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New contributions to the stratigraphy of the Mesoproterozoic Society Cliffs Formation, Borden Basin, northern Baffin Island, Nunavut

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Abstract: Rocks examined at three widely spaced locations in the Mesoproterozoic Society Cliffs Formation suggest that the basin was more paleoenvironmentally and bathymetrically differentiated than had hitherto been believed. Dolomitic, shallow subtidal and peritidal settings in the southeast pass through a platform-rimming facies and limestone-shale slope into a peculiar, dolostone-dominated basin floor in the northwest that was below storm wave-base. An unusual terrigenous dolowacke, containing angular to rounded quartz and lithic clasts and found at two of the three locations, suggests that synsedimentary faulting was more active during Society Cliffs time than has hitherto been recognized.

Résumé : Les roches de la Formation de Society Cliffs du Mésoprotérozoïque qui ont été examinées en trois endroits très espacés laissent supposer que le bassin dans lequel cette unité s'est déposée était davantage différencié sur les plans paléoenvironnemental et bathymétrique qu'on ne l'avait cru jusqu'à présent. Du sud-est au nord-ouest, des milieux péritidaux et subtidaux peu profonds à sédimentation dolomitique font place à un faciès de bordure de plate-forme, puis à un faciès de talus à sédimentation de calcaire-shale et, finalement, à un faciès de plancher de bassin océanique inusité où une sédimentation à dominante dolomitique s'est déroulée sous la base des ondes de tempête. L'observation en deux des trois endroits d'un dolo-wacke terrigène inhabituel à fragments lithiques et à quartz de forme anguleuse à arrondie laisse croire que des failles ont joué davantage qu'on ne l'avait établi jusqu'ici lors du dépôt de la Formation de Society Cliffs.

INTRODUCTION

Mesoproterozoic strata of the Society Cliffs Formation on Baffin Island host Zn-Pb showings, including the Nanisivik mine (1976–2002). Although the mine operated for decades, widespread exploration for carbonate-hosted base metals in the Borden Basin has not taken place since the 1970s, and structural, stratigraphic, and sedimentological controls on mineralization throughout the district have not been synthesized. Study and reanalysis of sedimentological, stratigraphic, structural, and metallogenic aspects of the district should provide new insights into the distribution of, and controls on, base metals in the Borden Basin, given that 1) mineralization at Nanisivik appears to have a stratigraphic control; 2) there have been considerable advances in understanding Proterozoic carbonate rocks in the last decade; and 3) improvements in the understanding of carbonate-hosted base-metal deposits have recently emerged. This contribution and the accompanying paper (Turner, 2003) are the result of a two-week study of stratigraphy and mineralization at three locations in the Borden Basin.

REGIONAL GEOLOGY

The Borden Basin contains approximately 6 km of unmetamorphosed Mesoproterozoic strata that accumulated in an intermittently tectonically active aulacogen (Jackson and Iannelli, 1981). The basin contains three syndepositional grabens, of which the Milne Inlet Graben is the largest and most economically promising. Regional, formation-scale stratigraphic patterns (Iannelli, 1992) identify four tectonostratigraphic stages (two episodes of rifting followed by passive subsidence). Stratigraphic and sedimentological work on the Society Cliffs Formation, the unit most relevant to known mineralization throughout the basin, includes that of Jackson and Iannelli (1981) and Kah's (1997) study of the Society Cliffs Formation in the eastern third of the basin. The latter resulted in interpretation of the eastern Society Cliffs basin as a very low angle, peritidal to shallow subtidal ramp (<5 cm/km). The formation was divided into lower and upper ramps, based on differences in terrigenous content and facies migration during relative sea-level changes. Metre- and decametre-scale cyclicity were attributed to different scales of eustatic sea-level variation. Thirteen chronostratigraphic packages, separated by marine flooding surfaces traceable over the entire basin, were postulated (Kah, 1997).

Outstanding problems, from both basin history and ore-modelling standpoints, concern the nature, distribution, and importance of sedimentary facies within the Society Cliffs Formation, particularly in the western half of the Milne Inlet Graben, where the majority of showings are located. Detailed stratigraphy and correlation have been done for only the easternmost third of the Milne Inlet Graben (Kah, 1997), an area with sparse, generally Zn-poor showings (*see* Turner, 2003). The effects of basin compartmentalization during Society Cliffs time and the basic distribution and interpretation of sedimentary facies in the western Milne Inlet Graben are poorly constrained; interpretation of the sedimentology and diagenesis of Society Cliffs strata in the Nanisivik area would benefit immensely from reanalysis. Lateral facies relationships and possible synsedimentary tectonism have not been addressed, and primary lithological influences on porosity development and fluid flow remain unexamined.

For this study, strata of the Society Cliffs Formation were examined at three locations across approximately 140 km (Fig. 1): Tay Lakes and Alpha River, both of which were identified by Kah (1997), and Adams River, which was identified by Iannelli (1992). Stratigraphy in a fourth area (Nanisivik–Arctic Bay) was outlined by Patterson and Powis (2002). Sections and descriptions presented here are superficial due to the limited time available. Refer to Kah (1997) for alternate versions of the sections at Tay Lakes and Alpha River.

STRATIGRAPHY

Tay Lakes (NTS area 38 B)

The formation was measured in three segments (Fig. 1C, 2A), two of which overlap stratigraphically (TL2 and TL3); air-photo interpretation suggests that fewer than 30 m of unexposed strata are present between TL1 and TL2. Typical lithofacies are shown in Figure 3.

Segment TL1

[start UTM 17, 0552942E, 8003087N; end UTM 17, 0553142E, 8003773N; total thickness 79.3 m]

Arctic Bay Formation

The contact of Arctic Bay and Society Cliffs formations is exposed in a creek on the north shore of the southern of two 5 km long lakes in the low area between Tay Sound, White Bay, and Eskimo Inlet. Uppermost Arctic Bay strata consist of interlayered dolostone (variably vuggy, fenestral, syneresis cracked, desiccation cracked, argillaceous, millimetre-scale laminated), grey shale, and minor fine- to medium-grained, moderately sorted, micaceous sublitharenite to quartz arenite (total 9 m), overlain by green-grey structureless mudstone with pyrite nodules (7.4 m).

Society Cliffs Formation

The contact with the Society Cliffs Formation is abrupt but conformable, at the base of a small cliff. Lowermost strata (approx. 70 m) consist of vuggy dolostone that locally exhibits traces of millimetre-scale microbial layering. Much of the following 46 m is covered; scattered outcrops of microbial laminite and vuggy dolostone are present.

Segment TL2

[start UTM 17, 0553417E, 8004933N; end UTM 17, 554871E, 8004554N; total thickness 268 m]

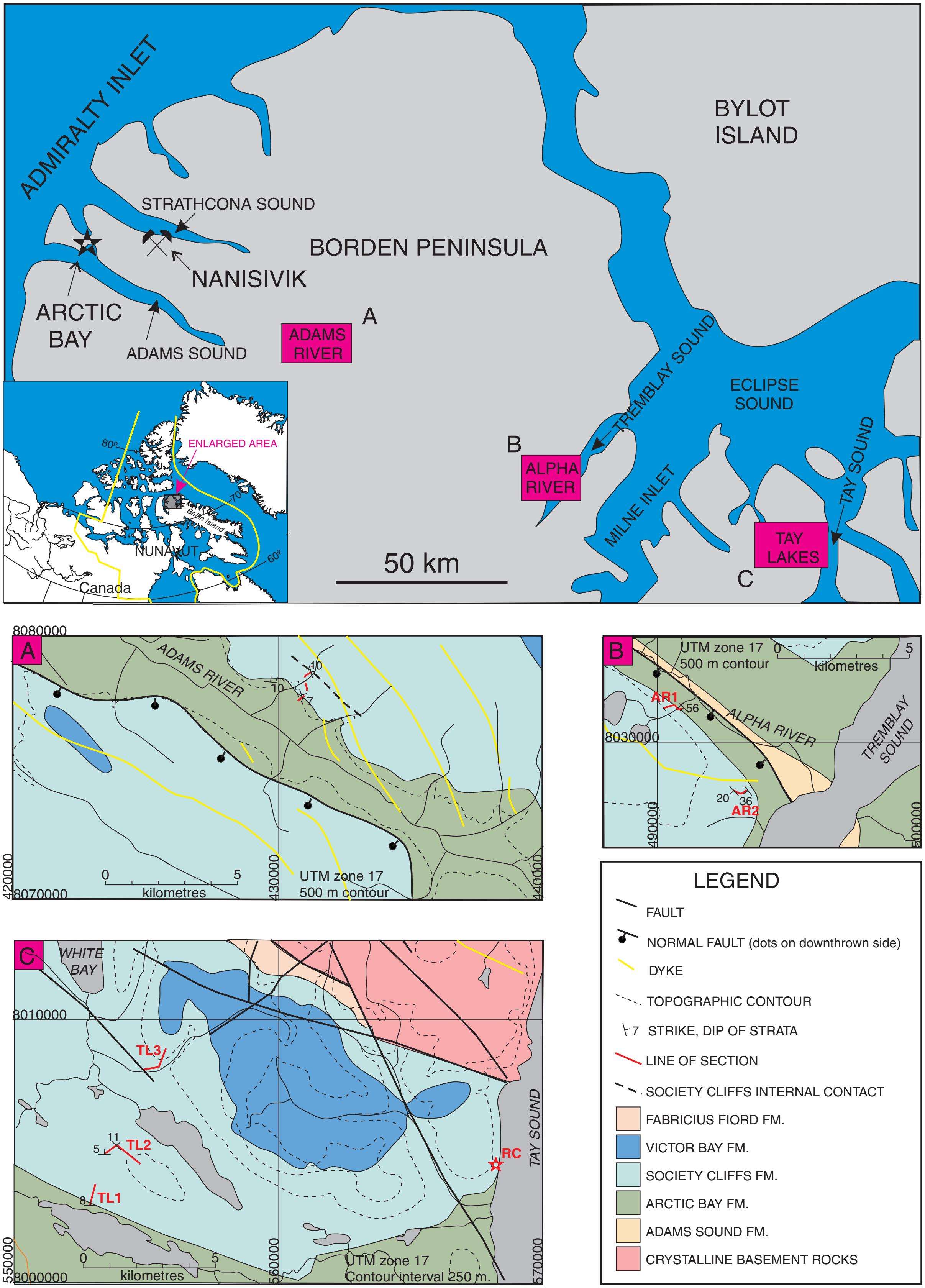

Figure 1. *Location of the Adams River (**A**), Alpha River (**B**), and Tay Lakes (**C**) locations (geology* after *Scott and deKemp, 1998). Abbreviation: RC, Rainbow Cliffs locality.*

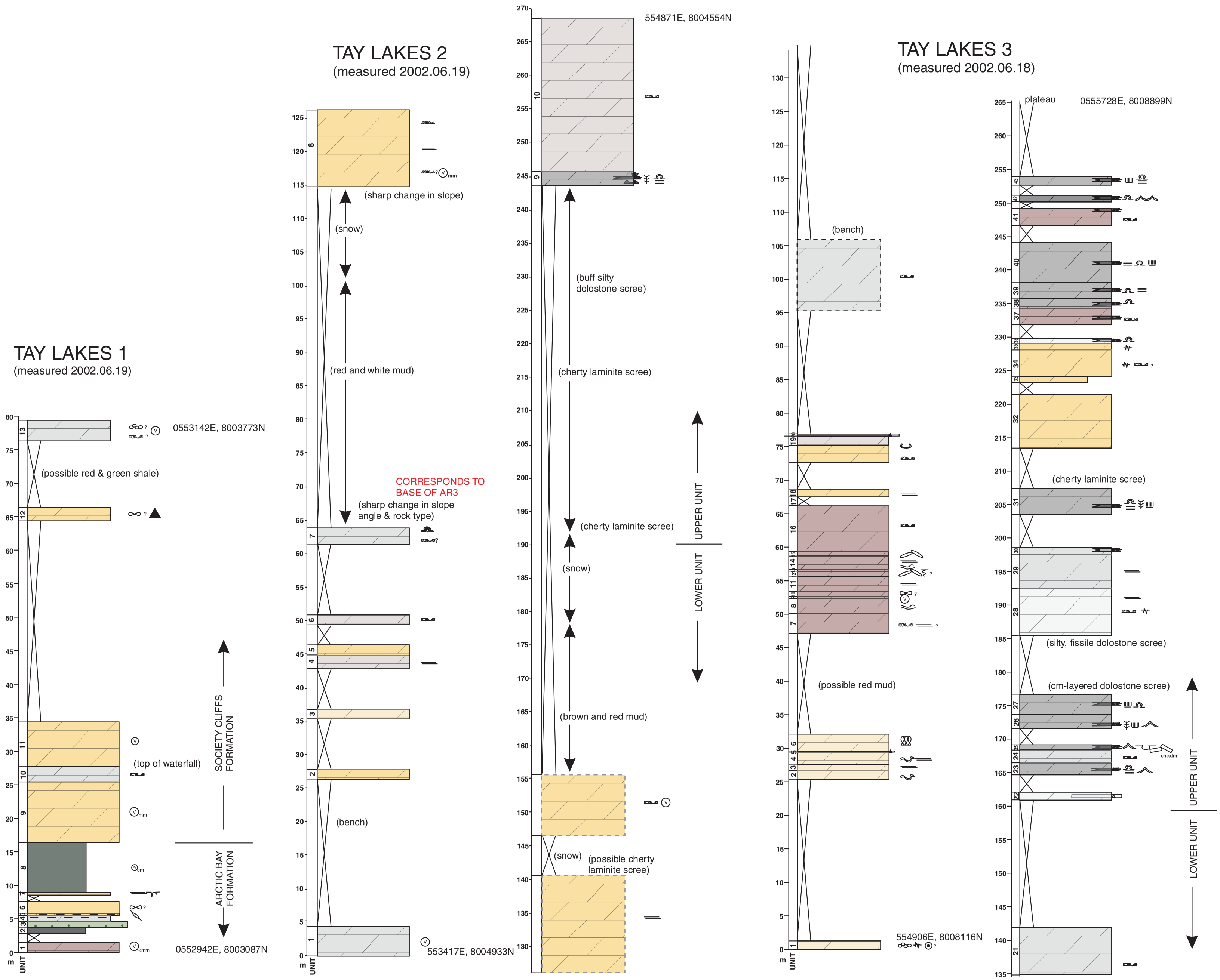

Figure 2A. *Stratigraphy at Tay Lakes. Column width reflects weathering profile and colour of units loosely depicts their weathering colour in the field.* See *Figure 1 for section locations.*

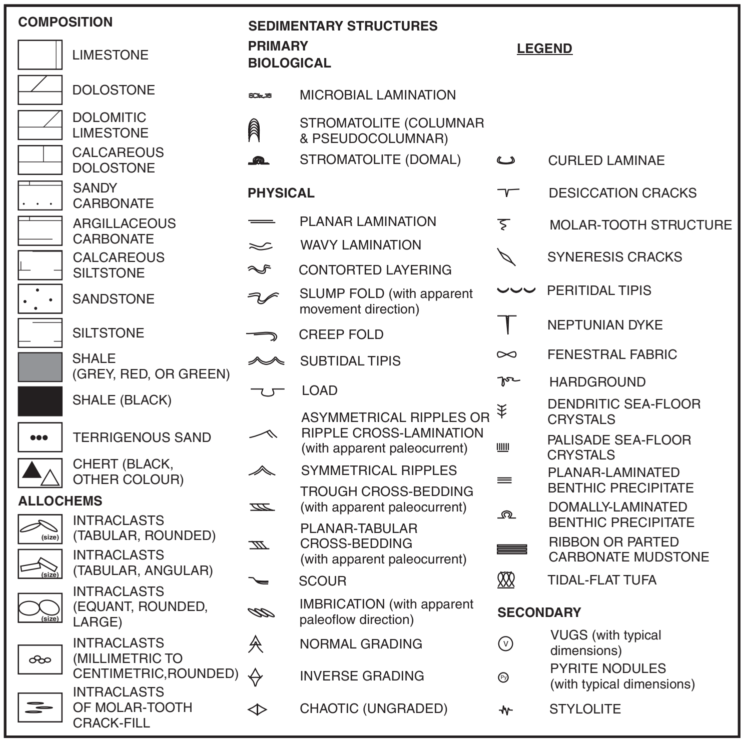

Figure 2B.

Legend for Figures 2A and 4.

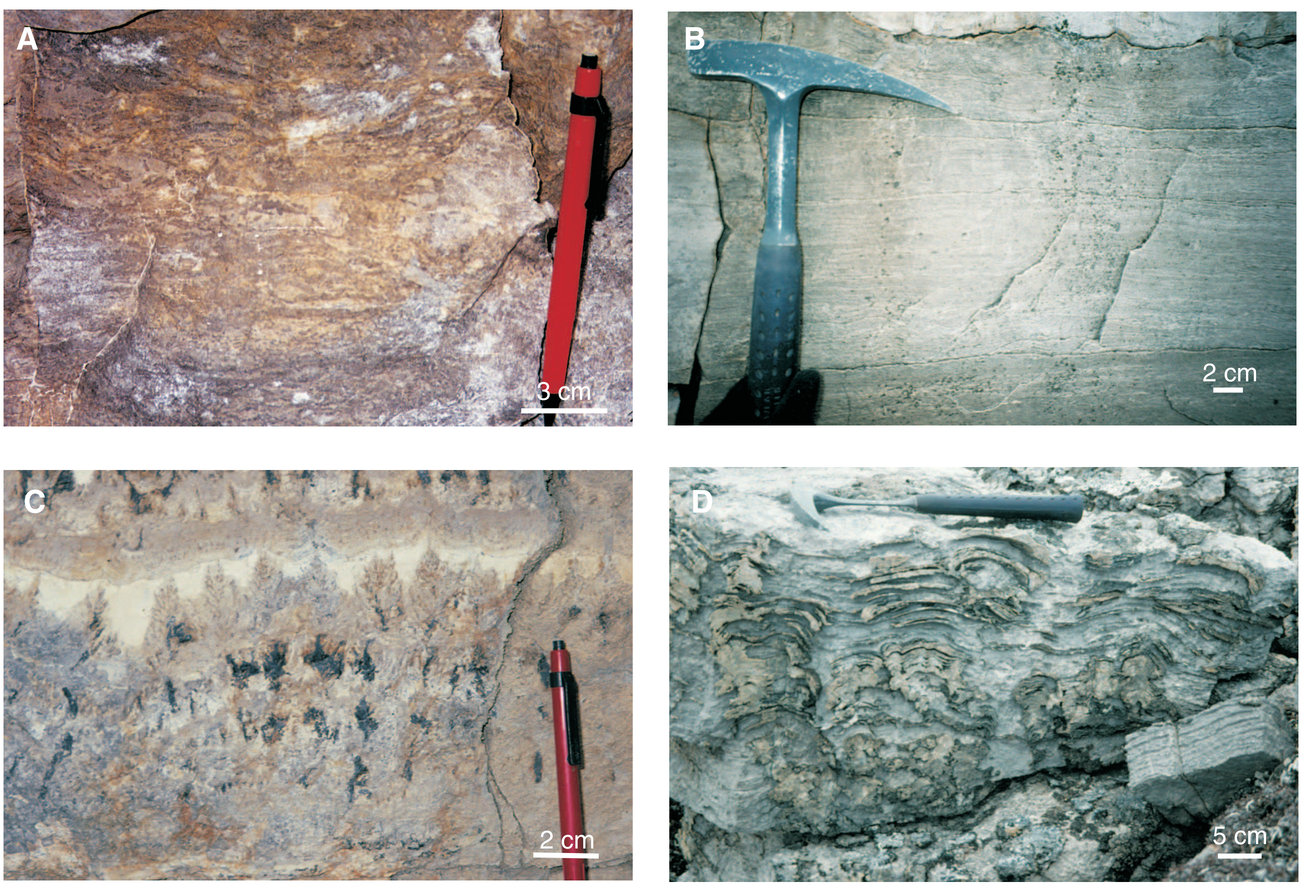

Figure 3. *Typical lithofacies from Tay Lakes section:* ***A)*** *irregularly laminated microbialite;* ***B)*** *planar-laminated dolostone;* ***C)*** *partly silicified dendritic seafloor crystals; and* ***D)*** *partly silicified domal laminite.*

The section resumes on the south side of a hill between the two lakes and ascends poorly exposed, very gently northeast-dipping strata on the hill's west flank (*see also* Kah, 1997). The lowest 63 m consist of intermittently exposed, planar-laminated to irregularly microbially laminated, locally vuggy dolostone. This is sharply overlain at approximately 64 m by at least 35 m of red mudstone, best exposed on the north side of the hill (where the section was not measured); Kah (1997) noted desiccation cracks and ripple marks in red shale. Above a covered interval (15 m) are 40 m of irregularly microbially and parallel-laminated, buff-coloured dolostone (Fig. 3A, B). An overlying 65 m covered interval corresponds, in part (approx. 155 to 170 m), to a second red mudstone on the hill's north flank. Talus on the 25 m of covered ground above resembles material in the last 26 m of exposure: irregularly microbially laminated, buff-coloured dolostone; and partially silicified, dendritic, and laminated benthic precipitates (Fig. 3C, D).

Segment TL3

[start UTM 17, 0554906E, 8008116N; end UTM 17, 0555728E, 8008899M; total thickness 264.9 m]

This section ascends through very gently northeast-dipping strata (approx. 5°) on a steep, south-facing hillside west of a creek 1.5 km north of the northern lake (*see* Kah, 1997); it overlaps with the upper 205 m of TL2. One metre of microbial laminite in the creek is succeeded by a 24 m covered interval and 8 m of tidal-flat tufa and convolute laminated dolostone with discontinuous, centimetre-thick, black chert layers. The following 15 m of covered ground (32 to 47 m) has local hints of red mud: the entire thickness above the first bed may correspond to the thick red mudstone unit in TL2. The overlying 32 m consist of parallel- and irregularly microbially laminated dolostone, with sparse intraclasts in the flat-laminated parts and rare molar-tooth structure; the uppermost 1 m contains discontinuous, centimetre-thick, black chert layers. Much of the following 83 m is covered, but intermittent outcrop and talus of buff, irregularly microbially laminated dolostone are present.

The upper, approximately 95 m of section consist of partly silicified planar and domal isopachous laminite units, some interlayered with benthic dendritic carbonate crystals (Fig. 3C, D); these facies alternate with microbial laminite, forming packages 10 to 30 m thick. Rock exposure ends at a drift-covered plateau; *see* Scott and deKemp (1998) for the position of the Victor Bay contact.

Interpretation

Total thickness is not known precisely, owing to the absence of an exposed upper contact and the small gap between TL1 and TL2. Shallow dip angles demand a significant overlap between TL2 and TL3, which is supported by the stratigraphy documented. Total thickness is probably about 400 m; Kah's (1997) composite section for Tay Lakes is approximately 705 m. For the section at Rainbow Cliffs, 12 km to the east, Jackson et al. (1974) indicated approximately 610 m, Iannelli (1979) and Jackson and Iannelli (1981) showed 550 m, Hofmann and Jackson (1991) showed almost 900 m, and Iannelli (1992) showed 823 m. Much of the lower part of the section at Tay Lakes is covered, hampering accurate measurement, correlation, and sequence-stratigraphic interpretation.

Uppermost, mixed-composition strata of the Arctic Bay Formation were deposited in a shallow marine to peritidal setting with episodic, storm-related influxes of sand-grade and finer terrigenous material. The topmost greenish mudstone records marine transgression, and is followed by wholly subtidal deposits of the lower Society Cliffs Formation.

Subtidal carbonate sedimentation (approx. 290 m) is dominated by irregular microbial laminite units deposited on a substrate that was either below storm-wave base or firm enough to withstand erosion by turbulent water motion. Cyclic-alternation between microbial and intraclastic carbonate units in the middle of the formation reflects varying depth and/or basin restriction. Increased basin restriction or shallowing led to development of partly silicified, isopachously laminated, and dendritic benthic precipitates that show no sign of biogenic origin; rare tidal-flat tufa is the only carbonate facies with evidence for significant subaerial exposure, attesting to episodic intertidal to supratidal conditions during carbonate-dominated intervals. Repeated alternation between two lithofacies types in the upper 95 m of the succession records repeated chemical restriction and/or shallowing from unsilicified biogenic benthic precipitate (irregular microbial laminite) to silicified abiogenic benthic precipitate (planar and domal laminites, and crystal dendrite); *see* Kah (1996) for insight into microfacies.

Considering only its carbonate component, the formation can be divided into a lower unit, consisting predominantly of planar and microbial laminites (17 to 80 m of TL1; 0 to 140 m of TL2; 0 to approx. 150 m of TL3), and an upper unit, in which these lithofacies alternate with partly silicified benthic precipitate (140 to 267 m of TL2; approx. 150 to 255 m of TL3). Superimposed on this pattern are red mudstone intervals, in the middle of the formation, whose stratigraphic positions do not coincide with the gradual change between lower and upper units, as defined by carbonate lithofacies. Although carbonate sedimentation was shut off by terrigenous mud deposition, the absence of any marked change in the carbonate lithofacies associated with, and lying above, red mud units suggests that no significant change in sea-level or bathymetry accompanied the mud influxes. Rather than recording significant sea-level change, they may instead reflect some other change in terrigenous material supply.

Alpha River (NTS area 48 A)

The formation (>546 m, incomplete; Fig. 5A) can be divided into two units (cf. Iannelli, 1979 [400 m, incomplete]; Iannelli, 1992 [625 m total]; Kah, 1997 [>564 m total]). Two stratigraphic sections (Fig. 1B, 4) have been correlated using a distinctive brown cliff unit where shaly intercalations decrease sharply and steep cliffs begin. The lower contact with the Arctic Bay Formation is well exposed; the upper contact with the Victor Bay Formation is not. Strata dip

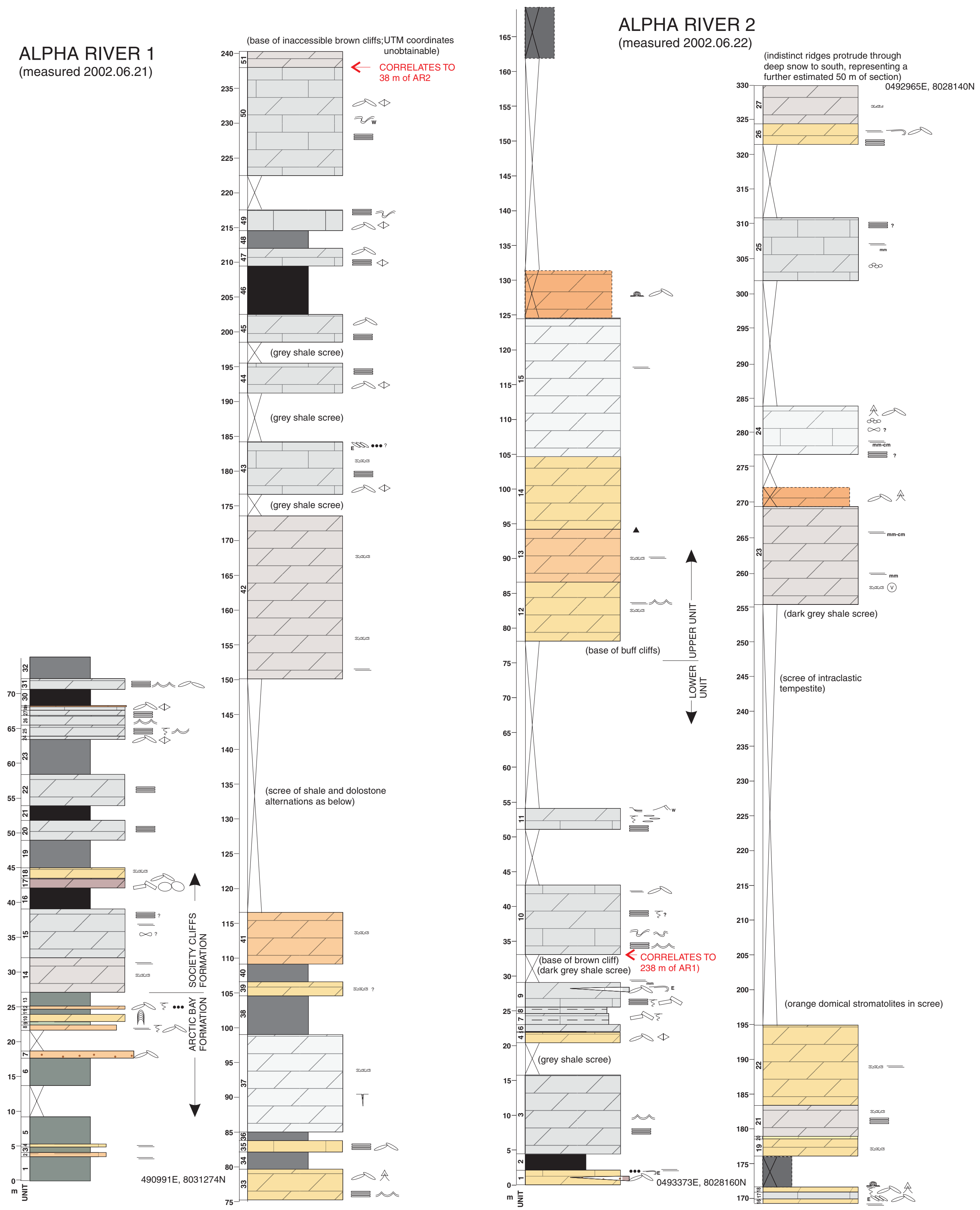

Figure 4. Stratigraphy at Alpha River. Column width reflects weathering profile and colour of units loosely depicts their weathering colour in the field. See *Figure 1 for locations.*

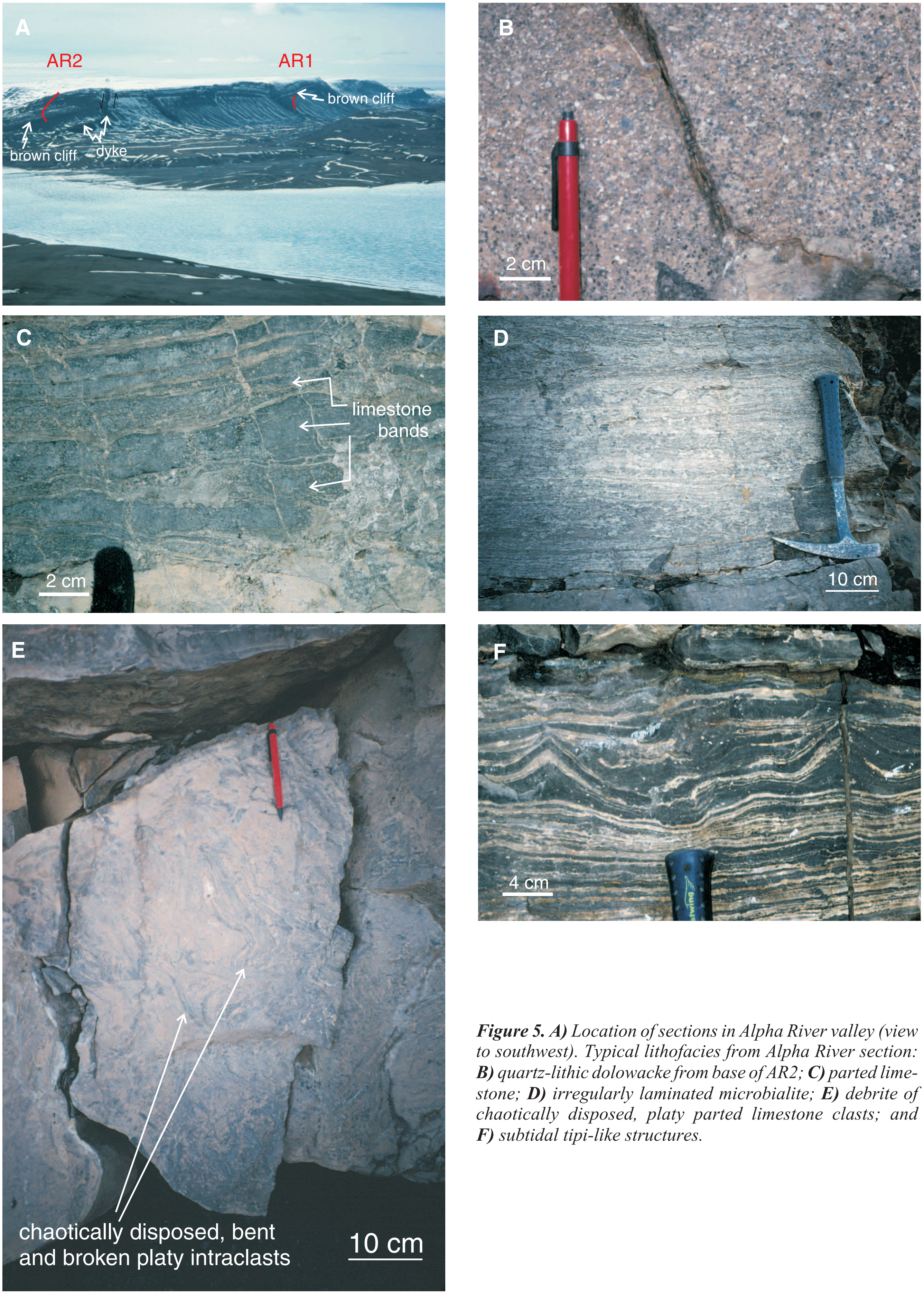

Figure 5. A) *Location of sections in Alpha River valley (view to southwest). Typical lithofacies from Alpha River section:* ***B)*** *quartz-lithic dolowacke from base of AR2;* ***C)*** *parted limestone;* ***D)*** *irregularly laminated microbialite;* ***E)*** *debrite of chaotically disposed, platy parted limestone clasts; and* ***F)*** *subtidal tipi-like structures.*

moderately southwest (approx. 20 to 36°); steeper dips (up to 56°) are present close to a normal fault. Typical lithofacies are shown in Figure 5.

Segments AR1 and AR2

[Segment AR1 start UTM 17, 490991E, 8031274N; end (no satellite connection; base of vertical cliffs west of stream-cut); total thickness 239 m. Segment AR2 start UTM 17, 4933731E, 8028160N; end UTM 17, 492965E, 8028140N; total thickness 330 m]

Arctic Bay Formation

Uppermost Arctic Bay strata (27 m), exposed below the contact with the Society Cliffs Formation, are dominated by grey-green, fissile siltstone, interlayered in the uppermost 10 m with fine-grained litharenite and molar-tooth and intraclastic dolostone. A 1 m thick unit of pseudocolumnar, 15 cm wide stromatolites is present at 23 to 24 m. This interval of increasing carbonate content forms a gradational transition to the Society Cliffs Formation.

Society Cliffs – Lower Unit (AR1, approx. 27 to 239 m; AR2, 1 to approx. 78 m)

The lower unit (approx. 260 m) consists of resistantly weathering limestone and dolostone alternating with recessive grey shale intervals. The lower contact is at the base of the lowest thick dolostone layer.

Dolomitic limestone consists of dark grey, parted lime mudstone (Fig. 5C), locally slump-folded or buckled into tipi-like structures that lack axial zones (Fig. 5F), together with chaotic, ungraded beds and lenses of tabular-intraclast rudstone to floatstone (Fig. 5E) and graded tabular-intraclast rudstone to grainstone. Rare molar-tooth structure is present in the uppermost 75 m of this lower unit. Monotonous, pale brown weathering, finely crystalline dolostone consists almost exclusively of irregular, medium brown, microbial laminae in a pale brown background (Fig. 5D). Shale is dark grey, with rare black intervals. There is at least one layer of ungraded, dolostone matrix–supported, angular to rounded, quartz dolowacke (unit 1 of segment AR2; Fig. 5B).

Carbonate strata in the lower unit are intercalated with shale units (typically <10 m thick) and alternate between limestone and dolostone three to four times (uncertain owing to a significant covered interval).

Society Cliffs – Upper Unit (AR2, approx. 78–330 m)

The upper unit (250 m) forms cliffs of dolostone with minor shale. Two dolostone varieties are present. Pale brown weathering, massive dolostone contains irregular microbial lamination identical to that of the lower unit. Lamination is commonly rhythmic and laterally continuous in the interval from 257 to 330 m (segment AR2). Buff to medium grey weathering, locally calcareous dolostone contains graded intraclast rudstone to grainstone and dolo-lime mudstone with molar-tooth structure. Ripple crosslamination is present in sand-grade parts of graded beds, and molar-tooth structure is present in their carbonate mudstone tops.

The upper unit contains at least three packages, each about 60 to 100 m thick, encompassing microbial dolostone and intraclastic dolostone. Tops of two such intervals are marked by thin (1–3 m), bright orange, stromatolitic and intraclastic units, followed by covered intervals probably underlain by shale. The contact with the Victor Bay Formation was not observed due to snow cover.

Interpretation

Sedimentary features in limestone-shale intervals of the lower unit are characteristic of carbonate-slope environments: parted limestone, debrite of slope-derived lime-mudstone clasts, turbidite deposits of mixed slope-derived and shallow-water material, slumps, and tipi-like structures formed by buckling of thin lime-mudstone layers during cementation all depict a standard slope setting below storm-wave base. Dolostone intervals, in contrast, contain only irregularly laminated microbialite and lack mechanical sedimentary structures; they likely accumulated in a quiescent environment below storm-wave base and within the photic zone. Alternation of limestone-dominated slope strata and dolostone-dominated quiescent subtidal strata, on a scale of 50 to 75 m, is likely caused by changes in relative sea-level that controlled shallow-water carbonate productivity and the distribution of paleoenvironments. The upward transitions between slope and lagoonal facies are, however, abrupt, with the exception of the 75 m shallowing interval, characterized by development of molar-tooth structure, that forms a transition to the formation's upper unit. This abruptness, together with the peculiar quartz-lithic dolowacke (discussed below, under Adams River), suggests that there might have been a significant tectonic contribution to substrate bathymetry and inclination.

Orange stromatolitic layers of the upper unit are interpreted as marine-flooding surfaces; the overlying shale as transgressive; microbial dolostone as the highstand deposit of a quiescent, possibly slightly restricted outer ramp; and intraclastic and molar-tooth carbonates as late highstand tempestite units. Transition of lamination from irregular (microbial) to planar (possibly precipitated) suggests that variable water chemistry played a role in carbonate production and facies distribution (*see* Kah, 1997). There is no evidence of tectonic control over lithofacies or stratigraphic packaging in the upper unit.

Adams River (NTS area 48 A)

Exposure of in situ strata is sparse in the central Borden Peninsula; a crude overview of Society Cliffs stratigraphy was conducted by traversing felsenmeer perpendicular to strike near location 1I250-250A (Iannelli, 1992; Fig. 1A). Structural dip is 7 to 10°NE. The contact with the Arctic Bay Formation is marked by a subtle break in slope along hillsides on the north side of the Adams River, where siltstone talus is sparsely exposed (*see* Scott and deKemp, 1998). With one salient exception, Society Cliffs lithofacies here are different from those described from Alpha River and Tay Lakes. Typical lithofacies are shown in Figure 6.

Extrapolating thickness from sparse dip measurements, the lower 100 to 150 m of the formation consists of brown-weathering, medium-crystalline, featureless dolostone, with interbedded lenticular deposits of matrix- to framework-supported terrigenous dolowacke to arenite (angular to rounded quartz and angular lithic clasts in dolostone matrix; Fig. 6A, C). These deposits are 0.01 to more than 2 m thick and 0.1 to more than 100 m long (parallel to strike), and are particularly common in the lowermost 50 m of the formation (up to 20% of total thickness; Fig. 6A). Wacke is commonly ungraded and structureless. Less commonly, it is crosslaminated or graded. Some thicker layers contain a lower unit of chaotically mixed quartz, dolostone, and shale clasts that grades into a cross-stratified arenite. Others grade upwards into background dolostone lithofacies. Such particulate beds are present intermittently throughout the approximately 200 m (stratigraphic) of surveyed section, standing out in the vast areas of dark dolostone felsenmeer as strike-parallel, laterally limited stripes of pale rubble (Fig. 6B). Rarely, brown dolostone contains sparse, floating, terrigenous sand-silt particles. Northward paleocurrents (n=3) in crosslaminated units (037°, 304°, 348°) support a southerly source, possibly the nearby normal fault. Terrigenous layers are associated with solution breccia, dolospar, and Mississippi Valley–type (MVT) mineralization in enclosing dolostone (*see* Turner, 2003).

Approximately 100 to 150 m above the formation's base, monotonous brown dolostone passes to millimetre-scale planar-laminated, dark brown and white striped dolostone with sparse layers of terrigenous dolowacke. The lowermost 50 m of this upper unit are exposed as patchy outcrop passing eastward into expanses of felsenmeer and snow. The true thickness of the laminated unit at Adams River is unknown, but given the contact with the Victor Bay Formation 4 km to the northeast and structural dip of 7 to 10°, the actual thickness of the laminated unit could be as much as 680 m. Iannelli (1992) showed a 650 m thick section for this area. In the Nanisivik area, the laminated unit has variable thickness, and contains small, early sediment-deformation structures such as healed synsedimentary faults.

The laminated facies contains what has been called 'breccia' in the Nanisivik–Arctic Bay area (Olson, 1984), where it is conspicuous in the upper, laminated part of the formation (Patterson and Powis, 2002). Irregular masses of broken and variably displaced rock, millimetres to decimetres wide, crosscut layering; interstices between breccia clasts are filled with pale grey-brown, finely crystalline dolostone (Fig. 6D). At Adams River, this type of solution collapse is common in the laminated facies, but is also present in the uppermost part of the lower, homogeneous dolostone unit. In both, some breccia masses are in beds below wacke layers. Terrigenous particles are locally present within the pale dolostone between breccia clasts, in the few centimetres below a quartzose layer (Fig. 6E). In some cases, terrigenous layers sag into the tops of underlying collapsed areas (Fig. 6F). Terrigenous grains are not found in breccia masses that lack closely overlying wacke layers; most breccia masses do not have any such grains in their interstices.

Interpretation

With the exception of the terrigenous dolowacke (which is identical to that in lowermost segment AR2), lithofacies in this area do not resemble any Society Cliffs rock types from the eastern localities. Four enigmatic characteristics summarize rocks at Adams River: 1) terrigenous units; 2) featureless brown dolostone; 3) even, millimetre-scale, brown and white lamination; and 4) brecciation.

The angular nature of many of the quartz clasts in the terrigenous units, together with the compositional immaturity of other clasts and the unsorted, ungraded nature of many beds, indicates that they are locally sourced debrite deposits. Planar- and crosslamination and grading in some beds suggest that debrite flows evolved into turbidity currents with a north to northwest transport direction. A major fault zone 4 km south of the most northerly terrigenous bed is one of several identified (Jackson and Iannelli, 1981; Iannelli, 1992) as major structures that were episodically active during basin filling and have likely been intermittently reactivated since then. Although it currently exhibits a south-down displacement, paleofault movement could have had a different sense (*see* figures in Iannelli, 1992). The composition of terrigenous layers resembles coarse, fault-derived material near the Central Baffin Fault Zone, in which conglomerate clast size and wedge thickness die out 500 m from the fault (Jackson and Iannelli, 1981). Alternatively, material at Adams River could be wedges of the Fabricius Fiord Formation, a deltaic unit, in part coeval with the Society Cliffs Formation, consisting of immature terrigenous material deposited up to 10 km from a southern basin-margin fault. Jackson and Iannelli (1981) noted that similar material is locally found elsewhere in the stratigraphic column, adjacent to major fault zones. It is more likely that the compositionally immature, angular particles at Adams River are related to synsedimentary movement of a nearby fault than to the distant Fabricius Fiord Formation, or to transport from a cratonic source area.

Lamination of the upper Society Cliffs Formation in the western part of the basin was at one time interpreted as stromatolitic ('algal'), and the depositional environment as shallow subtidal to peritidal (Geldsetzer, 1973; Jackson and Iannelli, 1981; Olson, 1984). A peritidal interpretation for the primary sedimentary features is not defensible, because all of the standard indicators of peritidal deposition are absent (e.g. desiccation cracks, flat-pebble conglomerate, crinkly-laminated microbial facies, supratidal tipis, m-scale cycles, fenestral fabric, sabkha features). Laminite units bear little evidence of microbial influence, and instead loosely resemble the even, planar, subtidal, abiogenic laminite of the eastern basin; the western laminite units are interpreted here as deep-subtidal, largely abiogenic precipitates of a somewhat different ilk. The basin floor was beyond the reach of fine terrigenous or slope- and/or platform-derived carbonate material, but was amply supplied with locally formed carbonate of the dominant, enigmatic laminite facies.

Brecciation zones in dolostone strongly resemble rubble-choked conduits that form by dissolution and collapse during early (meteoric) karstification or late influx of acidic fluid (as during the process of MVT mineralization). For this reason, their origin in the Society Cliffs Formation has been much debated: meteoric karstification or collapse caused by dissolution of (now absent) interlayered tidal-flat evaporites, postdating deposition of the Society Cliffs Formation but predating the Victor Bay Formation, was suggested as a cause of brecciation (Geldsetzer, 1973; Clayton and Thorpe, 1982; Olsen, 1984). At Adams River, intrastratal 'brecciation' (unrelated to similar dolo-spar-filled solution features in mineralized areas) is present to

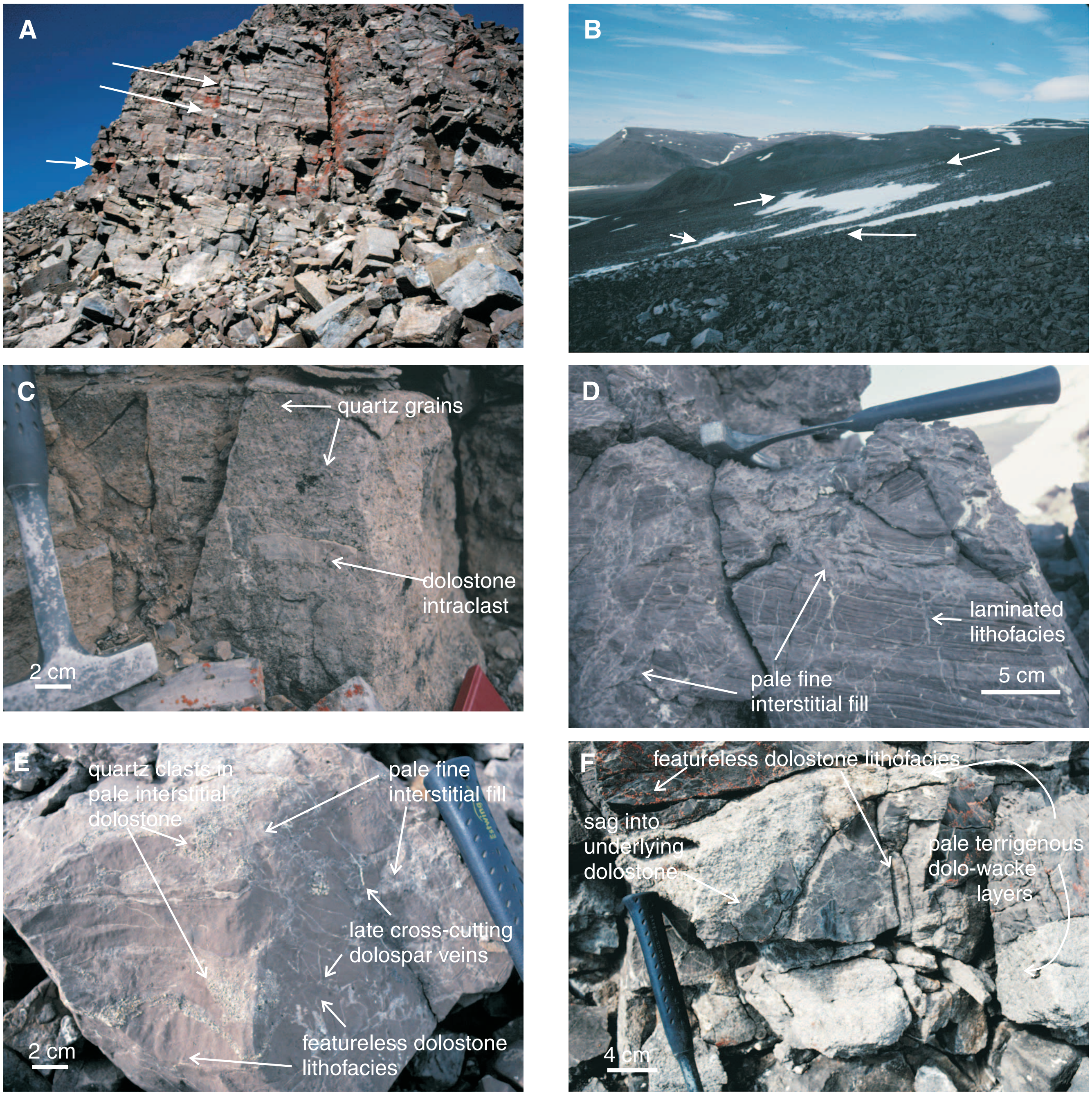

Figure 6*. Typical lithofacies from the Adams River locality:* ***A)*** *pale terrigenous dolowacke layers (e.g. at arrows) stand out against brown dolostone in the basal Society Cliffs Formation; section is about 10 m high;* ***B)*** *pale debrite layer rubble contrasts with brown dolostone felsenmeer;* ***C)*** *terrigenous dolowacke with aligned, large dolostone clasts and granule-sized quartz grains;* ***D)*** *laminated facies of upper Society Cliffs Formation; lithified layers underwent early solution collapse, and interstices between resultant breccia clasts are filled by pale dolostone;* ***E)*** *terrigenous material intermixed with pale dolostone in interstices of an early solution breccia below a terrigenous layer;* ***F)*** *terrigenous layer draped into low formed by early solution collapse in underlying dolostone, suggesting that collapse postdated deposition of the terrigenous layer but predated its lithification.*

within 100 to 150 m of the formation's base, in both laminated and featureless dolostone. For the effects of post–Society Cliffs meteoric karstification to reach so deep would require a meteoric lens hundreds of metres thick to be developed over this region after Society Cliffs deposition, and a correspondingly dramatic sea-level fall or tectonic uplift throughout the entire western half of the Milne Inlet Graben only. There is no evidence for either of these.

This area is interpreted herein as a comparatively deep (below storm-wave base), carbonate-dominated basin; detailed analysis of the unusual dolostone lithofacies will shed further light on their origin. Some as yet unidentified form of early collapse affected the basinal dolostones of both the laminated and featureless types, causing both soft-sediment deformation and dissolution-brecciation of lithified material in the shallow subsurface. Synsedimentary solution collapse of evaporite deposits is plausible in a deep, episodically restricted basin with fluctuating water salinity. Interpretation of the brecciation as early and in the shallow subsurface is supported by the distribution of quartz grains in interstitial dolostone within breccia masses up to a few decimetres below terrigenous layers.

This indicates that, although laminated host rock was lithified enough to break into angular clasts, terrigenous wacke was not similarly lithified and allochthonous clasts were mobile enough to migrate downward into cracks. Breccia-filled conduits throughout the thick interval affected by brecciation did not form a single hydrologically continuous system of interconnected karstic conduits through which such exotic material could freely move over large distances. Instead, solution-collapse took place early, repeatedly, and locally, in early-lithified, shallow subsurface material. Terrigenous and dolomitic material trickled into interstices from debrite deposited either atop already collapsed material, or through fractures that formed in the shallow subsurface. Partly lithified dolostone layers over buried collapsed areas were plastically deformed. Brittle and plastic deformation of carbonate layers requires further investigation, but was clearly penecontemporaneous with sedimentation.

DISCUSSION

The eastern part of the Society Cliffs basin (Tay Sound to Milne Inlet) had a low gradient (Kah, 1997): it was a protected, possibly stratified, and hypersaline lagoon (Fig. 7). Lithofacies in this area range from supratidal, desiccated, terrigenous mud and tidal flat tufa to shallowest subtidal seafloor precipitates and quiescent, sub-wave-base, irregularly microbially laminated dolostone. Between Milne Inlet and Tremblay Sound was a zone dominated by high-energy, platform-margin, ooid-intraclast shoals and stromatolites (Kah, 1997). At Alpha River, parted limestone, debrite, and shale of a carbonate-dominated slope alternate with irregularly laminated, microbial dolostone in the lower unit, illustrating repeated progradation of outer-ramp facies over the upper slope. The upper unit contains level-bottom, microbial and storm-dominated, calcareous intraclastic facies recording a shallower environment that developed over the underlying slope; a slope may be present farther west in the upper Society Cliffs Formation. Eastern environments were characterized by decametre-scale cyclicity described by Kah (1997). To the west, however, was an extensive, flat basin floor where peculiar, monotonous, noncyclic, laminite accumulated below storm wave-base. The ensemble of paleoenvironments and paleobathymetries depicts a carbonate system combining rimmed platform, distally steepened ramp, and restricted basin features. Superimposed on this, depending on the proximity of each location to a synsedimentarily active fault, are local influxes of texturally and compositionally immature allochthonous material.

The nature of the transition from limestone-dominated slope facies to dolomitic basin-floor laminite is as yet unknown. The near absence of shale from the western basin (*see* stratigraphic section in Patterson and Powis, 2002), together with its possibly restricted water composition and the lack of any facies that resemble those in the east, suggest that the basin was compartmentalized into separate basin-water domains and sedimentary regimes, which is plausible given syndepositional fault movement. This mysterious division would be located somewhere within the 70 km that separate the Alpha River and Adams River locations.

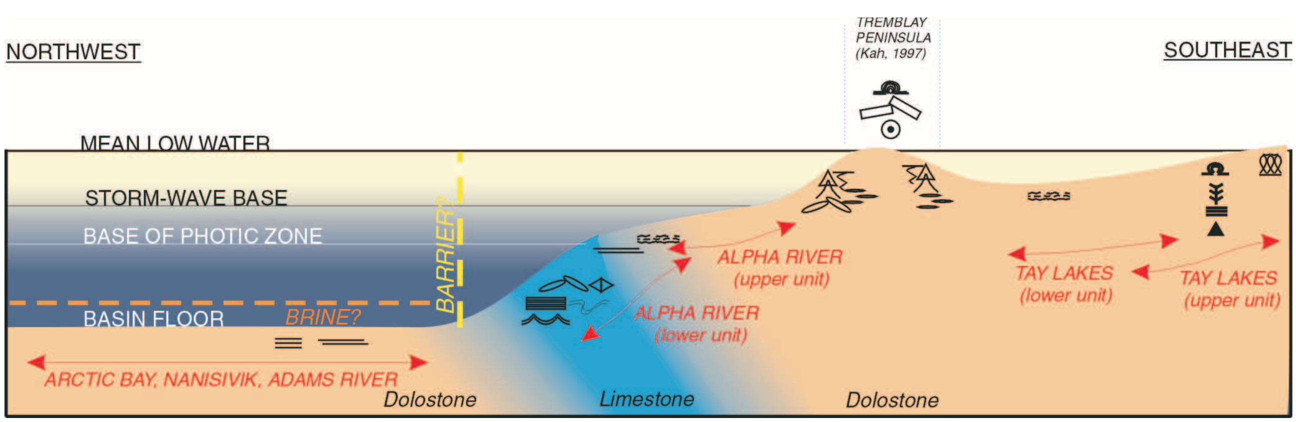

Figure 7. *Interpretation of Society Cliffs basin, with range of lithofacies present in cycles at each location. Symbols as in Figure 2B. Dissolution of evaporative basinal facies (now absent) might have been responsible for early solution collapse of lithified carbonate layers. Evaporative carbonate and postulated evaporite units might have been deposited from a stratified water body.*

The degree of synsedimentary tectonic activity during Society Cliffs deposition is now known to be greater than that envisaged by Jackson and Iannelli (1981): evidence for impressive fault activity is reported herein (debrite-turbidite transport for >4 km), and subtler evidence (e.g. dolo-arenite debrite in the Nanisivik area) will likely be revealed with further work (Patterson and Powis, 2002). The presence of a slope separating the shallow-water lagoon and platform-rimming shoals from a basin floor is another new complexity in interpretation of this formation. Together, these discoveries mean that correlation over even short distances may be difficult or even meaningless, owing to pronounced lateral facies changes related to platform geometry or synsedimentary tectonic activity. The sedimentary, stratigraphic, diagenetic, and tectonic characterization of this formation resulting from this study have already shed light on local controls on mineralization in this basin (*see* Turner, 2003). Continued work will assuredly yield further revelations regarding both mineralization in the Borden Basin and carbonate sedimentation in the Mesoproterozoic.

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