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THE GLEN FALLS FORMATION – AN EXAMPLE OF A BARRIER ISLAND RETREATED BY SHOREFACE EROSION

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ABSTRACT

The Glen Falls Formation constitutes part of the Cambrian-Early Ordovician Saint John Group which is exposed in southern New Brunswick, Canada. Six facies, i.e. laminated quartzite, channelized quartzite, pebbly quartzite and conglomerate, massively bedded quartzite, trough cross-stratified quartzite, and black sandstone facies, are recognized within the formation. These facies were deposited in varied environments within a barrier island and include storm washover deposits through dune, backshore to shoreface deposits. Most of the facies are laterally restricted and there is an uneven distribution of both the facies and the formation as a whole. Detailed analysis of strata of the Glen Falls Formation suggest that they represent the remnants of a barrier island which was retreated by shoreface erosion.

INTRODUCTION

Strata of the Cambrian-Ordovician Saint John Group, of which the Glen Falls Formation is the medial of the three Lower Cambrian formations (Tanoli and Pickerill, 1988), are exposed in and around the city of Saint John in southern New Brunswick, Canada (Fig. 1). This area belongs to the Avalon Zone of Williams (1978, 1979). The formation was originally proposed by Hayes and Howell (1937) for the dominantly white coloured coarse-grained quartzite beds overlying the lowermost Cambrian Ratcliffe Brook Formation or the Etchemenian Series of Matthew (1889) and underlying the uppermost Lower Cambrian Hanford Brook Formation (Fig. 2). The stratotype is the Glen Falls area (latitude 45° 19′ 10″ N and longitude 66° 00′ 20″ W) in the eastern suburbs of the city of Saint John where the strata are exposed along and in the immediate vicinity of the Cold Brook River (Fig. 1). Previous sedimentological studies on the Glen Falls Formation are lacking.

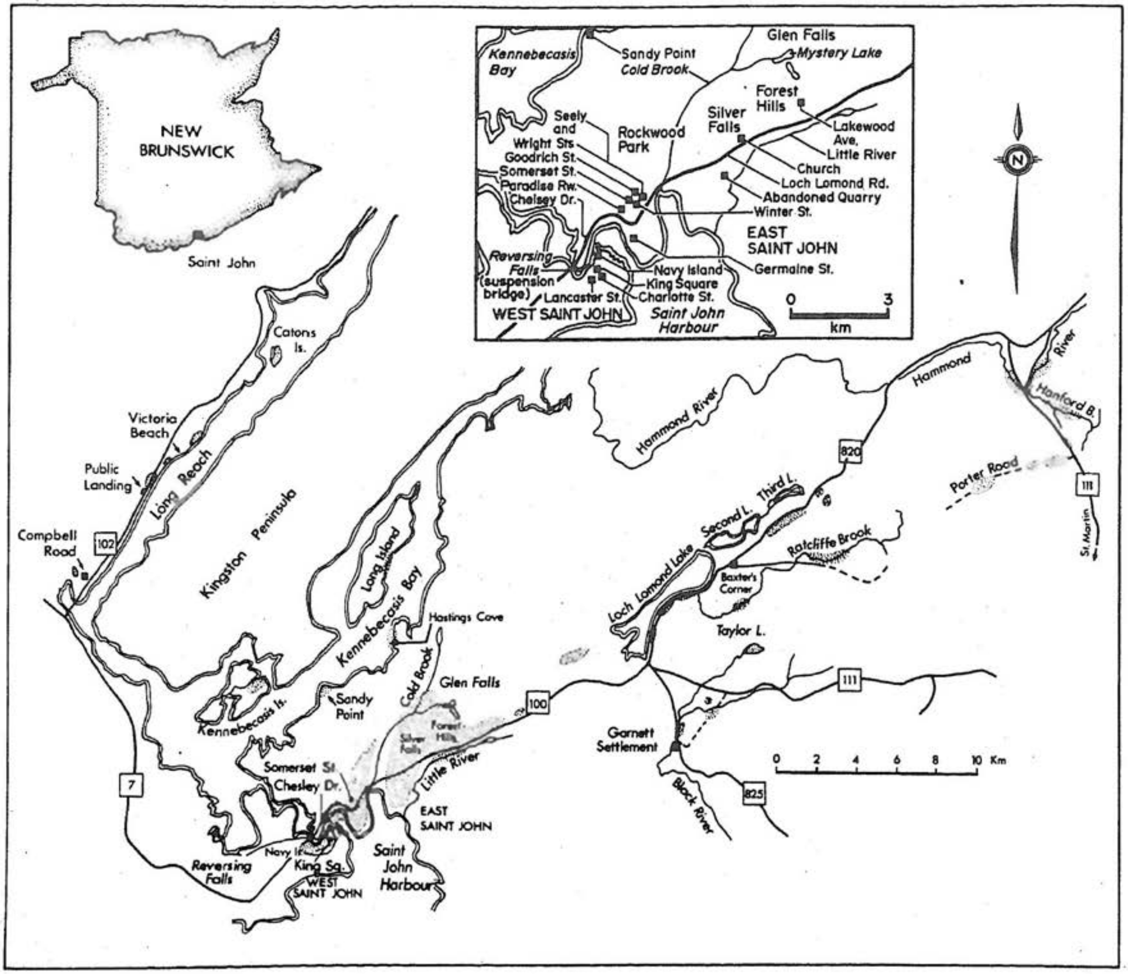

Fig. 1. **General locality map showing the distribution of the Saint John Group (stippled) in the Long Reach — Saint John — Ratcliffe Brook — Hanford Brook areas of southern New Brunswick, Canada.**

In areas where shorelines are marked by the presence of a lagoonal and barrier island physiography, such as the one during the Early Cambrian of the Saint John Basin (Tanoli, 1987), marine transgression occurs either by shoreface erosion, or by in-place drowning of the barrier island (Rampino and Sanders, 1980, 1981). Barrier retreat by a shoreface erosion mechanism is favoured by slow rates of transgression which allows waves to rework the shoreface sediments. On the other hand, in-place drowning occurs in areas with relatively rapid rates of transgression. In the present article, an example of an ancient barrier island which was retreated by shoreface erosion is reported.

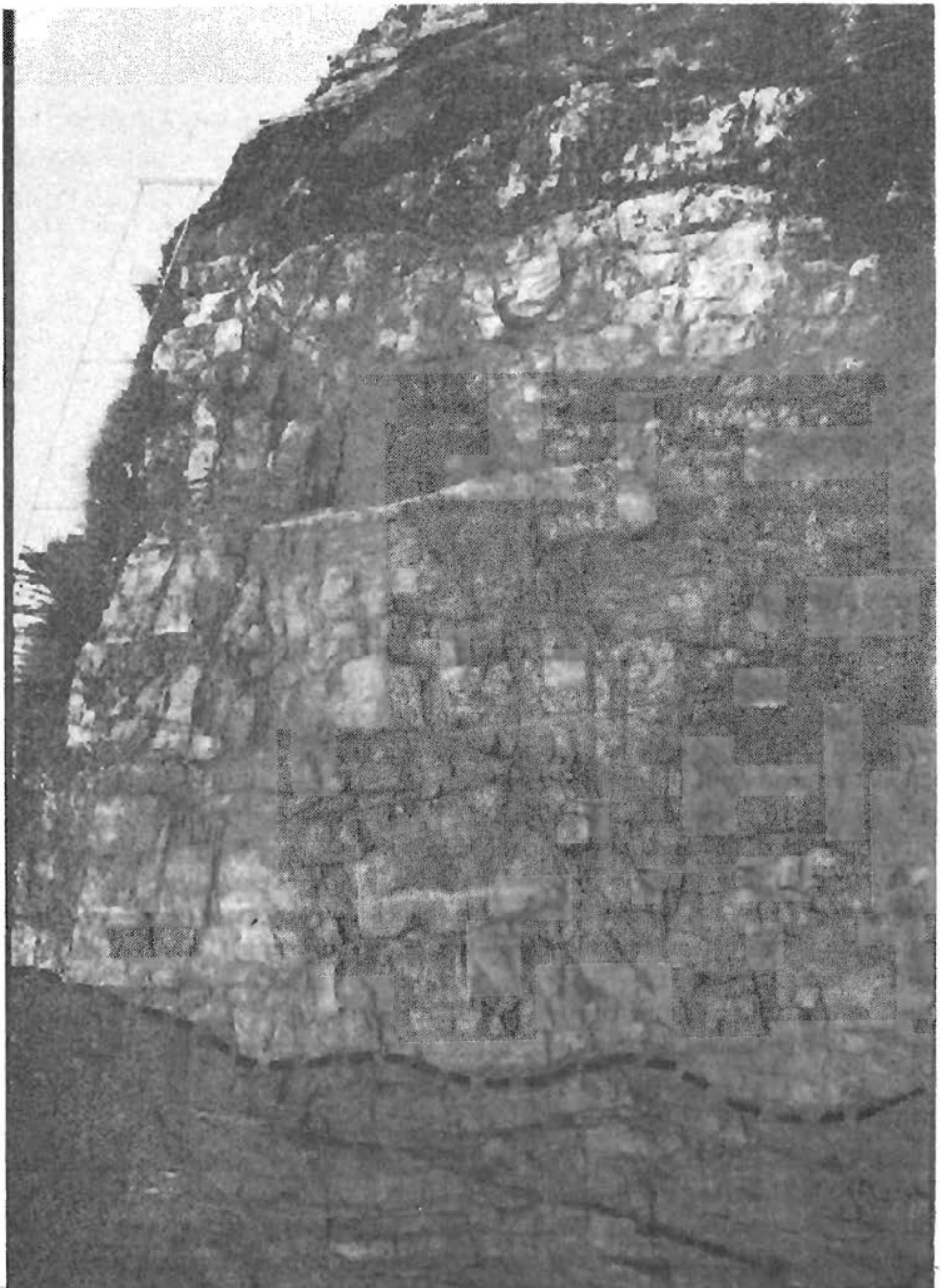

Fig. 2. Exposure of the Glen Falls Formation (white beds) at the Somerset-Winter streets intersection in Saint John. Lower contact, marked by dotted line in left of the photograph, with dark colour lagoonal facies of the Ratcliffe Brook Formation and the upper contact, marked by dotted line in far right of the photograph, with relatively dark colour open marine strata of the Hanford Brook Formation is visible. Total exposure in the photograph *ca.* 14m.

FACIES DESCRIPTIONS

The Glen Falls Formation is generally poorly exposed thus inhibiting the facies detailed description and interpretation. Six lithofacies have, however, been distinguished based upon variations in the bedding style, internal organization and mineralogical composition. These facies are: (1) Laminated quartzite, (2) Channelized quartzite, (3) Pebbly quartzite and conglomerate, (4) Massively bedded quartzite, (5) Trough cross-stratified quartzite, and (6) Black sandstone. Strata in most of these facies exhibit excellent textural and compositional maturity. These facies are intimately interrelated and appear to have formed a temporal and spatial continuum with periodic fluctuations in local depositional conditions. The stratigraphical distribution and facies relationships at the best exposed sections are shown in Figure 3. Table 1 summarizes the essential characteristics of the six facies recognized within the Glen Falls Formation.

Facies GF1 — Laminated quartzite lithofacies

Location Hanford Brook and Forest Hills (Fig. 1).

Description

This facies consists of amalgamated quartzite beds, each of which is up to 70cm thick but generally ranging from 20cm to 40cm. Two varieties of internal organization are common: (1) basal structureless and massive portions passing into alternating light and dark coloured parallel-laminated horizons (Fig. 4a), and (2) alternating light and dark coloured parallel-laminae throughout (Fig. 4b). In rare examples, individual beds exhibit feebly developed normal grading in their lower portions and inverse grading in their upper horizons. The laminae are horizontal to wavy. The light coloured laminae are generally thicker, ranging from 2cm to 5cm, while the dark laminae range from 4mm to 1cm in thickness. Small scale (mm to cm) cross-laminae are rarely observed. Upper and lower bedding surfaces are planar or slightly wavy, most probably a function of weathering and tectonism. On outcrop scale the beds are laterally persistent. Total thickness of this facies at Hanford Brook, where it is best exposed, is 24m.

Interpretation

The characteristics exhibited by this facies (e.g. bed thickness, laminae thickness, laminae style and grading) are similar to modern washover deposits documented from Pea Island, North Carolina, by Schwartz (1975, 1982). Storm washover deposits develop on the lagoonal side of the barrier system when storm waters overtop and also cut through the crest of the barrier. The resultant deposits typically form either lobate or sheet deposits which may or may not extend into the lagoon (Reinson, 1984; Boothroyd *et al.*, 1985). The alternations of light and dark coloured laminae in the quartzites of facies GF1 also resemble those described from interpreted backshore sandstone facies by Campbell (1971)

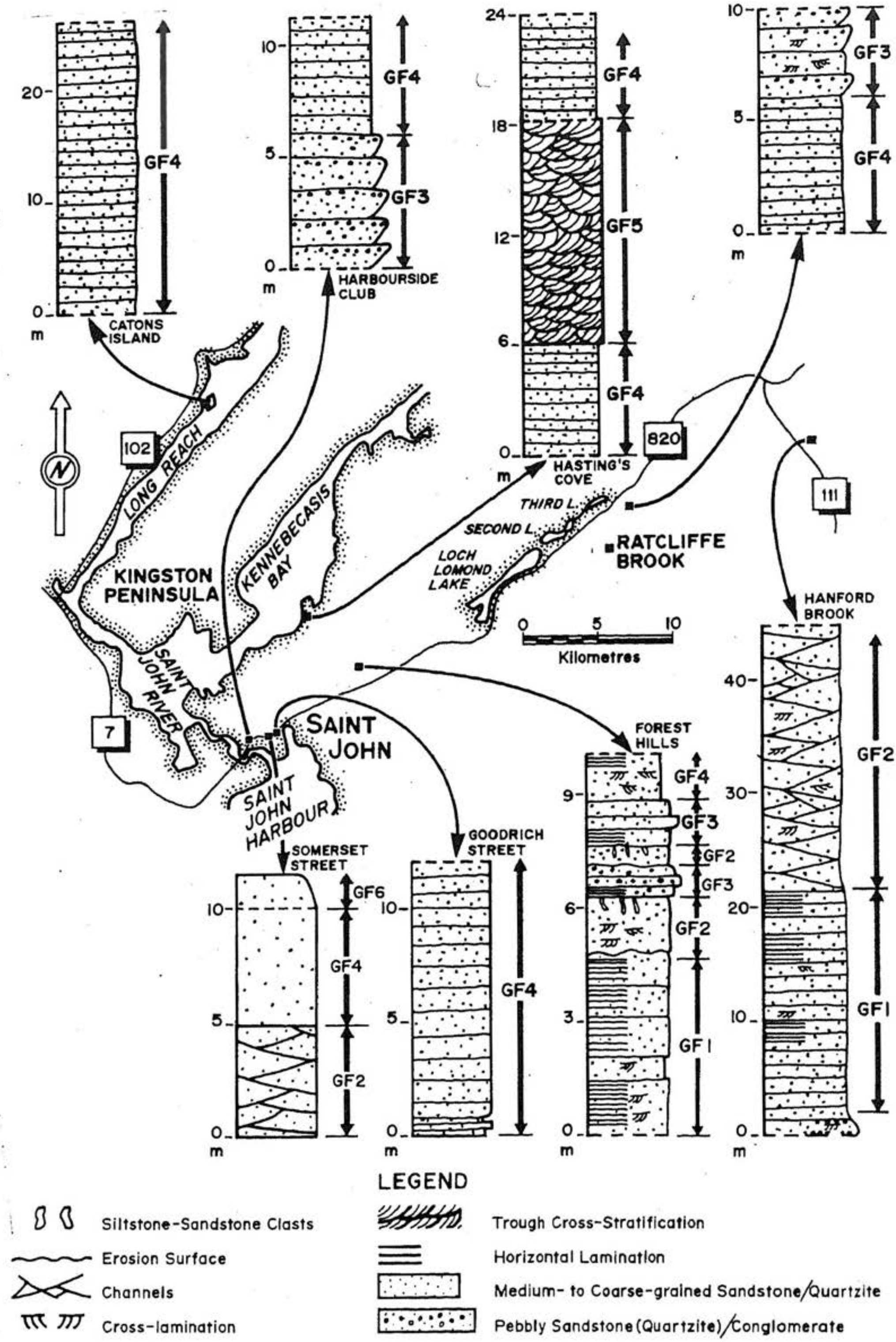

Fig. 3. Principal measured sections of the Glen Falls Formation with lithofacies distribution. Broken lines at the base or top of individual sections indicate unexposed contacts; solid lines represent contacts with, respectively, underlying or overlying stratigraphic units.

Table 1 Summary of characteristics of facies of the Glen Falls Formation.

FACIES	LITHOLOGY	CONTACTS LOWER	CONTACTS UPPER	COLOUR	UNIT THICKNESS [m]	BED THICKNESS [cm]	BED REGULARITY	BEDDING PLANES	INTERNAL ORGANIZATION	OTHER CHARACTERISTICS	ENVIRONMENTAL INTERPRETATION
GF6	Coarse-to medium-grained black sandstone	Gradational and conformable	Transitional, possibly a paraconformity and disconformity	Black	1-2	----	----	----	Massive, general normal grading	Becomes medium-grained near the contact with the overlying facies, consists unoxidized iron and manganese and chlorite	Quiet shelf [shallow marine]
GF5	Coarse-grained quartzite	Sharp	Unobserved	White	>12	30-65	Lenticular	Curved	Trough cross-stratification	Troughs are superimposed on one another. Unidirectional cross-stratification.	Foredune, eolian
GG4	Coarse-grained quartzite	Variable	Variable, usually gradational to facies GF6	White with weathered pink and green	2.5-25	5-115	Persistent	Commonly wavy, rarely planar	Massive, rare horizontal to slightly wavy lamination	Compositionally homogeneous, texturally mature	Nearshore marine [foreshore-shoreface]
GF3	Pebbly quartzite and conglomerate	Sharp	Variable, sharp to gradational	White	0.82-6	7-60	Persistent	Planar, non-erosive	Both normal and inverse grading, also massive	No intervening shales. Clasts 1cm to 12cm in length, mostly rounded quartz clasts	Backshore environments
GF2	Medium-grained sandstone	Sharp	Sharp where observable	White	1.4-22	30-200	Lenticular	Curved, erosive	Massive, bi-directional cross-laminae	Intervening shales are absent, sometimes beds are stacked	Temporary storm-surge channels or storm + tidal channels [breachways]
GF1	Medium-to coarse-grained sandstone	Unobserved	Sharp	White with dark coloured layers	5-24	20-70	Persistent	Planar, non-erosive to slightly wavy	Alternating light and dark coloured laminae	Normal grading within some individual laminae, rare small scale cross-laminae	Storm washover deposits

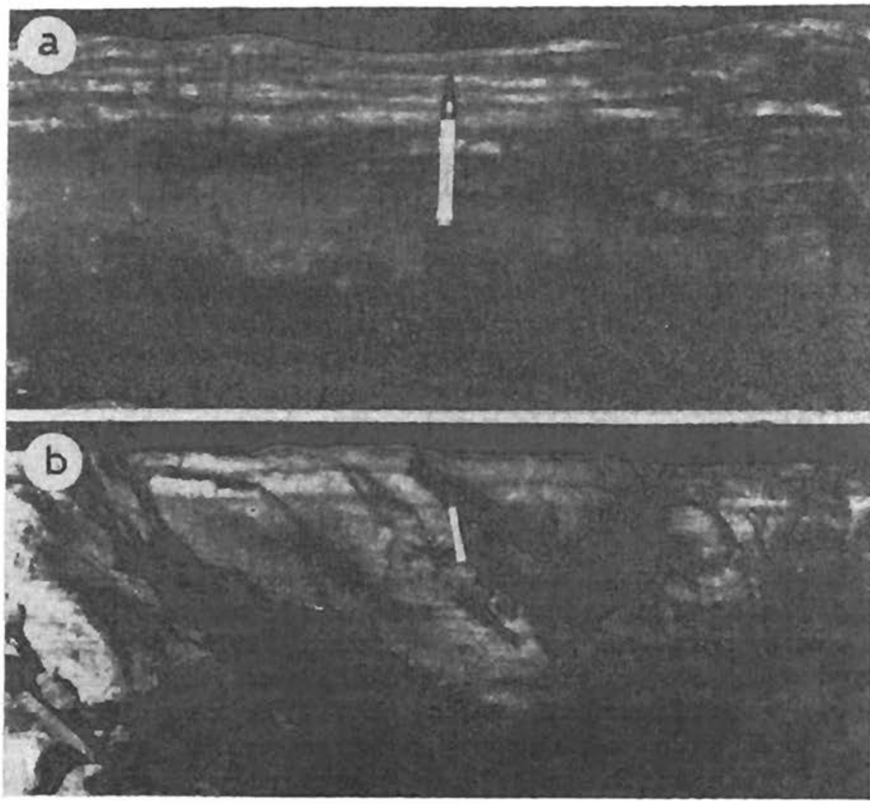

Fig. 4. Facies GF1 at Hanford Brook. Marker as a scale is 15cm long.
(a) A bed with lower massive portion and upper portion consisting of alternations of light and dark coloured laminae.
(b) A bed with alternations of light and dark coloured laminae throughout its thickness.

and beach facies by Clifton (1969). However, the stratigraphic position of this facies, for example as observed at Hanford Brook (see Fig. 3) where it underlies bar crest channel facies (facies GF2 — see below), supports its interpretation as probably representing washover deposits.

Facies GF2 — Channelized quartzite lithofacies

Location

Hanford Brook, Forest Hills, and at the intersection of Somerset Street and Paradise Row (Fig. 1).

Description

Channelized beds of laterally discontinuous quartzitic sandstone characterize this facies (Fig. 5). Lack of outcrop does not permit estimates on their complete size range but, where observable, individual channels are several meters (< 15m) in width and less than 2m in maximum depth (at Hanford Brook typically 30cm to 90cm). Channels are infilled with massive quartzitic sandstone which possibly represent apparently single depositional units (Fig. 5b), or less commonly, and as revealed by internal erosion surfaces, by composite units (Fig. 5c). The basal erosive contact of the channels is typically highly irregular. No intervening shales are present, thereby giving the facies a stacked and amalgamated appearance. Internally, most sandstones are apparently massive. Bi-directional and undirectional cross-laminated sets, up to 15cm but more typically 6cm to 8cm in thickness, may, however, be present in rare instances. Such sets are typically observed in the upper horizons of the channel infill, though are not necessarily restricted to those horizons. At Forest Hills a single unit of this facies is exposed, at the top of which are aligned and rounded quartz pebbles (up to 11cm in length) and siltstone and quartzite fragments (generally over 30cm in length). Estimated maximum thickness of facies GF2, at Hanford Brook, is 22m.

Interpretation

This facies consists of channelized quartzites, the channels presumably representing either storm washover passes which were breached through the barrier crest by storm waves and currents (*cf.* Pierce, 1970; Schwartz, 1975; Boothroyd *et al.,* 1985) or the remains of tidal inlets which breached the barrier complex (*cf.* Kumar and Sanders, 1974). Bi-directional cross-laminae obviously developed due to the reversing flow of either tidal currents in the channels (*cf.* Kumar and Sanders, 1974) or landward and oceanward flow in the breached storm surge channels during storm events.

Facies GF3 — Pebbly quartzite and conglomerate lithofacies

Location

Near the northeastern end of Third Lake in Loch Lomond, behind the Harbourside Club in Saint John, and at Forest Hills (Fig. 1).

Description

Even in the areas noted above this facies is poorly- exposed, at Loch Lomond due to heavy vegetation cover and in Saint John as a result of intense folding and faulting. Maximum observed thickness of the facies is 6m though this may be underestimated as a result of intense deformation. Individual beds, which range in thickness from 7cm to 60cm, are composed of matrix-supported pebbly quartzite and quartz pebble conglomerate (Fig. 6). The lateral continuity of the beds is uncertain although they are continuous on outcrop scale. The beds possess planar and sharp and also occasionally wavy basal contacts and sharp, occasionally lagged upper contacts. Intervening shales are absent. Internally most beds are massive but do exhibit normal and, or, inverse grading, the latter being particularly conspicuous. Bi-directional cross-laminae are rarely present within some pebbly quartzite beds.

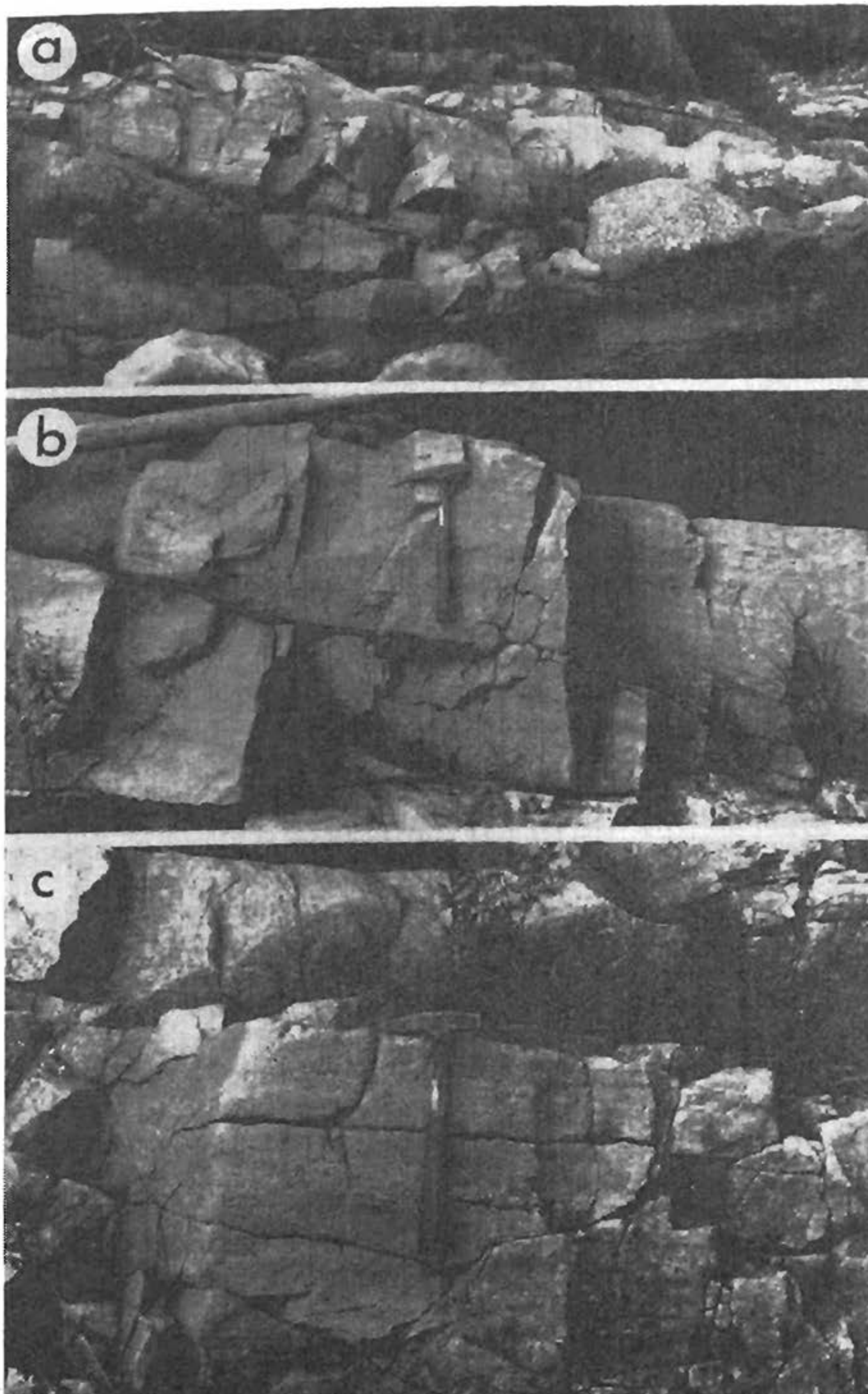

Fig. 5. Facies GF2 at Hanford Brook. Length of hammer = 32cm.
(a) Photograph showing superimposed quartzose lenticular beds.
(b) A close-up of a part of (a) showing more clearly the lenticularity of beds.
(c) An example of a composite unit consisting of lenticular beds.

Fig. 6. **Rounded quartz clasts on the upper surface of a conglomerate bed of facies GF3 behind the Harbourside Club in Saint John. Length of notebook = 19cm.**

Interpretation

The observable features of this facies are not by themselves characteristic of any single depositional environment. However, textural and compositional maturity of the pebbles does indicate high energy conditions *(cf.* Folk, 1974). The grading, specifically the inverse grading, in strata of this facies and the relative coarse grain size possibly suggest the deposition of facies GF3 in backshore environments *(cf.* Campbell, 1971) but this conclusion remains tentative.

Ficies GF4 — Massively bedded quartzite lithofacies

Location

Ratcliffe Brook in the Loch Lomond area, Hastings Cove, Glen Falls, Forest Hills, southern slopes of Rockwood Park, Goodrich Street, Somerset Street, Paradise Row and Campbell Road and Catons Island in the Long Reach area (Fig. 1).

Description

Facies GF4 is the most commonly occurring and geographically widespread of all facies within the Glen Falls Formation and, where sections are more complete, such as at Goodrich Street, reaches up to 12m in thickness. Generally, this facies is composed of white, sometimes weathered pink or green, coarse-grained quartzite beds which range in thickness from a few to in one case 115cm (average *ca.* 25cm) (Fig. 7). The beds are laterally continuous on outcrop scale and generally lack internal features with the exception of rarely observed slightly wavy laminae as seen, for example, along Paradise Row (Fig. 1). The internal organization is not obvious due perhaps to the essentially

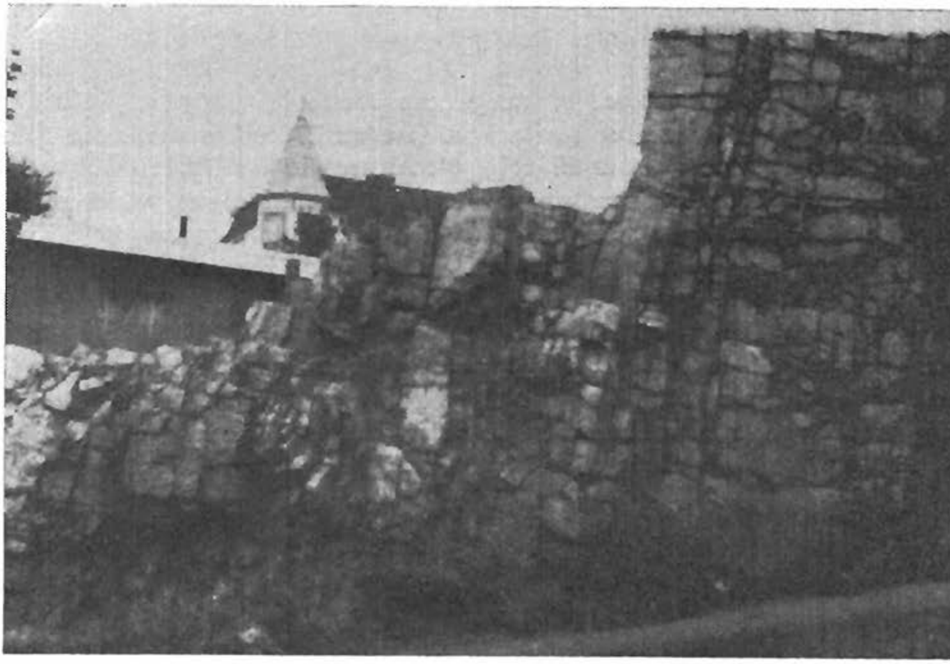

Fig. 7. White quartzose beds belonging to facies GF4 and exposed along Goodrich Street in the city of Saint John. Exposure *ca.* 10m across.

unimodal coarse grain size and compositional homogeneity. At some locations such as at Campbell Road this facies is relatively finer grained and is composed of grey, hard, fine- to medium-grained quartzite or sandstone instead of the more typical coarse-grained quartzose lithology. Lower bedding planes are commonly planar and wavy. Upper bedding surfaces, where discernible, are commonly wavy. Interbedded shales are conspicuously absent so that at some locations, for example along Somerset Street, individual beds are difficult to recognize, the sequence appearing totally massive.

Interpretation

Such characteristics as compositional homogeneity, textural maturity, lateral bed persistence, slightly wavy lamination, together with the absence of interbedded shale in strata of facies GF4, suggest their deposition under high energy conditions in a nearshore marine setting (*cf.* Davies *et al.*, 1971; Davies and Ethridge, 1971; Clifton, 1973; Folk, 1974; Mack, 1978; Cotter, 1983). Similar facies have previously been interpreted to represent foreshore to shoreface environments (for example, see Young and Reinson, 1975; Carter, 1978).

Facies GF5 — Trough cross-stratified quartzite lithofacies

Location

Hastings Cove (Fig. 1).

Description

This facies is composed of trough cross-stratified quartzites, individual troughs being in the order of 2m to 3.5m (average 270cm) in width and 30cm to 65cm (average 50cm) in depth (Fig. 8). All troughs are infilled with unidirectional cross-sets (sets consisting of 1cm to 3cm thick layers) which consistently dip at approximately 22° and indicate a paleocurrent towards 120°. Individual troughs are superimposed on one another and intervening shales are absent. A distinctive feature, particularly in the upper portions of the facies, is the presence of brown and red alteration spots. The upper surface of one trough was observed to possess a pebbly quartzite lag. Total minimum exposed thickness of this facies is 12m, though notably it is only exposed at Hastings Cove (Fig. 3). Though superficially similar to facies GF2, this facies can, on close examination, be easily ditsinguished (see Table 1, and compare Figs. 5 and 8).

Fig. 8. A view of the exposure of facies GF5 at Hastings Cove depicting trough cross beds with unidirectional cross-sets. Length of hammer is 32cm.

Interpretation

Strata of this facies are interpreted to represent remnants of subaerially exposed dunes which were continuously subject to unidirectional winds. Similar unidirectional cross-bedded sets have been documented by Bigarella *et al.* (1969) from sections cut parallel to the prevailing wind direction in coastal dunes from Brazil. Similar strata from the Cretaceous Gallup Beach Complex of New Mexico have been interpreted as dune deposits by Campbell (1971). High angle trough cross-stratification can also potentially form by scour and fill due to the action of longshore currents in the upper shoreface area, for example as described by McCubbin (1982) from another section of the Gallup Sandstone of New Mexico. However, the flow directions in that case are bi-directional rather than unidirectional, as observed in facies GF5. The presence of scattered, more or less aligned, quartz pebble lags at the top of one bed may suggest occasional overtopping of storm waves over the dune.

Facies GF6 — Black sandstone lithofacies

Location

Glen Falls, Forest Hills, H.W. 1 exit, Somerset Street, Paradise Row, near the intersection of Bentley Street and Chesley Drive (Fig. 1).

Description

This facies is composed of generally coarse-grained massive and internally structureless black sandstone (Fig. 9). The quartzose sandstone possesses a matrix which, as revealed by standard polarizing microscope, Scanning Electron Microscope and X-ray diffraction analysis, is composed predominantly of iron chlorite which effects the dark colour of the sandstone (Fig. 9 b and c). This facies is 1m to 2m thick and individual beds cannot be distinguished. The grain size may decrease upward and near to the contact with the overlying Hanford Brook Formation may be medium- to fine-grained (Figs. 2 and 9b). Near the intersection of Bentley Street and Chesley Drive (Fig. 1) this facies is composed of dark fine-grained sandstone. The lower contact of this facies is gradational with facies GF4 of the Glen Falls Formation but the upper contact with the Hanford Brook Formation is more likely a paraconformity at most localities (Fig. 9c) and a disconformity at some localities such as at Lancaster Street (Fig. 1), where the Glen Falls Formation is completely missing.

Interpretation

No characteristic sedimentary structures are present in this facies to aid in the recognition of its environment of deposition. However, as the facies gradationally overlies facies GF4 (of shallow marine origin) and as it is succeeded by shallow marine facies of the Hanford Brook Formation with or without an upward gradational decrease in grain size (Fig. 9), these strata are interpreted to represent portions of the reworked barrier bar sediments which were redistributed in a quiet shallow marine shelf as the lower Cambrian transgression continued. Such an interpretation is further supported by the randomly distributed quartz grains in the dominantly chloritic matrix (Fig. 9c) which also contains traces of apatite and pyrite. These observations were made under the microscope, and by S.E.M. and X.R.D. analysis of the samples at the contact with the overlying Hanford Brook Formation. The presence of traces of pyrite in these sediments possibly suggests a slightly reducing environment (*cf.* Lajoie and Chagnon, 1973).

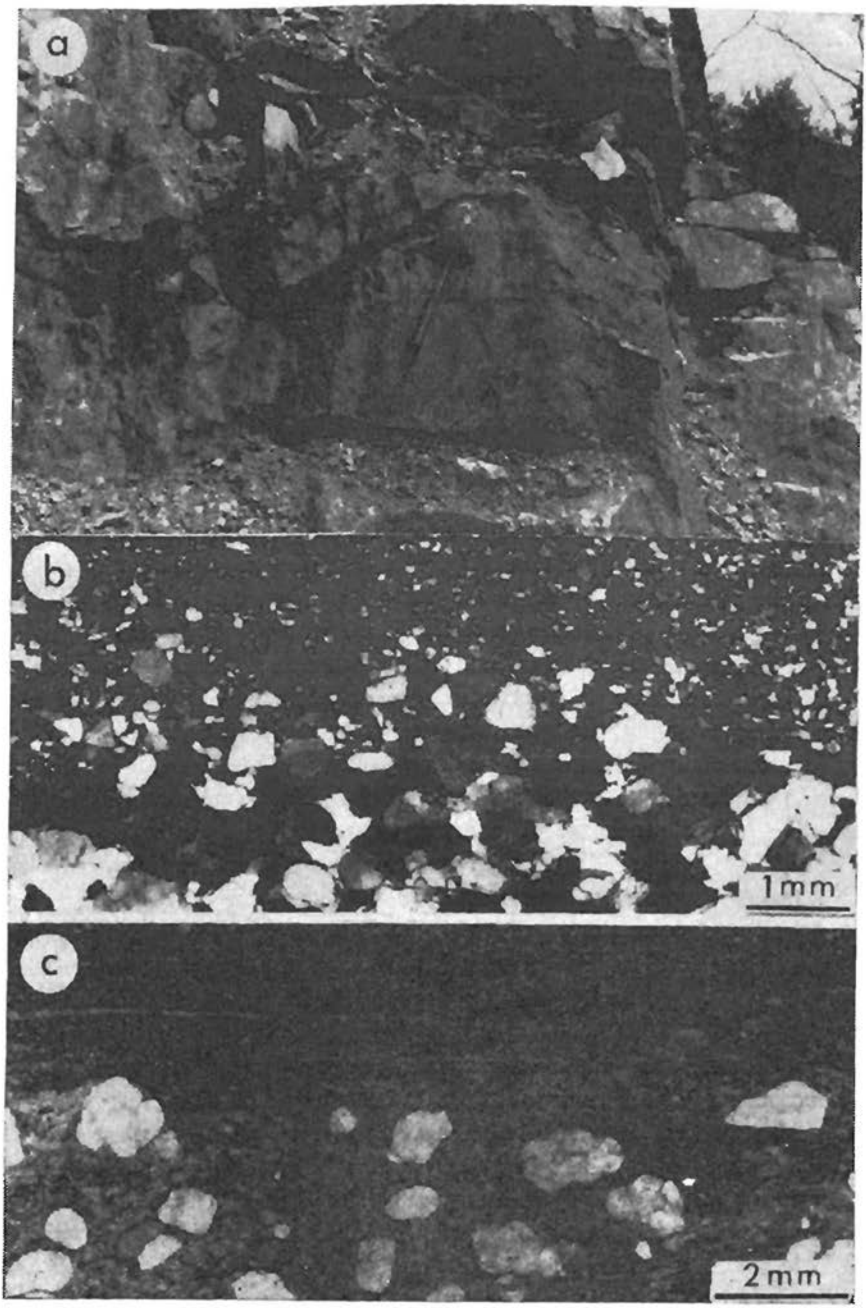

Fig. 9. **Facies GF6.**

(a) Massive black sandstone near Reversing Falls. Length of hammer = 32cm.

(b) Photomicrograph showing the contact between the black sandstone (coarser lower portion) and the overlying Hanford Brook Formation (finer upper portion). Crossed-nicols. Sample collected from Glen Falls.

(c) Photomicrograph depicting another style of contact between the black sandstone and the Hanford Brook Formation. The quartz grains (white) of the black sandstone float in a chloritic matrix before passing into very fine-grained sandstone of the Hanford Brook Formation (upper portion of the photograph). Plane-polarized light. Sample collected from Paradise Row.

In addition to the six facies already described, at a few localities such as at Goodrich Street, the transition between the Ratcliffe Brook and Glen Falls Formations is composed of alternating shale/siltstone beds which are very similar to underlying lagoonal facies of the Ratcliffe Brook Formation and the white quartzites typical of the Glen Falls Formation (Fig. 10). The upper surfaces of these quartzite beds consist of broad symmetrical and asymmetrical ripple marks. These beds, at Goodrich Street for example, overlie lagoonal sediments of the Ratcliffe Brook Formation and underlie nearshore shallow marine sediments (*i.e.* facies GF4) of the Glen Falls Formation. The transitional lithology and the stratigraphic position of these beds would suggest their deposition in the tidal flat region behind the barrier island (*cf.* Reinson, 1984). The shoreface facies of the Glen Falls Formation (*i.e.* facies GF4) are now in direct contact with these strata due to erosion of the barrier island (*i.e.* bar crest) by the transgressing sea.

At Lancaster Street in west Saint John (Fig. 1), the Glen Falls Formation is completely missing. Shelf strata of the overlying Hanford Brook Formation disconformably overlie lagoonal strata of the underlying Ratcliffe Brook Formation, thus suggesting the former existence of a barrier island between them. The disconformity is marked by an approximately 40cm thick unit consisting of dominantly iron chlorite and possibly subordinate phosphate material associated with which are scattered quartz grains. It is suggested that the barrier island (*i.e.* Glen Falls Formation) at Lancaster Street was completely eroded and reworked during transgression (*cf.* Hine and Snyder, 1985) prior to deposition there of the Hanford Brook Formation.

FACIES ASSOCIATIONS

The vertical facies sequences for the better exposed sections of the Glen Falls Formation are illustrated in Figure 3. None of these sections contain all of the facies, and some facies, for example facies GF5, are only exposed at single locations. The vertical association between facies GF1 and GF2, and between facies GF4 and GF6 is, however, very consistent. At Hanford Brook and Forest Hills, where both facies GF1 and GF2 are exposed, facies GF1 underlies facies GF2. Where both facies GF4 and GF6 are exposed, facies GF4 always precedes facies GF6. For other facies, such as facies GF3, the vertical association with other facies is not consistent. This facies overlies facies GF4 in the Loch Lomond area near the northeastern end of Third Lake, but it underlies facies GF4 at Forest Hills and behind the Harbourside Club localities (see Fig. 3). With the exception of facies GF4 which is exposed at several localities, the lateral continuity of several facies does not extend from one section to the other. Therefore, in general, lateral facies variations and relationships are very difficult to assess.

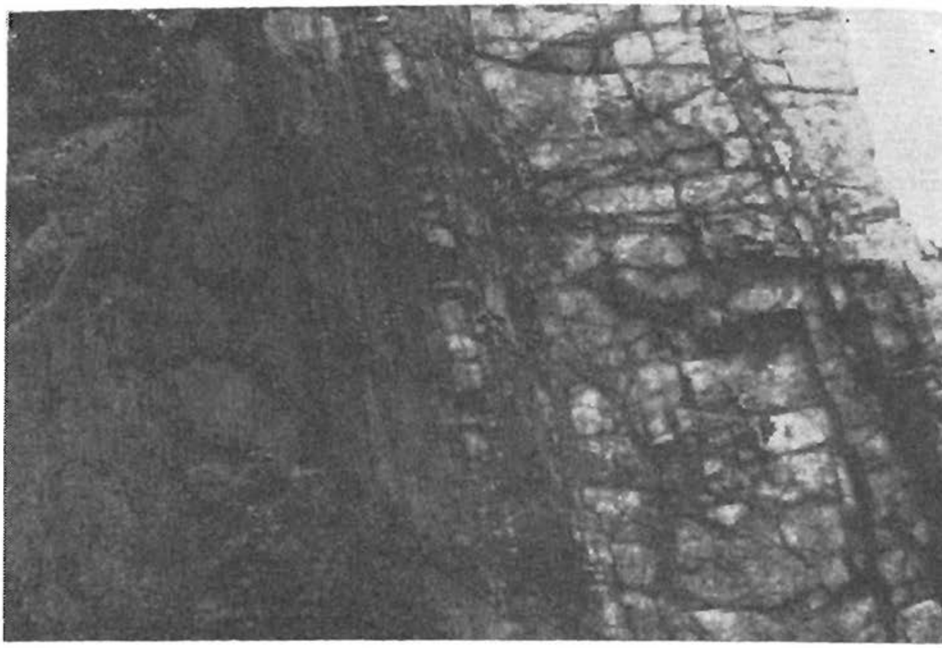

Fig. 10. Transitional unit *ca.* 1.5m thick, in middle of the photograph, consists of alternating beds of dark colour, typical of the underlying Ratcliffe Brook Formation (left part of the photograph), and light colour, typical of the overlying Glen Falls Formation (right part of the photograph). Exposure along Goodrich Street in the city of Saint John.

DISCUSSION

The excellent textural maturity and the various bedforms exhibited by most of the above described facies suggest their deposition under high energy conditions (*cf.* Folk, 1974; Davies and Ethridge, 1975; Cotter, 1983). With the exception of facies GF5, which was perhaps deposited under the influence of eolian processes (see above), the facies are considered to be the result of nearshore high energy marine processes. The position of the Glen Falls Formation in the stratigraphic column, where it overlies lagoonal facies of the Ratcliffe Brook Formation and underlies shallow marine facies of the Hanford Brook Formation (Fig. 2), together with the characteristics of individual facies, suggest it to have formed as a part of a barrier island complex (Fig. 11). Comparison of the total facies association with variably described barrier island facies from both recent (*e.g.* Bigarella *et al.*, 1969; Kraft, 1971; Sanders and Kumar, 1975; Schwartz, 1975, 1982; Moslow and Heron, 1978; Boothroyd *et al.*, 1985; Belknap and Kraft, 1985) and ancient environments (*e.g.* Campbell, 1971; Young and Reinson, 1975; Carter, 1978; Franks, 1980; Cotter, 1983), further supports

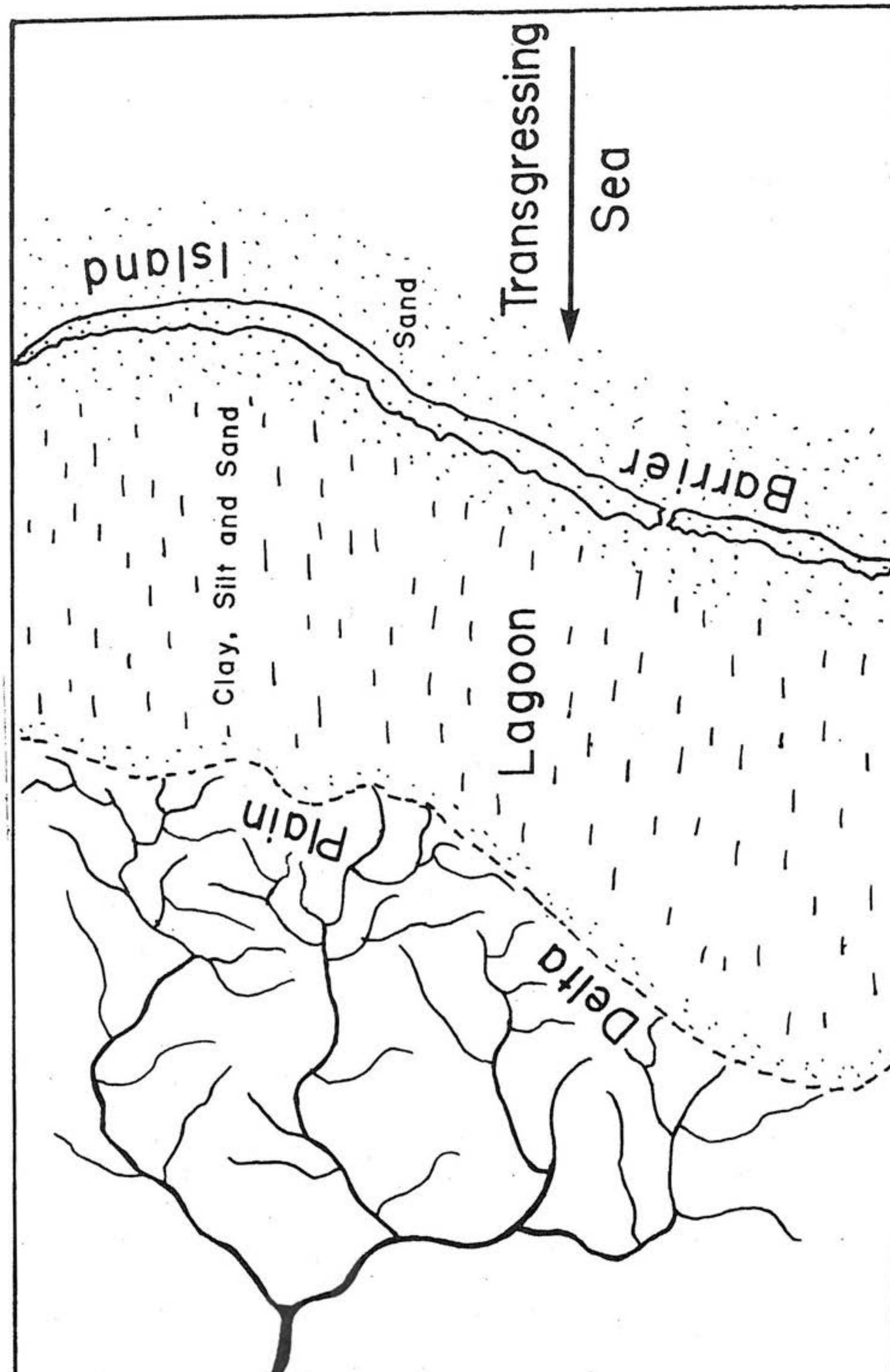

Fig. 11. A cartoon showing the most probable situation of the shoreline of Saint John Basin in Early Cambrian time. The remnants of the barrier island make up the present Glen Falls Formation.

its formation in a barrier island complex. The geographic variations, as now observed, in the characteristics of strata of the Glen Falls Formation may be attributed to the selective preservation of specific parts of the barrier complex and also due to the fact that specific processes, such as storms, may not necessarily have influenced the whole barrier at any one time.

This generally thin, patchy and localized and varying presence of the facies of the barrier bar is probably a result of the selective preservation of certain portions of the barrier island complex. The preservation potential appears to have been particularly influenced by factors such as localized conditions, for example, sediment availability (hence local barrier build up), and also the spatially restricted presence of certain facies (such as storm washovers). The stratigraphic position of the Glen Falls Formation, which overlies lagoonal facies of the Ratcliffe Brook Formation and underlies shallow marine facies of the Hanford Brook Formation, suggests conditions of transgression (*cf.* Kraft, 1971; Sanders and Kumar, 1975). The patchy distribution of the facies of the Glen Falls Formation suggests that the barrier bar at least partially retreated by shoreface erosion mechanisms (*cf.* Rampino and Sanders, 1980, 1981). The preservation of barrier bar facies in the rock record is favoured, according to Kraft (1971), by rapid sea level rise under transgressive conditions together with an excess sediment supply. Alternatively, however, Hine and Snyder (1985), have argued that under transgressive situations the preservation potential of barrier bar complexes is low. Shoreface erosion and retreat requires slow rates of relative sea level rise but, however, if sediment supply from offshore areas or through longshore drift is sufficient, the barrier might build upward (*cf.* Swift, 1975). Local small scale regressive phases within a general transgressive cycle could potentially be conducive to preservation of parts of a barrier island. In fact, Belknap and Kraft (1985), from their study on Delaware's barrier systems have shown that the entire stratigraphic column, including sediment formed on the shoreface, can be locally preserved under such conditions.

To conclude, it is proposed that either one or some combination of the following general conditions were responsible for the preservation of localized, patchy and varying facies of the Glen Falls Formation.

a) A combination of barrier retreat by shoreface erosion and in-place drowning. The initial slow sea level rise would allow reworking of the shoreface sediments and a sudden sea level rise would drown the retreating barrier. This may be the result of the unstable nature of the retreating barrier with its wide and deep lagoon (*cf.* Rampino and Sanders, 1980). In such a case, the surf zone would overstep to the landward margin of the lagoon. If this mechanism is in fact responsible for the preservation of the Glen Falls Formation, the deficiency in availability of sediments to the new surf zone would be a reasonable explanation for not developing a new barrier bar there.

b) Excess sediment supply and rapid subsidence. The rapid sedimentation rates may have helped promote rapid subsidence of some units of the barrier bar under generally slowly rising sea level conditions. The excess sediment supply may have served to protect the underlying sediments from being reworked.

c) Small regressive phases within a general transgression. During localized regressive phases the earlier barrier sediments may have got burried under newly deposited sediments which acted as a cover from erosion to some deeper parts of the bar during renewed transgression. This is well illustrated by the section at Hastings Cove where shoreface facies GF4 both underlie and overlie dune deposits of facies GF5 (see Fig. 3).

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