uOttawa

L'Université canadienne
Canada's university

FACULTÉ DES ÉTUDES SUPÉRIEURES ET POSTOCTORALES

uOttawa

L'Université canadienne
Canada's university

FACULTY OF GRADUATE AND POSDOCTORAL STUDIES

Claude Farley
AUTEUR DE LA THÈSE / AUTHOR OF THESIS

M.Sc. (Earth Sciences)
GRADE / DEGREE

Department of Earth Sciences
FACULTÉ, ÉCOLE, DÉPARTEMENT / FACULTY, SCHOOL, DEPARTMENT

Sediment Dynamics and Stratigraphic Architecture of a Mixed Carbonate-Siliciclastic Ramp: The Upper Ordovician (Hirnantian) Ellis Bay Formation, Anticosti Island, Québec, Canada

TITRE DE LA THÈSE / TITLE OF THESIS

Dr. A. Desrochers
DIRECTEUR (DIRECTRICE) DE LA THÈSE / THESIS SUPERVISOR

CO-DIRECTEUR (CO-DIRECTRICE) DE LA THÈSE / THESIS CO-SUPERVISOR

EXAMINATEURS (EXAMINATRICES) DE LA THÈSE / THESIS EXAMINERS

Dr. G. Dix

Dr. B. Arnott

Gary W. Slater
Le Doyen de la Faculté des études supérieures et postdoctorales / Dean of the Faculty of Graduate and Postdoctoral Studies

SEDIMENT DYNAMICS AND STRATIGRAPHIC ARCHITECTURE OF A MIXED CARBONATE-SILICICLASTIC RAMP: THE UPPER ORDOVICIAN (HIRNANTIAN) ELLIS BAY FORMATION, ANTICOSTI ISLAND, QUÉBEC, CANADA.

CLAUDE FARLEY

Thèse soumise à la
Faculté des études supérieures et postdoctorales
Université d'Ottawa
en vue de l'obtention de la maîtrise ès sciences en
Sciences de la Terre

Centre Géoscientifique d'Ottawa-Carleton
et
Université d'Ottawa
Ottawa, Canada

Thesis submitted to the
Faculty of Graduate and Postdoctoral Studies
University of Ottawa
in partial fulfillment of the requirements for the
M.Sc. degree in the Earth Sciences

Ottawa-Carleton Geoscience Center
and
University Ottawa
Ottawa, Canada

Your file Votre référence
ISBN: 978-0-494-46474-8
Our file Notre référence
ISBN: 978-0-494-46474-8

RÉSUMÉ

La Formation de Ellis Bay sur l'île d'Anticosti, Québec, Canada, offre une chance unique d'étudier l'architecture stratigraphique de dépôts mixtes carbonatés-silicoclastiques mis en place lors d'un épisode glaciaire majeur à l'Hirnantien (Ordovicien Supérieur) sur une rampe tropicale influencée par les tempêtes et une lente subsidence. La ceinture d'affleurement, légèrement oblique au paléo-rivage, s'étend d'ouest en est sur ~180 km, offrant de superbes affleurements côtiers aux extrêmes ouest et est de l'île. Les sections de l'ouest (90 m d'épaisseur) sont formées par l'empilement cyclique de calcaires et de mudstones argileux déposés sur une rampe médiane à externe dominée par les tempêtes. Des dépôts oncolitiques et récifaux de la rampe interne sont aussi présents dans la partie supérieure de la formation. Les sections de l'est sont plus minces (45 m d'épaisseur) et composées à la base de grès et de mudstones argileux formant une succession continue allant : 1) d'une vallée incisée, à 2) un delta influencé par les tempêtes, à 3) une plage plane dominée par les tempêtes. Au-dessus de ces grès se trouvent d'abord des dépôts de tempêtes mixtes carbonatés-silicoclastiques de la rampe médiane à externe, lesquels sont surmontés de tempestites carbonatées pures et, finalement, d'unités oncolitiques et récifales corrélables avec celles de l'ouest. La diminution graduelle vers le haut du contenu silicoclastique dans les sections de l'est est attribuée au déplacement par incrément (avulsion) d'un delta (i.e. source des silicoclastiques) confiné à l'est de la Plateforme d'Anticosti. Autrement, cette diminution pourrait résulter d'avulsions combinées à un changement graduel des conditions climatiques, de relativement humides à plus arides. Malgré les changements latéraux importants de faciès, la reconnaissance de quatre séquences transgressives-régressives permet une corrélation précise entre les sections de l'ouest et de l'est. Ces séquences (ou cycles) sont probablement d'origine glacio-eustatique, associées à la glaciation de Gondwana à la fin de l'Ordovicien.

ABSTRACT

The Upper Ordovician (Hirnantian) Ellis Bay Formation on Anticosti Island, Québec, Canada provides a unique opportunity to study the stratigraphic architecture of mixed carbonate-siliciclastic deposits that formed during a period of major glaciation on a storm-influenced, slowly subsiding tropical ramp. The west-east-trending Ellis Bay outcrop belt is ~180 km long, slightly oblique to the paleoshoreline, and offers superb coastal exposure at both ends of the island. The western sections (90 m thick) consist of stacked cycles of mid- to outer-ramp, storm-dominated carbonates with argillaceous mudstones. Inner-ramp oncolitic and reefal carbonates are also present in the uppermost part of the formation. The thinner eastern sections (45 m thick) are composed of basal sandstone and argillaceous mudstone units forming a continuous succession from 1) incised-valley fill to 2) storm-influenced delta to 3) storm-dominated strandplain deposits. Overlying these basal sandstones are mid- to outer-ramp, mixed carbonate-siliciclastic tempestites capped by pure carbonate tempestites and, finally, oncolitic and reefal units that correlate with those in the western section. The gradual upward decrease in siliciclastic content in the eastern sections is attributed to the incremental migration (avulsion) of a siliciclastic-supplying delta confined to the eastern Anticosti Platform. Alternatively, it could result from river avulsion coupled with a gradual shift from relatively humid to more arid climatic conditions. Despite these important lateral facies changes, the recognition of four major transgressive-regressive sequences allows a precise correlation between the western and eastern sections. These sequences (or cycles) are likely driven by glacio-eustasy in association with the end-Ordovician Gondwanan glaciation.

ACKNOWLEDGEMENTS

This work represents part of an M.Sc. research project conducted at the University of Ottawa under the highly appreciated supervision of André Desrochers. Many thanks go to R.W.C. Arnott for invaluable comments. Thanks to George Dix for reviewing the manuscript. M. Smith and Z. Khan are thanked for insightful discussions. The Natural Sciences and Engineering Research Council of Canada (NSERC) provided the financial support for this research with grants to Claude Farley. The Ministère des Ressources naturelles et de la Faune du Québec (MRNF) and Société des établissements de plein air du Québec (SÉPAQ) both supplied the logistical support for the fieldwork during the summers of 2004, 2006, and 2007. R. Thériault of the MRNF provided the access to the NACP core. P. Bertrand is acknowledged for his help drafting the figures in this manuscript.

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

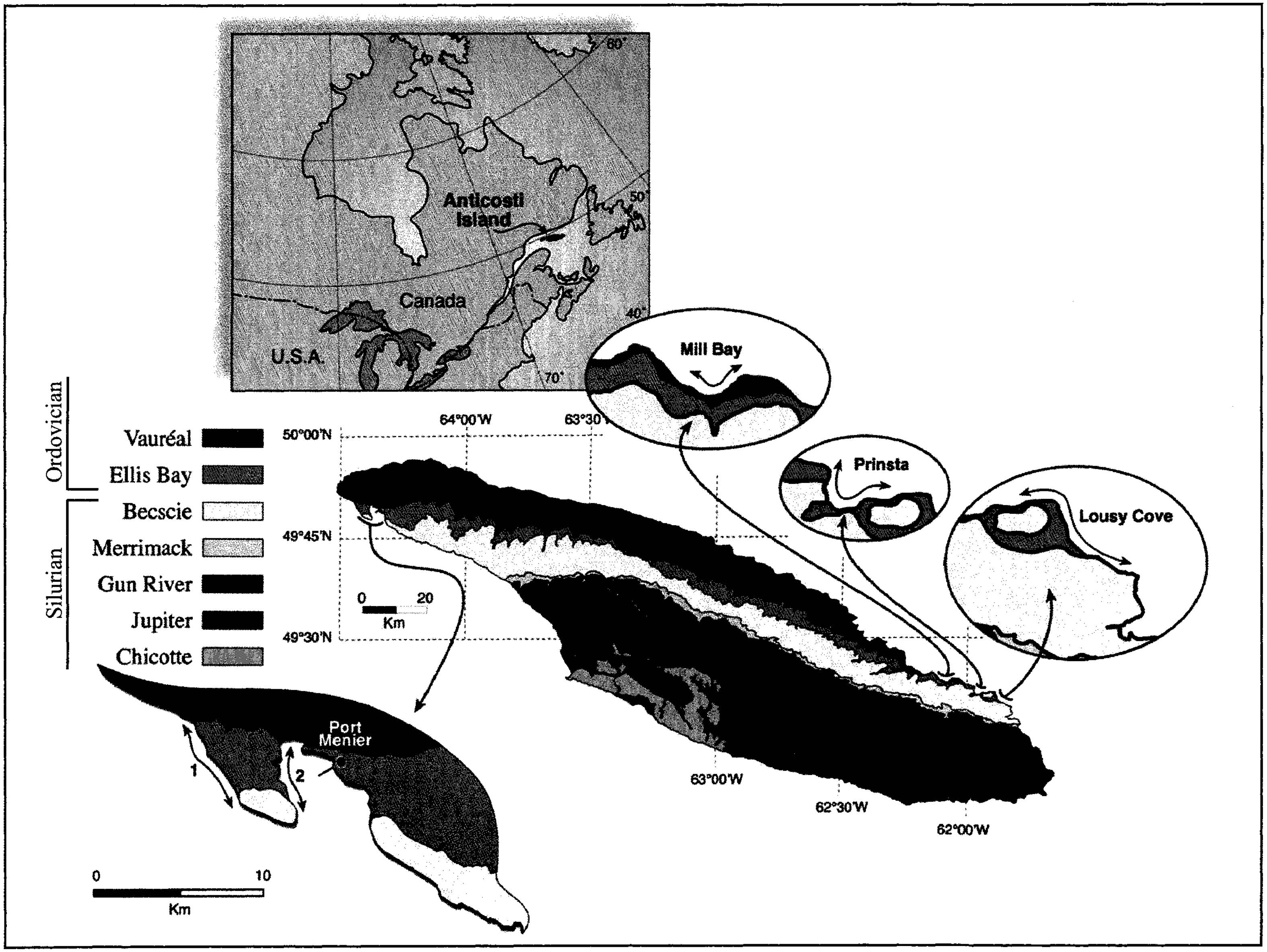
The Upper Ordovician Ellis Bay Formation exposed on Anticosti Island, Québec, Canada is of particular interest because it forms a thick, almost continuous, fossiliferous, and largely undeformed succession of shallow marine deposits of Hirnantian age, equivalent to the much thinner, deeper water, and graptolite-rich deposits of other known Hirnantian sections (e.g. Scotland, China). Furthermore, the Ordovician-Silurian (O/S) boundary lies at or just above the top of the Ellis Bay Formation. The Ellis Bay Formation was extensively studied on various paleontological (Copper, 1975, 1976, 1981, 1995, 2001; Cocks & Copper, 1981; McCracken & Barnes, 1981; Lespérance, 1985; Racheboeuf & Copper, 1986; Jin & Copper, 1997; Soufiane & Achab, 2000; Zhang & Barnes, 2002; Richardson & Ausich, 2007; Melchin, *in press*) and geochemical (Orth et al., 1986; Long, 1993; Wang et al., 1995; Brenchley et al., 2003; Young et al., 2005; Bergström et al., 2006) aspects, but only few studies addressed its sedimentology and stratigraphic architecture (Petryk, 1981; Long & Copper, 1987*a*, 1987*b*).

The limestone, sandstone, and calcareous shale of the Ellis Bay Formation provide a unique opportunity to study the sediment dynamics of mixed carbonate-siliciclastic deposits that formed on a storm-influenced, slowly subsiding tropical ramp during a period of major glaciation (Hirnantian) and sea-level fluctuation. The specific objectives of this research are: 1) to present a revised description of the facies of the Hirnantian Ellis Bay Formation, 2) to explain both the lateral and vertical changes in siliciclastic content throughout the formation, and offer an alternative interpretation of the depositional environment of the sandstone units in the eastern sections, 3) to correlate the distinct western (carbonate-dominated) and eastern (siliciclastic-rich) sections based on sequence stratigraphy, and 4) to relate the Ellis Bay Formation within the larger-scale Hirnantian context and the O/S boundary.

STUDY AREA AND GEOLOGICAL CONTEXT

Anticosti Island is located in the Gulf of St. Lawrence in eastern Canada, about 75 km northeast of the Gaspé Peninsula and 30 km south of the Côte-Nord region of Québec (Fig. 1). The island is 222 km long and up to 56 km wide, for a total area of ~8000 km^2. Strata strike northwest-southeast with an average dip of 2° toward the southwest.

Figure 1. Location of Anticosti Island and study area. The "western sections" include two measured sections labelled "1" and "2", located on both sides of Pointe aux Ivrognes. The "eastern sections" include several sections measured along Mill Bay, Prinsta Bay, and Lousy Cove (labelled as the Mill Bay, Prinsta, and Lousy Cove sections). The drill core (not shown) is located at 49°37'20.2"N and 63°26'17.5"W.


U.S.A.
Canada
Anticosti Island
80°
50°
40°
70°
Ordovician
Silurian
Vauréal
Ellis Bay
Becscie
Merrimack
Gun River
Jupiter
Chicotte
50°00'N
49°45'N
49°30'N
64°00'W
63°30'W
63°00'W
62°30'W
62°00'W
0
20
Km
Mill Bay
Prinsta
Lousy Cove
Port Menier
1
2
0
10
Km

The sequence exposed on Anticosti Island consists of up to 900 m of fossiliferous limestone, calcareous shale, and minor siliciclastics that were deposited in a shallow epeiric sea along the margin of eastern Laurentia (Long, 2007). Following a passive margin phase, the Anticosti Basin initially developed as a foreland basin in the Middle Ordovician (Caradoc) during the partial closure of the Iapetus Ocean at the onset of the Taconic orogeny. In the Late Ordovician (Ashgill) through Early Silurian (Llandovery), it evolved into a residual basin as tectonic activity ceased or considerably diminished (Long, 1993, 2007). This limited tectonic activity prevented the basin from major movements which, combined with continuous load subsidence, provided the ideal conditions to record and preserve subtle eustatic changes and form what is now probably one of the thickest and most complete carbonate section spanning the O/S boundary (Barnes, 1988). Given the position of the basin, the strata remained largely undisturbed by Taconic and post-Taconic deformation.

During deposition of the Anticosti succession, the Anticosti Basin was situated at 10-20°S on the northwestern margin of the Iapetus Ocean (Fig. 2; Cocks & Torsvik, 2002; Fortey & Cocks, 2003). The succession was dominated by tropical storm deposits interpreted to have formed predominantly on a middle to outer carbonate-dominated ramp, below fairweather wave base, in water depths of up to 120 m (Sami & Desrochers, 1992; Long, 1993; Zhang & Barnes, 2002).

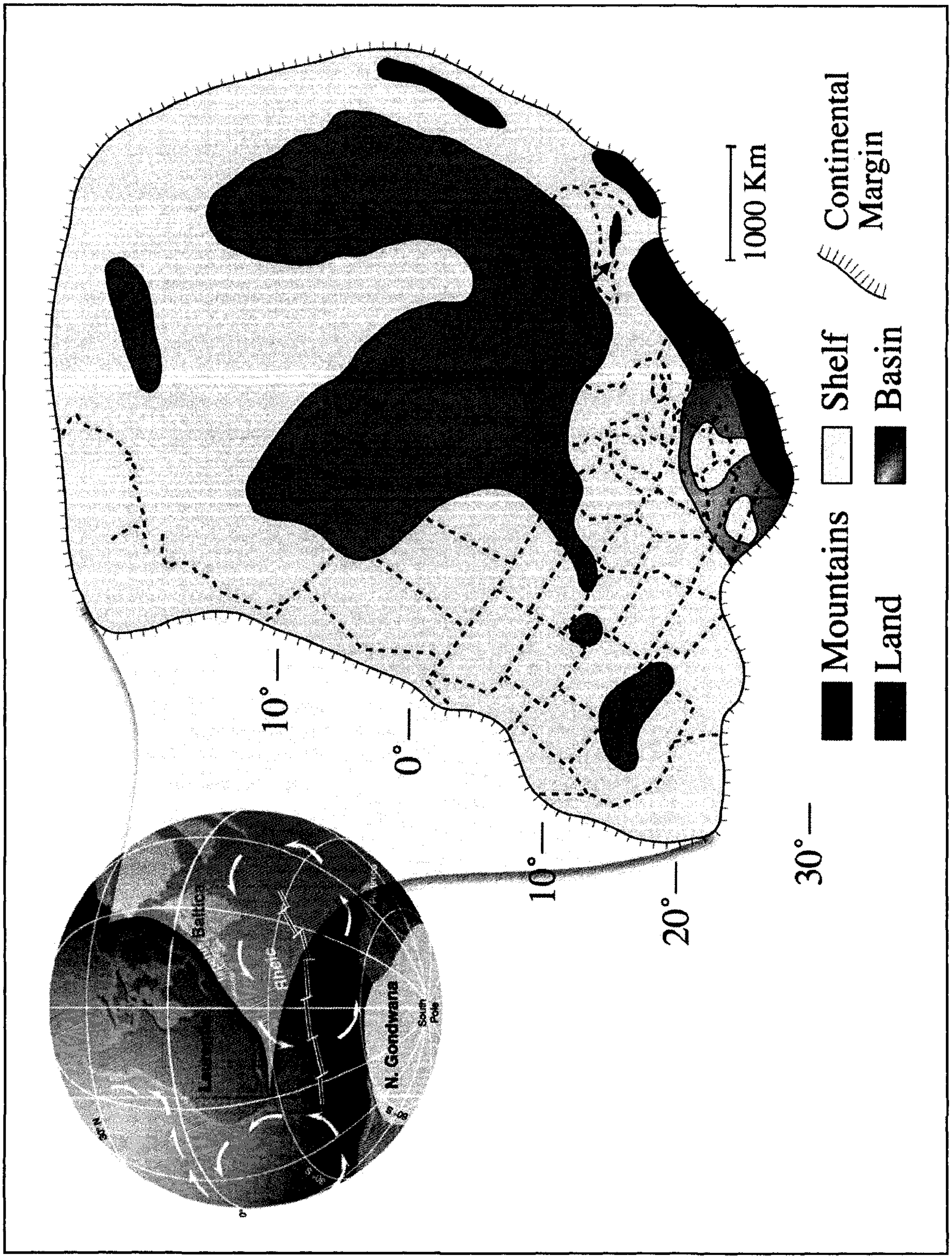
The Hirnantian, which is 1.9 My in duration (Cooper & Sadler, 2004), was a time characterized by glaciation centered on the paleocontinent Gondwana, then located at the South Pole (Fig. 2; Brenchley, 1994; Ghienne, 2003). The glaciation caused important global sea-level fluctuations during this period, which are recorded in the Hirnantian Ellis Bay Formation, and was also responsible for the second most important extinction event in the Phanerozoic (Sheehan, 2001).

STRATIGRAPHY

The present study focuses on strata of the uppermost Vauréal, Ellis Bay, and lowermost Becscie formations.

The uppermost Vauréal interval considered here consists of the resistant weathering Mill Bay and recessive weathering Schmitt Creek members as defined by Long & Copper (1987*a*). At the west end of the island, the Mill Bay Member is 8 to 10 m thick and consists

Figure 2. Location of the Anticosti Basin (arrow) in Late Ordovician time along the eastern margin of Laurentia. Note glaciation on Gondwana at the South Pole. Modified from Achab & Paris (2007) and McLaughlin & Brett (2007).



Mountains
Land
Shelf
Basin
1000 Km
Continental Margin
10°
0°
10°
20°
30°
Baltica
N. Gondwana
South Pole

mainly of bioturbated, subnodular, thin- to medium-bedded mudstone to grainstone interbedded with calcareous shale. In the east, it consists of 9.25 m of hummocky to swaley cross-stratified very fine-grained sandstone and cross-bedded coarse grainstone interbedded with minor calcareous shale (modified from Long & Copper, 1987). At both ends, the Schmitt Creek Member comprises 4 to 6.5 m of calcareous shale with minor thin, more resistant, discontinuous beds of mudstone, siltstone, sandstone, and grainstone (Fig. 3; Long & Copper, 1987*a*; Long & Copper, 1994).

The Ellis Bay Formation comprises the Grindstone, Velleda, Prinsta, Lousy Cove, and Laframboise members (Long & Copper, 1987*a*), for a total thickness of 90 m and 43 m at the western and eastern sections, respectively (Fig. 3). In the west, the first four members consist of stacked units of predominantly calcareous shale, thin nodular (bioturbated) mudstone-wackestone, and thick lenticular mudstone (Fig. 3). The topmost Laframboise Member is composed of a basal oncolite bed overlain by bioherms and associated interbioherm facies. This differs from Petryk (1981) who divided the Ellis Bay Formation into seven numbered members, where members 1, 3 and 5 defined more argillaceous and recessive units, and members 2, 4 and 6 more resistant units. Member 7 consisted of the basal "oncolitic platform bed" overlain by the biohermal and interbiohermal beds, corresponding to the Laframboise Member. However, he placed the base of the formation about 13 m above its current position. In the east, the lower two members of the Ellis Bay Formation are dominated by hummocky (HCS) and swaley (SCS) cross-stratified sandstone, whereas the overlying units are composed mostly of very thin- to medium-bedded laminated sandstone to grainstone (mixed carbonate-siliciclastic) and eventually pure limestone (mainly mudstone), interbedded with calcareous shale (Fig. 3). The uppermost member consists of a basal oncolite bed overlain locally by bioherms, and correlates 180 km westward and thus serves as an important marker throughout the island.

A post-Richmondian or Gamachian (Hirnantian?) age was clearly assigned to the Ellis Bay Formation on the basis of conodont zones erected by McCracken & Barnes (1981) and McCracken & Nowlan (1986) and associated brachiopod, chitinozoan, and to a lesser extent, graptolite faunas (Lespérance, 1981). Recent studies on brachiopods suggest that the entire Ellis Bay Formation is Hirnantian, with the Grindstone and Velleda members being lower Hirnantian and the Prinsta, Lousy Cove, and Laframboise members being upper Hirnantian

Category 1: Calcareous shale

Facies 1 Calcareous shale

Category 2: Sandstone and Grainstone Interbedded with Calcareous Shale

Facies 2A Nodular sandy grainstone

Facies 2B Tabular sandstone / grainstone

Facies 2C Hummocky cross-stratified sandstone

Facies 2D Cross-stratified and rippled sandstone

Facies 2E Parallel-laminated siltstone

Category 3: Mudstone and Wackestone Interbedded with Calcareous Shale

Facies 3A Nodular mudstone-wackestone

Facies 3B Lenticular mudstone

Category 4: Sandstone and Grainstone

Facies 4A Wave-rippled grainstone

Facies 4B Hummocky to swaley cross-stratified sandstone

Facies 4C Cross-bedded sandstone / grainstone

Facies 4D Bioturbated sandstone

Facies 4E Channelized sandstone

Facies 4F Interbedded grainstone and siltstone

Category 5: Oncolitic and Reefal Limestone

Facies 5A Oncolitic grainstone

Facies 5B Calcimicrobial-coral bioherms

Category 6: Grainstone Lag

Facies 6 Grainstone lag

Carbonate-dominated

Mixed carbonate-siliciclastic

Siliciclastic-dominated

Balls and pillows

Shallowing

MFS

Deepening

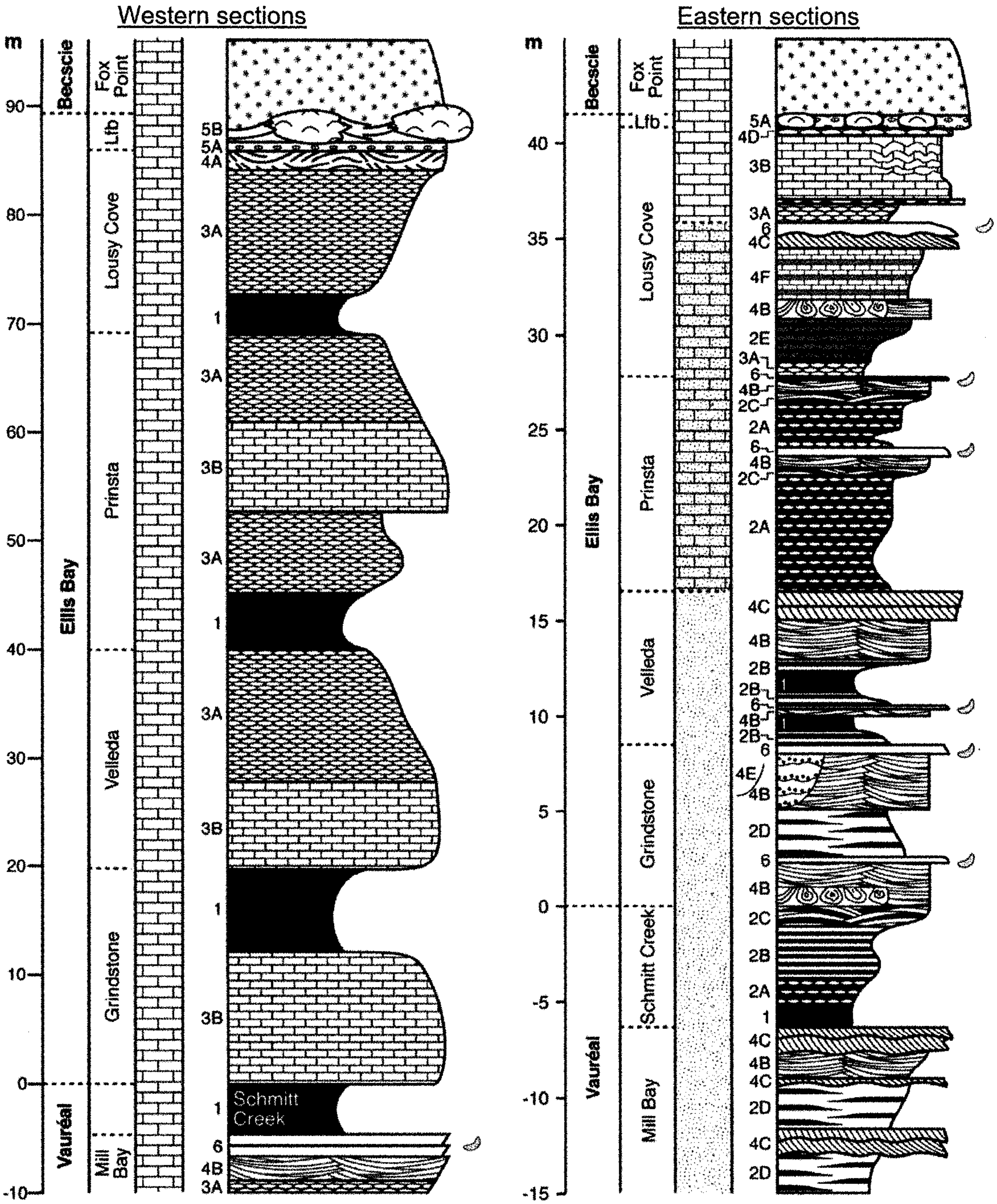


Figure 3. Stratigraphy of the Ellis Bay Formation and associated strata (upper Vauréal and lowermost Becscie formations). The western sections (left) consist entirely of carbonates, whereas the eastern sections (right) show an upward change in lithology, from siliciclastic-dominated to mixed carbonate-siliciclastic to carbonate-dominated. Note scale difference between the two sections. MFS = maximum flooding surface. Fourth column from left indicates facies numbers (see descriptions below). Facies legend for figures 4 and 22.

(Copper, 2001). This is supported by the identification throughout the formation of brachiopods that are regarded as Hirnantian faunas, and particularly *Hindella* in the lower part of the Grindstone Member (Copper, 2001) and *Hirnantia* in the basal Prinsta (Jin & Copper, *in press*) and Lousy Cove (Cocks & Copper, 1981) members. As for graptolites, re-examination of previous collections as well as identification of newly collected specimens showed that all or most of the Lousy Cove Member is upper Hirnantian (Melchin, *in press*), supporting Copper's (2001) interpretation that the entire Ellis Bay Formation is Hirnantian. Thus, Hirnantian strata are not restricted to the Laframboise Member and its distinctive positive $\delta^{13}C$ excursion as previously proposed by Underwood et al. (1997) and Brenchley et al. (2003). Based on chitinozoans (Soufiane & Achab, 2000), the top of the Hirnantian may correspond to the top of the Laframboise Member or occur in the lowermost Becscie Formation. A more detailed review of the age of the Ellis Bay Formation can be found in Melchin (*in press*).

The Becscie Formation consists of several limestone rock types that suggest, overall, a low-energy, muddy, carbonate to argillaceous ramp episodically affected by high-energy storms (Sami & Desrochers, 1992). It shows a long-term shallowing-upward trend superimposed on an initial rapid deepening at the base of the formation (Sami & Desrochers, 1992). Indeed, the first five meters of the Becscie Formation consist of coarse and locally hummocky cross-stratified grainstones (representative of relatively proximal tempestites) that rapidly give way upward to thinly-bedded mudstones (representative of more distal tempestites). These basal grainstones rest on a continuous erosion surface capping the Ellis Bay Formation and, where present, onlap the positive topography of the underlying Laframboise bioherms (Fig. 3, Plate 5B).

METHODOLOGY

Data for this research were collected along exceptional river and coastal exposure at the west and east ends of the island, and from a single drill core (Fig. 1). The western and eastern sections are ~180 km apart. Access to the sections was greatly facilitated by the recently enhanced road network on the island.

Two sections were measured at the west end of the island (Fig. 1). The first one is on the west side of Pointe aux Ivrognes, starting about 300 m north-west of Anse aux Fraises and ending just passed Pointe Laframboise. It covers the uppermost 15 m of the Vauréal

Formation, all of the Ellis Bay Formation, and the first five meters of the Becscie Formation. Although most of the section was studied along shore bluffs, parts were studied on the tidal flats due to the local absence of cliff exposures. The second section is located approximately 3 km east of the first section, on the east side of Pointe aux Ivrognes. Because the base of the Ellis Bay Formation is poorly exposed, this section starts about 26 m above the Vauréal – Ellis Bay contact. It covers the upper 64 m of the Ellis Bay Formation and the lower 15 m of the Becscie Formation. It was entirely studied along coastal bluffs as these are well exposed and continuous. Finally, these two sections being slightly incomplete at different levels, they were combined into one complete composite section (Fig. 3). A total of over 350 samples were collected within these two sections, of which 57 were selected for thin-sections.

At the eastern end of the island, 12 sections were measured, starting with the Mill Bay Member in Baie Mill (Mill Bay) and ending with the Laframboise Member just west of Pointe du Renard, in Lousy Cove (Fig. 1). Sections were measured in Rivière aux Saumons, where only the Laframboise Member was studied in detail. All these sections were put together to produce one composite section (Fig. 3). Overall, 106 samples were collected for thin-sections.

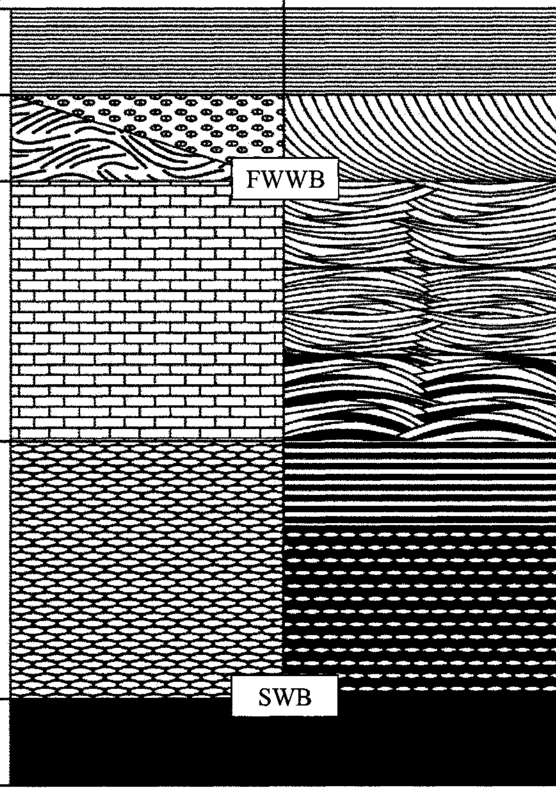
The drill core (NACP – D – 003; 49°37'20.2"N, 63°26'17.5"W) intersects the entire Ellis Bay Formation, which is here 63.5 m thick (intermediate between the 90 m and 43 m of the western and eastern sections, respectively). Thirty-four (34) samples were collected from the upper Vauréal through basal Becscie formations and studied in thin-sections. However, the Ellis Bay Formation as described from the core overall duplicates the facies and stacking patterns observed at the western sections, and so no detailed description is provided in this study.

TERMINOLOGY

Siliciclastics strata are described using the Udden-Wentworth scale, and carbonates are described using the Dunham classification. The general term "calcareous shale" is herein assigned to any dark, very fine (clay- to silt-sized), recessive-weathering, and locally fissile material that has both a siliciclastic and a calcareous component in varying proportions. The use of the " / " symbol between two lithologies indicates that the designated beds are characterized by a continuum between the two lithologies. For example, "sandstone / grainstone" means that beds of sandstone, bioclastic sandstone, sandy grainstone, and

Figure 4. Shallowing-up facies of a storm-dominated carbonate ramp (left) and a storm-dominated siliciclastic strandplain (right) as observed in the Ellis Bay and associated strata on Anticosti Island. The delta front / prodelta boundary for the delta sequence (not shown) coincides with the base of the lower shoreface. Note the corresponding facies between the carbonate and siliciclastic systems in this model. FWWB = fairweather wave base. SWB = storm wave base.

Carbonate System		Siliciclastic System	
Setting	**Sedimentary Structures**	**Sedimentary Structures**	**Setting**
Inner Ramp	Flat-laminated grainstone	Flat-laminated sandstone	Foreshore
	Small-scale wave-ripple cross-stratified grainstone and Oncolitic grainstone	Cross-stratified sandstone	Upper Shoreface
Proximal Mid-Ramp	Lenticular mudstone (interbedded with shale)	SCS sandstone	Middle Shoreface
		HCS sandstone (amalgamated)	Lower Shoreface
Mid Mid-Ramp		HCS to parallel laminated sandstone/grainstone (interbedded with shale)	Transition Zone
	Nodular (bioturbated) mudstone-wackestone (interbedded with shale)		
Distal Mid-Ramp		Nodular (bioturbated) sandstone/grainstone (interbedded with shale)	
Outer Ramp	Shale	Shale	Shelf



grainstone are present. The use of the " - " symbol between two lithologies indicates that the beds have an intermediate composition between the two lithologies. For example, "mudstone-wackestone" refers to beds that are at the limit between a mudstone and a wackestone in terms of composition, having more or less 10% bioclasts or grains.

In the present study, the siliciclastic beach-to-offshore profile is divided into foreshore, shoreface, transition zone, and shelf, with the shoreface being subdivided into upper, middle, and lower shoreface. Fairweather wave base (FWWB) is placed below the upper shoreface (generally characterized by cross-bedding), whereas storm wave base (SWB) is placed below the transition zone (Fig. 4). As for the carbonate ramp profile, it is divided into inner, mid-, and outer ramp, with the mid-ramp being subdivided into proximal, mid, and distal mid-ramp. FWWB is placed below the inner ramp, and SWB is placed below the (distal) mid-ramp (Fig. 4).

FACIES DESCRIPTIONS

Facies were differentiated on the basis of lithology, primary sedimentary structures, degree of burrowing, and particular features such as the presence of oncoids, bioherms, and channels. This led to the identification of 17 distinct facies grouped into six categories (summarized in Table 1). Unless otherwise specified, the siliciclastic fraction in all of the following facies is composed of grains of quartz and lesser feldspar.

The detailed identification of the various fossils observed in these strata is beyond the scope of this study. Nonetheless, the following observations were made. The dominant fauna consists of crinoids, brachiopods, ostracods, and bryozoans, while the accessory fauna includes molluscs (e.g. gastropods, bivalves), trilobites, calcareous algae (*Rhabdoporella, Wetheredella, Girvanella, Rauserina notata, Anticostella incrustans, Obruchevella spiralis, Flabellia ufensis, Vermiporella, Halysis, Sphaerocodium*), sponges, corals, and stromatoporoids. At this high taxonomic level, no obvious vertical changes in biotic assemblages were observed. The Laframboise Member (uppermost Ellis Bay Formation) shows a particular biotic assemblage that was described in detail by Long & Copper (1987*a*) and Copper (2001).

Facies Description for the Ellis Bay Formation

Facies	Composition	Description	Depositional setting
Calcareous shale (1)	Calcareous shale (50-80%) Siltstone / sandstone / grainstone (20-50%)	***Calcareous shale:*** Thin- to thick-bedded (3-40cm). Fissile to subnodular. ***Siltstone / sandstone / grainstone:*** Very thin- to medium-bedded (2-15cm). Siltstone is commonly bioclastic. Sandstone is very fine to fine grained and commonly bioclastic. Grainstone is commonly sandy (very fine to fine sand). Parallel laminated, generally graded, and slightly bioturbated. Subnodular bedding. Discontinuous.	Shelf / Outer ramp
Nodular sandy grainstone interbedded with calcareous shale (2A)	Sandy grainstone (50-80%) Calcareous shale (20-50%)	***Grainstone:*** Very thin- to thin-bedded (2-8cm). Usually sandy (very fine to fine sand). Locally parallel laminated. Highly bioturbated. Nodular bedding. Discontinuous. ***Calcareous shale:*** Very thin- to thin-bedded (2-10cm). Fissile to subnodular.	Lower part of transition zone / Distal mid-ramp
Tabular sandstone / grainstone interbedded with calcareous shale (2B)	Sandstone / grainstone (50-80%) Calcareous shale (20-50%)	***Sandstone / grainstone:*** Very thin- to medium-bedded (2-15cm). Sandstone is very fine to fine grained and commonly bioclastic. Grainstone is commonly sandy (very fine to fine sand). Parallel laminated, generally graded, and slightly bioturbated. Tabular to subnodular bedding. Relatively continuous. ***Calcareous shale:*** Very thin- to thin-bedded (2-10cm). Fissile to subnodular.	Middle to upper part of transition zone / Mid mid-ramp
HCS sandstone interbedded with calcareous shale (2C)	Sandstone (50-80%) Calcareous shale (20-50%)	***Sandstone:*** Thin-bedded (4-10cm). Very fine grained. Hummocky cross-stratified. Non-bioturbated. Discontinuous. ***Calcareous shale:*** Very thin- to thin-bedded (2-10cm). Fissile to subnodular.	Upper part of transition zone
Cross-stratified and rippled sandstone interbedded with calcareous shale (2D)	Sandstone (70-80%) Calcareous shale (20-30%)	***Sandstone:*** Very thin- to medium-bedded (2-20cm). Very fine grained. Hummocky to swaley cross-stratified, up to wave and current rippled and ripple cross-stratified. Graded. Soft-deformed. Highly discontinuous. ***Calcareous shale:*** Very thin- to medium-bedded (2-15cm). Fissile to subnodular. Dark grey. Locally abundant synaeresis cracks and *Planolites* burrows.	Upper part of transition zone to lower shoreface
Parallel-laminated siltstone interbedded with calcareous shale (2E)	Siltstone (50-80%) Calcareous shale (20-50%)	***Siltstone:*** Very thin- to medium-bedded (1-15cm). Generally graded, parallel laminated, and slightly bioturbated. Tabular to subnodular bedding. Discontinuous. ***Calcareous shale:*** Very thin- to thin-bedded (2-10cm). Fissile to subnodular.	Lower part of transition zone / distal mid-ramp
Nodular mudstone-wackestone interbedded with calcareous shale (3A)	Mudstone-wackestone (~80%) Calcareous shale (~20%)	***Mudstone-wackestone:*** Very thin- to thin-bedded (2-5cm). Locally graded and parallel laminated. Pervasively bioturbated. Highly nodular bedding. Discontinuous. ***Calcareous shale:*** Very thin-bedded (≤2cm). Fissile to subnodular.	Distal to mid mid-ramp
Lenticular mudstone interbedded with calcareous shale (3B)	Mudstone (~80%) Calcareous shale (~20%)	***Mudstone:*** Thin- to medium-bedded (5-15cm). Commonly graded (thin, coarser base of wackestone, packstone, or grainstone). Slightly bioturbated. Lenticular but locally more tabular bedding. ***Calcareous shale:*** Very thin-bedded (1-3cm). Commonly silty. Fissile to subnodular.	Mid to proximal mid-ramp

Facies Description for the Ellis Bay Formation

Facies	Composition	Description	Depositional setting
Wave-rippled grainstone (4A)	Grainstone (~100%)	***Grainstone:*** Small-scale wave ripple cross-stratified (wavelengths of 10-20 cm), amalgamated in cosets 10-25 cm thick. Commonly silty. Slightly graded (thin, coarser bioclastic base).	Inner ramp
Hummocky to swaley cross-stratified sandstone (4B)	Sandstone (100%)	***Sandstone:*** Hummocky to swaley cross-stratified (wavelengths of 3-8 m), amalgamated into cosets 5-50 cm thick. Very fine grained. Commonly micaceous. Graded (thin, coarser and slightly bioclastic base with frequent rip-up clasts).	Lower to middle shoreface
Cross-bedded sandstone / grainstone (4C)	Sandstone / grainstone (100%)	***Sandstone / grainstone:*** Fine to coarse grained sand, with up to pebble-size, strained, and polycrystalline quartz grains. Sandstone is usually bioclastic. Grainstone is usually sandy. Large-scale cross-bedded, in sets of 15-60 cm and cross-bedding usually oriented landward. Graded.	Upper shoreface / Inner ramp
Bioturbated sandstone (4D)	Sandstone (100%)	***Sandstone:*** Thin- to medium-bedded (4-20cm), amalgamated. Very fine grained. Bioclastic and peloid-rich, with rare and local poorly-developed oncoids. Locally flat laminated, commonly graded, and highly bioturbated. Nodular bedding. Vertical burrows and/or water escape structures truncate the planar laminations.	Foreshore
Channellized sandstone (4E)	Sandstone (100%)	***Sandstone:*** Medium-bedded (10-30cm), amalgamated. Fine to medium grained, with up to pebble-size, strained, and polycrystalline quartz grains. Bioclastic. Parallel laminated and graded.	Transgressive channel fill
Interbedded grainstone and siltstone (4F)	Grainstone (40-50%) Siltstone (50-60%)	***Grainstone:*** Very thin- to thin-bedded (2-10cm). Commonly sandy (very fine sand). Occasionally parallel laminated. Moderately bioturbated. Subnodular bedding. Discontinuous. ***Siltstone:*** Very thin- to thin-bedded (2-10cm). Laminated to bioturbated. Subnodular bedding. Discontinuous.	Middle part of transition zone / Distal to mid mid-ramp
Oncolitic grainstone (5A)	Grainstone (100%)	***Grainstone:*** Thin- to thick-bedded (4-70cm), amalgamated. Oncoid-rich and commonly intraclast-rich. Locally cross-bedded and overlain by small-scale wave ripple cross-stratified peloid-rich grainstones. Graded (upward decrease in size and abundance of oncoids). Tabular to subnodular bedding. Continuous.	Inner ramp
Calcimicrobial-coral bioherms (5B)	Boundstone (≥85%) Calcareous shale (≤15%)	***Boundstone:*** Framework of mainly corals, stromatoporoids, and calcimicrobes. Matrix of silty mudstone. Calcareous shale interbeds of the interbioherms cut through and pinch in the bioherm core. Interbioherm facies consists of oncoid-poor and bioturbated silty grainstones interbedded with calcareous shales, except in the eastern sections where it consists of amalgamated but stratiform oncolitic grainstones (Facies 5A).	Likely below FWWB
Grainstone lag (6)	Grainstone (100%)	***Grainstone:*** Very thin- to medium-bedded (2-30cm). Commonly sandy (very fine to fine sand). Massive to parallel laminated. Locally graded. Sharp-based. Continuous.	Transgressive lag

Table 1. Description of the facies identified in the Ellis Bay Formation.

CATEGORY 1: CALCAREOUS SHALE

FACIES 1 – CALCAREOUS SHALE

This facies consists of dark, fissile to subnodular (slightly bioturbated) calcareous shale with only minor discontinuous beds of generally laminated, sharp-based, very thin- to medium-bedded (2-15 cm) siltstone / sandstone / grainstone (Fig. 5, Plates 4A and 5E). The amount of calcareous shale varies between 50% and 80% in volume within this facies. The more resistant beds vary in thickness laterally. Where present, the siliciclastic sand particles are angular and very fine grained.

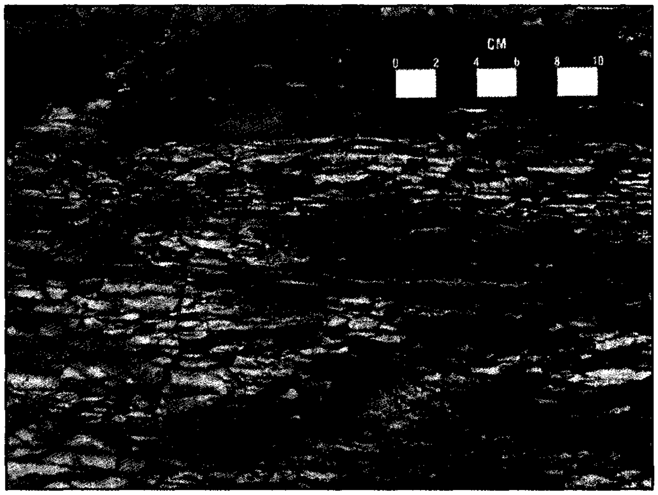


Figure 5. Facies 1 (from the basalmost Schmitt Creek Member at the Mill Bay section).

Facies 1 is interpreted to have formed below storm wave base where the seafloor was only rarely affected by storms as evidenced by the high amount of calcareous shale and sparse storm beds.

CATEGORY 2: SANDSTONE AND GRAINSTONE INTERBEDDED WITH CALCAREOUS SHALE

Five varieties of interbedded sandstone / grainstone and calcareous shale are identified on the basis of lithology and degree of burrowing of the sandstone / grainstone beds. The siliciclastic sand fraction in both sandstone and grainstone is angular to subangular. Beds of calcareous shale are 2 to 10 cm thick and make 20% to 50% in volume of these facies.

FACIES 2A – NODULAR SANDY GRAINSTONE

This facies consists of very thin- to thin-bedded (2-8 cm), nodular, highly to pervasively bioturbated sandy grainstones interbedded with calcareous shale (Fig. 6, Plate 2B to 2E). Parallel lamination is present locally, but commonly it has been obliterated by intense bioturbation. The siliciclastic fraction consists of very fine to fine sand. Beds of nodular sandy wackestone / packstone are occasionally present. This facies commonly underlies Facies 2B.

The sandy grainstones of Facies 2A are interpreted as storm beds deposited by return currents beyond fairweather wave base (FWWB) given the limited bed thickness and extensive bioturbation. The presence of numerous grainstone beds suggests deposition above storm wave base (SWB) where the seafloor was frequently influenced by storm events (Burchette & Wright, 1992). Thus, Facies 2A is taken to represent deposition in the lower part of the transition zone, between the shoreface and shelf, and corresponds to the distal mid-ramp (Burchette & Wright, 1992).

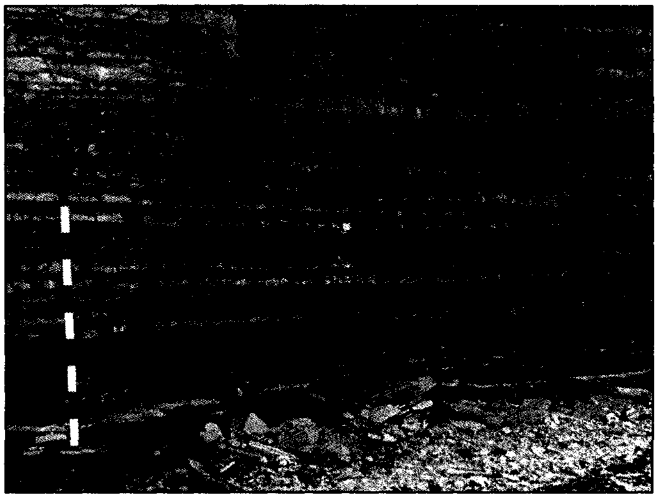


Figure 6. Facies 2A (from the basal Schmitt Creek Member at the Mill Bay section).

FACIES 2B – TABULAR SANDSTONE / GRAINSTONE

This facies consists of very thin- to medium-bedded (2-15 cm), tabular to subnodular, and generally parallel laminated sandstone / grainstone interbedded with calcareous shale. The sandstones / grainstones are sharp based, generally graded, and slightly bioturbated, with *Chondrites* burrows locally abundant (Fig. 7). The siliciclastic fraction consists of very fine to fine sand. The beds are generally continuous at the scale of the outcrop, but may nevertheless vary laterally in thickness and locally be truncated by cut and fill structures.

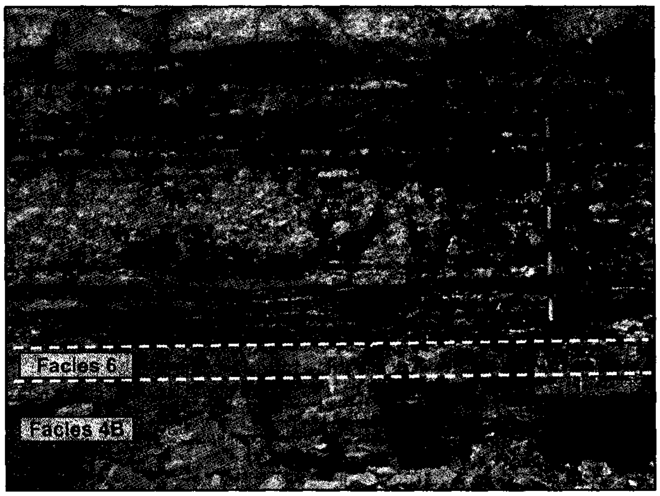


Figure 7. Facies 2B at the base and top of the meter stick, with Facies 2A in the middle (from the upper Prinsta Member, about 25 m above the base of the Ellis Bay Formation, at Lousy Cove section). Below is an HCS sandstone unit (Facies 4B) with a thin transgressive lag (Facies 6).

Considering the greater bed thickness and lesser amount of bioturbation, Facies 2B is taken to represent storm beds deposited at depths shallower than those of Facies 2A, but still below FWWB as evidenced by the occurrence of calcareous shale (Seilacher & Aigner, 1991).

Facies 2B is interpreted to reflect deposition in the middle to upper part of the transition zone, which corresponds to a mid mid-ramp setting following Burchette & Wright (1992).

FACIES 2C – HUMMOCKY CROSS-STRATIFIED SANDSTONE

This facies consists of discontinuous, non-bioturbated, 4 to 10 cm thick beds of very fine grained HCS sandstone interbedded with calcareous shale (Fig. 8, Plate 2D). Where present Facies 2C grades into the "amalgamated HCS" of Facies 4B.

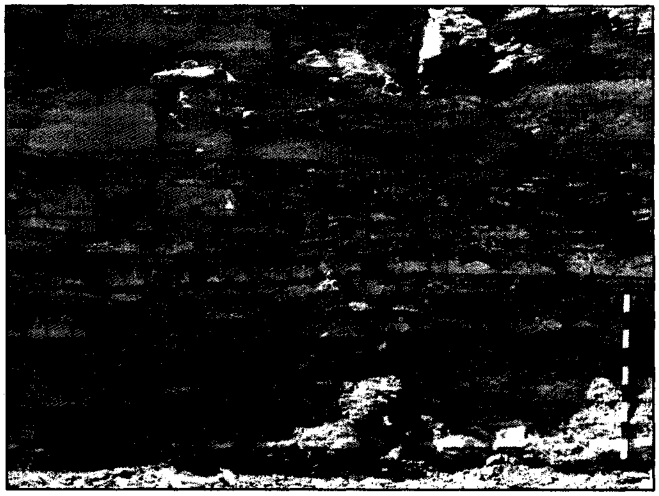


Figure 8. Facies 2C (from the middle Velleda Member at Lousy Cove section). It is overlain by an HCS sandstone unit (Facies 4B).

It is generally accepted that the transition from sand to mud along a coastline coincides with the base of the shoreface and that hummocky cross-stratification is a structure formed by oscillatory-dominated combined flows during storms (Duke et al., 1991; Clifton, 2006). Thus, the interbedded HCS sandstone and calcareous shale of Facies 2C are interpreted to reflect deposition just beyond the base of the shoreface (i.e. in the upper part of the transition zone), where sandy deposits were commonly transported by enhanced return currents and then reworked by combined flows to form HCS.

FACIES 2D – CROSS-STRATIFIED AND RIPPLED SANDSTONE

This facies consists of very thin- to medium-bedded (2-20 cm), very fine grained sandstone interbedded with dark grey calcareous shale (Fig. 9, Plate 1D to 1H). The sandstones are characterized by hummocky and swaley cross-stratification (HCS and SCS), which commonly grade up into 2D or 3D wave and current ripples or ripple cross-lamination. The sandstones are erosionally based, cutting into the underlying calcareous shale or sandstone beds, or both, which often results in amalgamated and highly discontinuous and lenticular beds forming cut and fill structures. Rip-up clasts are commonly present at the base of sandstone beds. Other beds show a coarser base of grainstone or bioclastic sandstone. Small soft-sediment deformation structures (balls and pillows) commonly occur in these sandstones.

Sandy starved ripples are also present in the calcareous shale. The calcareous shale beds are up to 15 cm thick with locally abundant synaeresis cracks and *Planolites* burrows.

The grading of HCS and SCS into rippled beds may reflect deposition from episodic waning flows. Synaeresis cracks are most commonly attributed to salinity changes reflecting periodic influx of freshwater (Burst, 1965; Collinson & Thompson, 1989). This represents a stressed environment for marine organisms and explains the restricted marine fauna (*Planolites*) present in this facies. Also, the organic-rich calcareous shale indicates an environment relatively close to the continent in addition to common soft-sediment deformation that most probably indicates rapid deposition of sand onto a water-rich, soupy substrate (Bhattacharya & Walker, 1991). These features are typical of river-influenced shallow marine environments and closely resemble those described by Bhattacharya & Walker (1991) for river-dominated delta front deposits. However, the ubiquitous HCS and SCS suggest that these deposits were also significantly influenced by storm waves. Facies 2D was likely deposited on a wave-influenced delta front similar to that described by Bhattacharya & Walker (1991), as it shows characteristics of both river-dominated delta front and storm-dominated shoreface deposits.

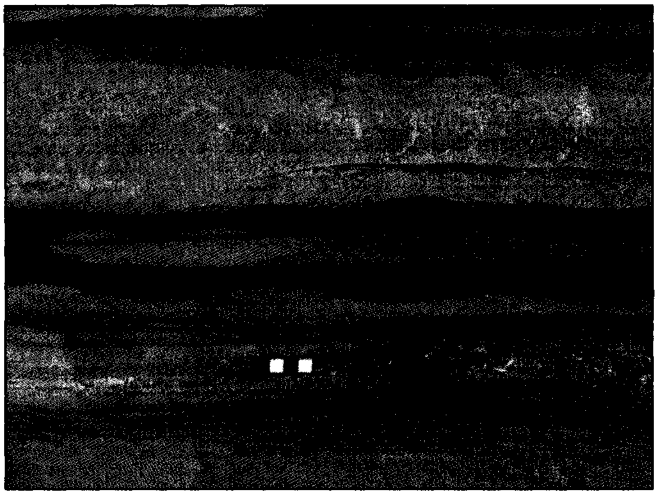


Figure 9. Facies 2D (from the middle Grindstone Member at Table Head, in the northernmost part of Lousy Cove section).

FACIES 2E – PARALLEL-LAMINATED SILTSTONE

This facies consists generally of parallel laminated, very thin- to medium-bedded (1-15 cm), graded, and slightly bioturbated (tabular to subnodular) siltstone to very fine sandstone interbedded with calcareous shale (Fig. 10). Bioclastic material is rare. This facies lies immediately below Facies 4F.

Contrasting with Facies 4F, Facies 2E shows argillaceous interbeds and only scattered bioclastic material. This, combined with the generally finer grain size, parallel lamination, and stratigraphic context (see Facies 4F and DS-4), suggests that Facies 2E was deposited by weaker storm currents in an environment slightly deeper than Facies 4F, possibly around the lower part of the transition zone (and equivalent distal mid-ramp).

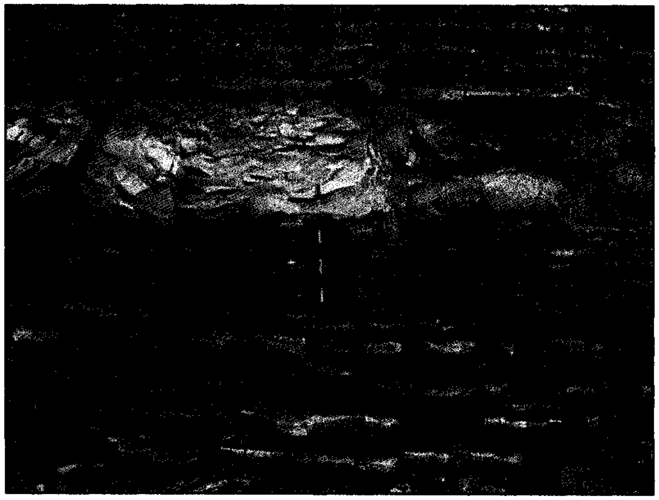


Figure 10. Facies 2E (from the basal Lousy Cove Member at Lousy Cove section). Note the characteristic large balls and pillows.

CATEGORY 3: MUDSTONE AND WACKESTONE INTERBEDDED WITH CALCAREOUS SHALE

The mudstones and wackestones in this category contain a small amount of siliciclastic silt particles. The calcareous shale interbeds are generally ≤2 cm thick and form about 20% of the lithologies.

FACIES 3A – NODULAR MUDSTONE-WACKESTONE

This facies consists of discontinuous, nodular to highly nodular, pervasively bioturbated beds of very thin- to thin-bedded (2-5 cm) mudstone-wackestone and minor packstone / grainstone interbedded with calcareous shale (Fig. 11, Plates 2G, 4B, 4C, 5E to 5G). Despite the extensive bioturbation, some beds show normal grading and parallel lamination. Rare thicker (4-8 cm), continuous, and

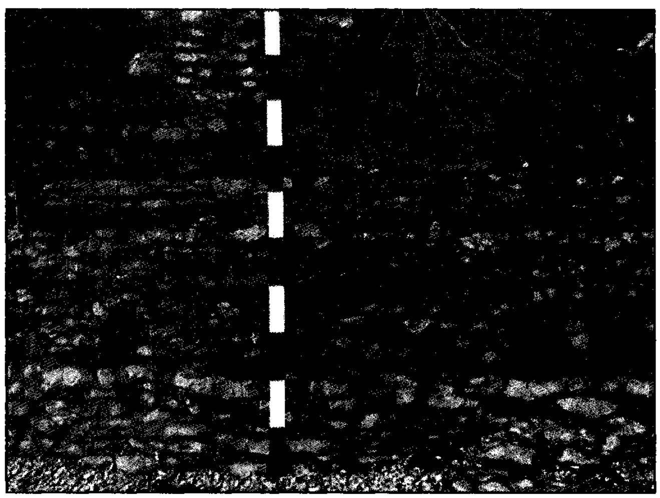


Figure 11. Facies 3A (from section 2 at the west end of the island).

tabular beds of laminated and graded packstone / grainstone also occur.

The normal grading and planar laminae suggest that these beds were emplaced by waning flows, while the intense bioturbation, small bed thickness, and presence of argillaceous interbeds point to a relatively deep environment (Aigner, 1982; Seilacher & Aigner, 1991). On this basis, the mudstones-wackestones (and lesser packstones / grainstones) of Facies 3A are interpreted as having been deposited out of suspension by density currents in a distal to mid mid-ramp setting (distal tempestites) and subsequently extensively bioturbated (Aigner, 1982).

FACIES 3B – LENTICULAR MUDSTONE

This facies consists of highly discontinuous and lenticular beds of thin- to medium-bedded (5-15 cm) mudstone and lesser wackestone interbedded with calcareous shale (Fig. 12, Plates 2H, 4D, 4E, 5E, 5F). The beds are up to few tens of meters in length. Ubiquitous bed truncation and common amalgamation, combined with local flute casts suggest that the lenticular (or hummock) shape of the beds is mainly erosional (cut and fills) rather than depositional (pinch and swells). The thin layers of calcareous shale draping the hummock-shaped storm (mudstone) beds represent fairweather sedimentation following erosion and sediment bypass. Alternatively, these thin layers of calcareous shale may correspond to fairweather sedimentation directly following the storm deposit, implying that some of the hummock-shaped beds may also be depositional. The mudstone-wackestone beds commonly show a thin coarser base of packstone / grainstone and *Chondrites* burrows. Bioturbation is generally low to moderate. These mudstones are locally continuous and tabular at the scale of the outcrop.

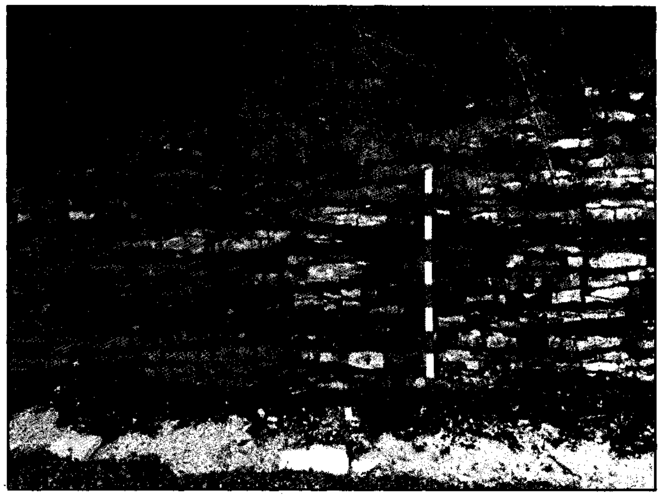


Figure 12. Facies 3B (from section 2 at the west end of the island).

Facies 3B is viewed as muddy tempestites deposited from density currents, but the greater bed thickness and lesser bioturbation suggest a shallower environment than Facies 3A

(Seilacher & Aigner, 1991). Accordingly, Facies 3B is taken to reflect deposition on a carbonate mid to proximal mid-ramp.

CATEGORY 4: SANDSTONE AND GRAINSTONE

This category comprises facies composed of amalgamated beds of sandstone and/or grainstone, showing only rare thin (≤1 cm) calcareous shale interbeds. On the basis of the different sedimentary structures, seven facies are recognized.

FACIES 4A – WAVE-RIPPLED GRAINSTONE

This facies consists of silty and locally peloid-rich fine-grained grainstones organized into amalgamated, 10-25 cm thick cosets (or beds) of small-scale wave ripple cross-stratification with wavelengths of 10-20 cm (Fig. 13, Plates 4F, 4G, 5G, 5H). The cosets (or beds) usually have a thin erosional and slightly coarser bioclastic base, and show a weak normal grading. Frequent vertical burrows and/or water escape structures truncate the small-scale lamination.

Figure 13. Facies 4A (from section 2 at the west end of the island). Note the vertical burrows.

The amalgamated small-scale wave ripple cross-stratification suggests that Facies 4A was formed in an inner ramp setting (above FWWB) where the shallow depth and associated short wavelength waves restricted the formation of larger ripples (Clifton, 2006; Dumas & Arnott, 2006). Alternatively, the small-scale wave ripple cross-stratification could be the result of large waves reworking the sea-bottom at greater depths (e.g. between FWWB and SWB), but the absence of calcareous shale interbeds rather suggests a shallower, constantly agitated environment.

FACIES 4B – HUMMOCKY TO SWALEY CROSS-STRATIFIED SANDSTONE

This facies consists of commonly micaceous, angular and very fine grained sandstone organized into amalgamated, 5-50 cm thick cosets (or beds) of HCS and/or SCS with wavelengths of 3-8 m (Fig. 14, Plates 1D, 2A, 2D). The cosets (beds) have an erosional and usually coarser, slightly bioclastic base with abundant rip-up clasts. Amalgamated HCS and SCS typically occur above the interbedded HCS of Facies 2C. Where both are present in a single succession, HCS grades upward into SCS.

The proper conditions for the generation of amalgamated HCS (e.g. large and fast wave orbitals, symmetric waves, slow unidirectional currents, low net sedimentation rates) are typically found on the lower shoreface during storms (Dumas & Arnott, 2006). It is also thought that HCS and SCS must form below FWWB in order to avoid subsequent reworking by fairweather waves and currents. The presence of rip-up clasts of calcareous shale at the base of HCS/SCS cosets also suggests that they were formed below FWWB rather than above it. Therefore, Facies 4B is interpreted as having been emplaced on the lower to middle shoreface (HCS and SCS, respectively), below FWWB.

Figure 14. Facies 4B (from the basal Grindstone Member at Prinsta section).

Facies 4C – Cross-bedded sandstone / grainstone

This facies consists of graded and large-scale cross-bedded, subrounded to rounded, fine to coarse grained sandstone to sandy grainstone with up to pebble-size, rounded, strained, and polycrystalline quartz grains (Fig. 15, Plate 2A, 2B, 2G). The siliciclastic fraction in some beds is bimodal, showing an additional component of angular, very fine sand. The sets are 15-60 cm thick and cross-bedding is oriented landward (n = 11, mean = 35°). Facies 4C is erosionally based and typically occurs at the top of major coarsening-upward (progradational) successions. It is underlain by either Facies 2B or Facies 4B and overlain by Facies 2A or Facies 6.

The presence of strained and polycrystalline quartz grains indicates derivation from metamorphic rocks, probably from the northerly adjacent Precambrian Canadian Shield. Based on cross-bedding, coarse grain size, and stratigraphic context, Facies 4C is interpreted to correspond to the upper shoreface (or inner ramp), above FWWB. Also, because upper shoreface cross-bedding is generally oriented landward when formed during fairweather conditions but seaward when generated during storms (Clifton, 2006), Facies 4C is interpreted to reflect fairweather deposition.

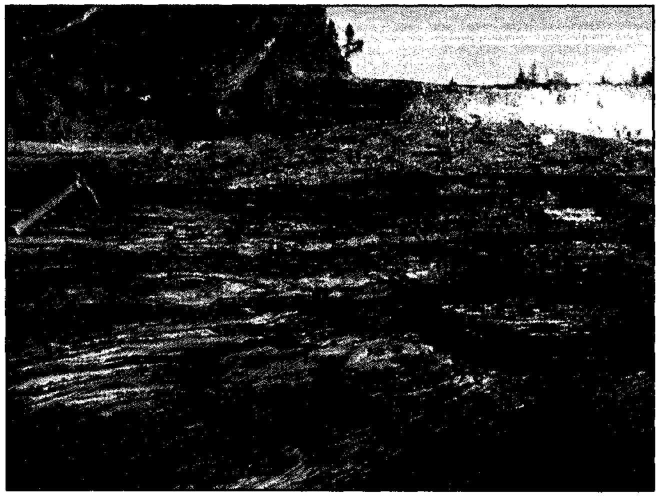


Figure 15. Facies 4C (from the uppermost Velleda Member at the top of the Schmitt Falls, about 800 m from the mouth of Schmitt River in Mill Bay). Cross-bedding is just above the hammer, underlain by SCS sandstones.

Facies 4D – Bioturbated Sandstone

This facies consists of thin to medium (4-20 cm) beds of amalgamated, highly bioturbated, nodular, often graded, generally peloid-rich, and very fine-grained bioclastic sandstone or, occasionally, sandy grainstone (Fig. 16, Plates 2H, 3A to 3D). Flat lamination is commonly present in rare small non-bioturbated "windows" and in a 5-20 cm thick bed at the top of the unit. Where present, the laminae are typically truncated by vertical burrows and/or water escape structures. Small poorly-developed oncoids are present but rare.

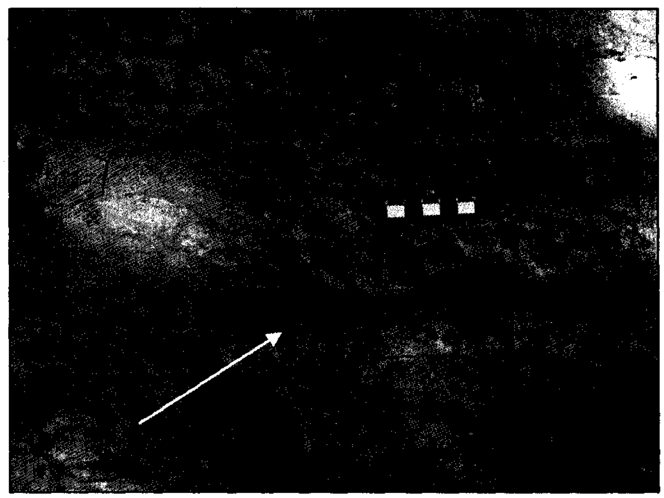


Figure 16. Facies 4D (from the uppermost Lousy Cove Member in Schmitt River, 1.8 to 2 km from the the mouth of the river in Mill Bay). Note the non-bioturbated "window" about 20 cm from the bottom (arrow).

Based on the flat lamination, vertical burrows and/or water escape structures (both indicative of high deposition rate), and stratigraphic context, Facies 4D is interpreted as a shallow marine deposit emplaced above FWWB, possibly in the foreshore where flat lamination can form.

FACIES 4E – CHANNELLIZED SANDSTONE

This facies consists of medium-bedded (10-30 cm) and amalgamated fine- to medium-grained sandstone with strained and polycrystalline quartz grains up to pebble size (~5 mm; Fig. 17). Beds are graded and parallel laminated and generally bioclastic. This facies is present at the top of a major coarsening-upward (progradational) succession and is confined within a channel-shaped structure that incises underlying lithologies (Facies 4B and locally Facies 2D). Overall, there is an upward decrease in grain size from bottom to top of the channel fill. It is

Figure 17. Facies 4E (from the uppermost Grindstone Member in Prinsta section). The picture in the lower left corner shows a closer view of the coarse facies at the bottom of the channel.

overlain by a transgressive lag (Facies 6).

The upward decrease in grain size and the presence of marine organisms suggest that the channel fill records a marine transgression rather than prograding fluvial deposits.

FACIES 4F – INTERBEDDED GRAINSTONE AND SILTSTONE

This facies consists of very thin- to thin-bedded (2-10 cm), subnodular, moderately bioturbated, and occasionally parallel laminated coarse grainstone to sandy grainstone interbedded with very thin to thin beds (2-10 cm) of laminated to bioturbated siltstone (Fig. 18, Plate 2F and 2G). Very fine-grained sandstone with occasional HCS is locally present at the base of the siltstone interbeds. The grainstone beds are erosionally based and generally discontinuous at the scale of the outcrop (50-100 m), either pinching or being scoured and occasionally amalgamated with an overlying grainstone bed. *Chondrites* burrows are common in the grainstone beds.

Facies 4F is interpreted as having been emplaced on a mixed carbonate-siliciclastic shoreface (or ramp) where the grainstones represent storm deposits (tempestites) and the fine siliciclastics the fairweather background sedimentation derived from an adjacent river plume (see Discussion below). Overall, the common storm beds, combined with the general absence of sedimentary structures (lamination), the moderate bioturbation, and the preservation of interbedded fine siliciclastic sediment, is interpreted to reflect a relatively low energy environment between FWWB and SWB, suggesting that Facies 4F was deposited approximately in the middle part of the transition zone (and equivalent distal to mid mid-ramp).

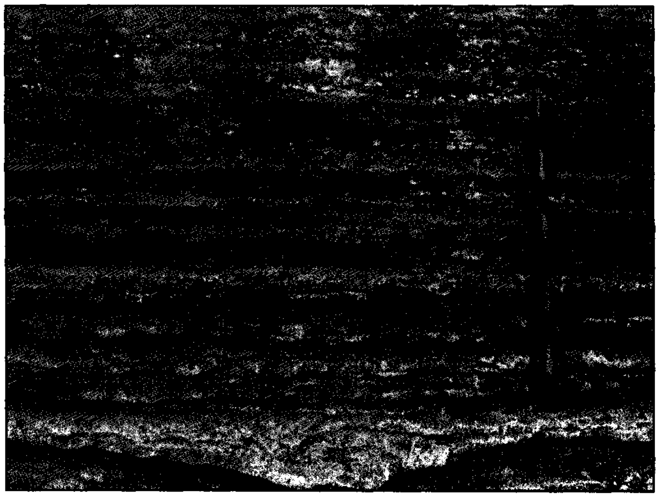


Figure 18. Facies 4F (from the middle Lousy Cove Member in Lousy Cove section). The reddish and more resistant beds are grainstones, whereas the grey and more recessive beds are siltstones.

CATEGORY 5: ONCOLITIC AND REEFAL LIMESTONE

These facies have a particular fauna assemblage, which was described in detail by Long & Copper (1987*a*) and Copper (2001).

FACIES 5A – ONCOLITIC GRAINSTONE

This facies consists of amalgamated, tabular to subnodular, thin- to thick-bedded (4-70 cm) oncoid-bearing grainstones (and lesser packstones) with intraclasts of the underlying lithologies (Fig. 19, Plates 2H, 3A to 3D, 4H, 5A, 5H). The oncoids are rather elongated, globally aligned, subparallel to the base of the bed, and decrease in size and abundance upward. Noteworthy is the smaller size of the oncoids in the eastern sections (up to 2 cm long) compared to those present elsewhere on the island. Although minor differences exist along the outcrop belt, this facies defines the only unit traceable from west to east, serving as an important marker unit in the study area.

In the western Anticosti sections, this facies consists of structureless thin- to medium-bedded (4-15 cm) packstones / grainstones forming a unit approximately 40 cm thick.

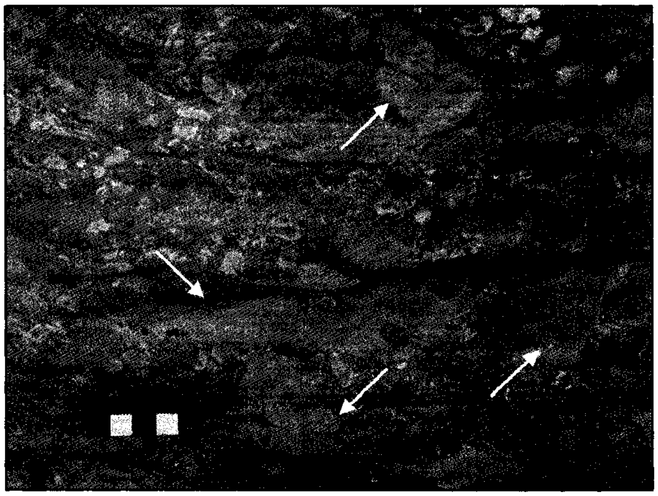


Figure 19. Facies 5A (from an isolated block along the road close to Saumons Camp at the east end of the island). Note the numerous laminated intraclasts (arrows).

In the eastern Anticosti sections where it is up to 70 cm thick, the oncolitic facies appears as a single massive thick bed, but locally shows argillaceous partings and even faint fining-upward “packages” suggesting amalgamation of several thinner (5-20 cm) beds. The oncolitic grainstones are locally cross-bedded and overlain by oncoid-free small-scale wave ripple cross-stratified peloid-rich grainstones.

Considering the concentrically-laminated (although not spherical) oncoids, Facies 5A is interpreted as having been emplaced above FWWB in a constantly agitated environment where waves were able to roll the oncoids (Boggs, 2001). Where present, the cross-bedding and the small-scale wave ripple cross-stratification support such a shallow and energetic environment, corresponding to an inner ramp setting. However, the fining-upward trend suggests an upward decrease in energy probably associated with a modest relative sea-level rise.

FACIES 5B – CALCIMICROBIAL-CORAL BIOHERMS

This facies consists of bioherm cores and their associated interbiohermal strata, both capped by an erosion surface. A detailed account of the internal architecture of the Laframboise bioherms is beyond the scope of the present study but presented elsewhere (Desrochers et al., 2008).

The bioherms consist of lenticular-shaped bioconstructions with a framework of corals, stromatoporoids, and calcimicrobes and a matrix of silty mudstone (Fig. 20, Plates 3D, 5B, 5H). Minor argillaceous interbeds are traced across the bioherms. These interbeds are the extensions of argillaceous interbeds from the time-equivalent interbioherm facies. The top of both bioherms and interbioherms consists of a black, pyrite-rich hardground (Plate 5C) with up to 2 m of relief at Pointe Laframboise and possibly 8 m in Rivière aux Saumons. In the western sections, the interbioherm facies gradationally overlies Facies 5A and consists of bioturbated, nodular, generally graded and laminated silty grainstones with few oncoids and interbedded with calcareous shales. The oncoids decrease in size and abundance upward. In the eastern sections, the interbioherm facies consists of the fining-upward oncolitic grainstones of Facies 5A.

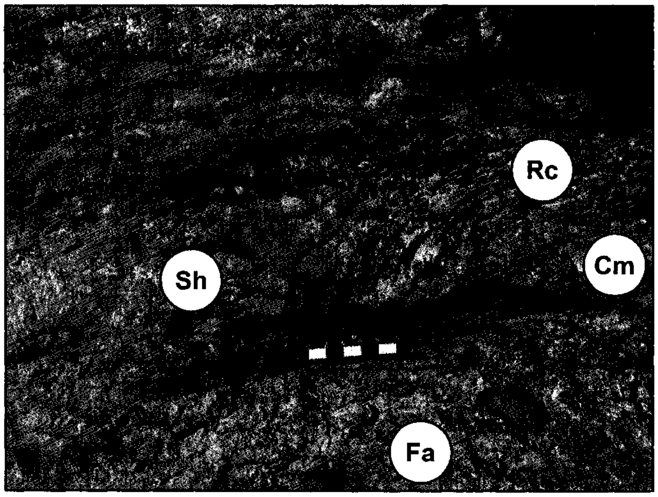


Figure 20. Facies 5B (from the Laframboise Member in section 1 at the west end of the island). Fa = Favosites coral; Rc = colonial rugose corals; Cm = calcimicrobes (small reddish nuggets); Sh = calcareous shale.

The upward decrease in size and abundance of the oncoids in the interbioherms from both the western and eastern sections suggests a decrease in energy associated with a modest deepening (transgression). Yet, the presence of oncoids in the interbioherms suggests that they were, along with their contemporaneous bioherms, formed in a shallow marine environment. The hardground probably formed following a time of non-deposition and erosion prior to deposition of the Becscie Formation.

Category 6: Grainstone Lag

Facies 6 – Grainstone lag

This facies generally consists of sharp-based very thin to medium (2-30 cm) beds of massive to parallel laminated and locally graded grainstone to sandy grainstone. The siliciclastic sand fraction is very fine to fine. Although varying in thickness laterally, this facies forms a continuous layer that overlies minor and major coarsening-upward (progradational) successions (Fig. 21, Plate 2D and 2G), usually with shallow sandstone deposits below (Facies 4B) and deeper argillaceous deposits above (Facies 2A, 2B or 2D).

Figure 21. Facies 6 (capping the Grindstone Member in Lousy Cove Section). The *Paleofavosites* coral-rich lag (immediately below the meter) is underlain by SCS sandstones (Facies 4B) of the Grindstone Member and overlain by sandstones / grainstones interbedded with shale (Facies 2A to 2B) of the Velleda Member.

The distinct occurrence of HCS and SCS sandstone below and marine calcareous shale above the sharp-based grainstone beds suggests that the latter represent transgressive lags (Bhattacharya & Walker, 1991). These carbonate-dominated strata of Facies 6 highly contrast the underlying siliciclastic-rich lithologies, suggesting that siliciclastic sediment was most probably trapped closer to shore. This change in lithology is a common occurrence during transgression where much of the river-fed sand is trapped in estuaries instead of reaching the basin (Allen, 1991), thus supporting the transgressive lag interpretation.

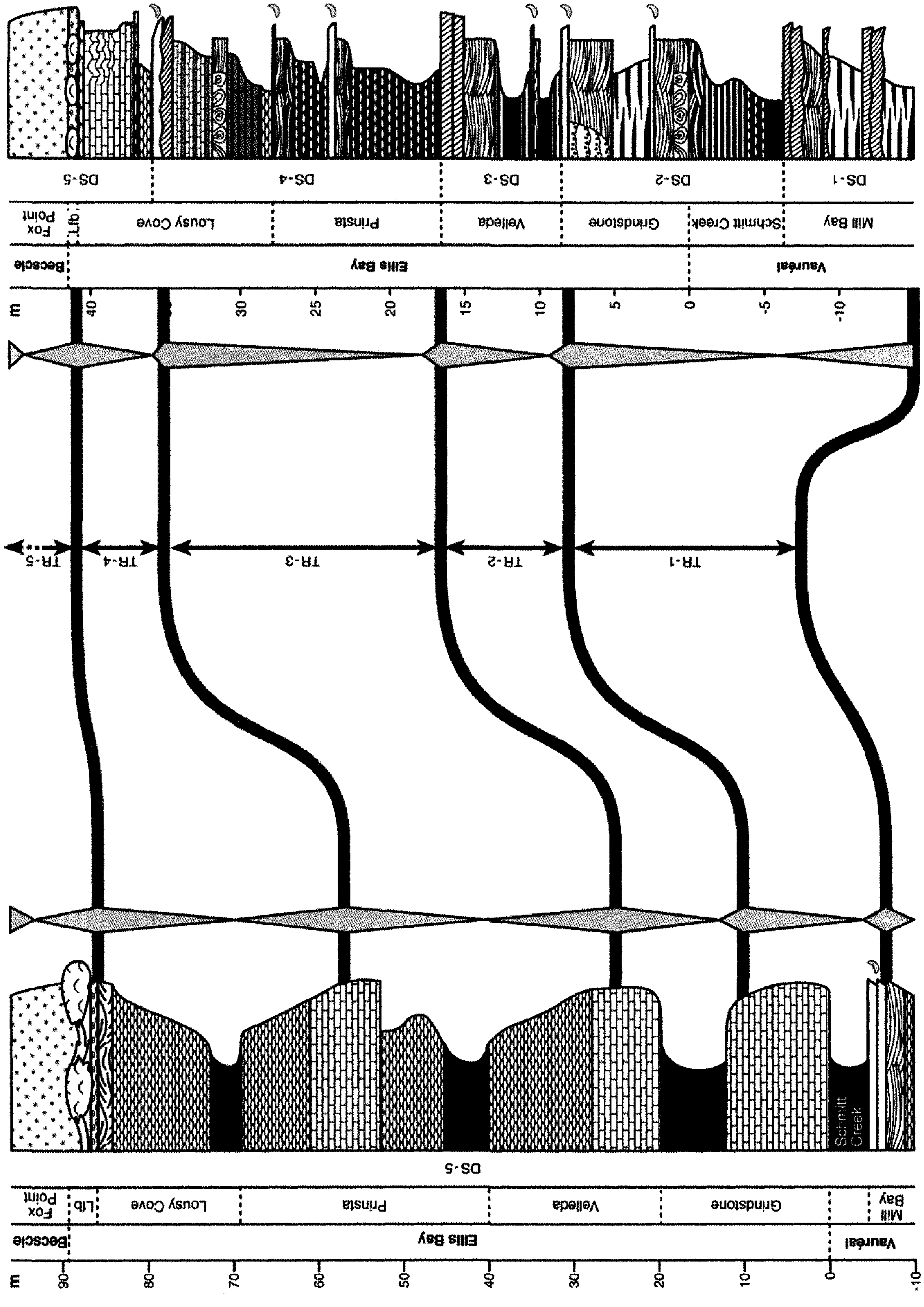
DEPOSITIONAL SYSTEMS

The vertical and lateral distribution of the Ellis Bay and associated facies described above define five facies successions (labelled as interpretive depositional systems below; Fig. 22). In the eastern siliciclastic-rich sections, individual facies successions display an overall coarsening-upward character (except for the first one) capped by a transgressive surface, and correspond to a distinct siliciclastic-dominated, mixed carbonate-siliciclastic, or carbonate-dominated depositional system (DS-1 to DS-5). In the western carbonate sections, the overall facies succession displays a cyclic pattern associated with a longer-lived, storm-influenced carbonate depositional system (DS-5).

DEPOSITIONAL SYSTEM 1 – INCISED-VALLEY FILL

Depositional System 1 (DS-1) is only present in the eastern sections (Fig. 22). It is at least 9 m thick, terminates approximately 6.5 m below the Vauréal – Ellis Bay contact (at the

Figure 22. Stratigraphy of the western (left) and eastern (right) Ellis Bay Formation and associated strata with their corresponding depositional systems (DS-1 to DS-5). Note that the eastern sections are defined by the stacking of five depositional systems (DS-1 to DS-5), whereas the western sections are only defined by DS-5. TR-1 to TR-5 designate five major transgressive-regressive sequences, which were used to establish a precise correlation between the eastern and western sections (thick red lines).



m
Becscie
Ellis Bay
Vauréal
Fox Point
Lfb.
Lousy Cove
Prinsta
Vellede
Grindstone
Schmitt Creek
Mill Bay
DS-1
DS-2
DS-3
DS-4
DS-5
TR-1
TR-2
TR-3
TR-4
TR-5
Schmitt Creek

Mill Bay – Schmitt Creek contact), and corresponds to the Mill Bay Member (*sensu* Long & Copper, 1987*a*). The Mill Bay was only briefly described in the field as it was originally not part of this project. For this reason, its constitutive facies are not included in the descriptions above. Preliminary observations are provided below.

This succession comprises sandstone and grainstone interbedded with 1-10 cm thick calcareous shale (Plate 1A), resembling Facies 2D. The sandstones are very thin- to medium-bedded (1-20 cm), very fine- to medium-grained, and sometimes amalgamated into <50 cm thick beds. They are hummocky to swaley cross-stratified and commonly grade upward into ripple cross-stratified, or rippled sandstone. They commonly have an erosive, coarser, bioclastic base. They are frequently cut and filled by grainstones and occasionally deformed by small to large (<50 cm thick) ball and pillow forms. Grainstones are very thin- to thick-bedded (2-60 cm), coarse, commonly sandy, reddish-looking, typically normally graded and cross-bedded in sets up to 60 cm thick, and erosionally based. Cross-bedding is typically sigmoidal with mud drapes. Overall, sandstone-dominated units alternate with grainstone-dominated units (a sandstone-dominated unit still contains several beds of grainstones, and vice-versa). Paleocurrent data show a clear basinward orientation (mean = 170°). The uppermost part of the succession consists of coarse generally cross-bedded grainstones that contain large (<1.5 m in diameter) *in situ* hemispherical colonies of *Paleofavosites* corals (Long & Copper, 1987; Plates 1B and 3E) and some medium- to coarse-grained sand particles.

More details on the Mill Bay strata in the eastern sections can be found in Long and Copper (1987*a*). However, it should be noted that I interpret their "brown sandstones" and some of their "coarse-grained" and "trough cross-bedded sandstones" as corresponding to my reddish-coloured coarse grainstones. In my opinion, cross-bedding in the Mill Bay is characteristic of coarse grainstones whereas sandstones are mostly hummocky to swaley cross-stratified.

Sigmoidal cross-bedding and mud drapes are interpreted to represent a tidal origin (Kreida & Moiola, 1986), where sigmoidal cross-bedding reflects the varying intensity of tidal currents within a month (changing the angle of the cross-bedding), and mud drapes correspond to the sediment fallout during slack tides. Hummocky and swaley cross-stratification, as well as the abundant marine bioclasts forming the grainstones point to a shallow storm-influenced marine environment. Together with the stratigraphic position of DS-1 (lying immediately below a major marine flooding surface and overlain by DS-2, interpreted as a storm-influenced delta deposit), these features suggest that DS-1 was deposited in an incised valley where tidal currents were amplified and able to form large-scale dunes. The presence of HCS and SCS and abundant bioclasts also points to an environment where the marine influence was important, placing DS-1 in the outer, marine-dominated region of the valley, also referred to as the mouth of the incised valley (Reinson, 1992; Boyd et al., 2006). Although the basal erosion surface associated with the incised valley lies lower in the succession, the overall upward increase in bioclastic material (grainstones) is interpreted to reflect increasing marine influence associated with a relative sea-level rise.

Depositional System 2 – Storm-Influenced Delta

Depositional System 2 (DS-2) is also characteristic of eastern Anticosti sections only (Fig. 22). It extends from 6.5 m below the Vauréal – Ellis Bay contact to 8.5 m above. It comprises the argillaceous Schmitt Creek and overlying sandy Grindstone members (*sensu* Long & Copper, 1987*a*). It displays an overall shallowing-upward character, with one to two superimposed smaller-scale shallowing-upward sub-sequences (or cycles). It directly overlies coarse cross-bedded grainstones of the Mill Bay Member, above a transgressive ravinement surface.

In this study, the Grindstone Member has an average thickness of 8.5 m (up to 12 m), but the thickness of internal units (Facies 2D and 4B) varies laterally. This contrasts the 18.25 m proposed by Long & Copper (1987*a*), which most likely reflects the misidentification of the Grindstone Member in different sections. For example, they suggested that only the basal 14.1 m is exposed at the type section (i.e. Grindstone Cliff), implying that the entire cliff exposure consists of the Grindstone Member. At the type section, I really recognize not only the fully exposed Grindstone Member (~8 m) but also the overlying Velleda Member (8-10 m thick). This is supported by hummocky cross-stratification and trough cross-bedding that Long & Copper (1987*a*) observed in the upper part of the cliff and considered to be part of the upper Grindstone Member. These depositional features, however, are similar to structures observed in the upper Velleda Member in the Lousy Cove section (see DS-3). Similarly, Long & Copper (1987*a*) considered the top of the Schmitt Creek Falls as the basal Velleda Member, while I attribute it to the basal, recessive-weathering Prinsta Member where aulacerid-rich beds are abundant. This implies that the falls themselves correspond to the underlying Velleda rather than the Grindstone Member. Accordingly, I placed the Grindstone – Velleda contact about 1.5 m above the base of the falls, at the top of a 70 cm thick unit comprising several amalgamated and erosionally-based beds of graded and laminated bioclastic very fine- to fine-grained sandstone with large aulacerids and corals (correlative with the transgressive lag observed elsewhere). The latter unit, in turn, is overlain by a recessive-weathering unit of calcareous shale (Facies 1) characteristic of the basal Velleda Member (Long & Copper, 1987*a*), thus supporting my interpretation. Finally, Long & Copper (1987*a*) reported that the Grindstone Member forms most of the cliff on which the lighthouse is built at Table Head. The Grindstone Member in this study forms about half of the cliff, with the very top of the cliff corresponding to the contact between resistant sandstone in the upper Velleda Member and the recessive-weathering aulacerid-rich basal Prinsta Member. This is supported by the presence of numerous broken aulacerids in talus immediately adjacent to the top of the cliff.

DS-2 is interpreted as a prograding storm-(or wave-) influenced delta deposit. A more complete delta system could not, however, be unequivocally identified due to the limited control and lack of 3D subsurface analysis. It shows a coarsening- and shallowing-upward trend as well as characteristics of both river-dominated delta front and storm-dominated shoreface deposits (Bhattacharya & Walker, 1991; 1992; Bhattacharya, 2006). The presence of marginal marine conditions (as indicated by the synaeresis cracks and limited fauna, *Planolites*, in Facies 2D) suggests a stressed shallow marine environment characterized by periodic freshwater influx, while the presence of HCS and SCS indicates an important storm wave influence. On this basis, DS-2 is interpreted as a storm-influenced delta deposit, which is further supported by the common balls and pillow structures reflecting high sedimentation rates and the angular-shaped nature of the sand particles indicating a short travel distance and relatively little reworking. However, it should be noted that both synaeresis cracks and soft-sediment deformation structures could also result from contemporaneous seismic activity (Pratt, 1998) associated with active faulting until latest Ordovician time (Bordet et al., *in press*). Alternatively, DS-2 could correspond to a storm-dominated strandplain deposit located very close to an adjacent delta. The fissile calcareous shales (Facies 1) passing upward into the interbedded HCS (Facies 2C) of the Schmitt Creek Member represents a prograding muddy prodelta succession (Bhattacharya, 2006), with increasing number of preserved storm events and increasing bed thickness attributed to gradually more proximal (and shallower) conditions. The mixed carbonate-siliciclastic nature of the prodelta tempestites likely represents fine siliciclastic particles transported relatively far from the delta as suspended load (plume) and deposited on a sea floor with abundant marine organisms and carbonate shells. As expected, the observed shallowing is accompanied by an increase in siliciclastics due to the advancing siliciclastic input. The upward transition into amalgamated HCS and SCS sandstone (Facies 4B) of the Grindstone Member indicates further progradation and marks the passage into the sandy delta front (Bhattacharya, 2006). The next unit, characterized by interbedded sandstone and calcareous shale (Facies 2D), represents a slight deepening, and is followed by another shallowing as indicated by the second unit of amalgamated SCS sandstone (Facies 4B) of the Grindstone Member. The channels (Facies 4E) that locally cut into this last sandstone unit reflect the maximum progradation recorded in this depositional system and imply a possible subaerial exposure of the surrounding incised strata under forced regression conditions. The grainstone transgressive lag (Facies 6) capping both the SCS and channel sandstones may actually represent transgressive shoals (Bhattacharya, 2006; Arnott, pers. comm., 2007) as it locally consists of several superimposed pinching grainstone beds.

DEPOSITIONAL SYSTEM 3 – STORM-DOMINATED STRANDPLAIN

Depositional System 3 (DS-3) is only present in the eastern sections (Fig. 22). It extends from 8.5 m to approximately 18 m above the base of the Ellis Bay Formation and corresponds to the Velleda Member (*sensu* Long & Copper, 1987*a*). It shows a coarsening- and shallowing-upward trend interrupted by a slight deepening near its base, thus defining two smaller shallowing-upward sub-sequences. It disconformably overlies the transgressive grainstones capping the Grindstone Member.

DS-3 is interpreted as a prograding, storm-dominated strandplain deposit as it shows a vertical succession very similar to the typical succession of a storm-dominated prograding shoreface (Bhattacharya & Walker, 1991; Clifton, 2006). However, sparse synaeresis cracks and soft-sediment deformation structures (balls and pillows) suggest an environment slightly affected by periodic influxes of freshwater and high sedimentation rates, respectively, in the vicinity of a delta. Yet, the vertical succession of DS-3 (see below), combined with the lesser amount of synaeresis cracks and soft-sediment deformation structures suggest an environment slightly more distant from the delta compared to DS-2. The transition from basal, offshore calcareous shale (Facies 1) to middle shoreface amalgamated SCS sandstone (Facies 4B) represents a first phase of shallowing accompanied by an increased storm and wave influence. This is followed by a gradual deepening as indicated by the overlying interbedded tabular sandstone / grainstone (Facies 2B) and calcareous shale (Facies 1) representing the upper transition zone and shelf, respectively. The second and more important shallowing-upward phase begins with calcareous shale (Facies 1) passing into interbedded HCS sandstones (Facies 2C) that eventually grade upward into amalgamated HCS and SCS sandstones (Facies 4B) typical of the lower and middle shoreface. The overlying cross-bedded fine-grained sandstone grades into cross-bedded medium- to coarse-grained sandstone (Facies 4C) which reflect continued shallowing (coarsening) within the upper shoreface. Flat-laminated sandstone is not present above the cross-bedded sandstones, likely having been eroded during the ensuing transgression considering that the top of the cross-bedded sandstones corresponds to a transgressive ravinement surface; or they were never deposited. The mixed carbonate-siliciclastic tempestites of the transition zone are interpreted to result of suspension deposition of fine siliciclastic material derived from a river plume on a sea floor largely covered with marine organisms and shells, where both siliciclastic particles and carbonate shells were reworked during storms.

Depositional System 4 – Storm-Dominated Mixed Carbonate-Siliciclastic Ramp

Depositional System 4 (DS-4) is also only present in the eastern sections (Fig. 22). It extends from 18 m to about 37.5 m above the base of the Ellis Bay Formation. It comprises the entire Prinsta Member and the lower half of the overlying Lousy Cove Member (*sensu* Long & Copper, 1987*a*, but see below). It defines a thick shallowing sequence composed of three well-defined thin shallowing-upward sub-sequences. It disconformably overlies sandstones of the Velleda Member.

Long & Copper (1987*a*) placed the top of the Prinsta Member at the top of a distinct nodular unit characterized by "grapefruit-sized pseudo-nodules" (26.5 m to 28 m from the base of the Ellis Bay Formation; Plate 2E), considering the overlying SCS sandstonee as the base of the Lousy Cove Member. Based on lithology, I include these SCS sandstonee and the capping grainstone lag in the Prinsta Member and assign the base of the Lousy Cove Member to the overlying thinly interbedded bioturbated mudstone-wackestone and calcareous shale. I obtain a thickness of 11.3 m for the Prinsta Member, compared to 9 m proposed by Long & Copper (1987*a*).

Considering the high degree of mixing of carbonate and siliciclastic particles, the ubiquitous storm features, and the overall shallowing-upward trend, DS-4 is interpreted as a prograding, storm-dominated mixed carbonate-siliciclastic ramp deposit. The first two shallowing sub-sequences begin with bioturbated sandy grainstones interbedded with calcareous shales (Facies 2A), representing the lower part of the transition zone (distal mid-ramp) where storm influence is minor. These grade upward into interbedded laminated grainstones (Facies 2B) and hummocky cross-stratified sandstones (Facies 2C) reflecting a greater storm influence as progradation continues, which culminates in SCS sandstones (Facies 4B) of the middle shoreface. Both HCS and SCS sandstones are followed by transgression as indicated by the capping grainstone lag (Facies 6). The upward decrease in aulacerid abundance in the first sub-sequence supports the shallowing interpretation as these cylindrical stromatoporoids probably lived only in relatively deep environments in order to avoid constant breaking by shallower waves.

As for the distinctive grapefruit-sized nodules in the second sub-sequence, they are here interpreted to result from extensive bioturbation in an environment characterized by slow sedimentation, rather than representing starved ripples as was proposed by Long & Copper (1987*a*). The thinly interbedded mudstones-wackestones (Facies 3A) overlying the second transgressive lag are also interpreted to be transgressive, resulting from the nearshore trapping of siliciclastic sand that typically occurs during transgression.

The third and final shallowing-upward sub-sequence of this depositional system begins with the reappearance of siliciclastic sediment, which first forms the interbedded laminated siltstones (Facies 2E) interpreted as distal tempestites deposited in the lower part of the transition zone (distal mid-ramp). The overlying interbedded grainstones and siltstones (Facies 4F) reflect more energetic and proximal conditions associated with progradation of the ramp, which is supported by the absence of argillaceous interbeds. This shallowing culminates in the cross-bedded grainstones (Facies 4C) of the upper shoreface (inner ramp). The bioturbation, erosive base, and coarse grain size of the overlying second coarse grainstone unit suggest a transgressive lag interpretation (Facies 6). The dark, pyritized surface defining the top of the first coarse grainstone unit corresponds to a hardground developed during a period of non-deposition associated with the transgression.

Depositional System 5 – Storm-Dominated Carbonate Ramp

Depositional System 5 (DS-5) is present in both the eastern and western sections. In the eastern sections, DS-5 begins approximately 37.5 m above the base of the Ellis Bay Formation; it extends from the upper half of the Lousy Cove Member (*sensu* Long & Copper, 1987*a*) to the top of the Laframboise Member and unconformably overlying Becscie Formation. It includes the fourth and last major shallowing-upward sequence in the Ellis Bay Formation (Fig. 22). In the western sections, the entire succession is defined by DS-5 (Fig. 22), where the Ellis Bay Formation comprises four shallowing-upward sequences (each followed by a deepening).

Eastern Anticosti

DS-5 in the eastern sections is interpreted as a prograding storm-dominated carbonate ramp recording a shallowing-upward sequence. Distal mid-ramp mudstones-wackestones (Facies 3A) are overlain by thicker bedded and lesser bioturbated mudstones (Facies 3B) of the mid to proximal mid-ramp. These mudstones are more continuous and tabular than those in the western sections (Plate 2H), and locally slump-deformed. More proximal conditions are further recorded by the overlying coarser-grained sandstones to grainstones (Facies 4D) of which the locally preserved flat lamination (produced by swash and backwash) indicate deposition on the inner ramp (foreshore). The base of the overlying Laframboise "oncolitic platform bed" (Facies 5A) is erosional (Plate 3A and 3C), cutting into the underlying flat-laminated sandstones (Facies 4D) and locally into the underlying mudstones (Facies 3B). Consequently, the "oncolitic platform bed" incorporated numerous flat-laminated and locally mudstone intraclasts (Fig. 19). This "oncolitic platform bed" (Facies 5A) is interpreted to have been emplaced in a constantly agitated proximal setting corresponding to the inner ramp, which is further supported by the local cross-bedding and small-scale wave ripple cross-stratification. However, the fining-upward trend (decrease in size and abundance of the oncoids) and the grading of locally cross-bedded oncolitic grainstones to small-scale wave ripple cross-stratified peloidal grainstones (see Facies 5A) suggest an upward decrease in energy associated with a slight deepening. Bioherms are small and only locally present, showing little positive relief ($\leq$ 20 cm) in relation to the interbioherms. The hardground capping both the bioherms and interbioherms probably formed following a time of non-deposition and erosion prior to deposition of the Becscie Formation. The Becscie Formation comprises at least 4 to 5 m of laminated and graded thin- to medium-bedded grainstone and lesser thin-bedded mudstone tempestites, interbedded with calcareous shales. These change upward to predominantly interbedded mudstones and calcareous shales (Sami & Desrochers, 1992).

WESTERN ANTICOSTI

DS-5 in the western sections is interpreted as a storm-dominated carbonate ramp. It shows five shallowing-upward sequences (followed by deepening), four of which are within the Ellis Bay Formation.

The first shallowing recorded is in the upper Mill Bay Member (*sensu* Long & Copper, 1987*a*; Long & Copper, 1994), where the distal mid-ramp bioturbated mudstones-wackestones are gradually overlain by SCS grainstones of the proximal mid-ramp (middle shoreface). A major deepening is indicated by the overlying bioturbated aulacerid- and coral-rich packstones / grainstones interpreted as a transgressive lag, in turn overlain by outer ramp calcareous shales (Facies 1) of the Schmitt Creek Member (*sensu* Long & Copper, 1987*a*).

The second shallowing is marked by the recessive-weathering Schmitt Creek calcareous shales (Facies 1) passing into the more resistant-weathering basal Grindstone Member (*sensu* Long & Copper, 1987*a*). The latter is composed of more proximal thin-bedded, laminated, and bioturbated (subnodular) mudstones-wackestones interbedded with calcareous shales, with minor laminated and graded thicker grainstones (facies intermediate between Facies 3A and 3B). A deepening is indicated by the upward transition into outer ramp calcareous shales (Facies 1) of the upper Grindstone Member (*sensu* Long & Copper, 1994; Copper, 2001).

The third shallowing sequence is marked by the gradual upward increase of storm deposits in this upper Grindstone shaly unit (Facies 1), culminating in the overlying Velleda (*sensu* Long & Copper, 1994; Copper, 2001) tempestite-dominated unit of mid to proximal mid-ramp lenticular mudstones (Facies 3B). Subsequently, the increase in bioturbation and decrease in bed thickness (Facies 3A) record a gradual deepening which reaches its maximum at the base of a calcareous shale unit (Facies 1) in the lowermost Prinsta Member (*sensu* Long & Copper, 1994; Copper, 2001).

The fourth shallowing is indicated by the increasing number upward of preserved tempestites within the basalmost Prinsta outer ramp calcareous shales (Facies 1). These pass progressively upward into distal mid-ramp bioturbated mudstones-wackestones (Facies 3A). Approximately 5 m above the base of the Prinsta Member is a distinct continuous 20 cm thick algae- and peloid-rich grainstone unit (composed of three amalgamated tabular beds), likely representing a higher-frequency maximum shallowing (Plate 5F). Above this unit, bed thickness gradually decreases and bioturbation increases, marking a slight deepening associated with the higher-frequency shallowing. This is sharply overlain by mid to proximal mid-ramp lenticular mudstones (Facies 3B). A subsequent deepening is indicated by a gradual transition to bioturbated mudstones-wackestones (Facies 3A) and to a calcareous shale unit comprising several mudstone to grainstone tempestites (facies intermediate between Facies 1 and 3A). This last shaly unit is herein considered to correspond to the base of the Lousy Cove Member based on Long & Copper (1994) who described the lower 5 m of the member as being recessive and probably dominated by [calcareous shales].

The fifth shallowing-upward sequence is indicated by a gradual transition from outer ramp calcareous shales (Facies 1) of the lowermost Lousy Cove Member to distal mid-ramp bioturbated mudstones-wackestones (Facies 3A) up to inner ramp small-scale wave ripple cross-stratified grainstones (Facies 4A) of the uppermost Lousy Cove Member (*sensu* Long & Copper, 1987*a*; Long & Copper, 1994; Long, 2007). The latter represents among the shallowest facies recorded in the western Ellis Bay Formation which, combined with the higher abundance of siliciclastic silt particles and the higher degree of bed amalgamation of both Facies 3A and 4A, points to a long-term shallowing-upward trend for the entire Ellis Bay Formation. The overlying Laframboise Member (*sensu* Long & Copper, 1987*a*) represents a slight deepening. The "oncolitic platform bed" (Facies 5A) defining the base of the member was likely deposited on the inner ramp where constant water agitation allowed the formation of concentric oncoids. However, common shale interbeds in the gradually-overlying interbiohermal strata (Facies 5B) points to a more distal environment, below FWWB, where the smaller and fewer oncoids were likely transported from upramp during storms. The overall upward decrease in size and abundance of the oncoids within the Laframboise Member suggests a modest progressive deepening. Accordingly, the irregular and locally darkened erosion surface found at the base of the "oncolitic platform bed" consists of a composite surface representing a maximum shallowing (regression) and an initial deepening (transgression). This erosion surface is responsible for the dark laminated intraclasts locally present in the "oncolitic platform bed", likely eroded from the underlying small-scale wave ripple cross-stratified grainstones. The Laframboise bioherms and interbioherms (Facies 5B) are capped by another continuous pyritized erosion surface recognized as a major transgressive surface. This is supported by $\delta^{13}C$ and $\delta^{18}O$ isotopes (Long, 1993) and paleontological evidence (Soufiane & Achab, 2000; Zhang & Barnes, 2002). The interbiohermal strata were preferentially eroded so the bioherm cores stand in positive relief up to 2 m high, which then were onlapped by grainstones at the base of the Becscie Formation. These thin- to medium-bedded grainstone tempestites interbedded with very thin calcareous shales are characteristic of the basalmost Becscie Formation and pass upward into thinly-bedded sharp-based mudstones, indicating continuous deepening (Sami & Desrochers, 1992).

According to this study, the Grindstone Member is 20 m thick, the Velleda Member 20 m thick, the Prinsta Member 29 m thick, the Lousy Cove Member 17 m thick, and the Laframboise Member 3.5 m thick, for a total thickness of 89.5 m for the western Ellis Bay Formation (Fig. 22). This contrasts with the 72 m reported by Long & Copper (1994). Yet, Petryk (1981) had previously obtained a thickness of 75 m for the western Ellis Bay Formation, placing the base of the formation at the base of the 7 m thick shale unit at the top of the Grindstone Member. Therefore, adding the remaining 13 m of the more resistant basal Grindstone Member now recognized as lowermost Ellis Bay (Long & Copper, 1987) to the 75 m of Petryk sums up to 88 m, which is similar to the thickness obtained in the present study.

DISCUSSION

1) EVOLUTION OF THE EASTERN DEPOSITIONAL SYSTEMS: VERTICAL CHANGES IN SILICICLASTIC CONTENT

As outlined above, the eastern succession from the Mill Bay through the Laframboise members is defined by the stacking of five different depositional systems (DS-1 to DS-5):

1) incised-valley fill, 2) storm-influenced delta, 3) storm-dominated strandplain, 4) storm-dominated mixed carbonate-siliciclastic ramp, and 5) storm-dominated carbonate ramp (Fig. 22). There is a temporal shift from siliciclastic-dominated (DS-1 to DS-3), to mixed carbonate-siliciclastic (DS-4), and finally to carbonate-dominated (DS-5) strata (Fig. 3 and 22). These changes in depositional systems and siliciclastic content are interpreted to result from avulsion and incremental sidestepping to the east of a major siliciclastic-feeding river (Fig. 23).

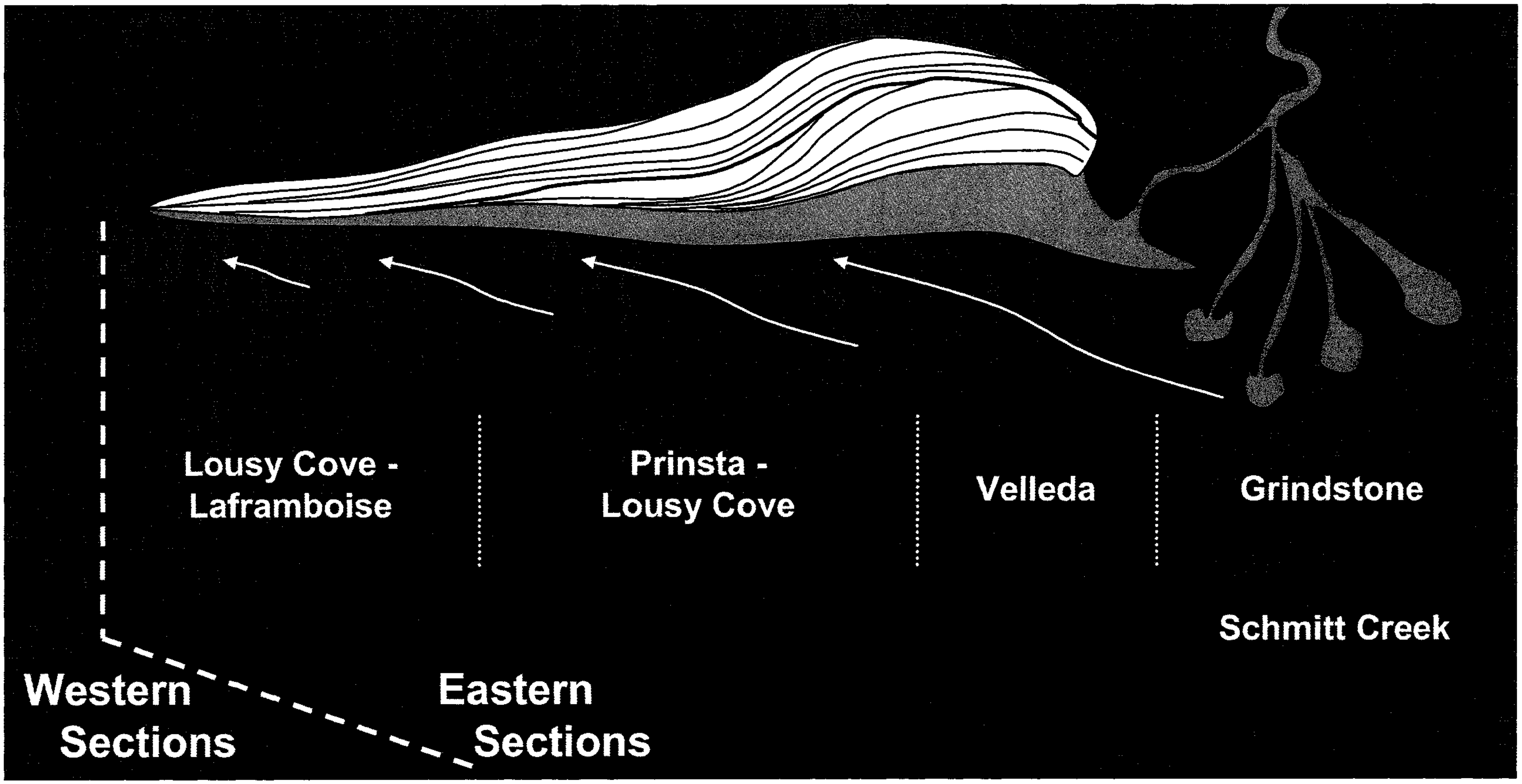
1) The Mill Bay Member is interpreted as an incised-valley fill. The valley is thought to have formed by fluvial erosion during a relative sea-level fall (under forced regression conditions), whereas the fill accumulated during the ensuing relative sea-level rise.

2) The incised valley is interpreted to have acted as a distributary channel during the following shallowing, depositing the prodelta calcareous shales of the Schmitt Creek Member and, as progradation continued, the Grindstone delta front sandstones. As mentioned above, these deposits may also represent a storm-dominated shoreface succession in the close vicinity of a delta.

3) In contrast, the overlying Velleda sandstones show a vertical succession very close to the typical succession of a storm-dominated prograding shoreface deposited along a strandplain. Avulsion of the river-delta system likely accompanied the transgression at the Grindstone – Velleda contact. A displacement to the east is favoured based on the paucity of siliciclastic strata in the Ellis Bay Formation on central or western Anticosti. During Velleda time, siliciclastic sediment supply was probably delivered from an adjacent delta and transported to the study area by longshore currents.

4) The decrease in siliciclastic content observed in the overlying Prinsta and lower Lousy Cove members, both deposited on a storm-dominated mixed carbonate-siliciclastic ramp, likely resulted from repeated avulsion forcing the deltaic system to move further eastward. This was combined with a marked initial deepening at the base of the Prinsta Member. Consequently, a smaller volume of siliciclastic sediment was able to reach the study area by longshore currents with increasing distance from the siliciclastic source (i.e. delta). The strandplain (or mixed ramp) at the time of deposition of the Prinsta Member was characterized by a narrower siliciclastic shoreface compared to that of the Velleda Member, with a carbonate-dominated ramp juxtaposed just downramp of it. A more significant

Figure 23. Schematic diagram showing the evolution of the eastern depositional systems. The incremental sidestepping to the east of a siliciclastic-feeding river (and delta) caused the study area to record a transition from 1) deltaic (Schmitt Creek and Grindstone members), to 2) strandplain (Velleda Member), to 3) mixed carbonate-siliciclastic ramp (Prinsta and lower Lousy Cove members), to 4) carbonate ramp (upper Lousy Cove and Laframboise members) deposits. This is accompanied by a decrease in siliciclastic content with time. The arrows indicate the transport of siliciclastics from the delta by longshore currents. The western sections received no siliciclastic sand because of their remote location relative to the siliciclastic source (delta).


Lousy Cove -
Laframboise
Prinsta -
Lousy Cove
Velleda
Grindstone
Schmitt Creek
Western
Sections
Eastern
Sections

shallowing was probably needed in order to record shoreface sandstones in the study area. The mixed carbonate-siliciclastic distal tempestites of the Prinsta Member were likely formed by the downramp transport during storms of nearshore siliciclastic sand into the deeper and more offshore carbonate-dominated realm where both types of particles were mixed and deposited under the influence of storm-induced currents. During lower Lousy Cove time, individual mixed carbonate-siliciclastic tempestites were covered by fairweather fine-grained siliciclastics delivered by river plumes associated with a relatively distant delta. Very fine and fine sand were transported by longshore currents, but clay and silt were transported in suspension and settled in deeper, more offshore environments. Marine organisms (mainly crinoids, brachiopods, and ostracods) lived on the silty substrate. During storms, waves and currents reworked both carbonate and siliciclastic particles, sorting and eventually settling the denser and coarser carbonate shells (and upramp transported coarser siliciclastics) while finer siliciclastic particles were "flushed" away and deposited further down on the ramp. Between storm events, the fine siliciclastic "rain" from river plumes settled again, overlying the carbonate-dominated storm bed, and marine organisms repopulated the new silty substrate. The base of the siliciclastic interbeds may be slightly coarser (very fine sand) and deposited by weak remaining storm currents, but most siliciclastics represent suspension deposition. This lithological change observed at the Prinsta – Lousy Cove contact reflects a modification in sediment dynamics, possibly related to continuous river sidestepping to the east.

5) Finally, the upper Lousy Cove and Laframboise members are largely composed of storm-dominated carbonate deposits, except for some bioturbated bioclastic sandstones to sandy grainstones in the uppermost part of the Lousy Cove Member. This final incremental decrease in siliciclastic content likely resulted from further river sidestepping causing the siliciclastic source (distributary channel and delta) to move far away and virtually starved this area of the basin of siliciclastic sediment. The strandplain was likely characterized by a very narrow band of nearshore siliciclastics. Consequently, it recorded a high content of carbonate material, even at times of maximum regression (e.g. bioclastic sandstones and sandy grainstones of the uppermost Lousy Cove Member). The overlying Becscie Formation corresponds to a typical storm-dominated carbonate ramp setting with limited sand-size siliciclastic influx (Sami & Desrochers, 1992). By that time, the siliciclastic input was largely restricted east of the study area.

In summary, it is suggested that a delta system originally located east of the study area switched location to affect the eastern Anticosti Platform and gradually switched back to a more easterly position with time (Fig. 23). In this view, the eastern Ellis Bay Formation (and particularly the Grindstone Member) corresponds to the westernmost reach (or lobe) of a delta system existing in the Anticosti/western Newfoundland basin.

ALTERNATIVE INTERPRETATIONS

Alternative interpretations for the upward decrease in siliciclastic content through the eastern Ellis Bay Formation include: 1) long-term transgression and 2) climate changes.

River backstepping and nearshore trapping of siliciclastics associated to a long-term transgression can readily be refuted because the Ellis Bay Formation records an overall sea-level fall associated to the Gondwanan glaciation (see Discussion below). However, the climate interpretation deserves closer attention. The upward decrease in siliciclastic content could result from a gradual decrease in continental runoff, likely associated to a progressively more arid climate induced by the Hirnantian glacial period. Indeed, studies by Soreghan (1994) and Rankey (1997) on the impact of glacioclimatic change on Pennsylvanian-Permian cyclostratigraphy showed that falls of relative in sea-level (glacial periods) are accompanied by more arid conditions, whereas highs of relative sea-level (interglacial periods) are accompanied by more seasonal (humid) conditions. Based on these interpretations, the transition from the siliciclastic-rich Mill Bay to the carbonate-rich Laframboise members should correspond to increasing arid conditions, lower continental runoff, and lower siliciclastic input. This climate-related interpretation is refuted for two reasons: 1) the interglacial strata of both the underlying Vauréal (below the Mill Bay Member) and overlying Becscie formations are carbonate-dominated (Sami & Desrochers, 1992; Long, 2007), and 2) it is in contradiction with the shorter-term variations in siliciclastics within the formation where maximum regressions (glacial phases) are systematically characterized by sandstone rather than carbonate units. In addition, siliciclastics are generally confined to the east, suggesting a point source of siliciclastics and further supporting the river avulsion interpretation.

The easterly-confined delta and river avulsion interpretation herein presented contrasts with Long & Copper (1987*b*) who interpreted the eastern siliciclastics as subaqueous sand-wave complexes. It also differs from Petryk (1981) who suggested that the "Eastern

Transitional Carbonate-Siliciclastic Platform Facies" represent shallower deposits than the deeper "Western Carbonate Platform Facies" along a continuously siliciclastic paleoshoreline oriented oblique to the outcrop belt, where the eastern outcrop belt was closer to the paleoshoreline.

2) DEPTH OF DEPOSITION: COMPARISON OF THE EASTERN AND WESTERN SECTIONS

Based on lithology, it is apparent that the Ellis Bay Formation on eastern Anticosti was deposited in a shallower environment than its western counterpart. Overall, the eastern sections record shallower facies and show sedimentary structures representative of shallower and more energetic conditions than those in the west. For example, HCS and particularly SCS of the lower and middle shoreface are ubiquitous throughout the formation in the east but rare in the west (Fig. 22), where the vast majority of the succession is dominated by more distal mid-ramp deposits (equivalent to the transition zone below the shoreface).

Stratigraphically equivalent members and units show shallower facies in the east than in the west. For example, the eastern upper Velleda Member is characterized by middle shoreface SCS and upper shoreface cross-bedded sandstones (Fig. 22), the latter defining the shallowest facies recorded in the east (excluding the uppermost Lousy Cove and Laframboise members). In contrast, its western counterpart consists of mid to proximal mid-ramp lenticular mudstones (equivalent to the upper transition zone to lower shoreface), which designate the western shallowest facies (excluding the uppermost Lousy Cove and Laframboise members).

Although the Laframboise Member is present at both ends of the island, the widespread oncolite bed in the eastern sections displays local cross-bedding, larger oncoids, more bed amalgamation (absence of shale interbeds), and a well developed basal erosion surface, all pointing to a shallower environment than in the western sections. Finally, erosive channels likely caused by fluvial incision are present only in the east, also suggesting a shallower water environment (Fig. 17 and 22).

3) SEQUENCE STRATIGRAPHY AND E-W CORRELATION

The stratigraphic correlation of the eastern (siliciclastic-rich) and western (carbonate-dominated) Ellis Bay Formation and members has been problematic because of their different lithologies (Long & Copper, 1987*a*; Copper, 2001). In spite of these lithological changes, this study establishes a high-resolution E-W correlation with four major transgressive-regressive sequences (TR-1 to TR-4) present in the Ellis Bay and associated strata at both ends of the island (Fig. 22). Smaller-scale sub-sequences or cycles are locally present within each sequence, but are not discussed below. A slight diachronism may exist between the eastern and western sections due to higher subsidence in the latter.

TR-1 SEQUENCE

In the eastern sections, TR-1 comprises the Mill Bay and Schmitt Creek member, and most of the Grindstone Member (Fig. 22, Plate 3E to 3G). It is characterized by: 1) a basal sequence boundary likely formed by fluvial incision during a period of forced regression but reworked during a subsequent flooding or transgressive event at the base of the Mill Bay Member, 2) a maximum flooding surface near the base of the Schmitt Creek Member, and 3) an upper composite sequence boundary in the uppermost Grindstone Member (see TR-2 below). These TR-1 surfaces can be correlated with the following surfaces present in the western sections: 1) a sequence boundary capping a major regressive succession at the top of the Mill Bay Member overlain by a basal transgressive lag with abundant reworked corals and aulacerids, 2) a maximum flooding surface near the base of the Schmitt Creek Member, and 3) an upper maximum regressive surface (see TR-2 below).

It is worthwhile noting that Mill Bay strata exposed at both ends of the island, and originally defined by Long and Copper (1987*a*), are not genetically related. The eastern Mill Bay strata represent the transgressive infill of an incised valley (lower TR-1) while the western strata record a major regression associated with an older transgressive-regressive (TR) sequence. Mill Bay strata exposed along Rivière Vauréal and Rivière aux Saumons, located ~50 and ~25 km respectively west of the Mill Bay section, suggest that the western limit of this incised valley lies somewhere between these two river outcrops. In the lower TR-1 in the western sections (Fig. 22), the sharp contact between deep and shallower regressive deposits is interpreted as a basal surface of forced regression.

TR-2 SEQUENCE

In the eastern sections, TR-2 includes the uppermost Grindstone and Velleda members (Fig. 22, Plate 3F and 3G), and is defined by: 1) a basal composite sequence boundary near the top of the Grindstone Member, made up of local fluvial incisions formed under forced regression conditions and later reworked by a flooding (transgressive) event, 2) a maximum flooding surface near the base of the Velleda Member, and 3) an upper composite sequence boundary at the Velleda – Prinsta contact (see TR-3 below). In the western sections, correlative surfaces associated to TR-2 are: 1) a basal maximum regressive surface in the upper resistant part of the Grindstone Member, 2) a maximum flooding surface near the base of the upper Grindstone calcareous shale unit, and 3) an upper maximum regressive surface (see TR-3 below). In the western sections, the sharp contact between the calcareous shale and lenticular mudstone units in the upper TR-2 (Plate 5E) corresponds to a basal surface of forced regression.

TR-3 SEQUENCE

In the eastern sections, TR-3 consists of the Prinsta and the lower half of the Lousy Cove members (Fig. 22, Plate 3G and 3H). It is characterized by: 1) a basal composite sequence boundary consisting of a maximum regressive surface reworked by a transgressive ravinement surface at the Velleda – Prinsta contact, 2) a maximum flooding surface in the basal Prinsta Member, and 3) an upper composite sequence boundary (see TR-4 below). In the western sections, these TR-3 surfaces can be correlated with: 1) a basal maximum regressive surface in the lower Velleda Member, 2) a maximum flooding surface in the basalmost Prinsta Member, and 3) an upper regressive maximum surface (see TR-4 below). The base of the resistant mudstone unit in the upper TR-3 (Plate 5F) is interpreted as a basal surface of forced regression.

TR-4 SEQUENCE

In the eastern sections, TR-4 comprises the upper Lousy Cove and the basal Laframboise members (Fig. 22, Plate 3H). It is defined by: 1) a basal sequence boundary again marked by a transgressive ravinement surface (and its associated transgressive lag) superimposed on a maximum regressive surface in the middle of the Lousy Cove Member, 2) a maximum flooding surface immediately above the transgressive lag, and 3) an upper composite sequence boundary at the base of the Laframboise "oncolitic platform bed" (see below). These TR-4 surfaces define the youngest TR sequence within the Ellis Bay Formation and can be correlated with the following surfaces in the western sections: 1) a basal maximum regressive surface in the middle of the Prinsta Member, 2) a maximum flooding surface in the basalmost Lousy Cove Member, and 3) an upper composite sequence boundary at the base of the "oncolitic platform bed" (see below). In the uppermost TR-4 at the eastern end, the base of the bioturbated and flat-laminated sandstone unit underlying the "oncolitic platform bed" is interpreted as a basal surface of forced regression, and correlates westward with the sharp base of the wave-rippled grainstone unit. A more detailed description of this key TR-4 (and overlying oncolitic and reefal units) is beyond the scope of the present thesis (see Desrochers et al., 2008).

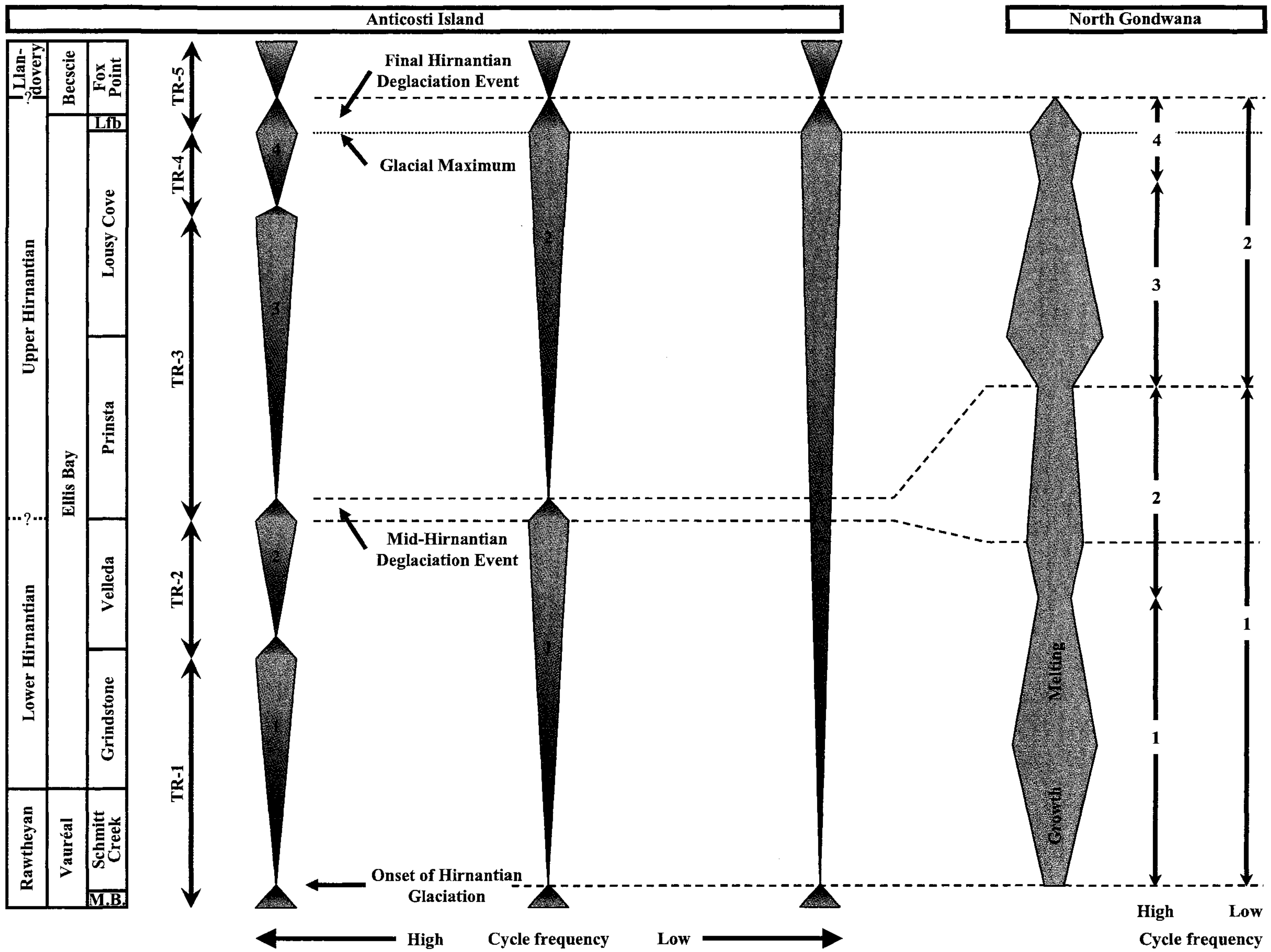
In both eastern and western sections, the base of the "oncolitic platform bed" corresponds to a composite sequence boundary consisting of a maximum regressive surface (with possible subaerial exposure as evidenced by the presence of vadose cement) reworked by a subsequent flooding or transgressive event (Plates 3A to 3C, 4H). It marks the beginning of a fifth major transgressive-regressive sequence (TR-5) culminating higher in the Silurian Becscie Formation. The top of the biohermal and interbiohermal unit of the Laframboise Member corresponds to a major transgressive ravinement surface (Plates 3D, 5B, 5C, 5H), while the maximum flooding surface of TR-5 lies in the lowermost Becscie strata.

In summary, the Mill Bay through the Laframboise members define four transgressive-regressive (TR-1 to TR-4) sequences (Fig. 22), which are interpreted to reflect sea-level fluctuations associated to glacial cycles of the Hirnantian glaciation located in northern Gondwana.

4) Global Implication – Gondwanan Glaciation

The study of the North Gondwana record in northern Africa allowed the recognition of four (five?) glacial-interglacial cycles during the Hirnantian (1.9 My long), grouped into two lower-frequency cycles divided by a major mid-Hirnantian deglaciation event (Fig. 24; Ghienne, 2003; Ghienne et al., *in press*). This study of the Hirnantian Ellis Bay Formation and associated strata on Anticosti Island duplicates these cycles (Fig. 24). The four Ellis Bay TR sequences (see above) closely correspond to the four glacial-interglacial cycles (advances and retreats of the northern Gondwanan ice sheet) observed in Africa. The Velleda – Prinsta contact is interpreted as an important transgressive surface associated with the mid-Hirnantian deglaciation event, thus dividing the Ellis Bay succession into two lower-frequency sequences.

Figure 24. Sea-level fluctuations in the Ellis Bay Formation of Anticosti Island correlated with glacial cycles (ice-sheet growth and melting) of North Gondwana. The first column on the left corresponds to geological time stages. The second and third columns correspond to the studied geological formations and members on Anticosti Island. The Ellis Bay stratigraphy used in this figure is that of the eastern sections. TR-1 to TR-5 correspond to transgressive-regressive sequences described above for the Ellis Bay and associated strata. Both the Anticosti and North Gondwana sections comprise four cycles (numbered 1 to 4) grouped into two lower-frequency cycles (numbered 1 and 2) on the basis of a major mid-Hirnantian deglaciation event. Cycle frequency refers to sea-level fluctuations for the Anticosti section and to glacial advances and retreats for the North Gondwana section. North Gondwana section modified from Ghienne (2003).


Anticosti Island
North Gondwana
Llan-dovery
Upper Hirnantian
Lower Hirnantian
Rawtheyan
Becscie
Ellis Bay
Vauréal
Fox Point
Lfb
Lousy Cove
Prinsta
Velleda
Grindstone
Schmitt Creek
M.B.
TR-5
TR-4
TR-3
TR-2
TR-1
Final Hirnantian Deglaciation Event
Glacial Maximum
Mid-Hirnantian Deglaciation Event
Onset of Hirnantian Glaciation
High
Cycle frequency
Low
Melting
Growth
4
3
2
1
2
1
High
Low
Cycle frequency

This transgressive surface (i.e. Velleda – Prinsta contact) occurs at or near the early/late Hirnantian boundary on Anticosti Island (see Stratigraphy above), which is tentatively correlated with the mid-Hirnantian deglaciation event of Ghienne (ibid.).

Ghienne et al. (2007) also demonstrated the "global and virtually instantaneous nature of the Hirnantian glacial event". On Anticosti Island, the onset of the Hirnantian glaciation is interpreted to correspond to the fluvial incision at the base of the eastern Mill Bay Member in association with an initial forced sea-level fall. It is worthwhile mentioning though that the glaciation of northern Gondwana during the Hirnantian corresponds only to the peak of a longer-lived glaciation that existed from late Middle Ordovician to early Silurian, with smaller ice sheets restricted to South America and the continental interior of Africa (Pope & Read, 1997; Crowell, 1999; Ghienne, 2003; Pope & Steffen, 2003; Pope, 2004).

Ghienne et al. (2007) further identified three important surfaces in the upper Hirnantian and associated strata of North Gondwana: 1) a glacial maximum/transgressive surface, 2) a transgressive ravinement surface, and 3) a maximum flooding surface. In the upper glacially-related Djebel Serraf Formation, they traced a bounding surface (termed BS 7) that probably corresponds to the Hirnantian ice-maximum and above which a noticeable transgressive trend is present. This surface defines a transgressive surface and also the base of a TR sequence that culminates in the overlying Silurian strata. A transgressive ravinement surface (post-glacial tidal and wave ravinement surfaces) in the uppermost Djebel Serraf Formation marks the limit between glacial and post-glacial sediments associated with the Hirnantian deglaciation (transgression). A maximum flooding surface is finally present in the overlying lowermost Silurian Oued Ali Formation. On Anticosti Island, these three surfaces correspond respectively to: 1) the base of the Laframboise "oncolitic platform bed", which also defines the base of a TR sequence (i.e. base of TR-5), 2) the top of the Laframboise biohermal and interbiohermal unit, marked by an important continuous pyrite-rich erosion surface, and 3) a maximum flooding surface in the overlying basalmost Silurian Becscie Formation (Fig. 22 and 24).

In summary, the TR sequences present in the Hirnantian Ellis Bay and associated strata on Anticosti Island correspond closely to glacio-eustatic fluctuations related to the northern Gondwanan ice sheet growth and melting (Fig. 24). Considering a duration of 1.9 My for the Hirnantian (Cooper & Sadler, 2004), it is here suggested that the four Ellis Bay TR sequences were controlled by ~400 ka long eccentricity Milankovitch cycles, as proposed by Long (2007).

CONCLUSIONS

- This study of the Ellis Bay Formation and associated strata led to the identification of 17 facies grouped into five facies successions, or depositional systems (DS-1 to DS-5).
- The eastern sections are siliciclastic-rich, but record an upward decrease in siliciclastic content associated with a temporal change of depositional systems (DS-1 to DS-5), from siliciclastic-dominated at the bottom to carbonate-dominated at the top.
- The western sections are entirely carbonate-dominated, characterized by a longer-lived depositional system (DS-5) with a cyclic pattern of facies successions.
- This lateral facies change within the Ellis Bay Formation (eastern siliciclastic-rich vs. western carbonate-dominated) is explained by the presence of a siliciclastic source (delta) confined to the eastern Anticosti Platform.
- The vertical facies changes within the eastern sections (siliciclastic-dominated to carbonate-dominated) are interpreted to result from the incremental sidestepping to the east of a major siliciclastic-feeding river (and its associated delta).
- Four complete transgressive-regressive sequences (TR-1 to TR-4) are recognized on the basis of sequence stratigraphy at both ends of the island, allowing a high-resolution E-W correlation.
- These TR sequences correspond to glacio-eustatic fluctuations related to the northern Gondwanan ice-sheet growth and melting.

Finally, more work is needed on the eastern Mill Bay Member to trace the erosion surface at the base of the incised valley and map the limit of the incised valley between Rivière Vauréal and Rivière aux Saumons. I also believe that the stratigraphic position of the Ellis Bay members should be revised to better match lithological changes associated with the four TR sequences described in the present study.

REFERENCES

ACHAB, A., PARIS, F., 2007. The Ordovician Chitinozoan Biodiversification and Its Leading Factors. Palaeogeography, Palaeoclimatology, Palaeoecology, v. 245, p. 5-19.

AIGNER, T., 1982. Calcareous Tempestites: Storm-Dominated Stratification in Upper Muschelkalk Limestones (Middle Trias, SW-Germany). *In* Cyclic and Event Stratification. *Edited by* Einsele, G., and Seilacher, A. p. 180-198.

ALLEN, G.P., 1991. Sedimentary Processes and Facies in the Gironde Estuary: A Recent Model for Macrotidal Estuarine Systems. *In* Clastic Tidal Sedimentology. *Edited by* Smith, D.G., Reinson, G.E., Zaitlin, B.A., and Rahmani, R.A. Canadian Society of Petroleum Geologists, Memoir 16, p. 29-40.

BARNES, C.R., 1988. Stratigraphy and Paleontology of the Ordovician-Silurian Boundary Interval, Anticosti Island, Québec. Bulletin of the British Museum of the Natural History (Geology), v. 43, p. 195-219.

BERGSTRÖM, S.M., SALTZMAN, M.M., SCHMITZ, B., 2006. First Record of the Hirnantian (Upper Ordovician) $\delta^{13}C$ Excursion in the Noth American Midcontinent and its Regional Implications. Geological Magazine, v. 143, No. 5, p. 657-678.

BHATTACHARYA, J.P., 2006. Deltas. *In* Facies Models Revisited. *Edited by* Posamentier, H.W. and Walker, R.G. SEPM Special Publication No. 84, p. 237-292.

BHATTACHARYA, J., WALKER, R.G., 1991. River- and Wave-Dominated Depositional Systems of the Upper Cretaceous Dunvegan Formation, Northwestern Alberta. Bulletin of Canadian Petroleum Geology, v. 39, p. 165-191.

BHATTACHARYA, J.P., WALKER, R.G., 1992. Deltas. *In* Facies Models : Response to Sea Level Change. *Edited by* Walker, R.G. and James, N.P. Geological Association of Canada. Chapter 9, p. 157-178.

BOGGS, S., 2001. Principles of Sedimentology and Stratigraphy (3rd ed.). Prentice Hall, 726 p.

BORDET, E., MALO, M., AND KIRKWOOD, D., *in press*. Structural Study of the Western Anticosti Island, St. Lawrence Platform, Quebec: Fracture Analysis and Integration of Surface and Subsurface Structural Data. Bulletin of Canadian Petroleum Geology.

BOYD, R., DALRYMPLE, R.W., ZAITLIN, B.A., 2006. Estuarine and Incised-Valley Facies Models. *In* Facies Models Revisited. *Edited by* Posamentier, H.W. and Walker, R.G. SEPM Special Publication No. 84, p. 171-235.

BRENCHLEY, P.J., MARSHALL, J.D., CARDEN, G.A.F., ROBERTSON, D.B.R., LONG, D.G.F., MEIDLA, T., HINTS, L., ANDERSON, T.F., 1994. Bathymetric and Isotopic Evidence for a Short-Lived Late Ordovician Glaciation in a Greenhouse Period. Geology, v. 22, p. 295-298.

BRENCHLEY, P.J., CARDEN, G.A., HINTS, L., KALJO, D., MARSHALL, J.D., MARTMA, T., MEIDLA, T, NÕLVAK, J., 2003. High-Resolution Stable Isotope Stratigraphy of Upper Ordovician Sequences: Constraints on the Timing of Bioevents and Environmental Changes Associated with Mass Extinction and Glaciation. Geological Society of America Bulletin, v. 115, p. 89-104.

BURCHETTE, T.P., WRIGHT, V.P., 1992. Carbonate Ramp Depositional Systems. Sedimentary Geology, v. 79, p. 3-57.

BURST, J.F., 1965. Subaqueously Formed Shrinkage Cracks in Clay. Journal of Sedimentary Petrology, v. 35, p. 348-353.

CLIFTON, H.E., 2006. A Reexamination of Facies Models for Clastic Shorelines. *In* Facies Models Revisited. *Edited by* Posamentier, H.W. and Walker, R.G. SEPM Special Publication No. 84., p. 293-337.

COCKS, L.R.M., COPPER, P., 1981. The Ordovician-Silurian Boundary at the Eastern End of Anticosti Island. Canadian Journal of Earth Sciences, v. 18, p. 1029-1034.

COCKS, L.R.M., TORSVIK, T.H., 2002. Earth Geography From 500 to 400 Ma Years Ago: A Faunal and Paleomagnetic Review. Journal of the Geological Society, London, v. 159, p. 631-644.

COLLINSON, J.D., THOMPSON, D.B., 1989. Sedimentary Structures (2nd edition). Unwin Hyman, London, 207 p.

COOPER, R.A., SADLER, P.M., 2004. The Ordovician Period. *In* A Geological Timescale 2004. *Edited by* Gradstein, F.M., Ogg, J.G., and Smith, A.G. Cambridge University Press, Cambridge, UK., p. 165-187.

COPPER, P., 1976. The Cyanophyte *Wetheredella* in Ordovician Reefs and Off-Reef Sediments. Lethaia, v. 9, p. 273-281.

COPPER, P., 1981. Atrypoid Brachiopods and Their Dsitribution in the Ordovician-Silurian Sequence of Anticosti Island. *In* Field Meeting, Anticosti – Gaspé, Québec, 1981; Vol. II: Stratigraphy and Paleontology. *Edited by* Lespérance, P.J. IUGS Subcommission on Silurian Stratigraphy, Ordovician-Silurian Boundary Working Group. Département de géologie, Université de Montréal, Montréal, Québec, p. 137-141.

COPPER, P., 1995. Five New Genera of Late Ordovician—Early Silurian Brachiopods from Anticosti Island, Eastern Canada. Journal of Paleontology, v. 69, p. 846-862.

COPPER, P., 2001. Reefs During the Multiple Crises Towards the Ordovician-Silurian Boundary: Anticosti Island, Eastern Canada, and Worldwide. Canadian Journal of Earth Sciences, v. 38, p. 153-171.

CROWELL, J.C., 1999. Pre-Mesozoic Ice Ages: Their Bearing on Understanding the Climate System. Geological Society of America, Memoir 192, 106 p.

DESROCHERS, A., FARLEY, C., LONG, D.G.F., 2008. Stratigraphic Architecture, Discontinuity Surfaces, and Atypical Carbonate Facies at the Ordovician / Silurian Boundary on Anticosti Island, Québec. GAC-MAC Annual Meeting, Quebec City, Program with Abstracts, v. 33.

DUKE, W.L., ARNOTT, R.W.C., CHEEL, R.J., 1991. Shelf Sandstones and Hummocky Cross-Stratification: New Insights on a Stormy Debate. Geology, v. 19, p. 625-628.

DUMAS, S., ARNOTT, R.W.C., 2006. Origin of Hummocky and Swaley Cross-Stratification – The Controlling Influence of Unidirectional Current Strength and Aggradation Rate. Geology, v. 34, p. 1073-1076.

FORTEY, R.A., COCKS, L.R.M., 2003. Paleontological Evidence Bearing on Global Ordovician-Silurian Continental Reconstructions. Earth-Science Reviews, v. 61, p. 245-307.

GHIENNE, J.-F., 2003. Late Ordovician Sedimentary Environments, Glacial Cycles, and Post-Glacial Transgression in the Taoudeni Basin, West Africa. Palaeogeography, Palaeoclimatology, Palaeoecology, v. 189, p. 117-145.

GHIENNE, J.-F., BOUMENDJEL, K., PARIS, F., VIDET, B., RACHEBOEUF, P., SALEM, H.A., 2007. The Cambrian-Ordovician Succecssion in the Ougarta Range (Western Algeria, North Africa) and Interference of the Late Ordovician Glaciation on the Development of the Lower Palaeozoic Transgression on Northern Gondwana. Bulletin of Geosciences, v. 82, p. 183-214.

GHIENNE, J.-F., LE HERON, D.P., MOREAU, J., DENIS, M., DEYNOUX, M., *in press*. The Late Ordovician Glacial Sedimentary System of the North Gondwana Platform. *In* Glacial Sedimentary Processes and Products. *Edited by* Hambry, M., Christoffersen, P., Glasser, P., Janssen, N., Hubbard, B., and Siegert, M. International Association of Sedimentologists, Special Publication No. 39. Blackwells, Oxford.

JIN, J., COPPER, P., 1997. *Parastrophinella* (Brachiopoda): Its Paleogeographic Significance at the Ordovician/Silurian Boundary. Journal of Paleontology, v. 71, p. 369-380.

KREISA, R.D., MOIOLA, R.J., 1986. Sigmoidal Tidal Bundles and Other Tide-Generated Sedimentary Structures of the Curtis Formation, Utah. Geological Society of America, Bulletin, v. 97, p. 381-397.

LESPÉRANCE, P.J., 1981. International Union of Geological Sciences, Subcommission on Silurian Stratigraphy, Ordovician-Silurian Boundary Working Group, Field Meeting, Anticosti-Gaspé, Québec, 1981. Volume II: Stratigraphy and Paleontology. Département de géologie, Université de Montréal, 321 p.

LESPÉRANCE, P.J., 1985. Faunal Distributions Across the Ordovician-Silurian Boundary, Anticosti Island and Percé, Québec, Canada. Canadian Journal of Earth Sciences, v. 22, p. 838-849.

LONG, D.G.F., 1993. Oxygen and Carbon Isotopes and Event Stratigraphy Near the Ordovician-Silurian Boundary, Anticosti Island, Québec. Palaeogeography, Palaeoclimatology, Palaeoecology, v. 104, p. 49-59.

LONG, D.G.F., 2007. Tempestite Frequency Curves: A Key to Late Ordovician and Early Silurian Subsidence, Sea-Level Change, and Orbital Forcing in the Anticosti Foreland Basin, Québec, Canada. Canadian Journal of Earth Sciences, v. 44, p. 413-431.

LONG, D.G.F., COPPER, P., 1987*a*. Stratigraphy of the Upper Ordovician Upper Vauréal and Ellis Bay Formations, Eastern Anticosti Island, Québec. Canadian Journal of Earth Sciences, v. 24, p. 1807-1820.

LONG, D.G.F., COPPER, P., 1987*b*. Late Ordovician Sand-Wave Complexes on Anticosti Island, Québec: A Marine Tidal Embayment? Canadian Journal of Earth Sciences, v. 24, p. 1821-1832.

LONG, D.G.F., COPPER, P., 1994. The Late Ordovician – Early Silurian Carbonate Tract of Anticosti Island, Gulf of St. Lawrence, Eastern Canada. Geological Association of Canada, Mineralogical Association of Canada, Joint Annual Meeting, Waterloo, Ontario, 20-25 May 1994. Field Trip Guidebook B4, 70 p.

MCCRACKEN, A.D., BARNES, C.R., 1981. Conodont Biostratigraphy Across the Ordovician-Silurian Boundary, Ellis Bay Formation, Anticosti Island, Québec. *In* Field Meeting, Anticosti – Gaspé, Québec, 1981; Vol. II: Stratigraphy and Paleontology. *Edited by* Lespérance, P.J. IUGS Subcommission on Silurian Stratigraphy, Ordovician-Silurian Boundary Working Group. Département de géologie, Université de Montréal, Montréal, Québec, p. 61-69.

MCCRACKEN, A.D., NOWLAN, G.S., 1986. The Gamachian Stage and Fauna 13. *In* The Canadian Paleontology and Biostratigraphy Seminar, Proceeding of Meeting. *Edited by* Landing, E. New York State Museum, Bulletin Number 462, p. 71-79.

MCLAUGHLIN, P.I., BRETT, C.E., 2007. Signatures of Sea-Level Rise on the Carbonate Margin of a Late Ordovician Foreland Basin: A Case Study from the Cincinnati Arch, USA. Palaios, v. 22, p. 245-267.

MELCHIN, M.J., *in press*. Restudy of Some Ordovician-Silurian Boundary Graptolites from Anticosti Island, Canada, and Their Biostratigraphic Significance. Lethaia.

ORTH, C.J., GILMORE, J.S., QUINTANA, L.R., SHEEHAN, P.M., 1986. Terminal Ordovician Extinction: Geochemical Analysis of the Ordovician/Silurian Boundary, Anticosti Island, Québec. Geology, v. 14, p. 433-436.

PETRYK, A.A., 1981. Stratigraphy, Sedimentology and Paleogeography of the Upper Ordovician – Lower Silurian of Anticosti Island, Québec. *In* Field Meeting, Anticosti – Gaspé, Québec, 1981; Vol. II: Stratigraphy and Paleontology. *Edited by* Lespérance, P.J. IUGS Subcommission on Silurian Stratigraphy, Ordovician-Silurian Boundary Working Group. Département de géologie, Université de Montréal, Montréal, Québec, p. 11-39.

POPE, M.C., 2004. Cherty Carbonate Facies of the Montoya Group, Southern New Mexico and Western Texas and Its Regional Correlatives: A Record of Late Ordovician Paleoceanography on Southern Laurentia. Palaeogeography, Palaeoclimatology, Palaeoecology, v. 210, p. 367-384.

POPE, M.C., READ, J.F., 1997. High-Resolution Stratigraphy of the Lexington Limestne (Late Middle Ordovician), Kentucky, U.S.A.: A Cool-Water Carbonate-Clastic Ramp in a Tectonically Active Foreland Basin. *In* Cool-Water Carbonates. *Edited by* James, N.P. and Clarke, J.A.D. SEPM Special Publication No. 56, p. 411-429.

POPE, M.C., STEFFEN, J.B., 2003. Widespread, Prolonged Late Middle to Late Ordovician Upwelling in North America: A Proxy Record of Glaciation? Geology, v. 31, p. 63-66.

PRATT, B., 1998. Synerersis Cracks: Subaqueous Shrinkage in Argillaceous Sediments Caused by Earthquake-Induced Dewatering. Sedimentary Geology, v. 177, p. 1-10.

RACHEBOEUF, P.R., COPPER, P., 1986. The Oldest Chonetacean Brachiopods (Ordovician-Silurian, Anticosti Island, Québec). Canadian Journal of Earth Sciences, v. 23, p. 1297-1308.

RANKEY, E.C., 1997. Relations between relative changes in sea level and climate shifts: Pennsylvanian–Permian mixed carbonate siliciclastic strata, western United States. GSA Bulletin, v. 109, p. 1089-1100.

REINSON, G.E., 1992. Transgressive Barrier Island and Estuarine Systems. *In* Facies Models : Response to Sea Level Change. *Edited by* Walker, R.G. and James, N.P. Geological Association of Canada. Chapter 10, p. 179-194.

RICHARDSON, J.G., AUSICH, W.I., 2007. Late Ordovician – Early Silurian Cryptospore Occurrences on Anticosti Island (Île d'Anticosti), Québec, Canada. Canadian Journal of Earth Sciences, v. 44, p. 1-7.

SAMI, T., DESROCHERS, A., 1992. Episodic Sedimentation on an Early Silurian, Storm-Dominated Carbonate ramp, Becsie and Merrimack Formations, Anticosti Island, Canada. Sedimentology, v. 39, p. 355-381.

SEILACHER, A., AIGNER, T., 1991. Storm Deposition at the Bed, Facies, and Basin Scale: The Geologic Perspective. *In* Cycles and Events in Stratigraphy. *Edited by* Einsele, G., Ricken, W., and Seilacher, A. Springler-Verlag, Berlin, p. 249-267.

SHEEHAN, P.M., 2001. The Late Ordovician Mass Extinction. Annual Review of Earth and Planetary Sciences, v. 29, p. 331-364.

SOREGHAN, G.S., 1994. The Impact of Glacioclimatic Change on Pennsylvanian Cyclostratigraphy. *In* Pangea: Global Environments and Resources. *Edited by* Embry, A.F., Beauchamp, B., and Glass, D.J. Canadian Society of Petroleum Geologists Memoir 17, p. 523-543.

SOUFIANE, A., ACHAB, A., 2000. Chitinozoan Zonation of the Late Ordovician and the Early Silurian of the Island of Anticosti, Québec, Canada. Review of Palaeobotany and Palynology, v. 109, p. 85-111.

UNDERWOOD, C.J., CROWLEY, S.F., MARSHALL, J.D., BRENCHLEY, P.J., 1997. High-Resolution Carbon Isotope Stratigraphy of the Basal Silurian Stratotype (Dob's Linn) and Its Global Correlation. Journal of the Geological Society, v. 154, p. 709-718.

WANG, K., CHATTERTON, B.D.E., ORTH, C.J., ATTREP, M., JR., 1995. Geochemical Analysis Through the "Transitional Zone" of Conodont Faunal Turnover in the Ordovician-Silurian Boundary Interval, Anticosti Island, Québec. Canadian Journal of Earth Sciences, v. 32, p. 359-367.

YOUNG, S.A., SALTZMAN, M.R., AUSICH, W.I., 2005. Richmondian-Hirnantian (Upper Ordovician) Carbon Isotope ($\delta^{13}C$) Stratigraphy from Anticosti Island, Québec: Implications for Oceanography, Glaciation, and Organic Carbon Burial. *In* Abstracts for the Second International Symposium of IGCP503 on Ordovician Palaeogeography and Palaeoclimate. *Edited by* Peter M. Sheehan and Thomas Servais. Insight, A Milwaukee Public Museum Series in Natural History, no. 2, p. 40.

ZHANG, S., BARNES, C.R., 2002. Late Ordovician – Early Silurian (Ashgillian – Llandovery) Sea Level Curve Derived from Conodont Community Analysis, Anticosti Island, Québec. Palaeogeography, Palaeoclimatology, Palaeoecology, v. 180, p. 5-32.

Plate 1. Field pictures from the eastern sections. All cross-section views, except for B) which shows a bedding plane view. GR = Grindstone Member; VE = Velleda Member. **A)** Typical outcrop of the Mill Bay Member, in Mill Bay section. Note the sigmoidal cross-bedding. Greyish beds are sandstones, reddish beds are grainstones, darker interbeds are calcareous shales. Meter for scale. **B)** Bedding plane view of the coarse cross-bedded grainstones of the uppermost Mill Bay Member at the Mill Bay – Schmitt Creek contact, in Mill Bay section. Note the large *Paleofavosites* coral (circled). Person for scale. **C)** Fully exposed shaly Schmitt Creek Member, in Mill Bay section. Note the large coral beside the meter. **D)** Grindstone Member almost fully exposed (0.5 to 1.0 m missing at the bottom), at Table Head in Lousy Cove section. The two thick sandstone units correspond to Facies 4B, while the interbedded sandstone and calcareous shale unit in the middle corresponds to Facies 2D. Meter for scale (circled). **E)** *Planolites* burrows (light-coloured dots) in Facies 2D of the Grindstone Member, at Table Head. Hammer for scale. **F)** Synaeresis cracks in Facies 2D of the Grindstone Member, at Prinsta section. Zigzag shape due to compaction after filling of the crack by the overlying sediments. Ruler for scale (5 cm). **G)** HCS sandstones in Facies 2D of the Grindstone Member, at Prinsta section. Ruler for scale (10 cm). **H)** Balls and pillows in Facies 2D of the Grindstone Member, at Prinsta section. Ruler for scale (10 cm).

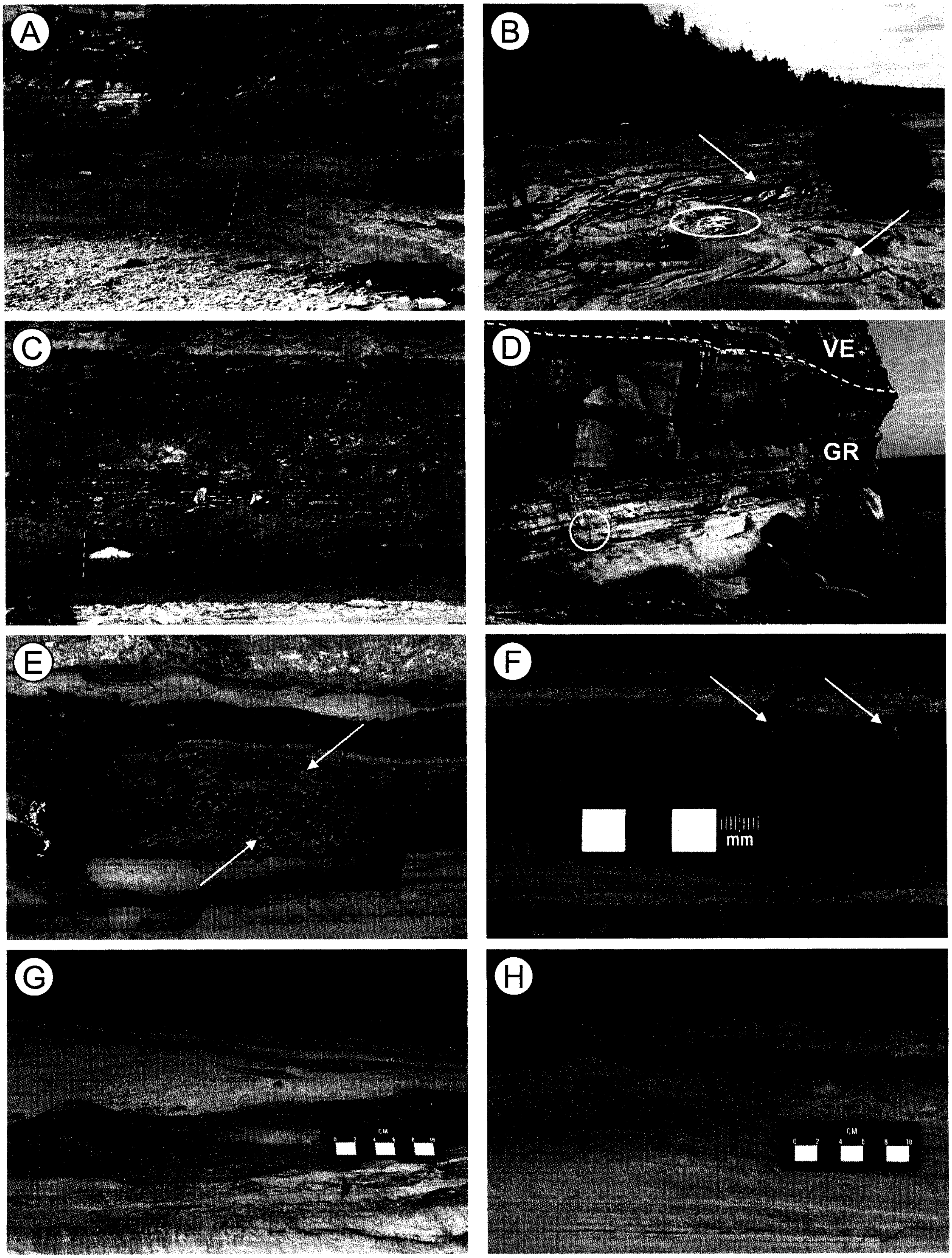

A
B
C
D
VE
GR
E
F
mm
G
CM
H
CM

Plate 2. Field pictures from the eastern sections. All cross-section views. VE = Velleda Member; PR = Prinsta Member; LC = Lousy Cove Member; LFB = Laframboise Member. Dotted lines separate different facies; dashed lines separate different members. **A)** Upper Velleda Member at Lousy Cove section, showing a vertical succession very similar to the typical succession of a prograding storm-dominated shoreface, from interbedded HCS (Facies 2C, transition zone), to amalgamated HCS and SCS (Facies 4B, lower to middle shoreface), to fine-grained cross-bedded (Facies 4C, upper shoreface), to medium- to coarse-grained cross-bedded (Facies 4C, upper shoreface) sandstones. Flat-laminated sandstones are absent above the cross-bedded sandstones; they have likely been eroded during transgression. Note the abundant light-coloured aulacerids in the shaly basal Prinsta Member. Backpack for scale. **B)** Velleda – Prinsta contact at Lousy Cove section, consisting of a transgressive ravinement surface. Note the medium- to coarse-grained cross-bedded sandstones (Facies 4C) of the uppermost Velleda Member and the abundant aulacerids of the basal Prinsta Member (Facies 2A). Hammer for scale. **C)** Close-up on aulacerids of the basal Prinsta Member, at Lousy Cove section. Ruler for scale (15 cm). **D)** Typical outcrop of the Prinsta Member (from approximately 21.5 to 25.5 m from the base of the Ellis Bay Formation), at Lousy Cove section. Note the shallowing-upward trend, from nodular sandy grainstones (Facies 2A, distal mid-ramp) to HCS and SCS sandstones (Facies 4B, lower to middle shoreface), also showing the mixed carbonate-siliciclastic nature of these deposits. Note also the coral-rich horizon in the lower part of the outcrop. Meter for scale. **E)** Distinct "grapefruit-sized nodules" (included in Facies 2A) of the Prinsta Member, in Prinsta River. These distinct nodules define a unit ranging from 26.5 to 28 m from the base of the formation. Backpack for scale. **F)** Facies 4F of the lower Lousy Cove Member, at Prinsta section. These interbedded grainstones (reddish and more resistant) and siltstones (greyish and more recessive) define a unit ranging from 33.3 to 36.1 m from the base of the formation. Meter for scale. **G)** Two distinct coarse grainstone units in the middle of the Lousy Cove Member, at Lousy Cove section. The lower grainstone unit (Facies 4C) marks the maximum regression within TR-3, while the upper bioturbated (nodular) grainstone unit (Facies 6) defines the basal transgressive lag of TR-4. The contact between the two is characterized by a pyritized hardground. Meter for scale. **H)** Facies 3B in the upper Lousy Cove Member, at Prinsta section. Note the continuous and tabular nature of the mudstone beds compared to their western counterpart (see Plate 4D). Meter for scale.

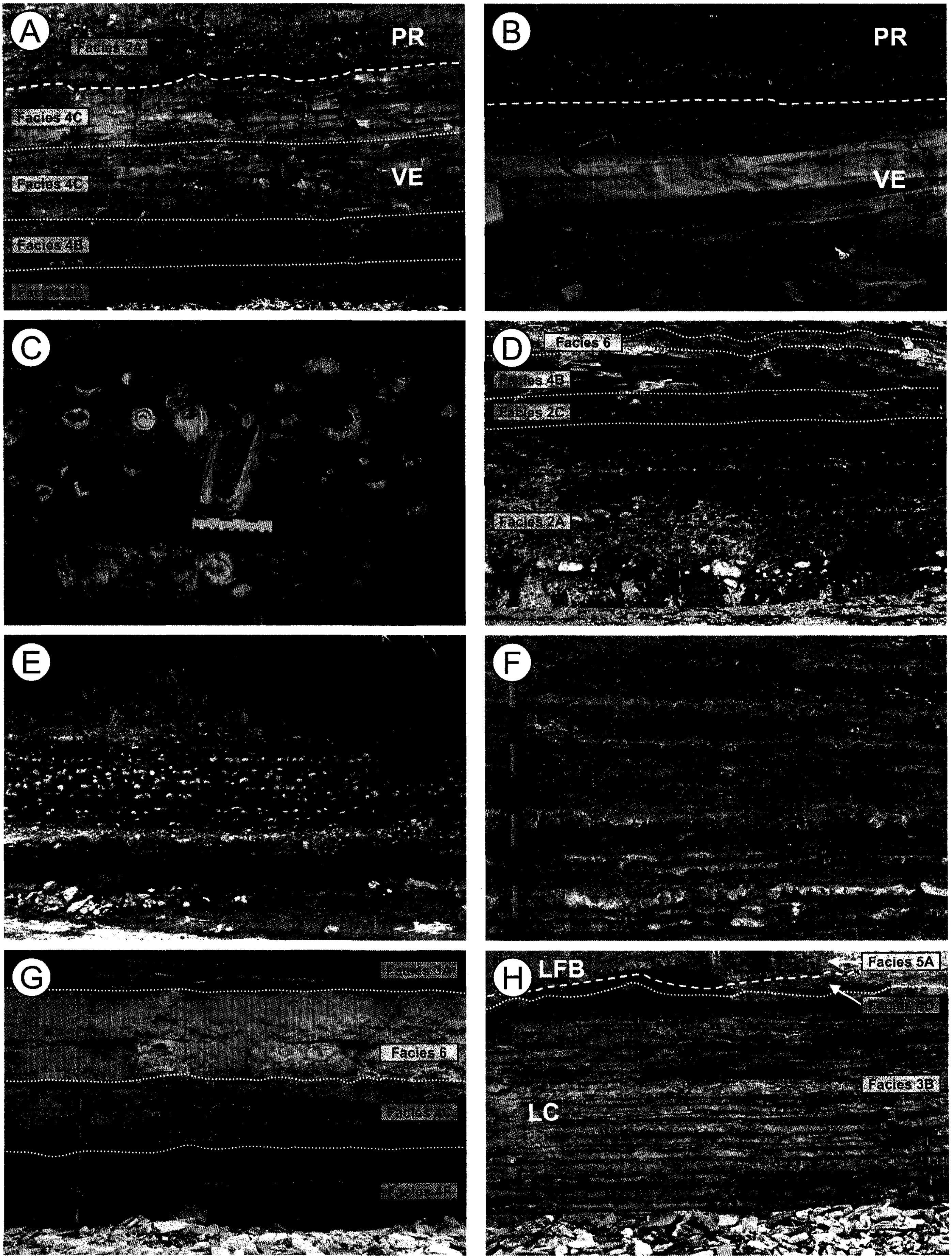

A
PR
Facies 4C
Facies 4C
VE
Facies 4B
B
PR
VE
C
D
Facies 6
Facies 4B
Facies 2C
Facies 2A
E
F
G
Facies 6
H
LFB
Facies 5A
Facies 3B
LC

Plate 3. Field pictures from the eastern sections. All cross-section views, except B) which shows a bedding plane view. MB = Mill Bay Member, SC = Schmitt Creek Member; GR = Grindstone Member; VE = Velleda Member; PR = Prinsta Member; LC = Lousy Cove Member; LFB = Laframboise Member; BE = Becscie Formation. Dotted lines separate different facies; dashed lines separate different members. **A)** Lousy Cove – Laframboise contact, in Prinsta River. Note the flat laminations in Facies 4D (characteristic of the foreshore, or inner ramp) and the erosive and bioturbated nature of the LC – LFB contact. Ruler for scale (5 cm). **B)** Bedding plane view of the LC – LFB contact, in Prinsta River. The darker areas consist of laminated sandstones of Facies 4D and stand in relief; they are bored at their top. The lighter areas consist of excavated burrows that have been preferentially eroded during the initial transgression at the base of the Laframboise "oncolitic platform bed". Ruler for scale (10 cm). **C)** LC – LFB erosional contact, on a transported block supporting the bridge crossing Prinsta River. Note the laminations below the contact and the well-developed oncoids above the contact. Ruler for scale (5 cm). **D)** Lenticular-shaped bioherm (Facies 5B) of the Laframboise Member overlain by thin- to medium-bedded mudstones to grainstones of the Becscie Formation, at Lousy Cove section. Meter for scale. **E)** Mill Bay – Schmitt contact within TR-1. Lighter beds at the bottom of the outcrop are sandstones; overlying thick reddish beds are grainstones. Meter for scale. **F)** Grindstone Cliff at Mill Bay section showing the first two transgressive-regressive sequences (TR-1 and TR-2) with the Schmitt Creek, Grindstone, and Velleda members fully exposed. The shore level closely corresponds to the Mill Bay – Schmitt Creek contact. Note the three characteristic units forming the Grindstone Member (Facies 4B – 2D – 4B), for a total of 8 to 10 m. **G)** Cliff at Prinsta section showing TR-1 to TR-3 with the Grindstone, Velleda, and Prinsta members fully exposed. Note the two shaly units characteristic of the lower Velleda Member, overlain by the thick sandstone unit showing a typical prograding storm-dominated shoreface succession (see Plate 2A). **H)** Cliff in the southern part of the Lousy Cove section, showing the end of TR-3 and TR-4. The light-coloured unit at the base of the outcrop consists of the two coarse grainstone units of the middle Lousy Cove Member (see Plate 2G). The Laframboise Member and the overlying Becscie strata form part of a fifth TR sequence (not identified).

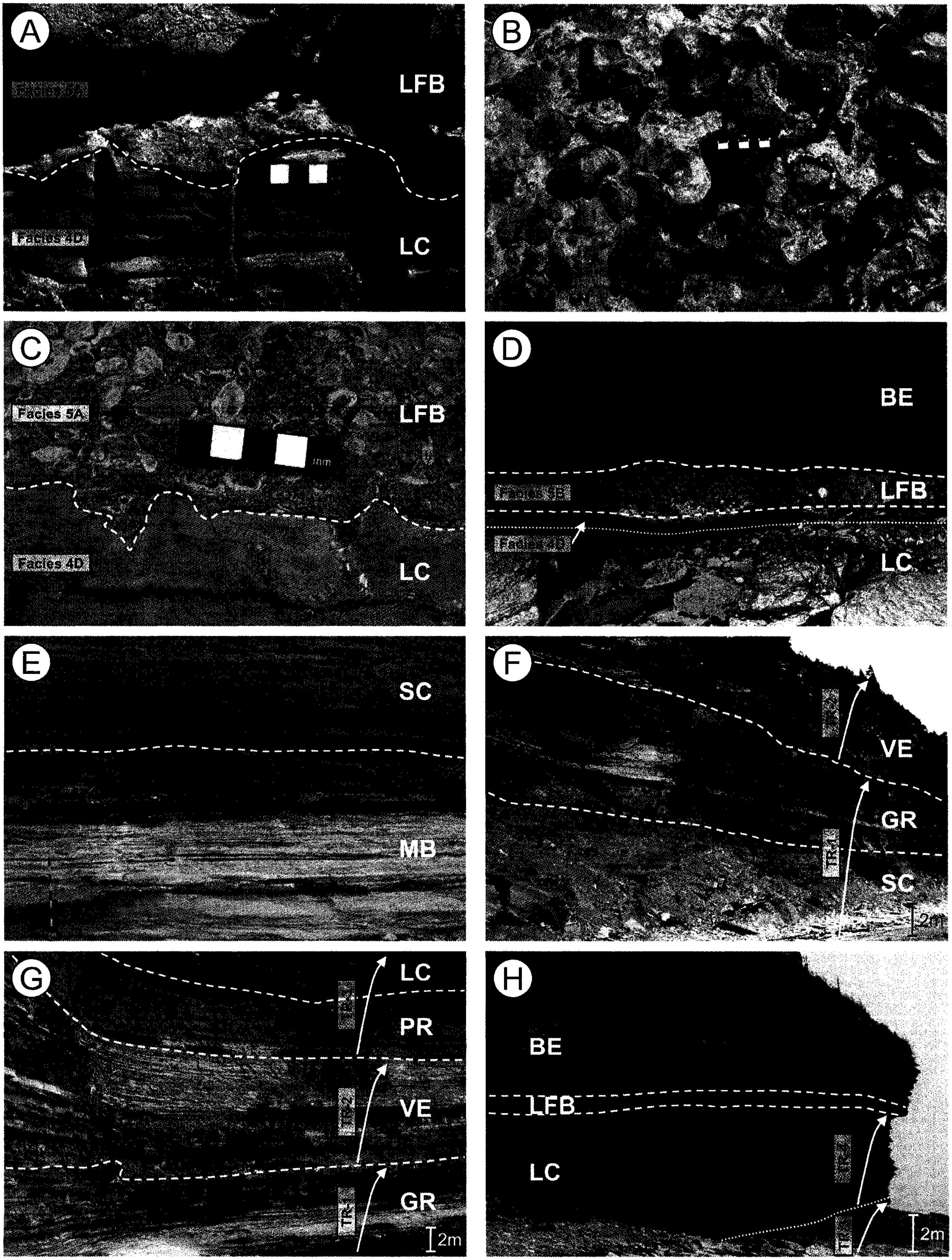

A
LFB
Facies 4D
LC
B
C
Facies 5A
LFB
Facies 4D
LC
D
BE
LFB
LC
E
SC
MB
F
VE
GR
SC
2m
G
LC
PR
VE
GR
2m
H
BE
LFB
LC
2m

Plate 4. Field pictures from the western sections. All cross-section views. LC = Lousy Cove Member; LFB = Laframboise Member. **A)** Facies 1 in the basalmost Prinsta Member, in section 2. Note the sparse more resistant tempestite beds. Meter for scale. **B)** Facies 3A below the distinct continuous 20 cm thick unit in the basal Prinsta Member, in section 2. Meter for scale. **C)** Close-up on the nodular Facies 3A in the basal Prinsta Member, in section 2. Ruler for scale. **D)** Facies 3B in the middle Prinsta Member, in section 2. Note the highly lenticular and discontinuous nature of these mudstones compared to their eastern counterpart (see Plate 2H). Meter for scale. **E)** Close-up on a typical tempestite bed of Facies 3B, in the middle Prinsta Member in section 2. Note the thin coarser and bioclastic base defining a weak normal grading. Finger for scale. **F)** Fully exposed Facies 4 unit of the uppermost Lousy Cove Member, in section 2. **G)** Close-up on small-scale wave ripple cross-stratifications of Facies 4A of the uppermost Lousy Cove Member, from a fallen block on the beach in section 1. Ruler for scale. **H)** Lousy Cove – Laframboise contact, in section 2. Note the highly erosional nature of this contact, and also the laminations below and the oncoids above it. Finger for scale.

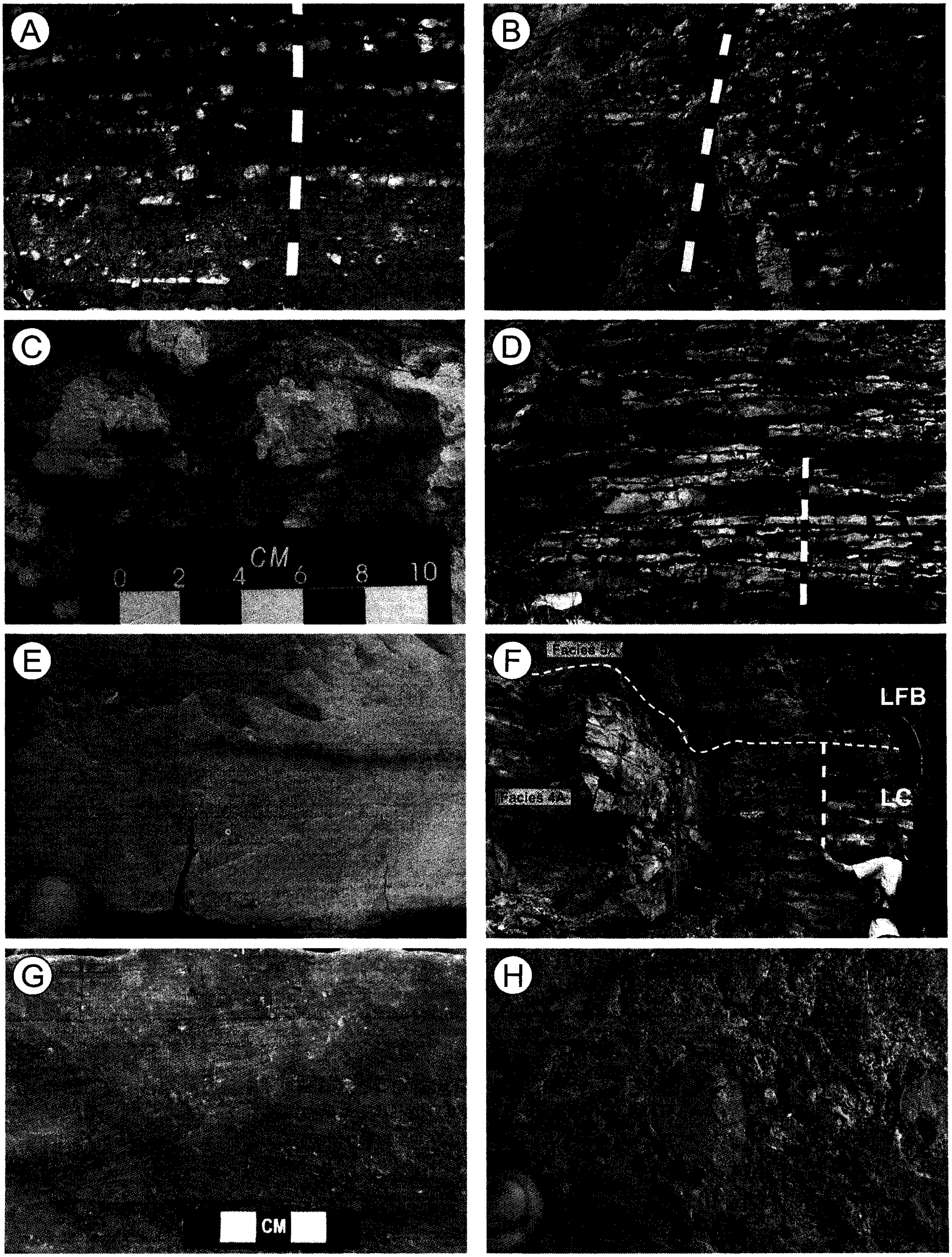
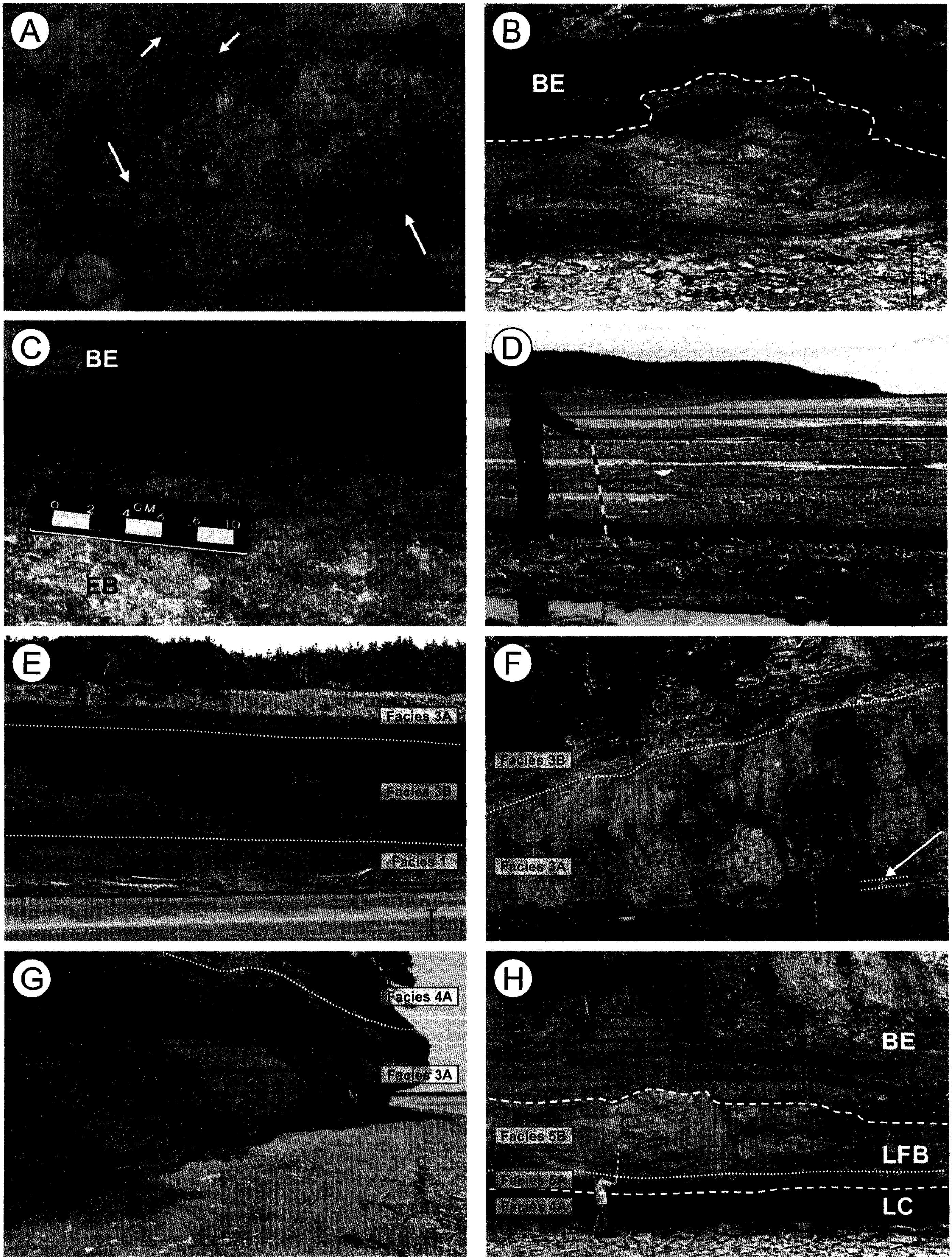

A
B
C
CM
0 2 4 6 8 10
D
E
F
Facies 5A
LFB
Facies 4A
LC
G
CM
H

Plate 5. Field pictures from the western sections. All cross-section views, except D) which shows a bedding plane view. LC = Lousy Cove Member; LFB = Laframboise Member; EB = Ellis Bay Formation; BE = Becscie Formation. Dotted lines separate different facies; dashed lines separate different members. **A)** Close-up on Facies 5A of the Laframboise "oncolitic platform bed", in section 2. **B)** Lenticular-shaped bioherm and preferentially eroded interbiohermal strata (Facies 5B) of the Laframboise Member, at Pointe Laframboise in section 1. Note the Becscie strata onlapping the bioherm. Black dotted line separates bioherm core from interbiohermal strata. **C)** Continuous pyritized erosion surface (dark hardground) at the Ellis Bay – Becscie contact (see black arrow), here capping a bioherm, at Pointe Laframboise in section 1. Ruler for scale. **D)** Highly resistant grainstone beds (base of the meter) marking the base of the Grindstone Member and of the Ellis Bay Formation at Anse aux Fraises, in section 1. In the background is Cap-de-la-Vache-Qui-Pisse. **E)** Succession of facies defining a shallowing followed by a deepening, at Cap-de-la-Vache-Qui-Pisse in section 1. Facies correspond to the uppermost Grindstone Member and about half of the Velleda Member. Person with meter for scale. **F)** Succession of facies showing an overall upward shallowing, in section 2. Facies correspond approximately to the lower half of the Prinsta Member. Note the distinct continuous 20 cm thick unit immediately above the meter, marking a higher-frequency maximum shallowing followed by an associated slight deepening, sharply overlain by more proximal strata of Facies 3B. Person and meter for scale. **G)** Shallowing-upward succession in the upper Lousy Cove Member, in section 2. Person with meter for scale. **H)** Facies relation at the Ellis Bay – Becscie contact. Black dotted line separates bioherm core from interbiohermal strata. Person with meter for scale.


A
B
BE
C
BE
0 2 4 CM 6 8 10
EB
D
E
Facies 3A
Facies 3B
Facies 1
2m
F
Facies 3B
Facies 3A
G
Facies 4A
Facies 3A
H
BE
Facies 5B
LFB
LC