Conjugate Margins Conference | Halifax 2008

Guidebook

Field Trip

FIELD TRIP #3

Onshore Equivalents of the Cretaceous Reservoir Rocks of the Scotian Basin: Detrital Petrology, Tectonics and Diagenesis

LEADERS

Georgia Pe-Piper
Saint Mary's University
Halifax, NS, Canada

David J.W. Piper
Geological Survey of Canada-Atlantic
Dartmouth, NS, Canada

ISBN:0-9810595-4

CENTRAL ATLANTIC CONJUGATE MARGINS CONFERENCE

Halifax, Nova Scotia, Canada

August 2008

Field trip 3

Onshore equivalents of the Cretaceous reservoir rocks of the Scotian Basin: detrital petrology, tectonics and diagenesis

Monday August 11th 2008

Georgia Pe-Piper
Department of Geology, Saint Mary's University, Halifax, Nova Scotia, B3H 3C3, Canada
gpiper@smu.ca

David J.W. Piper
Geological Survey of Canada (Atlantic), Bedford Institute of Oceanography, P.O. Box 1006, Dartmouth, Nova Scotia, B2Y 4A2, Canada
dpiper@nrcan.gc.ca

ISBN: 0-9810595-4

INDEX

PREFACE

This field trip will visit the only large outcrop of the Chaswood Formation in Nova Scotia, the West Indian Road pit in central Nova Scotia. We will then drive past the sub-surface type section of the Chaswood Formation. We will then return to Saint Mary's University and examine core from other localities of the Chaswood Formation: from the Elmsvale Basin, Brierley Brook, Belmont and Vinegar Hill.

Part 1 of this field guide is a general synopsis of the Chaswood Formation. Part 2 provides detailed information on the West Indian Road pit. Part 3 provides detailed information on the cores that will be examined at Saint Mary's University. At the back of the guide are notes on our two field stops.

SAFETY

The West Indian Road pit is a working sand pit. Permission must be obtained from Shaw Resources to enter the pit and all visitors must wear safety boots (steel toed), hard hats, safety glasses and fluorescent vests. Pay attention to trucks that may be loading from the stock piles. Note that the slopes of the pit may be unstable and liable to landsliding. Waterlogged sediments on the floor of the pit may liquefy. The deep water on the floor of the pit is a potential hazard. During the field trip, do not scrape faces clean in a manner that might lead to a fall of loose sediment onto yourself or others.

PART 1: The Chaswood Formation

Introduction

The early Cretaceous was a period of rapid sediment supply from crystalline rocks of the Appalachians as a result of fault reactivation related to the opening of the North Atlantic Ocean (Pe-Piper and Piper 2004; Tucholke et al. 2007). The resulting coarse sediment supply deposited thick deltaic sandstones. These sandstones are the reservoir rocks of the offshore gas fields of the Scotian Basin (Wade and MacLean 1990). The Chaswood Formation is the stratigraphically equivalent fluvial succession at the margin of the Scotian Basin.

The Chaswood Formation is a 200-m-thick succession of loosely indurated fluvial conglomerate, sandstone, and mudstone of Valanginian to Albian age (Fensome in Stea and Pullan, 2001; Falcon-Lang et al., 2007). It is preserved in several fault-bound basins in the provinces of Nova Scotia and New Brunswick (Fig. 1.1). It outcrops in only two sand and gravel pits and one clay pit, and is thus largely known from more than 250 boreholes.

Deposition was synchronous with strike-slip faulting, basin formation, and uplift of horsts that shed local detritus (Pe-Piper and Piper, 2004). Syn-sedimentary tectonic deformation along strike-slip faults led to local uplift that created intraformational unconformities (Gobeil et al., 2006) and these unconformities can be used for regional correlation (Hundert et al., 2006) and are also recognized in the proximal part of the Scotian basin, in the Orpheus graben (Pe-Piper and Piper, 2004; Weir-Murphy, 2004).

The Chaswood Formation is important for understanding the Lower Cretaceous rocks in the Scotian Basin for several reasons. It provides information on the sources of sediment and character of the hinterland for rivers entering the Scotian Basin. The record of diagenesis provides some constraints on diagenesis in the more proximal parts of the Scotian Basin, particularly the Laurentian sub-basin. The record of tectonism can be correlated with the Jeanne d'Arc, Whale and Scotian basins to provide a regional framework for the southeastern Canadian margin in the early Cretaceous.

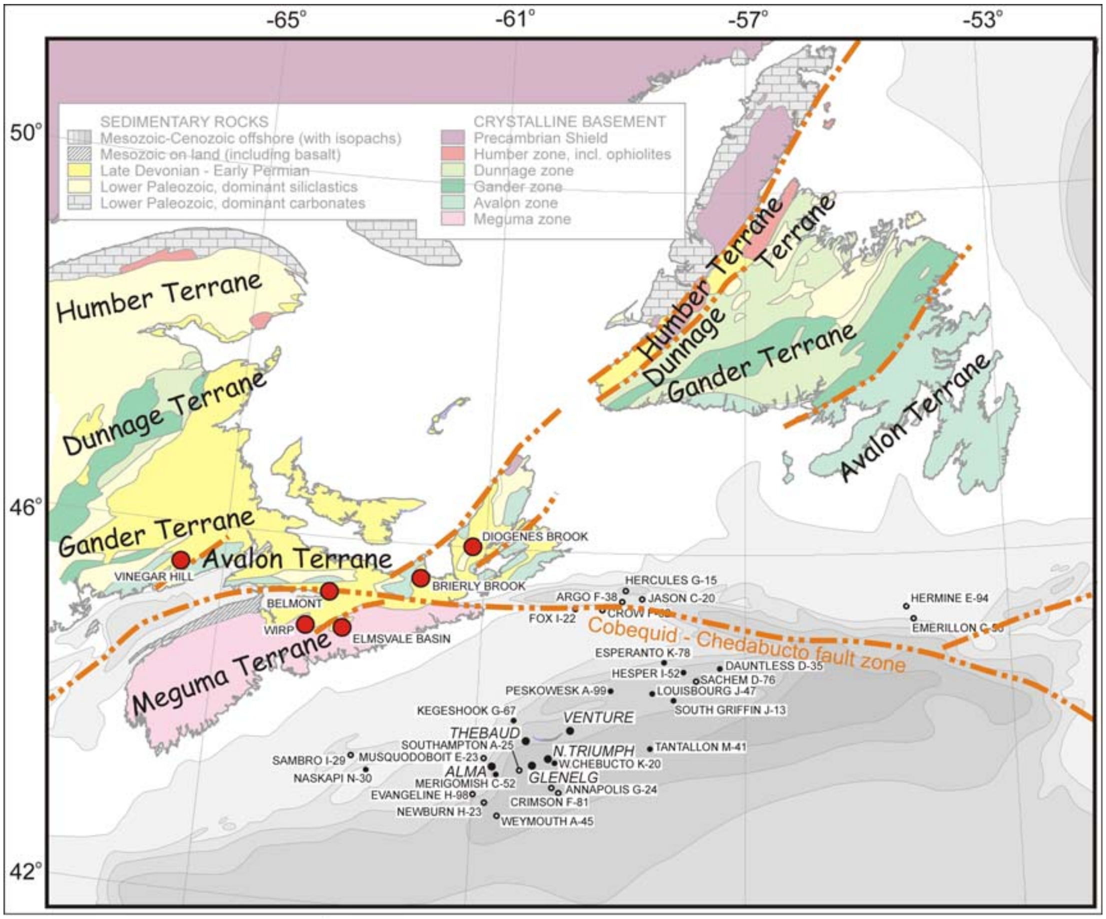


Figure 1.1. Regional map showing principal Chaswood Formation localities (large red dots), Scotian Basin isopachs (at 4 km intervals), and bedrock geology. Base map from Williams and Grant (1998).

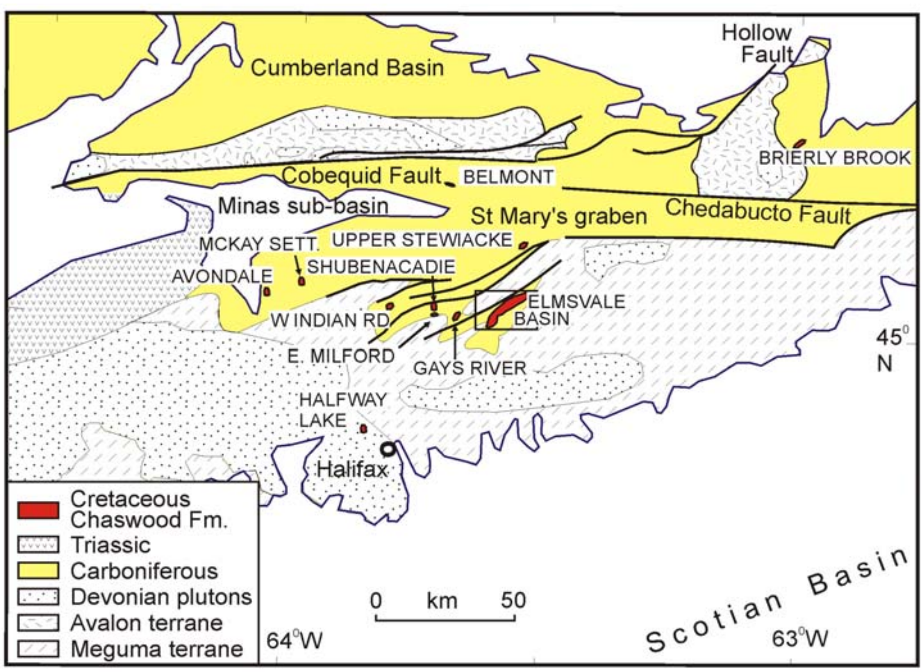


Figure 1.2. Map showing the distribution of the Chaswood Formation in central Nova Scotia.

Geology of the Chaswood Formation

Distribution

The Chaswood Formation is best preserved in a series of fault-bound basins in central Nova Scotia, including the Elmsvale basin and outliers at Shubenacadie and the West Indian Road pit (Fig. 1.2). Small outliers in northern Nova Scotia include Belmont, Brierly Brook and Diogenes Brook (Dickie 1986; Stea et al. 1994; Pe-Piper et al. 2005c). The Vinegar Hill outlier in southern New Brunswick (Falcon-Lang et al. 2004) is the only known occurrence of the Chaswood Formation in New Brunswick (Fig. 1.1).

The Chaswood Formation in central Nova Scotia overlies Carboniferous rocks that are preserved in basins developed unconformably over Meguma terrane basement rocks. The Elmsvale Basin extends some 15 km along the present Musquodoboit Valley and consists of <200 m of Chaswood Formation that thins rapidly across the Rutherford Road fault (Fig. 1.3) bounding the northwest side of a half-graben (Stea and Pullan 2001). The stratigraphy and sedimentology of the Chaswood Formation are well known from the many tens of boreholes cored in the basin during exploration for kaolin clays (Stea and Pullan 2001; Pe-Piper et al. 2005a; Piper et al. 2005).

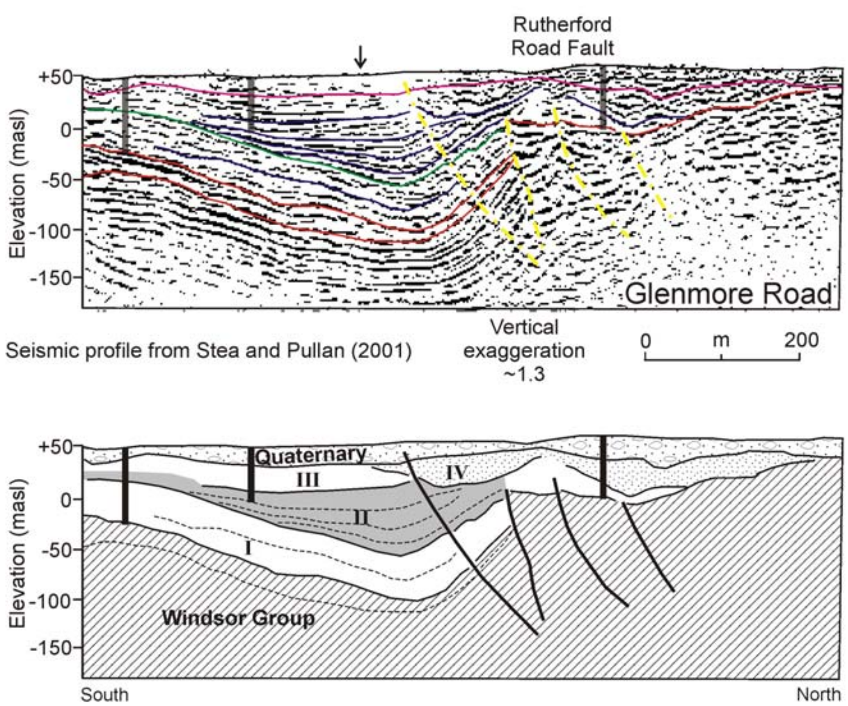


Figure 1.3 (above) Seismic cross-section of the Elmsvale Basin and (below) interpretation, showing seismic packets I – IV and deformation along the Rutherford Road Fault.

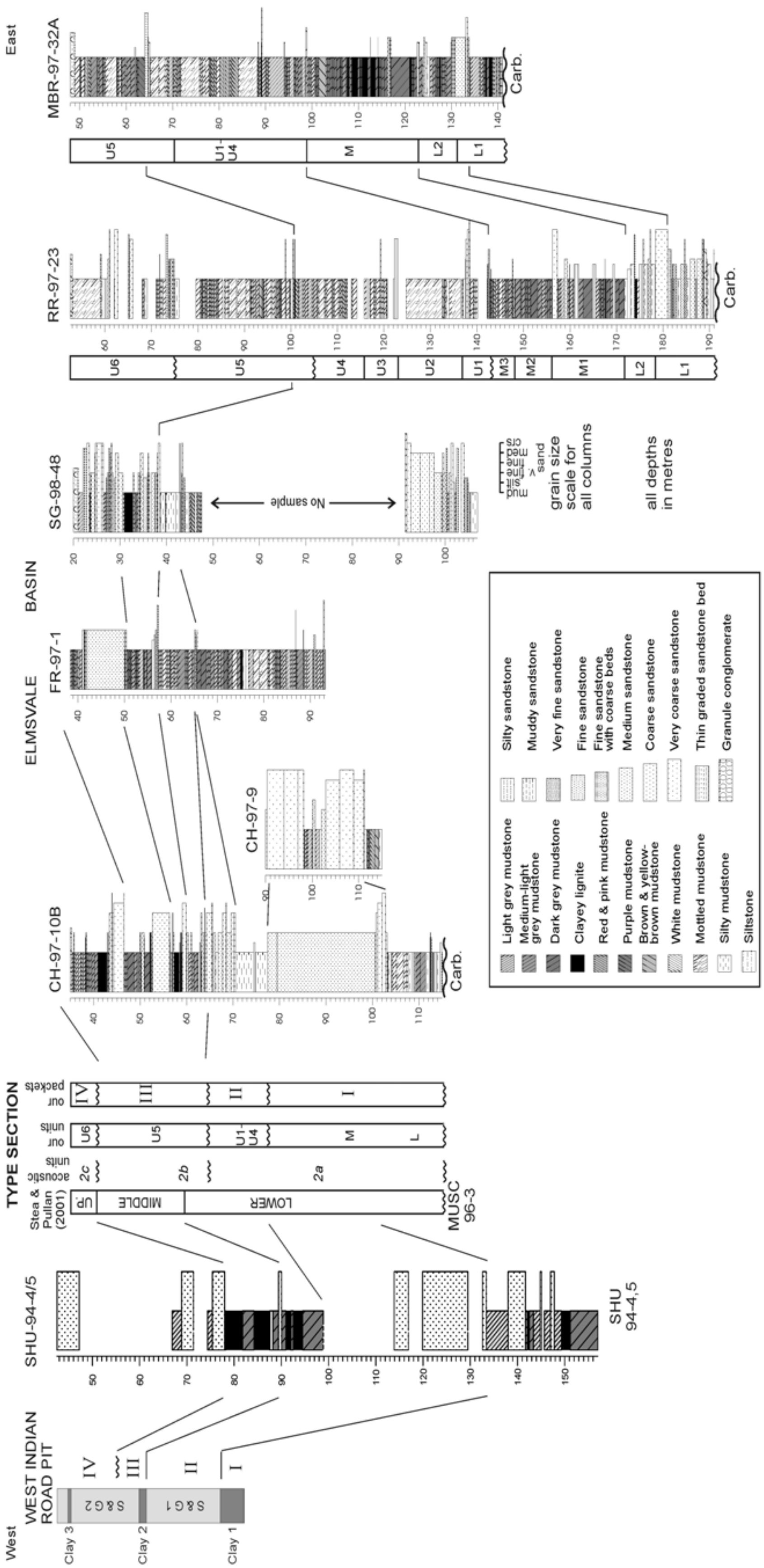


Figure 1.4. Stratigraphic columns from the Elmvale Basin showing stratigraphic nomenclature of Stea and Pullan (2001) at the type section; lithologic unit and seismic packet nomenclature of Pe-Piper and colleagues; and tentative correlation to Shubenacadie and the West Indian Road pit.

Stratigraphy and stratigraphic correlation

Based on seismic-reflection profiles, four unconformity-bound seismic packets (Figs. 1.3, 1.4) are recognised within the Chaswood Formation of the Elmsvale Basin (Hundert et al., 2006). The basal unconformity separates Packet I from underlying Carboniferous Windsor Group rocks. Packet I is slightly deformed along the Rutherford Road fault and unconformably overlain by Packet II. Packets I and II correspond to the Lower member of the Chaswood Formation defined by Stea and Pullan (2001). Packets I and II are folded into a monocline along the Rutherford Road Fault and are unconformably overlain by Packet III (Middle Member), which is itself only slightly deformed. The unconformably overlying Packet IV (Upper Member) is only locally preserved (including at the West Indian Road pit) and is undeformed.

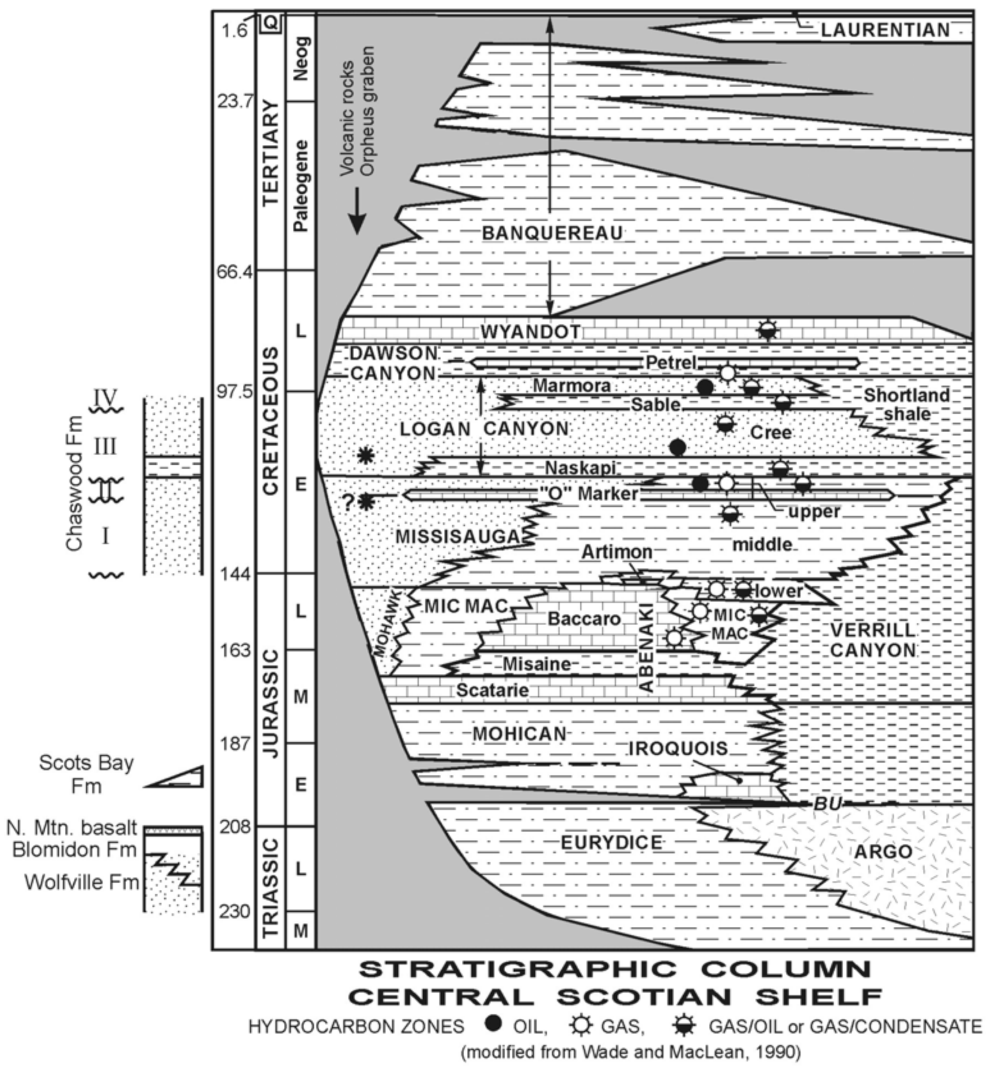


Figure 1.5. Stratigraphic column for the offshore Scotian Basin showing principal reservoir rocks and correlation with Mesozoic rocks on land.

Biostratigraphy

The middle part of the Chaswood Formation has been generally assigned to the Aptian-Albian, whereas older Early Cretaceous biostratigraphic ages (Valanginian to Barremian) have been determined for some isolated deposits apparently from the lower part of the Chaswood Formation (Falcon-Lang et al. 2007). The Chaswood Formation is thus broadly equivalent to the Mississauga and Logan Canyon formations offshore in the Scotian Basin (Wade and MacLean 1990) (Fig. 1.5) and of similar age to the fluvial Mattagami Formation in the Hudson Bay lowlands of central Canada (Telford and Long 1986).

Lithofacies

Seven principal facies associations are recognised in the Chaswood Formation, on the basis of frequency of transitions between facies (Pe-Piper et al., 2005a). The **light grey mudstone** facies association consists of light to medium grey massive mudstone that locally contains organic detritus, but overall has low bulk organic carbon content. Some mudstones have pinkish mottling, and where mottling is intense, the beds are included in the paleosol facies association (see below). The **dark grey mudstone** facies association has a higher organic carbon content including charcoal, indicating wildfires (Scott and Stea, 2002). **Carbon-rich sediments** include lignitic mudstone, in beds < 0.5 m thick, which resembles the dark grey mudstone but has more organic material. Lignite (with > 30% organic carbon) is locally present and some contains volcanic ash (Pe-Piper et al., 2006). The **paleosol** facies association consists mostly of red, pink, yellow or purple mudstone and lesser fine sandstone. Paleosol features include sub-vertical tubular mottles that may be root traces and diagenetic nodules and mottles rich in hematite on a range of scales. The **debris-flow** facies association consists of contorted blocks of mudstone, in some cases with pebbles, with a mud or mud-sand matrix (Pe-Piper et al., 2005b). The **silty mudstone and muddy sandstone** facies association includes a range of poorly sorted lithologies. Generally it gradationally overlies fine-grained sandstone and passes upward into light grey mudstone.It is distinctly micaceous and commonly contains plant fragments. **Sorted sandstone and conglomerate** is commonly in graded beds with sharp bases. Sandstone beds typically fine upward into silty mudstone, but some are isolated as individual 1 to 2 metre beds with sharp contacts within mudstone.

Detrital petrology

Petrographic studies based on heavy minerals have indicated that the Chaswood Formation was sourced from local Carboniferous sedimentary rocks and from crystalline Appalachian rocks including granitoid rocks and metapelites (Piper et al, 2007). Studies of lithic clasts in conglomerate in the Chaswood Formation shows that at all stratigraphic levels there was a component of sediment supply from local (< 50 km) crystalline basement and from reworking of Carboniferous sedimentary rocks (Gobeil et al. 2006; Piper et al. 2007). Geochronology of detrital monazite (Pe-Piper and MacKay 2006) also shows that at all stratigraphic levels there was also a supply of distant travelled detritus from the northern Appalachians. The proportion of local and far-travelled components varies stratigraphically, with the greatest amount of local reworked Carboniferous detritus at lower stratigraphic levels in most localities (Gobeil et al. 2006; Noftall 2007). The studies of detrital monazite on land (Pe-Piper and MacKay 2006) and offshore (Pe-Piper et al., 2008) and unpublished work on detrital zircon (with M. Tubrett), detrital muscovite (with P. Reynolds), and heavy minerals allow a preliminary interpretation of the distribution of rivers that deposited the Chaswood Formation and the offshore Missisauga and Logan Canyon formations (Fig. 1.6).

The limitation of such petrographic techniques is that they track only sediment sources with characteristic minerals. The geochemistry of 60 samples from a complete section through the Chaswood Formation in borehole RR-97-23 in the Elmsvale Basin (Fig. 1.4) shows that the detrital signature is partially obscured by diagenetic processes, which caused the concentration of K, P, Sr and U at three regional unconformities intersected by the borehole and recognised from seismic-reflection profiles. The elements Ti (in ilmenite and its alteration products), Zr (in zircon), Th and Y are largely controlled by the abundance of heavy minerals in the rocks. Ilmenite is the dominant first-cycle heavy mineral, whereas much of the zircon is of polycyclic origin, so that the Ti/Zr ratio is a guide to the proportion of first-cycle sediment supply from crystalline basement. High concentrations of Cr (given the absence of detrital chromite) and Sr (except where diagenetic P-bearing minerals are present) and the high Ni/Co ratio in mudstones appear related to supply from weathered mafic crystalline basement. Three cycles of sediment supply are recognised in borehole RR-97-23, each overlying a regional unconformity. These reflect uplift of horsts bounded by strike-slip faults that resulted first in shedding of readily eroded Carboniferous sandstones, followed by rapid erosion of crystalline basement and, finally, greater supply of deeply weathered regolith.

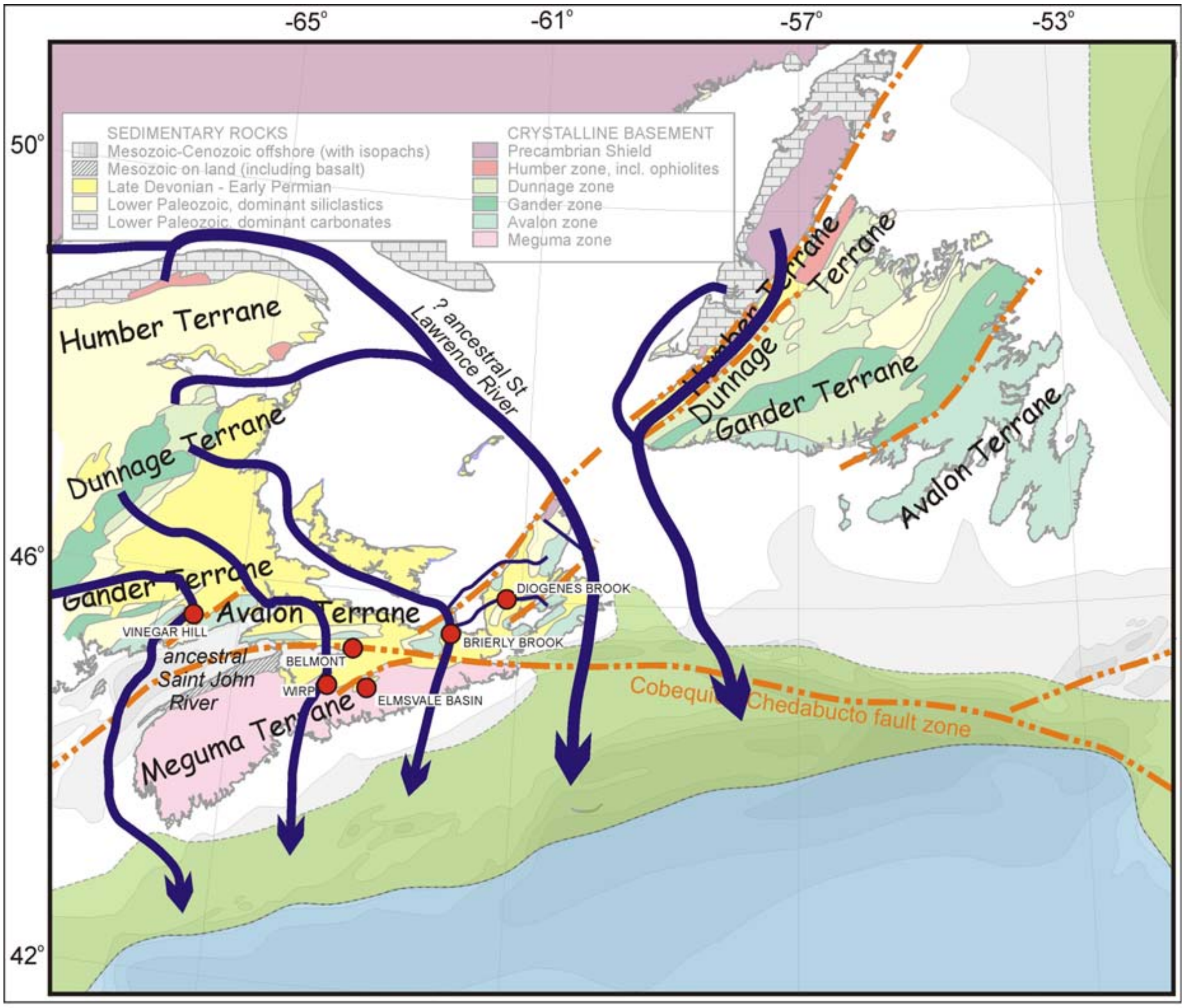


Figure 1.6. Tentative interpretation of the Early Cretaceous drainage pattern to the Scotian Basin.

Burial history and thermal maturation

Studies at Shubenacadie and nearby localities have shown low vitrinite reflectance Ro values (0.31 ±0.02%) in the Upper and Middle members of the Chaswood Formation, increasing to 0.41 - 0.48±0.08 % in the Lower member (Davies et al., 1984; Stea et al., 1996) (Fig. 1.7). The present Chaswood Formation was probably formerly buried by ~ 800 m of Upper Cretaceous and Lower Tertiary strata: evidence includes the equilibrium moisture content of lignites in the Chaswood Formation (Hacquebard, 1984); apatite fission track data in underlying basement (Arne et al., 1990; Grist and Zentilli, 2003); and the presence of such strata along strike in the Orpheus Graben (Fig. 1.1) (Wade and MacLean, 1990; Weir-Murphy, 2004). The steep Ro gradient was the result of the hydrothermal circulation driven by early Albian volcanism, known from the Cree Member in the Orpheus graben along strike from the Elmsvale Basin.

Diagenesis

Diagenesis in the Chaswood Formation has been shown to involve soil forming processes and widespread kaolinitization by groundwater recharge from meteoric water (Pe-Piper et al. 2005a; Piper et al. in revision) (Fig. 1.8). Three styles of soil formation are recognised. The dark grey mudstone facies association is interpreted as deposits in flood plain ponds and as immature gley soils in areas that experienced persistently high water table (Pe-Piper et al., 2005a). In porous gravelly sandstones, highly leached oxisols are developed. Muddy oxidised reddened paleosol horizons are widespread in the Chaswood Formation and are most prominent at regional intraformational unconformities (Hundert et al., 2006) (Fig. 1.9).

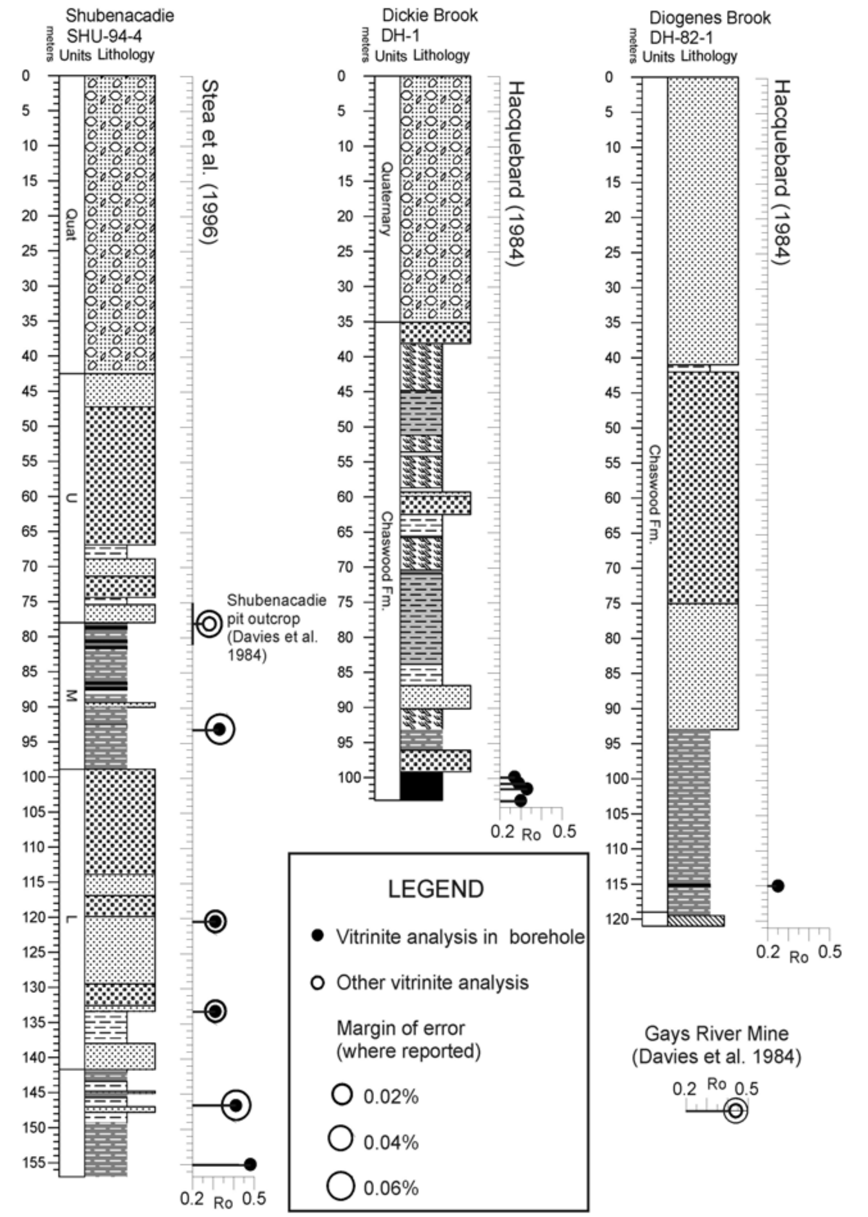


Figure 1.7. Summary plot showing variation in vitrinite reflectance in boreholes at Diogenes Brook, Dickie Brook (Elmsvale Basin), and Shubenacadie, and from outcrops at Shubenacadie and mine workings at Gays River.

The kaolinitization of mudstones involved the oxidation of organic matter and whitening of the mudstones, as described from Georgia by Hurst and Pickering (1997). In the sandstones, unstable minerals including feldspars were altered and kaolin minerals were precipitated in pores. FT-Raman spectroscopy shows the presence of dickite near the base of the Chaswood Formation

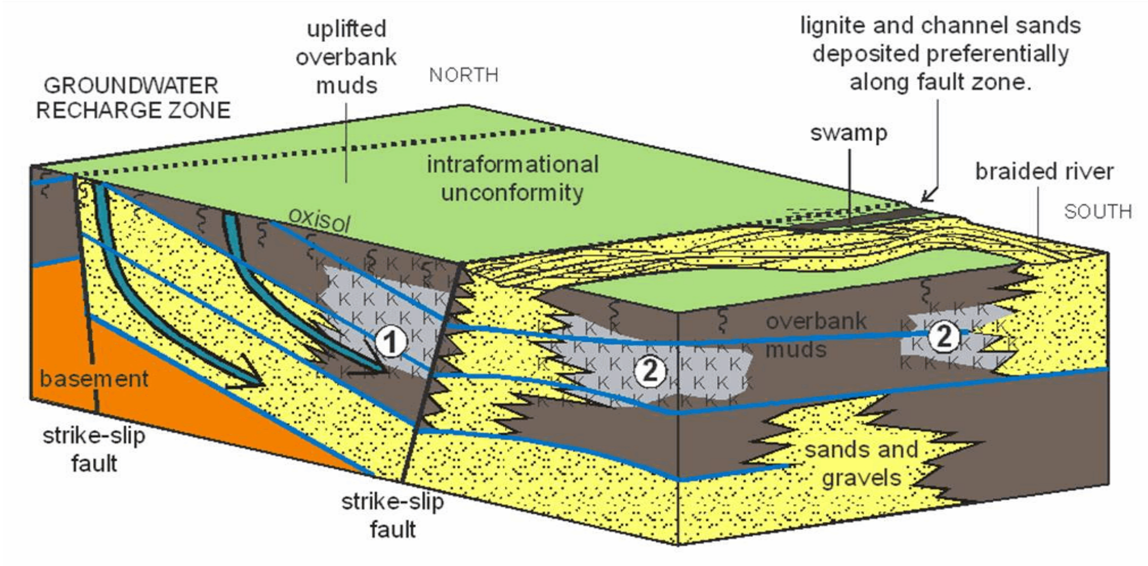


Figure 1.8. Schematic model showing relationships between tectonics, sedimentation and diagenesis in the Chaswood Formation.

in Elmsvale basin, supported by images of blocky kaolin crystals. It formed during the short-lived high geothermal gradient resulting from hydrothermal circulation driven by early Albian volcanism.

Prominent diagenetic illite in the Upper member of the Chaswood Formation appears to pseudomorph small kaolinite booklets. Larger illite booklets are found in the middle part of the Lower member, again perhaps pseudomorphing kaolinite. Similar blocky illite has been previously reported to pseudomorph dickite from deeply buried sandstones (Patrier et al., 2003). Some evidence that the illite has formed as a result of the reaction of kaolinite and K-feldspar is seen from the presence of small euhedral quartz overgrowths on silt-sized quartz in the Upper member at Belmont. The presence of barite cement in most samples that contain

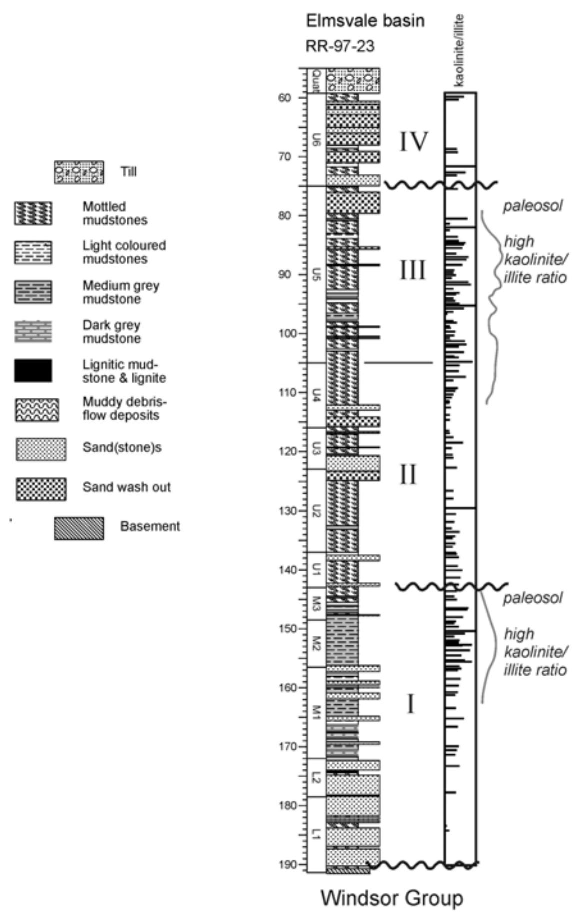


Figure 1.9. Sedimentary log of borehole RR-97-23 showing kaolinite/illite ratio in relation to major unconformities

diagenetic illite is further evidence of the role of K-feldspar. This co-occurrence of halloysite and diagenetic illite is rare and and the occurrence of diagenetic illite in sandstones with such low vitrinite reflectance (Ro = 0.31 ±0.02%) is most unusual.

Structure

Seismic-reflection data

In the Elmsvale basin, seismic reflection profiles controlled by boreholes (Fig. 1.3) clearly show that the lower Chaswood Formation was deformed prior to deposition of younger units and that this deformation involved both folding and faulting. The main ENE-trending Rutherford Road fault on the north side of the Elmsvale basin is a complex reverse fault with some evidence for flower structure. The lower part of the Lower member of the Chaswood Formation (units L and M; packet I) was deposited widely over Carboniferous Windsor Group basement, but was then folded into a syncline along the Rutherford Road fault. The upper part of the Lower member (units U1-U4; packet II) onlaps the lower part of the Lower member and is also deformed along the Rutherford Road fault. The Middle and Upper members (units U5 and U6; packets III and IV) post-date formation of the syncline, but show minor fault offset. Steeply dipping brittle fault contacts and brecciated clays in some boreholes confirm that some of the faulting took place after compaction and lithification and parts of the Rutherford Road fault unequivocally cut the youngest Chaswood Formation strata.

Outcrop and borehole observations

Deposition of the Chaswood Formation appears strongly influenced by syn-sedimentary faulting. The work of Gobeil (2002) in the West Indian Road pit shows clearly that the thickness of sedimentary units varies rapidly across faults (Fig. 2.3), even on a horizontal scale of a few hundred metres. Thickness variations in some cases are much greater than any post-Cretaceous offset on the faults. The most remarkable syn-sedimentary feature in the West Indian Road pit is the recognition of two local angular unconformities in the east wall of the pit, where beds are locally rotated to almost vertical (Fig. 2.5), yet are overlain by sub-horizontal sands and gravels. In places in the West Indian Road pit, there are rapid lateral facies changes from sand to gravel across faults. Both observations suggest that faults must have created a slight topographic effect on the depositional environment. The observation that paleocurrents in the West Indian Road pit are consistently to the southeast, however, implies that the syn-sedimentary faulting had little effect on regional river flow direction. Sand injection structures in Clay Unit 2 provide evidence for earthquake-related deformation at the time of deposition.

A 5 km long, 2-5 m thick unit of tilted blocks, interpreted as a large landslide, in western Elmsvale basin confirms that a significant gradient was present at times in the Chaswood Formation to allow failure of many metres of previously deposited sediment.

At Brierly Brook, where no seismic-reflection profiles are available, the restriction of units C and D to the central part of the basin and their absence in boreholes only 100 m distant (Fig. 1.10) imply syn-sedimentary faulting. The sedimentary facies are inconsistent with accumulation in a local sink hole.

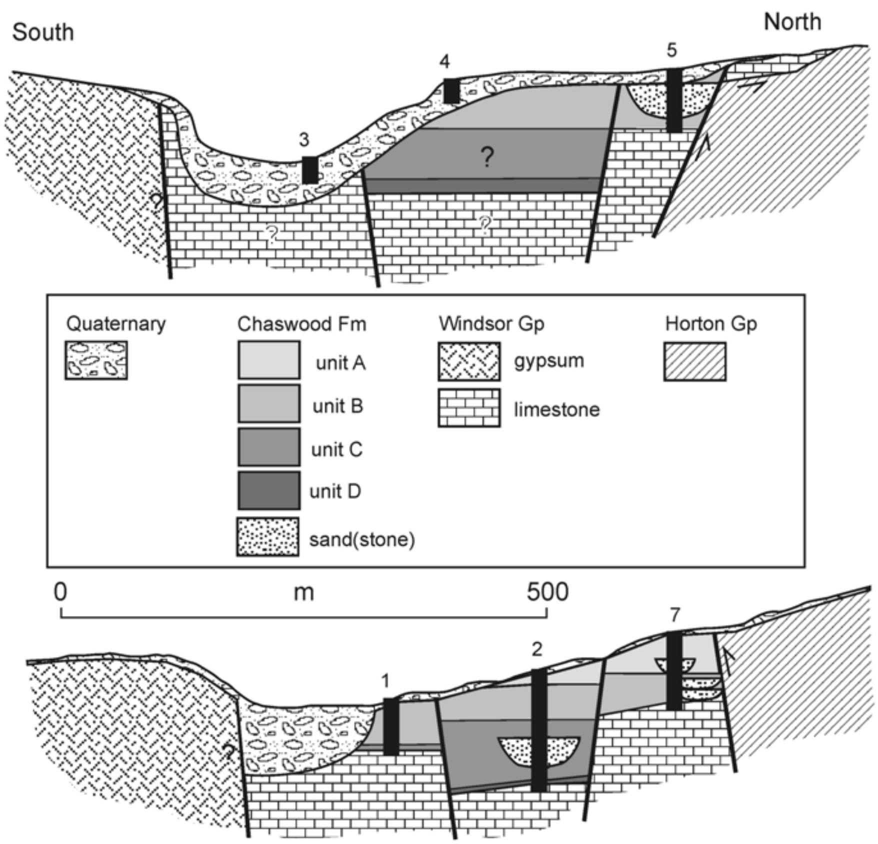


Figure 1.10. Structural cross-sections at Brierly Brook inferred from correlation of boreholes.

Structural evolution

The structural style of the faulting in the Chaswood Formation is typical of strike-slip faulting, with abrupt local rotation of beds and sediment thickness changes. Syn-sedimentary faulting within the Chaswood Formation can be related to secondary shear zones produced by the master Cobequid-Chedabucto fault. Pe-Piper and Piper (2004) argued that there was mid-Cretaceous dextral slip on the Cobequid-Chedabucto-SW Grand Banks fault, producing the regional shortening in the Minas basin and several kilometres of post-early Jurassic dip slip motion on the Cobequid fault system recognised by Withjack et al. (1995). This slip also resulted in 3 km of dextral offset of the early Jurassic North Mountain Basalt on the Gerrish Mountain Fault (Donohoe and Wallace 1985, p. 42). This deformation was synchronous with rotation of crustal blocks in southern Connecticut dated by Roden-Tice and Wintsch (2002) and the development of unconformities between the Missisauga and Logan Canyon formations in Orpheus graben (Weir-Murphy 2004) and the SW Grand Banks (Pe-Piper et al. 1994).

Dextral slip on a master Cobequid-Chedabucto-SW Grand Banks fault would result in secondary reverse faulting on NE-trending faults (Fig. 1.11), such as imaged by seismic profiles along the Rutherford Road fault zone. Similar faulting near the Vinegar Hill pit may have influenced the SW paleocurrents there. The initiation of Chaswood Formation deposition in the Cretaceous implies extensional basin formation, which under conditions of dextral slip on the Cobequid-Chedabucto fault would tend to parallel the observed SE paleocurrents in the West Indian Road pit.

Pe-Piper and Piper (2004) also argued that Oligocene uplift on the eastern Scotian Shelf was a consequence of strike-slip reactivation of the Cobequid - Chedabucto - SW Grand Banks fault system, either sinistral motion on the E-W fault segments or dextral motion on the SSE-NNW trending SW Grand Banks fault. Since compressive deformation appears lacking along the SW Grand Banks margin, they concluded that dextral strike-slip along the SSE-NNW trending SW Grand Banks transform was more likely. If that were the case, the compressive deformation of Triassic - Jurassic rocks along the Cobequid Fault described by Withjack et al. (1995) might be of

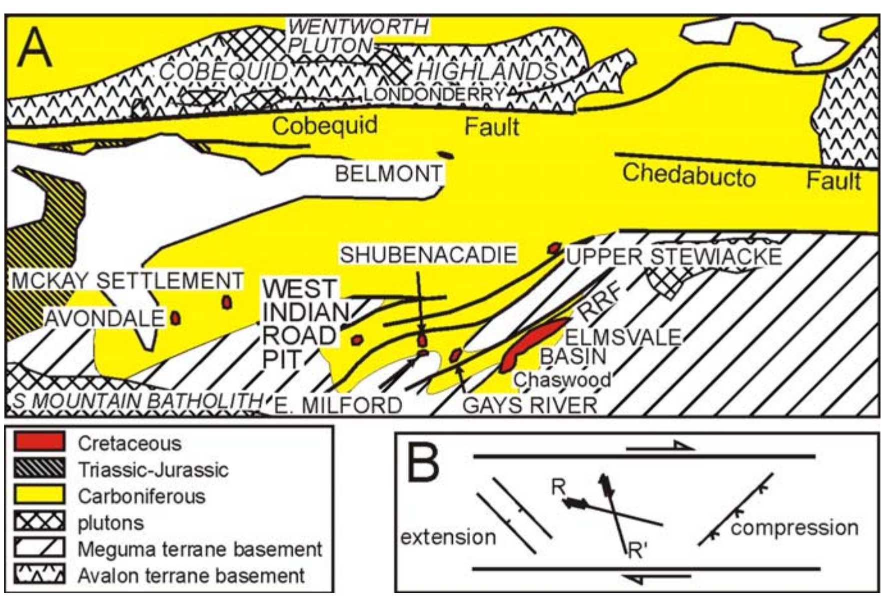


Figure 1.11. (A) Structural features related to the Chaswood Formation in central Nova Scotia. (B) Intepretation of structural features in terms of dextral strike slip on the Cobequid–Chedabucto fault zone.

Oligocene rather than Cretaceous age. Regardless of the origin of this Oligocene deformation, it was likely responsible for the young deformation of the Chaswood Formation in a style quite different from the Cretaceous syn-sedimentary deformation (e.g., at the West Indian Road pit: Fig. 2.1). It could also have been responsible for widespread uplift of the Chaswood Formation, such as that inferred on the northern side of the Rutherford Road fault. Similar uplift was interpreted by Grist and Zentilli (2003) from apatite fission-track modelling. They concluded that at least 700 m of Upper Cretaceous and Paleocene strata were deposited over a wide area of the southern part of the Maritime Provinces and then eroded in the Neogene. The estimates of depth of burial of lignite by Hacquebard (1984), confirmed by more recent calibration of moisture content of lignite, is consistent with this interpretation.

PART 2: The West Indian Road pit

General setting

The West Indian Road deposit (Fig. 2.1) (also previously referred to as Brazil Lake or Grant Brook) occurs within a fault-bound basin in Carboniferous MacDonald Road Formation (Windsor Group) gypsum and was originally interpreted as a large sink hole (Dickey 1986). The regular stratigraphic succession and tectonic tilting indicates that the deposit was originally more extensive and occupies its present position as a result of post-Cretaceous faulting and folding into syncline. The pit has been extensively exploited and studied by Shaw Resources (Price 2000). When first developed, it was studied by Stea and Fowler (1981), who noted the presence of exotic gravel clasts. More recently, it was the subject of an M.Sc. thesis by J.-P. Gobeil (2002), with a summary published by Gobeil et al. (2006).

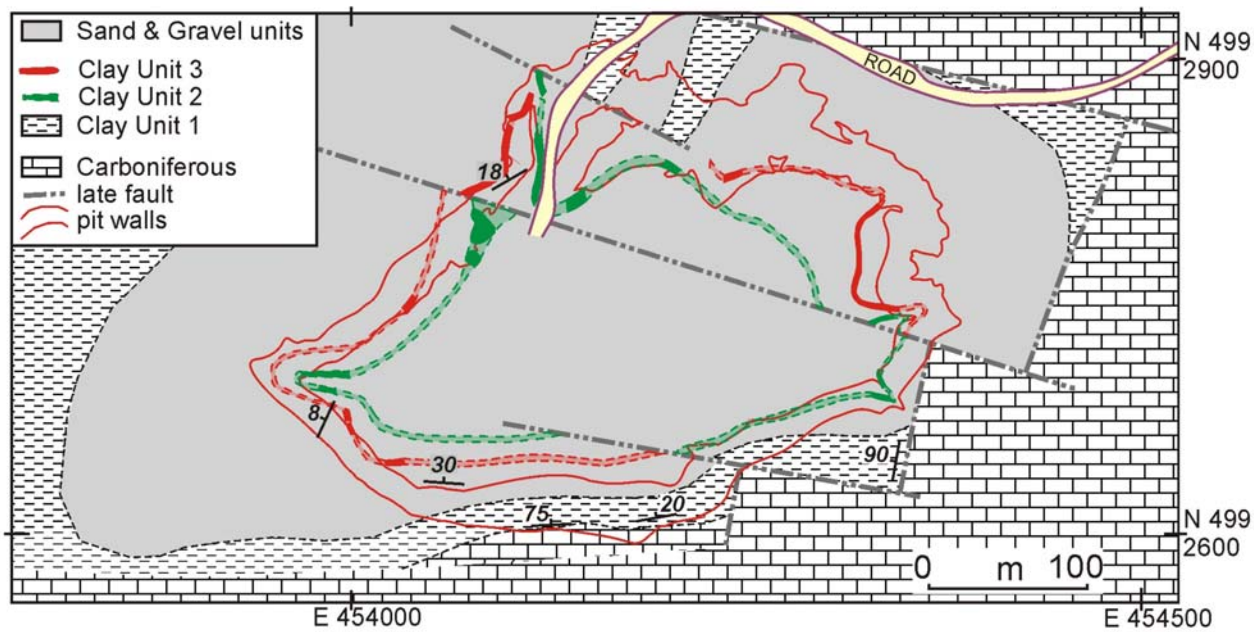


Figure 2.1 General geological map of the West Indian Road pit (from Gobeil 2002).

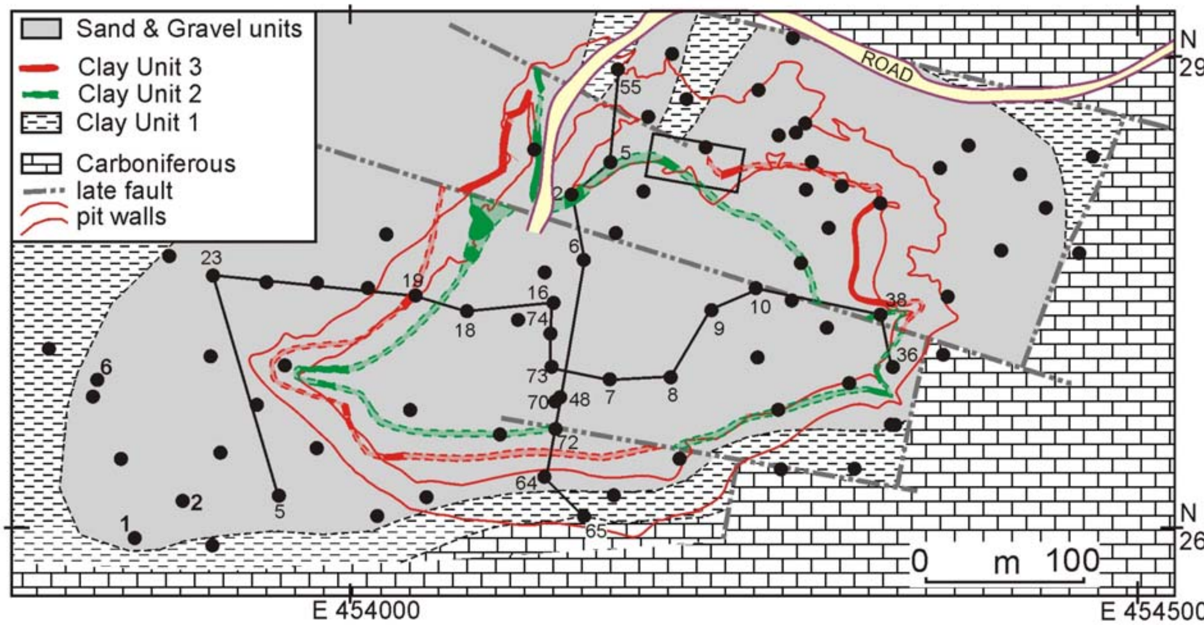


Figure 2.2. The West Indian Road pit showing borehole control for the sections in Fig. 2.3 and the details of Clay Unit 1 in Fig. 2.4.

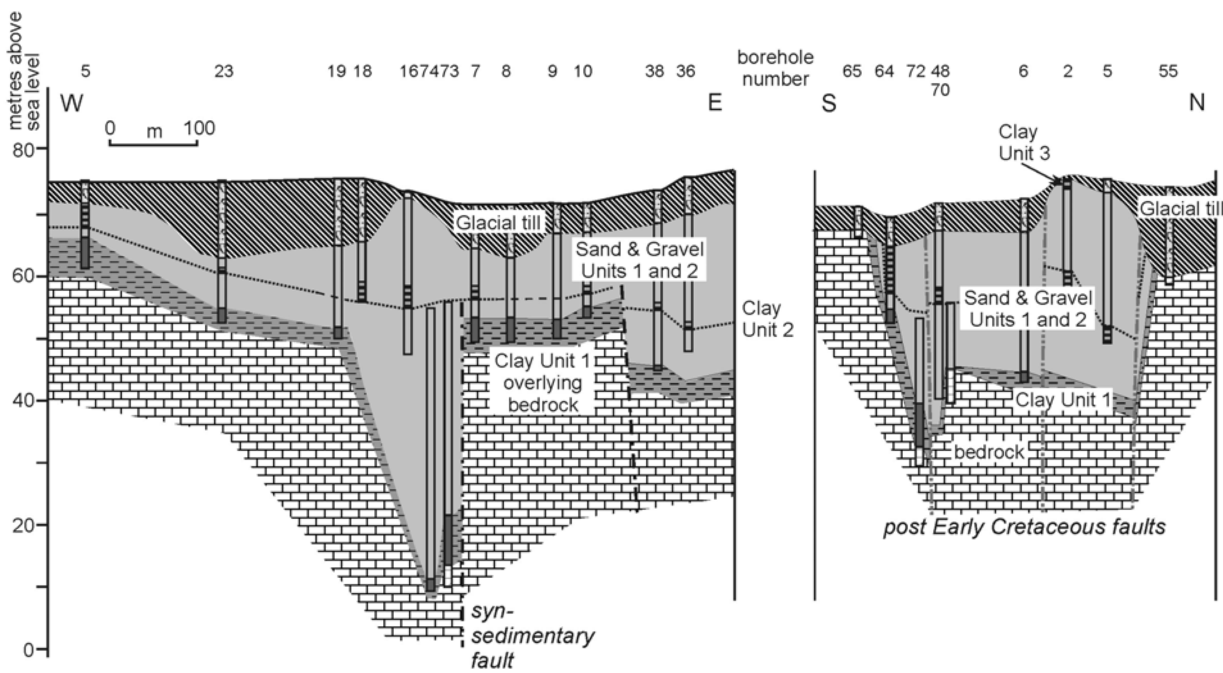


Figure 2.3. Borehole sections across the West Indian Road pit showing stratigraphic succession and lateral variations in thickness.

Stratigraphy

Three mudstone units (Clay Units 1, 2 and 3) are separated by three coarser grained units (Sand & Gravel Units 1, 2 and 3). Boreholes (Fig. 2.3) show that thicknesses are rather variable (Fig. 2.3). Clay Unit 1 (Fig. 2.4) is typically 3 to 10 m thick resting unconformably on the MacDonald Road Formation. It consists principally of dark grey clay, with some interbedded mottled brown, pink, red, purple and green clays and thin sands and gravels. Some clay beds show fine parallel laminations, but others appear to be debris-flow deposits consisting of clay-supported gravel clasts, all cut by both brittle and ductile deformation structures. The clays contain reworked Carboniferous palynomorphs and the gravel clasts consist of vein quartz and Horton Group calcarenites.

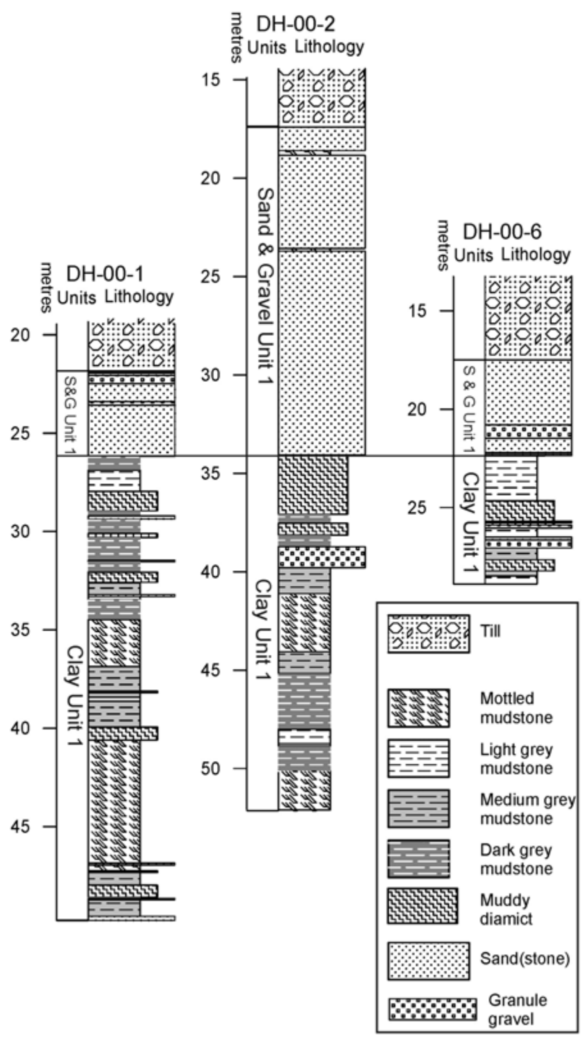


Figure 2.4. Borehole logs through Clay Unit 1.

Sand & Gravel Unit 1 is known mostly from boreholes and is 3 - 20 m thick. It consists of conglomerates and sandstones, commonly in fining-upward sequences. Clay Unit 2 is 0.5 - 3.6 m thick and consists of medium grey clay with pink colouration in its upper 10 - 30 cm. In places it is disrupted by sand injection and was not identified in all boreholes. Sand & Gravel Unit 2 is typically 15 m thick and consists of cross-bedded pebbly sandstone and lesser conglomerate, with local erosional unconformities (Fig. 2.5). Clay Unit 3 is a 0.5 m thick pink clay bed found throughout the pit. It is overlain locally by thin sediments of Sand & Gravel Unit 3 and then by glacial till.

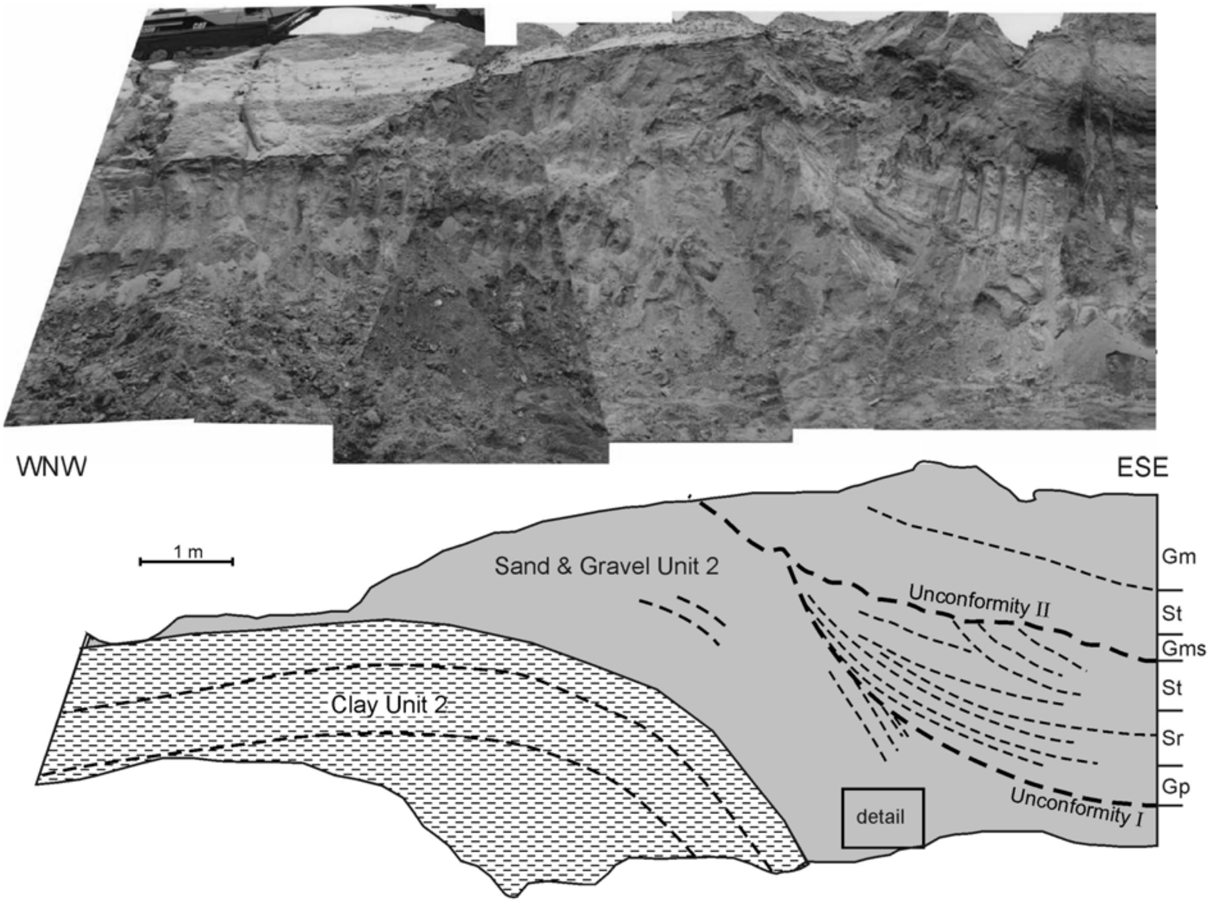


Figure 2.5. Cut face, now destroyed, showing anticline in Clay Unit 2 and overlying Sand & Gravel Unit 2, cut by two local unconformities. Detail is shown in Fig. 2.7.

Structure of the Chaswood Formation

Syn-sedimentary deformation

The West Indian Road pit has clear evidence for syn-sedimentary tectonic deformation. Clay Unit 2 is folded into two anticlines (Fig. 2.6), one with a faulted margin on its eastern side, against which Sand & Gravel Unit 2 onlaps with local unconformities (Fig. 2.5). Faulted sediments (Fig. 2.7) are overlain unconformably by unfaulted sediments, all within Sand & Gravel Unit 2. Within the fault zone, bedding is tilted to sub-vertical and sub-horizontal shear zones predominate. This style of faulting is consistent with strike-slip faulting under a low vertical confining stress. Both the anticlines and the fault zone strike NNE. Rapid variations in unit thickness, particularly in Sand & Gravel Unit 1 (Fig. 2.2), are also suggestive of syn-sedimentary faulting creating accommodation. Major depocentres trend approximately N-S, parallel to the syn-sedimentary faults (Fig. 2.6).

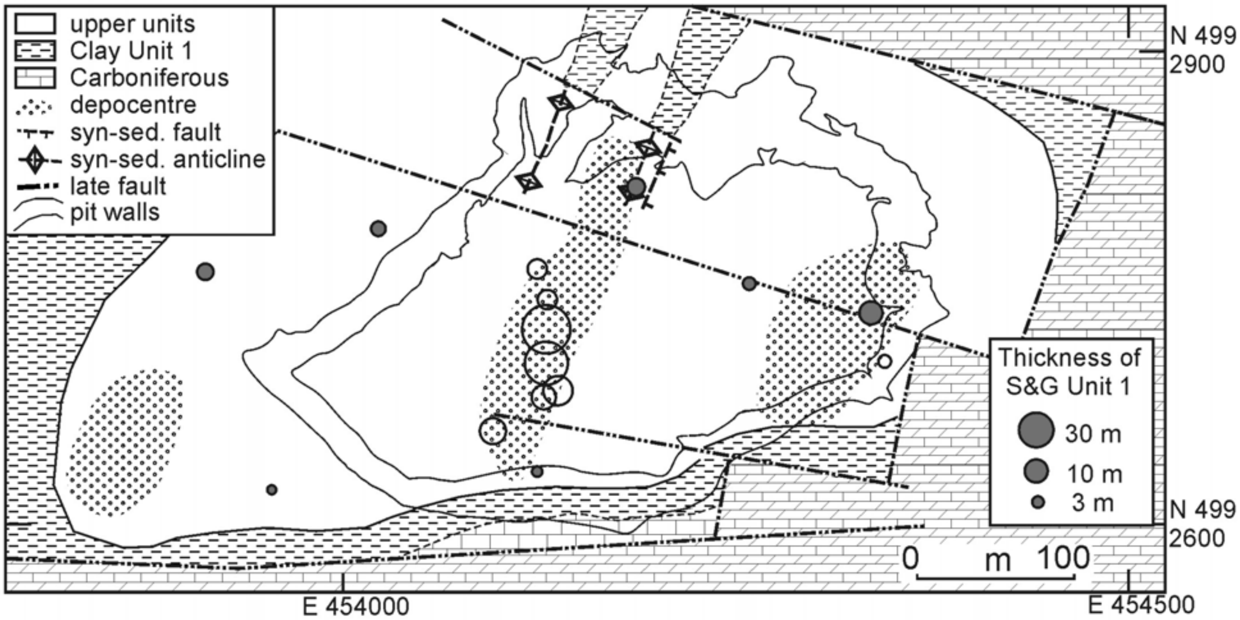


Figure 2.6. Map of the West Indian Road pit showing syn-sedimentary deformational features and principal depocentres.

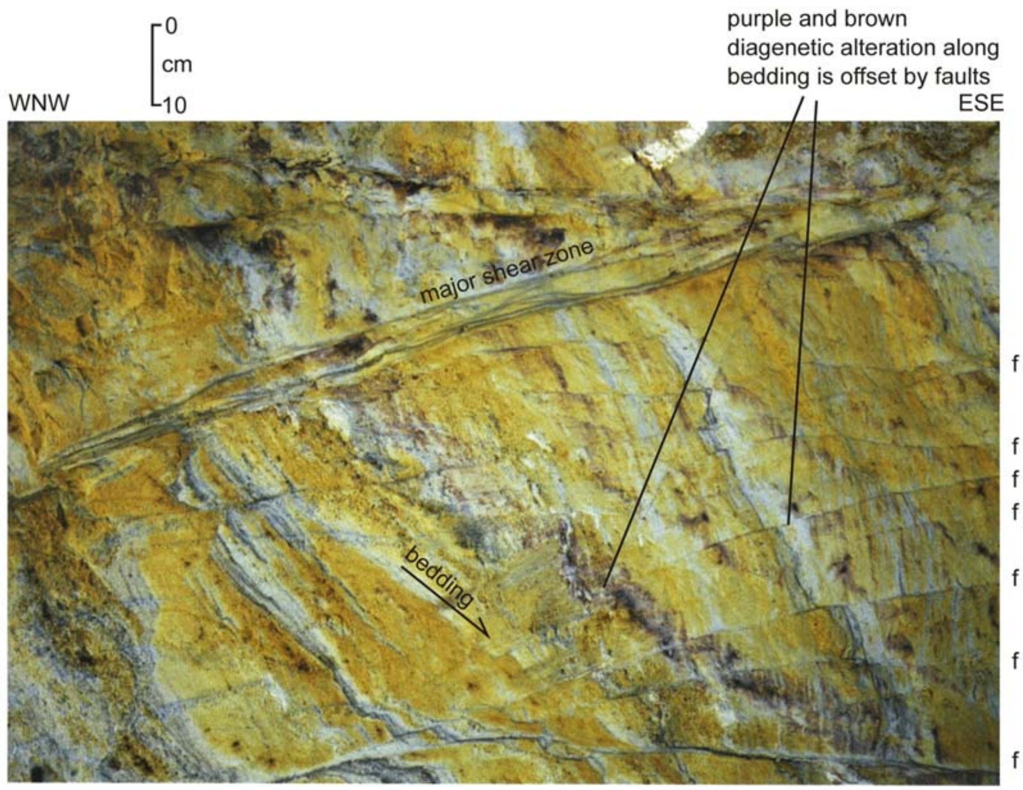


Figure 2.7. Detail of syn-sedimentary faulting (now destroyed) on the flank of the anticline shown in Fig. 2.5.

Post-Chaswood deformation

Late deformation folded the Chaswood Formation into an E-W trending syncline, with subvertical dips close to bounding E-W or WNW-ESE trending faults. The Chaswood Formation is also faulted against Carboniferous basement at the eastern end of the pit by NNE-trending faults (Fig. 2.1), which parallel the mid-Cretaceous syn-sedimentary faults and may be reactivated structures. The overall offset of the eastern end of the pit suggests dextral strike-slip on the master E-W faults.

Synthesis of structural evolution

The structural style of the syn-sedimentary faulting in the Chaswood Formation is typical of strike-slip faulting, with abrupt local rotation of beds and sediment thickness changes (e.g., Nilsen and Sylvester 1995). The principal faults are inferred to trend NNE, parallel to the anticlines (Fig. 2.6) and many secondary faults (Fig. 2.7).

Syn-sedimentary faulting within the Chaswood Formation can be related to secondary shear zones produced by the master Cobequid-Chedabucto fault. Pe-Piper and Piper (2004) argued that there was Early Cretaceous dextral slip on the Cobequid-Chedabucto-SW Grand Banks fault that resulted in secondary reverse faulting on NE-trending faults, such as imaged by seismic profiles along the Rutherford Road fault zone (Fig. 1.3) (Stea and Pullan 2001; Piper et al. 2005). The initiation of Chaswood Formation deposition in the Cretaceous implies extensional basin formation. Under conditions of dextral slip on the Cobequid-Chedabucto fault, such basins would trend SE (Fig. 1.11B), subparallel to the observed ESE paleocurrents in the West Indian Road pit (Fig. 2.8). Original basin margins have been obscured by younger faulting and erosion.

The younger deformation that created the E-W syncline and WNW-ESE trending faults at the West Indian Road pit does not appear to be a continuation of the syn-sedimentary folding and faulting. The orientation of structures is quite different. Deformation on syn-sedimentary faults ended prior to latest Chaswood Formation deposition at the West Indian Road pit, as shown by the lack of deformation above unconformity II (Fig. 2.5) and the apparent lack of significant growth faulting from sediment thickness variations above Clay Unit 2 (Fig. 2.2). The termination of syn-depositional deformation prior to latest Chaswood Formation deformation has also been interpreted from seismic-reflection profiles in the Elmsvale basin (Piper et al. 2005). Neither in the Elmsvale basin nor at the West Indian Road pit is there any control on the age of the younger deformation.

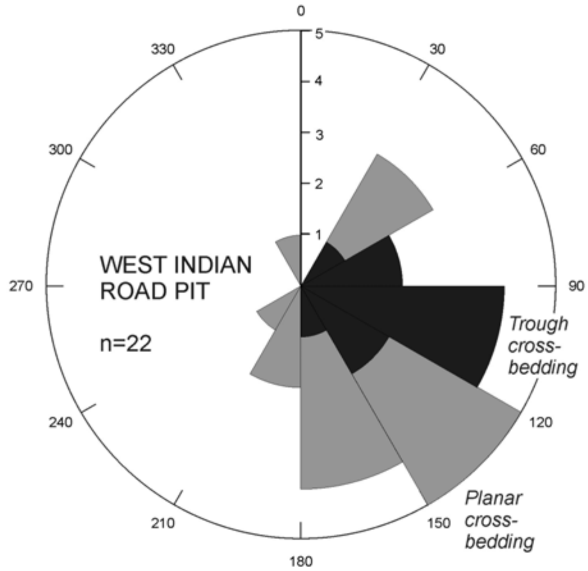


Figure 2.8. Measured paleocurrents in the West Indian Road pit. Black - trough cross bedding; grey - planar cross bedding.

Sedimentology of sand and gravel facies

When the pit is pumped out (Fig. 2.9), the following sand and gravel facies can be recognised (Gobeil et al., 2006). Massive to horizontally laminated gravel (**Gm**) beds form the base of fining-upward successions, in places forming amalgamated beds up to 1.5 m thick. Clasts may be either pebble or granule size. Massive graded gravel (**Gms**) beds are 0.5 to 0.8 m thick, generally with an erosive base with a pebble lag. Trough cross-bedded gravel (**Gt**) occurs in multiple sets 0.3 - 0.5 m thick interbedded with other types of gravel deposit. Planar cross-bedded gravel (**Gp**) forms single sets 0.4 - 2.1 m thick. Crudely cross-bedded sand with an erosional scoured base (**Se**) forms beds up to 0.8 m thick, with a pebble-granule lag at the base. In places, this facies passes laterally into massive sand (**Ss**) with broad, shallow scours and in some beds normal grading. Planar cross-bedded sand (**Sp**) forms single sets 0.2 - 0.7 m thick. Trough cross-bedded sand beds (**St**) occur in multiple sets 0.2 - 1 m thick, commonly with granule lags at the base of sets. They pass up into horizontally laminated sand beds (**Sh**) and then into thin ripple cross-laminated sand (**Sr**).

Within the lower part of Sand & Gravel Unit 2, several metre-scale fining upward successions are developed with gravel facies (**Gm**, **Gms** or **Gp**) at the base, passing up into **Sp** or **St**. In the upper part of the unit, the most common succession is **Gm** → **Sh.** Paleocurrents in the Sand & Gravel units, determined principally from facies **Gt** and **St**, are unimodal to the SSE (Fig. 2.8).

Figure 2.9. View of the West Indian Road pit when it was pumped dry in 2001.

Groups of beds can be correlated over distances of hundreds of metres by their relationship to the Clay units, but single beds can only rarely be traced laterally for distances of more than 10 – 20 m. Prominent channels were not recognised; visible erosional surfaces at the bases of beds have relief of only 1 m although lateral correlation between measured sections shows variation in thickness of groups of beds of several metres.

The sand-gravel facies are characteristic of deposition in coarse-grained bedload rivers (e.g. as summarized by Collinson 1996; Lunt et al. 2004). In Sand & Gravel Unit 2 in the northeast part of the pit, there is a repetitive sequence of erosion surfaces overlain by gravel facies (**Gm**, **Gt**, **Gms**) that pass up into cross-bedded sands (**Sp** or **St**). Two of the erosion surfaces correspond to the local unconformities in Figure 2.5. Individual facies can be interpreted, but lateral relationships are rarely seen. Facies **Gm** and **Gms** probably developed in longitudinal bars under high flood conditions, with erosive bases and pebble lags representing channel erosion, whereas planar cross-bedded facies **Gp** and **Sp** are developed at bar margins (e.g., Miall 1977). Trough cross-bedded sands (**St**) in places are seen to occupy metre-deep channels. Rippled sands (**Sr**), interpreted as deposited during low water stages (Smith 1971), may overlie any of the other facies. In the upper part of Sand & Gravel Unit 2, the lithofacies are principally massive gravel (**Gm**) overlain by horizontally bedded or trough cross-bedded sands (**Ss**, **Sh, St)**, with a 2.5 m deep inferred channel in one locality of trough cross-bedded fine gravel (**Gt**). Thus deposition appears dominated by bars in the lower part of Sand & Gravel Unit 2 with a greater importance of channel deposition in the upper part of the unit. Paleocurrents in trough cross-bedded facies developed in channels are consistently to the ESE, with a much greater spread in planar cross-beds that typically develop at bar margins (Fig. 2.8). The width of individual channels is not well constrained, although observations suggest a width of tens of metres, rather than metres or hundreds of metres, for the gravel filling channels at the top of Sand & Gravel Unit 2.

Detrital petrology

Pebbles were visually separated into about 20 lithologic types (Fig. 2.10). Most pebbles are quartz-rich lithologies, either vein quartz or quartz arenite or subarkose. Pebbles are subrounded to well rounded, with low to moderate sphericity. The quartz arenite and subarkose pebbles contain detrital resistant heavy minerals including zircon and tourmaline. In addition, however, there are deeply weathered “exotic” pebbles including numerous mafic igneous rocks, originally gabbro or

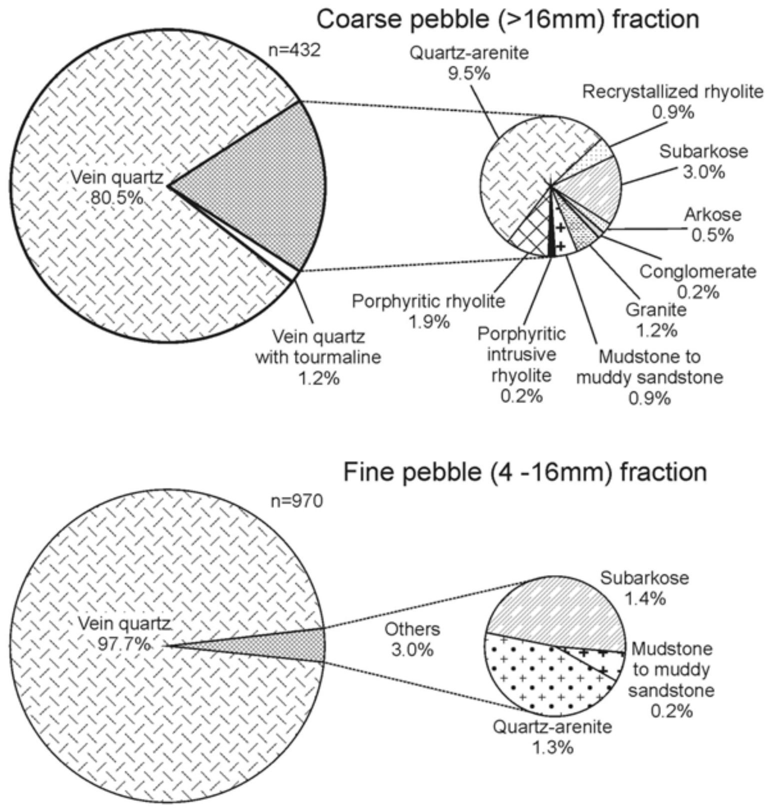


Figure 2.10. Gravel petrology at the West Indian Road pit.

diorite. Some pebbles consist of hornblende largely altered to actinolite, plagioclase, ilmenite, and K-feldspar; others consist principally of epidote, chlorite and feldspar. Other exotic pebbles include pink granite and both porphyritic and recrystallised rhyolite. Pebbles also include clasts of pebbly sandstone with a cement of opaque iron oxide (probably ilmenite) and fractured vein quartz with ilmenite filling the fractures. No systematic differences in pebble petrology could be detected between Sand & Gravel units 1 and 2. No pebbles of the distinctive Meguma Group metasediments have been found.

In Clay Unit 1, the pebbles consist only of vein quartz and quartz arenites resembling Horton Group sandstones. These clays contain predominant reworked Carboniferous palynomorphs (R. Fensome, pers. comm. 2002).

Sand grains are predominantly of sub-angular quartz, with a few percent of mica and traces of heavy minerals. Heavy minerals have been analysed from Sand & Gravel Unit 2, where they are concentrated as lags along foresets in cross-stratified sands. The dominant heavy minerals are ilmenite and its alteration products (cf. Pe-Piper et al. 2005d), rutile, zircon and tourmaline, with lesser staurolite, andalusite, monazite and cassiterite. This assemblage is similar to that found in nearby boreholes at Shubenacadie and in the Elmsvale basin (Fig. 1.2) (Pe-Piper et al. 2004; 2005a).

Single-crystal $^{40}Ar/^{39}Ar$ age determinations have been made on detrital muscovite from three samples in the West Indian Road pit. The ages are a little older than the muscovite ages for the South Mountain batholith determined by Carruzzo (2003), but the mean of 374 Ma is within the range of precise U-Pb ages for the batholith and its satellite plutons as summarized by Kontak et al. (2004).

Interpretation of paleogeography

Most of the Chaswood Formation is of similar lithologic character throughout the southern Maritime Provinces, comprising well sorted fluvial sand(stone) (locally gravelly) and overbank mudstones with paleosols and some lignite beds (Dickie 1986). The coarsest-grained sediment are found at the Vinegar Hill pit in southern New Brunswick (Falcon-Lang et al. 2004), suggesting a northerly provenance.

The earliest Chaswood Formation deposits at West Indian Road pit, Clay Unit 1, include small fluvial channel deposits and locally derived debris-flow deposits, suggesting deposition in a steep-sided local basin. Analogous local sediment supply to a confined basin is inferred for the oldest Chaswood Formation at Brierly Brook (Pe-Piper et al. 2005c). Overlying Sand & Gravel Unit 1 and younger strata contain clasts with a more distant provenance and are the deposits of a coarse bedload river system that deposited more widely over Nova Scotia than is represented by the present erosional remnants in outliers.

During deposition, there was ongoing tectonic deformation, resulting in the folding, faulting and local unconformities at the West Indian Road pit. Sedimentation kept pace with the creation of accommodation, so that local unconformities were overlain by further sand and gravel deposits and the mean paleocurrent direction to the SSE was almost orthogonal to the most active syn-sedimentary faults. Similar patterns are seen in many modern actively deforming basins (e.g., Leeder and Jackson 1993). The deformation of unconformities (Fig. 2.5) suggests that sediment accumulation may have taken place over a long period of time in the Early Cretaceous, with most fluvial sediment bypassing and accumulation taking place only as accommodation was created. Cessation of coarse sediment supply during deposition of Clay Units 2 and 3 could have been the result of tectonic deformation temporarily diverting the river to a new course.

Horsts within the Maritime Provinces shed coarse-grained detritus, including quartz arenites from the Horton Group of central Nova Scotia and igneous rocks from the Cobequid Highlands. Regionally, detrital monazite from boreholes yield predominantly Ordovician ages, suggesting important sediment supply from rocks deformed in the Taconic orogeny in northern New Brunswick (Pe-Piper and MacKay 2006).

The West Indian Road pit has a higher proportion of sand and gravel facies (> 90 %) compared with other parts of the Chaswood Formation. Only the Vinegar Hill pit (Falcon-Lang et al. 2004) has a similarly high proportion of coarse-grained sediment. Diogenes Brook (Dickie 1986) and Belmont (Pe-Piper et al. 2005c) have about 70% sand; the eastern Elmsvale basin (Stea and Pullan 2001; Pe-Piper et al. 2005b) has as little as 10% sand. Grain size analysis shows that gravel units at the West Indian Road pit are coarser grained than sand and gravel in the Chaswood type section (Stea and Pullan 2001) and the Shubenacadie outlier (Stea et al. 1996), suggesting that the West Indian Road pit lay on the principal drainage route from the northwest (Fig. 2.11).

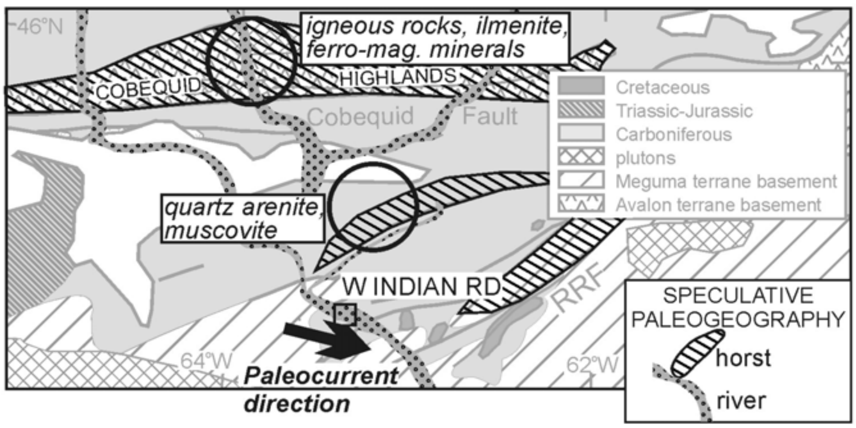


Figure 2.11. Sources of detritus for the West Indian Road pit and speculative paleogeography.

PART 3: Cores from outliers

Introduction

The field trip will end at Saint Mary's University in Halifax, where we will examine cores that show the range of lithofacies and diagenesis that is found in the Chaswood Formation. In this part of the field guide, we provide information on the principal outliers of Chaswood Formation that are represented by drill core.

Reference core RR-97-23 in the Elmsvale Basin

Stratigraphy

Borehole RR-97-23 in the central Elmsvale basin (Fig. 2.1) provides a continuously cored section of the Chaswood Formation located on a seismic-reflection profile (Fig. 2.2). The core is of wider diameter than that at the type section and thus more sample is available for laboratory studies. Pe-Piper et al. (2005a) therefore used this borehole as a reference section for detailed mineralogical and sediment facies studies of the Chaswood Formation.

Carboniferous rocks below 190.3 m comprise light gray-green silty dolomitic shale, and fine to medium sandstone of the Green Oaks Formation of the upper Windsor Group. The base of the Chaswood Formation is marked by a pebbly sandstone with granules and fine pebbles of underlying lithologies in a very fine sandstone matrix (termed breccia by Stea and Pullan 2001). The sandstone and minor interbedded silty mudstone beds from 185.8 m to 188.75 m are lithified, but not as indurated as the Carboniferous sandstone, and have similar detrital mineralogy to the basal pebbly sandstone, including <5% feldspar, apatite, tourmaline and sparse, apparently detrital, dolomite.

The Chaswood Formation is divided into eleven lithostratigraphic units (termed L1-2, M1-3, U1-6) on the basis of predominant lithologies and mineralogy (Fig. 2.1). The lowest unit, L1, from 190.3 to 178.4 m, consists predominantly of sandstone beds, with minor interbedded silty mudstone, resting on a basal pebbly sandstone. Unit L2, to 171.7 m, has thin-bedded sandstone and thicker interbedded muddy fine sandstone, with one horizon of lignitic mudstone overlying mottled medium gray mudstone. Unit M1 to 156.25 m includes 15% thick-bedded sandstone and muddy sandstone beds. Unit M2 to 148.0 m consists almost entirely of gray mudstone. Unit M3 to 143.0 m consists of gray mudstone with some red and purple mottling.

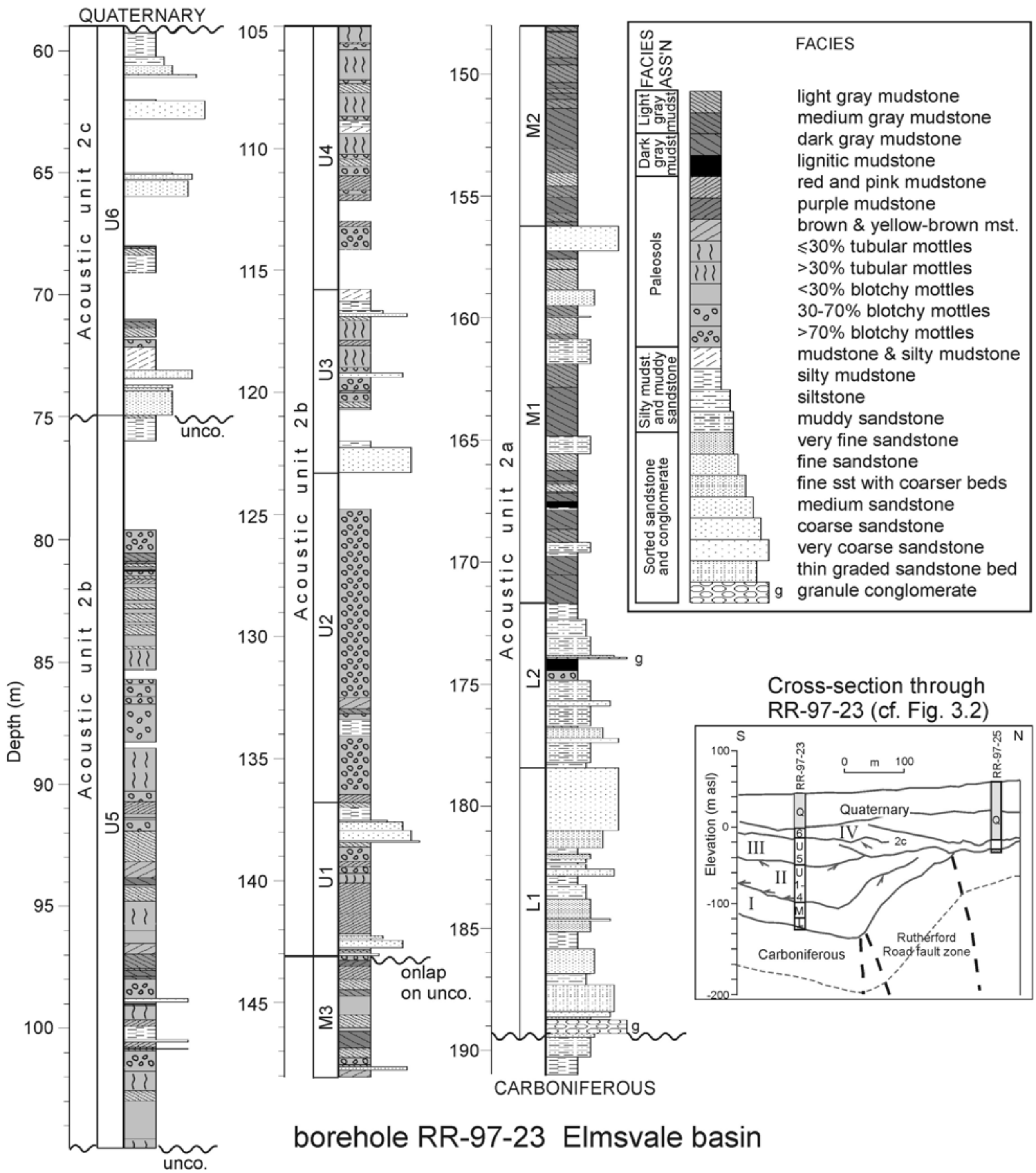


Figure 3.1. Detailed log of borehole RR-97-23 from the Elmsvale Basin

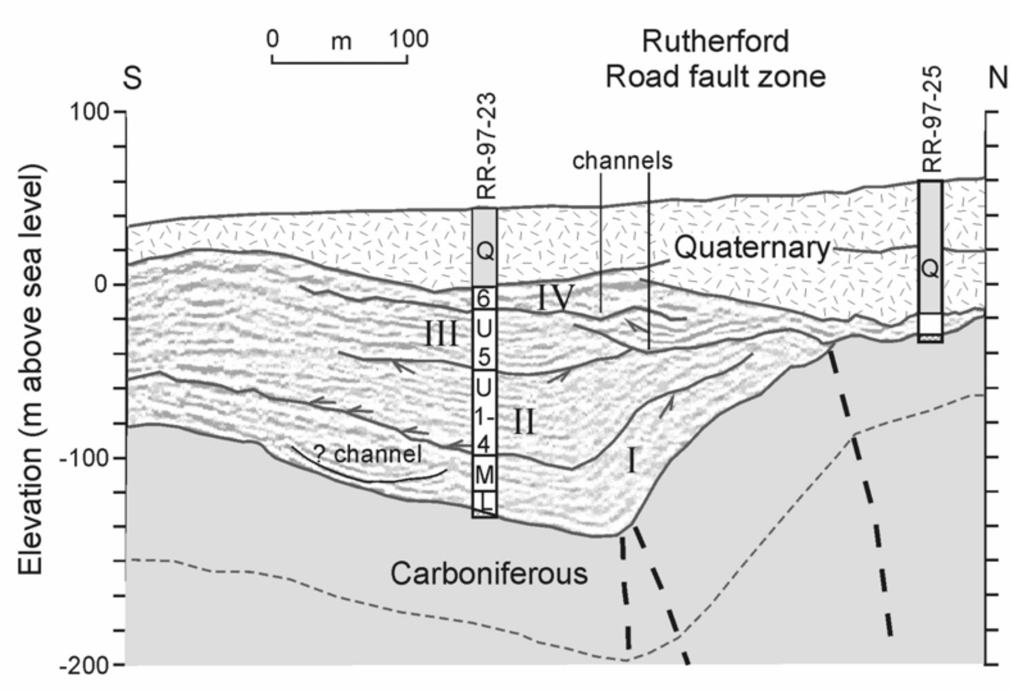


Figure 3.2. Seismic section through borehole RR-97-23 showing packets I – IV.

The overlying succession, from 143.0 m, has red mottled mudstone, with rare, generally thin, sandstone beds. Unit U1, to 136.8 m, is predominantly red and purple mudstone, gray mudstone with red mottles, and some thin-bedded sandstone. Unit U2, to 123.3 m, is mostly gray mudstone with 70% red mottles. Unit U3, to 115.8 m, has sandstone beds alternating with light gray and pink mudstone, with red mottles. Unit U4, to 104.9 m, is red mudstone and light gray mudstone with red mottles. Unit U5, to 75.0 m, consists of gray mudstone, red mudstone, mottled mudstone and rare thin-bedded sandstone. Unit U6, above 75 m, has only about 50% recovery, and consists of loose medium and coarse sands, minor sandstone, silty mudstone, and some light gray mudstone with only minor red mottling.

Seismic interpretation

South of RR-97-23, the base of the Chaswood Formation appears channeled and higher amplitude oblique reflections are interpreted as sandy channel fill. At the borehole site, the acoustic facies consists of lower amplitude slightly oblique reflections that correspond to alternating sandstone and mudstone in the borehole. These acoustic facies continue to the top of unit M1. Units M2 and M3 are characterised by laterally continuous planar reflections of moderate amplitude. The entire succession from L1 to M3 (corresponding to Packet I), together with the underlying Windsor

Group, was folded into a syncline along the Rutherford Road fault prior to and during deposition of units U1 to U4 (Packet II), which onlap the gently northward dipping top of M3 in the south and unconformably overlie the steeply dipping lower part of the formation in the north. In general, seismic reflections from Units U1 to U4 are of moderate amplitude and become progressively less folded upward. The base of Unit U5 (Packet III) is an unconformity and in the north, reflections are of rather higher amplitude and the unconformity is more strongly channeled. In borehole RR-97-23, U5 is predominantly mudstone, but the high-amplitude reflections with a channelled base are interpreted as a sandy channel. An acoustically similar facies, with a channeled erosive base, corresponds to Unit U6 (Packet IV) in the borehole, consisting predominantly of loose sands.

Detrital petrology and provenance

In borehole RR-97-23, sandstones are principally quartz arenites with minor litharenite in unit L1 (Fig 3.3). Sandstones from the base of the borehole are well indurated, whereas those near the top are friable or loose. Framework grains in unit L1 include 2–5 % each of muscovite and K-feldspar (Pe-Piper et al. 2004). Framework grains include up to 15% polycrystalline quartz in Unit L1, up to 3% in units L2 to U1, and less than 1% in units U3 and U6 (Fig. 3.4). The proportion of polycrystalline quartz that is either deformed or shows metamorphic foliation is higher in unit U6 than in lower units, where polycrystalline quartz is probably largely sourced from quartz veins.

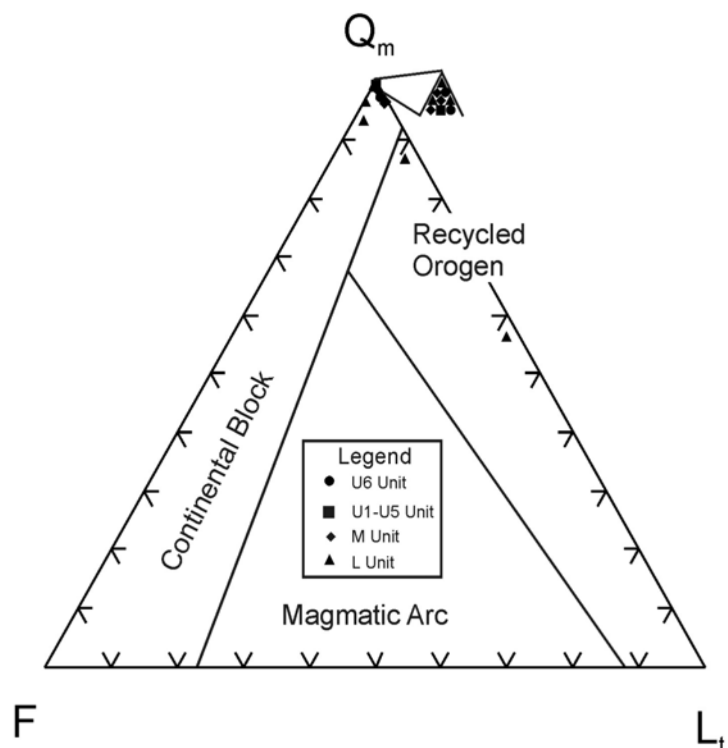


Figure 3.3. QFL diagram for sandstones from borehole RR-97-23

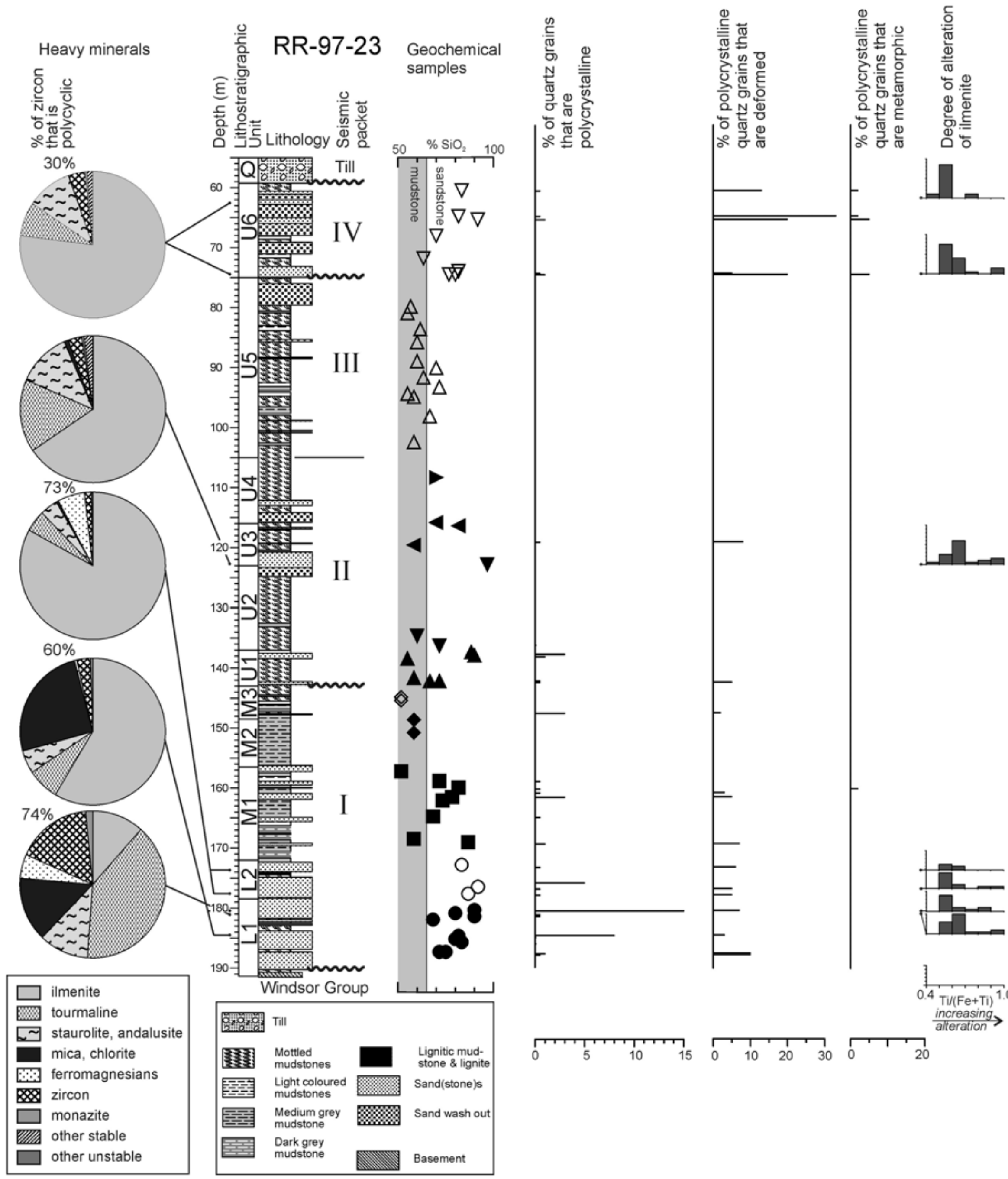


Figure 3.4. Summary of petrographic data from borehole RR-97-23

Detrital heavy minerals in the 63–250 μm range are composed principally of ilmenite (typically 60–80%), although some samples from unit L1 have little ilmenite (Fig. 3.4). Geochemical and textural studies of detrital ilmenite in the Chaswood Formation (Pe-Piper et al. 2005b) show that detrital ilmenite is generally altered to pseudorutile or leucoxene, with progressive loss of Fe. The relative abundance of ilmenite (sensu stricto) and high-Fe pseudorutile (Fig. 3.4) is thus an indicator of supply of relatively fresh ilmenite. Units L1 and L2 include 5–10% ferromagnesian minerals (excluding mica). Staurolite, tourmaline, zircon and monazite are found at all stratigraphic levels (Pe-Piper et al. 2004). Detrital zircons are principally either euhedral, of first-cycle igneous origin, or highly abraded, interpreted as polycylic in origin. The proportion of abraded zircons is 65% in unit L1 and 30% in unit U6 (Noftall 2007). Single-grain dating of monazite from units L1 and U6 by Pe-Piper and MacKay (2006) yielded early Silurian to Ordovician ages that suggest there was also a major source from the more inboard Gander and Humber terranes of the Appalachians, which are dominated by granitoid rocks of this age.

Diagenesis

Diagenesis in borehole RR-97-23 has been discussed in part 1 of this report and some diagenetic features are illustrated in Figures 1.8 and 1.9.

Other cores in Elmsvale Basin

Some information on other cores in Elmsvale Basin is provided in Figures 1.3 and 1.4 of this report.

Brierly Brook

General setting

Brierly Brook is located west of Antigonish in northeastern mainland Nova Scotia. A narrow strip of Cretaceous rocks rest on Windsor Group and is fault bound to the north by Horton Group sandstones that overlie Neoproterozoic basement of Browns Mountain Group (Fig. 3.5). Previous drilling by Kaoclay Resources at the western end of the basin had recovered 30 ft of dark grey clay at the northern edge of Kell's Enterprises Ltd. gravel pit (KH96-3, see Gillis 1997), but thick Pleistocene elsewhere in the pit and elsewhere in the Brierly Brook area. Stea et al.(1994) had reported an apparent outcrop of silica sand and our field investigations in 2002 (by D. Smeltzer) and 2003 (Stea et al. 2004) showed outcrops of silica sand, some with dark clay, in a zone WSW along strike between Kell's gravel pit and the outcrop discovered by Stea et al. (1994). In addition, dark clays outcropped on the northeast side of a low ridge immediately north of the Kell's gravel pit, near the Kaoclay borehole. Farther north on the Browns Mountain Road, poorly sorted and moderately

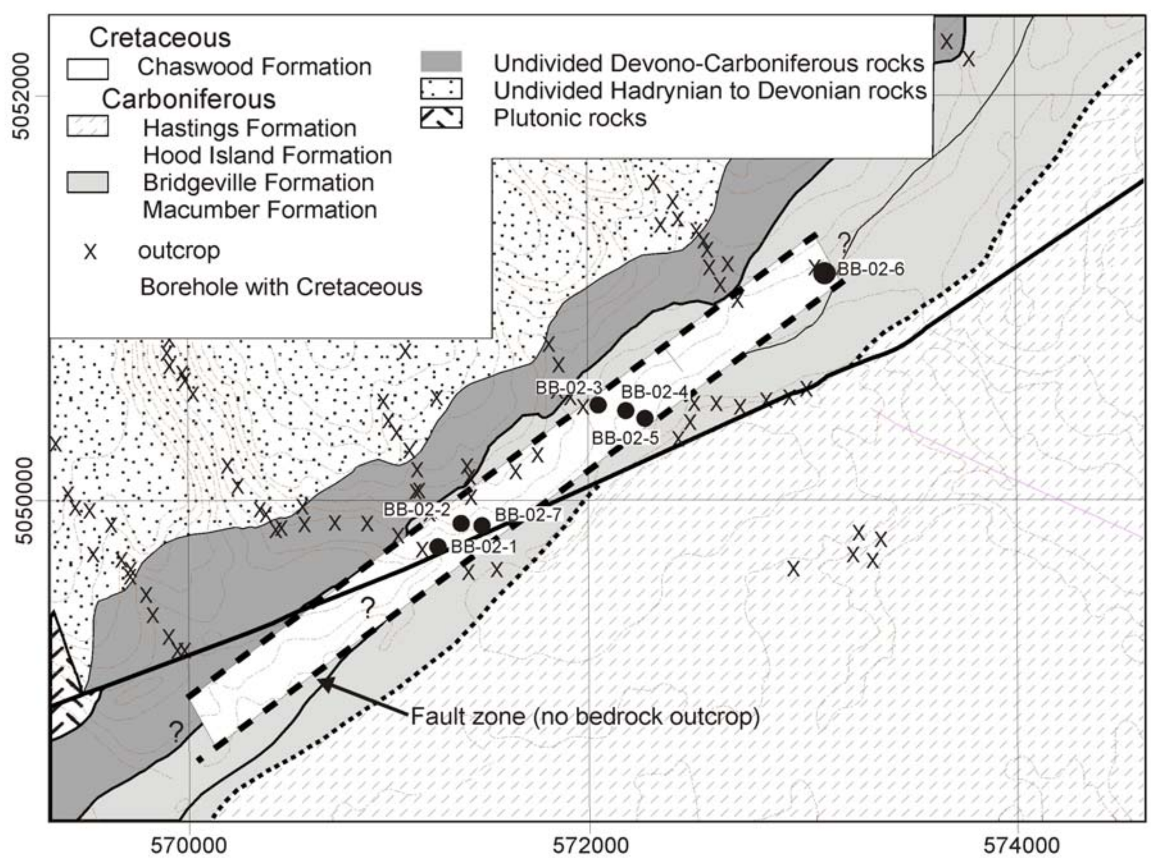


Figure 3.5. Geological map of the Brierly Brook inlier, showing location of boreholes (solid circles).

lithified polymictic coarse sandstone and conglomerate of the Horton Group outcrops. Windsor Group gypsum is widespread on the south side of Brierly Brook.

New Brierly Brook boreholes

Seven holes were drilled in 2002, with depths of up to 42 metres (Fig. 3.6). Recovery was quite variable and poor in loose sands. Boreholes 1, 2 and 7 in the west of the area provided a stratigraphic cross-section across the entire narrow basin (Figs. 1.10; 3.7). Boreholes 3, 4 and 5 formed a similar transect farther east: boreholes 3 and 4 encountered thick Pleistocene deposits, but Cretaceous sands were recovered on the northern edge of the basin at borehole 5. This borehole was adjacent to a large cut face in glacial till with thin Cretaceous rocks at the base. Borehole 6, at the

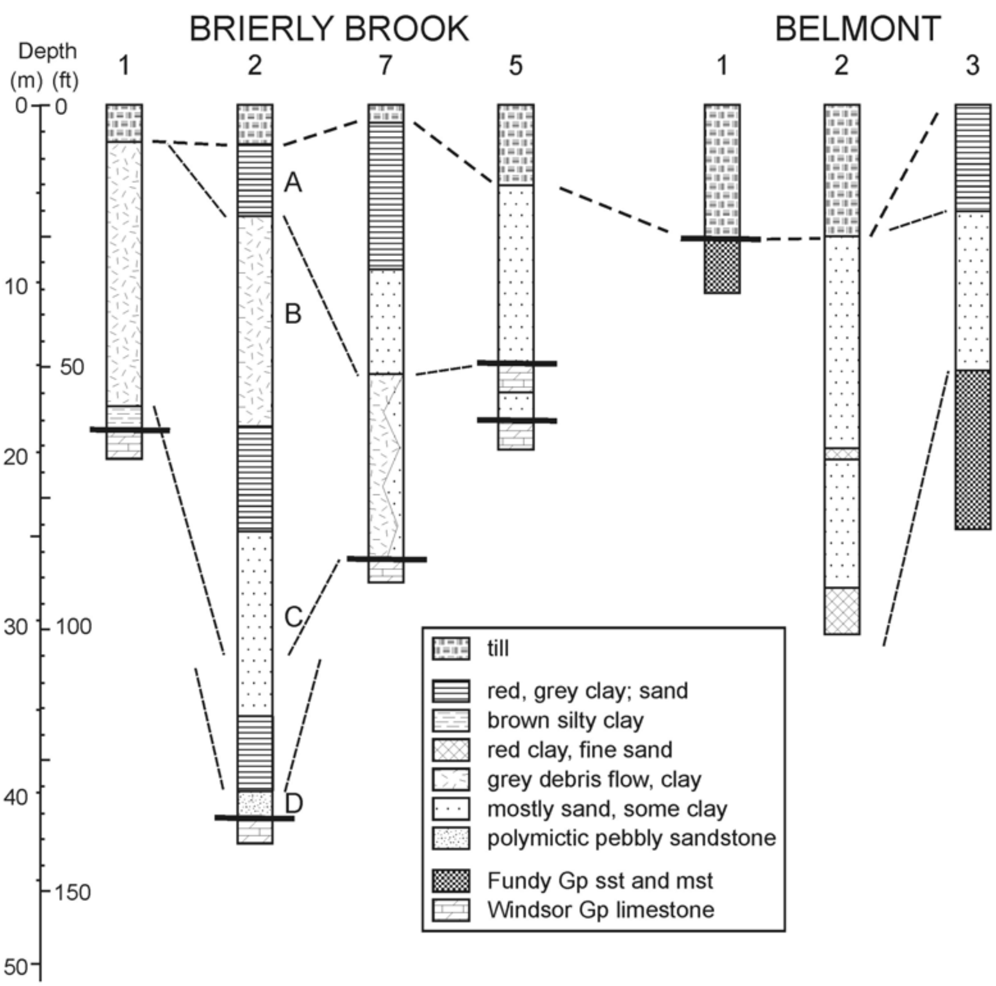


Figure 3.6. Summary core logs of boreholes drilled in 2002 at Brierly Brook and Belmont.

eastern end of the basin was drilled beside a bank with spoil of silica sand, but encountered Windsor Group limestone bedrock beneath thin fill.

The following stratigraphic section is recognised (Fig. 3.7):

Unit A varicoloured clays, some silica sand, particularly on the north side of the basin.

Unit B dark grey clay, some with quartz granules and clay clasts (debris-flow facies). In borehole 7, this unit has considerable interbedded sand. This facies resembles the Clay Unit 1 at the West Indian Road pit (Gobeil 2002).

Unit C varicoloured clays, some sands.

Unit D polymictic sandstone, resting unconformably on a weathered surface of Windsor Group limestone

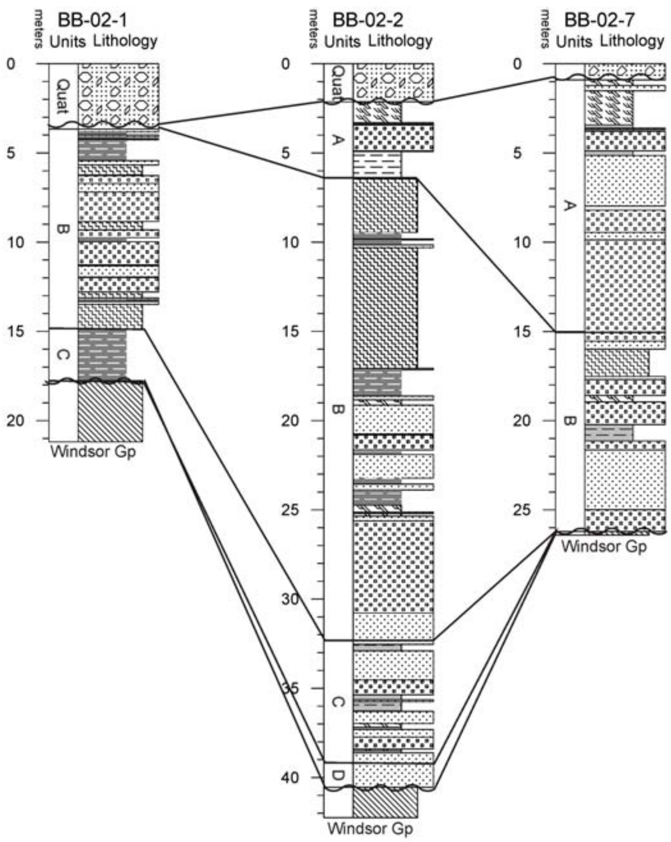


Figure 3.7. Boreholes 1, 2 and 7 at Brierly Brook. Legend as in Fig.1.9.

The dip section of holes 1, 2 and 7 (Fig. 1.10) suggests that silica sand is most abundant near the northern faulted margin of the basin. This is consistent with the abundance of sand in hole 5 and the presence of sand near the site of hole 6. The possible duplication of basement Windsor Group limestone in borehole 5 (Fig. 3.6) is based on speed of drilling and colour of returns. It is interpreted to mean that there is some thrusting at this contact. This interpretation is consistent with the faulting observed in the outcrops of Cretaceous strata in the cut bank behind the site of the borehole. Thus the Brierly Brook Cretaceous deposits are preserved in a very narrow basin and syn-depositional tectonism of the basin margin is demonstrated by the limited distribution of units C and D (Fig. 1.10). As argued by Stea et al. (2004), the deep but narrow fault-bound basin suggests an origin from strike-slip faulting.

Belmont

The Belmont silica sand locality is located on the north side of the road that runs east from Belmont. A silica sand pit (Fig. 3.8) was operated by Shaw Resources some time in the late 1960's or early 1970's. There are no outcrops associated with this pit, but on the north side is large stock pile of silica sand and on the south side a stock pile in less pure sands. Immediately to the southwest is a large sand pit in Pleistocene sediments extracted by Canada Cement.

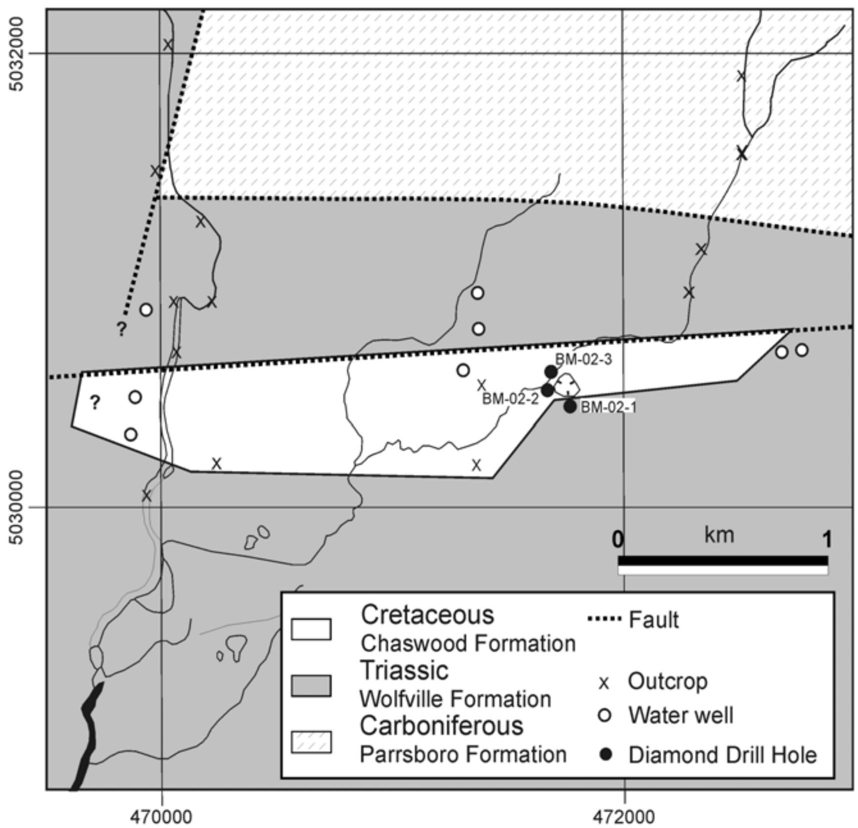


Figure 3.8. Map of the Belmont inlier showing pit and boreholes.

Three boreholes were drilled, each 30 m apart (Fig. 3.6). Borehole 1, although on strike from the pit, went through 8 m of till overlying Triassic Wolfville Formation sandstone. Boreholes 2 and 3 both sampled Cretaceous deposits up to 20 m thick (Fig. 3.9), but there were hole control problems with the loose sands. Hole 3 is interpreted to have reached Triassic Blomidon Formation red mudstones at 20.5 m. Some of the Cretaceous sands were cemented, showing cross-bedding and heavy mineral concentrations. Mudstones are generally red in colour.

Previous geological mapping and seismic-reflection profiles show that in the Belmont area, principal faults strike east-west (Fig. 3.8). The boreholes show that southwest of the pit, Wolfville Formation sandstone underlies < 9m of till, yet 40 m to the north there is > 20 m thickness of Cretaceous sediment (including thick silica sand) and a further 30 m to the north, Cretaceous sediment is 20 m thick, but has much thinner sand. The identification of Cretaceous sands in the nearby wells suggests that the Chaswood Formation forms a narrow E-W striking deposit.

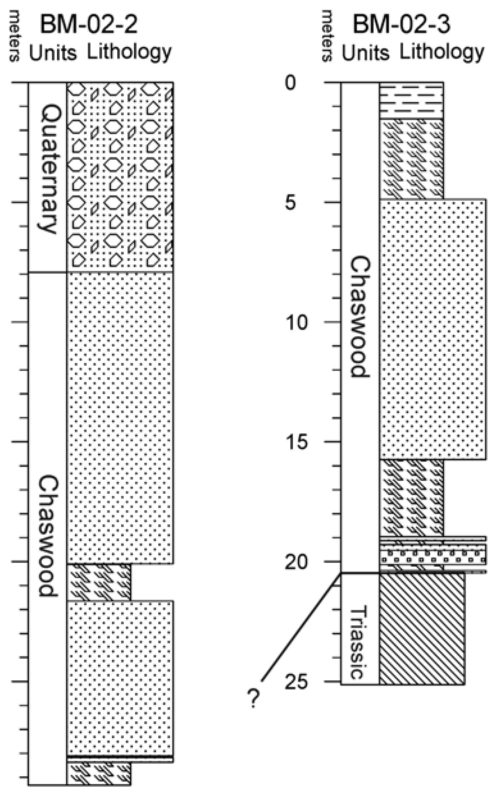


Figure 3.9. Logs of boreholes at Belmont. Legend as in Fig. 1.9.

Vinegar Hill

General setting

The Vinegar Hill deposit (Fig. 3.10) of Chaswood Formation (Falcon-Lang et al. 2004) unconformably overlies Mabou Group and is bound by young NE-striking faults. The northeastern part of the pit is underlain by Cretaceous clay, which dips southward at 20-35° and is overlain by a sequence of gravel and sand. The lower part of the

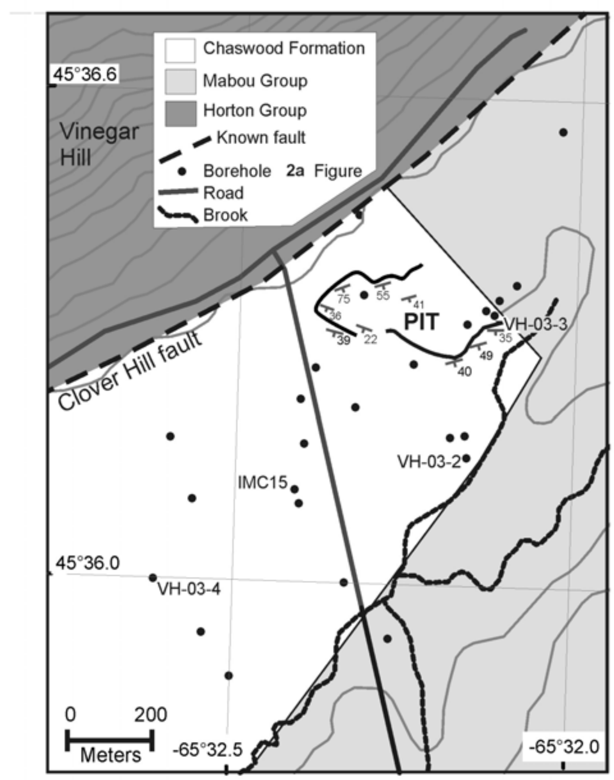


Figure 3.10. Map of the Vinegar Hill pit showing boreholes

Figure 3.11. Unconformity in the Vinegar Hill pit between the Lower and Upper Sand & Gravel units. Photo in 2001 by Rob Fensome.

gravel-sand succession has a similar dip, but in the face photographed by Fensome in 2001 and now excavated (Falcon-Lang et al. 2004) is unconformably overlain by almost horizontal gravel (Figs. 3.11, 3.12).

Stratigraphy

The lowest stratigraphic unit is the lower mudstone unit, which has a proved thickness of 12 m in borehole VH-03-3 (Fig. 3.13). It is overlain in the southeast part of the pit by coarse conglomerate and then a succession of conglomerate and sandstone in the main part of the pit, with a total thickness of at least 30 m. In the northeast part of the pit, the contact with the lower mudstone unit appears unconformable, where the mudstone dips at 60°. This conglomerate and sandstone in

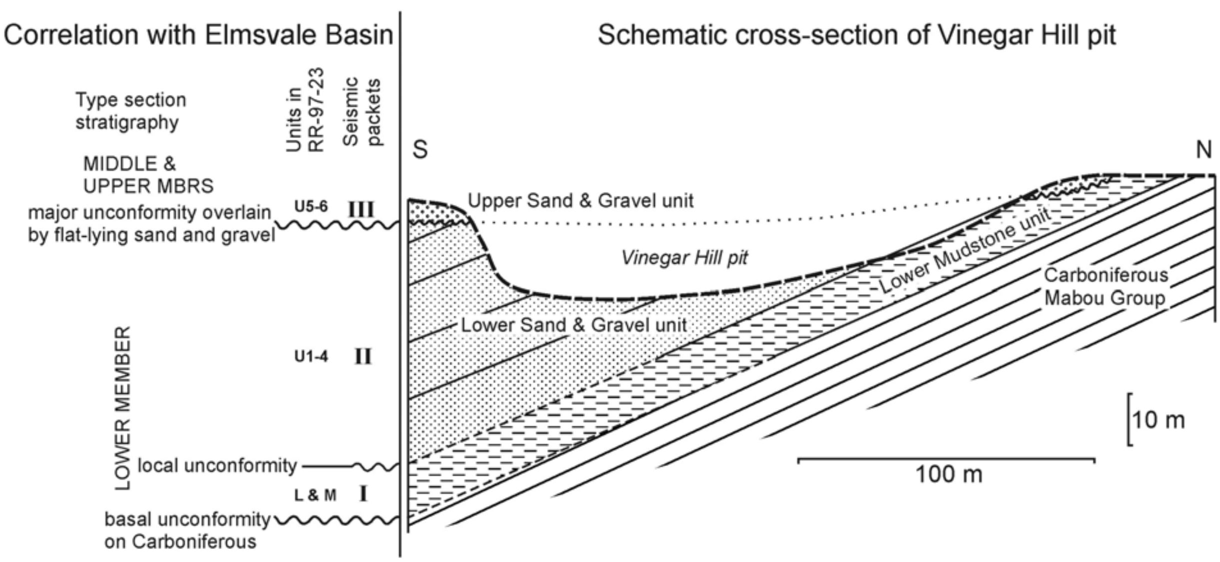


Figure 3.12. Schematic cross-section through the Vinegar Hill pit showing comparison with the Elmsvale Basin

the main part of the pit may be overlain unconformably by sandstone and conglomerate (Figs. 3.11, 3.12), as discussed above. The maximum known thickness of sand and gravel is 60 m.

Sedimentology and paleocurrents

The sedimentology of the conglomerates is generally similar to that described by Gobeil (2002) from the West Indian Road pit, with massive or poorly graded beds (**Gm**, **Gms**) predominating. Rare deposits of laminated fine sand are found, which tend to have concentrated plant fragments ("tea leaves") and large mica flakes. No cross lamination was seen at any of these localities.

Only three paleocurrent indicators have been found. Trough cross-bedding in coarse sand is to 260° and bar- margin planar cross bedding is to 190° and 230°. Collectively, these probably indicate mean paleocurrents generally to the southwest, parallel to the margin of Vinegar Hill.

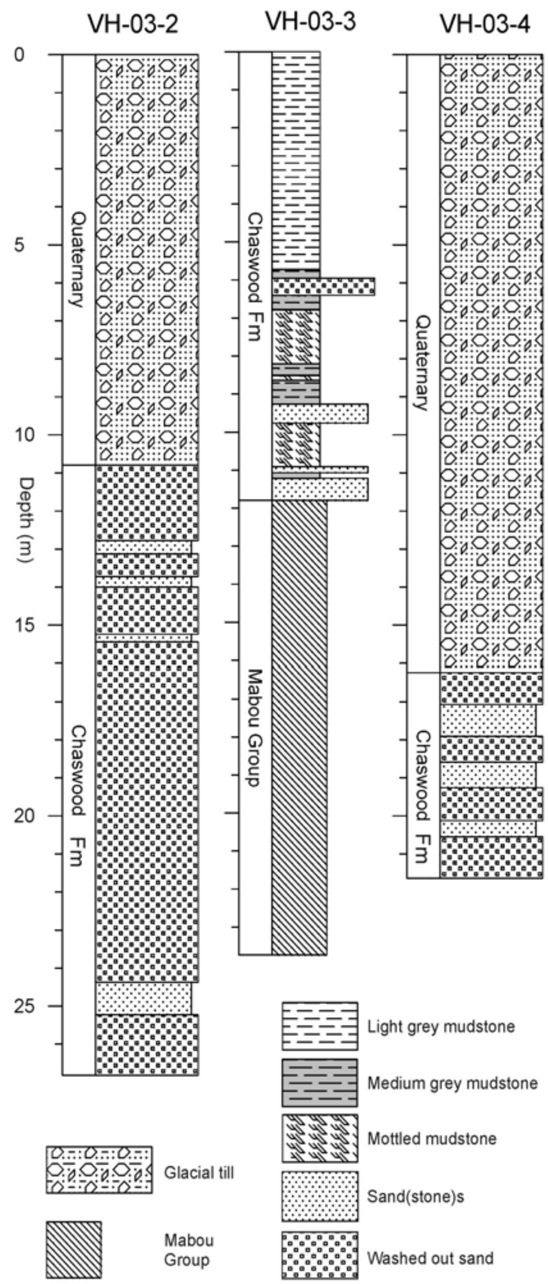


Figure 3.13. Logs of boreholes from near the Vinegar Hill pit. Locations shown in Fig. 3.10.

Acknowledgments

We thank Thian Hundert, Steve Ingram, Lila Dolansky and Ann Okwese for assistance with laboratory work and Mary Feetham, Jean-Philippe Gobeil, Ralph Stea, and Venu Venugopal for assistance with fieldwork. We acknowledge the critical role of Dave Brown in initiating this project. We thank Gordon Dickie and Jeff Newton of Shaw Resources for their willingness to provide access to and information on the West Indian Road pit. Work on the Chaswood Formation was funded by the ExxonMobil Sable Project, Petroleum Research - Atlantic Canada, the Natural Sciences and Engineering Research Council of Canada, and the Geological Survey of Canada.

References

Arne, D.C., Duddy, I.R., and Sangster, D.F. 1990. Thermochronologic constraints on ore formation at the Gays River Pb-Zn deposit, Nova Scotia, Canada, from apatite fission track analysis. Canadian Journal of Earth Sciences, v. 27, p. 1013-1022.

Carruzzo, S. 2003. Granite-hosted mineral deposits of the New Ross area, South Mountain Batholith, Nova Scotia. Ph.D. thesis, Dalhousie University, 571 p.

Collinson, J.D. 1996. Alluvial sediments. Chapter 3, in H.G. Reading, ed. , Sedimentary environments, 3rd edition. Blackwell, Oxford, p. 37-82.

Davies, E.H. 1983. Palynological analysis of the Cretaceous semiunconsolidated sediments, Diogenes Brook, Cape Breton Island, Nova Scotia. Geological Survey of Canada (Atlantic) Internal Report no EPGS-PAL.3-83EHD.

Davies, E.H., Akande, S.O. and Zentilli, M. 1984. Early Cretaceous deposits in the Gays River lead-zinc mine. Current Research, part A, Geological Survey of Canada Paper 84-1A, p. 353-358.

Dickie, G. B. 1986. Cretaceous deposits of Nova Scotia. NS Dept. of Mines and Energy, Paper 86-1, 54 p.

Donohoe, H.V. Jr., and Wallace, P.I. 1985. Repeated orogeny, faulting and stratigraphy of the Cobequid Highlands, Avalon Terrane of northern Nova Scotia. Geological Association of Canada - Mineralogical Association of Canada Joint Annual Meeting, Guidebook 3, Fredericton, N.B.

Eisnor, K. 2002. Palynology of the Lower Cretaceous Chaswood Formation, Elmsvale Basin and Shubenacadie Outlier, Nova Scotia. B.Sc. hons. thesis, Dalhousie University, 68 p.

Falcon-Lang, H., Fensome, R.A. and Venugopal, D.V. 2004, The Cretaceous age of the Vinegar Hill silica deposit of southern New Brunswick: evidence from palynology and paleobotany: Atlantic Geology, v. 39, p. 39-46.

Falcon-Lang, H. J., Fensome, R. A., Gibling, M. R., Malcolm, J., Fletcher, K. R., and Holleman, M., 2007. Karst-related outliers of the Cretaceous Chaswood Formation of Maritime Canada. Canadian Journal of Earth Sciences, v. 44, p. 619–642.

Gillis, M.X., 1997. A report on the 1996-1997 exploration program for kaolin clays in the Musquodoboit, Stewiacke, Shubenacadie and Antigonish regions of Nova Scotia. N.S. Dept. of Natural Resources, Assessment Report 97-027, 93 p., plus numerous unpaginated appendices.

Gobeil, J.-P. 2002. Stratigraphy, sedimentology, and provenance of the Chaswood Formation, West Indian Road pit, Shubenacadie, Nova Scotia. M.Sc. thesis, Dalhousie University.

Gobeil, J.-P., Pe-Piper, G., Piper, D.J.W., 2006. The Early Cretaceous Chaswood Formation in the West Indian Road pit, central Nova Scotia. Canadian Journal of Earth Sciences, v. 43, p. 391–403.

Grist, A.M. and Zentilli, M., 2003. Post-Paleocene cooling in the southern Canadian Atlantic region: evidence from apatite fission track models. Canadian Journal of Earth Sciences, v. 40, p. 1279-1297.

Hacquebard, P.A., 1984. Composition, rank and depth of burial of two Nova Scotia lignite deposits.

Geological Survey of Canada Paper 84-1a,
Hundert, T., Piper, D.J.W., Pe-Piper, G., 2006. Genetic model and exploration guidelines for kaolin beneath unconformities in the Lower Cretaceous fluvial Chaswood Formation, Nova Scotia. Exploration and Mining Geology, v. 15, p. 9–26.
Hurst, V.J., Pickering, S.M., 1997. Origin and classification of coastal-plain kaolin, southeastern USA, and the role of groundwater and microbial action. Clays and Clay Minerals, v. 45, p. 274–285.
Kontak, D.J., Ham, L.J., and Dunning, G. 2004. U-Pb dating of the Musquodoboit Batholith, southern Nova Scotia: evidence for a protracted magmatic-hydrothermal event in a Devonian intrusion. Atlantic Geology, v. 40, p. 207-216.
Leeder, M.R. and Jackson, J.A. 1993. The interaction between normal faulting and drainage in active extensional basins, with examples from the western United States and central Greece. Basin Research, v. 5, p. 79-102.
Lunt, I.A., Bridge, J.S. and Tye, R.S. 2004. A quantitative, three dimensional depositional model of gravelly braided rivers. Sedimentology, v. 51, p. 377-414.
Miall, A.D. 1977. A review of the braided-river environment. Earth Science Reviews, v. 13, p. 1-62.
Nilsen, T.H. Sylvester, A.G. 1995. Strike-slip basins. In: Busby, C.J., Ingersoll, R.V.(Eds.), Tectonics of sedimentary basins, Blackwell, Oxford, p. 425-457.
Noftall, R., 2007. Detrital zircons as provenance indicators in the Cretaceous Chaswood Formation. B.Sc. honours thesis, Saint Mary's University, Halifax, N.S., 69 p.
Patrier, P., Beaufort, D., Laverret, E. & Bruneton, P. (2003) High-grade diagenetic dickite and $2M_1$ illite from the Middle Proterozoic Kombolgie Formation (Northern Territory, Australia). *Clays Clay Miner.* v. 51, p. 102-116.
Pe-Piper, G., Mackay, R.M., 2006. Provenance of Lower Cretaceous sandstones onshore and offshore Nova Scotia from electron microprobe geochronology and chemical variation of detrital monazite. Bulletin of Canadian Petroleum Geology, v. 54, p. 366–379.
Pe-Piper, G., Piper, D.J.W., 2004. The effects of strike-slip motion along the Cobequid-Chedabucto-SW Grand Banks fault system on the Cretaceous–Tertiary evolution of Atlantic Canada. Canadian Journal of Earth Sciences, v. 41, p. 799–808.
Pe-Piper, G., Dolansky, L., Piper, D.J.W., 2005a. Sedimentary environment and diagenesis of the mid-Cretaceous Chaswood Formation, Elmsvale Basin, Nova Scotia. Sedimentary Geology, v. 178, p. 75–97.
Pe-Piper, G., Jansa, L.F. and Palacz, Z. 1994. Geochemistry and regional significance of the Early Cretaceous bimodal basalt-felsic associations on Grand Banks, eastern Canada. Geological Society of America Bulletin, v. 106, p. 1319-1331.
Pe-Piper, G., Okwese, A., Piper, D.J.W., 2006. Volcanic ash and lignite of the Lower Cretaceous Chaswood Formation, central Nova Scotia. Geological Survey of Canada Open File 4973.
Pe-Piper, G., Piper, D.J.W., Hundert, T., Stea, R.R., 2005b. Outliers of Lower Cretaceous Chaswood Formation in northern Nova Scotia: results of scientific drilling and studies of sedimentology and sedimentary petrography. Geological Survey of Canada Open File 4845, 305 p.
Pe-Piper, G., Piper, D.J.W., Dolansky, L.M., 2005c. Alteration of ilmenite in the Cretaceous sands of Nova Scotia, southeastern Canada. Clays and Clay Minerals, 53, 490–510.
Pe-Piper, G., Stea, R.R., Ingram, S., and Piper, D.J.W. 2004. Heavy minerals and sedimentary petrology of the Cretaceous sands from the Shubenacadie outlier, Nova Scotia. Nova Scotia Department of Natural Resources, Open File Report ME 2004-5, 78 p.
Pe-Piper, G., Triantafyllidis, S. and Piper, D.J.W., 2008. Geochemical identification of clastic sediment provenance from known sources of similar geology: the Cretaceous Scotian Basin, Canada. Journal of Sedimentary Research (in press)
Piper, D.J.W., Pe-Piper, G., Douglas, E.V., 2005. Tectonic deformation and its sedimentary consequences during deposition of the Lower Cretaceous Chaswood Formation, Elmsvale basin, Nova Scotia. Bulletin of Canadian Petroleum Geology, v. 53, p. 189–199.

Piper, D.J.W., Pe-Piper, G., Hundert, T., Venugopal, D.K., 2007. The Lower Cretaceous Chaswood Formation in southern New Brunswick: provenance and tectonics. Canadian Journal of Earth Sciences, v. 44, p. 665–677.

Price, J. 2000. Silica sand exploration in the Shubenacadie Basin 1999/2000. Shaw Resources, unpublished exploration report.

Roden-Tice, M.K. and Wintsch, R.P., 2002. Early Cretaceous normal faulting in southern New England; evidence from apatite and zircon fission-track ages. Journal of Geology, v. 110, p. 159-178.

Stea, R.R. and Fowler, J.H. 1981. Petrology of Lower Cretaceous silica sands at Brazil Lake, Hants County, Nova Scotia. Mineral Resources Division Report of Activities, Report 81-1, p. 47-64.

Stea, R. and Pullan, S. 2001. Hidden Cretaceous basins in Nova Scotia. Canadian Journal of Earth Sciences, v. 38, p. 1335-1354.

Stea, R.R., Finck, P.W., Prime, G, and Demont, G.J., 1994. New discoveries of silica sand and kaolinite near Brierly Brook, Antigonish County. Minerals and Energy Branch report of Activities 1994, Report 95-1, p. 159-162.

Stea, R.R., Finck, P.W., Pullan, S.E., and Corey, M.C. 1996, Cretaceous deposits of kaolin clay and silica sand in the Shubenacadie and Musquodoboit valleys, Nova Scotia, Canada. N.S. Dept. of Natural Resources, Mines and Minerals Branch, Open File Report 960003, 58 p.

Stea, R.R., Pe-Piper, G. and Piper, D.J.W., 2004. Early Cretaceous outliers in northern Nova Scotia: the fault connection. Atlantic Geoscience Society Colloquium Program and Abstracts, v. 30, p. 29.

Telford, P.G. and Long, D.G.F., 1986. Mesozoic geology of the Hudson platform. In: I.P. Martini (ed.), Canadian Inland Seas, Elsevier Oceanography Series 44, p. 43-54.

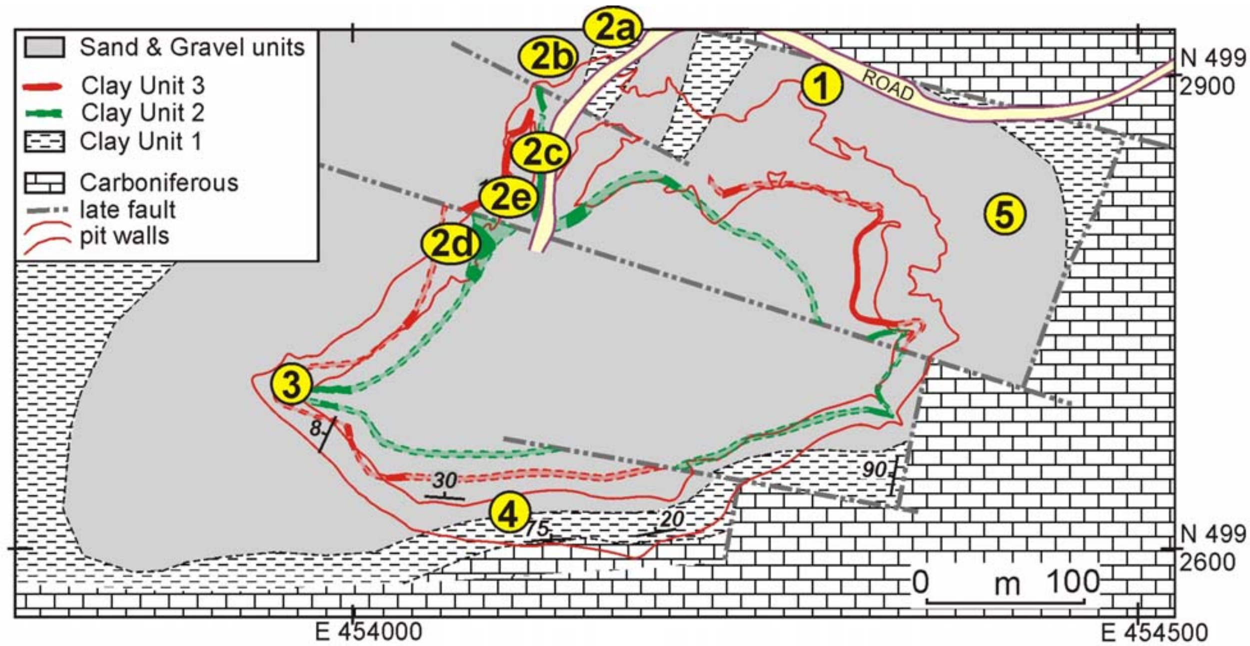
Tucholke, B.E., Sawyer, D.S. and Sibuet, J.-C., 2007. Breakup of the Newfoundland–Iberia rift. Geological Society of London Special Publication 282, p. 9–46.

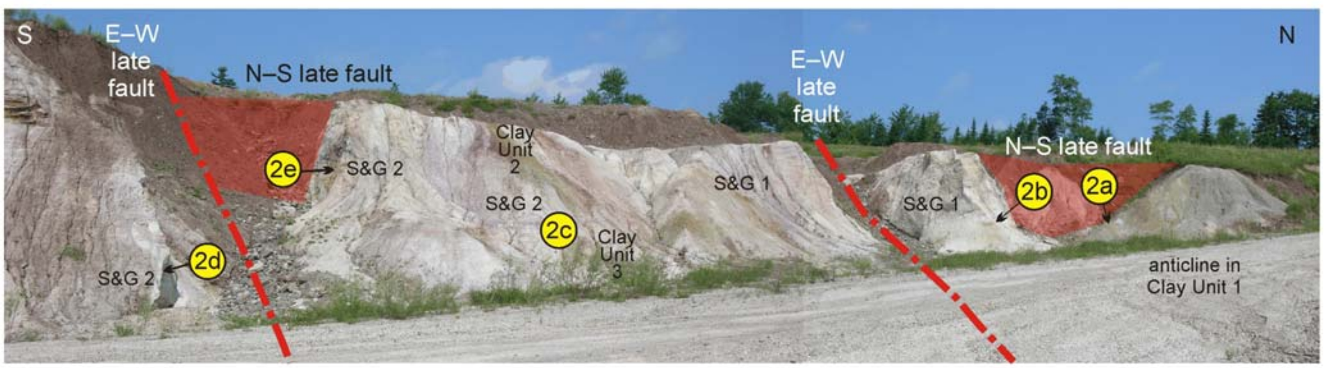
Wade, J.A. and MacLean, B.C. 1990. Aspects of the geology of the Scotian Basin from recent seismic and well data. Geology of Canada, 2, v. 190-238.

Woodcock, N.H. and Schubert, C. 1994. Continental strike-slip tectonics. *In* Continental deformation. *Edited by* P.L. Hancock. Pergamon Press, pp.

Weir Murphy, S.L., 2004. Cretaceous rocks of the Orpheus graben, offshore Nova Scotia. M.Sc. thesis, Saint Mary's University.

Brief description of stops at the West Indian Road pit





Stop 1. Walk to the edge of the pit and discuss overview of pit

Stop 2a. Anticline in Clay Unit 1. Faulted margin of unknown age.
Stop 2b. Sedimentology of Sand and Gravel Unit 1.
Stop 2c. Clay unit 3; Clay Unit 2 farther back in cliff.
Stop 2d. Sedimentology of Sand and Gravel Unit 2. Apparent syn-sedimentary deformation of fine sands.
Stop 2e. Sedimentology and structures in Sand and Gravel Unit 2. Possible analogue of Fig. 2.7.

Stop 3. *This outcrop is under water in August 2008.* Clay unit 2 showing deformation. Sedimentology of sands.

Stop 4. Bedding plane surfaces in Clay Unit 1.

Stop 5. Stock pile. Examine clast petrology.

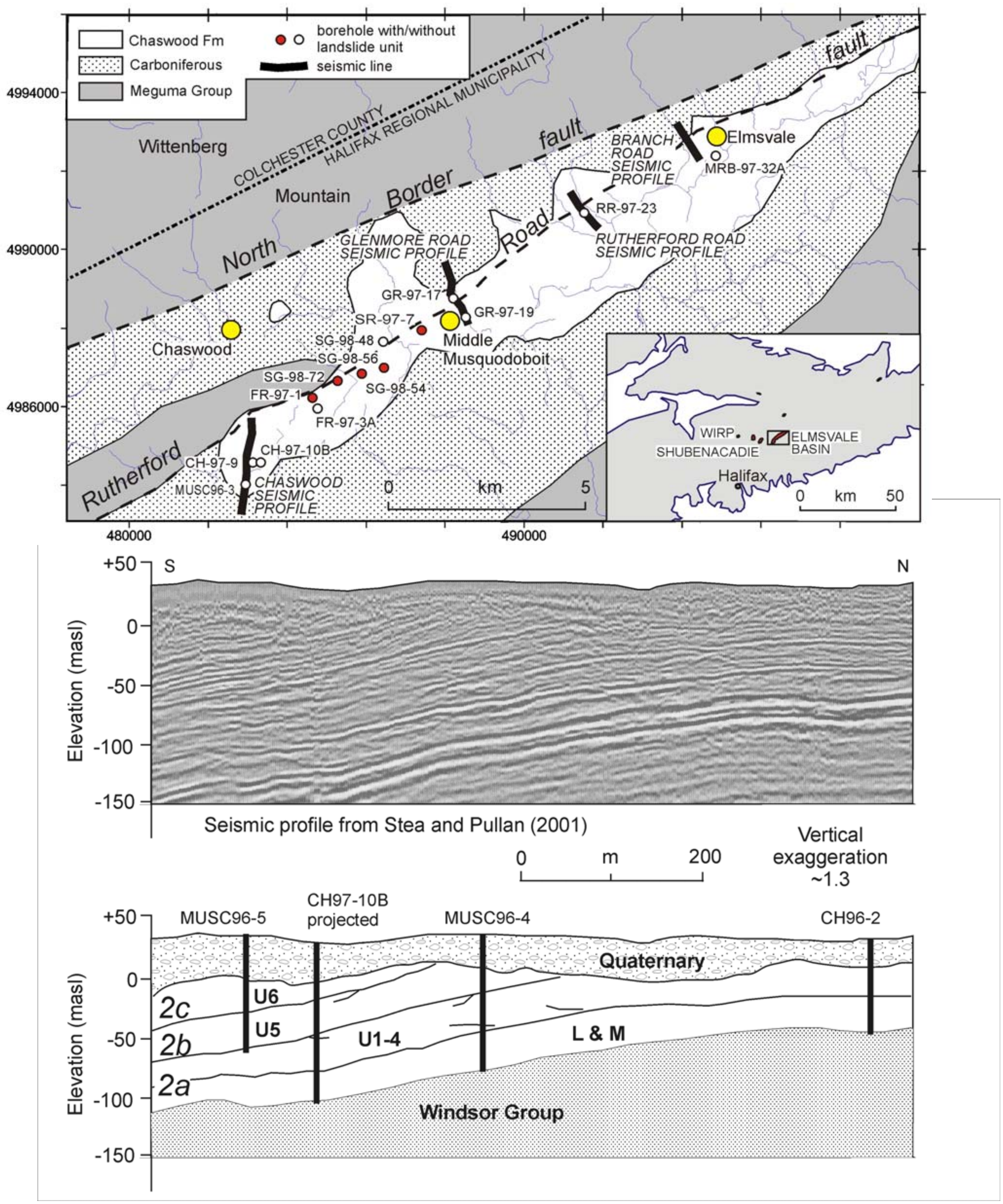
NOTES

NOTES

NOTES

The Chaswood type section

In the middle of Chaswood, take Meadow Road south towards Elderbank: on descending from the hill about 2 km south of Chaswood, there is a view to the east of the Rutherford Road Fault line in the topography and the type section of the Chaswood Formation from seismic and boreholes across the flat land to the south.



NOTES

NOTES

NOTES

Conjugate Margins Conference
Halifax 2008

OETR
CNSOPB — CANADA-NOVA SCOTIA OFFSHORE PETROLEUM BOARD
NOVA SCOTIA Department of Energy

Diamond $15,000+

BR PETROBRAS
bhpbilliton resourcing the future

Platinum $10,000–$14,999

ExxonMobil
Husky Energy
Atlantic Canada Opportunities Agency — Agence de promotion économique du Canada atlantique — Canada
EnCana energy for people

Gold $6,000–$9,999

Bronze $2,000–$3,999

CANADIAN SUPERIOR ENERGY INC.
RPS Energy
ion

Schlumberger
Petroleum Research Atlantic Canada

Patron $1,000–$1,999

Natural Resources Canada — Ressources naturelles Canada — Canada
Geological Survey Canada 1842 — Commission géologique

Partners $500 - $999

Minerals Management Service

SUPPORTERS

Geological Journal
DALHOUSIE UNIVERSITY Inspiring Minds
Canadian Society of Petroleum Geologists
American Association of Petroleum Geologists
PESGB
AGS
Houston Geological Society