

Fluvio-estuarine sedimentation in the Late Carboniferous Malagash Formation of Nova Scotia, Canada

R. D. Naylor, A. W. Archer¹, F. W. Chandler² and P. W. Fralick³

Abstract

The Westphalian C-D Malagash Formation of Nova Scotia is dominated by thick, fluvial sandstones and redbeds containing calcrete-bearing vertisols. These volumetrically dominant facies, which constitute approximately 85% of the Malagash Formation, suggest braided fluvial deposition alternated with extensive periods of floodplain development. The Malagash Formation, unlike its stratigraphic equivalents, lacks economic deposits of coal and has been considered to be an upland equivalent to laterally correlative coal measures that were deposited basinward. Despite the apparently upland character of the dominant facies, 12% of the Malagash Formation comprises heterolithic facies containing fine-scale laminations and agglutinated foraminifera indicative of estuarine and tidal influences during sedimentation.

The Westphalian C-D was a period of high frequency, high amplitude glacio-eustatic flux and the resultant base level changes appear to have influenced the facies-stacking patterns. The calcrete vertisols suggest a strongly seasonal, potentially monsoonal, paleoclimatic overprint at paleolatitudes that were approximately equatorial.

Introduction

Purpose of Investigation

The Late Carboniferous strata of Atlantic Canada traditionally have been ascribed a nonmarine origin based on the absence of marine fossils and general similarities to fluvial and lacustrine deposits. Earlier workers used the characteristics of the Late Carboniferous coals to suggest that some were deposited within proximal marine (paralic) settings (Haquebard *et al.*, 1967; Haquebard and

Donaldson, 1969). Direct evidence of marine influenced deposition was not noted by these authors.

Discovery of fossil protozoans (agglutinated foraminifera) in the Sydney Coalfield (Fig. 1) (Thibaudeau and Medioli, 1986) initially provided evidence for Late Carboniferous marine influences in Atlantic Canada. These organisms closely resemble those found in modern estuaries and saline marshes. Subsequently, cyclothems inferred to have been controlled by base-level (eustatic) flux, that contained similar foraminiferal assemblages (Wightman *et al.*, 1993), were delineated within the Sydney Coalfield (Bird, 1987; Gibling and Bird, 1994). Detailed analysis of the sedimentology, stratigraphy and agglutinated foraminifera of an individual cyclothem (Gibling and Wightman, 1994) allowed the differentiation of coastal plain, paleovalley-fill, and alluvial-plain deposits. Recently, similar foraminiferal assemblages have been documented from Late Carboniferous coal-bearing strata of the Gulf of St. Lawrence Basin (Fig. 1) (Wightman *et al.*, 1994a). Calder (1998) asserted that some of the Late Carboniferous fossil fauna of Atlantic Canada, that has traditionally been described as nonmarine, be interpreted to have a nearshore marine affinity. Calder (1998) also pointed out that paleogeographic, paleoflow and faunal 'trends' suggest that a Mid-Euramerican Sea existed between the Maritimes and Europe throughout the Carboniferous.

Until now, the search for evidence of marine influence within the Late Carboniferous strata of Atlantic Canada has been confined to the coal measures. This study focuses on the Malagash Formation; a largely non coal-bearing succession of sandstone and red mudrock, which is age equivalent to the Westphalian C-D coal measures. The purpose of our research is to look for evidence that may suggest marine influence, inland from the coal measures, in what has traditionally been considered a fluvial dominated nonmarine setting.

¹Department of Geology, Kansas State University, Manhattan, Kansas 66506, U.S.A.

²Geological Survey of Canada, 601 Booth Street, Ottawa, Ontario K1A 0E8

³Department of Geology, Lakehead University, Thunder Bay, Ontario P7B 5E1

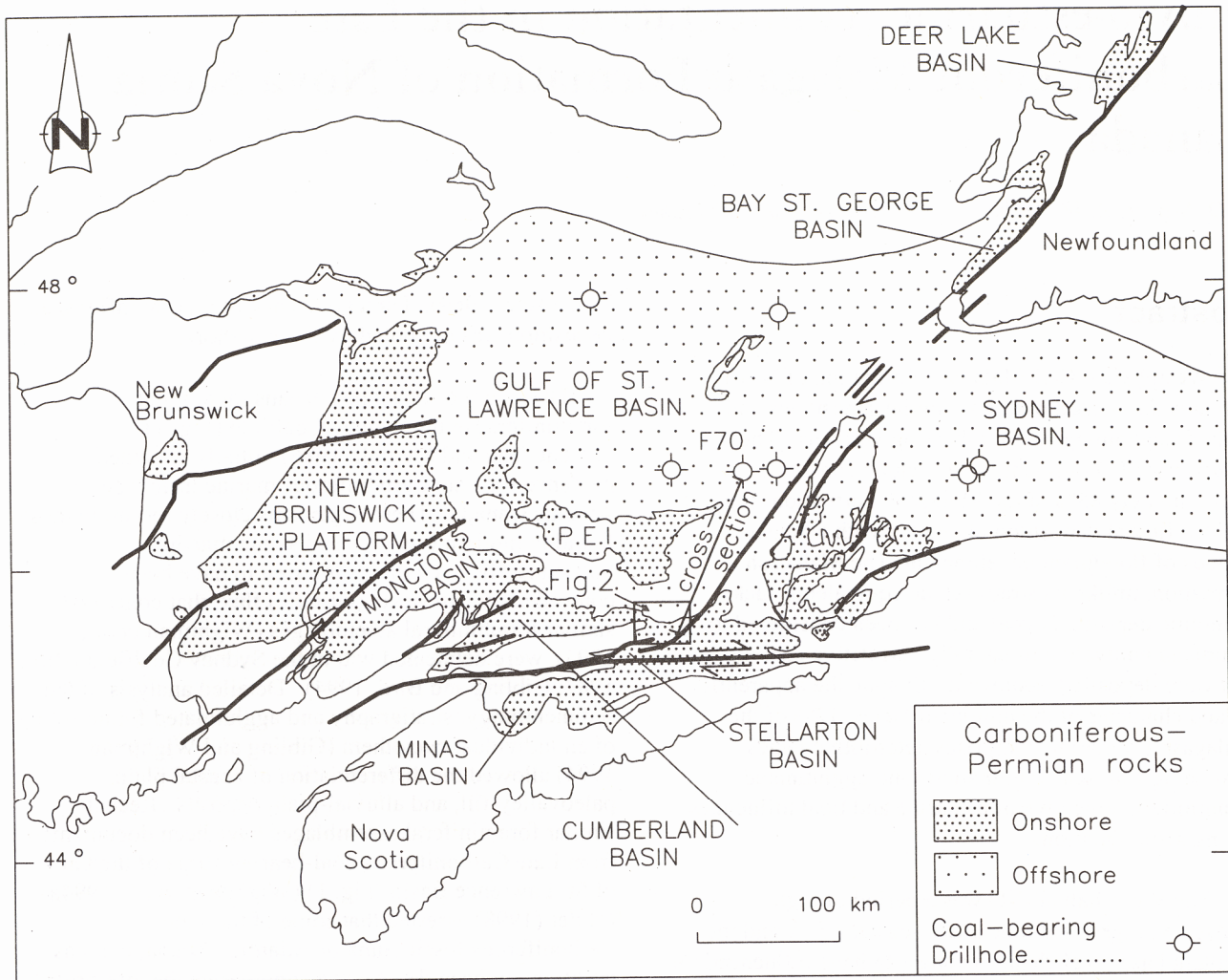


Figure 1. Distribution of Carboniferous basins in Atlantic Canada showing location of study area and cross-section illustrated in Figures 2 and 4 respectively.

General Geological Setting

Sediment deposition and concurrent development of mires was widespread in Atlantic Canada during the Westphalian C-D. Much of the detritus was deposited in the regionally extensive Sydney and Gulf of St. Lawrence basins (Fig. 1); however, unusually thick (2600 m) Westphalian successions also accumulated in small (120 km²), rapidly subsiding basins within major strike slip fault systems, such as the Stellarton Basin (Figs. 1, 2) (Fralick and Schenk, 1981; Yeo and Ruixiang, 1987; Naylor *et al.*, 1992). Sediment, which may have been sourced as far away as the Central Appalachians (Gibling *et al.*, 1992), was carried into the depositional basins by

northeastward flowing rivers. Erosion of local uplifts also provided a source of sediment as evidenced by onlap of proximal portions of alluvial fans onto basement (Fralick and Schenk, 1981).

The study area (Fig. 2) is contained within the Gulf of St. Lawrence Basin, a large (46 620 km²), predominantly submerged basin that contains an average of 1000 m of Westphalian C-D strata (Haquebard, 1986; T. A. Rehill, personal communication, 1995). Westphalian C-D coals are well developed in central, northern and eastern areas of the basin (Haquebard, 1986); however, in the southern part of the basin, which includes the study area (Fig. 2), the Malagash Formation contains only rare, thin (<0.3 m), impure coals.

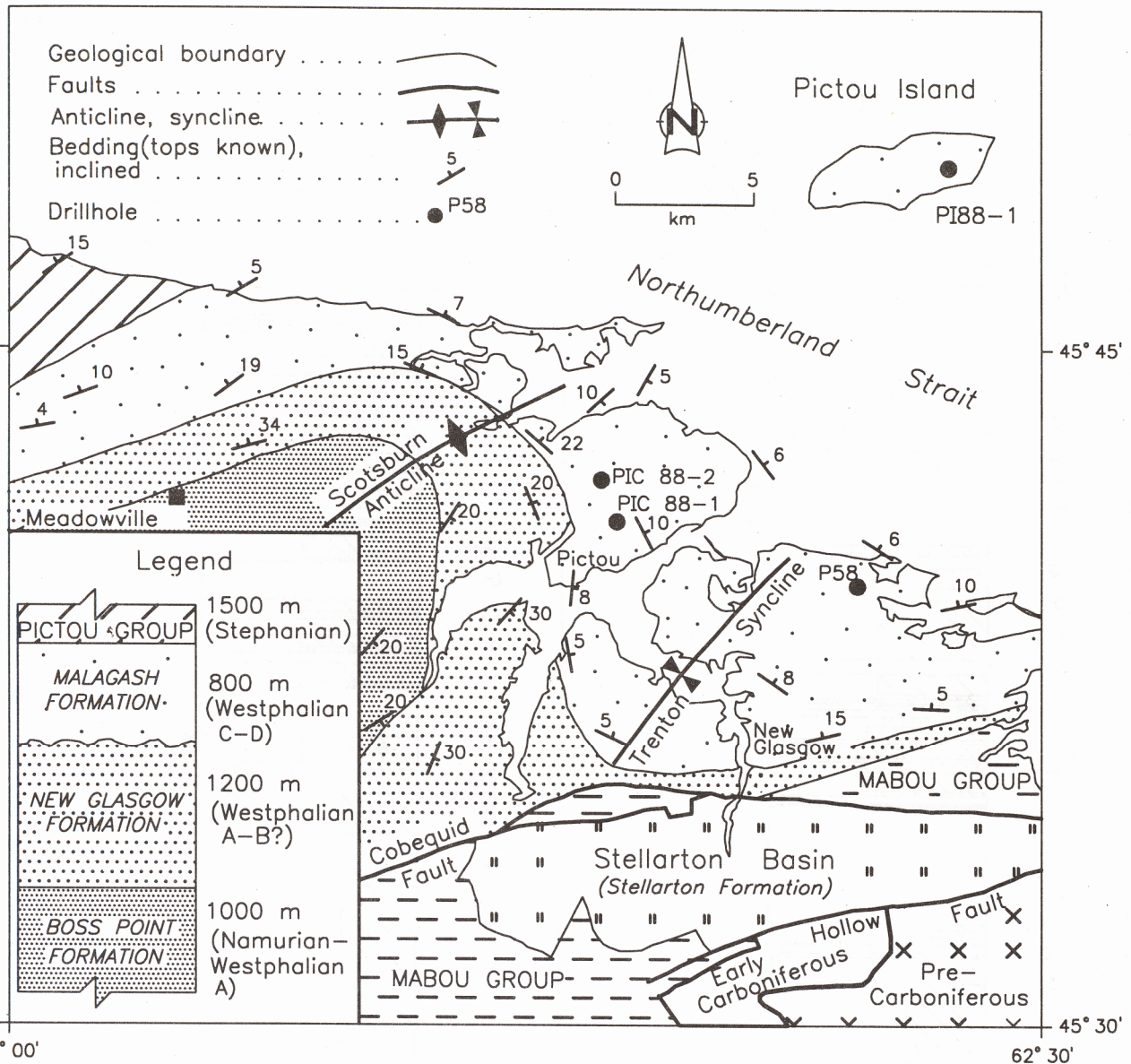


Figure 2. General geological map of the study area, Pictou County, Nova Scotia.

General Stratigraphy

The Malagash Formation (Ryan *et al.*, 1991) also was referred to as the Merigomish Formation (Yeo and Ruixiang, 1987). For the purposes of this paper, the term Malagash Formation is used for consistency with the regional nomenclature of Ryan *et al.* (1991). Within the study area, the Malagash Formation is 800 m thick and consists of units of grey sandstone, red mudrock, grey mudrock, and rare, thin, impure coals (Fig. 3). In the southernmost part of the study area, the base of the Malagash also includes black shales/oil shales and a stromatolitic limestone (Yeo and Ruixiang, 1987; Palmer,

1991). Detailed stratigraphic correlation of individual sandstone and mudrock units is not possible because of the limited number of drillholes and the lack of good exposures of the mudrock-rich facies.

The Malagash Formation disconformably overlies the Westphalian A-B New Glasgow Formation of Bell (1940) (alluvial fan deposits) and grey sandstone dominated Westphalian A-B strata that are, here, informally assigned to the Cumberland Group (Fig. 4). Northeast of the Trenton Syncline, down paleoslope, the Malagash Formation interfingers with the predominantly grey Westphalian C-D coal measures of the Inverness

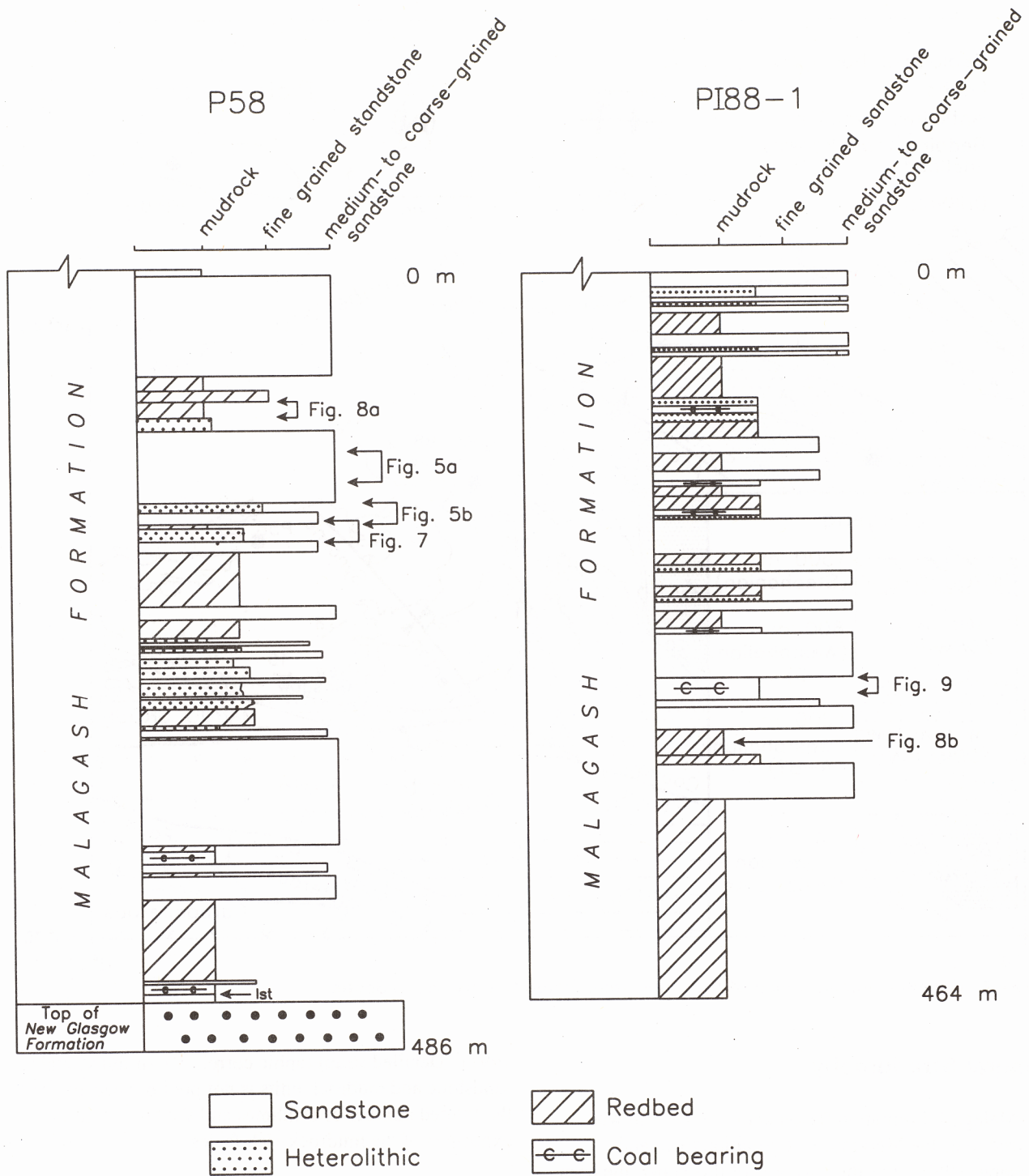


Figure 3. Graphic logs of drillholes P58 and PI88-1 illustrating the vertical arrangement of facies associations within the Malagash Formation and the locations of detailed lithologic profiles. See Figure 2 for drillhole locations.

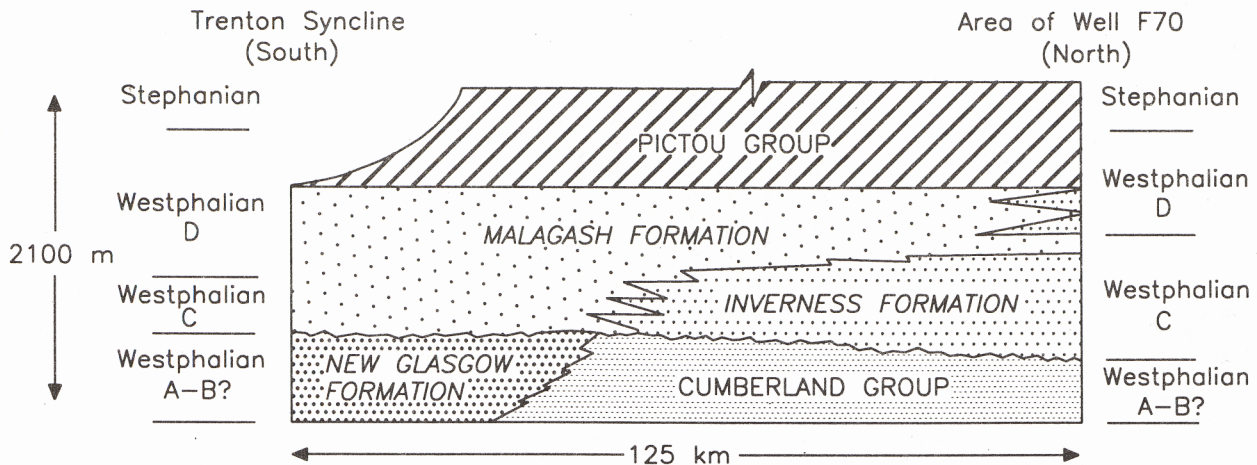


Figure 4. Cross-section illustrating down paleoslope change in Westphalian stratigraphy from the study area to the central eastern Gulf of St. Lawrence Basin. See Figure 1 for location of cross-section.

Formation. West of the study area, along depositional strike, the Malagash Formation thins (100-400 m), but is still traceable to at least the area of the Moncton Basin in New Brunswick (Fig. 1; about 150 km) (Ryan *et al.*, 1991). The Malagash Formation may be equivalent to the Richibucto Formation and part of the Salisbury Formation in New Brunswick (S. Johnson, personal communication, 1995).

The Stellarton Basin/Pictou Coalfield lies immediately south of the study area, across the strike-slip Cobequid Fault system (Fig. 2). This basin contains the Stellarton Formation, a 2600 m thick, grey, coal-bearing lacustrine succession that is age equivalent to the Malagash Formation (Yeo and Ruixiang, 1987; Naylor *et al.*, 1989).

Description of Facies Associations

All outcrops and drillcores of the Malagash Formation were examined within the study area. Cores were available from four drillholes PIC 88-1, PIC 88-2, P58 and PI88-1 (Fig. 2). All of these holes were continuously cored. Drillcores proved particularly useful for describing the sedimentology of mudrock dominated units and for recognizing large scale vertical arrangement of facies. Drillholes P58 and PI88-1 represent the most complete sections in the study area (Figs. 2, 3).

Within the study area the Malagash Formation can be subdivided into the following four facies associations: (1) sandstone, (2) heterolithic, (3) redbed, and (4) coal bearing. The most common vertical arrangement of these

facies associations comprises sandstone facies overlain by heterolithic facies that grade upward into redbeds (Fig. 3). Rocks of the coal-bearing association are uncommon. Information on each facies association is presented in detail in the following sections.

Sandstone Association

The sandstone association comprises 53% of the Malagash Formation in the study area (Fig. 3). This association is composed of lithic-feldspathic grit to quartzose sandstone that contains fresh detrital biotite, chlorite, muscovite, and fresh to altered plagioclase and microcline grains. Quartz grains are very angular and do not show embayments or hematite-filled fractures.

Coarser facies are pale grey and finer facies are pale green grey. Intraformational conglomerates are common and comprise grey mudrock, calcrite clasts and occasional extraformational quartz and granitic pebbles (Figs. 5a, 6a). Red mudrock intraclasts are conspicuously absent except for very rare occurrences adjacent to some contacts with redbeds. Carbonized to coaly plant material is locally common and ranges in size from transported logs up to 5 m in length to finely macerated debris that defines ripple and planar laminae. Plant fragments are occasionally pyritized (Figs. 5a, b).

The sandstones of this association are 1-60 m thick and can be subdivided into thick and thin units. Thick (14-60 m) sandstones (Fig. 5a) are multistoried and generally lack well-developed vertical changes in the scale of sedimentary structures (Yeo and Ruixiang, 1987;

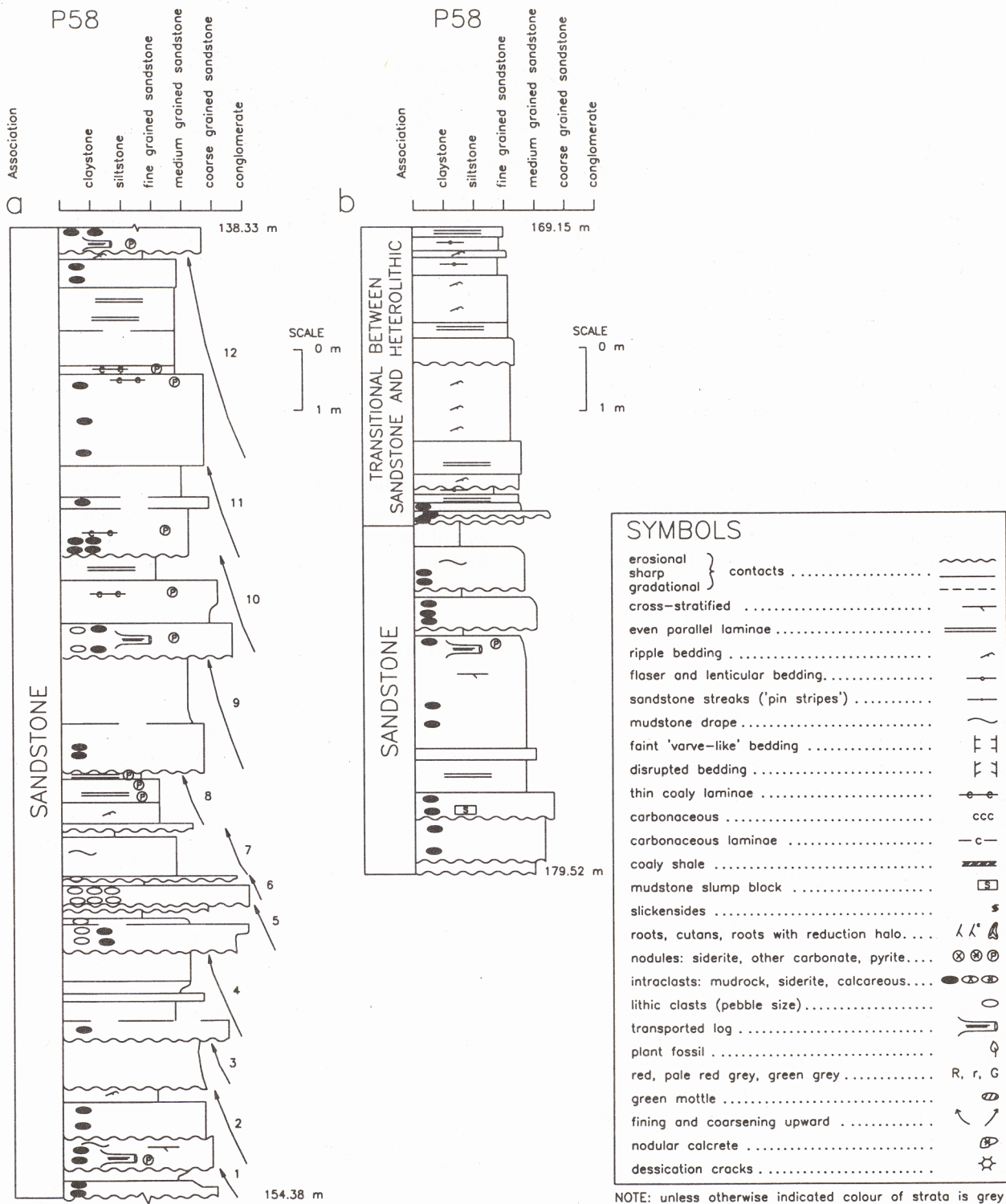


Figure 5. Detailed profiles illustrating the sedimentology of the sandstone facies association. For locations see Figure 3. (a) Thick multistoried sandstones. (b) Thin sandstone unit overlain by a sandstone that is transitional with the heterolitic facies association.

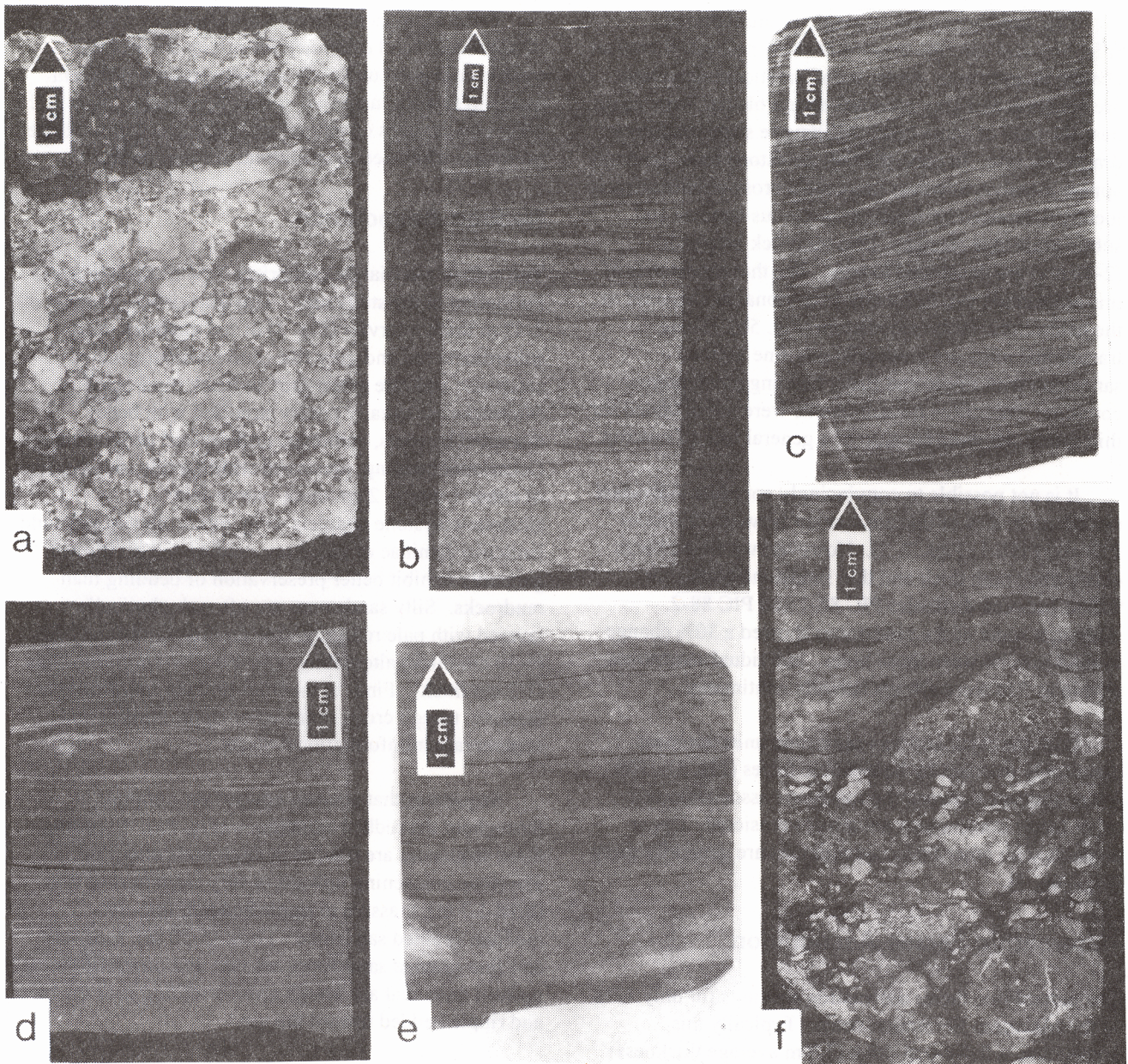


Figure 6. Photographs of typical lithologies from various facies associations. (a) Intraformational lag (sandstone association). (b) Thin mudstone drapes at a transition between the sandstone and heterolithic facies associations. (c) Flaser lenticular and streaked bedding in the heterolithic facies. See Figure 7 for location. (d) Streaked bedding in the heterolithic facies. See Figure 7 for location. (e) 'Varve-like' bedding within mudrocks (redbed association). See Figure 8 for location. (f) Nodular calcrite overlain by mottled green-grey mudrock. See Figure 8 for location.

Palmer, 1991; Ryan and Boehner, 1994). Individual storeys are 0.70-10 m thick, commonly fine-upward and are usually separated by intraformational conglomerates or pebbly sandstone layers (Fig. 5a). In outcrop, large scale trough cross-stratification is the predominant bedform; planar cross-stratification and ripple bedding are rare. Grain size variation and smaller scale structures, defined by carbonaceous or coaly laminae, can be observed in cores (Fig. 5a). Cored intervals that comprise

larger scale crossbeds are more difficult to recognize because they usually appear massive. Millimetre scale mudstone drapes occur within some thick sandstone units (Figs. 5a, 6b). Thin (2-10 cm) mudrock interbeds are rare and most commonly cap an individual storey. Paleoflow measurements within thick multistoried sandstones indicate a strongly developed northward transport direction (Yeo and Ruixiang, 1987).

Thin sandstones can be single or multistoried (Fig. 5b), and can fine upward or show no overall vertical change in grain size. Grey, intraformational mudclasts are common and grey mudrock slump blocks were noted near the base of some beds. Millimetre scale mudstone drapes are rare. In core, the thin sandstone units generally appear massive, however large scale cross-stratification is locally delineated by faint carbonaceous laminae and subtle grain size changes. Thin mudrock interbeds (2-30 cm) are developed locally. The thin sandstones of this association can be locally transitional in character to the heterolithic facies association (Fig. 5b). These transitional units are predominantly fine grained sandstone with ripple and flaser bedding much more common. Paleoflow measurements were not obtained for thin sandstone units because of a general lack of outcrop.

It is not possible to convincingly correlate individual sandstone bodies of this association between drillholes P58 and PI88-1 (Figs. 2, 3). However, we were able to easily trace both thick and thin sandstone bodies for 920 m between drillholes PIC 88-1 and PIC 88-2. Although some of the sandstones showed a 30% change in thickness between these holes, individual sandstones as thin as 5 m were always laterally continuous.

Both the thick and thin sandstone units are most commonly overlain by heterolithic facies (Fig. 3). The lower contacts between the sandstone association and other facies associations are always erosional. Upper contacts with other facies associations are generally sharp (Figs. 6b, 7).

Heterolithic Facies Association

The heterolithic facies association accounts for only 12% of the Malagash Formation strata. Typically this association is 0.4-8.0 m thick (3.0 m average thickness) and abruptly overlies the sandstone association (Figs. 6b, 7). The transition of underlying sandstones to overlying heterolithic facies is commonly sharp and usually marked by a thin interval of well developed mud drapes (Fig 6b). The heterolithic facies generally comprises grey siltstone with pale grey lenticular and even parallel ('pin stripe') sandstone laminae (Fig. 6c, d). Interbeds (5-30 cm thick) of grey ripple-bedded or massive, fine- to medium-grained sandstone occur in the heterolithic facies. Commonly, the massive beds are overlain gradationally by unidirectional rippled beds. Sedimentary structures are usually well preserved except near contacts with redbeds. These contacts are characterized by root bioturbation and pedogenic overprinting. Plant fossils are rare to absent in the heterolithic facies association.

Three samples of the heterolithic facies were disaggregated and examined for microfossils. One sample contained uncoiled, agglutinated foraminifera assigned to the genus *Ammotium* (Wightman, 1995). The other two samples contained no specimens that could be positively identified as agglutinated foraminifera.

Redbed Association

The redbed association comprises 31% of the Malagash Formation in the study area. This association consists of 2-42 m thick intervals (Fig. 3) of red mudrock with subordinate red and grey fine- and medium-grained sandstone and rare green-grey to black mudrock. Mudrocks are usually poorly stratified with beds disrupted by roots, carbonate nodules and pedoturbation. Occasional bedding, preserved within mudrocks, consists of either 1 mm to 2 cm thick 'varve-like' siltstone-claystone couplets (Fig. 6e) or 'pin stripes' and lenticular laminae of pale grey sandstone. Sandstones generally exhibit better preservation of bedding than mudrocks. Silty sandstones are often rhythmically layered with pale red-grey, fine grained sandstone beds (5-10 cm thick) alternating with red silty-claystone beds (1-2 cm thick). Fine- to medium-grained sandstones are massive, trough cross-stratified or ripple bedded and contain rare intraformational clasts.

Sequences that coarsen upward are common throughout the redbed association (Fig. 8a). Typically these sequences are 0.5-3.0 m thick and consist of claystone coarsening upward to silty sandstone or thin (0.10-1.7 m), massive to ripple bedded, fine- to medium-grained sandstone. Thick (5-12 m), medium- and fine-grained sandstones are rare and comprise fining upward units that are trough cross-stratified near the base and ripple bedded toward the top.

Stacked paleosol profiles, that locally appear superimposed, are common throughout the Malagash redbeds (Chandler, 1995) (Fig. 8a, b). Individual paleosol profiles are up to 3.0 m thick, rich in smectite and exhibit varied stages of development. The simplest profiles contain root traces, rare carbonized roots, green mottles (in layers or around roots), poorly preserved plant material and pedogenic slickensides. More complex profiles can include all of the above features plus dispersed calcareous nodules and in some cases thin (<40 cm) layers of nodular stage 3 calcrete (Machette, 1985) (Figs. 6f, 8a, b). A 0.02-1.50 m interval of green-grey to black claystone commonly overlies individual soil profiles (Figs. 6f, 8a). Strata immediately above these claystones commonly exhibit much less

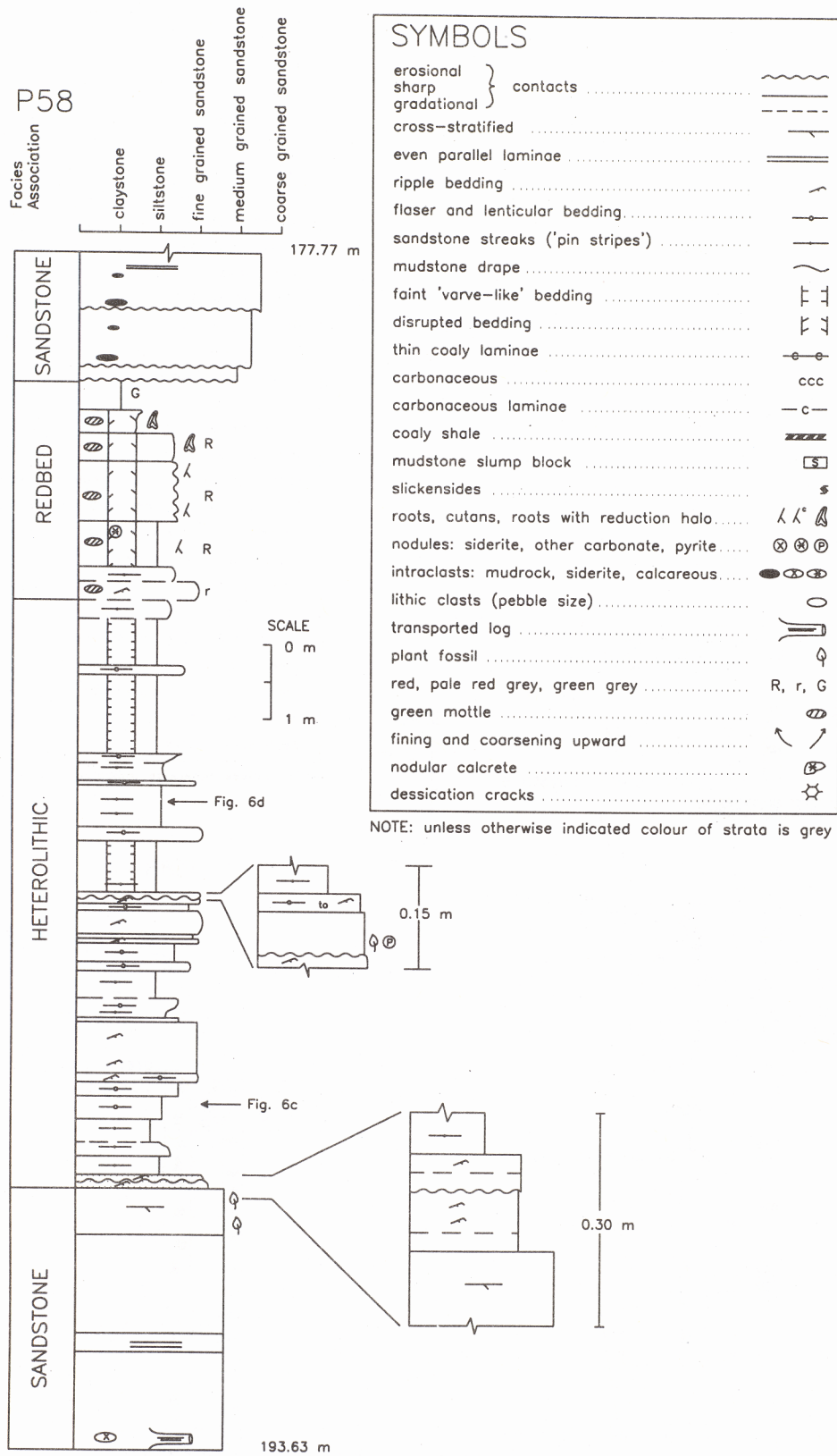


Figure 7. Detailed profiles illustrating the sedimentology of the heterolithic facies association and the typical vertical transition from channel sandstones through heterolithic facies to redbeds. See Figure 3 for location.

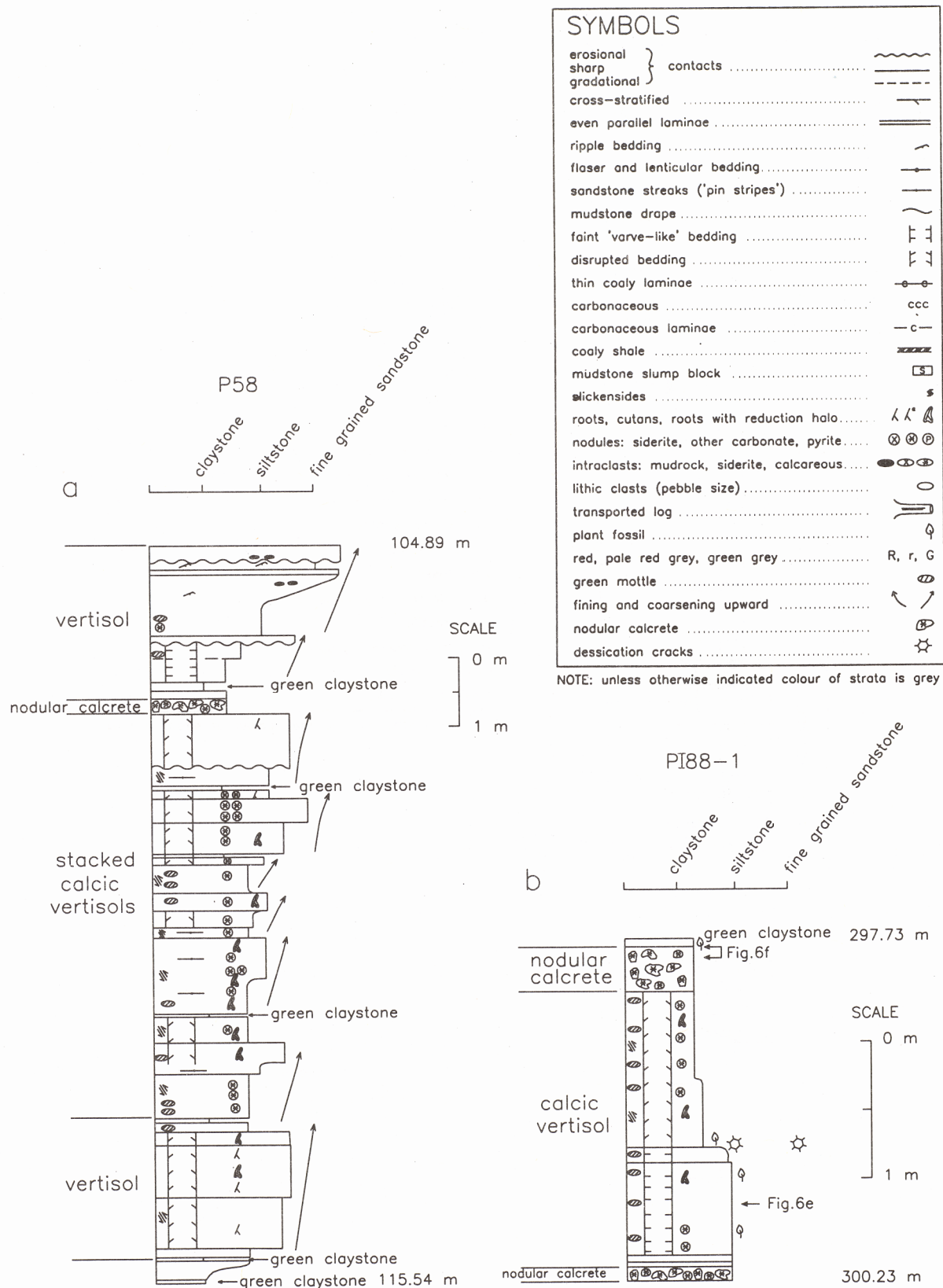


Figure 8. Detailed profiles illustrating the sedimentology of the redbed association. (a) Coarsening upward cycles and stacked vertisols. (b) Two nodular calcrete layers separated by a calcic vertisol. For locations see Figure 3.

disruption and homogenization of bedding than strata immediately below (Fig. 8a).

Coal-Bearing Association

The coal-bearing facies association (17 m maximum thickness) accounts for only 4% of the Malagash Formation strata and generally occurs directly above a sandstone association unit (Fig. 3). Typically the coal-bearing association consists of 0.5-3.0 m thick sequences of carbonaceous mudrock coarsening upward to grey siltstone to fine grained sandstone (Fig. 9). Coal layers are rare and coaly shales are more commonly developed; these are less than 0.3 m thick. Nodular carbonate and siderite concretions occur locally and fossil plant impressions are rare to occasional.

Bedding is generally very disrupted by roots, however, ripple bedding, lenticular laminae and 'pin stripes' are preserved within some siltstone and sandstone beds. Varve-like laminae consisting of fine grained sandstone and claystone couplets (2 cm maximum thickness) were observed within some of the less disrupted, coarser grained units.

Depositional Environments

Sandstone Association

Previous workers have described the channel sandstones of the Malagash Formation as deposits of a wide spectrum of river systems including: braided to meandering (Yeo and Ruixiang, 1987), braided or anastomosing (Palmer, 1991), and anastomosing (Ryan and Boehner, 1994). Indecision regarding the origin of these channel sandstones can largely be attributed to the following: (1) the paradox of having what appear to be thick braided river deposits interbedded with thick overbank successions (ie. redbed association), and (2) insufficient stratigraphic control to define the geometry of individual sand bodies.

A general overall lack of vertical change in type and scale of sedimentary structures and low variance in sediment transport directions suggests the thick multistoried sandstones of this association are not deposits of meandering rivers. An anastomosed origin also appears unlikely because modern anastomosing systems generally have a very high percentage (60-90%) of associated wetland and floodplain deposits (Smith, 1983). In contrast, floodplain deposits (redbed and coal-bearing facies) appear to comprise only about 33%

of the Malagash Formation. Smith (1983) reported modern anastomosed channel deposits range from 5-15 m in thickness. This is considerably thinner than a maximum thickness of 60 m for the channel sandstones of the Malagash Formation. A final argument against an anastomosed origin is that the thick channel sandstones appear to maintain their thickness laterally between drillholes PIC 88-1 and PIC 88-2.

In light of the above, a braided origin appears most probable for the thick multistoried channel sandstones of the Malagash Formation. Campbell (1976) described similar multistoried braided channel deposits from the Morrison Formation, northwestern New Mexico, with each storey (average 4 m) consisting of intra- and extraformational lags overlain by trough cross-stratified sands. However, the Morrison Formation contains significantly less fine facies than the Malagash Formation. This suggests some differences in fluvial style may have existed during formation of the two formations. One possible difference is suggested by the thin mud drapes that occur within some thick Malagash sandstones. Similar mudstone drapes have been cited by numerous authors as evidence of tidal influence.

The thin and thick sandstone units of this association of the Malagash Formation have many features in common suggesting they have a similar origin. A crevasse channel or overbank origin for the thin sandstones is unlikely given the common occurrence of intraformational clasts and absence of roots. It appears more likely that the thin sandstones were deposited in river channels that appeared braided at flood stage and accumulated muds at lower stages. The common occurrence of grey intraformational clasts may represent reworking of within channel fines (e.g. heterolithic facies) as opposed to erosion of overbank deposits. Mudstone drapes, thin mudstone interbeds, and the occurrence of units that are transitional in character to the heterolithic facies association may suggest a possible tidal influence (see discussion of heterolithic facies below).

Heterolithic Facies Association

The presence of *Ammotium* in one sample of the heterolithic association indicates the depositional environment was at least periodically brackish and suggests estuarine-type deposition (Wightman, 1995). *Ammotium* has also been used to infer estuarine and marine influences in other Carboniferous sequences in Nova Scotia (Gibling and Wightman, 1994; Wightman *et al.*, 1993, 1994a, 1994b; Archer *et al.*, 1995).

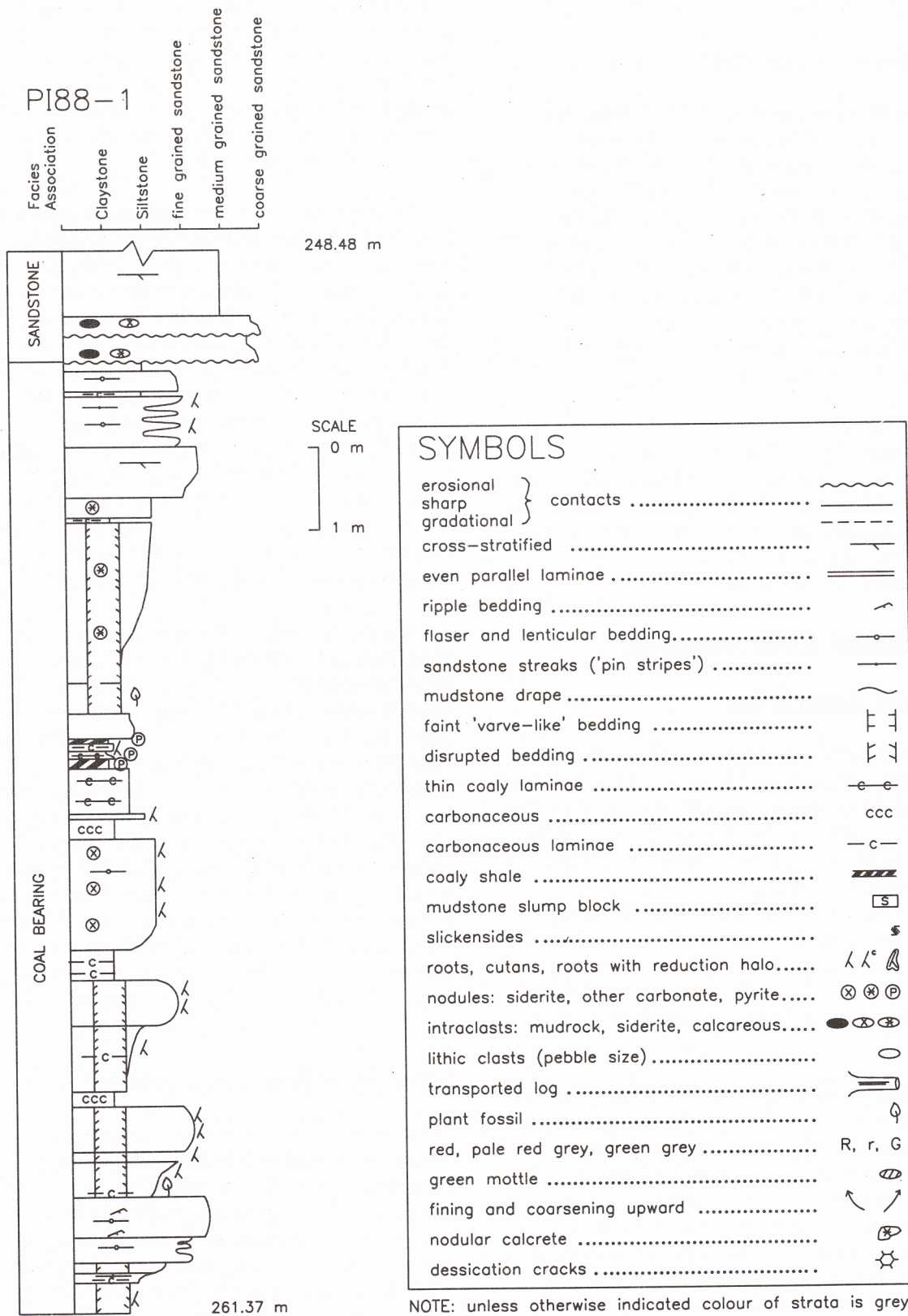


Figure 9. Detailed profile illustrating the sedimentology of the coal-bearing association. See Figure 3 for location.

Flaser, lenticular and 'pin stripe' bedding characterize the heterolithic facies and are typical of tidal influences (e.g. Reineck and Wunderlich, 1968; Klein, 1977; Allen, 1991). In terms of process-oriented sedimentology, however, such facies merely indicate repeated, short-term variations in flow velocity. Thus such facies have also been reported from modern lacustrine deltas (e.g. Coleman, 1966; Dunne and Hempton, 1984) and fluviially dominated interdistributary bays (e.g. Coleman and Prior, 1982). The heterolithic facies of lacustrine and bay fill deposits generally form part of thick, fine grained successions composed of metre scale, coarsening upward sequences (Coleman and Prior, 1982; Tye and Coleman, 1989). In contrast the heterolithic facies of the Malagash Formation usually abruptly overly channel sandstones and do not exhibit any tendency to coarsen upward at the metre scale.

Fine grained heterolithic facies (Figs. 6c, 6d, 7) that are closely associated with channel sandstones have been interpreted as estuarine deposits by a variety of authors (e.g. Wood and Hopkins, 1989; Shanley *et al.*, 1992; Hettinger, 1995). This is largely based on description of similar facies from modern estuaries such as the tidal point bar deposits described by Allen (1991) in the Gironde Estuary of France. Excellent examples of Carboniferous heterolithic facies form part of 'clastic wedges' in the coal-measures of the United States midcontinent (Wanless, 1964; Gluskoter and Hopkins, 1979). These wedges were originally interpreted largely as the products of fluvial, overbank or deltaic deposition (e.g. Edwards *et al.*, 1979; Eggert, 1987; Burke *et al.*, 1987). Recently they have been re-interpreted to be tidally influenced, estuarine-related facies based on recognition of tidal rhythmites within the heterolithic facies (Archer and Kvale, 1993; Archer *et al.*, 1994a).

Although the heterolithic facies of the Malagash Formation do not appear to contain tidal rhythmites, they are lithologically very similar to the heterolithic facies of the midcontinental United States. In addition, both generally exhibit very little bioturbation. This suggests that although the heterolithic facies might be tidally influenced from a depositional-energy perspective, they may not have commonly been subjected to marine salinities. This may, in part, explain why only one sample of the heterolithic facies contained agglutinated foraminifera. Tidal effects can extend well beyond saline incursions in some modern estuaries. In the Gironde Estuary of France, for example, tides affect sedimentation up to 50 km inland from the salt intrusion (Allen, 1991). Tidal effects within the Seven Estuary of southeastern England extend inland for about 120 km and in the St. Lawrence Estuary of Canada, such effects extend over

700 km inland (Archer *et al.*, 1994b). The Amazon River experiences tidal effects at least 735 km upriver from the mouth without any accompanying salinity changes inland (Officer, 1976, p. 379).

Redbed Association

The fine facies of the redbed association have many attributes of vegetated floodplain deposits including: (1) disruption of bedding by roots, (2) paleosols, (3) fine grained strata, and (4) millimetre- to centimetre-scale rhythmites. The rare, thick sandstones of this association, that are trough crossbedded at the base, ripple bedded toward the top and fine upward overall, are interpreted as meandering river deposits. Many of the coarsening-upward sequences (Fig. 8a) of the redbed association appear to have formed due to progradation of overbank deposits onto floodplains (e.g. Bridge, 1984; Farrell, 1987). The red mudrocks, with highly disrupted bedding, are similar to well-drained swamp deposits ('rooted clays') of the lower Mississippi River valley described by Farrell (1987). Although the well-drained swamp deposits of the Mississippi River valley are not as oxidized as the 'disrupted' red mudrocks of the Malagash Formation, both are characterized by the following: (1) root mottles, (2) carbonate nodules, (3) extensive disruption of primary stratification, (4) poor preservation of organic material, and (5) local preservation of thin (millimetre scale), siltstone-claystone rhythmites. The green-grey to black mudrocks that form a minor part of the redbed association are believed to be analogous to the poorly drained swamp deposits of the Mississippi backswamps (cf. Coleman, 1966; Krinitzsky and Smith, 1969; Farrell, 1987). Rhythmically layered silty-sandstones of the redbed association are similar to levee and splay sediments of the Mississippi River valley described by Farrell (1987).

The redbed facies may also include some lacustrine-delta deposits that are broadly analogous to recent examples described from the Atchafalaya Basin by Tye and Coleman (1989). The lacustrine-delta deposits in the Atchafalaya Basin form sequences that coarsen upward from clays to fine to medium sands. Soils are not as well developed in the lacustrine deposits of the Atchafalaya Basin, probably because lake levels do not fluctuate significantly (Tye and Coleman, 1989). During deposition of the Malagash redbeds seasonal fluctuations in lake levels could have resulted in significant overprinting of lacustrine delta deposits by soils. As lakes became infilled plants would have colonized the surface of lacustrine deltas causing the underlying sediment to be disrupted by roots.

The redbeds of the Malagash Formation are generally much more oxidized than the overbank deposits of the lower Mississippi River valley and lacustrine-delta deposits of the Atchafalaya Basin. This may imply better drainage during deposition of the Malagash Formation redbeds. Alternatively a more strongly seasonal climate may be responsible for reddening of the Malagash mudrocks. The paleosols of the redbed facies are classified as vertisols based on the occurrence of pedogenic slickensides and nodular calcrete (Figs. 6f, 8a, b). The paleosols rich in pedogenic carbonate are probably more accurately described as calcic vertisols (cf. Mack *et al.*, 1993). Modern soils analogous to calcic vertisols currently form in subhumid to semiarid, strongly seasonal, tropical to subtropical climates with a rainfall of 180-1250 mm per year (Ahmad, 1988; Dudal and Eswaran, 1988; Retallack, 1990).

Coal-Bearing Association

The coal-bearing association is interpreted to have a similar origin to the redbed association. Lack of reddening suggests reducing conditions may have predominated because of a more stable water table. The coarsening upward sequences capped by organic-rich mudrocks or impure coals can be explained by either progradation of overbank deposits or by deltaic infilling of shallow lakes followed by development of swamps. A more continually wet climate or water table stabilization, related to local topographic variation on a floodplain, could explain lack of oxidation within the coal-bearing association.

Discussion

Bimodal tidal bedding, with current-reversal features such as herringbone cross-stratification, or ripples with reverse-flow crests, have not been observed within the Malagash Formation. This suggests, that the paleoflow regime was dominated by fluvial-transport despite the possible tidal influences indicated by agglutinated foraminifera, heterolithic facies, and rare mudstone drapes. The dominance of fluvial processes over tidal processes would be consistent with the inland depositional setting of the Malagash Formation. It is not surprising, however, that evidence of tidal influence may be preserved within the Malagash Formation. Tidal effects can be propagated for hundreds of kilometres upstream in large-scale river systems (Allen, 1991; Shanley *et al.*, 1992; Archer *et al.*, 1994b).

The absence of obvious Westphalian C-D marine strata in the Gulf of St. Lawrence Basin suggests that tidal

effects extended a considerable distance from the paleoshoreline. Although no marine strata have been recognized, Wightman *et al.* (1994a) reported agglutinated foraminifera of estuarine origin are common in the late Westphalian Inverness Formation (Fig. 4). They also determined that the distribution of foraminifera assemblages indicates an increasing marine influence toward northern areas of the Gulf of St. Lawrence Basin. This suggests tidal influence on sedimentation may have extended over 200 km inland during deposition of the Malagash Formation.

The exact nature of the estuaries that may have propagated tidal effects into the study area, during deposition of the Malagash Formation, is difficult to determine. An estuary is formed when a rise in sea level drowns an alluvial valley or causes the lower reaches of a river to become tidally influenced. It is difficult to distinguish paleovalley fills from fluvial facies that were deposited with minimal valley development. Recognition of paleovalleys requires either excellent outcrop exposure (e.g. Gibling and Wightman, 1994) or closely spaced drilling (e.g. Wood and Hopkins, 1989). We are currently unable to define paleovalleys in the study area. However, Gibling and Wightman (1994) have attributed formation of paleovalleys in the Late Carboniferous coal measures of the neighbouring Sydney Basin (see Fig. 1 for location) to a fall in sea level. This allows for the possibility that paleovalleys also developed in the Gulf of St. Lawrence Basin in response to Westphalian C-D sea level changes. Global sea level changes related to Gondwanan glaciation-deglaciation were apparently considerable during this period. Estimates of the magnitude of this eustatic flux have been based on: (1) theoretical Gondwanan ice-volume computations (Crowley and Baum, 1991), (2) depth assessments of specific highstand lithofacies (Heckel, 1986), and (3) determination of the depths of incision within lowstand paleovalleys (Archer *et al.*, 1994b). These three approaches all yield glacio-eustatic flux estimates of at least 30 m and as much as 100 m. Even considerably inland depositional systems, similar to those of the Malagash Formation, could have been affected by such significant eustatic changes.

High amplitude glacio-eustatic flux, coupled with an active tectonic setting, favours significant changes in sea level (cf. Posamentier *et al.*, 1988) during deposition of the Malagash Formation. A drop in sea level would have caused erosion, fluvial incision and the possible formation of alluvial valleys. During lowstands, much sand and all of the muddy sediment could have by-passed the upland setting of the study area. However, Gibling and

Wightman (1994) suggested Late Carboniferous paleovalleys in the Sydney Basin were infilled entirely with alluvial sediments during lowstand and early transgression. They attributed this, in part, to an abundant sediment supply that was sourced from the northern and central Appalachians (Gibling *et al.*, 1992). It is possible that the braided river deposits of the Malagash Formation also accumulated during a lowstand. The tendency for muddy facies, that we have interpreted to be estuarine deposits, to cap the braided river deposits in the Malagash Formation, however, indicates they may have been deposited during a rise in sea level. High rates of sediment supply during a slow rise in sea level may have forestalled marine transgression and facilitated deposition of thick braided river sands. When the rate of sea level rise increased, tidal effects moved inland and heterolithic facies were emplaced over braided river deposits.

Shanley *et al.* (1992) suggested deposition of tidally influenced facies immediately above braided river deposits requires a rapid rise in base level. A rapid rise in base level results in minimal alluvial aggradation because sediment supply is unable to keep up with sea level rise. As the rate of base level rise slows, rivers gradually adjust their profiles creating significant accommodation space for alluvial sedimentation (Shanley *et al.*, 1992). The meandering river and floodplain deposits of the redbed and coal-bearing associations would probably have been deposited during this period. It appears unlikely that floodplain sediments accumulated adjacent to estuarine or braided sections of the Malagash Formation rivers. Tides generally tend to dampen floods and effectively trap muds within estuarine channels (Allen, 1991). Therefore, when the rivers of the Malagash Formation were in flood stage, minimal amounts of floodplain sediment would have accumulated in tidally influenced sections. Although thick floodplain sequences can accumulate adjacent to braided rivers (McLean and Jerzykiewicz, 1978), it is not common. Therefore, the redbed and sandstone association facies are probably not coeval deposits.

Basinward, Gibling *et al.* (1994) described an alternation of braided river deposits and mudrock dominated successions in the Inverness Formation (Fig. 4) that is similar to the alternation of channel sandstones and fine facies in the Malagash Formation. They suggested that the thick (50-100 m) multistoried sandstones (braided river deposits) of the Inverness Formation were not coeval with the intervening, thick, grey mudrock and coal dominated units. They inferred an alternation between braided channel and 'wetland' phases caused by differential subsidence or eustasy, but did not

recognize any tidal sediments. The similarity between the channel sandstone facies of the Malagash and Inverness formations suggests significant progradation of channel deposits basinward following a lowering of base level. The redbed and poorly developed coal-bearing facies associations of the Malagash Formation are probably the better drained upland equivalents of the well-developed, grey mud rock dominated coal-bearing units (floodplain, lake, swamp and mire deposits) of the Inverness Formation.

Although changes in base level played an important role during deposition of the Malagash Formation, climate also appears to have significantly influenced sedimentation. In the Westphalian, Nova Scotia was in a low latitude, near equatorial position, which has been estimated to be approximately 5°S (Scotese and McKerrow, 1990). Distribution of coals has been used to suggest that the region lay within a zonal equatorial wet-climate belt (Witzke, 1990). Conversely, the assembly of Pangea would have predisposed Nova Scotia to a monsoonal climate (Kutzbach and Gallimore, 1989; Rowley *et al.*, 1985). Supportive evidence for monsoonal conditions comes from the presence of calcrete-bearing vertisols which have commonly been used as indicators of tropical seasonality (e.g. Bridges, 1970; Dudal and Eswaran, 1988). Calcareous vertisols have also been reported from the Westphalian C-D to Stephanian of the Sydney Basin (Gibling and Wightman, 1994).

In areas of strong seasonality, rivers exhibit extreme variations in seasonal levels and clastic flux. If the Malagash Formation rivers experienced such variations in seasonal discharge, the range of tidal influence may have fluctuated considerably throughout the year. In the Gironde Estuary, for example, the tidal range fluctuates approximately 30 km between high and low discharge (Allen, 1991). Evidence of tidal influence is generally only preserved down stream from the limit of tidal current reversal during high river discharge. This suggests muddy tidal sediment deposited upstream from this point, during low river discharge, must be completely eroded and reworked. The abundance of grey intraclasts, within the thick multistoried sandstones of the Malagash Formation, may signify, in part, complete erosion and reworking of heterolithic facies that accumulated in the upper reaches of estuaries between major floods. Thus, although deposition of the heterolithic facies may have been a common form of channel sedimentation, the rapidly deposited channel sands could have had a much higher net potential for preservation. Preservation of heterolithic facies in the study area would have required sandy sediment being diverted from a channel during

partial abandonment or a rise in base level that shifted estuarine systems significantly inland.

Conclusions

Despite the upland character of the Malagash Formation, the recognition of potential tidal sediments suggests that significant base level flux may have occurred during the Westphalian C-D. Tectonic subsidence undoubtedly exerted a strong control on these base level changes. However, comparison to age equivalent strata in other areas, such as the United States midcontinent, indicates that this time period exhibited major glacio-eustatic controls on base level as well, even within such a tectonically active area as Nova Scotia. The preservation potential of tidal sediments may have been reduced by a monsoonal climate. Seasonal flushing of estuaries may have eroded heterolithic facies that were deposited in the upper parts of estuaries during periods of low discharge.

Along with an increasing degree of marine influences being recognized in many coal measures throughout the world, this paper documents what appear to be subtle indicators of distal paralic influences within an upland sequence. These marine influences were manifested by generally nonbioturbated heterolithic facies, that contain estuarine-type agglutinated foraminifera. In most cases the heterolithic facies were deposited immediately above channel sandstones that contain rare mudstone drapes. Recognition and understanding of the significance of these criteria should provide useful information for the evaluation of other upland Carboniferous sequences. In particular, the delineation of marine-influenced facies should assist in the potential application of sequence-stratigraphic interpretations of such units, which have previously been interpreted as exclusively characterized by nonmarine conditions.

Acknowledgments

Support for this collaborative research was provided by a variety of sources. A. W. Archer was supported by a Faculty Development Award from Kansas State University. Winton Wightman provided identifications of the agglutinated foraminifera. Trent Rehill provided very useful discussion and information regarding the regional stratigraphy of the Gulf of St. Lawrence Basin. Early drafts of this manuscript were reviewed and greatly improved by suggestions from John Calder and Keith B. Miller.

References

- Ahmad, N. 1988: The management of vertisols in the humid tropics, Chapter 6; *in* Vertisols: Their Distribution, Properties, Classification and Management, eds. L. P. Wilding and Ruben Puentes; Technical Monograph, No. 18, Soil Management Support Services (1988), Texas A&M University, 193 p.
- Allen, G. P. 1991: Sedimentary processes and facies in the Gironde Estuary: a recent example of macrotidal estuarine systems; *in* Clastic Tidal Sedimentology, eds. D. G. Smith, G. E. Reinson, B. A. Zaitlin and R. A. Rahmani; Canadian Society of Petroleum Geologists, Memoir 16, p. 29-40.
- Archer, A. W., Feldman, H. R., Kvale, E. P. and Lanier, W. P. 1994a: Pennsylvanian (Upper Carboniferous) fluvio- to tidal estuarine coal-bearing systems: delineation of facies transitions based upon physical and biogenic sedimentary structures; *Palaeogeography, Palaeoclimatology, Palaeoecology*, v. 106, p. 171-185.
- Archer, A. W. and Kvale, E. P. 1993: Origin of gray-shale lithofacies ("clastic wedges") in U.S. midcontinental coal measures (Pennsylvanian): an alternative explanation; *in* Modern and Ancient Coal-Forming Environments: Boulder, Colorado, eds. J. C. Cobb and C. B. Cecil; Geological Society of America, Special Paper 286, p. 181-198.
- Archer, A. W., Lanier, W. P. and Feldman, H. R. 1994b: Stratigraphy and depositional history within incised paleovalley fills and related facies, Douglas Group (Missourian/Virgilian; Upper Carboniferous) of Kansas, U.S.A.; *Society of Economic Paleontologists and Mineralogists, Special Publication 51*, p. 175-190.
- Archer, A. W., Wightman, W. G., Calder, J. H., Gibling, M. R., Naylor, R. D. and Reid, D. R. 1995: Invertebrate trace fossils and agglutinated foraminifera as indicators of marine influence within the classic Carboniferous section at Joggins, Nova Scotia, Canada; *Canadian Journal of Earth Sciences*, v. 32, p. 2027-2039.
- Bell, W. A. 1940: The Pictou Coalfield, Nova Scotia; Geological Survey of Canada, Memoir 225, 80 p.
- Bird, D. J. 1987: The depositional environment of the Late Carboniferous, coal-bearing Sydney Mines

- Formation, Point Aconi area, Cape Breton Island, Nova Scotia; unpublished M.Sc. thesis, Dalhousie University, Halifax, Nova Scotia, 343 p.
- Bridge, J. S. 1984: Large-scale facies sequences in alluvial overbank environments; *Journal of Sedimentary Petrology*, v. 54, p. 583-588.
- Bridges, E. M. 1970: *World Soils*; Cambridge University Press, 89 p.
- Burke, M. K., Deshowitz, M. P. and Utgaard, J. E. 1987: Facies and depositional environments of the Energy Shale Member (Pennsylvanian) and their relationships to low-sulfur coal deposits in southern Illinois; *Journal of Sedimentary Petrology*, v. 57, p. 1060-1067.
- Calder, J. H. 1998: The Carboniferous evolution of Nova Scotia; *in The Past is the Key to the Present*, eds. D. J. Blundell and A. C. Scott; Geological Society of London, Special Publications 143, p. 261-302.
- Campbell, C. V. 1976: Reservoir geometry of a fluvial sheet sandstone; *American Association of Petroleum Geologists Bulletin*, v. 60, p. 1009-1020.
- Chandler, F. W. 1995: Geological mapping in the Stellarton Gap, (NTS 11E/7, 9, 10, 15), a status report; Atlantic Geoscience Society colloquium and Annual General Meeting, Antigonish, Nova Scotia, Program and Abstracts, St. Francis Xavier University, Antigonish, p. 9-10.
- Coleman, J. M. 1966: Ecological changes in a massive freshwater clay sequence; *Transactions, Gulf Coast Association of Geological Societies*, v. 16, p. 159-174.
- Coleman, J. M. and Prior, D. B. 1982: Deltaic environments of deposition; *in Sandstone Depositional Environments*, eds. P. A. Scholle and D. Spearing; American Association of Petroleum Geologists, Memoir 31, p. 139-178.
- Crowley, T. J. and Baum, S. K. 1991: Estimating Carboniferous sea-level fluctuations from Gondwanan ice extent; *Geology*, v. 19, p. 975-977.
- Dudal, R. and Eswaran, H. 1988: Distribution properties and classification of vertisols; *in Vertisols: Their Distribution, Properties, Classification and Management*, eds. L. P. Wilding and Ruben Puentes; Technical Monograph, No. 18, Soil Management Support Services (1988), Texas A&M University, p. 1-22.
- Dunne, L. A. and Hempton, M. R. 1984: Deltaic sedimentation in the Lake Hazar pull-apart basin, southeastern Turkey; *Sedimentology*, v. 31, p. 401-412.
- Edwards, M. J., Langenheim, R. L., Jr., Nelson, W. J. and Ledvina, C. T. 1979: Lithologic patterns in the Energy Shale Member and the origin of "rolls" in the Herrin (No. 6) Coal Member, Pennsylvanian, in the Orient No. 6 Mine, Jefferson County, Illinois; *Journal of Sedimentary Petrology*, v. 49, p. 1005-1014.
- Eggert, D. L. 1987: Earlier sediment differential compaction in Gibson County, Indiana; *International Journal of Coal Geology*, v. 8, p. 305-314.
- Farrell, K. M. 1987: Sedimentology and facies architecture of overbank deposits of the Mississippi River, False River Region, Louisiana; *in Recent Developments in Fluvial Sedimentology*, eds. F. G. Ethridge, R. M. Flores and M. D. Harvey; Society of Economic Paleontologist and Mineralogists, Special Publication 39, p. 111-120.
- Fralick, P. W. and Schenk P. E. 1981: Molasse deposition and basin evolution in a wrench tectonic setting: the late Paleozoic, Eastern Cumberland Basin, Maritime Canada; *in Sedimentation and Tectonics in Alluvial Basins*, ed. A. D. Miall; Geological Association of Canada, Special Paper 23, p. 77-97.
- Gibling, M. R. and Bird, D. J. 1994: Alluvial-dominated cyclothems in the Late Carboniferous of Atlantic Canada; *Geological Society of America Bulletin*, v. 106, p. 105-117.
- Gibling, M. R., Calder, J. H., Ryan, R., Van De Poll, H. W. and Yeo, G. 1992: Late Carboniferous and Early Permian drainage patterns in Atlantic Canada; *Canadian Journal of Earth Sciences*, v. 29, p. 338-352.
- Gibling, M. R., Marchioni, D. L. and Kalkreuth, W. D. 1994: Detrital and organic facies of Upper Carboniferous strata at Mabou Mines, western Cape Breton Island, Nova Scotia; *Geological Survey of Canada, Current Research 1994-D*, p. 51-56.
- Gibling, M. R. and Wightman, W. G. 1994: Paleovalleys and protozoan assemblages in a Late Carboniferous cyclothem, Sydney Basin, Nova Scotia; *Sedimentology*, v. 41, p. 699-719.
- Gluskoter, H. J. and Hopkins, M. E. 1979: Distribution of sulfur in Illinois coals; *in Depositional Environments*

in Parts of the Carbondale Formation - Western and Northern Illinois, eds. W. H. Smith, R. B. Nance, R. G. Johnson, M. E. Hopkins and C. W. Shabica; Illinois Geological Survey, Guidebook Series 8, p. 89-95.

Hacquebard, P. A. 1986: The Gulf of St. Lawrence Carboniferous Basin: The largest coalfield of Eastern Canada; Canadian Institute of Mining Bulletin, v. 79, p. 67-78.

Hacquebard, P. A., Birmingham, T. F. and Donaldson, J. R. 1967: Petrography of Canadian coals in relation to environment of deposition; *in* Energy, Mines, and Research Symposium on Science and Technology of Coal, Ottawa, p. 84-97.

Hacquebard, P. A. and Donaldson, J. R. 1969: Carboniferous coal deposition associated with flood-plain and limnic environments in Nova Scotia; Geological Society of America, Special Paper 114, p. 143-191.

Heckel, P. H. 1986: Sea-level curve for Pennsylvanian eustatic marine transgressive-regressive depositional cycles along the midcontinent outcrop belt, North America; *Geology*, v. 14, p. 330-334.

Hettinger R. D. 1995: Sedimentological descriptions and depositional interpretations, in sequence stratigraphic context, of two 300-metre cores from the Upper Cretaceous Straight Cliffs Formation, Kaiparowits Plateau, Kane County, Utah; United States Geological Survey, Bulletin 2115-A, 32 p.

Klein, G. deV. 1977: *Clastic Tidal Facies*; Continuing Education Publishing Company (CEPCO), Champaign, Illinois, 149 p.

Krinitzky, E. L. and Smith, F. L. 1969: Geology of backswamp deposits in the Atchafalaya Basin, Louisiana; U.S. Army Corps of Engineers, Waterways Experiment Station, Technical Report S-69-8, Vicksburg, Mississippi, 26 p.

Kutzbach, J. E. and Gallimore, R. G. 1989: Pangean climates, megamonsoons of the megacontinent; *Journal of Geophysical Research*, v. 94, No. 3D, p. 3341-3357.

Machette, M. N. 1985: Calcic soils of the southwestern United States; *in* Soils and Quaternary Geology of the southwestern United States, ed. D. L. Weide; Geological Society of America, Special Paper 203, p. 1-21.

Mack, G. H., James, W. C. and Monger, C. H. 1993:

Classification of paleosols; *Geological Society of America Bulletin*, v. 105, p. 129-136.

McLean, J. R. and Jerzykiewicz T. 1978: Cyclicity, tectonics and coal: Some aspects of fluvial sedimentology in the Brazeau-Paskapoo Formations, Coal Valley area, Alberta, Canada; *in* *Fluvial Sedimentology*; Canadian Society of Petroleum Geologists, Memoir 5, p. 441-468.

Naylor, R. D., Calder, J. H., Ryan, R. J. and Martel, T. A. 1992: Controls on formation of Upper Carboniferous coals in the intermontane Stellarton and Cumberland basins of Atlantic Canada; *Proceedings of the Canadian Coal and Coalbed Methane Geoscience Forum*, Parksville, British Columbia, Canada, p. 365-397.

Naylor, R. D., Kalkreuth, W. D., Smith, W. D. and Yeo, G. M. 1989: Stratigraphy, sedimentology and depositional environments of the coal-bearing Stellarton Formation, Nova Scotia; *Geological Survey of Canada, Paper 89-8*, p. 2-13.

Officer, C. B. 1976: *Physical Oceanography of Estuaries and Associated Coastal Water*; Wiley-Interscience, New York, 465 p.

Palmer, S. E. 1991: Carbonates and associated sediments in the Merigomish Formation of the Stellarton Gap, Nova Scotia; B.Sc. honours thesis, Department of Geology, Saint Mary's University, Halifax, Nova Scotia.

Posamentier, H. W., Jervey, M. T. and Vail, P. R. 1988: Eustatic controls on clastic deposition I-Conceptual framework; *in* *Sea Level Changes: An Integrated Approach*, eds. C. K. Wilgus, B. S. Hastings, C. G. St. C. Kendall, H. W. Posamentier, C. A. Ross and J. C. Van Wagoner; Special Publication of the Society of Economic Paleontologists and Mineralogists, v. 42, p. 109-124.

Reineck, H. E. and Wunderlich, F. 1968: Classification and origin of flaser and lenticular bedding; *Sedimentology*, v. 11, p. 99-104.

Retallack, G. J. 1990: *Soils of the Past, An Introduction to Paleopedology*; Unwin Hyman, Publishing, 520 p.

Rowley, D. B., Raymond, A., Totman Parrish, J., Lottes, A. L., Scotese, C. R. and Ziegler, A. M. 1985: Carboniferous paleogeographic, phytogeographic and paleoclimatic reconstructions; *International Journal of Coal Geology*, v. 5, p. 7-42.

- Ryan, R. J. and Boehner, R. C. 1994: Geology of the Cumberland Basin, Cumberland, Colchester and Pictou counties, Nova Scotia; Nova Scotia Department of Natural Resources, Mines and Energy Branches, Memoir 10, 212 p.
- Ryan, R. J., Boehner, R. C. and Calder, J. H. 1991: Lithostratigraphic revision of the Upper Carboniferous to Lower Permian strata in the Cumberland Basin, Nova Scotia and the implications for the Maritimes Basin in Atlantic Canada; Canadian Society of Petroleum Geologists Bulletin, v. 39, p. 289-314.
- Shanley, K. W., McCabe, P. J. and Hettinger, R. D. 1992: Tidal influence in Cretaceous fluvial strata from Utah, U.S.A: a key to sequence stratigraphic interpretation; Sedimentology, v. 39, p. 905-930.
- Scotese C. R. and McKerrow, W. S. 1990: Revised world maps and introduction; *in* Palaeozoic Palaeogeography and Biogeography, eds. W. S. McKerrow and C. R. Scotese; Geological Society of London, Memoir No. 12, p. 1-21.
- Smith, D. G. 1983: Anastomosed fluvial deposits: modern examples from Western Canada; *in* Modern and Ancient Fluvial Systems, eds. J. D. Collinson and J. L. Lewin; International Association of Sedimentologists, Special Publication 6, p. 155-168.
- Thibaudeau, S. A. and Medioli, F. S. 1986: Carboniferous thecamoebian and marsh foraminifera: new stratigraphic tools for ancient paralic deposits; Geological Society of America, Abstracts with Programs, v. 18, p. 771.
- Tye, R. S. and Coleman, J. M. 1989: Depositional process and stratigraphy of fluvially dominated lacustrine deltas: Mississippi Delta plain; Journal of Sedimentary Petrology, v. 59, p. 973-996.
- Wanless, H. R. 1964: Local and regional factors in Pennsylvanian cyclic sedimentation; *in* Symposium on Cyclic Sedimentation, ed. D. F. Merriam; Kansas Geological Survey, Bulletin 169, v. 2, p. 593-606.
- Wightman, W. G. 1995: Evaluation of microfossil techniques for Phalen Seam roof strata; Energy, Mines and Resources, Canada, Project Report PWGSC File No: 02SQ.23440-4-1218.
- Wightman, W. G., Grant, A. C. and Rehill, T. A. 1994a: Paleontological evidence for marine influence during deposition of the Westphalian coal measures in the Gulf of St. Lawrence-Sydney Basin region, Canada; Geological Survey of Canada, Current Research, Paper 1994-D, p. 41-50.
- Wightman, W. G., Scott, D. B., Medioli, F. S. and Gibling, M. R. 1993: Carboniferous marsh foraminifera from the coal-bearing strata of the Sydney Basin, Nova Scotia: a new tool for identifying coal-forming environments; Geology, v. 21, p. 631-634.
- Wightman, W. G., Scott, D. B., Medioli, F. S. and Gibling, M. R. 1994b: Agglutinated foraminifera and thecamoebians from the Late Carboniferous Sydney Coalfield, Nova Scotia: paleoecology, paleoenvironments and paleogeographical implications; Palaeogeography, Palaeoclimatology, Palaeoecology, v. 106, p. 187-202.
- Witzke, B. J. 1990: Paleoclimatic constraints for Paleozoic paleolatitudes of Laurentia and Euramerica; *in* Palaeozoic Paleogeography and Biogeography, eds. W. S. McKerrow and C. R. Scotese; Geological Society of London, Memoir No. 12, p. 57-73.
- Wood, J. M. and Hopkins, J. C. 1989: Reservoir sandstone bodies in estuarine valley fill: Lower Cretaceous Glauconitic Member, Little Bow Field, Alberta, Canada; American Association of Petroleum Geologists Bulletin, v. 73, p. 1361-1382.
- Yeo, G. M. and Ruixiang, G. 1987: Stellarton Graben: An Upper Carboniferous pull-apart basin in northern Nova Scotia; *in* Sedimentary Basins and Basin Forming Mechanisms, eds. C. Beaumont and A. J. Tankard; Canadian Society of Petroleum Geologists, Memoir 12, p. 299-309.

