Geological Survey of Canada

CURRENT RESEARCH
2004-B3

Stratigraphy of the Mesoproterozoic Society Cliffs Formation (Borden Basin, Nunavut): correlation between northwestern and southeastern areas of the Milne Inlet Graben

Elizabeth C. Turner

2004

Natural Resources Canada
Ressources naturelles Canada

Canada

CURRENT RESEARCH

ISSN 1701-4387
Catalogue No. M44-2004/B3E-PDF
ISBN 0-662-36599-2

A copy of this publication is also available for reference by depository libraries across Canada through access to the Depository Services Program's website at http://dsp-psd.pwgsc.gc.ca

A free digital download of this publication is available from the Geological Survey of Canada Bookstore web site:

http://gsc.nrcan.gc.ca/bookstore/

Click on Free Download.

Author’s address

E.C. Turner (eturner@nrcan.gc.ca)
626 Tumiit Building, P.O. Box 2319
Iqaluit, NU X0A 0H0

Publication approved by C-NGO, Nunavut

Original manuscript submitted: 2003-12-16

Final version approved for publication: 2004-03-08

Stratigraphy of the Mesoproterozoic Society Cliffs Formation (Borden Basin, Nunavut): correlation between northwestern and southeastern areas of the Milne Inlet Graben

Elizabeth C. Turner

Turner, E.C., 2004: Stratigraphy of the Mesoproterozoic Society Cliffs Formation (Borden Basin, Nunavut): correlation between northwestern and southeastern areas of the Milne Inlet Graben; Geological Survey of Canada, Current Research 2004-B3, 11 p.

Abstract: The existing stratigraphic nomenclature does not adequately portray the complex facies architecture and temporal relations in the upper Arctic Bay Formation–Society Cliffs Formation interval in the Milne Inlet Graben. The Society Cliffs Formation in the southeastern area is a carbonate ramp divided into lower and upper members on the basis of upward-declining terrigenous content. The lower member grades westward into basinal shale belonging to the upper Arctic Bay Formation, and, in scattered locations, deep-water carbonate mounds that formed topographically pronounced edifices rising from the basin floor. The upper member passes westward to deep-water carbonate laminite, which is the host rock for most base-metal showings in the region and for the Nanisivik orebody; although deep-water mound growth had ceased, the relict topography of mounds remained significant throughout laminite deposition. These temporal equivalencies should be taken into consideration in matters concerning basin evolution, fluid flow, and diagenetic patterns in the Milne Inlet Graben.

Résumé : La nomenclature stratigraphique existante ne reflète pas adéquatement l'architecture complexe des faciès et les relations temporelles dans l'intervalle comprenant la partie supérieure de la Formation d'Arctic Bay et la Formation de Society Cliffs dans le graben de Milne Inlet. La Formation de Society Cliffs, dans la partie sud-est de la région, est une rampe carbonatée séparée en un membre supérieur et un membre inférieur en fonction d'un contenu terrigène diminuant vers le haut. Le membre inférieur passe vers l'ouest à un shale de bassin de la partie supérieure de la Formation d'Arctic Bay et, à des endroits épars, à des monticules carbonatés formés en eau profonde qui constituaient des édifices topographiquement imposants s'élevant du fond du bassin. Le membre supérieur passe progressivement vers l'ouest à des laminites carbonatées d'eau profonde qui constituent l'encaissant de la plupart des indices de métaux communs de la région et du corps minéralisé de Nanisivik; bien que la croissance des monticules d'eau profonde ait cessé, leurs vestiges sont partout restés importants pendant toute la période d'accumulation des laminites. Ces équivalences temporelles devraient être prises en considération en ce qui a trait à l'évolution du bassin, à l'écoulement des fluides et aux configurations diagénétiques dans le graben de Milne Inlet.

GEOLOGICAL SETTING

The Milne Inlet Graben, one of three grabens in the aulacogenic Borden Basin (ca. 1.2 Ga; Fig. 1), contains unmetamorphosed sedimentary and volcanic rocks of the Bylot Supergroup (Fig. 2), the middle part of which is dominated by carbonate and fine terrigenous rocks of the Arctic Bay (Jackson and Iannelli, 1981; Iannelli, 1992), Society Cliffs (Geldsetzer, 1973a; Kah and Knoll, 1996; Kah, 1997; Kah et al., 2001; Turner, 2003a), and Victor Bay (Sherman et al., 2000; 2001) formations. The stratigraphy and sedimentology of the Society Cliffs Formation have been documented for the southeastern part of the Milne Inlet Graben (Kah, 1997), but little is known of their nature and origin in the northwestern two-thirds of the basin, an area in which the formation contains numerous base-metal showings and the Nanisivik Zn-Pb orebody (Fig. 1). The graben is characterized by a system of syndepositional, repeatedly reactivated, northwest-trending normal faults and variably oriented subsidiary structures. The general structure and stratigraphy of the basin have been described by Jackson and Iannelli (1981) and by Iannelli (1992).

This work forms part of a study designed to determine the structural, stratigraphic, and sedimentological controls on the distribution, nature, and origin of the numerous Pb/Zn/Fe (± Cu, Ag, F) showings known from the Milne Inlet Graben (Sangster, 1998; Jackson and Sangster, 1987). The most important of these mineral deposits is the Nanisivik Zn-Pb orebody (mined 1976–2002). Known mineralization in the Milne Inlet Graben is predominantly limited to distinct lithofacies and stratigraphic levels of the Society Cliffs Formation (e.g. Turner, 2003b); understanding the formation's composition, origin, and lateral facies relations may be critical to determining constraints on mineralization in the district.

STRATIGRAPHIC CONTEXT AND PREVIOUS WORK — SOCIETY CLIFFS FORMATION

The Society Cliffs Formation was originally described, and its type section erected, at the St. Georges Society Cliffs, near the present-day hamlet of Arctic Bay (Ikpiaryuk), near the western exposure limit of the Milne Inlet Graben (Blackadar, 1956; Lemon and Blackadar, 1963; Fig. 3A). It was described as being 900 feet (275 m) thick and consisting of 20 feet (6 m) of black argillaceous dolostone overlain by massive dolostone.

Consistently with the stratigraphic position of the type section, the term 'Society Cliffs Formation' was subsequently used to designate a continuously exposed, resistant

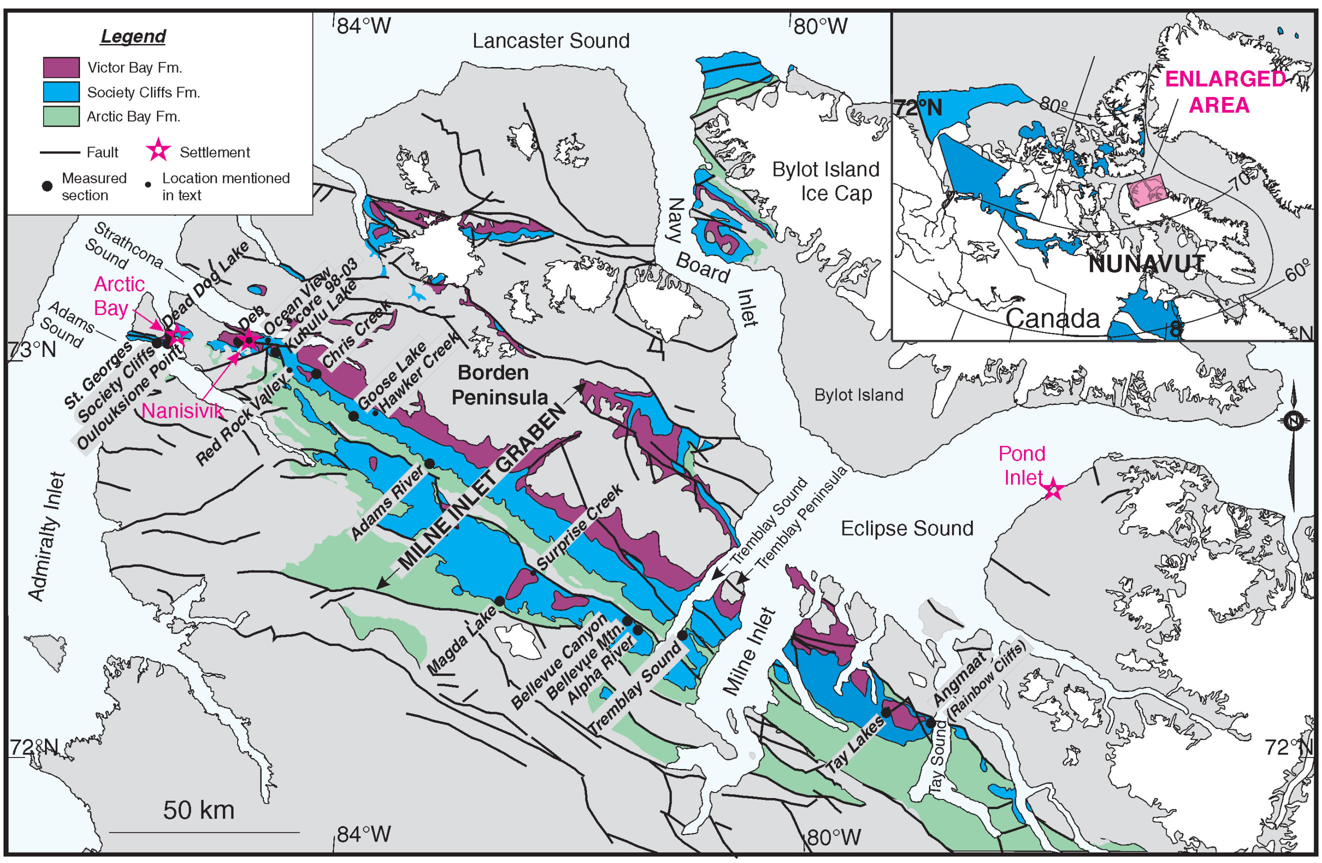

Figure 1. Map of northernmost Baffin Island showing exposure areas of Arctic Bay, Society Cliffs, and Victor Bay formations, major faults in the Borden Basin, and locations mentioned in text.

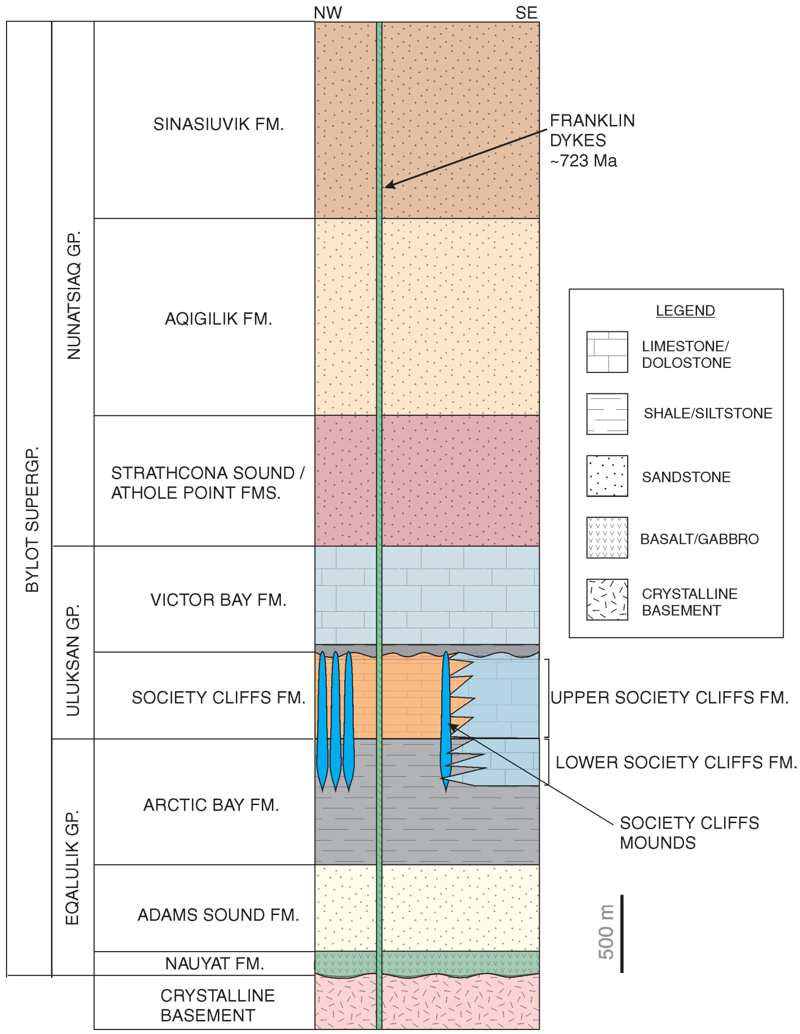

Figure 2.

Schematic stratigraphy of the Bylot Supergroup, northern Baffin Island. Lateral thickness variation and relative thickness of subunits are not accurately depicted.

dolostone between shale units across the width of the Milne Inlet Graben. Although pragmatic for mapping purposes, the use of these compositional units obscures the spatial and temporal relations between strata in southeastern and northwestern parts of the graben, thereby complicating the interpretation of the unusual carbonate rocks that dominate the northwestern two-thirds of the graben and host the base-metal showings. Table 1 summarizes how the observations of previous workers support new interpretations of the stratigraphy and sedimentology of the Society Cliffs Formation.

Expanding upon the work of Geldsetzer (1973a, b), Jackson and Iannelli (1981) and Iannelli (1992) distinguished two geographically distinct lithofacies assemblages (southeastern and northwestern) in Society Cliffs strata of the Milne Inlet Graben, with the division in the Milne Inlet area. The formation is also divided into lower and upper units, based on an upward decrease in the proportion of terrigenous material in the southeast.

Subsequent detailed work (Kah and Knoll, 1996; Kah, 1997; Kah et al., 2001) focused on lithofacies and stratigraphic packaging in the southeastern area (east of the mouth of the Alpha River), where the succession represents a very low-angle ramp. In the lower Society Cliffs Formation (~200 m), the inner-ramp area (Tay Sound to White Bay) consists of four packages of cyclically interbedded shallow subtidal to intertidal stromatolites, intertidal to supratidal microbial laminites, evaporites, and evaporite solution-collapse breccia, and supratidal desiccation-cracked red shale, whereas the mid-ramp (Milne Inlet–Alpha River) consists of black shale and 'microbrecciated carbonate', interpreted as lowstand deposits outboard of an incised platform margin. The transition from lower to upper Society Cliffs Formation is characterized by a sequence (~125 m) in which ooids appear on the mid-ramp, terrigenous input to the inner ramp decreases, and strata are dominated by thinly laminated microbial carbonate and seafloor cement. The upper Society Cliffs Formation consists of eight unconformity-bounded sequences. One- to ten-metre cycles of stromatolites, ooid-intraclast grainstone, tepee dolomudstone, and desiccation-cracked dolomudstone prevail in the mid-ramp, recording a high-energy, platform-margin intertidal shoal complex, whereas the inner ramp consists of 10 to 50 m cycles of stromatolites, laminated microbial dolostone, and seafloor cements, representing a high-intertidal to supratidal zone. Metre- and decametre-scale cyclicity are attributed to eustatic sea-level variation.

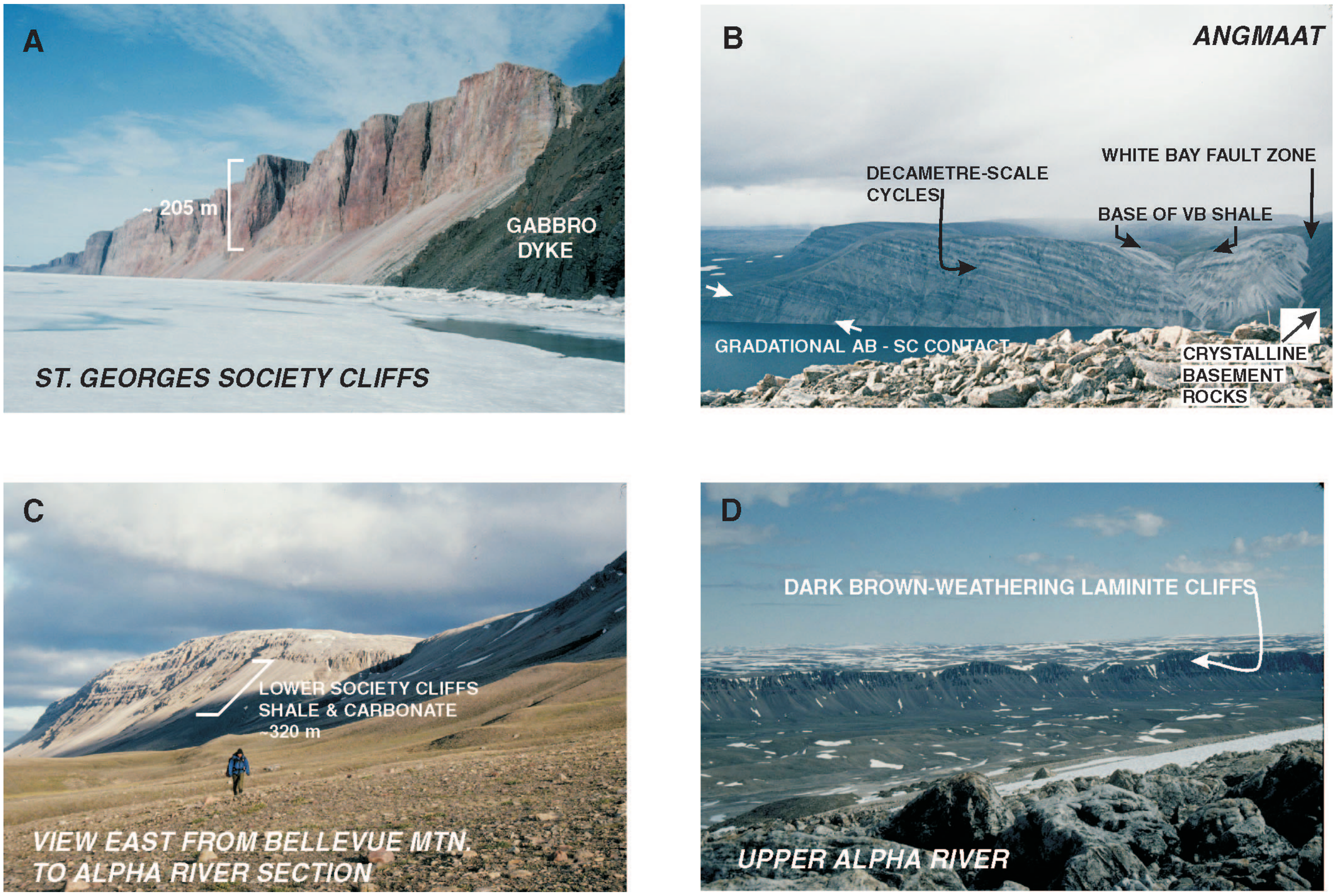

Figure 3. *Lateral facies variation in the Society Cliffs Formation. (**A**) Original type section of Society Cliffs Formation, at St. Georges Society Cliffs near Arctic Bay, transects part of a deep-water carbonate mound and is not representative of the formation in general. (**B**) Peritidal cyclic Society Cliffs Formation (~ 800 m thick) in the Angmaat section, in easternmost Milne Inlet Graben. AB = Arctic Bay Formation; SC = Society Cliffs Formation; VB = Victor Bay Formation. (**C**) Transition zone between southeastern and northwestern parts of the basin in the Alpha River section. (**D**) Massive, dark cliffs of basinal laminite facies characterize the Society Cliffs dolostone in most of the northwestern Milne Inlet Graben.*

None of the previous work has addressed in detail, or with a modern understanding of Precambrian carbonate rocks, the stratigraphy and sedimentology of the Society Cliffs Formation in the western two-thirds of the Milne Inlet Graben. This region is dominated by laminated dolostone, familiar to many as the Nanisivik mine host rock; based on its laminated character, this lithofacies was previously and erroneously considered to be peritidal and/or stromatolitic. Owing to the broad scale (entire Bylot Supergroup and entire Borden Basin; Jackson and Iannelli, 1981; Iannelli, 1992) and tight geographic focus (southeastern third of Milne Inlet Graben; Kah, 1997) of previous stratigraphic work and to the lack of focus on the western laminite lithofacies, the origin and depositional environment of these basinal rocks, the lateral relation between basinal rocks (northwestern) and cyclic ramp rocks (southeastern), and the relevance of primary host-rock characteristics to base-metal mineralization were not addressed. The present work aims to fill in these blanks in the sedimentology and stratigraphy of the Society Cliffs Formation, based on preliminary information from the ongoing field program and on previous work.

SOCIETY CLIFFS FORMATION STRATIGRAPHY

Lithofacies

Southeast of Milne Inlet, Society Cliffs Formation strata consist of pale-grey-weathering, cyclic peritidal dolostone (Fig. 3B), the lower part of which is interlayered with red and green shale or siltstone and with locally derived sand- to pebble-sized terrigenous clasts in the vicinity of syndepositionally active faults. In the Tremblay Sound and Alpha River sections (Fig. 3C), the lower Society Cliffs Formation consists of storm-affected, shallow-marine outer-ramp to slope carbonate rocks interlayered with shale; the upper Society Cliffs Formation is characterized by intermittently subaerially exposed, stromatolitic, oolitic, intraclastic platform-margin facies on eastern Tremblay Peninsula (as reported by Kah, 1997), and storm-affected outer-ramp facies in the Alpha River section. West of Bellevue Mountain (Fig. 3D), the entire dolostone unit between shale units of the Arctic Bay and Victor Bay formations consists of

Table 1. Stratigraphic and sedimentological observations of previous workers, with new interpretations arising from this study. AB = Arctic Bay Formation; SC = Society Cliffs Formation; VB = Victor Bay Formation; MIG = Milne Inlet Graben.

	OBSERVATION	ORIGINAL INTERPRETATION	REVISED INTERPRETATION (this work)
Lemon and Blackadar, 1963	SC type section at St. Georges Society Cliffs = 900' (275 m) consists of 20' (6 m) of black argillaceous dolostone overlain by massive dolostone.		Type section was chosen at a location that is not representative of the formation.
Geldsetzer, 1973a, b	Basal contact of SC dolostone sharp, locally angular, locally contains carbonate/shale-clast conglomerate.	AB shale - SC dolostone contact (west of Milne Inlet) is angular unconformity, with evidence of erosional downcutting, caused by regional uplift.	Shale-dolostone contact angular and intraclastic where mounds prograded over surrounding mud; contact everywhere conformable, with no regional uplift or unconformity; in west, shale-mound dolostone contact is diachronous and within time-frame of lower Society Cliffs deposition in east; shale-laminite contact coeval with lower-upper SC transition in east.
	Lower SC consists of gypsiferous nodular dolostone in westernmost MIG, subtidal stromatolites in east.	Lower SC deepened eastward: sabkha in west, subtidal stromatolites in east, with intervening terrigenous/carbonate intraclast shoal parallel to a western shoreline.	Nodular dolostone at base of SC in west is atypical, present at one location, and represents progradation of mound facies over shale; furthermore, it is not necessarily the base of the SC. Lower SC deepened westward from Tremblay Peninsula to a shale basin (with local mounds); terrigenous material in central Borden Peninsula was shed from synsedimentarily active faults exposing ?Adams Sound Fm.
	Upper SC: subtidal stromatolites in west, with intercalated carbonate mud derived from shoals (location unstated); subtidal stromatolites intercalated with supratidal and terrigenous facies in east.	Upper SC deepens westward, is regional, quiescent, subtidal 'algal-dominated' (i.e. microbial mats).	Upper SC deepened westward: shallow platform in east (benthic microbial facies and seafloor precipitates), distal steepening at Tremblay Peninsula; anoxic deep-water basin west of Tremblay Sound (non-stromatolitic, water-column-derived basinal carbonate laminites).
		SC interval terminated by uplift and erosion, with deep karstic solution-brecciation in west. Karstic porosity filled and cemented, followed by subsidence, and (unpreserved?) evaporative interval causing reflux dolomitization of entire SC interval and precipitation of massive sulphides (i.e. Nanisivik ore body).	SC interval terminated by subaerial and variable erosion across most of MIG; no clear evidence of subsurface karst development or other interpreted events. In deepest basin areas, away from mounds, laminite-shale contact is gradational.
Jackson and Iannelli, 1981	In west, basal shale-dolostone contact sharp; locally has dolostone conglomerate at base.	AB-SC contact is unconformable where dolostone conglomerate is present at base, but otherwise conformable.	Contact between shale and dolostone is everywhere conformable. Dolostone clast conglomerates at base of dolostone are only found near mounds, and are mound-derived progradational tongues.
		Planar laminites are stromatolitic.	Planar laminites are water-column carbonate precipitates affected by periodic organic blooms; no benthic microbial community involved.
	Lower SC consists of various dolostone types, with local terrigenous material and gypsum in east, and local, minor shale. (15 m in west, 45 m on eastern Borden Peninsula, 460 m at Angmaat).	Lower SC deepened westward: supratidal-intertidal (sabkha/alluvial plain) east of Milne Inlet; shallow subtidal-intertidal west of Milne Inlet.	Lower SC deepened westward from low-angle ramp east of Milne Inlet, steepening at Tremblay Sound, to shale basin west of Tremblay Sound.
	Upper SC (30 to >600 m) is dolostone with rare shale.	Upper SC is shallow subtidal-intertidal, with hinge line characterized by stromatolitic bioherms at Milne Inlet.	Upper SC is subtidal-intertidal platform in east, with platform-margin at Milne Inlet-eastern Tremblay Peninsula, steepened ramp at Tremblay Sound, and anoxic basin west of Tremblay Sound.
	Paleocurrents and stromatolite elongations are northwestward at Milne Inlet.	Currents were dominantly to northwest.	Subtle northwest-deepening slope / steepened ramp from Tremblay Peninsula to Alpha River.
	Upper SC contains dolostone-clast breccias on western Borden Peninsula; some breccias are reworked.	Brecciation was result of post-depositional solution collapse.	Brecciation of basinal laminites was penecontemporaneous with laminite deposition (Turner, 2003b). Postdepositional erosion of upper surface of SC was significant, but not characterized by karstic (or other) solution collapse.

Table 1 (cont.)

	OBSERVATION	ORIGINAL INTERPRETATION	REVISED INTERPRETATION (this work)
Clayton and Thorpe, 1982	Laminated dolostone is 'algal' (microbial), but much of the formation is a massive 'marble'. Bedding-parallel zones of massive dolostone are interbedded with laminites above ore body, as are layers of dolomudstone containing angular, white clasts.	Massive 'marble' resulted from recrystallization of laminite facies. Layers of white clasts are lags in intertidal channels; laminite facies inferred to be peritidal.	Massive, textureless dolostone is of mound origin and likely predates laminite deposition. Mounds had impressive topography above surrounding seafloor through most of SC deposition. Layers over main orebody may be olistoliths shed from a high-standing dead mound, or could represent renewed mound growth in upper SC time. White clasts are fragments eroded from high-standing mounds and deposited as debrites and turbidites on mound flanks.
	Lower VB shale does not infiltrate breccia interstices in upper SC.	Solution collapse & cementation of SC breccias took place before deposition of VB.	Breccia formation and occlusion of interstices took place synsedimentarily, commonly close to or at sediment-water interface.
	Thickness of lower VB shale varies markedly from one fault-bounded area to another at Nanisivik.	Normal faulting took place between deposition of SC and VB.	Episodic, local normal faulting took place during SC deposition. Significant normal faulting took place across the MIG after SC deposition, with evidence of erosional removal of over 200 m of SC strata at Angmaat, near eastern end of MIG.
Olson, 1984		Planar laminites are intertidal and former presence of interbedded evaporites (now vanished) can be assumed.	Planar laminites are of deep-water (sub-storm wavebase, sub-photic zone) origin. Former presence of deep-water evaporites possible.
	Brecciation of laminites on western Borden Peninsula is intrastratal; no meteoric precipitates or textures present.	Brecciation caused by intrastratal evaporite solution.	Brecciation not demonstrably related to evaporites.
	SC-VB contact is sharply disconformable, with tens of metres of topographic differential. Massive sulphide bodies in upper SC approximate sinuous cylinders.	SC deposition was followed by meteoric karstification and development of caves. Sulphides were deposited in caves.	SC deposition was followed by subaerial erosion, but no significant karst-feature development.
Iannelli, 1992	Lower SC in NW thinly laminated to thin bedded doloarenite and stromatolitic dolostone (10 m at Arctic Bay, 150 m at E Tremblay Sound, locally absent). Lower SC in SE is intraclastic and stromatolitic dolostone with interlayered pink-red shale, sandstone, gypsum, chert (thickness max. 475 m at Tay Sound). Upper SC in NW thinly laminated to thinly bedded dolostone, stromatolitic dolostone and intraclast conglomerate (thickens SE from 273 m at Arctic Bay to 706 m at eastern Tremblay Sound). Upper SC in SE buff-grey thinly bedded dolostone, stromatolitic, intraclastic dolostone, dololutite and doloarenite (348 m at Angmaat (Rainbow Cliffs).	SC 280 m at Arctic Bay, 856 m at Tremblay Sound, 823 m in southeast. SE MIG was semirestricted shallow marine in lower SC, stromatolitic platform in upper SC. NW MIG was restricted platform.	Lower SC in MIG was a low-angle ramp dominated by microbial mats and seafloor precipitates, with outer ramp at Tremblay Peninsula, gentle slope at Tremblay Sound, and shale basin west of Alpha River. Upper SC in MIG was platform with microbial mats and seafloor precipitates east of Milne Inlet, with stromatolitic/oolitic/intraclastic platform margin at Milne Inlet, ramp at Tremblay Sound – Alpha River, and anoxic basin west of Alpha River.
Kah and Knoll, 1996 Kah, 1997 Kah et al., 1999 Kah, 2000 Kah et al., 2001	Area east of Alpha River characterized by supratidal, desiccated terrigenous and carbonate tidal flats, seafloor precipitates, and microbial dolostone, with high-energy ooid-intraclast-stromatolite facies at Milne Inlet.	Eastern SC area represents high intertidal to supratidal low-angle ramp. Lower SC inner ramp was shallow subtidal to supratidal, outer ramp was deposits of incised lowstand platform margin. Upper SC inner ramp was evaporative microbially-dominated supratidal flat, outer ramp was intertidal shoal complex.	Lower SC was low-angle ramp east of Milne Inlet, distally steepened at Tremblay Sound, and basinal west of Alpha River. Upper SC was a carbonate platform, with ooid-intraclast-stromatolite platform margin at Milne Inlet, steepened outer ramp or shallow slope from Tremblay Peninsula to Alpha River, anoxic basin west of Bellevue Mtn.
		AB-SC contact is unconformable.	AB-SC contact is conformable.
	Lower SC ramp characterized by evaporites in both inner and mid-ramp. Upper SC ramp characterized by reduction of eastern terrigenous input, and development of ooid-intraclast shoals on mid-ramp.	Upper SC represents greater water depths than lower SC.	Upper SC represents greater water depths than lower SC.
		Lower SC contains 4 unconformity-bounded sequences; Upper SC contains 8 unconformity-bounded sequences.	Cyclic packaging is identifiable locally, but correlatability of the succession is compromised by syndepositional tectonism.

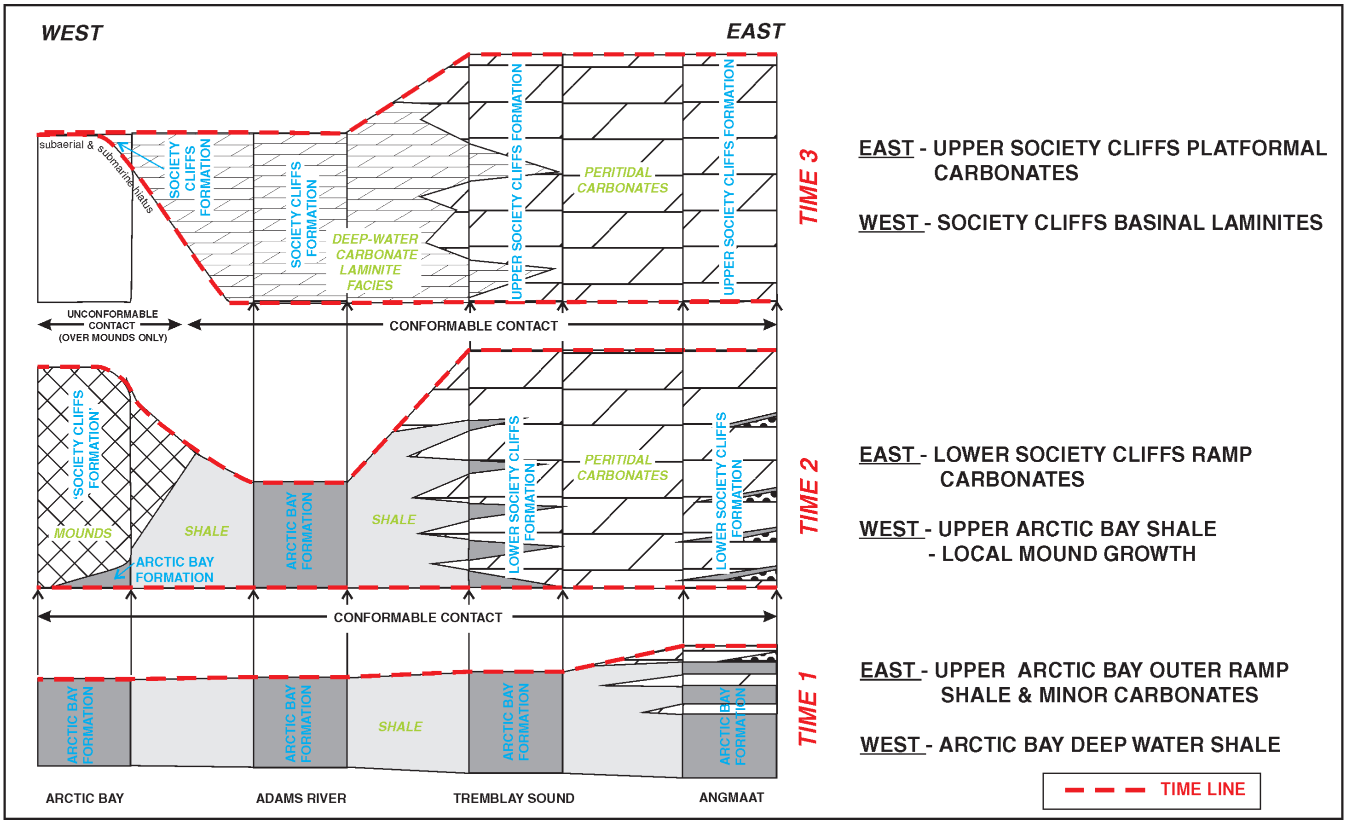

Figure 4. *Correlation panel showing new interpretation of lateral facies relations for three time intervals encompassing deposition of upper Arctic Bay and Society Cliffs formations.*

dark-brown-weathering, submillimetrically planar-laminated carbonate with pervasive crackle to rubble breccia; no cyclicity is present, nor are features indicative of peritidal, shallow marine, or slope paleoenvironments (Turner, 2004a).

Distribution and lateral relations of laminite lithofacies

The laminated Society Cliffs facies occupies the entire south limb of the Milne Inlet Graben west of Bellevue Mountain. Tongues of laminite extend as far east as western Tremblay Peninsula, where they interfinger with carbonate rocks of the upper Society Cliffs Formation outer ramp. Laminite is also geometrically laterally equivalent to upper parts of thick, unbedded pale dolostone units, shown in related work to be topographic relics of deep-water carbonate mounds up to 10 km across which grew prior to laminite deposition and remained topographically elevated through late Society Cliffs time (Turner, 2004b). These are particularly common in the western end of the Milne Inlet Graben.

Lower contact

The Arctic Bay Formation–Society Cliffs Formation transition in the southeast is gradational. The contact is located within an interval characterized by gradual changes in the proportion of carbonate and of red and green shale, and by an influx of coarse terrigenous material (Jackson and Iannelli, 1981; Iannelli, 1992); in the Angmaat section, the contact is placed at the base of the lowest shale-carbonate cycle (Iannelli, pers. comm., 2003). At other locations, the transition is more pronounced, as in the Tay Lakes section (Turner, 2003a), where green mudstone is abruptly overlain by massive dolostone. In the western part of the ramp (Tremblay Sound section), the contact is at the base of a shale-dominated interval through which thin, sparse carbonate beds are introduced and gradually become predominant. In the Alpha River section, the contact is located where shale changes from greenish to dark grey, and carbonate interbeds become common (Turner, 2003a).

In the west, the contact between shale and laminite facies is not well exposed. At the Adams River section (Turner, 2003a, b), in patchy outcrop, shale passes abruptly to laminite intercalated with fault-derived terrigenous debrites; underlying this transition is a 15 m interval of bituminous shale with centimetric to decimetric discoidal concretions of radiating carbonate crystals. In some sections in the basinal area (e.g. Magda Lake, Bellevue Canyon), peripheral mound facies separate shale and laminite: in the Bellevue Canyon and Magda Lake sections, concretion-bearing shale underlies mound-flank wedges and the overlying laminite.

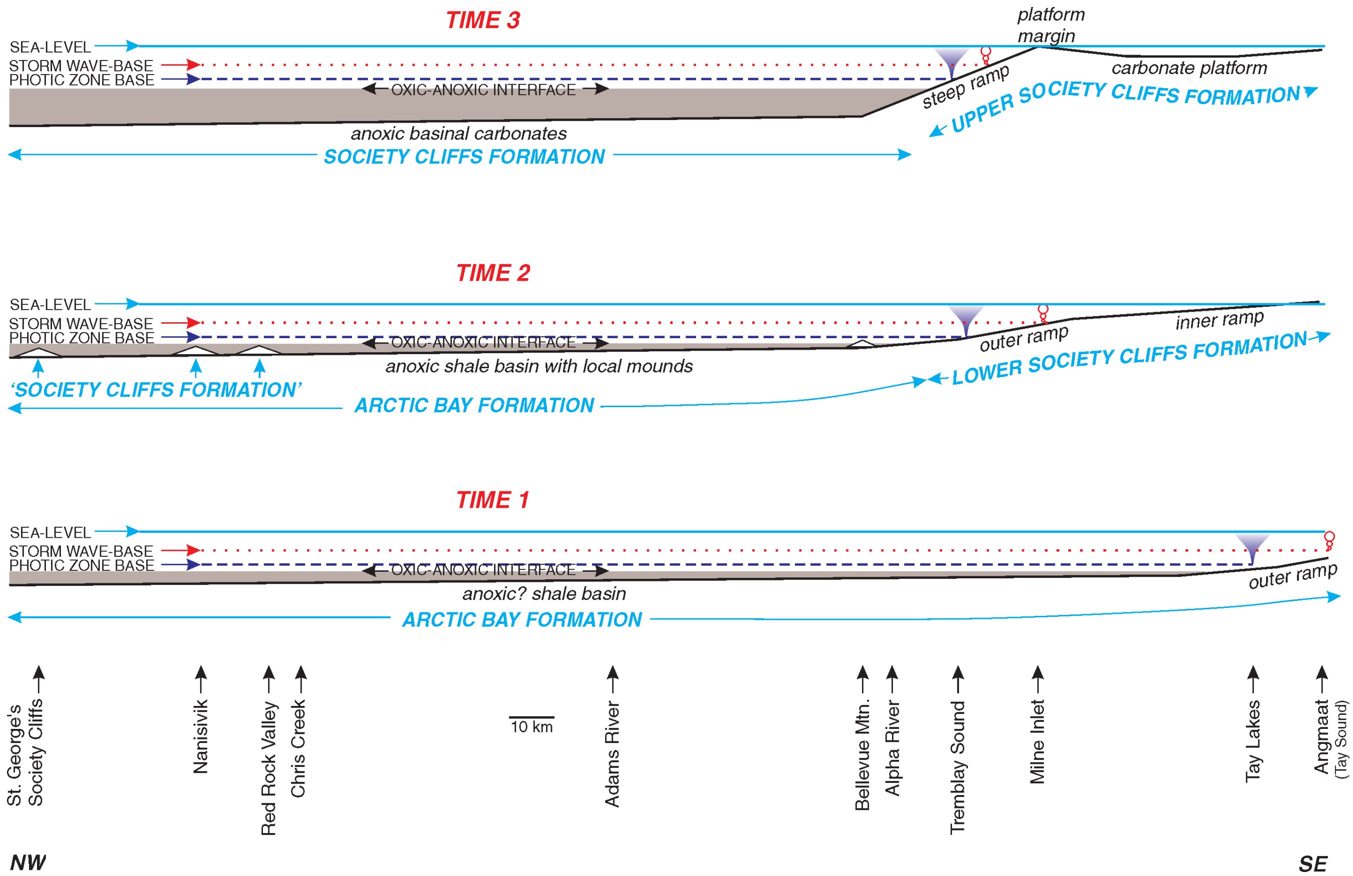

Figure 5. *Interpreted basin configuration for southern Milne Inlet Graben during the three time intervals delimited in Figure 4.*

Upper contact

In the southeast, the contact between Society Cliffs Formation peritidal dolostone and black shale of the lower Victor Bay Formation is abrupt. Airphotos clearly show a striking amount of erosion in the eastern end of the basin, where the contact cuts down at least 200 m stratigraphically over approximately 15 km between the Angmaat and Tay Lakes sections. Similar relations are visible elsewhere in the graben.

In the northwest, the contact between dolostone laminite and overlying shale is similarly abrupt. Although evidence for erosion at the contact is widespread, it is not ubiquitous: for example, in drill core 98-03, obtained from the north side of Strathcona Sound, away from the influence of mounds, the core consists of 417 m of laminite (plus an unknown thickness below the bottom of the hole) and an upper contact, gradational over 30 cm, in which laminite persists as shale content increases. Residual topography of deep-water mounds, and/or pre-shale tectonic activity, affected the nature and thickness of the overlying Victor Bay shale: at Nanisivik, shale is thick and black, whereas at Arctic Bay, shale is thin and pale.

INTERPRETATION — SOCIETY CLIFFS STRATIGRAPHY AND LATERAL FACIES RELATIONS

The original definition of the Society Cliffs Formation as a dolostone between two shale units does not adequately characterize its lateral facies variation and temporal evolution. The time interval during which the Society Cliffs Formation was deposited was characterized by considerable stratigraphic complexity, which is exacerbated by unforeseen ambiguity in the established nomenclature.

The eastern, ramp part of the Society Cliffs Formation contains a zone, from western Tremblay Peninsula to Bellevue Mountain, in which the lower Society Cliffs Formation consists of interlayered shale and carbonate facies, interpreted as an outer-ramp to slope environment (Turner, 2003a). This is not reconcilable with the original definition of the Society Cliffs Formation, which dictates a carbonate succession everywhere west of Bellevue Mountain, a mere 4 km away from the westernmost exposure of the outer lower ramp in the Alpha River section, where shale is sharply overlain by either brown, laminated basinal dolostone or pale, intraclastic to massive dolostone associated with mounds.

The following interpretation (Fig. 4) presents lateral transitions that more closely follow typical facies relations for laterally deepening carbonate depositional systems. Given the demonstrated westward deepening and westward-increasing shale component of the lower Society Cliffs ramp between Milne Inlet and Bellevue Mountain, the northwestern, deepest-water, most distal part of the basin should logically consist of basinal shale. This would be represented by the upper part of the shale unit that is mapped as the Arctic Bay Formation. The upper Arctic Bay and lower Society Cliffs time intervals, as defined in the east, are represented in the west by a single shale unit; it is, however, not possible at present to identify any horizon in the monotonous western shale that would correspond temporally to the stratigraphically definable, gradational Arctic Bay–Society Cliffs contact in the east.

The upper part of the eastern, shallow-water succession is coeval with the laminated dolostone of the western Milne Inlet Graben, as demonstrated by interfingering of basinal laminite with outer-ramp facies in the westernmost, deepest part of the outer ramp area (western Tremblay Peninsula) beginning in the upper Society Cliffs Formation.

The Society Cliffs Formation thus consists of a lower carbonate ramp and upper platform in the southeast, shaly (lower) and carbonate (upper) outer ramp facies in the Tremblay Sound–Alpha River region, and, in the northwestern two-thirds of the graben, a basinal shale (lower) and deep-water carbonate laminite (upper).

The type section of the Society Cliffs Formation is not representative of typical lithofacies for either the northwestern, deep part of the basin or the southeastern, shallow-water part. Instead, it consists of an unusual, local facies interpreted as deep-water mounds (Turner, 2004b) in diachronous contact with underlying shale. Geometric relations indicate that these mounds were deposited while upper Arctic Bay shale accumulated in the northwest, and lower Society Cliffs carbonate rocks were deposited in the southeast. During deposition of the upper Society Cliffs Formation in the east, no deposition took place atop the residual highs of the mounds; on mound flanks, in inter-mound areas, and throughout the rest of the deep-water basin, carbonate laminite accumulated. Although the mounds are laterally equivalent to the laminite, they are not temporally correlative. Shale of the Victor Bay Formation overlies mound tops and basinal laminite in the west, and shallow-water facies in the east.

Although it would be logical to reassign the Society Cliffs Formation to the entire, lithologically continuous, gradational succession from the top of the Arctic Bay Formation to the base of the Victor Bay Formation in the east (e.g. in the Angmaat section) and temporally correlative units in the west (lower shale and mounds, upper laminite), this is not practical from a mapping standpoint. Rather than subdividing the existing unit geographically or temporally, it is pragmatic to retain the existing nomenclature, so that mapping can be based on practical, easily identifiable lithological units. When dealing with issues related to basin evolution, however, the more complex stratigraphic architecture and temporal equivalencies of the succession must be taken into consideration.

Shallow, oxidized water in the eastern area fostered a benthic carbonate factory. This is where the formation's thickness is greatest, and where subsidence rates, creation of accommodation space, and carbonate accumulation rates were highest. Water with a well developed anoxic chemocline occupied the more slowly subsiding but deeper western region, probably throughout the lower and upper Society Cliffs time interval (Turner, 2004a; Fig. 5); shale deposition in the lower Society Cliffs Formation was followed in the upper Society Cliffs Formation by deposition of carbonate that precipitated in the water column. Although their stratigraphic and sedimentological compositions appear to contrast strongly, western and eastern regions were not isolated from one another, as demonstrated by the gradual westward increase of shale in the lower Society Cliffs Formation and the interfingering of basinal laminite with outer-ramp carbonate rocks in the Tremblay Sound section in the upper Society Cliffs Formation. The latter is consistent with a euxinic deep-basin water mass covering the basin floor and a chemocline that episodically migrated up the outer ramp.

DISCUSSION

Thickness of Society Cliffs Formation

The thickness of the Society Cliffs dolostone unit across the entire graben is varied, as a result of (1) various degrees of erosional removal at the formation's upper contact; (2) differential subsidence between and within fault-bounded graben subdomains; (3) varied input of terrigenous material across the graben's length (high in the extreme southeast and in the northwest); (4) apparent thickness variation of the laminite succession owing to varied effect of mounds and their flanking sediment; and (5) apparent thickness difference between ramp and basin areas, exaggerated by the convention that the Society Cliffs Formation on Borden Peninsula is defined as a lithological unit (the laminated dolostone), rather than a chronological unit temporally equivalent to the Society Cliffs dolostone in the east (dolostone plus some unknown thickness (likely <90 m) of shale). These variations imply that lateral correlations may be difficult to determine in the shallow-water region, and impossible to determine between shallow- and deep-water areas or within the deep-water area.

Stratigraphy

The revised understanding of the Society Cliffs Formation composition and lateral relations in the western part of the Milne Inlet Graben underlines the problems that can arise when lithological and chronological definitions of a formation disagree, or when considerable lateral facies variation is present within a single thick and areally extensive unit. The thickness of shale inferred to represent the lower Society Cliffs Formation depositional interval is likely <90 m, based on the total thickness of shale interbeds in the lower Society Cliffs Formation in the Alpha River section, and assuming a predominantly southeastern source area as suggested by Jackson and Iannelli (1981). Because of the shale's lithological uniformity, an intra-shale Arctic Bay–Society Cliffs contact cannot be identified, and so truly chronological rather than lithological units cannot be designated.

This new view of lateral facies variation in the Arctic Bay and Society Cliffs formations has important implications for interpreting basin evolution and synsedimentary tectonism, particularly because it eliminates one of the important tectonic phases originally included in the basin's history. It does away with the concept of an unconformable contact between Arctic Bay and Society Cliffs units (Geldsetzer, 1973a; Jackson and Iannelli, 1981; Iannelli, 1992; Kah, 2000), and the resulting interpretations invoking uplift and erosion (Geldsetzer, 1973a).

The vertical transition from basinal shale to carbonate laminite represents an abrupt and striking change in the western depositional system, which is not mirrored by as pronounced a change in the carbonate-dominated succession east of Milne Inlet. Although the abrupt shale-dolostone laminite contact in the western part of the basin is conformable, it probably represents a sudden change in basin conditions. This interpretation is supported by stratigraphic analysis in the eastern part of the basin, whereby the gradational transition to the upper Society Cliffs Formation is interpreted as having been caused by sharply rising sea level (Kah, 1997). This, together with the coeval termination of mound growth, itself interpreted as dependent on the long-term permeability of synsedimentary faults, and the pronounced thickness differences between western and eastern basin compartments, suggests that the lower to upper Society Cliffs transition was forced by a single tectonic event that increased the average depth of the graben, eliminated shale input, and restricted basinal water circulation enough to produce water-column carbonate precipitates in the basinal area. In the east, effects of this event are muted and superimposed on a background of large-scale eustatic sea-level cycles. In the west, however, only the tectonic event had any noticeable effect on sedimentation: the basin floor was below any depth that could be affected by cyclic metre- to decametre-scale shifts in the position of important physical boundaries (storm wave base; photic zone).

Subtle syndepositional tectonism has been documented in the basinal area for the interval during which the lowermost part of the laminite succession was deposited (Turner, 2003a). Such evidence is locally strong in areas near graben-controlling faults, where influxes of contrasting sediment are documented (within ~5 km). The sedimentary effects of such tectonic adjustments might be more subtle, however, in areas that were not in the immediate vicinity of uplifted fault blocks, or where material deposited from uplifted blocks did not contrast strongly.

ACKNOWLEDGMENTS

Field work was made possible thanks to volunteer assistants Celine Gilbert, Frances Turner, John Taylor, and Julie Beaulieu. Stable isotopes were analysed at the G.G. Hatch Isotope Laboratories, University of Ottawa. The Polar Continental Shelf Project (Natural Resources Canada) provided logistical support in 2003; Technical Field Support Services (Earth Sciences Sector, Natural Resources Canada) provided field gear; and the hamlets of Arctic Bay and Pond Inlet gave permission to access Inuit-owned land parcels. This work benefited from critical reading by Keith Dewing. Many thanks to the interlibrary loan staff at the Earth Science Information Centre at GSC Ottawa, and the helpful Indian and Northern Affairs archives geologists in Iqaluit. This paper is a contribution to project 000004 of the Canada-Nunavut Geoscience Office.

REFERENCES

Blackadar, R.G.
1956: Geological reconnaissance of Admiralty Inlet, Baffin Island, Arctic Archipelago, Northwest Territories; Geological Survey of Canada, Paper 55-6, 25 p.

Clayton, R.H. and Thorpe, L.
1982: Geology of the Nanisivik zinc-lead deposit; *in* Precambrian Sulphide Deposits, (ed.) R.W. Hutchinson, C.D. Spence, and J.M. Franklin; Geological Association of Canada, Special Paper 25, p. 739–758.

Geldsetzer, H.
1973a: The tectono-sedimentary development of an algal-dominated Helikian succession on northern Baffin Island, N.W.T.; Geological Association of Canada, Memoir 19, p. 99–126.

Geldsetzer, H.
1973b: Syngenetic dolomitization and sulfide mineralization; *in* Ores in Sediments, (ed.) G.G. Amstutz and A.J. Bernards; Springer, Berlin, p. 115–127.

Iannelli, T.R.
1992: Revised stratigraphy of the late Proterozoic Bylot Supergroup, northern Baffin Island, Arctic Canada: implications for the evolution of Borden Basin; Ph.D. thesis, University of Western Ontario, London, Ontario, 412 p.

Jackson, G.D. and Iannelli, T.R.
1981: Rift-related cyclic sedimentation in the Neohelikian Borden Basin, northern Baffin Island; Geological Survey of Canada, Paper 81-10, p. 269–302.

Jackson, G.D. and Sangster, D.F.
1987: Geology and resource potential of a proposed national park, Bylot Island and northwest Baffin Island, Northwest Territories; Geological Survey of Canada, Paper 87-17, 28 p.

Kah, L.C.
1997: Sedimentological, geochemical, and paleobiological interactions on a Mesoproterozoic carbonate platform: Society Cliffs Formation, northern Baffin Island, Arctic Canada; Ph.D. thesis, Harvard University, Cambridge, Massachusetts, 190 p.

Kah, L.C.
2000: Depositional $\delta^{18}O$ signatures in Proterozoic dolostones: constraints on seawater chemistry and early diagenesis; *in* Carbonate Sedimentation and Diagenesis in the Evolving Precambrian World, (ed.) J.P. Grotzinger and N.P. James; SEPM Special Publication 67, p. 345–360.

Kah, L.C. and Knoll, A.H.
1996: Microbenthic distribution of Proterozoic tidal flats: environmental and taphonomic considerations; Geology, v. 24, p. 79–82.

Kah, L.C., Lyons, T.W., and Chesley, J.T.
2001: Geochemistry of a 1.2. Ga carbonate-evaporite succession, northern Baffin and Bylot Islands: implications for Mesoproterozoic marine evolution; Precambrian Research, v. 111, p. 203–234.

Kah, L.C., Sherman, A.G., Narbonne, G.M., Knoll, A.H., and Kaufman, A.J.
1999: $\delta^{13}C$ stratigraphy of the Proterozoic Bylot Supergroup, Baffin Island, Canada: implications for regional lithostratigraphic correlations; Canadian Journal of Earth Sciences, v. 36, p. 313–332.

Lemon, R.R.H. and Blackadar, R.G.
1963: Admiralty Inlet area, Baffin Island, District of Franklin; Geological Survey of Canada, Memoir 328, 83 p.

Olson, R.A.
1984: Genesis of paleokarst and strata-bound zinc-lead sulphide deposits in a Proterozoic dolostone, northern Baffin Island, Canada; Economic Geology, v. 79, p. 1056–1103.

Sangster, D F.
1998: Mineral deposits compilation and metallogenic domains, northern Baffin Island and northern Melville Peninsula, Northwest Territories; Geological Survey of Canada, Open File 3635, scale 1:1 000 000.

Sherman, A.G., James, N.P., and Narbonne, G.M.
2000: Sedimentology of a late Mesoproterozoic muddy carbonate ramp, northern Baffin Island, Arctic Canada; *in* Carbonate Sedimentation and Diagenesis in the Evolving Precambrian World, (ed.) J.P. Grotzinger and N.P. James; SEPM Special Publication 67, p. 275–294.

Sherman, A.G., Narbonne, G.M., and James, N.P.
2001: Anatomy of a cyclically packaged Mesoproterozoic carbonate ramp in northern Canada; Sedimentary Geology, v. 139, p. 171–203.

Turner, E.C.
2003a: New contributions to the stratigraphy of the Mesoproterozoic Society Cliffs Formation, Borden Basin, northern Baffin Island, Nunavut; Geological Survey of Canada, Current Research 2003-B3, 13 p.
2003b: Lead-zinc showings associated with debrites shed from synsedimentary faults, Mesoproterozoic Society Cliffs Formation, northern Baffin Island, Nunavut; Geological Survey of Canada, Current Research 2003-B2, 7 p.
2004a: Origin of basinal carbonate laminites of the Mesoproterozoic Society Cliffs Formation (Borden Basin, Nunavut), and implications for base-metal mineralization; Geological Survey of Canada, Current Research 2004-B2.
2004b: Kilometre-scale carbonate mounds in basinal strata: implications for base-metal mineralization in the Mesoproterozoic Arctic Bay and Society Cliffs formations, Borden Basin, Nunavut; Geological Survey of Canada, Current Research 2004-B4.

Geological Survey of Canada Project 000004