. reteformis_. Boucot and Drapeau's (1968) assignment of their specimen to _S. compacta_ is either incorrect, or it would extend the range of _S._

compacta to include the Pridolian. Until more specimens can be found and measured the assignment of this specimen to the species level should be withheld.

Age: Rock is of Ludlow to Pridoli age.

Genus Syringopora Goldfuss, 1826

Syringopora sp. B

Pl. XVIII; figs. A-C.

Description: Corallites small, widely spaced, approximately 1.15mm apart from centre to centre (n=30; min.=0.63mm; max.=1.50mm), rarely in contact, corallites are long, parallel and joined by a long stolon; tabularium diameter 0.40mm (n=30; min.=0.23mm; max.= 0.41mm); tabulae infundibuliform, complete and commonly surround an axial tube.

Material: Two specimens were collected, one from the Sargent Bay Limestone, the other from the main limestone unit in the Lake Aylmer Formation near Saint-Adolphe-de-Dudswell. Both are overgrown by stromatoporoids. Recrystallization has masked internal structures. Sample number is MC23A and CCEM. A, B.

Discussion: Corallite spacing, diameter, and internal structure suggest a similarity between this species and S. compacta described in Young and Noble (1987). Vertical sections of S. compacta in Young and Noble (1987, Fig. 6), however, show common, short stolons between subparallel corallites unlike *Syringopora* sp. B. This species differs from *Syringopora* sp. A by having corallites less closely spaced, with fewer contacts and of smaller diameters. *Syringopora* sp. B may in fact be an end member of *Syringopora* sp. A, but until larger collections are made and accurate measurements taken from better preserved samples these two are presented here as separate species.

Age: Ludlow to Pridoli age.

Order Heliolitida Frech, 1897

Suborder Heliolitina Frech, 1897

Superfamily Heliolitcae Lindstrom, 1876

Family Heliolitidae Lindstrom, 1876

Genus Heliolites Dana, 1846

Heliolites sp. cf. H. lavieillenses

Pl. XIX ; figs. A-D.

Description: Corallum fragment, spherical; corallites round, diameter 1.11mm (n=11; min.=0.94mm; max.=1.31mm), corallites contain 12 short septal spines, corallite spacing is 0.73mm (n=10; min.=0.32mm; max.=1.22mm); tabulae mostly complete, spaced 0.42mm apart; tabulae spines present near corallum periphery.

Material and occurence: Samples were collected from the upper calcareous siltstone, Lake Memphremagog, where in Quinn Creek randomly oriented fragments of coralla form layers. Specimens were also collected from the main limestone unit of the Lake Aylmer Formation. Sample numbers:

CMR3A, B; QB2A, B; QB5A, B.

Discussion: A specimen was sent to O. Dixon for identification. He concluded that the specimen looked very much like Heliolites lavieillenses (Noble and Young, 1984). It has comparable corallite size and spacing, and short septa. Noble and Young (1984) noted that H. lavieillenses shows some affinities with H. interstinctus and H. subtubulatus. The species differs from these by having narrower corallites, and less regular tabulae. Noble and Young (1984) report an age of Late Llnadovery to Wenlock for Heliolites lavieillenses.

Age: Age of rock is Ludlovian-Pridolian.

RUGOSE CORALS

Order Cystiphyllida Nicholson, 1889

Family Tryplasmatidae Etheridge, 1907

Subfamily Tryplasmatinae Etheridge, 1907

Genus Tryplasma Lonsdale, 1845

Tryplasma sp.

Pl. VI; Fig. N; Pl. XX; Fig. C.

Description: Corallum both solitary and fasciculate, round, long, diameter 6.2mm (n=5; min.=5.7mm; max.=7.5mm); tabulae complete, subparallel, closely spaced, may intersect; dissepiments absent; septa short, holocanthine and rhabdacanthine, trabeculae become free away from the wall giving appearance of spines; rejuvenescent rings common in sectional view.

Material: Several specimens collected, sample numbers: MC25; DQ2A, 1A; CEM4B,3A.

Age: Silurian-Lower Devonian.

Order Stauriida Verill, 1865

Suborder Arachnophyllina Zhavoronkova, 1972

Family Entelophyllidae Hill, 1940

Genus ?Entelophyllum Wedekind, 1927

?Entelophyllum sp.

Pl. XX; figs. A & B.

Description: Corallum fragment, fasciculate; corallite diameter 6.6mm; thickened peripherally; major septa withdrawn from axis; dissepimentarium wide; tabulae domal, slightly depressed at centre with marginal troughs; outer wall absent; internal structure of corallite poorly preserved.

Material: One specimen collected from the upper calcareous siltstone in MacPherson Brook, sample number: MC5A, B.

Age: Silurian.

STROMATOPOROIDS

Several stromatoporoids were collected from both the Sargent Bay Limestone and the main limestone unit of the Lake Aylmer Formation. Four genera: Parallelstroma, Clathrodictyon, Ecclimadictyon, and possibly Stromatopora have been identified by C. W. Stearn and described by the author. Two species were identified, based on growth form and poorly preserved internal structure as E. stylotum and S. clarkei stylotum. Other stromatoporoids collected from the Dudswell area by A. Petryk and identified by C. W. Stearn, and not described in this study, include a second species of Parallelstroma, and Clathrodictyon, ?Gerronostroma sp., and ? Intexodictyon sp. Some stromatoporoids collected in this study could not be identified due to poor preservation and recrystallization. The classification used here was proposed by Stearn, 1980.

Class Stromatoporoidea Nicholson and Murie, 1879

Order Clathrodictyida Bogoyavlenskaya, 1969

Family Clathrodictyidae Kuhn, 1927

Genus Clathrodictyon Nicholson and Murie, 1879

Clathrodictyon sp.

Pl. XXI, figs. A & B.

Description: Regularly and closely spaced laminae, undulant, approximately 5.4 in 1mm; pillars regularly and closely spaced, 6.5 in 1mm, confined to interlaminar spaces, most are complete, taper downward, and rounded to subrounded in tangential view; astrorhizae not observed; mamelons absent.

Material and occurence: Single specimen collected from Sargent Bay Limestone in MacPherson Brook. Sample number MC29A, B.

Age: Silurian.

Genus *Parallelostroma* Nestor, 1966

Parallelostroma sp.

Pl. XVIII; figs. A-C.

Description: Coenostea laminar, slightly domal; very thick tissue producing small round galleries; laminae thin to very thick, with a spacing of 4 in 2mm; spool shaped pillars mostly confined to interlaminar space, but rarely superposed, 2.7 in 1mm; astrorhizae moderately to well developed.

Material and occurrence: One specimen collected from the main limestone unit in the Lake Aylmer Formation, adjacent to the cemetery in Saint-Adolphe-de-Dudswell. Sample number CCEMA, B.

Age: Lower Silurian-Middle Devonian.

Family Ecclimadictyon Nestor, 1964

Ecclimadictyon stylotum Parks, 1933

Pl. XXI;figs. C-D.

Description: Coenostea laminar slightly domal, latilaminar, dimensions are approximately 6cm in height with a diameter up to 15cm; coenosteum comprised of large vertical mamelon columns projecting upward from a basal layer; mamelons range from 4 to 7 mm in height, circular to elliptical in tangential section, many join to form clusters; internal structure masked by recrystallization.

Materials and occurence: Specimens were collected from the upper portion of the main limestone unit near Lime Ridge and from the basal layers of the Sargent Bay Limestone in MacPherson and Quinn creeks. Sample numbers: DOMF1A, B, C; QC9.

Age: Ludlovian-Pridolian.

Order Stromatoporida Stearn, 1980

Family Stromatoporidae Winchell,

Genus Stromatopora Goldfuss, 1826

Stromatopora clarkei Parks, 1909

? Stromatopora clarkei digitata

Pl. XXII; figs. A & B.

Description: Coenostea digitate, internal structure poorly preserved; astrorhizae not apparent; irregularly arranged laminae and pillars.

Material: One specimen collected (MC 25).

Age: Upper Silurian to (?) Lower Devonian.

ICHNOFOSSILS

Genus Planolites Nicholson, 1873

Planolites sp.

Description: Round to elliptical burrows parallel to near vertical with bedding plane, 2mm in diameter; tubes usually straight to slightly curved, rarely branching; rarely radiate from a central tube that parallels bedding; sediment infill lighter than surrounding sediment, internal structure lacking.

Material and occurance: Commonly found in the Lake Memphremagog area within well bedded calcareous shales.

Genus Chondrites von Sternberg, 1833

Chondrites sp.

Description: Round to elliptical burrows, 2mm in diameter, parallel with bedding; lighter in colour than surrounding calcareous shale; material within burrows commonly the same as the overlying unit.

Material and occurence: Found only in the Sargent Bay Syncline where it occurs within turbidite units.

APPENDIX A

GLENBROOKE CREEK SECTION

The section began on the northwest side of the foot bridge, 13.8m from the shoreline of Sargent Bay where Glenbrooke Creek enters the bay. The section was measured with a tape and brunten compass. Glenbrooke Creek contains the type section for the Glenbrooke Formation and Sargent Bay Limestone. Refer to map shown in Figure 7.

TRAVERSE NO.	DESCRIPTION	THICKNESS (m)	SAMPLE NO.
1 and 2	Glenbrooke Formation. Mostly covered section. Non-calcareous to slightly calcareous shale. Rare discontinuous lenses of calcareous siltstone, interiors appear massive, dimensions 3.5 x 8cm. Discontinuous beds of massive non-calcareous siltstone (may be dolomitic), length from less than 1m to several metres. Lime content increases up section. Thin beds of calcareous siltstone dominate the upper half of the traverse.	17.5	

3, 4, 5, 6, and 7.	Section covered in many places. Interbedded calcareous siltstone and slightly calcareous shale. Shales usually occur as partings separating beds of calcareous siltstone. Siltstone beds range in thickness from 2'to 50cm, with an average thickness of 20cm increasing up section to 50cm.	42
8 and 9.	This section is characterized by beds of beige dolomitic siltstone interbedded with brown-grey calcareous siltstone and shale partings. The 4cm thick dolomitic layers resist weathering and form distinct parallel ridges. On fresh surface the dolomitic siltstones show similar colour and grain size. Up section the ridges become more prominent, thicker and closely spaced within groups. The distance between groups averages 70cm. Nodules of dolomitic siltstone commonly occur between the ridges.	14

10, 11, 12 and 13.	Sargent Bay Limestone. First 2m are covered section. Massive blue-grey, finely crystalline limestone (lime mudstone). Cleavage parallel with bedding. Beds, 3-5cm thick, of lime mudstone are separated by shale partings.	40	
14 and 15.	Tightly folded, and thin bedded (3-5cm), blue-grey lime mudstone. Beige pseudonodules of fine dolomitic siltstone are elliptical with long axes parallel with bedding. Lobes of dolomitic siltstone commonly extend outwards from the pseudonodule. Stylolites are commonly orthogonal to bedding. This section is considered as the centre of the Sargent Bay Syncline.	30	GCS#3 (pseudonodule)
16, 17, 18, 19, 20, 21, 22, and 23.	Interbedded blue-grey, shaly mudstone, dolomitic siltstone, graded and non-graded calcarenities. Approximately sixty beds were counted, however, some portions of the section were poorly exposed, and therefore the exact	80	GC1-15B

number of beds is not known. The graded and non-graded calcarenites are concentrated in the lower 25m of the section. Siltstone pseudonodules lie within the top 10m of the section. The calcarenites usually form thin beds 10-20cm thick, but rarely in discontinuous lenses. Grading is towards the east.

24 and 25.	Glenbrooke Formation. Turbiditic limestones and calcareous siltstone. The latter forming more than 75% of the section. The mudstones exhibit burrows similar to <u>Chondrites</u>. Cross laminations indicate that up is to the east.	8
26, 27, 28 29, 30, 31, and 32.	Massive calcareous siltstones ~~with~~ shale partings. Orange-rust weathered surface, greenish-grey fresh surface. Weathered surface commonly pitted along cleavage planes. Unit becomes more shaly towards bottom of section.	60

33 to road. Massive non-calcareous slate. Most of the section is covered, however, it is presumed to be all slate.

GLENBROOKE ROAD SECTION

The section was started 406m east of the junction between Glenbrooke Road and the cottage road to Nowlton Landing, at the first appearance of the Peasley Pond Conglomerate. The section was measured with a tape from west to east.

TRAVERSE NO.	DESCRIPTION	THICKNESS (m)	SAMPLE NO.
1.	Peasley Pond Conglomerate. Massive, medium to find grained, well sorted quartz sandstone. Fresh and weathered surface are green. The quartz grains are well rounded.	22.12	
2.	Covered section.	45.82	
3.	Glenbrooke Formation. Interbedded siltstone, shale and calcareous siltstone and rarely, limestone. Units become siltier and more massive to the east. Elliptical burrows parallel with bedding were observed in the shales. Furthermore, siltstone lenses (2 to 6cm) within the shale show cross laminations.	22.06	
4.	Two metres of a well to moderately sorted, fine grained quartz sandstone.	2.0	

Grains are rounded within a very fine green coloured matrix. Unit very similar to Peasley Pond Conglomerate.

5.	Glenbrooke Formation. Same description as in transverse number 3.	39.14
6.	Covered section.	66.36
7.	Sargent Bay Limestone. Thin beds (less than 6cm) of blue-grey, shaly limestone and calcareous siltstone interbedded with very thin beds of calcareous shale. Elliptical burrows parallel with bedding were observed (probably Chondrites). Refer to Plate I, Figure A.	37.92
8.	Covered section.	142.20
9.	Sargent Bay Limestone. Interbedded shaly limestones, rarely calcareous siltstones and calcareous shales. Thin discontinuous beds (less than 10cm thick) of blue calcarenite were also noted. These beds are interpreted as	72.68

	allodapic units in the Lower Sargent Bay Limestone.	
10.	Interbedded calcareous shales and shaly limestones. Cleavage refraction is obvious (See Plate I, Fig. B). Approximately 70 beds were counted, with thicknesses ranging from 10 to 80cm. These units are considered as turbidites	75.84
11.	Covered section.	100.00
12.	Glenbrooke Formation. Calcareous siltstones interbedded with shales. Cross laminations were common. A brown dolomitic unit shows that units in this outcrop are intensely folded. Mullion structures are also common. See Pl. I, figures C & D.	65.00
13.	Covered section.	222.00
14.	Calcareous shale and siltstone beds with thicknesses up to 40cm.	7.9

15.	Covered section.	9.48
16.	Interbedded non-calcareous shale and siltstone units with calcareous siltstones and shales. Cross laminations are present in the siltstones. See Plate. I, Figure E.	95.59
17.	Covered section.	442.40
18.	A small outcrop of shaly limestone can be found in the Town of Austin (Bolton-Est) on the southeast corner of the intersection of Glenbrooke Road and the road to Abbey-St-Benoit-du-Lac.	

MACPHERSON BROOK SECTION

The section began on the west side of the bridge and was measured from east to west by tape and brunten compass towards MacPherson Bay. The brook also contains the type section for the Upper Calcareous Siltstone unit.

TRAVERSE NO.	DESCRIPTION	THICKNESS (m)	FOSSIL & SAMPLE #.
1, 2, 3, 4, and 5.	Upper Calcareous Siltstone. Well sheared and folded calcareous siltstone. Crinoidal debris (mostly ossicles) is ubiquitous. A tabulale coral (Favosites sp. G) and a colonial rugose coral (Entelophyllum sp.) were collected from a series of folded beds about 20m into the section. These folds are regarded as the centre of a small syncline. Several highly silicified alveolited corals were found forming nodules within the siltstone.	60	Favosites sp. G Sample Mc4 Entelophyllum sp. Sample Mc5 Alveolites sp. c Sample Mc12 Halysites catenularia McBL6
6, 7, and 8.	Sargent Bay Limestone. The first 5m consists of wackestone and crinoidal grainstone. Small discontinuous lenses (5 x 10m) of	16	Tryplasma sp. Mc25 Kirkidium sp. Mc25

	bioclastic debris (crinoids, digitate stromatoporoids, corals and brachiopods) were observed in the south side of the brook overlying a blue-grey crinoidal packstone bed. Most of the section is poorly exposed.		Stromatopora clarkei digitata Mc25, McB12 Ecclimadictyon Stylotum (no sample collected) Syringopora sp. Mc23 Clathrodictyon sp. Mc29
9.	Glenbrooke Formation. Nodular calcareous siltstone, shaly in sections.	25	Crinoids
9.	Covered section.	14	
10.	Calcareous siltstone, maybe nodular.	8	Crinoids
10.	Sargent Bay Limestone. Blue-grey crystalline packstone-wackestone.		Crinoids

11.	Upper Calcareous Siltstone. Alveolited corals (although no sample was collected) were observed.	5	*Alveolites* sp. Crinoids
12.	Largely covered section, but a calcareous siltstone is presumed.	15	Rare Crinoids
13.	Calcareous siltsone.	115	Rare Crinoids
14.	Covered section.	10m	
15.	Glenbrooke Formation. Slate member. Massive non-calcareous slate, mostly covered section towards MacPherson Bay.		End of section

QUINN CREEK SECTION

The section was started at the contact between the Ordovician basement and Silurian cover, approximately 455m, west of the road. A tape and brunten compass were used to measure the section from east to west. Note: Bedding was extremely difficult to identify, consequently only thicknesses of whole units are given unless otherwise stated.

TRAVERSE NO.	DESCRIPTION	THICKNESS (m)	FOSSIL & SAMPLE #.
1.	Glenbrooke Formation. Calcareous siltstone, nodular. Nodules are probably boudins of former beds.	15	Favosites (no samples collected) crinoids
2.	Sargent Bay Limestone. Blue-Grey shaly mudstone, and packstone.	10	bioclastic and crinoidal debris
3.	Upper Calcareous Siltstone. Calcareous siltstone interbedded with blue-grey skeletal grainstone-packstone. The grainstone-packstone beds are often segmented forming boudins. These grainstones and packstones are interpreted as allodapic units. Numerous, randomly oriented corallums of Heliolites sp. cf. H. lavieillenses were found in	24	Halysites sp. (no sample collected) Heliolites sp. QB2, QB3 Syringopora sp. A QC2 Kirkidium sp. see P. V, Fig. J.

	this section. Extraction was impossible for most and would need a power saw. Specimen of the brachiopod *Kirkidium* was found in several of the limestone boudins.		
4.	Sargent Bay Limestone. As in Traverse number 2.	8	
5.	Glenbrooke Formation. Calcareous siltstone and shale partings, beds up to 1m thick.	30	
6.	Slate. Massive non calcareous to weakly calcareous slate and siltstone.	15	
7.	Massive, Non-fossiliferous, calcareous siltstone.	45	
8.	Thinly bedded calcareous siltstone. Small, irregular, brown fragments may infact be highly deformed corals. Crinoids are common.	15	Crinoidal debris *Favosites* sp. (no sample collected)
9.	Sargent Bay Limestone. As in traverse number 2.	6	Crinoids

10.	Upper Calcaerous Siltstone. Calcareous siltstone with crinoidal debris, and corals.	33	Syringopora sp. (could not be extracted) and crinoids
11.	Sargent Bay Limestone. Blue-grey lime mudstone. Mudstone laminated, with the laminations persisting in lime-green nodules. The unit is shaly with shale partings separating the lime mudstone beds.	13	No fossils
12.	Sargent Bay Limestone. Largely folded rythmically bedded lime mudstone. There are a great number of small favositid corals within the nose of the folds. Upper units contain fragments of the stromatoporoid Ecclimadictyon stylotum in a lime mudstone giving the rock a bioturbated appearance.	75	Favosites sp. F cf. F. gothlandicus QC7, QB6 Ecclimadictyon Stylotum QC 9
13,	Upper calcareous siltstone. Boudins of a skeletal packstone separated by calcareous siltstone. Rock is well sheared		Sample QB9

APPENDIX B

KIRKIDIUM RUDSTONE, SAINT-ADOLPHE-DE-DUDSWELL

Pentameran brachiopods commonly found in growth position, that is with articulated shells in vertical position, umboes down, provide excellent opportunities for studies in population dynamics, ecological succession and replacement (Johnson, 1977; and Zeigler et. al., 1966). Can largely disarticulated and fragmented pentameran shells provide useful information to the above mentioned studies? Although the Kirkidium rudstone represents a coquina, conclusions can still be made regarding (1) population maturity, and (2) paleoecology. However, such conclusions can be made only after the effects of post mortem transport and deposition are taken into account.

Materials and Occurrence

The rudstone bed is located 2.5 km due north of Saint-Adolphe-De-Dudswell within a small drainage ditch. This locality was first discovered by Petryk (1986). The bed is approximately 1.4 m thick, dips at 73 degrees to the south, and is comprised of several layers of brachiopod coquina separated by a few centimeters of buff coloured calcareous siltstone. The enclosing sediment within each layer is largely made up of fine silt carbonate and minor silica. Common amongst the shells, are fragments of Favosites sp. and Heliolites cf. H. lavieillenses. The non-articulated shells are not considered to be now in growth position and the orientation of the shells is random. The majority of valves are pedicle valves. No valve was found completely intact. The line of breakage commonly occurs anterior of the median septa and spondylium. Due to metamorphism, in which the rock has taken on a schist-like appearance, complete extraction of specimens was impossible.

Thin beds of crinoidal packstone alternating with calcareous siltstone underlie the rudstone unit. Fossils include crinoids and corals (mostly Heliolites sp. cf. H. lavieillenses, and few unidentifiable stromatoporoids. The overlying limestone is coarse grained and contains such fossils as crinoids, brachiopods (Kirkidium sp.), corals, including both tabulate and rugose, and few stromatoporoids. The contacts between the overlying and underlying units are abrupt.

Method of study

A line was drawn across the thickness of the bed. Brachiopods were then counted and measured within a 20 cm strip on either side of the line. The parameters measured are shown in Figure A. The length and width of the median septa were considered to be the only viable measurements as the width of the shell depends on where the outcrop surface cut it. The orientation of the septa (Fig. A) was noted as either facing out of the bed or into the bed. The median septum parallels the long axis of the shell. A block sample was taken back to the lab for sectioning (Pl. IX, figs. K-L).

Results

The bed can be divided into three zones on the basis of septal orientation (Fig. B). The basal zone, 20cm thick consists of closely packed pedicle valves. Eighty five percent of the valves have their median septa lying parallel to the exposed surface of the bed. The top zone, of similar thickness, shows approximately 79% of the valves with their median septa pointed into the bed. In the middle zone the two orientations are about evenly mixed. The exact angle that each valve made with respect to the sectional plane through the bed could not be measured.

Because the brachiopod valves are fragmented and disarticulated the only reliable anatomical measurements that could be used for estimating population maturity were the length and width of the median septa. A univariate growth plot of length versus width (Fig. C), the coefficient of convexity (defined here as 1/g, Fig. D), and size frequency analysis (Fig. DI) of the median septa show a normal distribution with little variation for the entire sampled section. Size frequency analyses of individual layers, A through D (Fig. DII to DIV), show a slight increase in individual sizes across the measured section. All distributions are essentially skewed to the left, suggesting a collection (almost exclusively) dominated by valves of adult dimensions. Numerous fossils observed in sections taken from the block sample showed indentations and slight distortion of structure (Pl. IX, Fig. L).

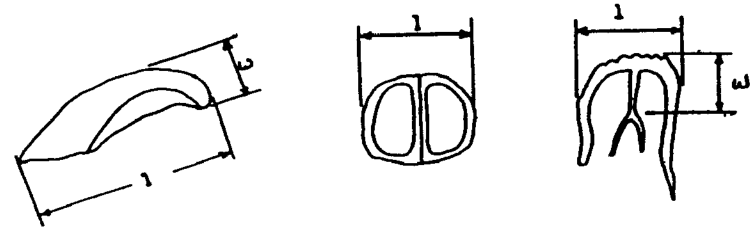
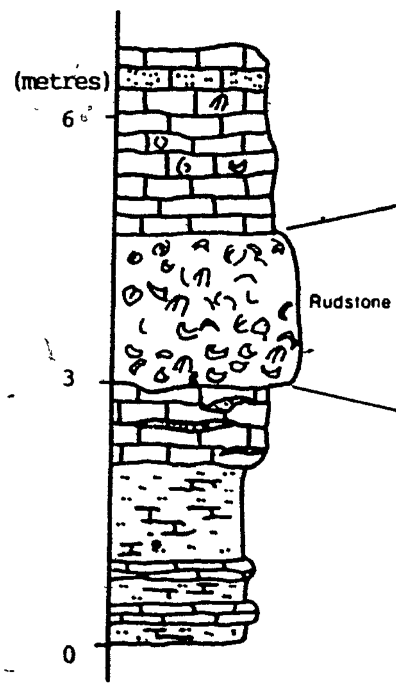


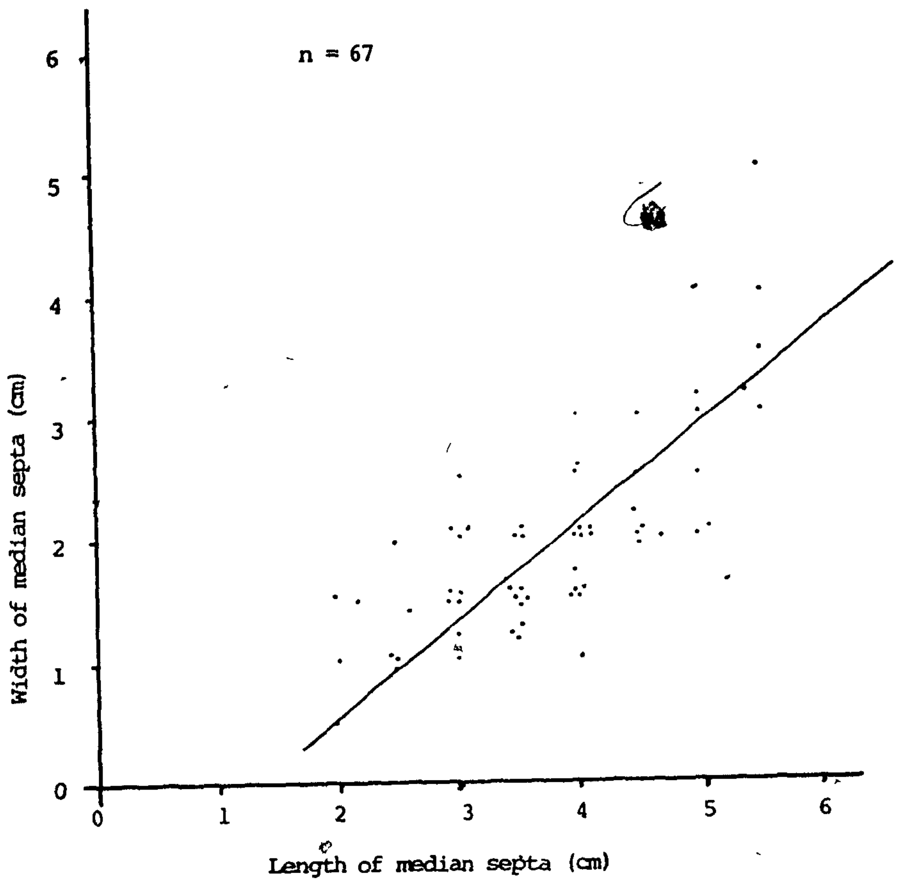
Figure A.



(mm)		Septa parallel to face of bed		Septa orthogonal to face of bed	
140–120	D	21%	n=5	79%	n=19
120–70	C	53%	n=24	47%	n=21
70–20	B	58%	n=15	42%	n=11
20–0	A	85%	n=23	15%	n=4

$C = \frac{l}{w}$	N	ZONE
0.62	5	Top D
0.49	24	Middle C & B
0.52	15	Middle C & B
0.53	23	Basal A

Figure B.



n = 67
Width of median septa (cm)
Length of median septa (cm)
0
1
2
3
4
5
6

Figure C.

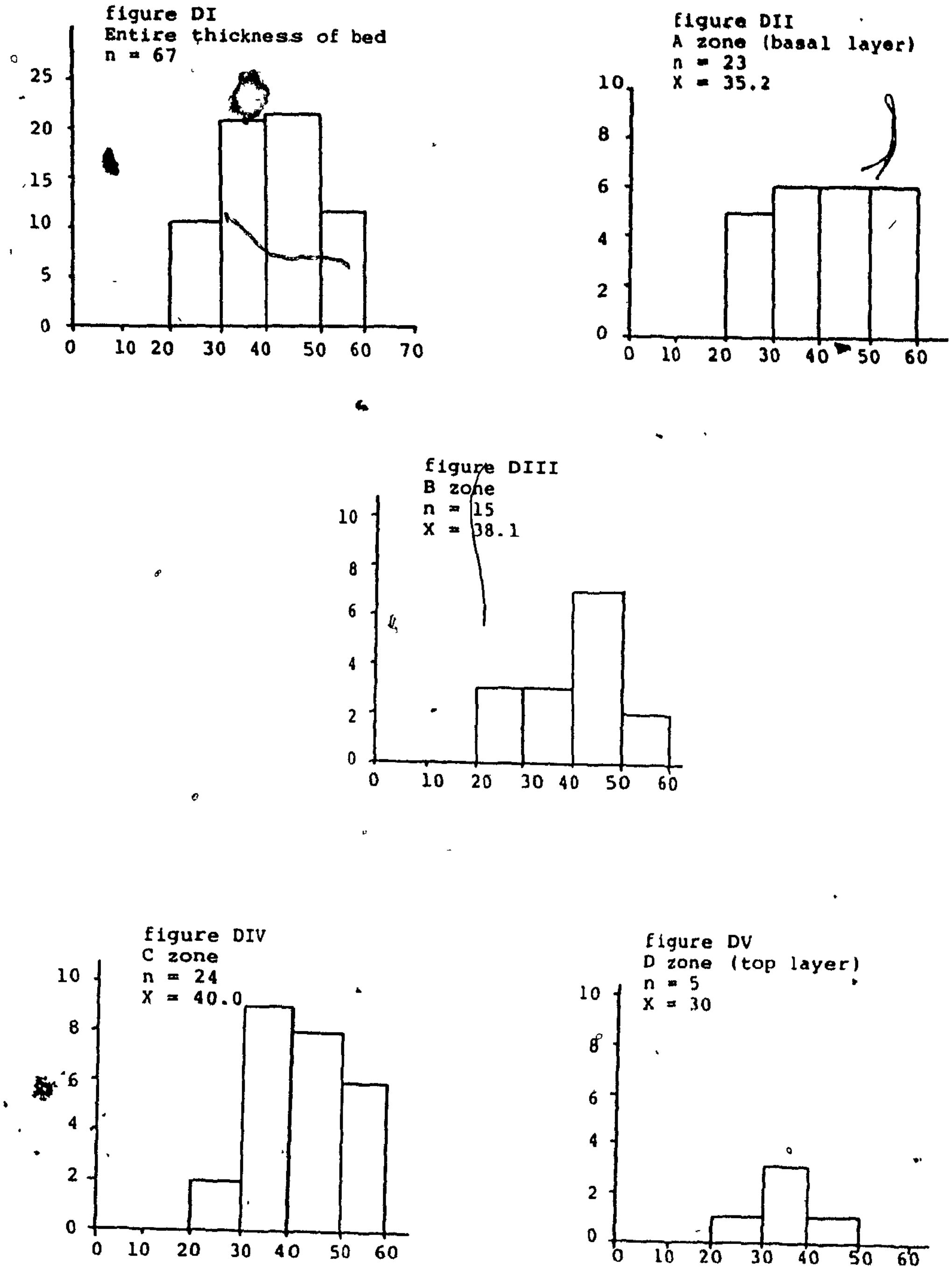


Figure D: Frequency analyses of median septa length over the entire length of the bed (figure DI) and for each layer within the bed (figures DII - V). Vertical axis is number of individuals, and the horizontal axis is the length of the median septa in mm.

Discussion

The original growth environment of Kirkidium sp. found within the drainage ditch is interpreted as similar to the rough water environment described in Boucot and Johnson (1979). These authors conclude that pentameran brachiopods, are indicative of a limited, roughwater, photic zone, warm water environment. More specifically, Boucot and Johnson (1979) contend: (1) various species of pentamerans aggregate into low diversity, single species communities; (2) the shells commonly show indentations indicating growth under crowded conditions within sand size sediment; (3) multiple layers of commonly disarticulated valves are interpreted as indicative of growth under relatively rough water conditions ; and (4) well oxygenated, photic zone and warm conditions are indicated by the lack of pyrite, high free carbon, and undisturbed laminae.

Based on the evidence presented above, the layers can be interpreted as deposits proximal to the area of growth. These deposits were certainly subjected to storm generated, turbulent action, and quite possibly wave generated turbulence as well. The layers are non-graded, composed of adult sized Kirkidium sp. brachiopods, and fragments of fossil coralla are not uncommon. The size frequency analyses, taken at face value, ~~suggests~~ a very low infant mortality for Kirkidium sp. This interpretation, however, is not totally valid as these shells have undergone post mortem transport.

There are several models that could explain this strong bias towards larger shell sizes. The first model involves proximal deposition of storm derived shells that produced a layer dominated by larger shell sizes. Proximal tempestites have been described by Westrop (1986), and Aigner (1982) as thickly bedded, coarse-grained and non-graded deposits. In the tempestite model, growth of Kirkidium sp. would have occurred under both normal and storm generated wave action. The observed alignment of the shells long axes is presumed to have resulted from storm agitation during which time the shells were removed from their place of growth and deposited down slope. The direction of storm wave action must have varied in order to produce the difference in alignment observed between the top and basal layers. It is unlikely that the coquina observed in the drainage ditch had consisted of only of brachiopods of adult dimensions. It seems highly probable that the complete absence of juvenile forms can be explained by fragmentation of thinner and therefore weaker shells of juveniles that may have been deposited with the mature forms.

A second and less likely model is that in which the coquina was developed within place of growth. The Kirkidium community grew to maturity and was terminated. The shells were then subject to size sorting through wave action and storm generated turbulence. Because the smaller and more juvenile shells were weaker they were more likely to be fragmented and winnowed away. The next layer would then represent a repopulation of the pentameran community and a repetition of the cycle similar to that proposed in Johnson (1977, Fig. 7). Almost all documented examples of pentamerans (where infant mortality was low) it was found that a suitable pavement or firm substrata had preceded the development of the pentameran community. The calcareous siltstones and crinoidal packstones underlying the basal layer of this bed is presumed to have been inadequate, unless they were partially lithified. Analysis of this sediment could not confirm this. Boucot and Johnson (1979) do suggest examples, although less common, in which pentamerans were presumed to have grown in a single, crowded layer within a micritic or silty matrix. Richards and Bambach (1975) report that under such conditions the competition for space would have resulted in increased infant mortality by crowding out of some individuals during growth. Furthermore, any turbidity action would have resulted in (1) the resuspension of unconsolidated sediment thereby clogging juvenile lophophores, and (2) in the burial of some brachiopods. Under these conditions one would expect to find a lower degree of fragmentation, and a greater abundance of articulated and disarticulated infant shells. Neither were observed in the field.

Deposition of the Kirkidium coquina through mass flow is a third and least likely model. An essentially random orientation (except for the basal and top layers) of large disarticulated brachiopods in a fine silt matrix could be the result of deposition in the proximal portion of a mass or debris flow. Debris flows are typically described as massive, poorly sorted with clasts floating within a mud or grain supported matrix (Mullins, 1983; and Cook, 1983). The clasts may exhibit a random fabric throughout the unit or be oriented subparallel. Inverse grading may be present. The clasts (in this case fossil brachiopods) within this particular deposit are not matrix supported and are essentially well sorted. The clasts do show a random fabric and a slight increase in size up the section, that may be interpreted as inverse grading. The individual layers within this bed, in contrast, do not exhibit grading. The debris flow model is therefore an unsatisfactory explanation for this rudstone.

Conclusions

(1) Evidence for ecologic succession is non-existent.

(2) The brachiopod community represented in each layer is concluded to have had low infant and high adult mortality, within a high energy environment under low sedimentation rates.

(3) Direction of dominant wave action varied from the basal to top layers.

(4) The deposit probably represents several layers of storm generated, proximal tempestites. Other alternatives have been proposed but they are considered as less likely.

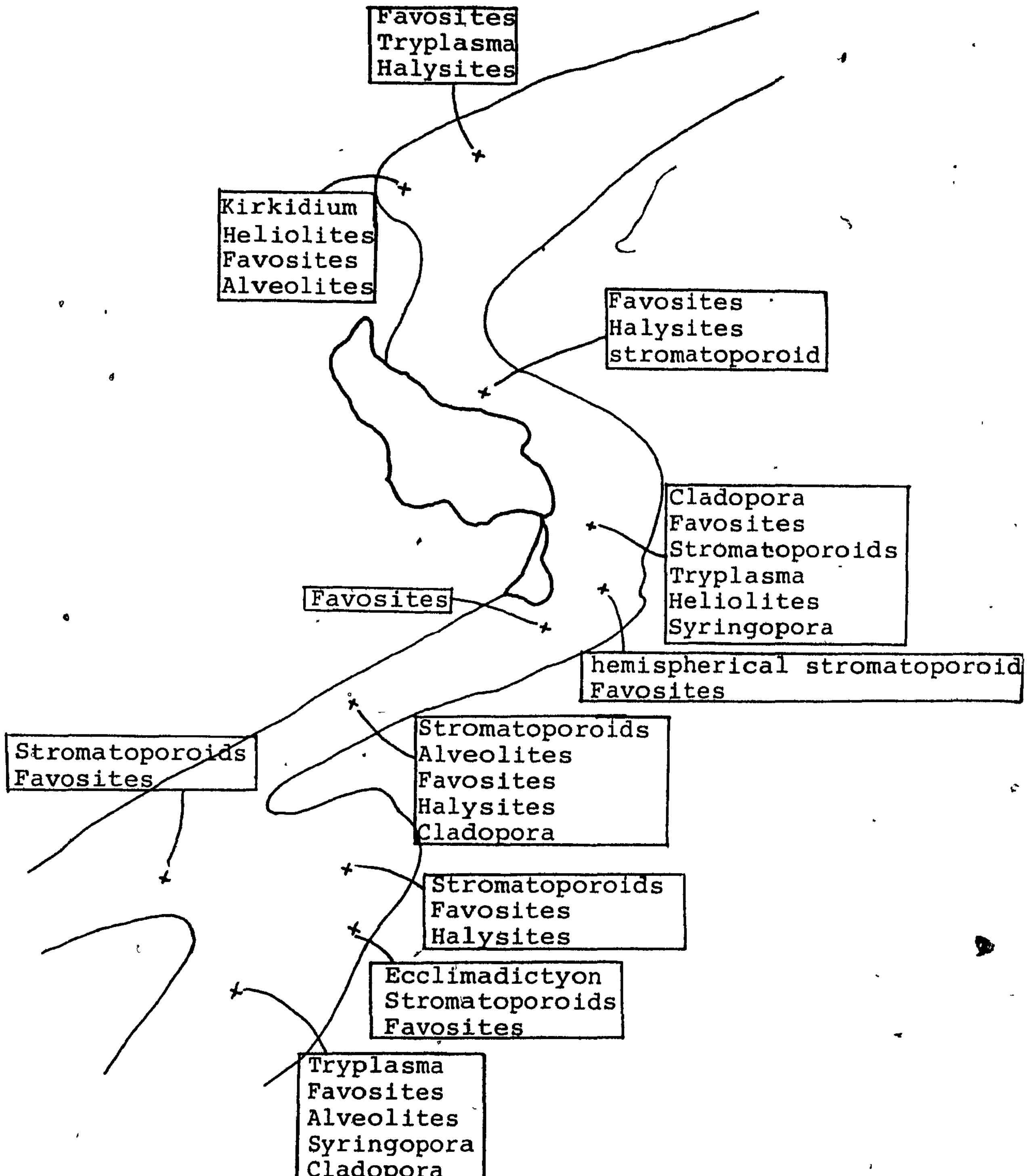
(5) Most juvenile brachiopods were transported post mortem by storm agitated waters away from this site, more distal positions, and those that were left behind were subjected to

a high degree of fragmentation because their shells were weaker.

(6) The environment in which these brachiopods were deposited is concluded to have been on the foreslope, proximal to the source.

APPENDEX C

Fossils and their localities in the Lime Ridge and Marbleton area.



Scale as in Figure 14

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Plate I

Glenbrooke Road Section

(A) Laminated calcareous siltstones and shaly limestones of the Sargent Bay Limestone. Arrows indicate displacement of strata. Left side is east.

(B) Interbedded calcareous shales and shaly limestones, Sargent Bay Formation. Note cleavage refraction. Right side is east.

(C) Glenbrooke Formation showing structure. Right side is east.

(D) Mullion structures in Glenbrooke Formation. Right side is east.

(E) Interbedded calcareous siltstones and shales Glenbrooke Formation. Right side is east. Beds dip to the west, cleavage to the east.

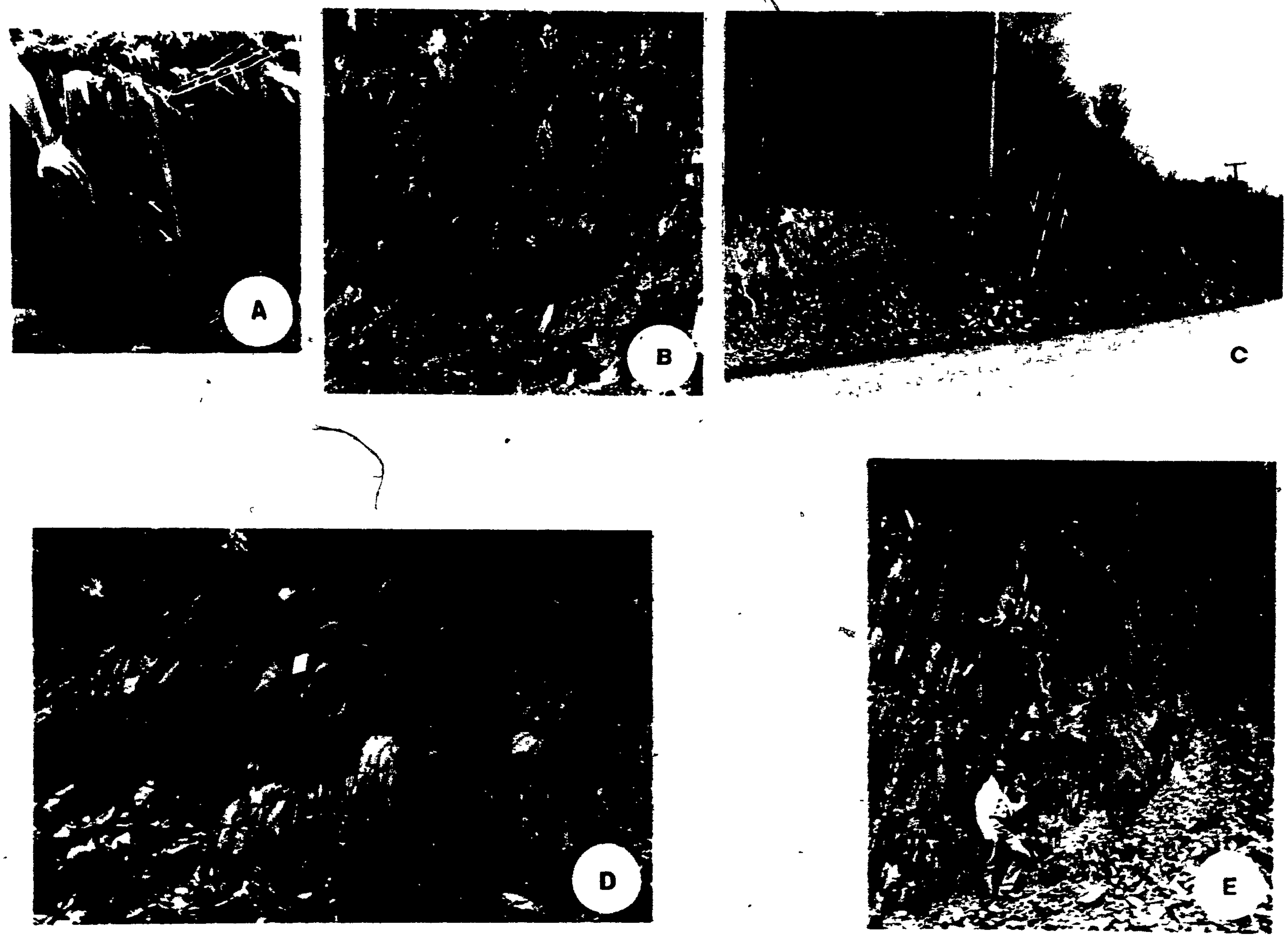
A
B
C
D
E

Plate II

Glenbrooke Creek Section
Sargent Bay Limestone, Lithofacies I

(A) Pseudonodule of laminated dolomitic siltstone in mudstone, Sargent Bay Limestone (scale in mm). Sample GCS #3.

(B) Graded grainstone-packstone overlying mudstone. Allodapic units, Sargent Bay Limestone (scale in mm). Sample GC1-15B.

(C) Enlargement of (B) showing rounded quartz grains, brachiopod and crinoid fragments (30x) GC1-15B.

(D) Cross laminated calcareous siltstone in mudstone, turbidite section, Sargent Bay Limestone. Sample SBI/26/86.

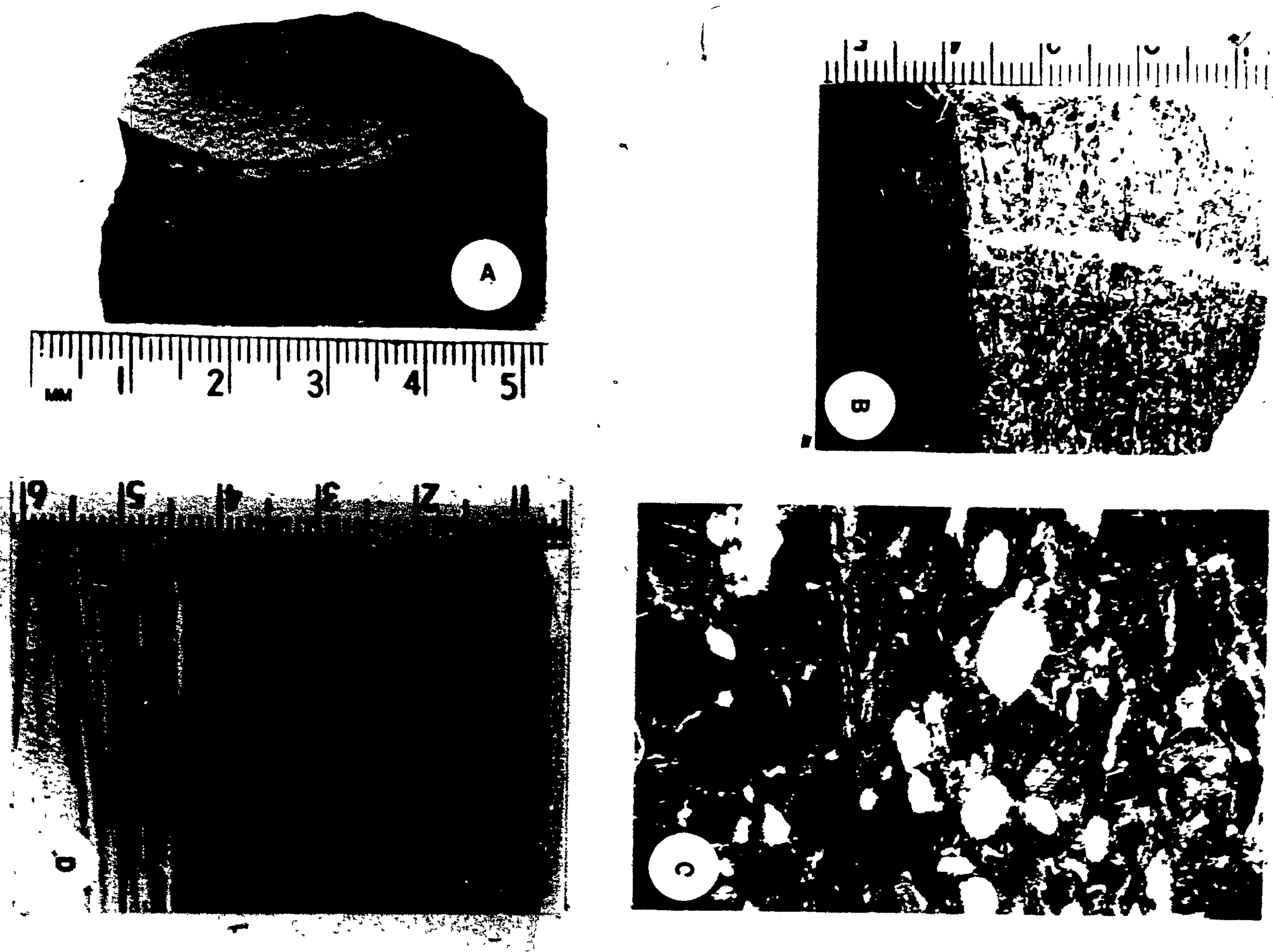
A
MM 1 2 3 4 5
B
C
D

Plate III

Sargent Bay Limestone

(E) Packstone-grainstone; lithofacies IV; MacPherson Brook. (1x). Sample MC25.

(F) Grainstone; lithofacies II; crinoids, quartz grains and brachiopod shell fragments. (1.5x). Sample GV1.

(G) Packstone, lithofacies III. Sample QB9.

(H) Enlargement of well rounded quartz grain with silica overgrowth. (60x). Sample GV1.

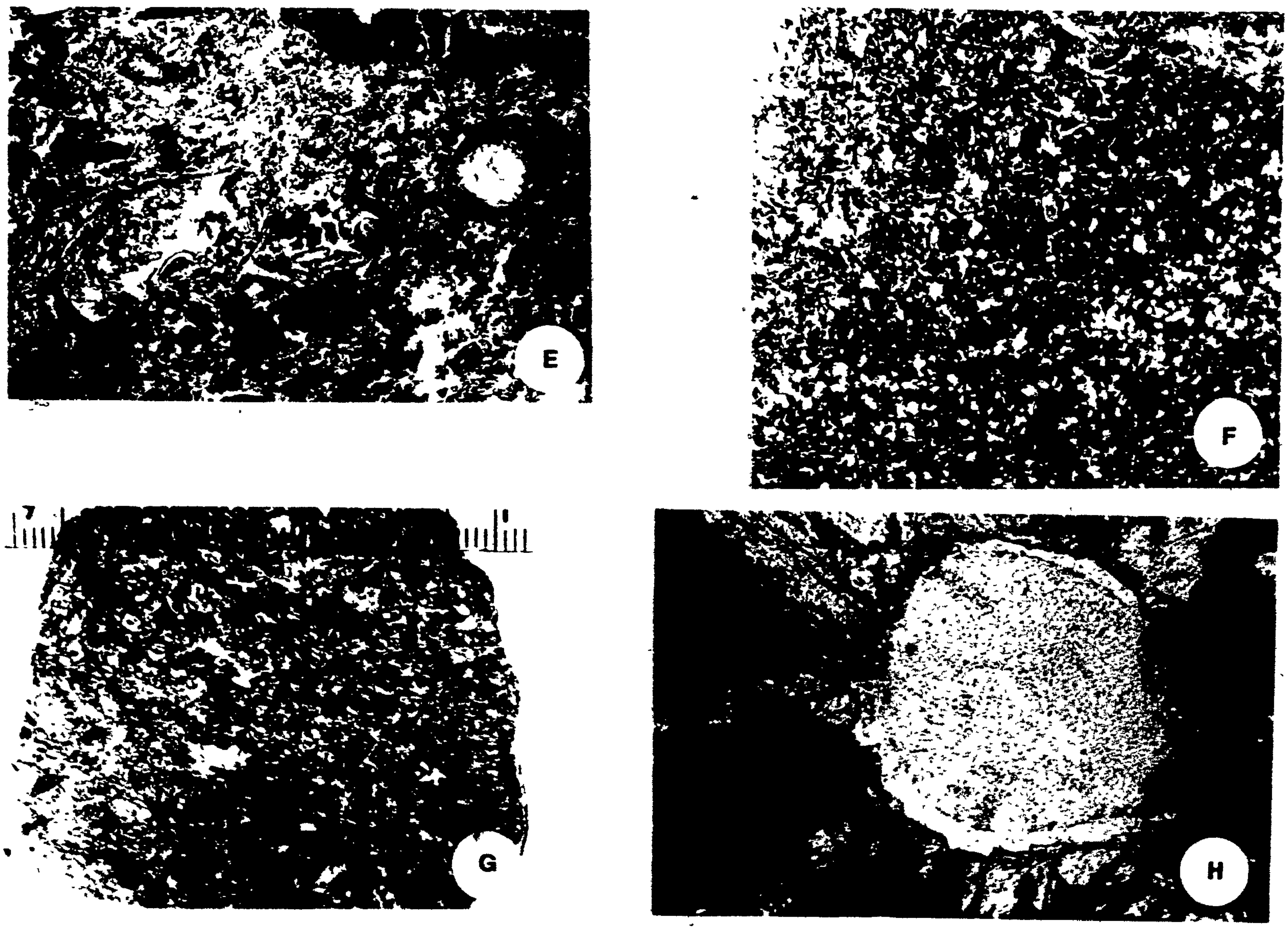
E
F
G
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Plate IV

Upper Calcareous Siltstone

(A-D) Interbedded dolomitic siltstone and blue-grey non-graded packstone. The packstones form pinch and swell structures. Outcrop located on Swartz Farm on Chemin du Lac.

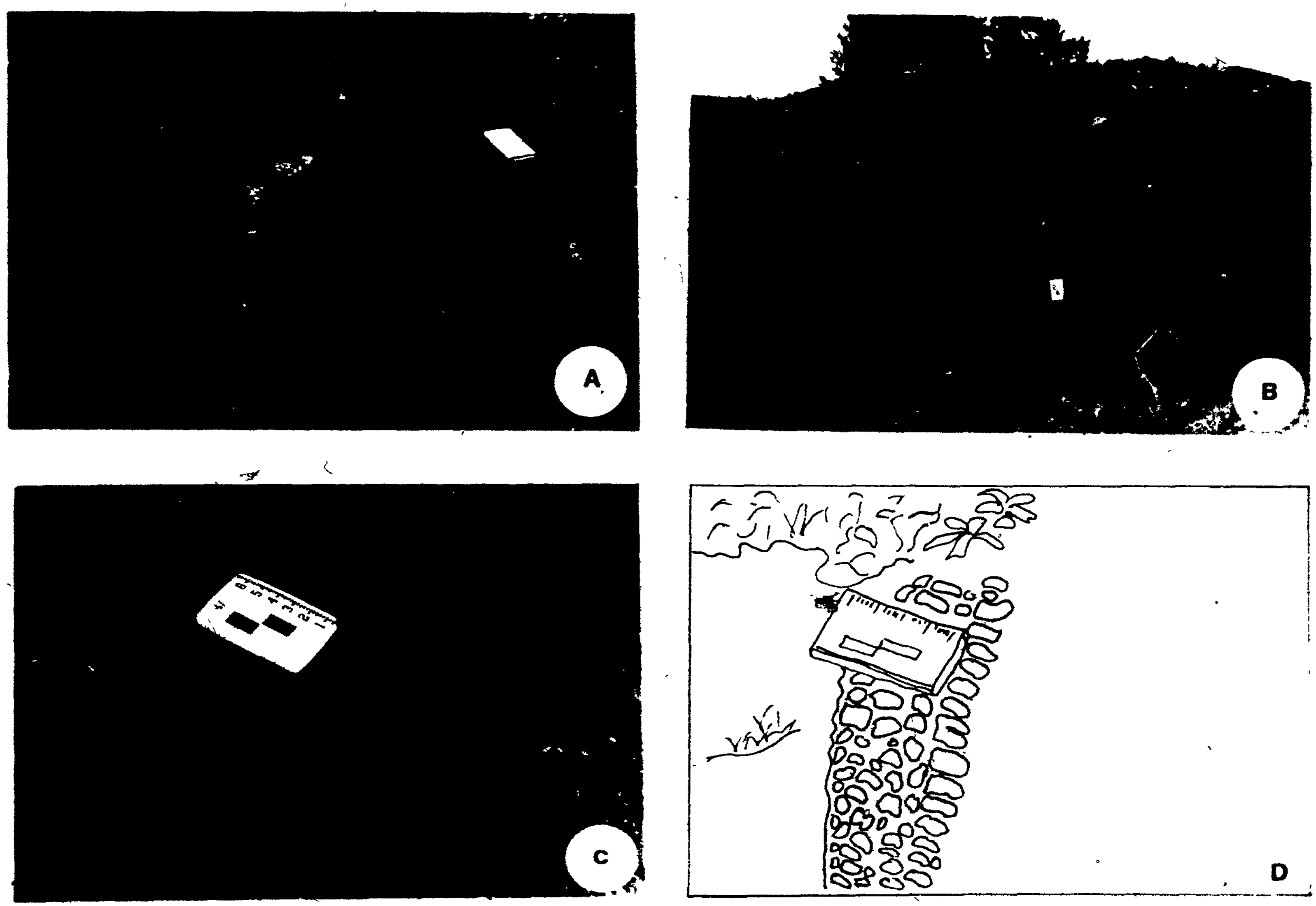

A
B
C
D

Plate V

(I) *Favosites* sp. F taken from Swartz Farm, Upper Calcareous Siltstone.

(J) Nodule of blue-grey packstone taken from Upper Calcareous Siltstone. K=Kirkidium.

(K) Floatstone. Favositid corals within a dolomitic siltstone matrix. Lithofacies III, Main limestone unit, Lake Aylmer Formation. (1.5x). Sample CEM1.

(L) Nodular calcareous siltstone, Lithofacies VIII, Upper calcareous siltstone, MacPherson Bay. Packstone nodules and *Cladopora* in dolomitic siltstone.

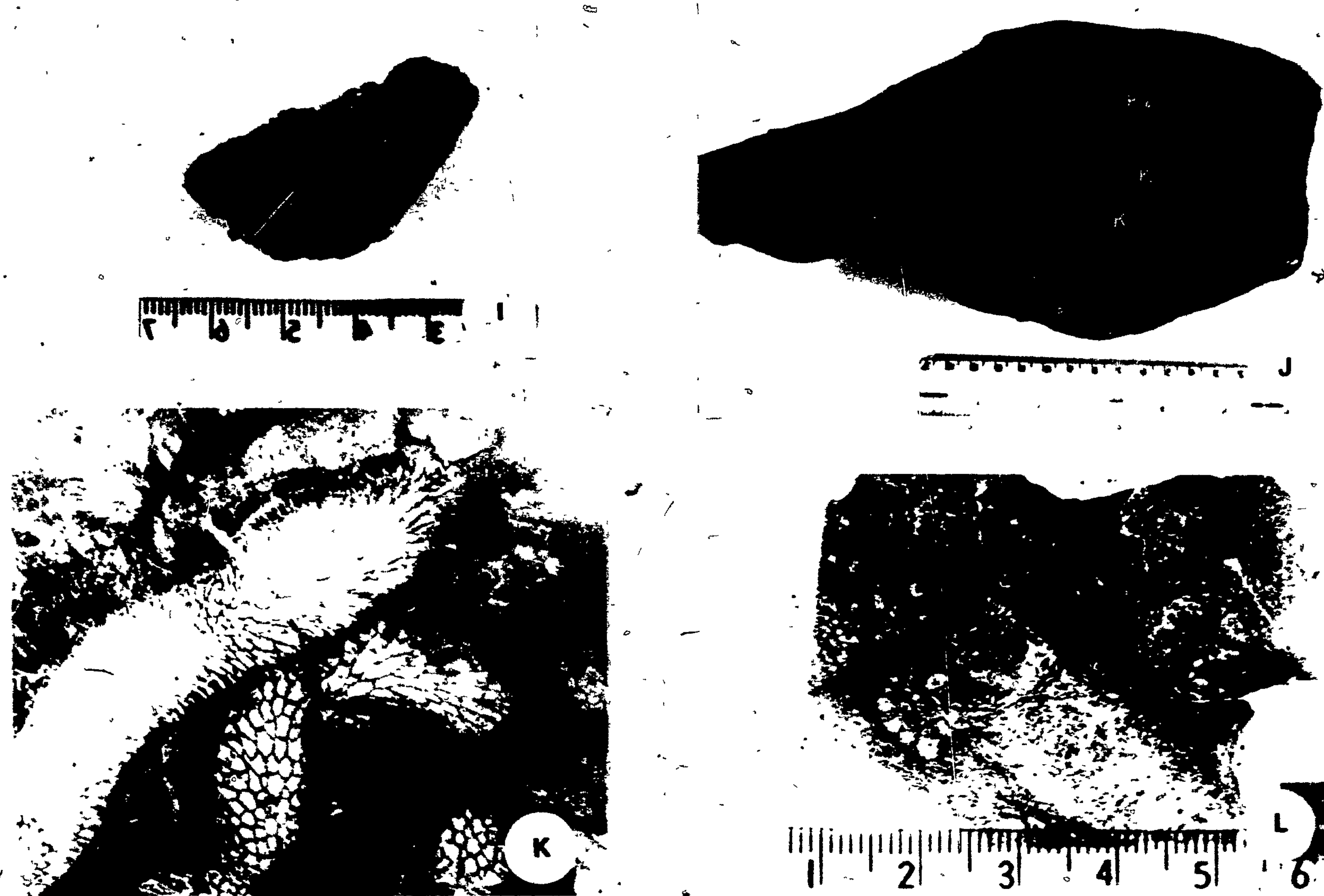

J
K
L
1 2 3 4 5 6

Plate VI

Main Limestone Unit

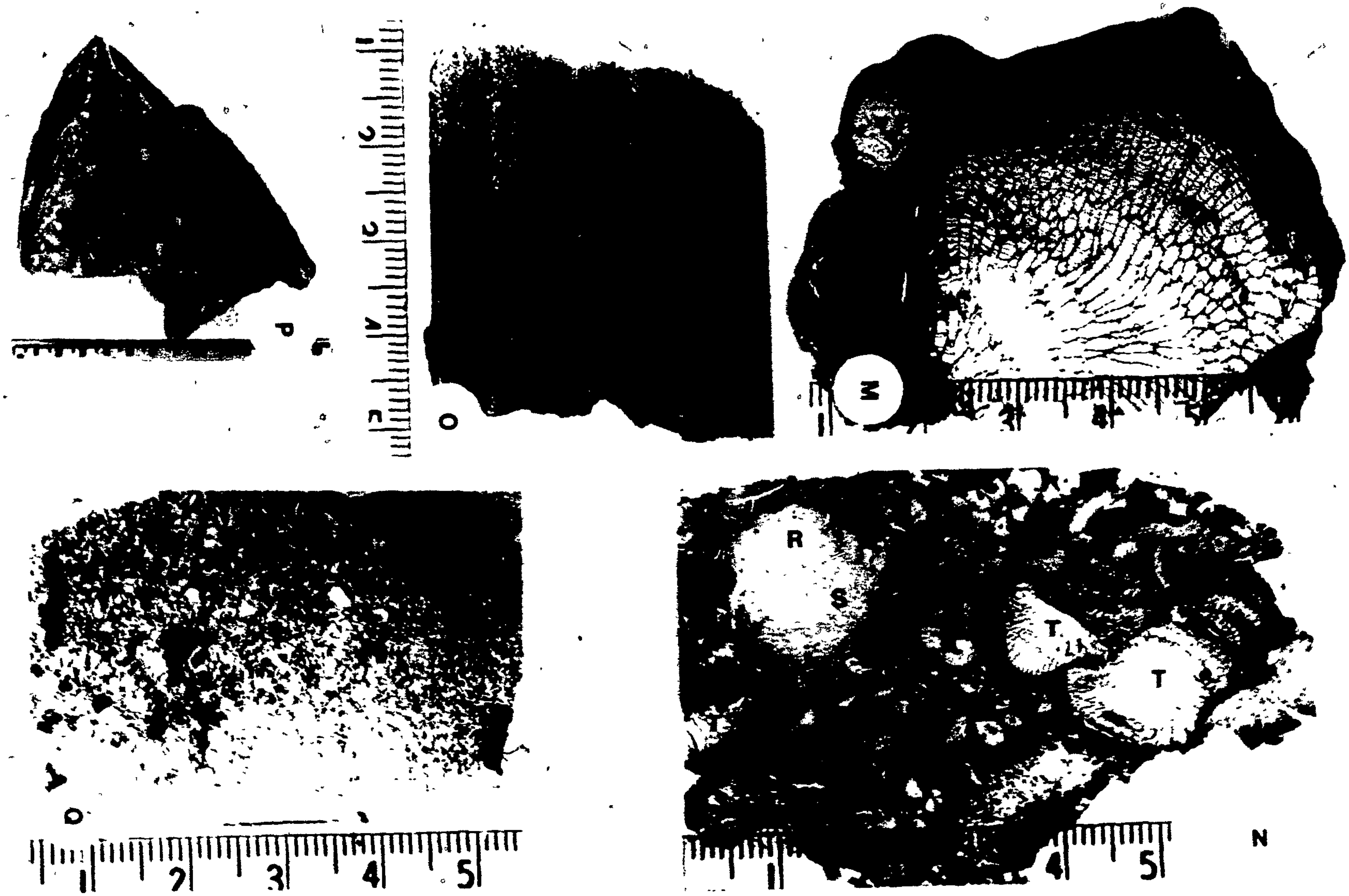
(M) Lithofacies III, Favosites sp. C, Tryplasma sp., Heliolites sp., Cladopora sp. and crinoid ossicles in dolomitic siltstone. Domlim #5 quarry.

(N) Lithofacies III, Tryplasma sp., stromatoporoid and Cladopora sp. and crinoid fragments in dolomitic siltstone. Domlim #3 quarry.

(O) Lithofacies III, graded calcarenite. Domlim #3 quarry.

(P) Lithofacies III, cross laminated calcarenite. Domlim #3 quarry.

(Q) Lithofacies III, graded calcarenite, note rip up clasts.



P
O
M
Q
R
S
T
T
N

Plate VII

Main Limestone Unit

(A-C) Lithofacies III. Allochthonous block of graded and cross laminated calcarenite in a floatstone. Domlim #3 quarry.

(D) Lithofacies III. Boundstone block. Cemetary in St-Adolphe-de-Dudswell.

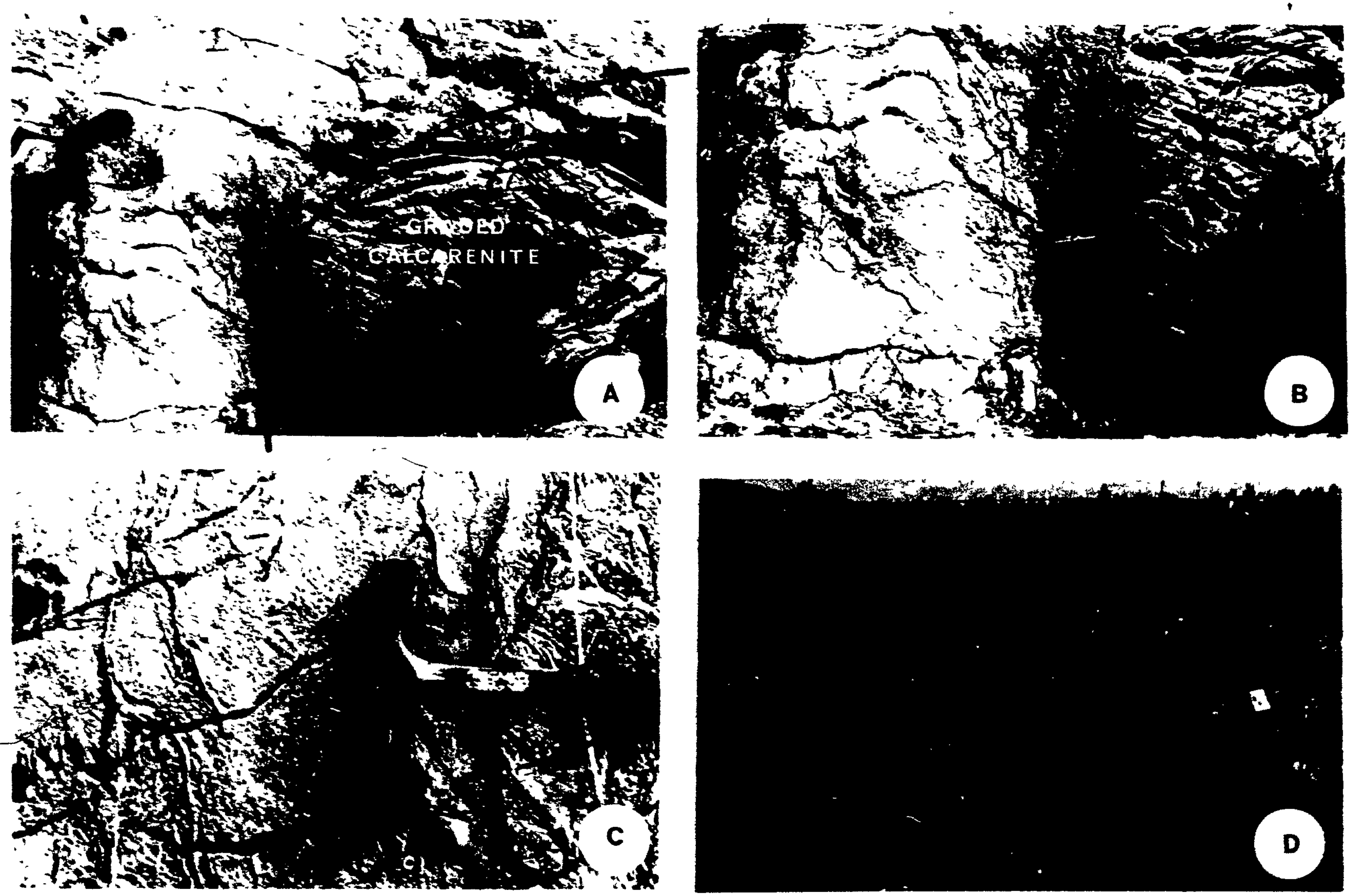

GRADED
CALCARENITE
A
B
C
D

Plate VIII

Main Limestone Unit

(E-F) Boundstone block at cemetary showing stromatoporoids and corals. (Scale same for both)

(G) Brachiopod Rudstone unit, lithofacies II.

(H) Heliolitid and alveolitid corals at base of rudstone, in lithofacies II. (scale not recorded)

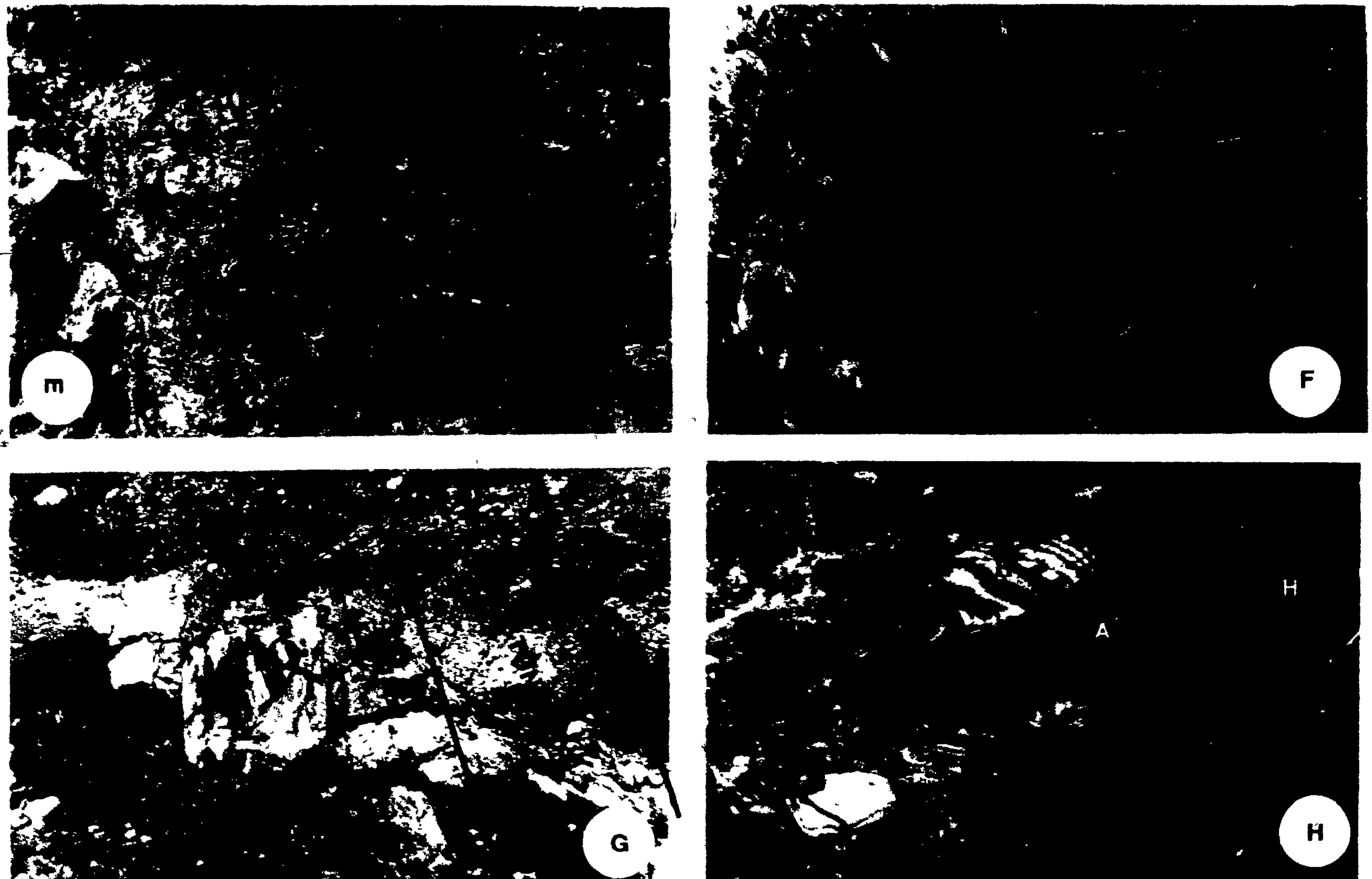

F
H
A
G
H

Plate IX

Main Limestone Unit

(I-L) Brachiopod rudstone, lithofacies II. A = Alveolites sp. The brachiopod prominent in figures J, K and L is Kirkidium.

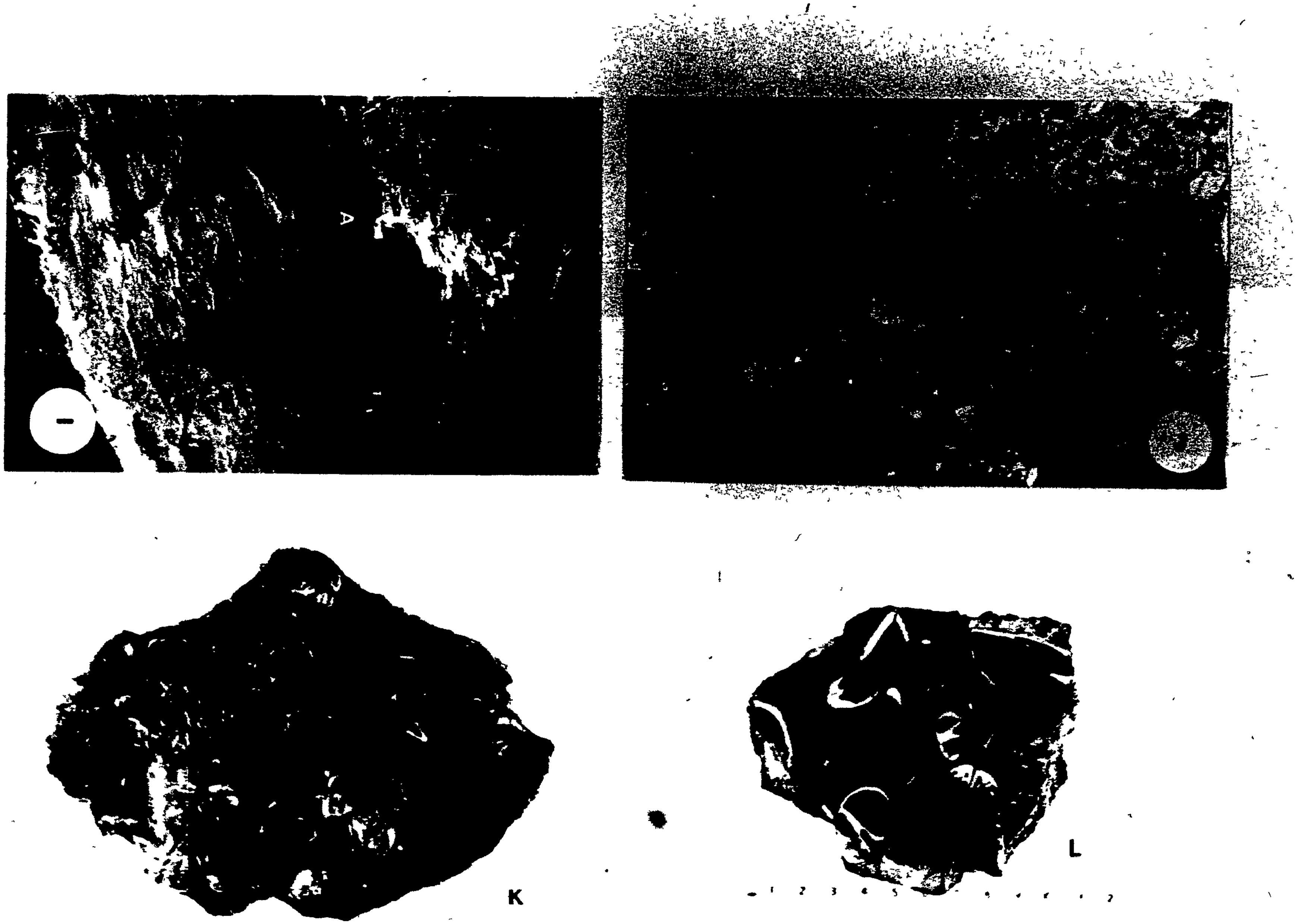

I
A
K
L

Plate X

(A-B) *Favosites* sp. A; MBS - 1A,B; tangential and sectional views. Main limestone unit. (10x).

(C-D) *Favosites* sp. B; Dom 23, A,B; tangential and sectional views. Main limestone unit. (10x).

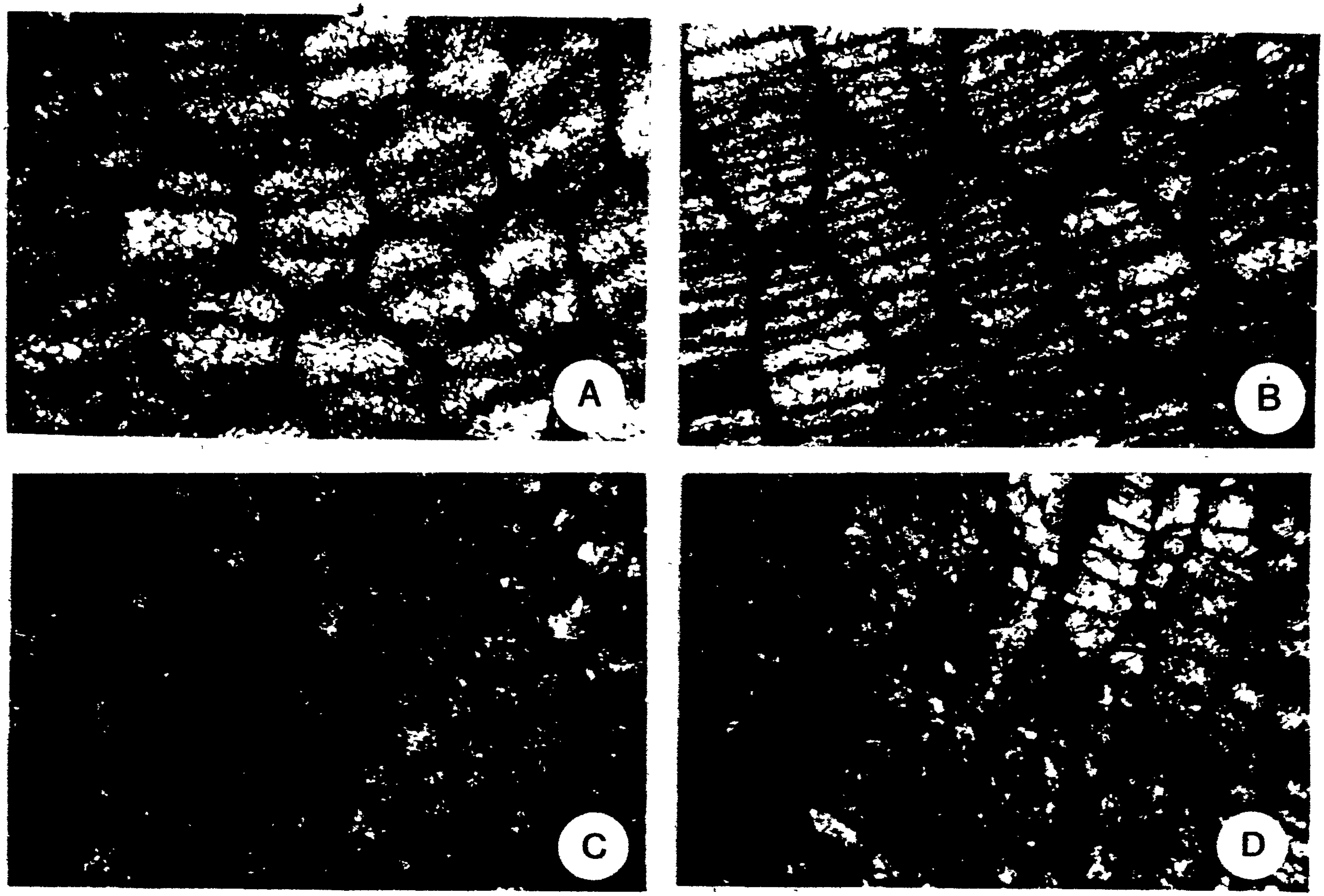

A
B
C
D

Plate XI

(A) *Favosites* sp. C; DQ1A; sectional view. Main limestone unit. (1.5x).

(B-D) *Favosites* sp. E; (B) McB2B (10x) (C) McBH3 (10x) (D) MBH1 (10x). MacPherson Bay.

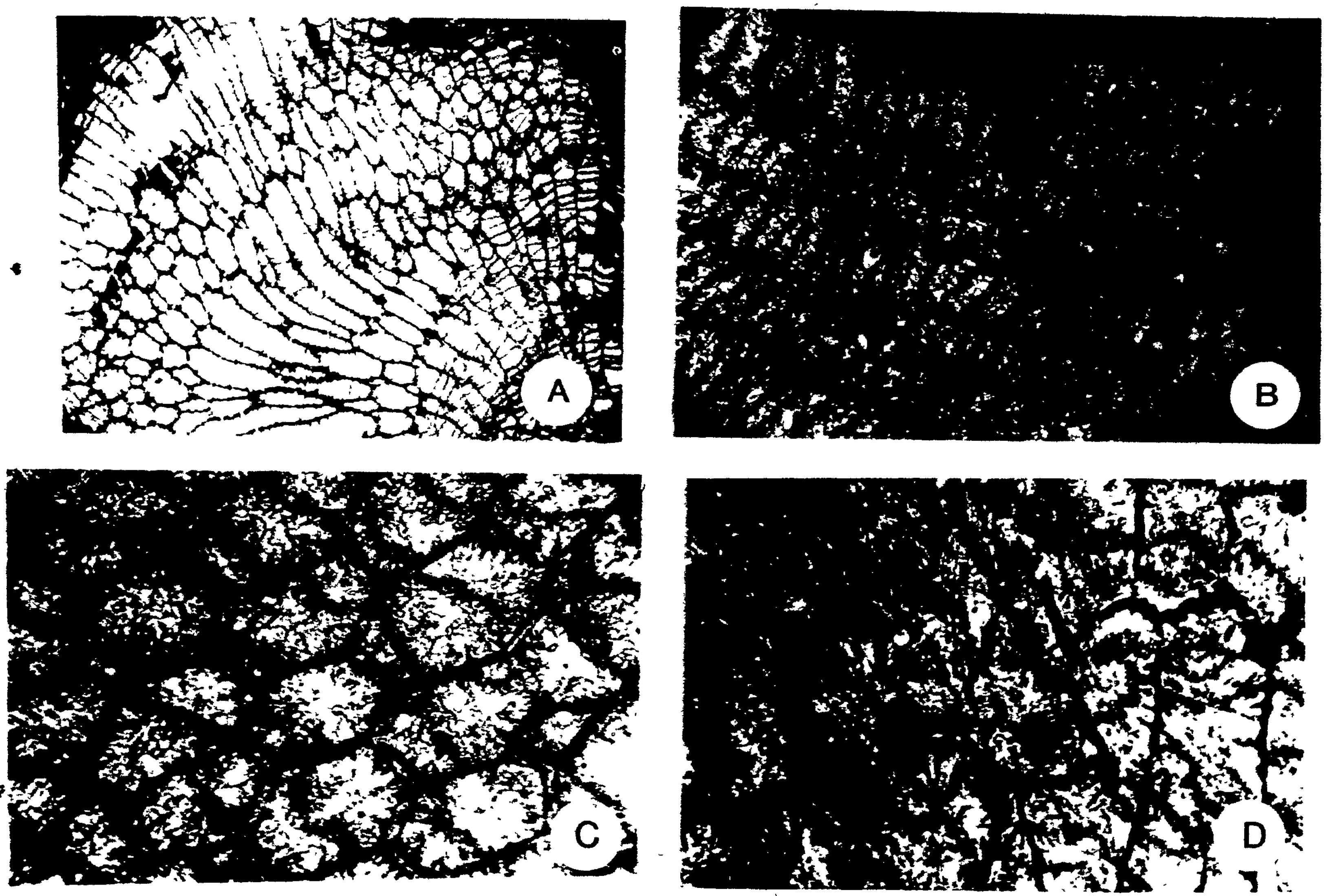

A
B
C
D

Plate XII

(A-B) *Favosites* sp. E; CMR4A (10x), MBH4 (25x); sectional views. Main limestone unit and Upper Calcareous siltstone, MacPherson Bay, respectively.

(C-D) *Favosites* sp. F cf. *F. gothlandicus*; MCB1A, B; tangential and sectional view. MacPherson Brook, Upper Calcareous Siltstone. (25x).

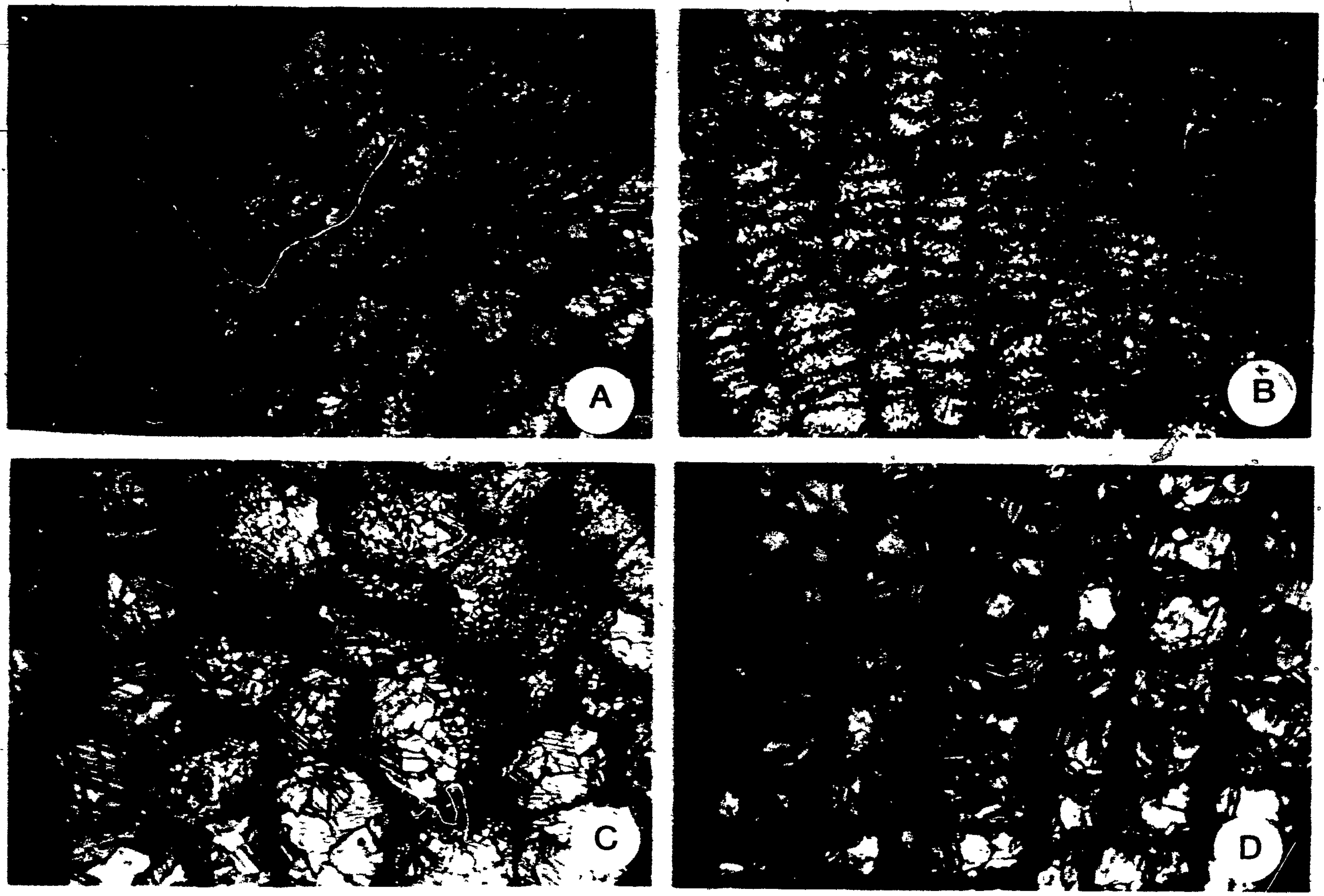

A
B
C
D

Plate XIII

(A-D) <u>Favosites</u> sp. F cf. <u>F.</u> <u>gothlandicus</u>; QC7, QB6B, QB6A (10x), Upper Sargent Bay Limestone; and CCEMA (scale in mm), Main Limestone unit.

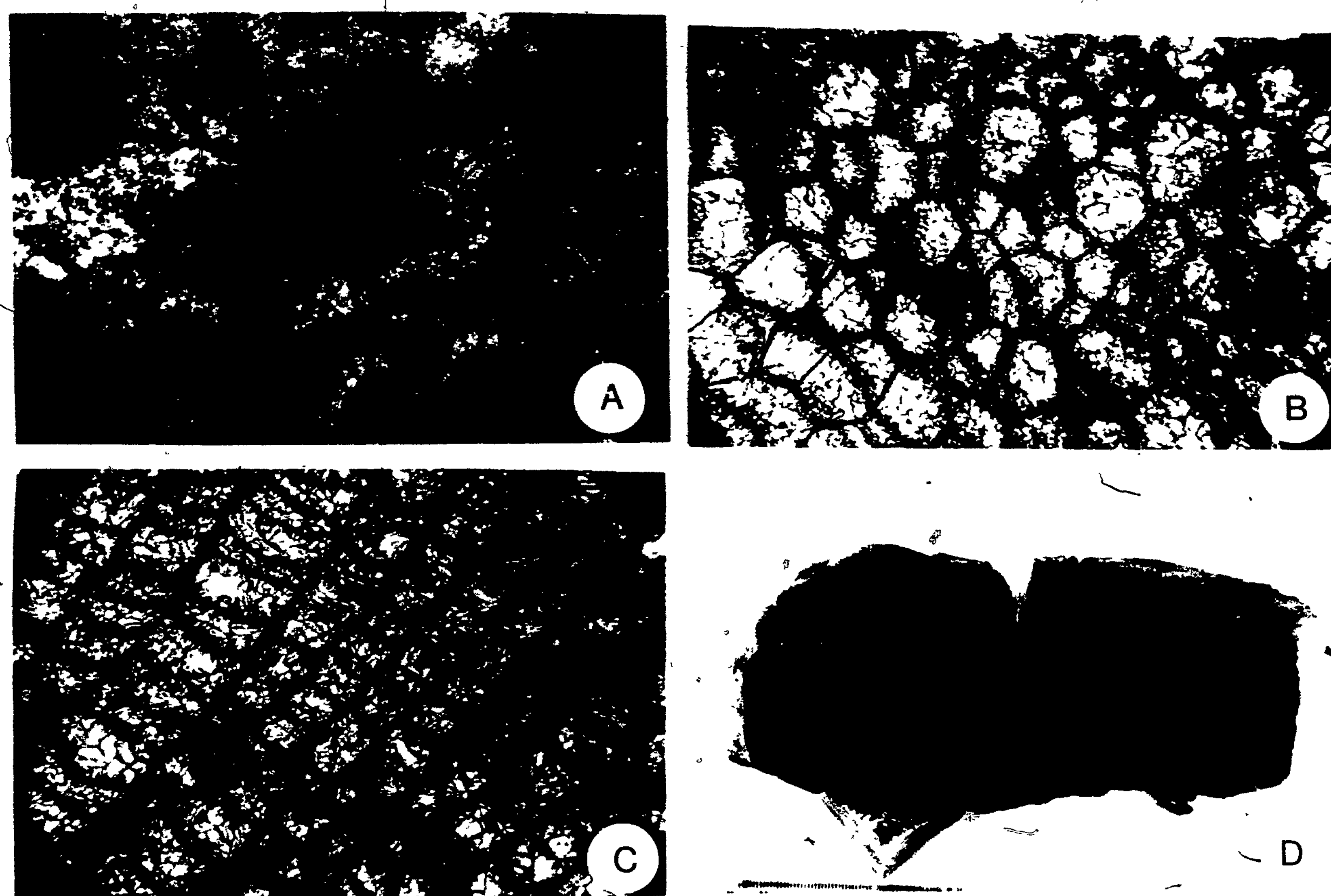

A
B
C
D

Plate XIV

(A-B) *Favosites* sp. G; MC 4A,B; tangential and sectional views. Upper Calcareous siltstone, MacPherson Brook. (10x).

(C-D) *Favosites* sp. H; CEM 1, CEM 4B, Main limestone unit. (10x).

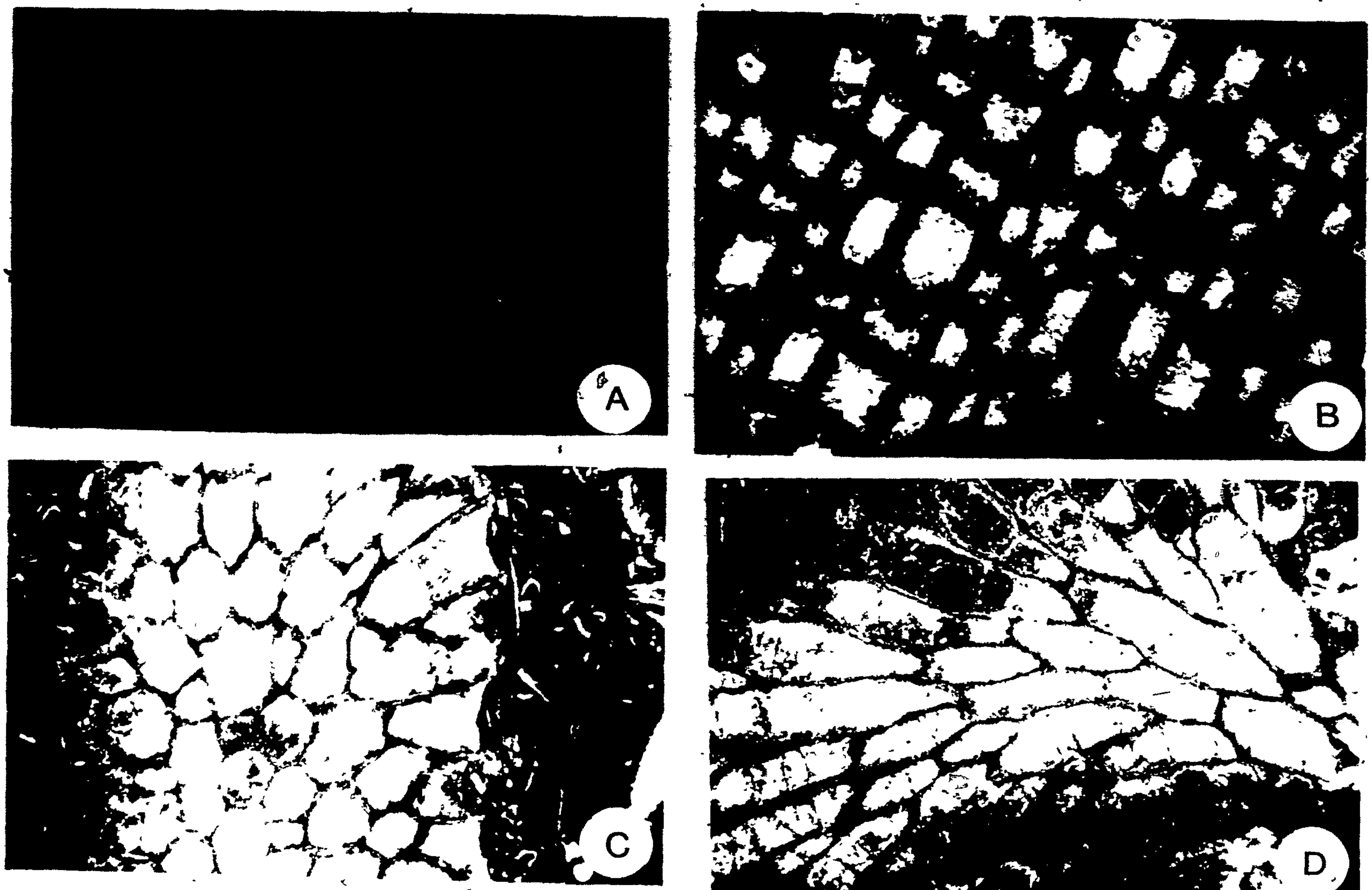

A
B
C
D

Plate XV

(A) *Cladopora* sp., *Alveolites* sp. A, and *Favosites* sp. H. CEM1. (10x).

(B) *Cladopora* sp.; CEM 1; Main limestone unit. (25x).

(C) *Alveolites* sp. A; MB4A; Upper Calcareous Siltstone. MacPherson Bay. (25x).

(D) *Favosites* sp. H; CEM 1. (10x).

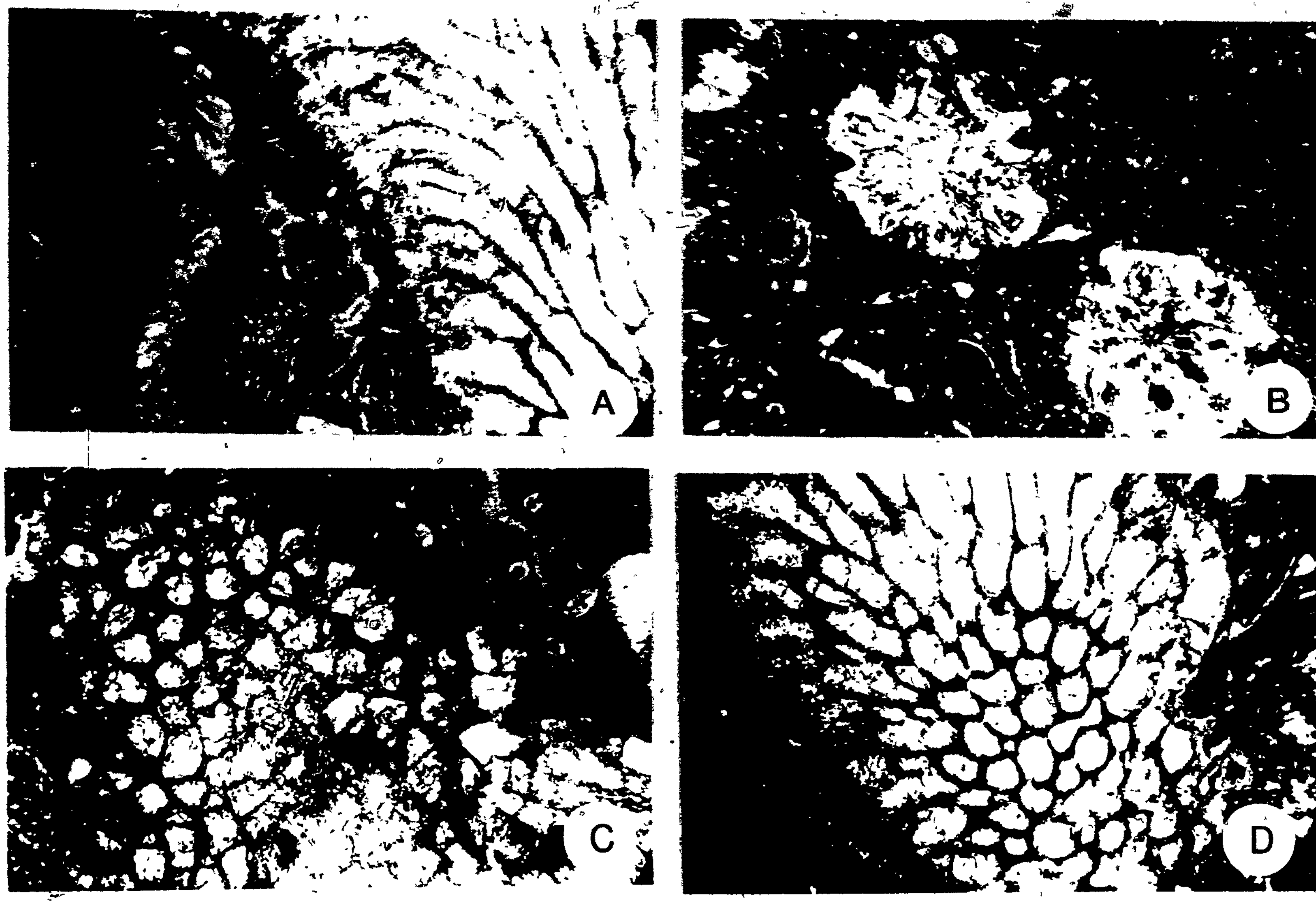

A
B
C
D

Plate XVI

(A-D) Alveolites sp. B; (A) D2-1-B (1.5x) tangential view (B-D) D2-2-A, tangential and sectional view (10x); Main limestone unit.

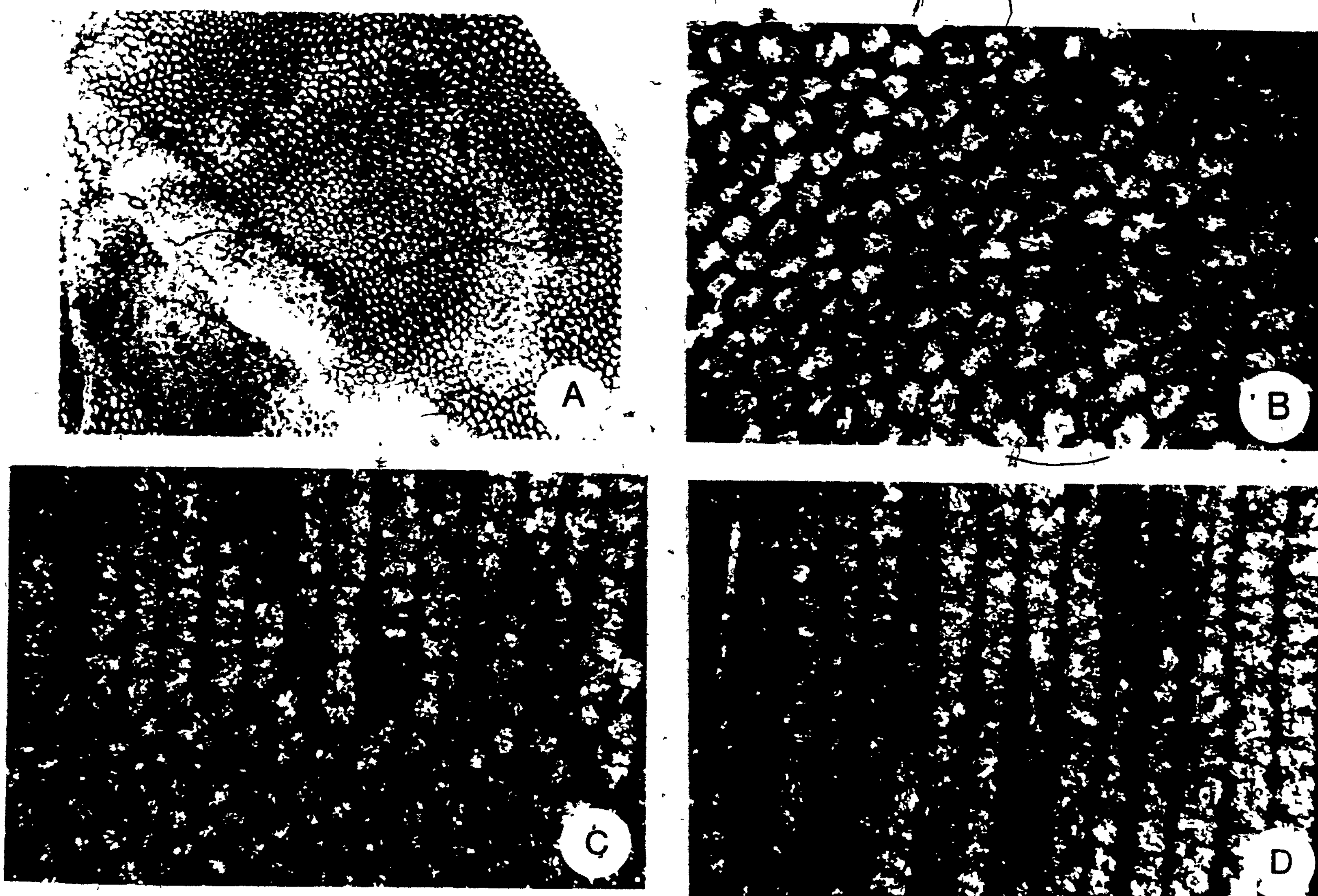

A
B
C
D

Plate XVII

(A) *Alveolites* sp. C; MC12A; Upper Calcareous Siltstone. MacPherson Brook. (10x).

(B) *Halysites catenularia*, MCBL1, Upper Calcareous Siltstone. MacPherson Brook. (10x).

(C-D) *Syringopora* sp. A; QC2; Upper Calcalerous Siltstone. Quinn Creek. (C) 1.5x, (D) 10x.

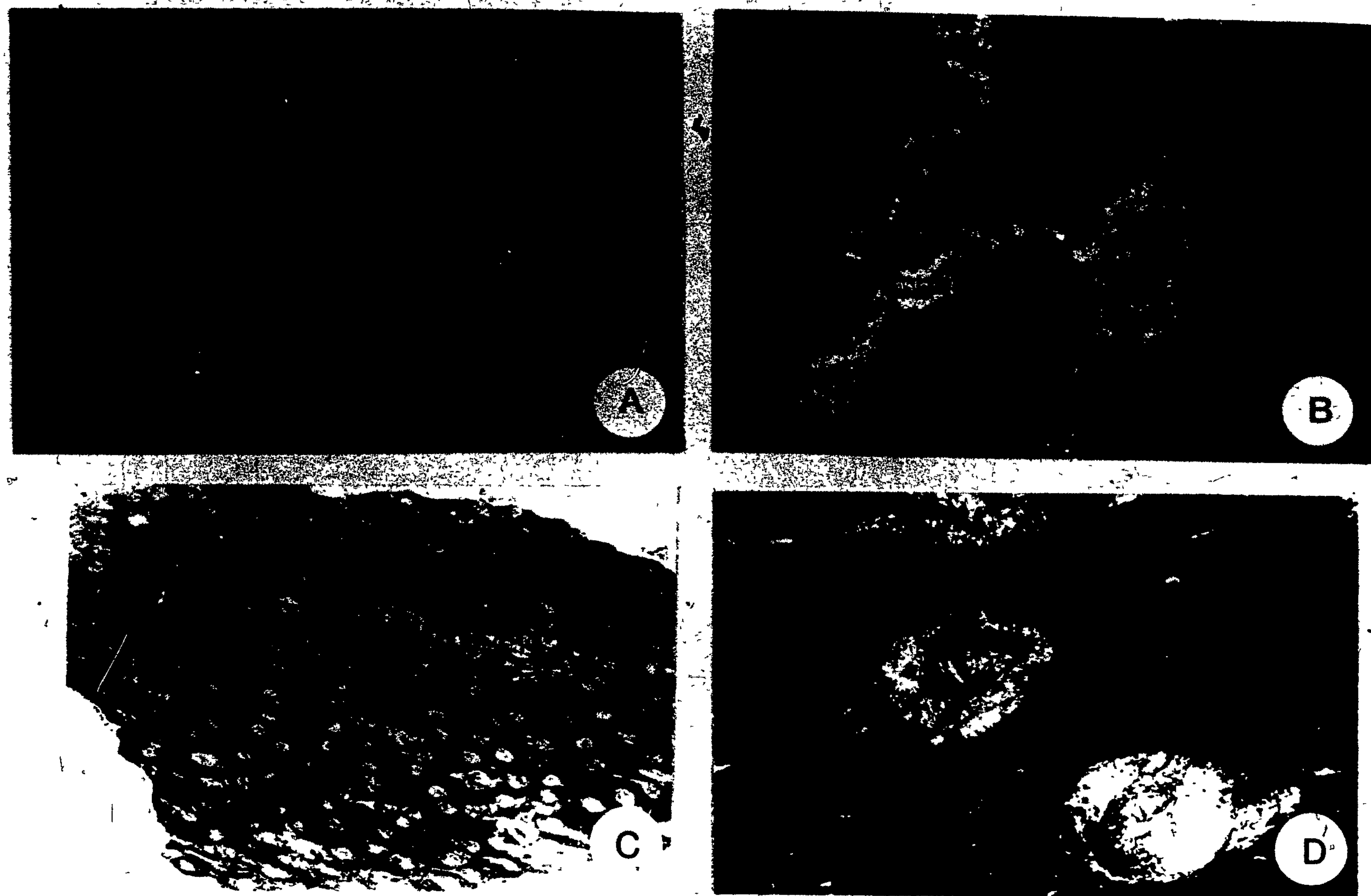

A
B
C
D

Plate XVIII

(A-C) *Syringopora* sp. B; CCEMA,B; Main limestone unit. *Syringopora* overgrown by the stromatoporoid, *Parallelostroma* sp. (10x).

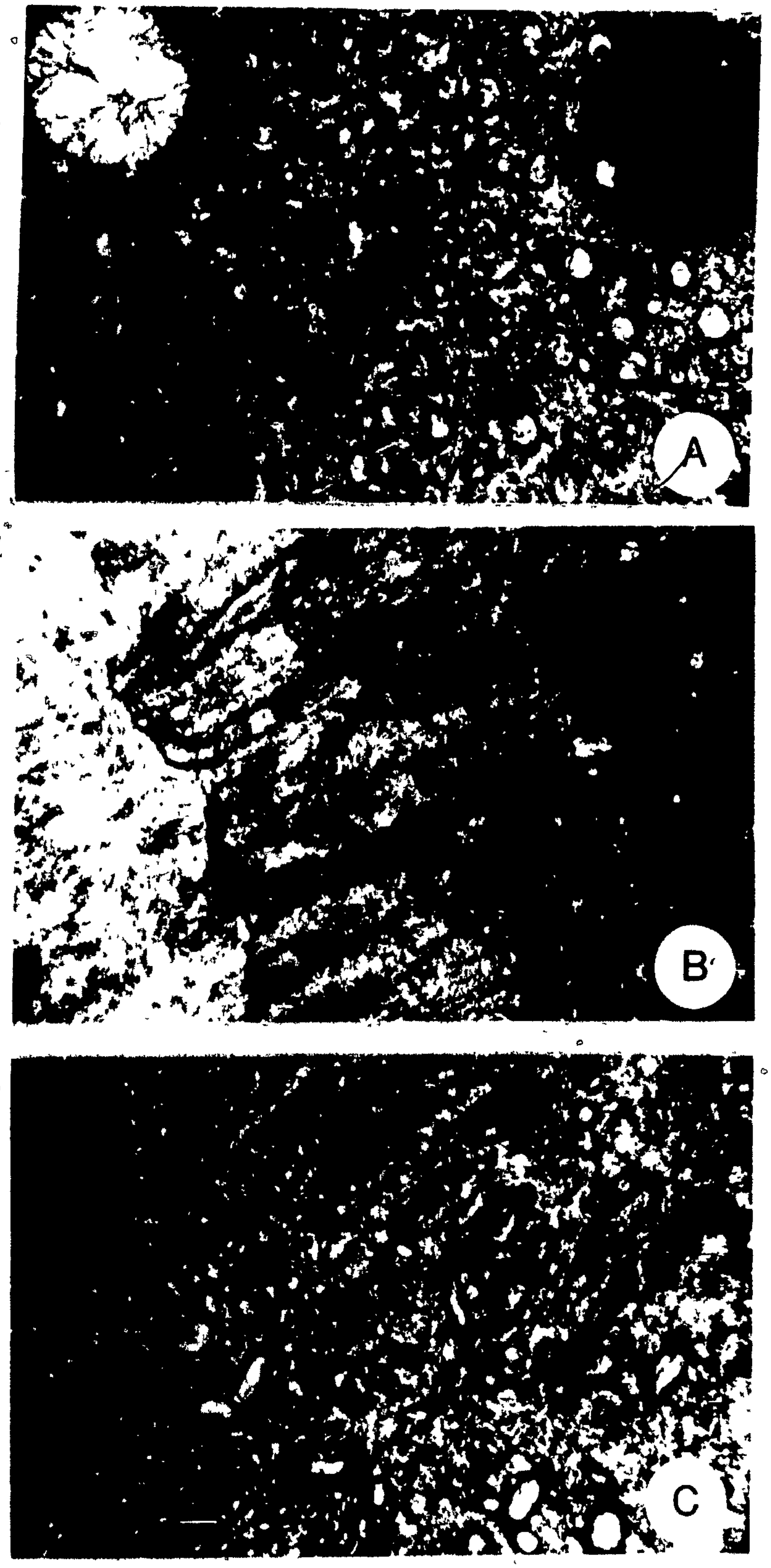

A
B
C

Plate XIX

(A-B) *Heliolites* sp. cf. *H. lavieillenses*; CMR3 Main limestone unit. (1.5x).

(C-D) *Heliolites* sp.; (C) QB2B, and (D) QB5B Upper Calcareous Siltstone. Quinn Creek. (10x).

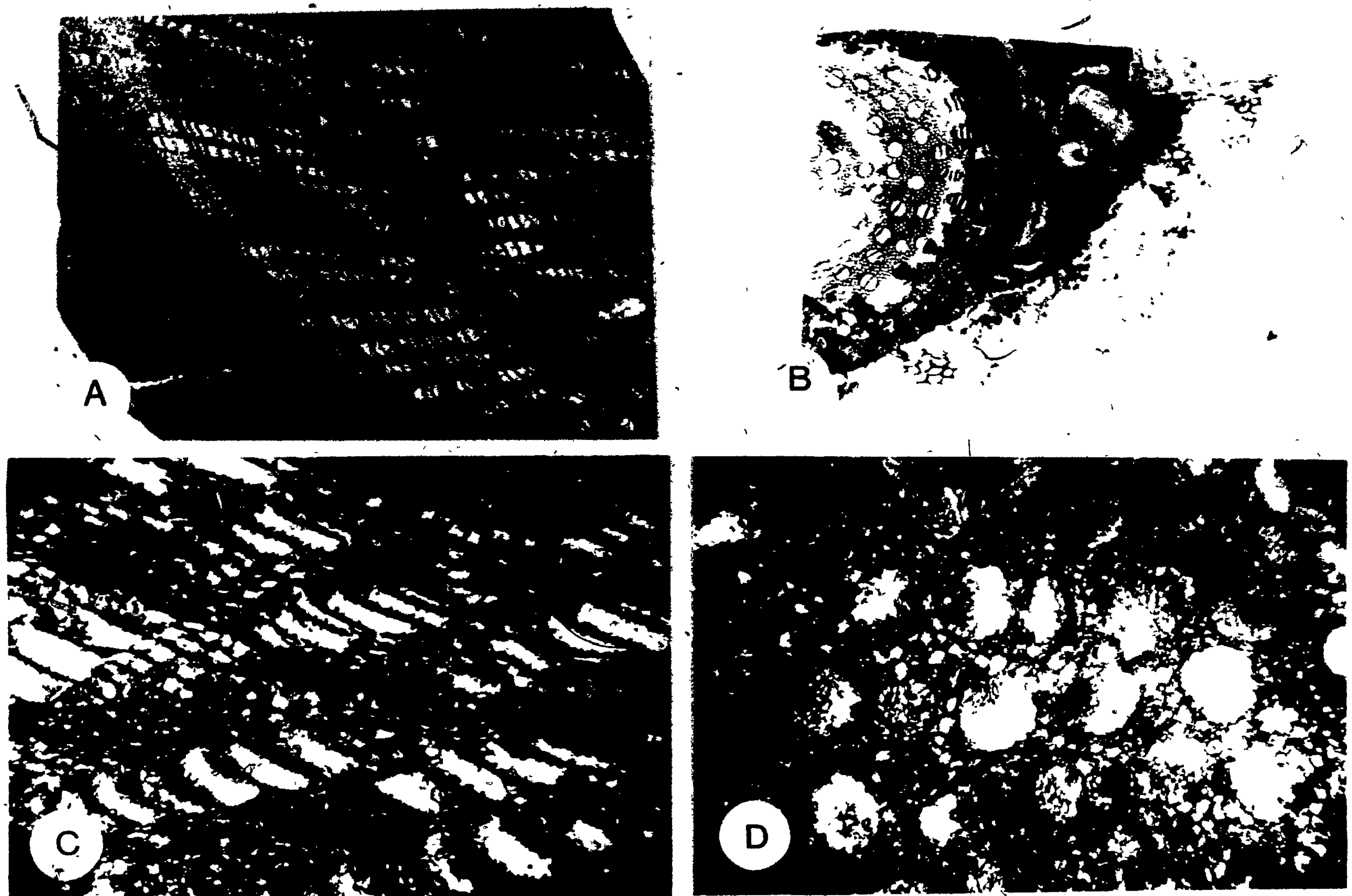

A
B
C
D

Plate XX

(A-B) Entelophyllum sp.; MC5A,B; Upper Calcareous Siltstone. MacPherson Brook. (A) 10x, (B) 1.5x.

(C) Tryplasma sp.; MC25, Sargent Bay Limestone. MacPherson Brook. (10x).

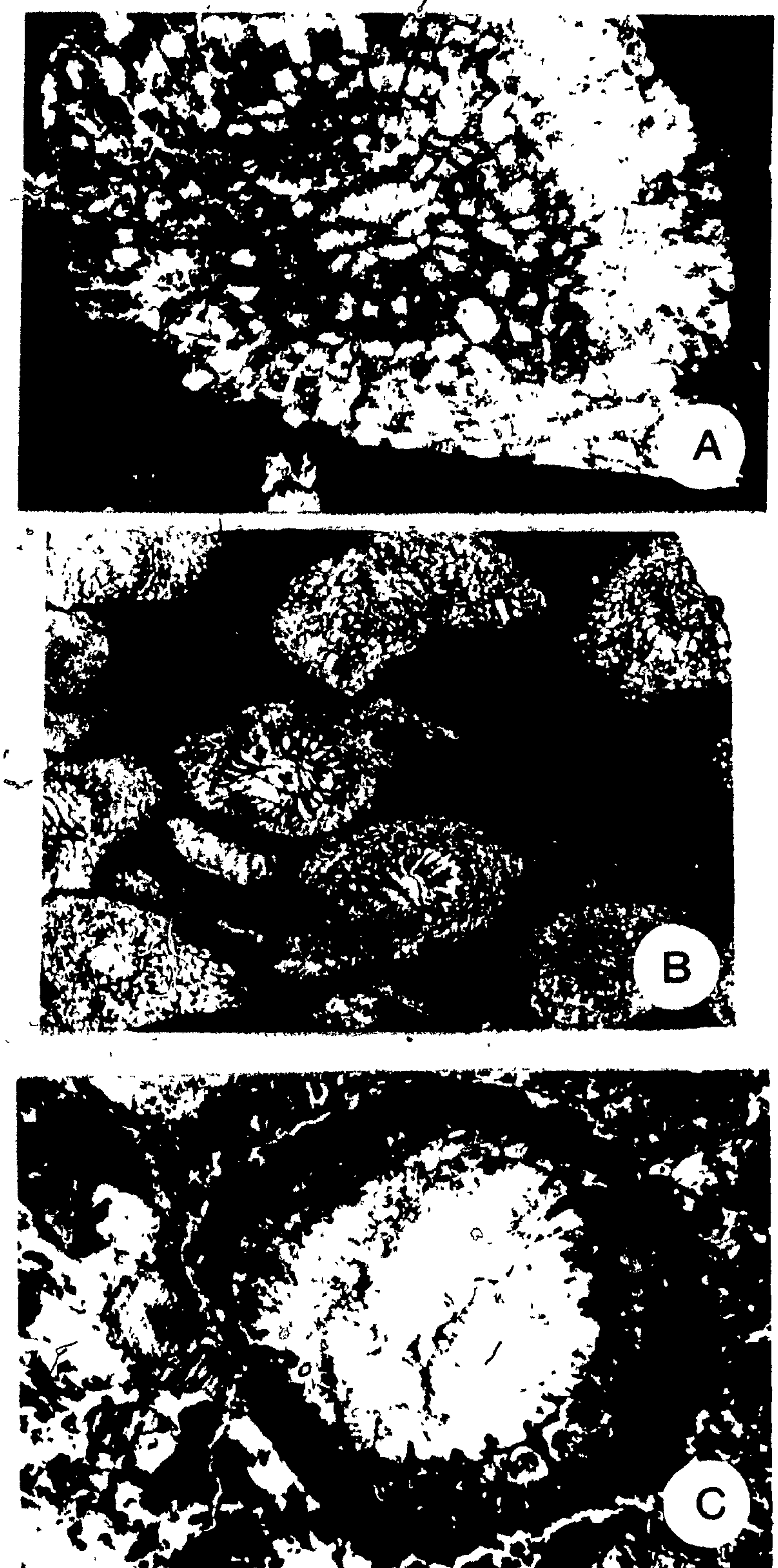
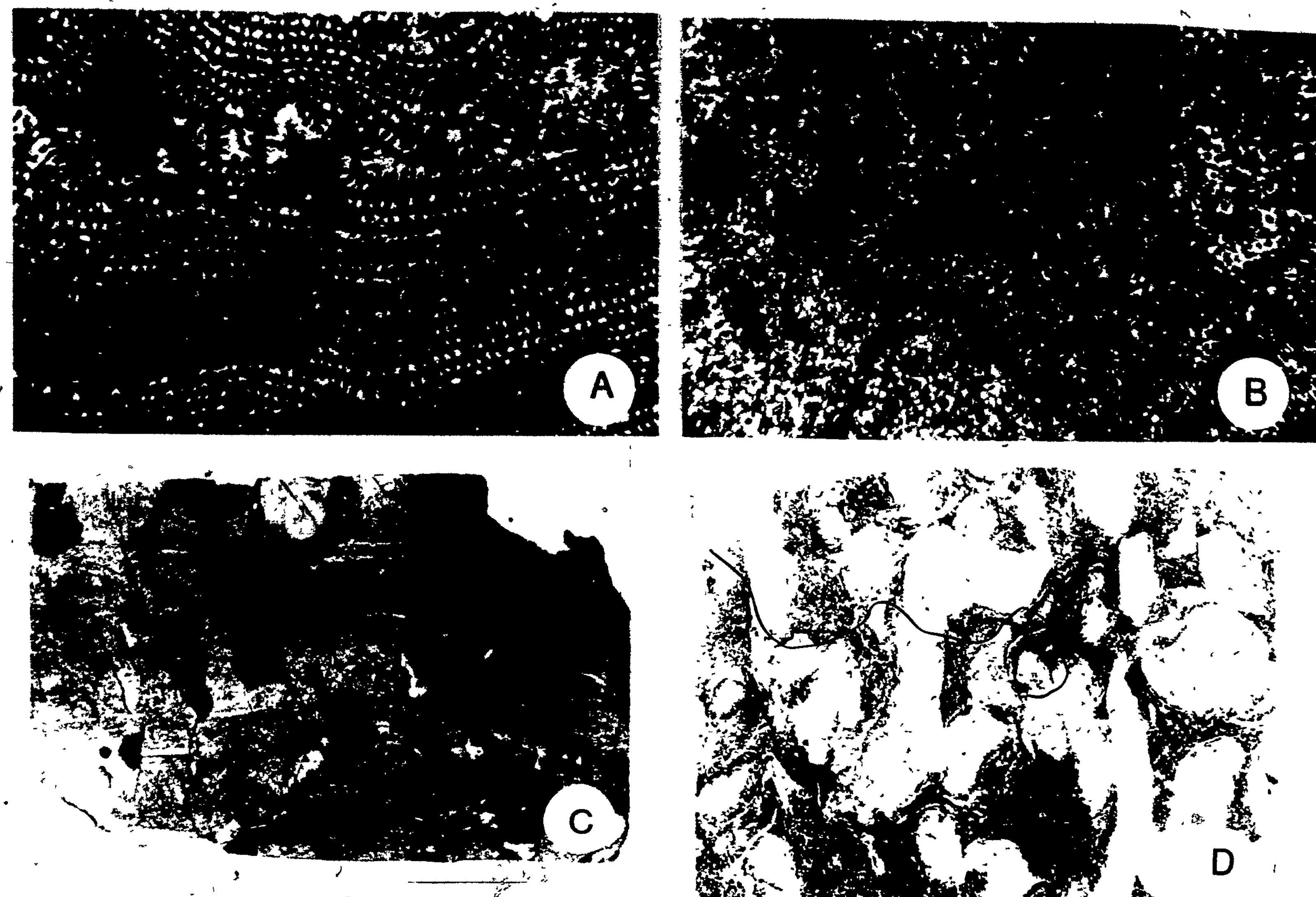

A
B
C

Plate XXI

(A-B) *Clathrodictyon* sp.; MC29A,B; sectional and tangential view; Sargent Bay Limestone, MacPherson Brook. (10x).

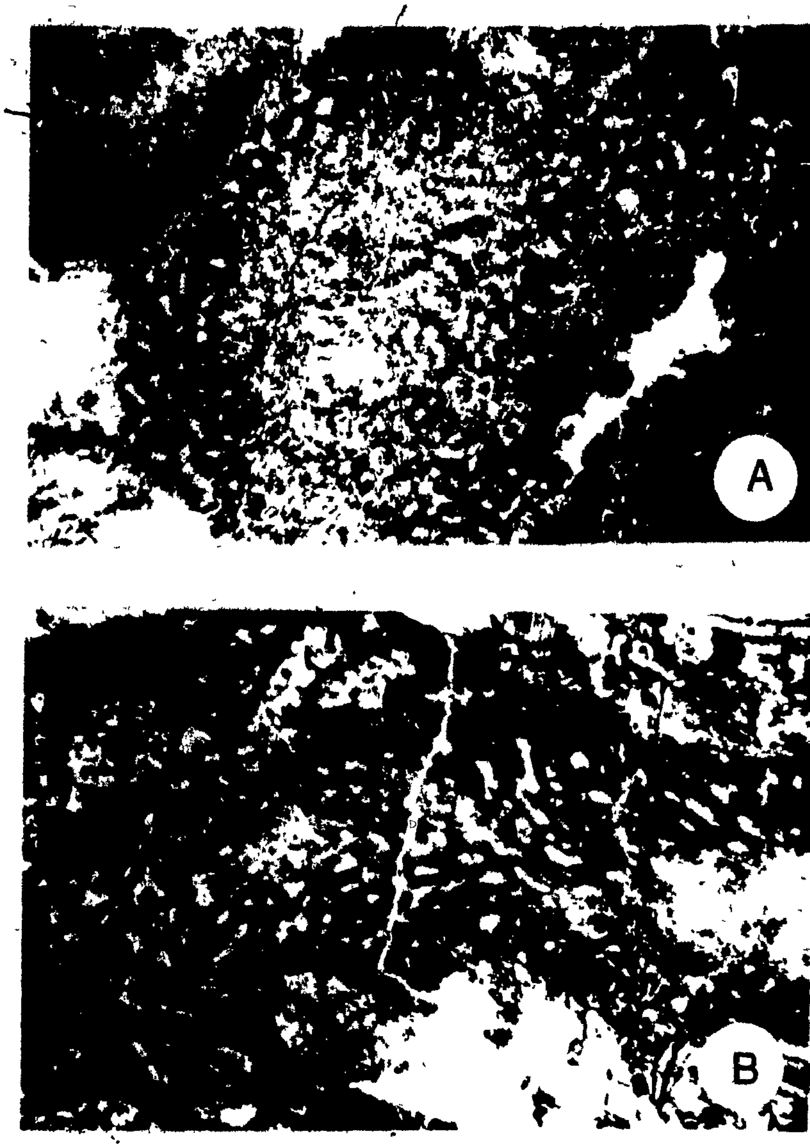
(C-D) *Ecclimadictyon stylotum*; (C) Dom F, Main limestone unit; (D) QC9, Sargent Bay Limestone, Quinn Creek. (1.5x).



A
B
C
D

Plate XXII

(A-B) Stromatopora clarkei digitata; MC25, Sargent Bay Limestone, MacPherson Brook. (10x).


A
B