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Sedimentology of the Halifax Formation, Nova Scotia: Lower Palaeozoic fine-grained turbidites

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SUMMARY: The Halifax Formation is a several kilometre thick, shale-rich succession that forms part of the (?) Cambro-Ordovician Meguma Group of Nova Scotia. The Meguma sediments were mostly deposited by sediment gravity flows on a prograding marine slope-rise complex of uncertain water depth. Eight separate facies of the Halifax Formation are recognized on a facies continuum from very shaley to very sandy. The two most sandy facies show partial Bouma sequences; the others are best interpreted in terms of a more detailed 'ideal sequence' for fine-grained turbidites. Vertical sequences show thinning-upward, thickening-upward and irregular patterns of sandstone and siltstone beds on a large-scale (100–200 m). There is also much wedging, subdivision and amalgamation of these coarse lithologies. Erosional features are locally common at the base of turbidite beds and still more widespread at the top. Slumps and bioturbation are less common. The depositional setting of most of the Halifax Formation is interpreted to be the mid- or upper-fan area of a muddy deep-sea fan, passing upwards into a prograding continental slope.

The Lower Palaeozoic Meguma Group of Nova Scotia (Fig. 1) comprises a thick succession (at least 10 000 m) of sandstone, siltstone and shale that has been interpreted as a prograding deep water slope-rise complex (Schenk 1978; Schenk *et al*. 1980). These rocks were folded, intruded and regionally metamorphosed during the Devonian Acadian orogeny (Poole 1970; Williams 1978). The major folds are open, upright and low-plunging, and a marked cleavage parallels their arcuate trend (Fyson 1966). The metamorphism varies regionally from greenschist to amphibolite facies (Taylor 1967, 1969; Clarke & Muecke, 1980). The lower grade metamorphism results in slates becoming indurated so that alternating slate and siltstone lithologies are in places unusually well preserved and exposed, although where cleavage is intense outcrops are poor. Sparse faunal data are all of Early Ordovician age (Schenk *et al*. 1980), so that the lower part of the Meguma Group may be Cambrian in age. The occurrence of possible tillite suggests that the top of the Halifax Formation may extend into the Late Ordovician (Schenk 1972; Schenk *et al*. 1980).

The Meguma Group comprises two partially coeval formations, the (mainly lower) Goldenville Formation of quartz metawacke and the (mainly upper) Halifax Formation, principally of slate. Halifax Formation lithologies overlie, intertongue with and may be intercalated with Goldenville Formation lithologies (Harris & Schenk 1975; Schenk *et al*. 1980). The Halifax Formation is overlain, probably conformably, by sandstones, shales and volcanic rocks of the White Rock Formation, which were deposited in a continental shelf environment (Lane 1976, 1981).

Harris & Schenk (1975) and Schenk *et al*. (1980) have reviewed the results of early mapping by the Geological Survey of Canada, and of previous sedimentological studies. In the last 20 years sedimentological work, chiefly on the Goldenville Formation, has established that the Meguma sediments were mostly deposited by sediment gravity flows (Phinney 1961; Campbell 1966; Taylor 1967; Schenk 1970; Harris 1971). The Goldenville Formation consists of sandy flysch, whereas the Halifax Formation is of shaly flysch. According to Schenk *et al*. (1980), on the facies classification of Walker & Mutti (1973), sand layers of the Halifax Formation correspond to Facies D ('classical' distal turbidites) and G (pelagic and hemipelagic muds and silts) with minor amounts of C (Bouma's T_{ae} proximal turbidites). Sands of the Goldenville Formation are mainly of Facies B2 (massive sandstones without dish structures) and Facies C with minor A2 (organized conglomerates), A4 (organized pebbly sandstone), and B1 (massive sandstones with dish structures). Goldenville lithologies represent channel deposition in the mid-fan area of submarine fan systems (Schenk *et al*. 1980).

The dispersal pattern appears almost constant throughout the time in which the Meguma Group was deposited (Schenk 1970). The palaeocurrents turn approximately 90 degrees from north in south-west Nova Scotia to east in the eastern part of the province (Fig. 2A) and local variations to this trend are consistently toward the north-west. The easterly palaeocurrent trend appears to parallel sedimentologic scalar properties, so that palaeocurrents trend along, not across, contours of such properties as layer thickness (Fig. 2B & C), sandstone-shale ratio (Fig. 2D) and percent

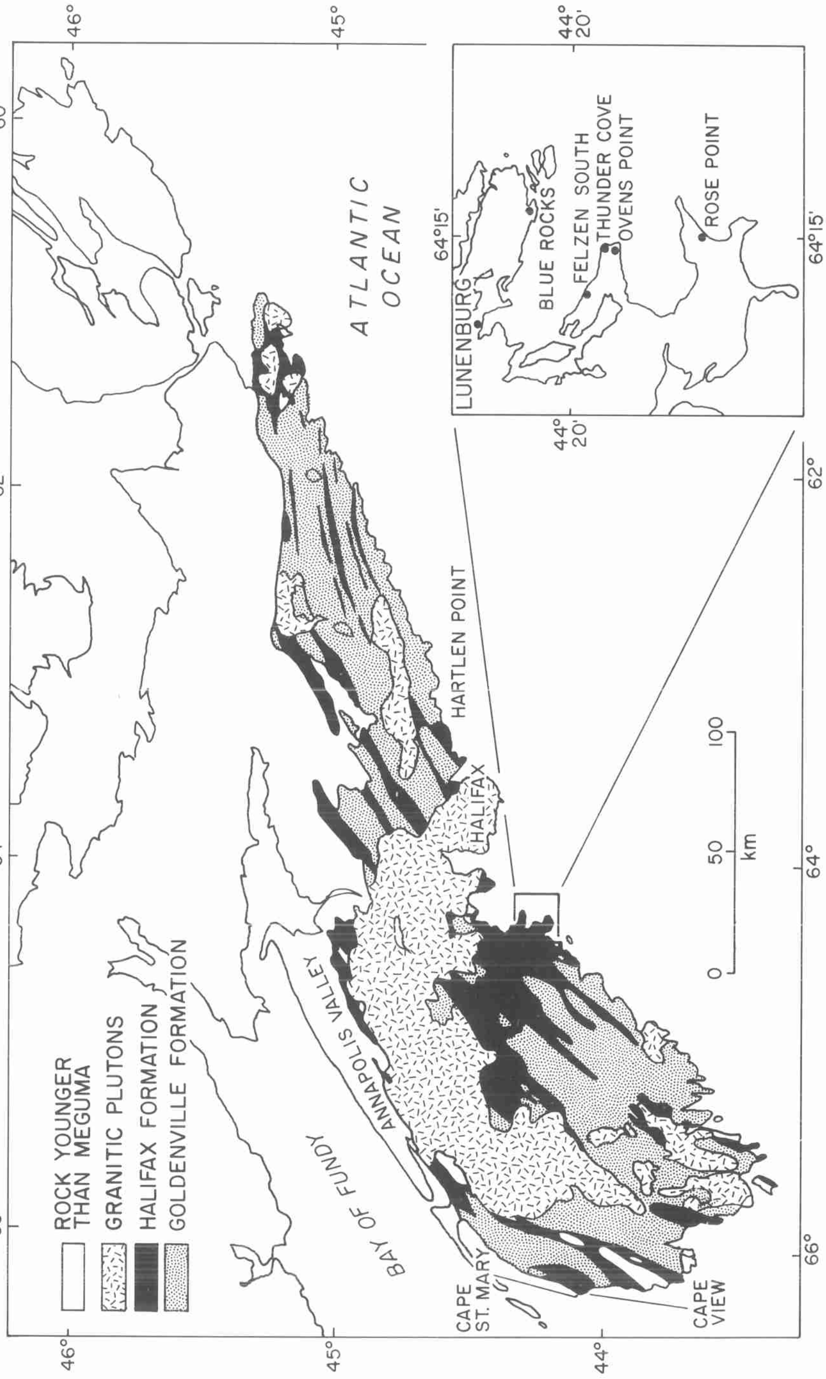
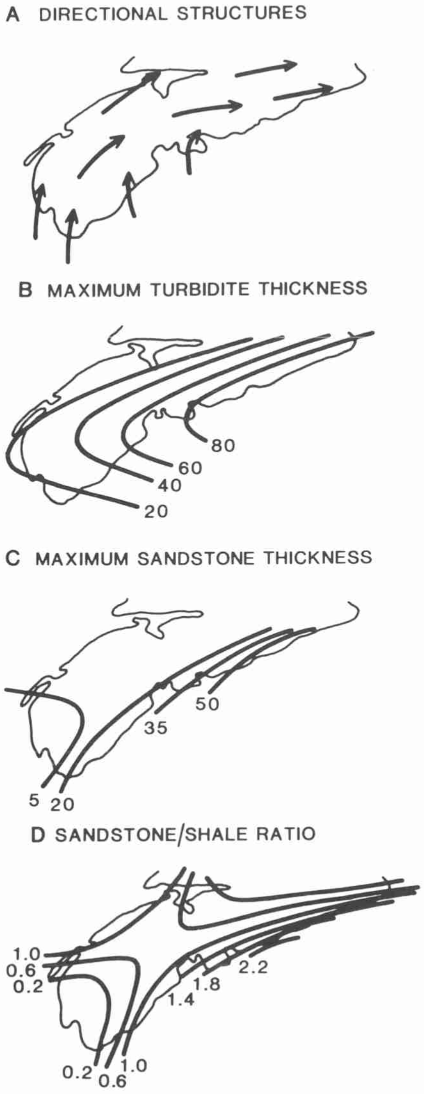


FIG. 1. Distribution of the Halifax and Goldenville Formations and location of measured sections.



A DIRECTIONAL STRUCTURES

B MAXIMUM TURBIDITE THICKNESS

C MAXIMUM SANDSTONE THICKNESS

D SANDSTONE/SHALE RATIO

FIG. 2. Trend surface maps (from Schenk 1970) of Halifax Formation showing regional variation in (A) directional structures (sole marks, cross-stratification) (B) maximum turbidite thickness (cm) (C) maximum sandstone thickness (cm) (D) sandstone/shale ratio.

lithic clasts (Schenk 1970). Thus the general trend of the continental margin on which the Meguma Group accumulated is probably ENE–WSW, with downslope transport in proximal areas and along-slope transport in distal areas. Schenk (1970) originally suggested that the along-slope transport was due to contour currents, but later (Schenk 1971) pointed out the analogy with turbidites of the Hatteras Abyssal Plain, which have flow paths to the south parallel to the North American continental margin (Horn *et al.* 1971).

The lack of stratigraphic markers seriously hinders regional sedimentologic interpretation of the Halifax Formation. The upper contact with the White Rock Formation in the Annapolis Valley appears to be synchronous (Schenk *et al.* 1980; Lane 1981). The lower contact with the Goldenville Formation, which Schenk used as a datum in his early reconnaisance studies (Schenk 1970, 1971) could be highly diachronous (Schenk *et al.* 1980). In addition, the regional tectonic structure of the Halifax Formation is poorly known.

The Halifax Formation of the Atlantic Coast of Nova Scotia is very variable on a small scale, from locally dominant sandstone to dominant shale facies. Packages of thin to thick sandstones (up to 1 m thick) occur in zones 1 to 20 m thick interbedded with siltstone-laminated shales. The sandstones are especially frequent near to the contact with the Goldenville Formation. The sequence in the Annapolis Valley region is generally finer-grained. Smitheringale (1973) identified three facies, from very silty, coarser and more quartz-rich to very shaley, finer and more chlorite-mica rich, and noted that these formed an overall coarsening-upward megasequence within a zone approximately 3000 m below the White Rock Formation. Lane (1976, 1981) described this silty-shale lithology in detail from the upper 1500 m of the Halifax Formation and noted a finer-grained slate with minor siltstone laminae for the 100 m or so immediately below the White Rock Formation.

This present work is based on detailed measurement and study of sections at six locations (Fig. 1): Cape St. Mary and Cape View on the Bay of Fundy to the west of the Annapolis Valley, and sections at Rose Point, Ovens Park (Ovens Point, Thunder Cave and Felzen South), Blue Rocks and Hartlen Point on the Atlantic coast of Nova Scotia. In addition, we have re-examined some of the sections described by Lane (1981) and Schenk (Harris & Schenk 1975; Schenk *et al.* 1980).

Sedimentary facies

Petrography

The Halifax Formation comprises dominantly shale and slate with a variable proportion of siltstone laminae and, in lesser abundance, thin to thick sandstone beds. The shales are black to light grey or greenish-grey in colour and are commonly silty and laminated. They contain dominantly quartz and feldspar, with accessory minerals including epidote, apatite, tourmaline, zircon, magnetite, ilmenite, graphite and micas. The metamorphosed matrix in lower grade rocks is of chlorite, muscovite, biotite and sericite and where the metamorphic grade is higher garnet, andalusite and cordierite occur. The lighter-coloured shales are more silty and quartz-rich, the darker shales are more carbonaceous and pyritic. Most siltstones are light grey and rich in quartz and feldspar. The sandstones are mostly very fine-grained, but rarely are medium-grained and contain shale rip-up clasts. They are mainly quartzo-feldspathic with a variable metamorphic matrix and a range of accessory minerals similar to those of the slates (Schenk *et al.* 1980).

Both fauna and faunal traces are rare. Rare graptolites and trilobites have been found. Trace fossils have been recently described by Pickerill & Keppie (1981) and include invertebrate feeding tracks and vertical, sand-filled burrows.

Sedimentary structures

Thicker-bedded sandstones show clear evidence of Bouma sequence turbidites. The thinner-bedded fine-grained facies of shale and siltstone include distinctive sedimentation units which correspond closely to fine-grained turbidite sequences defined by Piper (1978) and Stow & Shanmugam (1980). These units are variable and not always very distinct, but are typically 2–10 cm thick and comprise a thin basal siltstone or very fine sandstone layer, commonly cross-laminated or parallel-laminated, overlain by a thicker graded silstone-laminated shale.

The cross-lamination in places occurs as 'fading' ripples in which ripple crests of siltstone pass gradually into ripple troughs of shale (Stow & Shanmugam 1980; see also Fig. 13a). The coarser siltstone and sandstone beds display a variety of erosional and synsedimentary deformational structures, including flute and irregular scour marks, shale intraclasts, convolute lamination, and load and injection structures.

Facies types

In the measured sections presented in this paper, the slates have been sub-divided into six facies on the basis of sedimentary structures and the average siltstone/shale ratio (SIL/SH). The sandstones have been divided into two facies on the basis of bed thickness. These facies are described below and illustrated in Figs 3 and 4. We have to use such simple criteria for facies definition because weathering and cleavage frequently obs-

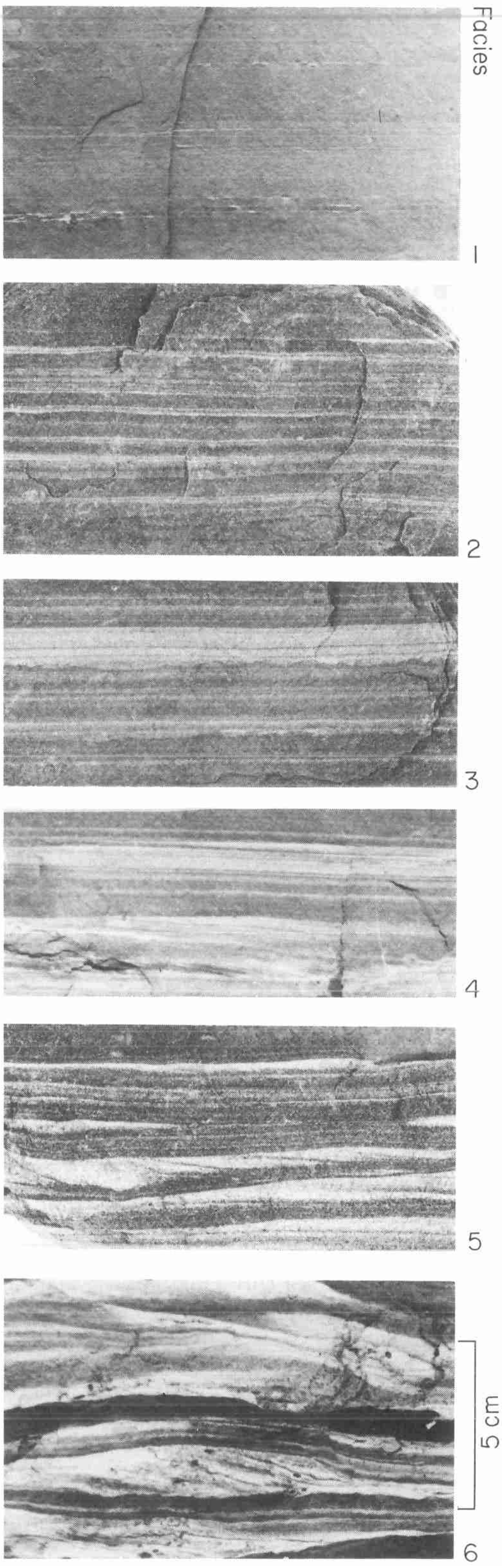


FIG. 3. Photographs illustrating siltstone-shale facies 1–6. For details, see text.

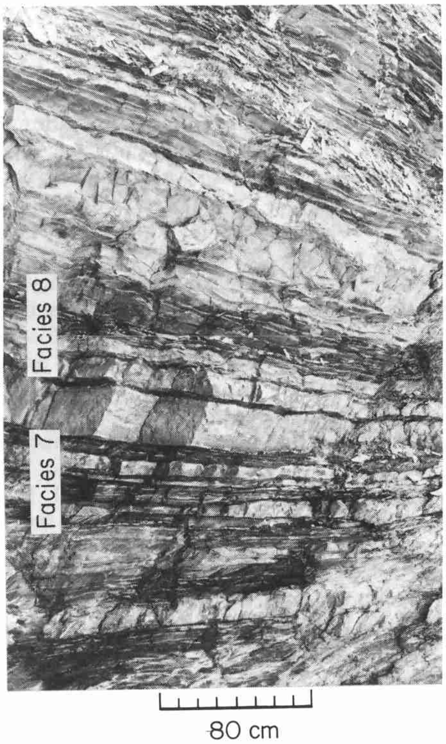


Fig. 4. Photograph illustrating sandstone facies 7 (thin-bedded, 1–10 cm) and 8 (thick-bedded >10 cm). For details see text.

cure primary structures, and there has been considerable plastic strain in many outcrops.

Facies (1): Shale, SIL/SH $<5/95$; structureless, rare[1] siltstone lenses. (Facies 7–9 of Lane 1980, are equivalent.)

Facies (2): Shale dominant, SIL/SH $<25/75$; infrequent, very thin (<1 mm), indistinct and/or discontinuous, parallel to wavy, siltstone laminae; gradational and sharp boundaries, rare normal grading. Rare thin sandstone beds. (Facies 4 and 6 of Lane 1980, are equivalent.)

Facies (3): SIL/SH $\approx 40/60$; frequent, thin (1–2 mm), regular, parallel siltstone laminae; rare low-amplitude long-wavelength ripples; gradational and sharp boundaries, some normal grading. Rare thin sandstone beds. (Facies 5 of Lane 1980, is equivalent.)

Facies (4): SIL/SH $\approx 50/50$; common, thin (2–4 mm), regular, parallel siltstone laminae; low-amplitude long-wavelength ripples; rare lenticular laminae; gradational and sharp boundaries, some normal grading and loaded or scoured bases. Rare thin sandstone beds.

Facies (5): SIL/SH $\approx 60/40$; very common, thin to thick (3–6 mm), parallel siltstone laminae, lenticular laminae, convolute laminae; low-amplitude long-wavelength ripples, fading ripples; gradational and sharp boundaries, normal grading, internal parallel and cross-lamination loading, scouring and injection structures. Thin sandstone beds rare to frequent.

or: SIL/SH $\approx 60/40$; very common, thin to thick (3–6 mm), regular, closely-spaced, parallel siltstone laminae. Thin sandstone beds rare to frequent.

Facies (6): Siltstone dominant, SIL/SH $\approx 75/25$; very common, thick (4–10 mm), parallel siltstone laminae, lenticular laminae, convolute laminae; fading ripples, gradational and sharp boundaries, normal grading, internal parallel and cross-lamination, loading, scouring, injection structures and mudstone rip-ups. Thin to medium-bedded sandstones rare to frequent.

Facies (7): Sandstone, thin-bedded (1–10 cm), commonly flat sharp base, also with flutes, scours and load casts, rarely gradational; sharp or gradational top; beds commonly lenticular, internal parallel and cross-lamination, with fading-ripples at top; normal grading common, rarely massive, partial Bouma sequences present (CDE).

Facies (8): Sandstone, medium to thick-bedded (>10 cm, up to 2 m); commonly flat sharp base, also scoured, loaded or channelled; sharp, gradational or eroded top; internal parallel and cross-lamination, the fading-ripples at top; shale partings, siltier and shalier zones indicate amalgamation common; shale rip-up clasts locally abundant, rare pebbly sandstone; normal grading, indistinct grading and massive, partial Bouma sequences present (AB, AE, BCD).

Facies associations and vertical sequences

The distribution of facies in vertical sections is

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[1] In the following facies descriptions the abundance of siltstone laminae per 10 cm of section is approximately quantified by rare (≤ 1), infrequent (1–3), frequent (3–5), common (5–8) and very common (>8).

shown in Figs 6 and 7. Facies (1) to (8) are convenient divisions on a facies continuum from very shaley to very sandy. The facies at the shaley end of this spectrum (1–4) tend to be closely associated with one another and, similarly, the more sandy facies (4–6) are closely associated. The thin-bedded (7) and thick-bedded (8) sandstones occur throughout the spectrum. These relationships are indicated on a facies transition probability matrix (Fig. 5), representing nearly 400 separate facies transitions (both sharp and gradational) in the measured sections at Ovens Point and Cape St. Mary.

Siltstone-rich facies with frequent sandstone are commonest on the Atlantic coast of Nova Scotia, particularly close to the Goldenville Formation boundary. About 370 m of well-exposed section were measured at Ovens Point (Fig. 6(b)). The sequence is one of rapid alternations of sandy and shaley facies with no large-scale overall pattern evident except for an upward increase in the frequency of thick-bedded sandstones over about the first 300 m. Medium-scale (10–20 m) coarsening-upwards and fining-upward sequences are common in the Thunder Cove section (also at Ovens Park), and the Rose Point and Hartlen Point sections. More random oscillations of sandstones and shales are also present. At the small-scale (1–2 m) too, coarsening-upwards, fining-upwards and irregular sequences are evident. These sequences are illustrated in Figs 7 and 8.

	UPPER FACIES							
LOWER FACIES	1	2	3	4	5	6	7	8
1	▨	3						
2	3	▨	8	4	1	1	10	4
3		8	▨	23	11	2	10	16
4		6	19	▨	13	5	21	18
5		2	8	10	▨	7	19	6
6			3	4	5	▨	2	7
7		9	11	24	18	2	▨	
8		9	26	10	8	5		▨

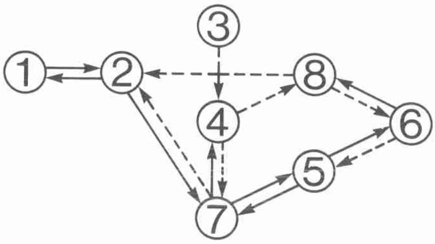

FIG. 5. Transition matrix for facies 1–8 for Ovens Point and Cape St. Mary measured sections, showing (above) actual number of transitions and (below) those transitions that are more common than random (thin line) and more than twice as common than random (thick line).

The measured sections at Cape St. Mary (Fig. 6(a)) and Cape View (Fig. 7(c)) represent the shale-rich facies association of the Halifax Formation. At Cape View, shale facies (1) and (2) alternate randomly through 50 m of sequence (Fig. 7(c)). The 400 m thick section at Cape St. Mary is faulted, and may not be stratigraphically continuous. Its upper contact with the White Rock Formation is tectonic (Lane 1981). Thick-bedded sandstones are restricted to the top 25 m. Both coarsening-upwards and fining-upwards large-scale (100–200 m) sequences are present. Superimposed on these are medium scale (10–20 m) sequences showing fine-coarse-fine oscillations, and with more frequent, thicker (up to 10 cm) sandstone beds associated with the coarser facies. At the small-scale (1–2 m), no very clear sequences were observed.

The shale rich facies association also occurs on the Atlantic coast of Nova Scotia, for example in parts of the Ovens Point (Fig. 6(b)), Rose Point (Fig. 8(b)) and Blue Rocks section (Fig. 8(a)).

Horizontal variability

The intersection of the shoreline with strike direction is such that individual beds of the Halifax Formation can only be traced laterally for 100–200 m at most. Lateral variation has been investigated in most detail in the sections on the Atlantic coast of Nova Scotia. Thin and medium-bedded sandstones and shales are commonly continuous over the length of the section (Fig. 9). The very thin siltstone layers are also laterally extensive and have been traced for over 50 m. The very thick (1–3 m) sandstones tend to wedge out over 50–100 m (Fig. 10) or, in some areas, occur as lenticular bodies over about 10 m of section (Figs 11 and 12). Beds of all thicknesses, however, can also vary considerably in thickness over relatively short distances (5–25 m) – pinching, swelling, subdividing and amalgamating (Figs 10, 11 and 12). Thin slump horizons have been traced over 5 m to 50 m of section.

Erosion and slumping

On a local scale there is much evidence for erosion

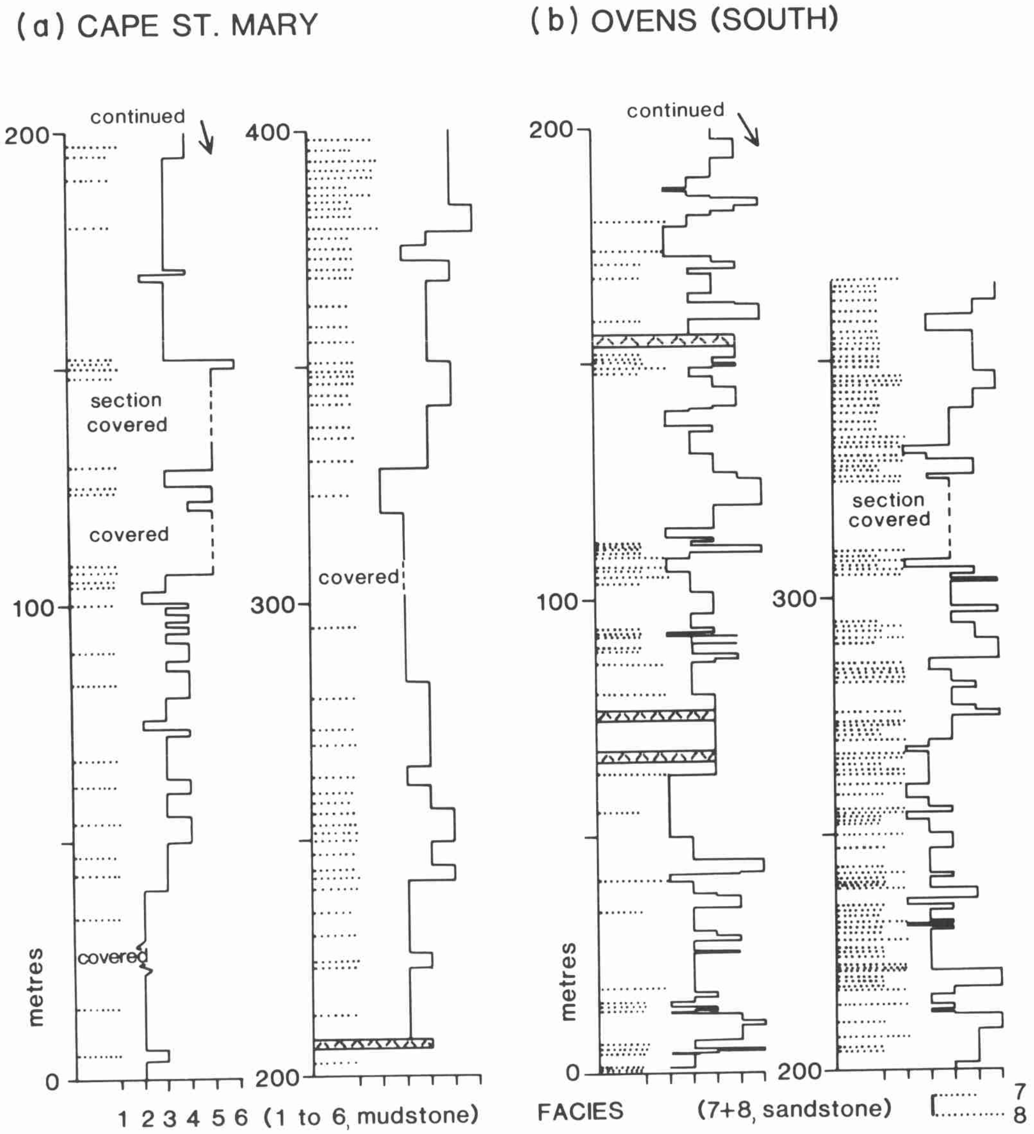

FIG. 6. Measured sections of Halifax Formation showing large-scale sequences, (a) Cape St. Mary (b) Ovens Point.

at the base of siltstone and sandstone beds, where there are scour and flute marks from a few mm to 20 cm deep (Fig. 13(e), (f)). These are locally very abundant, as in the Thunder Cove section at Ovens Park. In many cases, however, the base of a sand bed is relatively flat whereas the top has been eroded. Thin sandstone beds can be almost completely cut-out by small irregular depressions filled with shale. The tops of thicker sandstones may be irregularly eroded by up to 10 cm and, in one case, by a deep scour 50 cm deep (Fig. 13(c)). Thick, possibly channelized, lenticular sandstones are present in one section on Rose Point with abundant shale rip-up clasts on their lower margins (Fig. 13(d)). Commonly, rippled tops of siltstone or sandstone beds are eroded and overlain by shale. Many of these ripples are fading ripples (Stow & Shanmugan 1980), with crests of siltstones passing into troughs of shale. In some cases the eroded top of a ripple can be traced laterally into a perfectly gradational laminated transition from siltstone to shale (Figs. 13(a) and 13(b)).

Individual contorted and convolute laminae

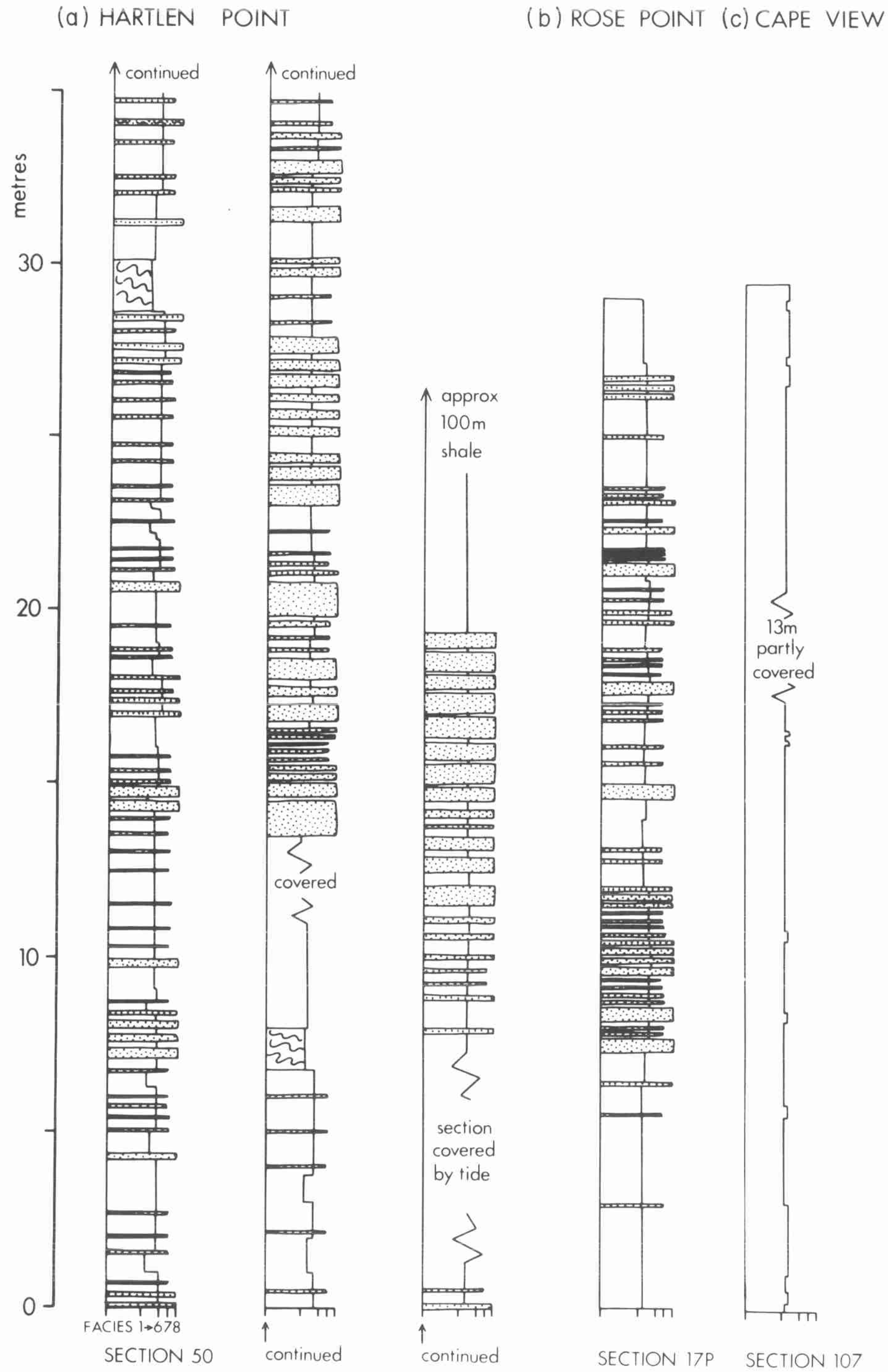

FIG. 7. Measured sections of Halifax Formation showing medium-scale sequences, (a) Hartlen Point (b) Rose Point (c) Cape View.

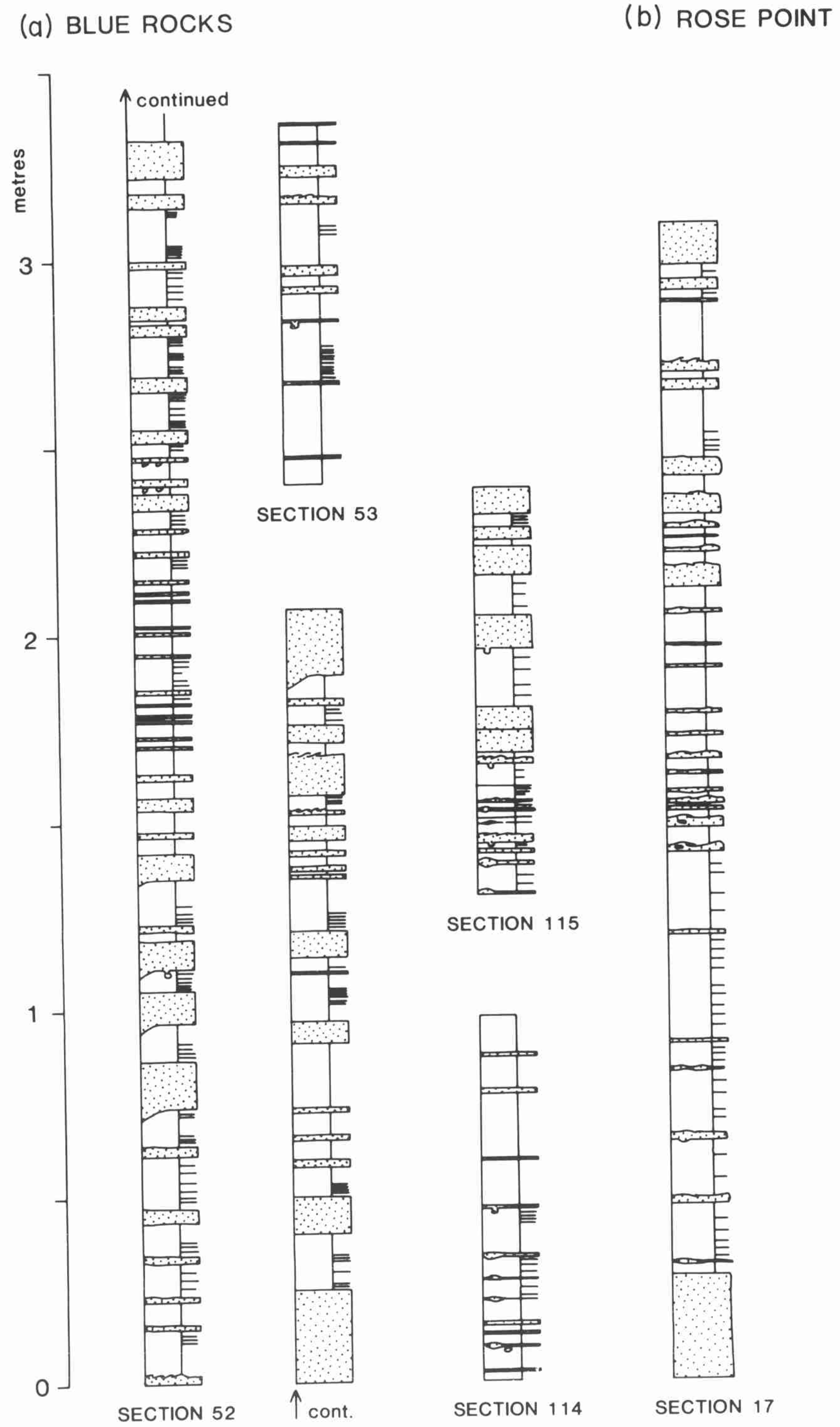

FIG. 8. Measured sections of Halifax Formation showing small-scale sequences, (a) Blue Rocks (b) Rose Point.

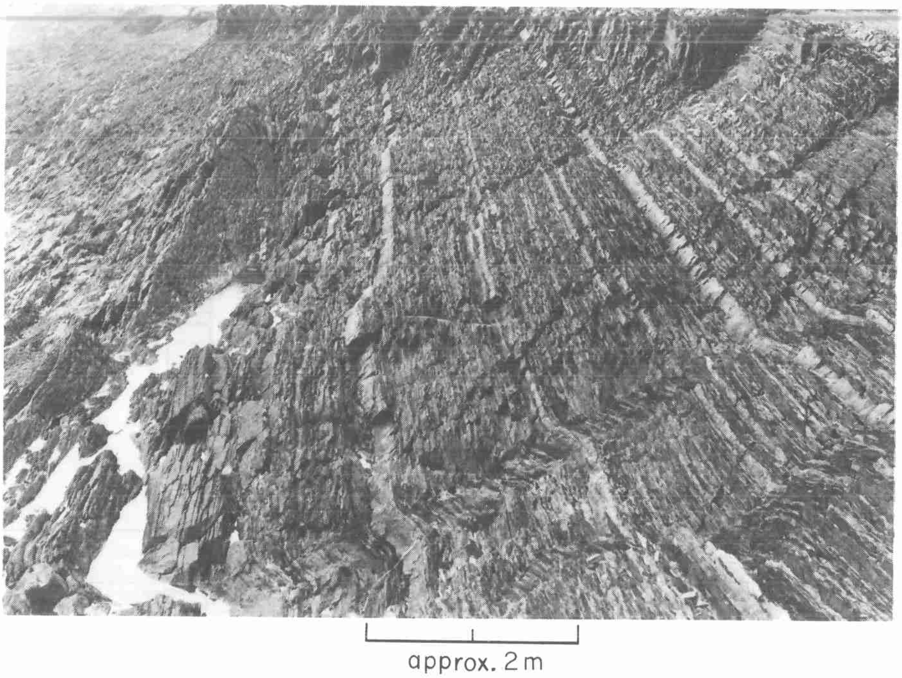

FIG. 9. Photograph illustrating horizontal continuity of bedded siltstone and shale, Halifax Formation, Rose Point.

are relatively common within otherwise undisturbed sections. Small-scale slump-deformed laminae and probable synsedimentary microfaults are also evident in parts. Larger-scale slump horizons are much less frequent, but have been observed at Rose Point and Blue Rocks. Chaotically disturbed sandstone/shale slump horizons are between 10 cm and 100 cm thick (Fig. 14) and can be traced laterally for variable distances up to more than 100 m.

Discussion

Depositional processes

From earlier work as well as from our own observations the Halifax Formation is clearly a turbidite-dominated sequence. Facies (7) and (8) comprise of thin- to thick-bedded classical turbidites that are directly comparable with Facies D1 and C respectively of Mutti & Ricci Lucchi (1972). However, the greater part of the Halifax Formation, Facies (1) to (6), is very thin-bedded shaly flysch equivalent to Facies D, E and G of Mutti & Ricci Lucchi (1972). Similar facies have been described recently by many authors from both modern (Piper 1978; Nelson *et al.* 1978; Stow 1979; Chough & Hesse 1980; Hesse & Chough 1980; Kelts & Arthur 1981) and ancient sediments (Mutti 1977; Ricci Lucchi & Valmori 1980; Shanmugam 1980; Hicks 1981; Pickering 1981a,b; Stow *et al.* 1982).

Much of the shaly flysch consists of fine-grained turbidites, recognized by such distinctive sedimentary structures as graded laminated beds (Piper 1972, 1978) and climbing ripples in the silt beds. These fine-grained turbidites do not show the Bouma structural sequence but can be better documented with either Piper's (1978) or Stow's (1977) (Stow & Shanmugam 1980) structural schemes. In using this latter scheme we can interpret the Halifax Formation Facies (1) to (6) as comprising repeated partial to nearly complete ideal sequences (Fig. 15). Facies (1), (2) and (3) comprise base-cut-out sequences beginning with the structural divisions T_{6-7}, T_{4-5} and T_3 respectively. Facies (4), (5) and (6) are more commonly top-cut-out sequences beginning with division T_{0-1} but missing one or more of the upper divisions. Other variations occur as, for example, the alternative Facies (5) type (closely-spaced parallel laminae) which can be interpreted as closely-repeated T_{3-4} sequences. Such partial sequences result from exactly the same process of downslope turbidity current evolution as has been invoked for partial Bouma sequences. On the whole, the top-cut-out sequences are more proximal and the base-cut-out ones more distal.

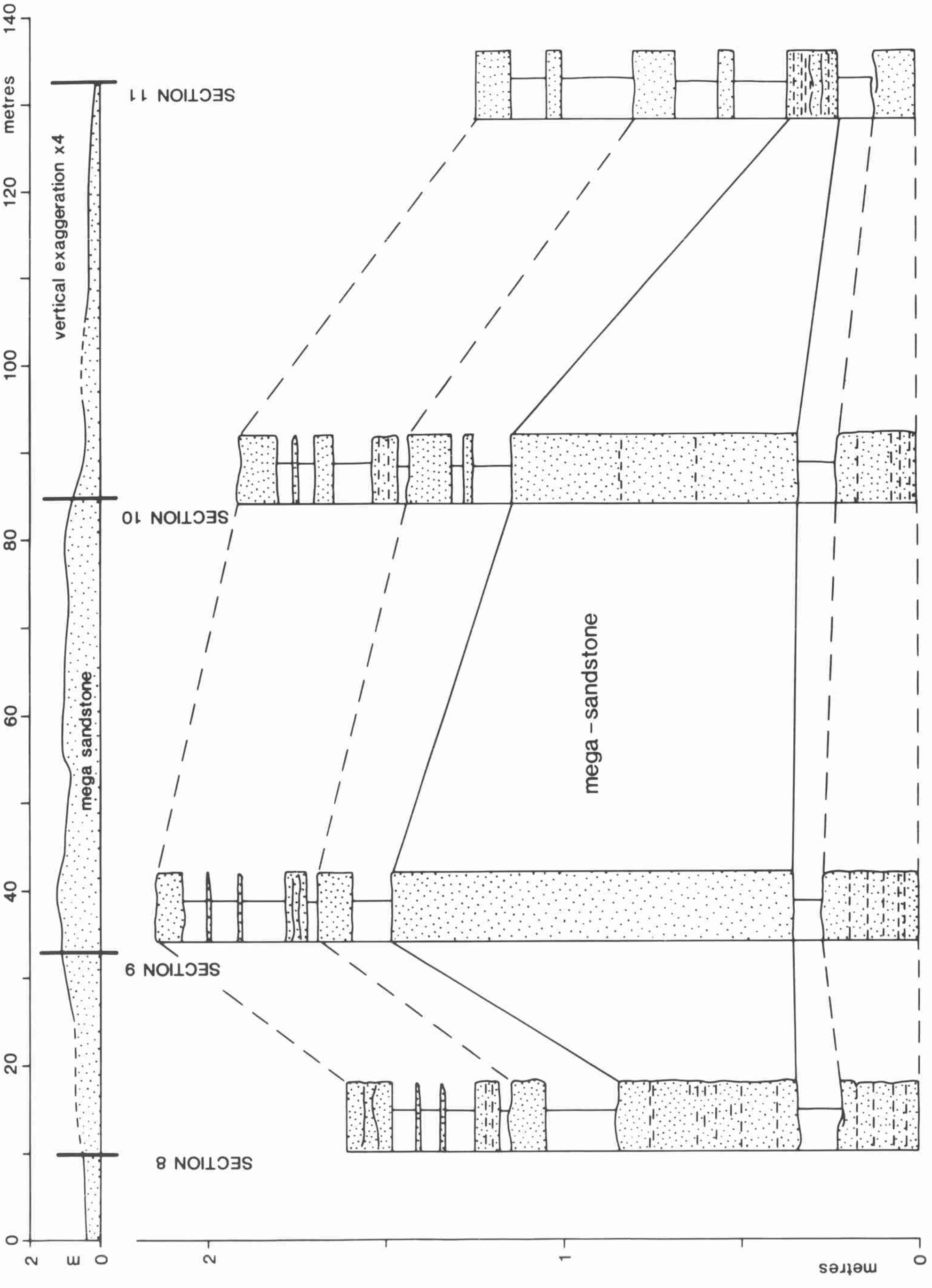

FIG. 10. Four measured sections along 140 m outcrop of thick lenticular sandstone and associated beds, Felzen South (Ovens). Note possible amalgamation in mega sandstone and lateral discontinuity of some thin sandstone beds. The thinnest sandstone beds pinch and swell along section. Current direction at high angle into plane of paper.

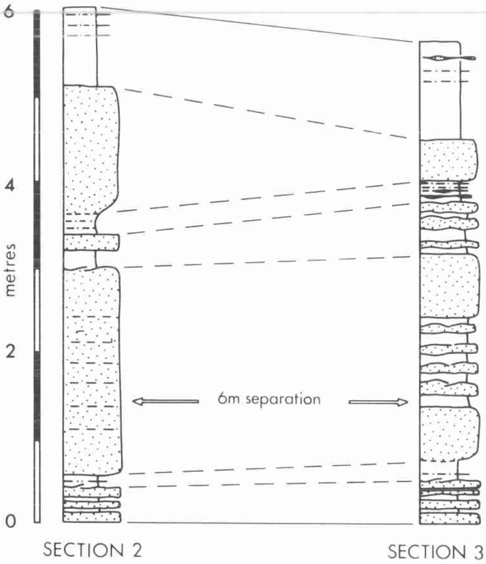

FIG. 11. Two measured sections from Thunder Cove (Ovens) showing lateral variability over 6 m of section. Note amalgamation, lenticularity, pinching and swelling. Current direction at high angle into plane of paper.

Similar sequences have been described recently from the South Atlantic (Stow, in press).

It should be noted that the base-cut-out sequences identified in facies (1) and (2) are not intrinsically very distinctive; and within facies (1) to (4) the proportion of relatively featureless shale is high. Although some of the silt beds in these facies are demonstrably turbidites, we cannot show that the entire sequence is turbidite.

We see some similarities with high sedimentation rate continental slopes (i.e. Hill, this vol.; Pickering, this vol.). For example, the Pleistocene of the Scotian Slope (Hill, this vol.) shows abundant sediment similar to Facies (1)–(4), although generally lacking ripples, with rare interbedded turbidites.

Schenk has suggested (e.g. Harris & Schenk 1975; Schenk *et al.* 1980) that parts of the Halifax Formation may be contourite deposits, based on criteria for contourites proposed by Bouma & Hollister (1973). Although this interpretation is consistent with the regional palaeocurrent pattern, we believe many of Bouma & Hollister's criteria to be incorrect (Piper & Brisco 1975). For example, starved ripples may result from deposition of all silt-sized material in a turbidity current, and are not necessarily evidence of contourites. Indeed, the lateral passage of fading ripples into characteristically turbidite graded laminated silt to mud beds suggests that the ripples must also be turbidites. Structures now recognized as typical of modern contourites, such as wispy, irregular lenses of silt (Stow & Piper, this vol.) are absent.

D'Orsay (1981, 1984) has demonstrated by sequence analysis in the Ovens Point and Thunder Cove sections that prominently rippled Facies (2)–(5), with regular lenticular or wavy lamination, are associated with Facies (6)–(8) containing Bouma AB sequences and common slump and scour features. Planar laminated developments of Facies (2)–(5) are spatially distinct. Such a distribution of facies is the inverse of that

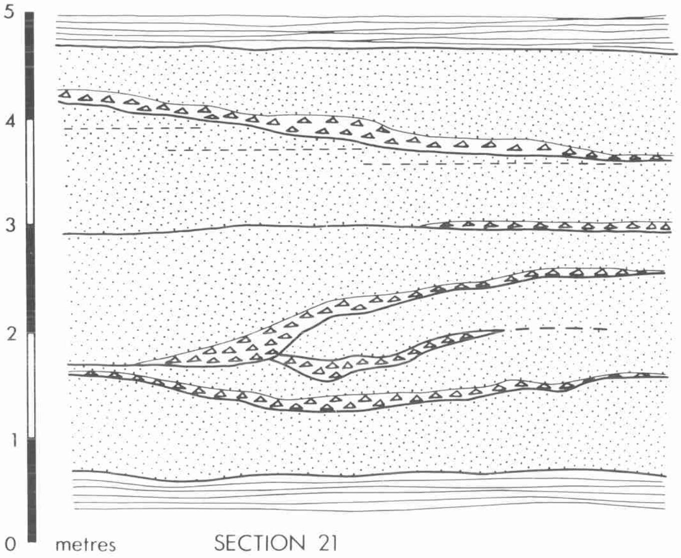

FIG. 12. Measured section from Kings Bay (Rose Point) showing thick lenticular sandstones with erosive bases separated by shale rip-up zones. Horizontal and vertical scales are equivalent.

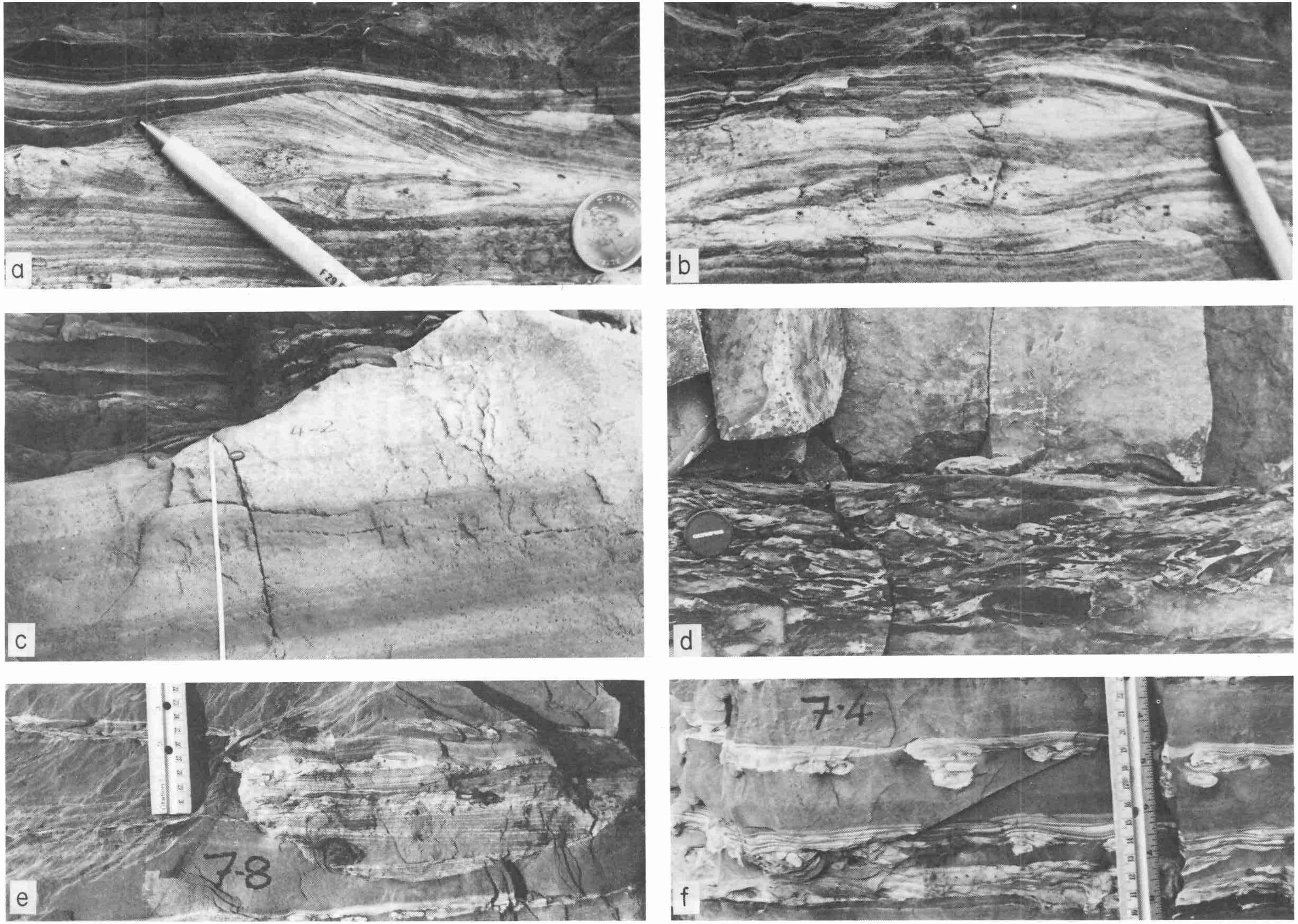

FIG. 13. Photographs illustrating erosinal features in Halifax Formation: (a)–(b) lateral transition from eroded ripple top (a) to graded laminated bed (middle of b); (c) deep scour at top of thick sandstone bed; (d) thick lenticular sandstone bed with shale rip-ups at base; (e) siltstone-sandstone filled erosional scour in shale; (f) highly loaded thin sandstone bed.

FIG. 14. Photographs of slump units in Halifax Formation, (a) Rose Point (b) Blue Rocks.

expected for a contourite model, where silt starvation would be commonest furthest away from the source in the channel areas. In a turbidite model, the observation can be explained in terms of flow becoming both slower and steadier away from channel spill-over. D'Orsay (1981, 1984) suggests that facies (6)–(8) and the lenticular laminae development of facies (2)–(5) were deposited in a turbidity current channel-levee complex while the planar laminated development of facies (2)–(5) is inferred to represent overbank deposition further from channels.

Erosional features are widespread in the Halifax Formation sections just above the Goldenville contact on the Atlantic Coast of Nova Scotia. Load, scour and flute marks at the base of beds are common. Very rapid variation in bed thickness, associated with shale rip-up clasts and slumped sediments indicates the existence of local relief, associated with either channel-levee complexes or giant flute marks (Normark *et al*. 1979). The common erosion at the *surface* of sandstone layers is less commonly reported and less readily explained. In some rippled beds of fine sandstone or siltstone, erosion results from autoerosion by ripple migration during a single depositional event prior to mud deposition. In most examples the causal process is unknown. Schenk (pers. comm.) suggests such erosion may be evidence of a pro-delta environment.

Depositional environment

Several authors have interpreted vertical sequences of facies in terms of progradation of depositional environments or cyclic depositional processes. Basin-fill or megasequences are commonly related to gradual evolution of the tectonic

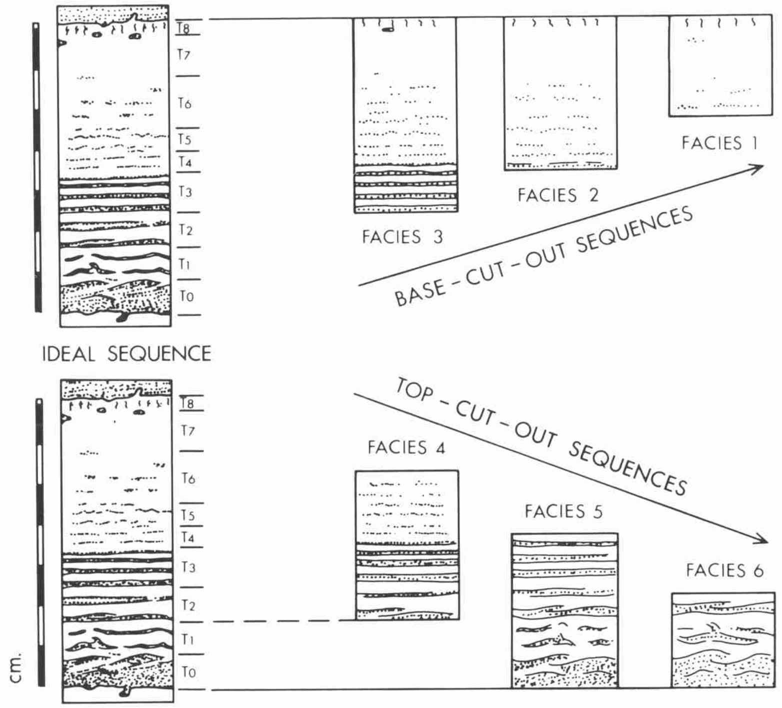

FIG. 15. Stow and Shanmugam's (1980) ideal scheme of sedimentary structures for silt-mud turbidites and its application to facies recognized in the Halifax Formation. Silt-stippled, shale-blank.

regime, sediment supply or depocentre location. Ideal large-scale sequences include coarsening-upwards, fining-upwards and uniform arrangements of turbidites over tens to a few hundreds of metres. These have been interpreted as representing, respectively, mid-fan lobe, channel and basin-plain environments (Mutti & Ricci Lucchi 1972; Rupke 1977). More recently, however, it is being recognized that the 'ideal' sequence is rare and that partial, interrupted and mixed sequences are more common (Mutti 1977; Ricci Lucci 1977; Hicks 1981; Pickering 1981a,b). Shanmugam (1980) and Stow (1981) have used both the small-scale rhythms and individual fine-grained turbidite sequences, over a few millimetres to a metre of section, to characterize different sub-environments and controls of turbidite sedimentation.

The following characteristics of the Halifax Formation are of importance in inferring its depositional environment:

(1) the presence of large-scale (100–200 m) fining-upward, coarsening-upward and irregular sequences;
(2) the oscillation between packets of shale-rich and sandstone/siltstone-rich facies over intervals of 10–20 m;
(3) the relative uniformity and flat bedding of the thin sandstones and finer-grained facies, together with a slight lenticularity of most thicker sandstones over 50–100 m of section;
(4) local small-scale erosion, channelling and slumping.

In addition, the stratigraphic position of the Halifax Formation between the proximal sandy flysch of the Goldenville Formation and the shelf sequence of the White Rock Formation places constraints on possible depositional settings.

The large-scale cyclicity of the Halifax Formation may reflect progradation of muddy deep-sea fan lobes or levees (coarsening-upward), interrupted by muddy channel-filling sequences (fining-upward). Alternatively, the cyclicity may reflect progradation and retreat of a shelf source area, either deltaic or pro-glacial.

The lack of coarse channel-filling sandstones within the Halifax Formation does not conform with a classical deep-sea fan interpretation. The lenticularity of thicker sandstones, the occurrence of packets of sandstone and siltstone-rich rock, and the evidence of erosion, channelling and slumping suggests that these sandier rocks may represent a 'channel' facies in a predominantly muddy sequence lacking coarse sediment supply.

There is no direct evidence for the water depth in which the Halifax Formation accumulated, so that the sediments could have accumulated in a relatively shallow pro-delta environment (Schenk, pers. comm.) similar to the turbidite facies described by de Raaf *et al.* (1964), Kepferle (1978) and Pickering (1981b and this volume).

The lower part of the Halifax Formation on the Atlantic coast of Nova Scotia shows many features characteristic of deposition on channel-levee complexes of modern muddy deep-sea fans. The Holocene upper supra-fan of Navy Fan off California (Normark *et al.* 1979) can be used as an example. The levees have frequent erosional scours, often partially filled with fine-grained material. Back slopes of levees on modern deep-sea fans often have gradients of several degrees and show slumping. Coarse spillover from channels is rare, and related to occasional levee breaching, thus producing a fining-up sequence of muddy flysch as the breach is healed. The abundant wavy bedding and autoerosion is probably related to unstable flow conditions associated with rapid flow expansion and entrainment as the current overtops the levee (Bowen *et al.* 1984). Whether the channel facies is fine-grained and represented by Facies (6)–(8) of the Halifax Formation, or whether it is represented by occasional intercalations of Goldenville Formation lithology is uncertain. We see no evidence for more distal deep-sea fan deposition associated with lobes or basin plain: there is a lack of distal turbidite sands, and the muddy turbidites lack distal characteristics such as extremely fine laminated silts (Piper 1978).

The finer upper parts of the Halifax Formation (as seen in the Annapolis Valley) show similarities with Quaternary continental slope sequences in areas where there is a large fluvial or glacial discharge of fine sediment, but coarse sediment is trapped in the continental shelf (Hill, this vol.).

Conclusions

The Halifax Formation is a thick shaly flysch succession which shows various scales of cycles of resedimented shale and siltstone facies, with rare turbidite sandstone intercalations. The lower part of the Formation closely resembles modern deep-sea channel-levee complexes; the upper may have accumulated principally from turbidity currents on a rapidly prograding continental slope.

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