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LITHOSTRATIGRAPHIC MODEL, GEOCHEMISTRY AND SEDIMENTOLOGY OF THE COTTRELLS COVE GROUP, BUCHANS–ROBERTS ARM VOLCANIC BELT, NOTRE DAME SUBZONE

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ABSTRACT

The Cottrells Cove Group (Notre Dame Subzone, Dunnage Zone) is represented by volcano-sedimentary rocks of the Fortune Harbour Formation and by conformably overlying sedimentary rocks of the Moores Cove Formation. The Cottrells Cove Group is broadly correlated with the Roberts Arm Group. The Chanceport Fault outcrops as a minor structure restricted to the rocks of the Cottrells Cove Group and does not separate distinct geological units. The lowest N-MORB pillow lavas of the Fortune Harbour Formation are in a possible conformable relationship with the underlying pillow lavas of the Moretons Harbour Group. The remaining, thrust-bound sections of the Fortune Harbour Formation consist of younger, island-arc lavas, followed by a 1250-m-thick succession of radiolarian cherts and volcaniclastic deposits, representative of an oversupplied basin plain. E-MORB pillow lavas and the overlying radiolarites are considered the youngest rocks of the Fortune Harbour Formation. The overlying Moores Cove Formation is represented by the coarsening-upward succession of lower-slope–basin-plain and submarine-fan deposits and contains in the upper part detritus reminiscent of the Upper Ordovician–Lower Silurian deep-sea turbidites of the Exploits Subzone. Its provenance differs significantly from that of the exclusively volcaniclastic, tuffaceous deposits of the Fortune Harbour Formation.

INTRODUCTION

The Early Ordovician Buchans–Roberts Arm volcanic belt in central Newfoundland constitutes an extensive portion of the Notre Dame Subzone (Dunnage Zone). It incorporates broadly correlated volcano-sedimentary units of the Buchans, Roberts Arm, Cutwell, Cottrells Cove and Chanceport groups. Conodonts from the Buchans and Cutwell groups indicate ages ranging from late Arenig to late Llanvirn (Nowlan and Thurlow, 1984; O'Brien and Szybiński, 1989), consistent with U–Pb dates of 473^{+3}_{-2}, 473 ± 2 and 469^{+5}_{-3} Ma from the Buchans, Roberts Arm, and Cutwell groups (Dunning *et al.*, 1987; Dunning and Krogh, 1988).

Regional studies of the whole-rock geochemistry of mafic volcanic rocks show that the Buchans and Roberts Arm groups formed in an island-arc setting and in a transitional arc to back-arc environment (Swinden, 1992). Major volcanic massive sulphide deposits at Buchans and Pilley's Island and the Lake Bond stockwork deposit, although widely separated are hosted by geochemically similar island-arc volcanic rocks.

The lithostratigraphy of the Roberts Arm Group has been proposed by Bostock (1988). Other detailed lithostratigraphic and related structural and paleomagnetic studies in the Buchans–Roberts Arm volcanic belt include Swinden and Sacks (1986), Thurlow and Swanson (1987), Calon and Green (1987), Pope *et al.* (1990), Van der Voo *et al.* (1991), van der Pluijm *et al.* (1990, 1993) and Lafrance and Williams (1992).

GEOLOGICAL SETTING

The Cottrells Cove Group was defined by Dean (1978, p. 150). Its volcano-sedimentary rocks remain undated but form a natural eastward extension of the Roberts Arm Group and correlate with the undated Chanceport Group on New World Island (Strong and Payne, 1973; Lafrance and Williams, 1992). The Cottrells Cove Group is exposed on the Fortune Harbour Peninsula and on numerous islands in New Bay and Bay of Exploits (Figures 1 and 2). According to Dean (1978) melange of the Boones Point Complex represents the lowest unit of the Cottrells Cove Group and is overlain in succession by the Moores Cove and Fortune Harbour formations. O'Brien (1990, 1991a,b) re-defined the Cottrells Cove Group by excluding from it the Boones Point Complex and by placing the Moores Cove Formation conformably above the Fortune Harbour Formation.

Lafrance and Williams (1992, p. 1903) considered the Cottrells Cove and Chanceport groups as the 'Chanceport Terrane'. In the area of New World Island (the original extent of the Chanceport Group) the terrane was subdivided into

[1] Mineral Deposits Section

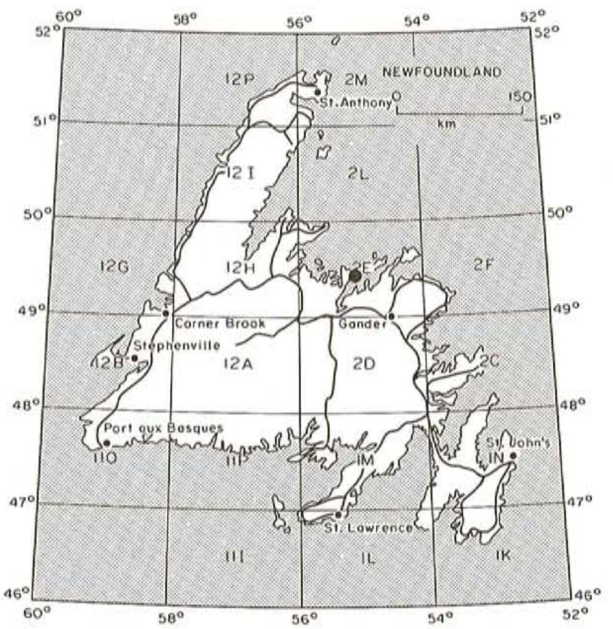


Figure 1. *Index map showing the location of the study area.*

a lower volcanic unit, overlain by an upper sedimentary unit. On the Fortune Harbour Peninsula (the main outcrop of the Cottrells Cove Group) the upper sedimentary unit was additionally overlain by an upper volcanic unit.

The rocks of the Cottrells Cove and Chanceport groups are arranged in a system of steeply dipping thrust slices (O'Brien, 1993; Strong and Payne, 1973). Younging directions within the fault-bound volcano-sedimentary packages vary from north to south, although north-facing directions are most common (Figures 3 and 4).

The melange of the Boones Point Complex and the Lukes Arm Fault marks the southern boundary of the Cottrells Cove Group (Helwig, 1967, 1969; Nelson, 1981; Lafrance, 1989; Figure 2). This boundary defines, in part, the Red Indian Line, which separates rocks of Notre Dame and Exploits subzones (Williams *et al.*, 1988; O'Brien, 1991b; but see also van der Pluijm *et al.*, 1990, 1993 and Van der Voo *et al.*, 1991). The melange contains fragments of polymictic conglomerate, sandstone, black shale, chert, pillow basalt, and limestone containing Llanvirn–Llandeilo conodonts (Helwig, 1967, 1969; Nelson, 1981). Some of the melange components resemble Llanvirn–Upper Ashgill sedimentary rocks of the Exploits Subzone (Strong Island Chert, Caradocian black shale, turbiditic sandstones of the Point Leamington Formation and Randels Cove ('Goldson') Conglomerate; Dec *et al.*, 1992, 1993). Volcanic and sedimentary rocks of the Cottrells Cove Group (Notre Dame Subzone) have also been incorporated into the melange, namely the turbiditic deposits of the Moores Cove Formation and the lavas of the Fortune Harbour Formation (this report, and Nelson, 1981).

The northeastern and northern boundaries of the Cottrells Cove and Chanceport groups have previously been interpreted as a major structural break, the Chanceport (or Lobster Cove–Chanceport) Fault (Dean and Strong, 1977; Kean, 1977; Strong and Payne, 1973; Williams and Payne, 1975; van der Pluijm *et al.*, 1990, 1993; Johnson *et al.*, 1991; Van der Voo *et al.*, 1991; Lafrance and Williams, 1992; Figure 2). The fault has been shown to separate the Moretons Harbour Group from the Cottrells Cove and Chanceport groups (Dean and Strong, 1977; Strong and Payne, 1973) or the Twillingate and Chanceport terranes (of Lafrance and Williams, 1992; see also van der Pluijm *et al.*, 1990, 1993). The field relationships exhibited along the fault and the preliminary geochemical data from mafic lavas of the Fortune Harbour Formation are incompatible with the existing status of the Chanceport Fault as a prominent structural boundary. At a number of localities on the Fortune Harbour Peninsula, Exploits Island, Little Black Island and New World Island, the 'Chanceport Fault' outcrops as a minor dislocation restricted to the rocks of the Cottrells Cove and Chanceport groups.

This progress report presents a preliminary lithostratigraphic model of the Cottrells Cove Group. It summarizes part of the ongoing studies of the volcano-sedimentary rocks in the area of Notre Dame Bay (Figure 1), carried out by T. Dec in support of the 1:50 000-scale mapping project led by B.H. O'Brien. The present paper utilizes unpublished work by S.H. Swinden on the geochemistry of the mafic volcanic rocks of the Cottrells Cove Group and its lateral equivalent–the Chanceport Group (Figure 2).

ROCKS OF THE COTTRELLS COVE GROUP

SEDIMENTARY ROCKS

Fortune Harbour Formation

Irregular rafts and a few metres-thick packages of greyish-red radiolarian cherts and volcaniclastic sediments are widespread within mafic pillow and massive lava flows that constitute the base of the Fortune Harbour Formation (Figure 5). Similar deposits form a continuous and at least 1250-m-thick sequence, which is superbly exposed on the eastern shore of the Fortune Harbour Peninsula (Figure 3) and on the Duck Islands (Figure 4). This main, northwest-facing, sedimentary member of the Fortune Harbour Formation stretches between Hare Island and Fortune Harbour Peninsula (Figure 2). Similar deposits associated with mafic lavas form an extensive outcrop in the area of Fortune Harbour (O'Brien, 1990).

A southeast-facing, radiolarite-dominated sequence, overlying pillow lava is exposed on Grassy Island (Figure 4).

Volcaniclastic Deposits

The main sedimentary member of the Fortune Harbour Formation is underlain by massive and pillow lavas and starts with an approximately 200-m-thick olistostrome (Figure 5). This composite mass-flow unit contains rafts of massive basalt

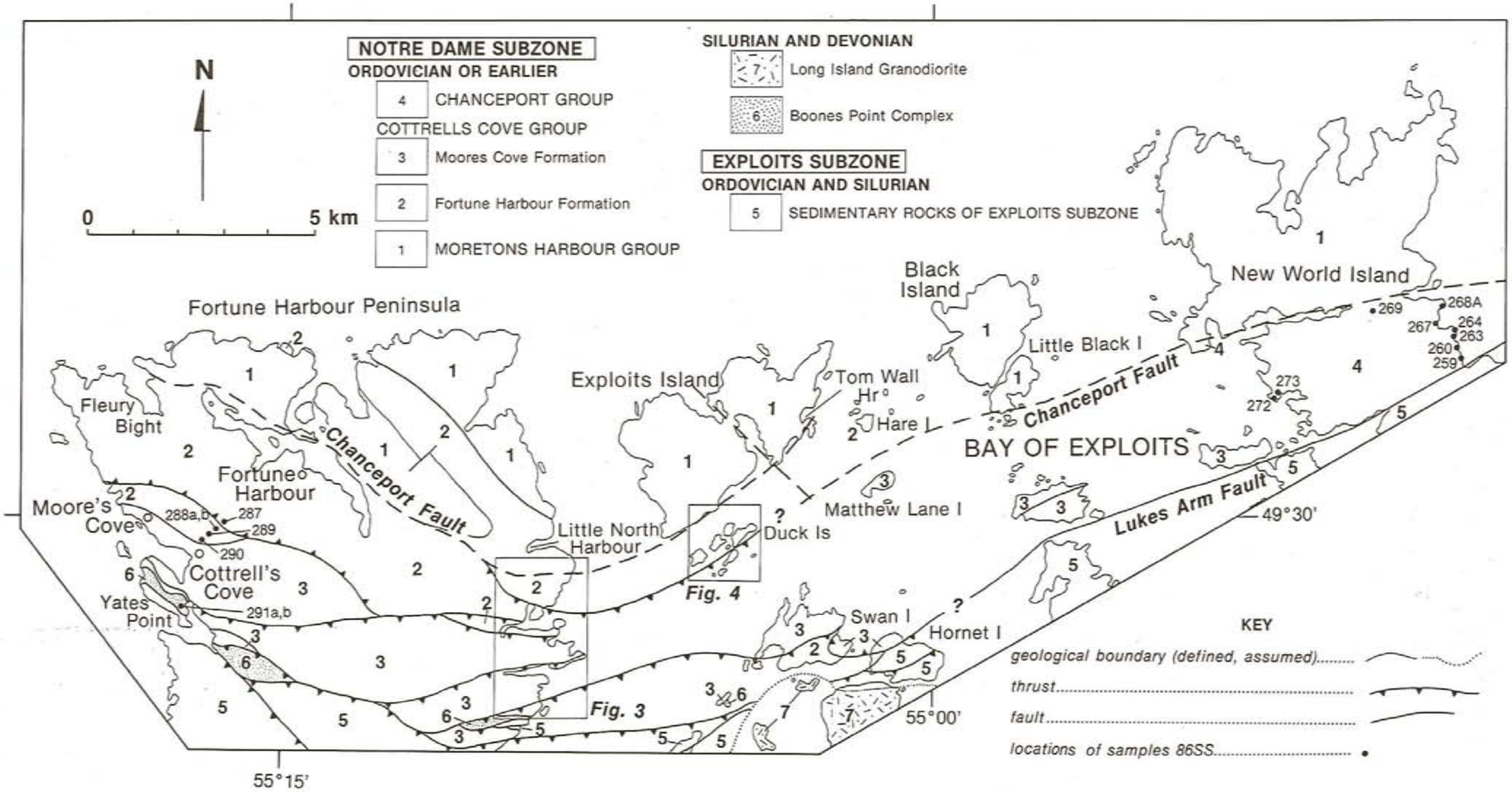


Figure 2. *General geological map of the Cottrells Cove and Chanceport groups; modified from Kean (1977), Dean and Strong (1977) and O'Brien (1991a,b). Locations of 86SS samples and the locations of Figures 3 and 4 are shown. Changes are made to previous depictions of the geological relationships along the Chanceport Fault between the Cottrells Cove and Moretons Harbour groups. Note that in the area of Little North Harbour and Hare Island the fault is restricted to the Cottrells Cove Group. A similar situation exists on Little Black Island and on New World Island but no detailed mapping has been carried out in these areas and the correct relationships are not depicted on this map.*

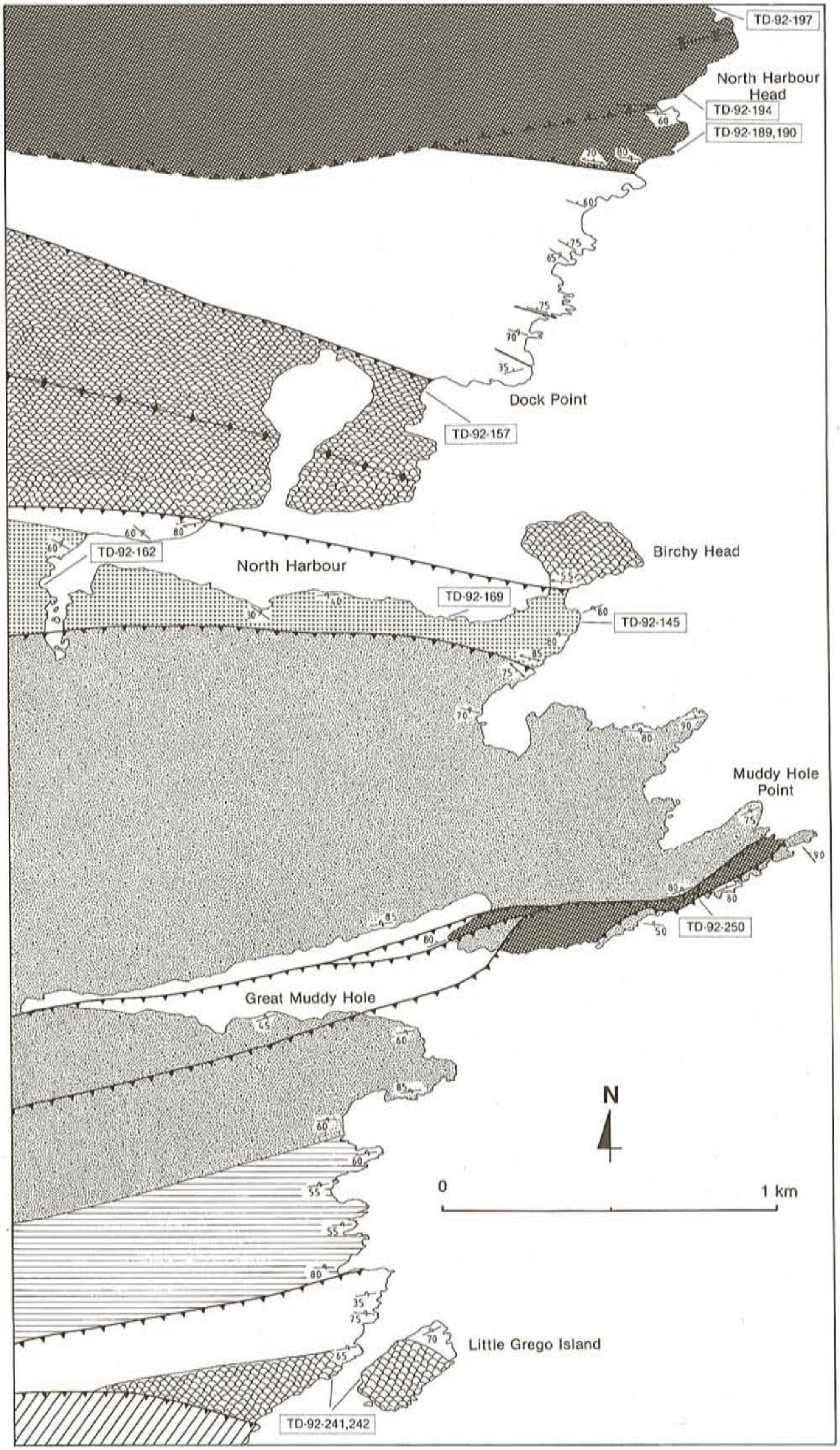


Figure 3. *Geology of the Cottrells Cove Group on the eastern side of the Fortune Harbour Peninsula. Locations of samples collected by Dec in 1992 are shown.*

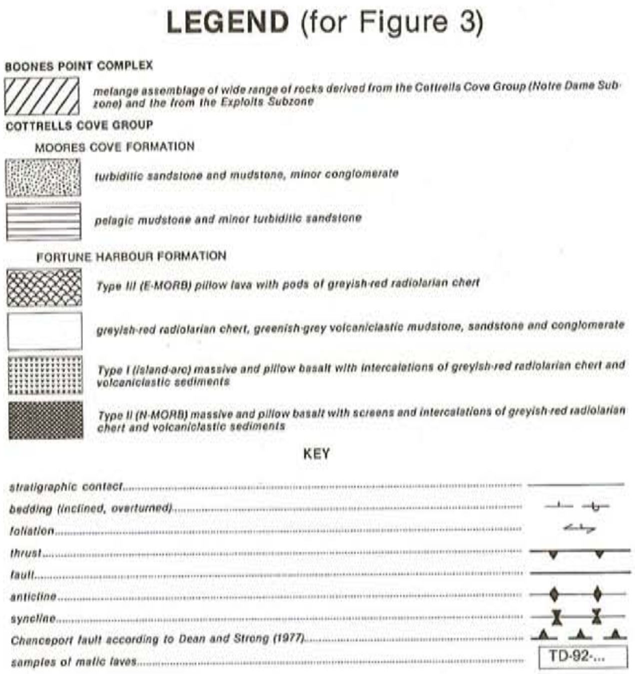


Figure 3. *(continued).*

and greyish red–greyish green[1] radiolarian chert set in a coarse-grained, epiclastic sandstone matrix. The irregularly shaped, lobate blocks are up to tens of metres in size and tend to be aligned and locally boudinaged parallel to the bedding. The disruption of the rafts, their bedding-parallel alignment and the pinch-and-swell deformation appear to have developed during mass-flow movement (Naylor, 1981; Cowan, 1982, 1985; Alvarez *et al.*, 1985). Mappable autochthonous lenses of massive basalt (Figure 4), capped by a thin mudstone bed, split the olistostrome unit into separate, large-scale mass-flow events. In the southwest corner of Upper Duck Island, the upper portion of the olistostrome contains exclusively rafts of greyish red chert (Figure 5).

The overlying, remaining portion of the main sedimentary package of the Fortune Harbour Formation consists of volcaniclastic conglomerates, sandstones and mudstones, radiolarian cherts and minor tuff (Figure 6). Structureless debris-flow deposits (debrites) form beds in excess of 16 m in thickness. They contain rafts of greyish red–greyish green chert up to 7 m in size, surrounded by volcaniclastic sandstone matrix and strongly resemble the basal olistostrome unit. Thick-bedded, tuffaceous turbidites also contain abundant intraformational radiolarite detritus. Their beds have flat, erosional bases with tool marks and can be traced for 2 km across Duck Islands (Figure 4). The tuffaceous turbidites are notable for the missing current ripple-laminated T_c division and for the direct transition from the parallel-stratified sandstones with chert rip-ups (T_b) into parallel-laminated mudstones deposited from suspension (T_d, Figure 6a). The parallel-laminated mudstones are normally very siliceous owing to the tuffaceous felsic component. They are greyish green, greenish grey, dark greenish grey, medium dark grey and dark grey (Figure 6). Structureless, greenish-grey mudstones, locally containing clusters of chert clasts and volcaniclastic detritus, form beds up to 10 m in thickness. They are interpreted as mass-flow deposits (Rodolfo *et al.*, 1992). Lithic tuffs constitute an insignificant fraction of the volcaniclastic deposits.

Radiolarian Cherts

The greyish-red, ferruginous radiolarites form packages in excess of 2 m in thickness and are internally thin and medium bedded. The beds are either parallel-laminated or massive and locally bioturbated. They commonly contain volcaniclastic interlaminations and thin turbiditic intercalations. A unique variety of the cherts is ferruginous 'pillow chert' (Figure 6a and Plate 1). This 0.8- to 2-m-thick marker bed can be traced across Duck Islands (Figure 4). It is probably a slump sheet that involved chert and subordinate volcaniclastic mud (Roep and Everts, 1992). The slump bed shown in Figure 6b represents an *en masse* remoulding of radiolarite and coarse-grained, volcaniclastic sand.

Clast Composition

The conglomerates, sandstones and mudstones of the Fortune Harbour Formation are exclusively volcanogenic, yet considerably enriched in the intrabasinal chert and mudstone detritus, including resedimented radiolarian tests. Fragments of basalt, andesite, dacite and rhyolite are accompanied by abundant volcanogenic quartz and albitized plagioclase. One sampled basalt raft from the olistostrome (TD-92-133, Figure 4) displays calc-alkalic geochemical signatures very similar to those in the underlying Type I (island-arc) lavas (see further in the text and Figure 8d).

Although the conglomerates and sandstones are mainly epiclastic, altered shards and pumice fragments are very common. The vitric material is concentrated in very fine-grained sandstones and mudstones giving them a conspicuous tuffaceous and tuff-like appearance. The volcaniclastic deposits lack any plutonic, metamorphic or other 'exotic' detritus. Alteration of the volcaniclastic deposits is representative of pumpellyite–prehnite-facies metamorphism.

Sedimentary Environment

The 1250-m-thick assemblage of radiolarian cherts, pelagic mudstones and abundant volcaniclastic deposits, including large-scale debris-flow units (the olistostrome), may have formed in a basin-plain setting. The basin was oversupplied with copious volcaniclastic detritus generated

[1] colour names follow the nomenclature in the GSA Rock-Color Chart (1991).

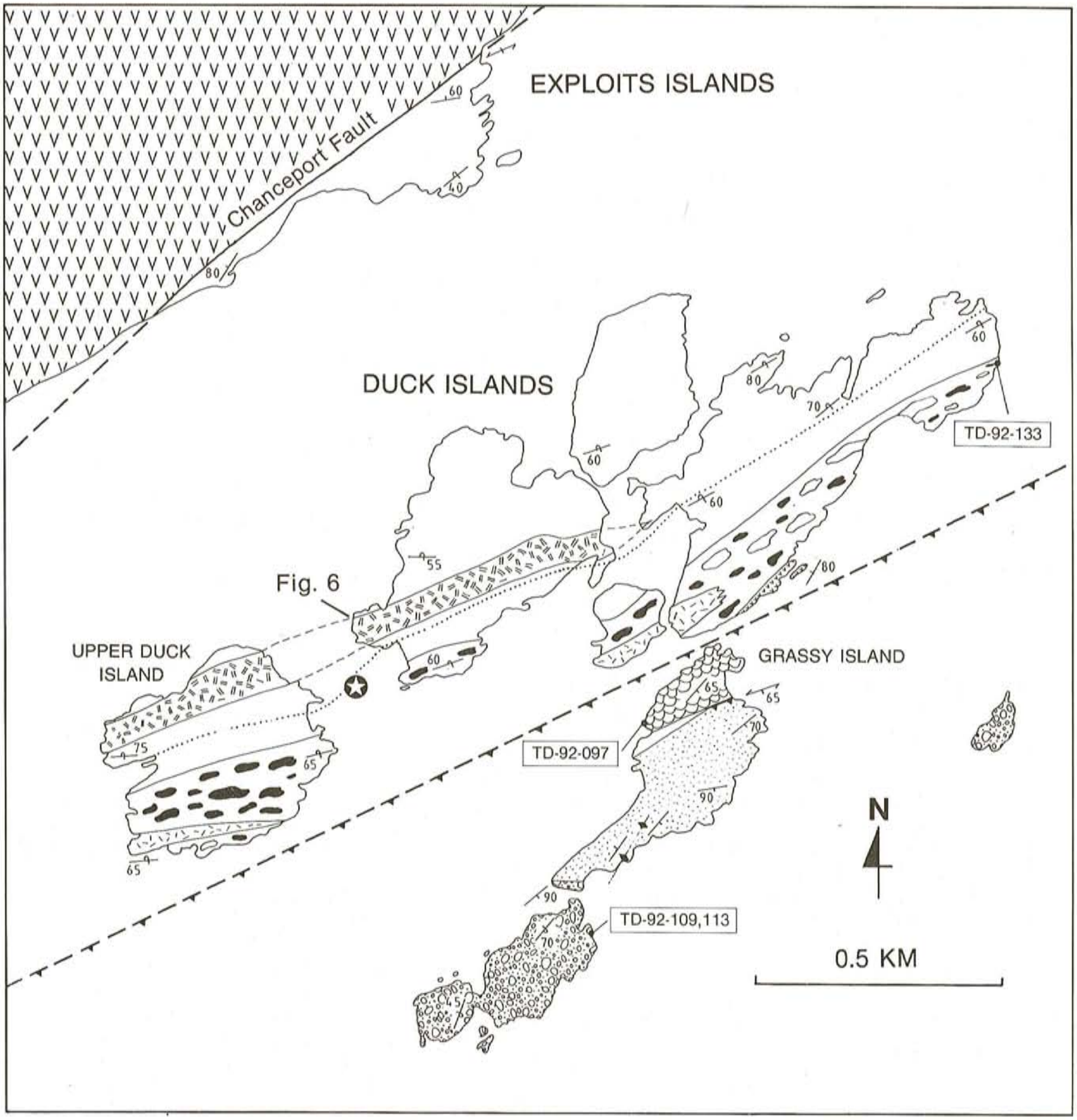
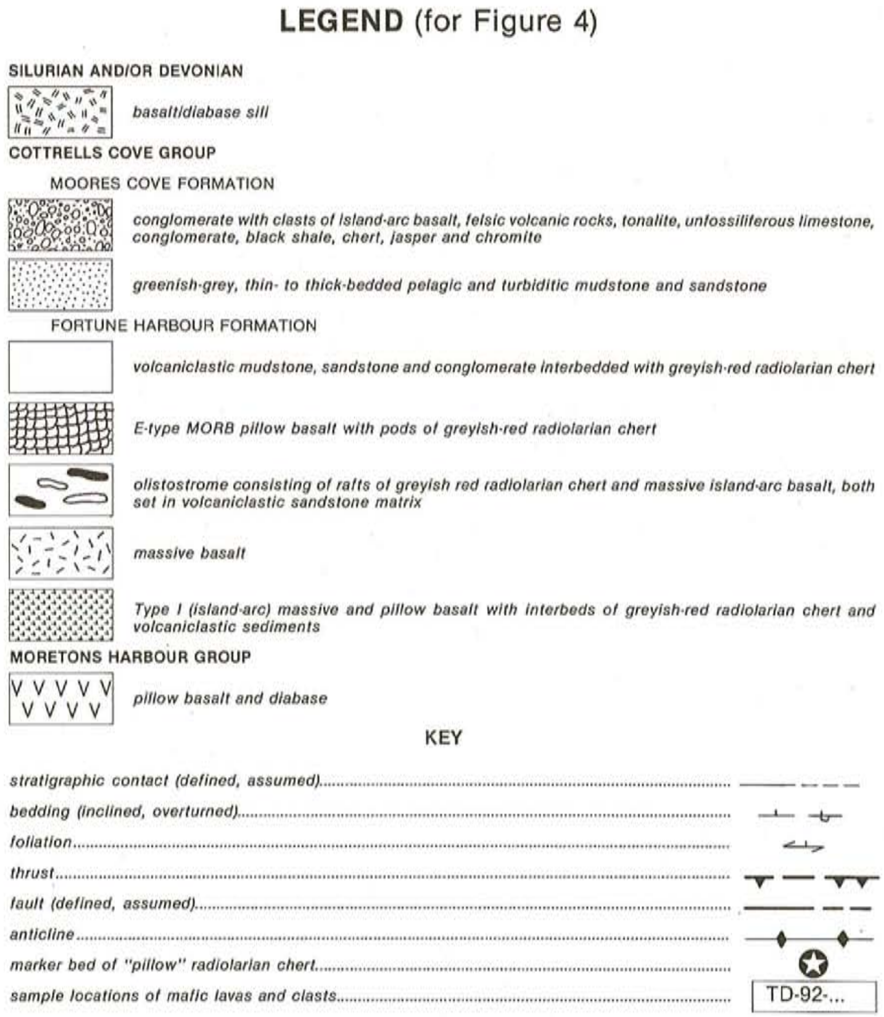


Figure 4. *Geology of Duck Islands and the southern shore of the Exploits Islands. Locations of samples collected by Dec in 1992 are shown.*

by contemporaneous pyroclastic volcanism (Stow and Piper, 1984; Stow, 1985).

Moores Cove Formation

The Moores Cove Formation is over 1200 m thick. The least-deformed and the most continuous sections are exposed in Moores Cove, Cottrells Cove and on the eastern coast of the Fortune Harbour Peninsula (Figures 2 and 7). Similar deposits are fairly well exposed on Swan Island, Hornet Island, Matthew Lane Island, Little Black Island and on New World Island (Strong and Payne, 1973). The entire sequence shows a coarsening-upward trend. The lowest, fine-grained member is dominated by pelagic, parallel-laminated and structureless mudstones. They are interbedded with minor thin- to thick-bedded turbidites and slumped deposits. On the fresh surface the mudstones display a fairly wide range of colours: greyish-red, pale yellowish brown, greenish grey,



dark greenish grey, medium dark grey, dusky yellow green and light olive grey. Slump folding has affected some of the beds and structureless mudstone beds, analogous to those in the Fortune Harbour Formation, may also represent mass-flow events.

The overlying, middle member of the Moores Cove Formation is composed of medium- to thick-bedded turbiditic sandstones and minor pebble conglomerates, interbedded with packages of mudstones and sandstones (Figure 7). The turbiditic deposits are greenish grey on the fresh surface yet the weathered rock faces are characteristically yellowish orange–moderately yellowish brown.

Many turbidites are structureless and contain mudstone rip-up clasts. The rip-ups were fairly soft during incorporation and show either a laminar shear-induced imbrication or folding with consistent vergence. Although many of these deposits can be interpreted as slumps, liquefied flows or some other kind of high-density mass-flow deposits (e.g. Lowe, 1976; Nilsen, 1989), sedimentary features in a number of beds suggest that their 'slumped' or 'slurried' appearance may actually be mainly a result of *in situ* liquefaction and/or mixing during collapse and inversion of sediment layers of different densities.

Soles of the sandstone turbidites commonly exhibit casts of irregularly meandering burrows *Helminthopsis* Heer, 1877. This trace fossil ranges through the latest Precambrian to the Holocene and occurs most commonly in deep-water flysch, at a sand–mud interface (R.K. Pickerill, written communication, 1993).

Conglomerates and minor turbiditic sandstones constitute the highest member of the Moores Cove Formation (Figure 5). They are exposed only on Grassy Island and on two islands to the southwest and to the east (Figure 4). Although the bedding and many other sedimentary structures may have been obscured by a moderate tectonic deformation, the conglomerates appear to have been originally mainly structureless. They are poorly sorted and commonly contain outsize clasts. The particles range from angular to well rounded and the maximum particle size ranges from pebbles to boulders and the conglomerates represent probably debris-flow/high-density turbidity-current sedimentation.

Clast Composition

In the light of preliminary studies of thin sections, the middle, turbiditic member of the Moores Cove Formation can be described in terms of two end-member petrofacies. Epiclastic sandstones, dominated by felsic detritus are particularly common in the lower part of the turbiditic member. The rhyolitic–rhyodacitic rock fragments, abundant volcanogenic quartz and albitized plagioclase are accompanied by minor clasts of approximately intermediate and mafic composition. There is no significant presence of reworked pyroclastic grains such as shards or pumice. Zircon, biotite and muscovite occur as accessory components.

The epiclastic turbidites grade upward into, and possibly interfinger with, coarser grained sandstones and pebbly sandstones that contain a wider variety of rock fragments and corresponding monomineral grains. Felsic, intermediate and mafic volcanic clasts are most common and coexist with intrusive clasts, foliated mica aggregates, shale fragments containing a pre-incorporation fabric, radiolarite and sandstone. Ubiquitous quartz and plagioclase are accompanied by accessory zircon, allanite, epidote, biotite, muscovite, clinopyroxene, hornblende and chromite.

The largest clasts in the conglomerate of the upper member of the Moores Cove Formation (up to 1 m in size) are basalt and basalt breccia and unfossiliferous limestone.

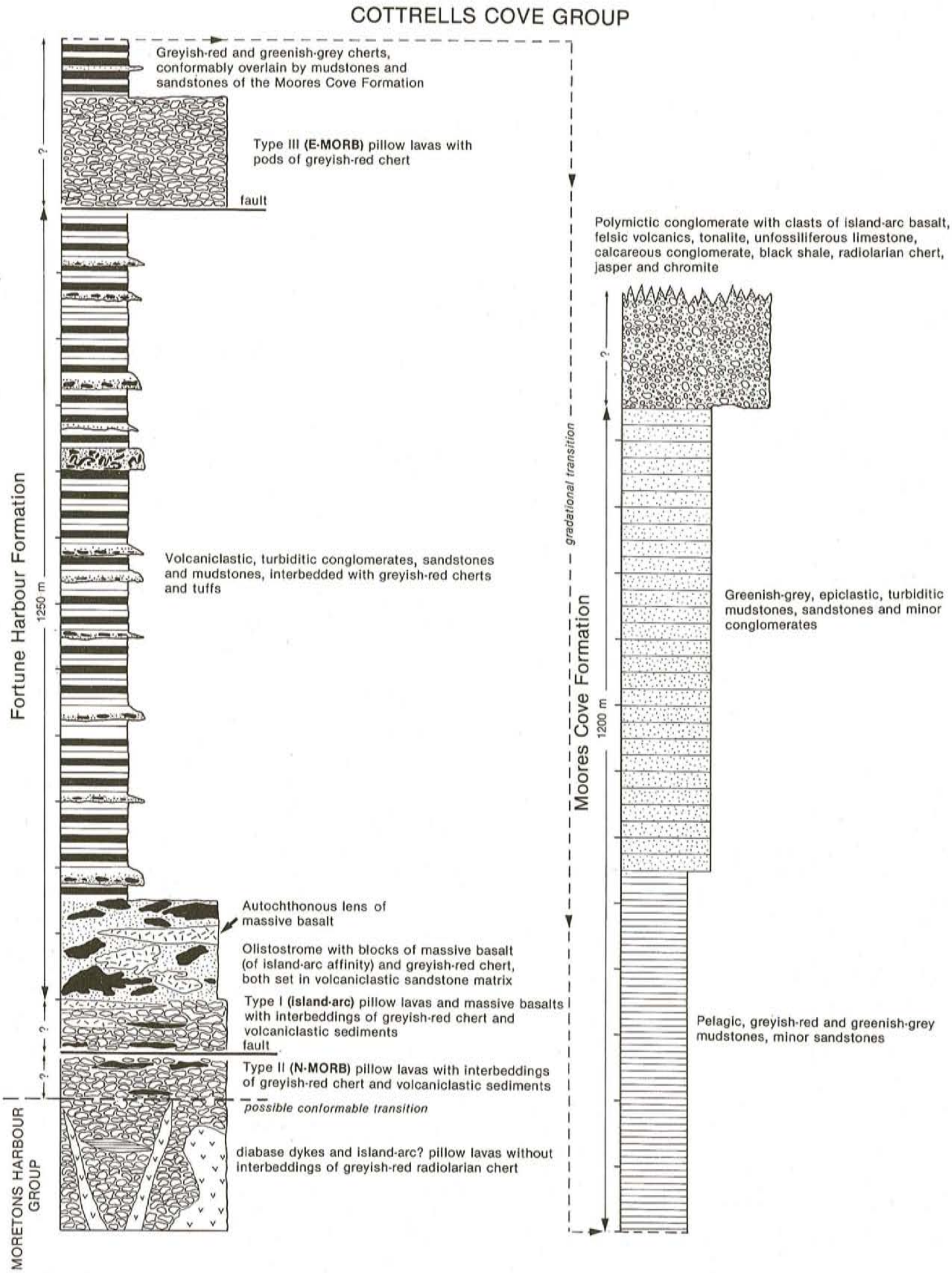


Figure 5. *Lithostratigraphic model of the Cottrells Cove Group.*

The latter have been found associated with the basalt. Two sampled basalt boulders show calc-alkalic geochemistry (TD-92-109,113; Figure 8d), similar to the Type I (island-arc) lavas of the Fortune Harbour Formation (see section on Volcanic Rocks). The conglomerate also contains fragments of red jasper, greenish radiolarian chert, siliceous black shale, calcarenite, carbonate-cemented conglomerate, felsic volcanic rocks and tonalite. Detrital chromite and altered ultramafic detritus have been found in the fragments of calcarenite as well as in the sandstone matrix. Accessory zircon, garnet, clinopyroxene and hornblende have also been identified from the matrix. The entire polymictic clast assemblage is similar to the one in the underlying turbiditic sandstones.

Sedimentary Environment

The lowest portion of the Moores Cove Formation represents a lower slope and/or basin-plain setting, dominated by pelagic sedimentation, which was occasionally overrun by turbidity currents and other, high-density mass flows (Stow and Piper, 1984; Thornton, 1984). The overlying, almost exclusively turbiditic, sandstones, mudstones and conglomerates are most characteristic of a deep-sea fan environment. Figure 7 depicts an example of such deposits, interpreted as transitional between outer-fan and fan-fringe setting (Van Vliet, 1978; Pickering, 1985; Nilsen, 1989).

VOLCANIC ROCKS

Introduction

Volcanic rocks of the Cottrells Cove Group are restricted to the Fortune Harbour Formation and form spectacular coastal exposures on the Fortune Harbour Peninsula and on numerous islands in the Bay of Exploits (Figure 2). Their thickness is impossible to determine because of folding and faulting. Pillow and massive basalts and pillow breccia are most common. Felsic lava has been found only in Fleury Bight, as lobate rafts and smaller fragments in volcanic breccia. Felsic volcanism in the Fortune Harbour Formation is mainly represented by reworked pyroclastic material in tuffaceous turbidites and debrites. The mafic lavas are mostly greenish grey and greyish red. They commonly contain rafts of greyish-red radiolarian chert and intercalations of chert and volcaniclastic sediments.

Whole-rock geochemical analyses of mafic volcanic rocks and mafic volcanic fragments in conglomerate and melange were carried out in an attempt to characterize the volcanic rocks. This in turn may provide evidence for stratigraphic correlation within the map area and regional correlation within the Notre Dame Subzone. The geochemistry may help to the interpret the tectonic environments represented by the volcanic rocks and their associated sedimentary rocks. The geochemical studies reported herein encompass two separate periods of geological observation and sample collection. One of us (HSS) carried out a reconnaissance sampling of pillow lavas in the Cottrells Cove and Chanceport groups and the Boones Point Complex near Cottrell's Cove in 1986. These samples are prefaced by '86SS' in Table 1 and Figure 2. More recent work by T.D. concentrated on systematic sampling of pillow and massive lavas and clasts on the eastern side of the Fortune Harbour Peninsula and on Duck and Grassy islands. These samples are prefaced by 'TD-92' in Table 1 and Figures 3 and 4.

Analytical Methods

For the samples prefaced '86SS', major elements and a standard suite of trace elements were analyzed by X-ray fluorescence at X-Ray Assay Laboratories Limited, under a contract issued by the Geological Survey of Canada. Rare-earth elements and the trace elements Sc, Th, Nb, Hf and Y were analyzed by ICP-MS at Memorial University of Newfoundland. Analytical methods are described by Jenner *et al.* (1990). All other trace elements were analyzed by X-ray fluorescence at Memorial University of Newfoundland.

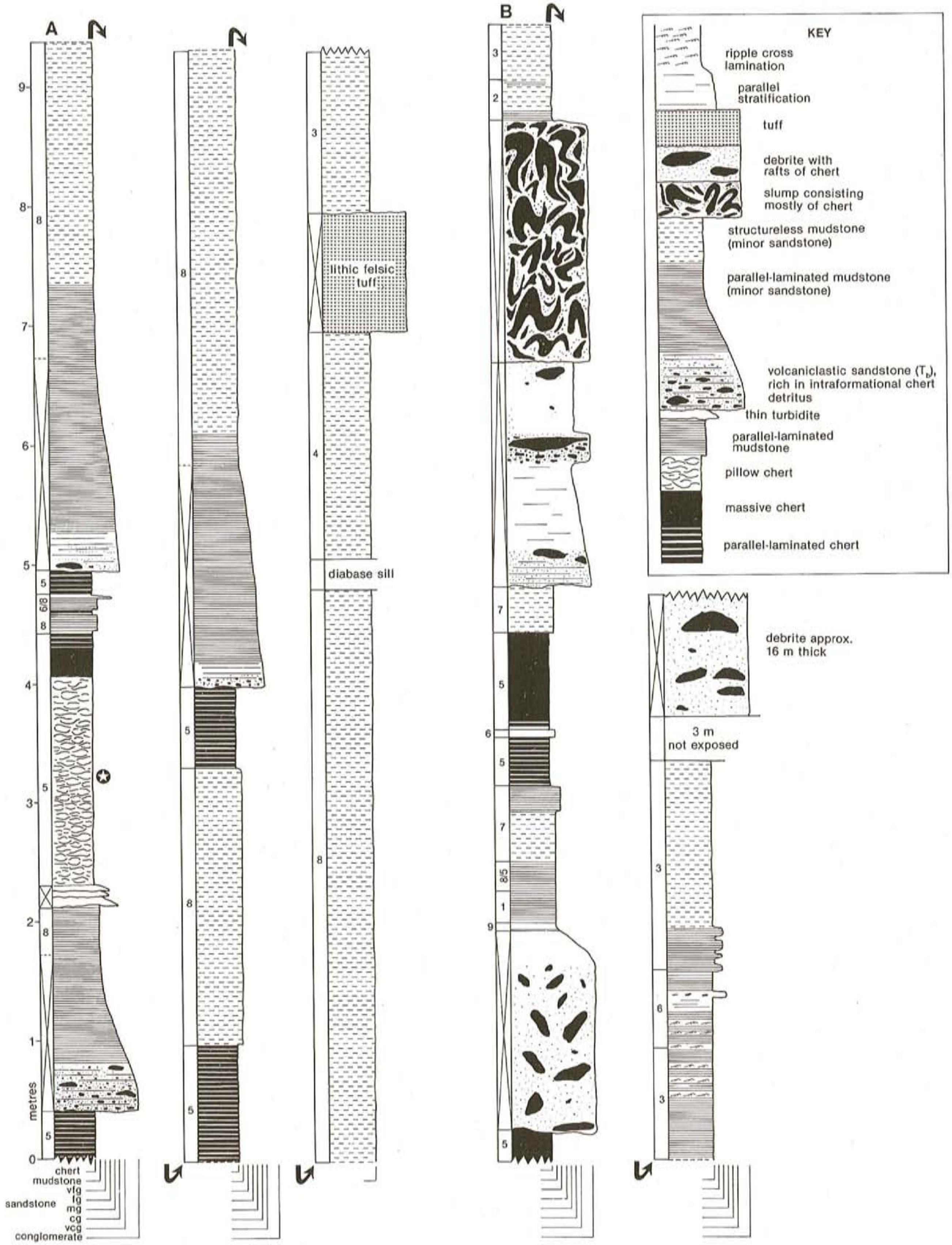
For samples prefaced 'TD-92', major elements and the trace elements Ba, Zr and Cr were determined by lithium metaborate fusion followed by inductively coupled plasma—optical emission spectrophotometry and the trace elements Ni, V, Rb, Sr, Cu, Pb and Zn by total multi-acid digestion and ICP-OES determination in the Newfoundland Department of Mines and Energy analytical laboratory. The rare-earth elements (REE) and the trace elements Sc, Th, Nb, and Y were analyzed at Memorial University by ICP-MS, as described above.

Results

The extended rare-earth-element plots for all samples from the study area (Figures 8 to 10) indicate that there are three broad types of mafic volcanic rocks present: i) rocks with significant light rare-earth-element (LREE) enrichment, herein termed Type I; ii) rocks with significant LREE depletion, herein termed Type II, and iii) rocks with approximately flat to slightly LREE-enriched extended rare earth patterns, herein termed Type III. Each type is described separately below.

Type I Mafic Volcanic Rocks

Type I mafic volcanic rocks are characterized by LREE-enriched extended REE patterns having strongly pronounced negative Nb and positive Th anomalies (Figure 8) and negative Ti anomalies. Type I rocks have been identified at four locations within the present study area: i) in a belt of mafic pillow lavas that outcrop along the southern shore of North Harbour on the east coast of the Fortune Harbour Peninsula (Figure 3); ii) in roadcuts between Cottrell's Cove and Fortune Harbour (Figure 2); iii) along the southern and northern sides of the Chanceport Group (Figure 2); and iv) as clasts in a Moores Cove Formation conglomerate and a Fortune Harbour Formation olistostrome on Duck and Grassy islands (Figure 4). These rocks are all subalkalic basalts or andesite, according to the Winchester and Floyd (1975) diagram (Figure 11a), and the general lack of increase of TiO_2


A
B
KEY
ripple cross lamination
parallel stratification
tuff
debrite with rafts of chert
slump consisting mostly of chert
structureless mudstone (minor sandstone)
parallel-laminated mudstone (minor sandstone)
volcaniclastic sandstone (T_b), rich in intraformational chert detritus
thin turbidite
parallel-laminated mudstone
pillow chert
massive chert
parallel-laminated chert
lithic felsic tuff
diabase sill
debrite approx. 16 m thick
3 m not exposed
metres
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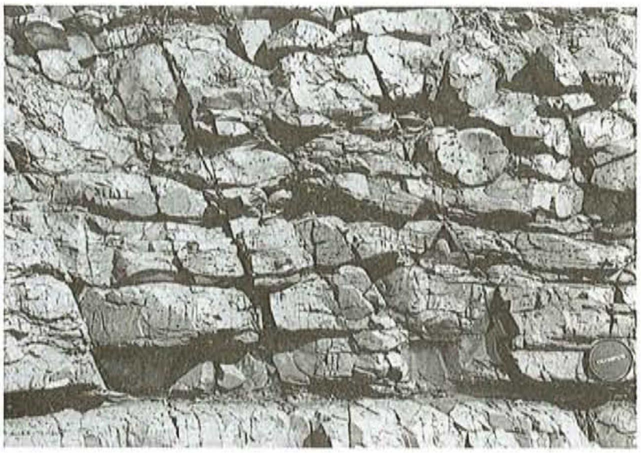

Plate 1. *Pillow chert with anostomosing fractures oriented sub-parallel to the bedding. The chert underwent* en masse *mixing with volcaniclastic mud and the vesicule-like cavities represent relicts of tuffaceous detritus that are locally replaced by calcite.*

with fractionation (Figure 11b) suggests that these rocks are calc-alkalic. This conclusion is in agreement with the LREE-enriched extended REE patterns, the pervasive negative Ti anomalies, and Th–La relationships (Figure 12a), which suggest that the rocks are dominantly medium to high-K andesites.

The negative Nb and positive Th anomalies on extended REE plots of intra-oceanic volcanic rocks are characteristic of magmas produced in subduction zones (Wood *et al.*, 1979; Sun, 1980; cf. Swinden *et al.*, 1989). An arc-related setting for Type I rocks is also indicated by ratios of more incompatible to less incompatible elements (e.g., Ti/V Figure 12b).

Although all volcanic rocks assigned to Type I have broadly similar geochemical signatures, there are significant contrasts among the various samples that preclude a simple petrogenetic association. For example, there is a considerable range of LREE enrichment represented in the Type I rocks overall (La/Yb ranges from 3.02 to 7.29). Two of the most LREE-enriched rocks (TD-92-145, 162) are found in the Cottrells Cove Group, south and east of Birchy Head (North Harbour). Nearby, one of the least LREE-enriched Type I rocks (TD-92-169) was sampled. Type I rocks in the Chanceport Group are generally less LREE-enriched than those exposed along Highway 352 between Cottrells Cove and Fortune Harbour. Locally-crossing extended REE patterns, even within single areas, preclude any simple fractionation relationships among these rocks.

Two boulders sampled from the top conglomerate of the Moores Cove Formation and one basalt raft from the olistostrome of the Fortune Harbour Formation (Figure 4) have Type I chemical signatures (Figure 8d).

Type II Volcanic Rocks

Type II volcanic rocks have strongly LREE-depleted patterns with no anomalies in Th or Nb. Type II rocks are found in several separate areas of the present study area. On the western side of the Fortune Harbour area, they outcrop along the northern boundary of the Cottrells Cove Group near the trace of the Chanceport Fault and along the shoreline west of Muddy Hole Point (Figures 3 and 9a). On the New World Island, they appear to outcrop in a belt through the centre of the Chanceport Group, bounded to the north and south by Type I rocks (Figures 3 and 9b).

All Type II volcanic rocks are subalkalic basalts and exhibit strongly increasing TiO_2 with fractionation indicating that they are tholeiitic (Figure 11b). Ratios of more incompatible to less incompatible elements are similar to N-MORB (Figure 12), consistent with the lack of Nb or Th anomalies in the extended REE plots. On this basis, Type II volcanic rocks are interpreted as N-MORB, and probably represent substantial degrees of partial melting of normal depleted mantle that has not been contaminated by subduction.

Basaltic rafts with N-MORB geochemical signatures are also found in the Boones Point Complex at Yates Point (Figures 2 and 9c).

Type III Volcanic Rocks

Type III volcanic rocks (Figure 10) outcrop in two areas along the east shore of the Fortune Harbour Peninsula, around Birchy Head and Little Grego Island (Figure 3) and near the north end of Grassy Island (Figure 4). These rocks have slightly LREE-enriched extended REE patterns and slight negative to positive Nb anomalies. The rocks are subalkalic basalts or andesites (Figure 11a), show sufficient TiO_2 enrichment that they are probably best interpreted as tholeiitic (Figure 11b), and exhibit trace-element ratios indicative of enriched mid-ocean-ridge-basalt (E-MORB) (Figure 12a). There are not enough samples to evaluate the significance of the minor Nb variation exhibited in Figure 10. The slight negative Nb anomalies in some samples (most prominent in TD-92-157) may indicate a slight arc signature in the source. Alternatively, this may be analytical variation and of no petrogenetic significance.

Figure 6. *Representative logs from the main sedimentary member of the Fortune Harbour Formation. Colour code (for fine-grained sediments only): 1–Greyish black (N2); 2–Dark grey (N3); 3–Medium dark grey (N4); 4–Medium grey (N5); 5–Greyish red (10R 4/2); 6–Dark greenish grey (5G 4/1); 7–Greenish grey (5G 6/1); 8–Greenish grey (5GY 6/1); 9–Greyish green (10G 4/2). The colour nomenclature follows the GSA Rock-Color Chart, 1991.*

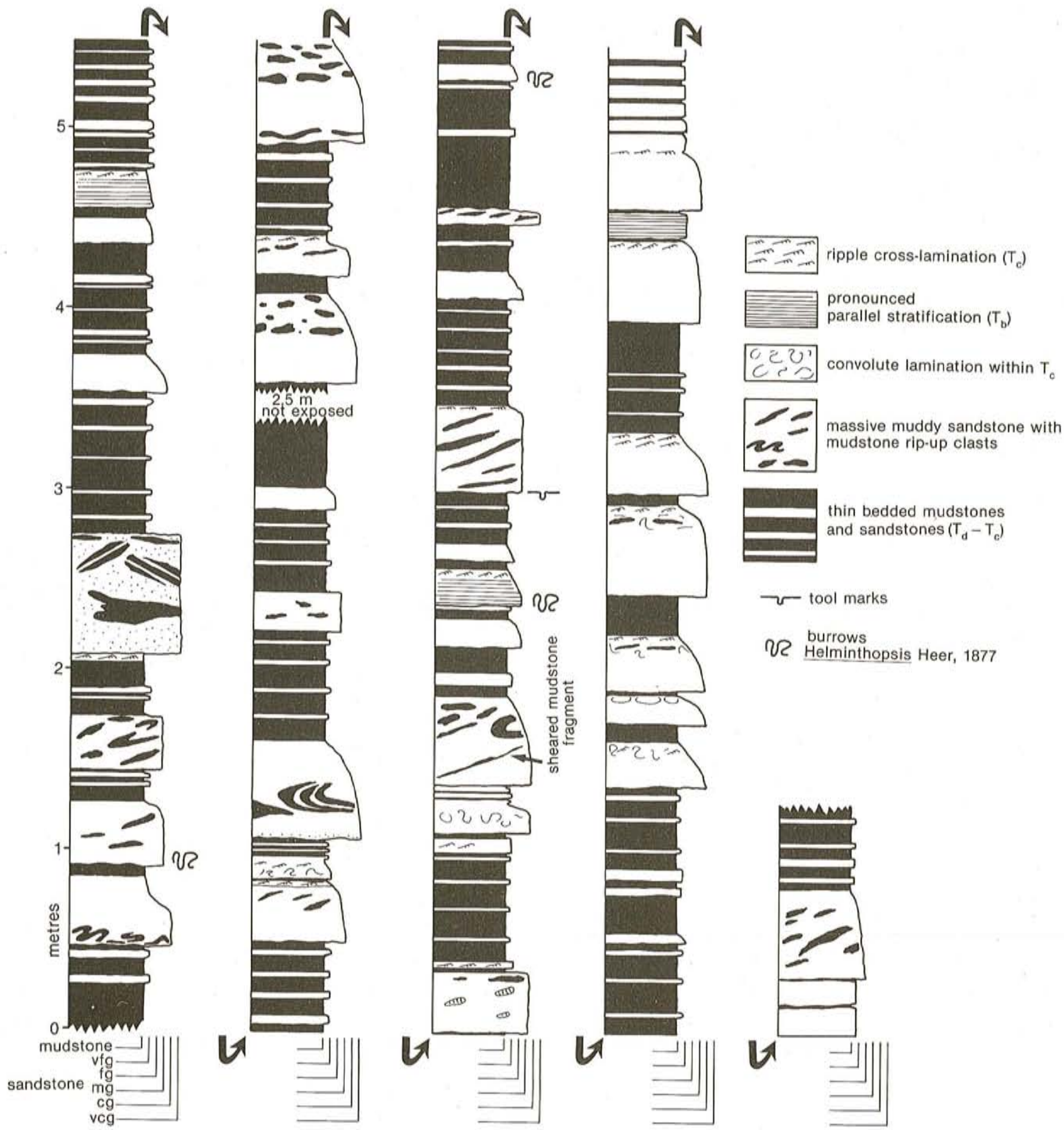

Figure 7. *Log from the upper portion of the Moores Cove Formation, measured along the coast in Cottrell's Cove. It depicts outer-fan to fan-fringe turbiditic deposits containing characteristic 'slumped' and 'slurried' beds.*

DISCUSSION

TECTONIC ENVIRONMENTS OF VOLCANISM AND SEDIMENTATION IN THE STUDY AREA

Mafic volcanic geochemistry gives evidence of at least two distinct environments of volcanic activity in the study area. Type I calc-alkalic lavas have geochemical signatures indicating they are subduction-related and probably formed in an island-arc environment. With respect to the overlying middle sedimentary member of the Fortune Harbour Formation (Figure 5), the inferred basin-plain sedimentation oversupplied with volcaniclastic detritus, may have occupied a marginal back-arc setting (Jenkyns and Winterer, 1982; Jones and Murchey, 1986; Dec *et al.*, 1992).

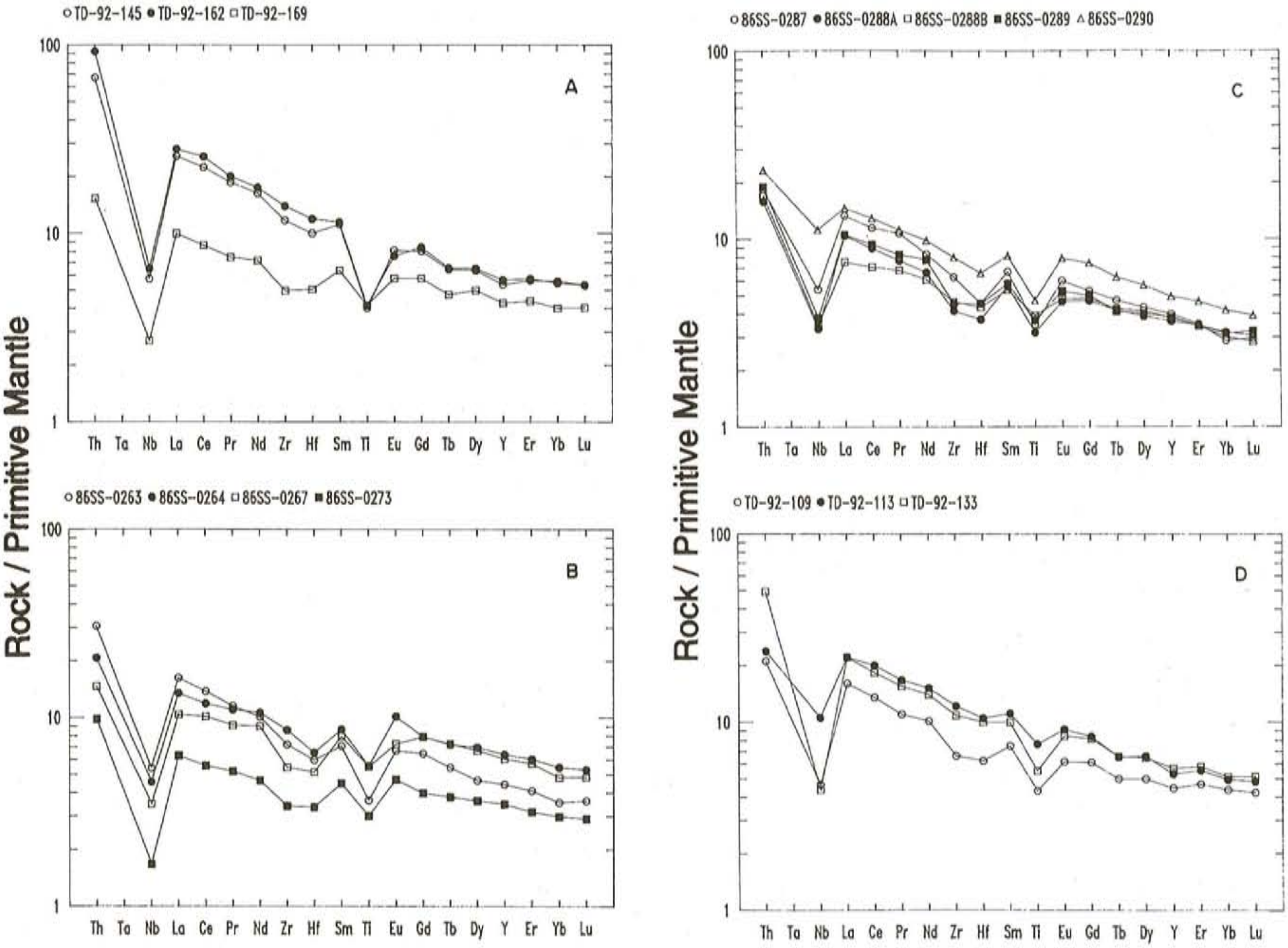

Figure 8. *Extended REE patterns for Type I volcanic rocks. Primitive mantle normalization after Swinden* et al. *(1990). A—mafic volcanic flows from the North Harbour area; B—mafic volcanic rocks collected along the Cottrell's Cove—Fortune Harbour road; C—mafic volcanics from the Chanceport Group; D—mafic volcanic clasts from the conglomerate at the top of the Moores Cove Formation (TD-92-109, 113) and the olistostrome of the Fortune Harbour Formation (TD-92-133).*

Type II LREE-depleted lavas are geochemically similar to N-MORB and Type III lavas are similar to E-MORB. Within the limits of analytical uncertainty, neither shows evidence of subduction. Analogues for both types of MORB lavas can be found on spreading ridges in oceanic basins and can also be related to spreading in back-arc basins. Our geochemical data do not allow us to definitively discriminate between these possibilities.

The basin-plain and submarine-fan sedimentation of the Moores Cove Formation probably took place in a tectonic setting that was significantly different from those suggested for the Fortune Harbour Formation. The considerable sedimentological differences, notably the absence in the Moores Cove Formation of radiolarian cherts, are coupled with changes in sediment provenance. The epiclastic turbidites in the lower portion of the Moores Cove Formation show no obvious evidence for the pyroclastic component that is so conspicuous in the Fortune Harbour Formation. They pass upward into polymictic turbidites, indicative of erosion of older magmatic arcs, ophiolitic complexes, as well as pre-existing sedimentary formations.

It is premature to speculate at this stage about the tectonic setting of the submarine-fan sedimentation of the Moores Cove Formation since the detailed sedimentology, including the closely related aspect of sediment provenance, have not been addressed. It should be noted, however, that in terms of sedimentary environment and provenance the Moores Cove Formation (considered to be a component of the Notre Dame Subzone; Williams *et al.*, 1988; Colman-Sadd *et al.*, 1992) strongly resembles the Upper Ordovician—Lower Silurian, deep-sea fan deposits of the Exploits Subzone such as the Point Leamington and the Milliners Arm formations (Helwig, 1967; Helwig and Sarpi, 1969; Nelson and Casey, 1979; Nelson, 1981; Watson, 1981; Pickering, 1987; Williams *et al.*, 1988; Williams, 1991; Dec *et al.*, 1993). According to Williams *et al.* (1988) these deposits are absent in the Notre Dame Subzone and this stratigraphic contrast has been the basis for their subdivision of the Dunnage Zone along the Red Indian Line (see also Williams *et al.*, 1992).

Table 1. Geochemistry of mafic lavas and clasts of mafic lavas

Sample	TD-92-189	TD-92-190	TD-92-194	TD-92-197	TD-92-250	TD-92-097	TD-92-157	TD-92-241
SiO_2	48.6	48.55	50.12	49.24	52.12	52.71	49.68	49.69
TiO_2	1.54	1.86	2.11	1.31	1.21	1.24	1.38	1.41
Al_2O_3	15.45	15.4	14.18	15.07	19.45	15.02	15.71	15.36
Fe_2O_3	2.16	2.24	2.11	0.69	10.11	1.83	4.37	2.21
FeO	8.97	9.26	9.72	9.3	1.22	6.61	6.36	7.53
MnO	0.26	0.22	0.22	0.19	0.15	0.22	0.19	0.18
MgO	9.36	7.74	5.68	7.74	1.81	5.86	7.12	7.33
CaO	9.89	11.34	12.01	13.21	6.15	12.07	9.72	12.22
Na_2O	3.48	3.12	3.53	2.91	6.08	4.17	4.08	3.8
K_2O	0.18	0.13	0.12	0.22	1.61	0.11	1.23	0.12
P_2O_5	0.11	0.14	0.2	0.11	0.09	0.16	0.16	0.15
LOI	4.05	4.06	3.56	3.21	4.01	5.98	7.88	5.08
Mg #	60.45	55.03	46.55	58.17	23.81	55.86	55.23	57.85
Cr	237	130	121	117	331	234	338	314
Ni	98	72	67	86	192	143	108	185
Sc	50	50	45	49	37	41	43	39
V	359	405	416	338	273	330	380	289
Cu	109	100	77	111	25	75	166	81
Zn	93	105	102	89	66	84	94	78
Rb	NA	NA	NA	NA	NA	NA	NA	NA
Ba	51	30	16	47	332	53	102	51
Sr	219	155	101	166	308	199	174	234
Ga	25	27	27	24	23	22	24	22
Nb	1.9	2.1	3.8	1.4	0.8	5.4	3.7	6.6
Hf	2.75	3.34	4.36	2.33	2.18	2.38	2.45	2.67
Zr	106	128	170	88	74	88	94	99
Y	30	34	42	28	33	25	25	26
Th	0.29	0.26	0.56	0.22	0.14	1	0.92	0.68
La	3.41	3.87	6.1	2.86	2.35	5.75	6.05	6.01
Ce	10.81	12.56	18.35	8.85	7.01	14.52	15.01	14.76
Pr	1.83	2.15	2.95	1.53	1.5	2.15	2.24	2.23
Nd	9.94	11.8	16.1	8.78	8.82	10.73	10.82	11.25
Sm	3.67	4.05	5.24	3.25	3.37	3.22	3.24	3.46
Eu	1.31	1.56	1.78	1.24	1.26	1.12	1.15	1.31
Gd	4.91	5.57	6.95	4.31	4.73	4.28	4.28	4.45
Tb	0.84	0.95	1.14	0.74	0.79	0.68	0.68	0.73
Dy	5.95	6.66	8.22	5.42	5.85	4.86	5.04	5.33
Ho	1.19	1.37	1.7	1.1	1.22	1	1.04	1.09
Er	3.44	3.96	4.91	3.25	3.56	2.98	3.07	3.04
Tm	0.51	0.61	0.73	0.47	0.5	0.43	0.45	0.44
Yb	3.35	3.86	4.74	2.92	3.2	2.79	2.86	2.8
Lu	0.49	0.59	0.71	0.46	0.49	0.42	0.44	0.44

Although the age of the Cottrells Cove Group remains unknown, the sedimentological and provenance similarities mentioned in this paper suggest a possible correlation of the Moores Cove Formation with the turbiditic sequences southeast of the Red Indian Line, for example with the Point Leamington Formation and with the overlying Randels Cove Conglomerate ('Goldson Conglomerate', Dec *et al.*, 1993). If such a correlation proves to be correct, the mappable subdivision of the Dunnage Zone into suspect terranes of the Exploits and Notre Dame subzones will lose its most compelling stratigraphic basis.

LITHOSTRATIGRAPHIC MODEL OF THE COTTRELLS COVE GROUP

The lithostratigraphic model of the Cottrells Cove Group (Figure 5) is based on examination of critical stratigraphic relationships and sedimentology within the imbricate volcano-

Table 1. *Continued*

Sample	TD-92-242	TD-92-109	TD-92-113	TD-92-133	TD-92-145	TD-92-162	TD-92-169	86SS-0259
SiO_2	48.53	48.21	49.07	52.05	54.82	57.14	49.83	46.97
TiO_2	1.5	0.93	1.62	1.12	0.81	0.83	0.86	1.11
Al_2O_3	16.78	18.65	16.5	18.58	17.4	18.26	17.03	18.83
Fe_2O_3	3.42	2.38	2.62	1.33	1.69	1.28	1.63	10.69
FeO	6.76	5.03	8.78	7.64	4.96	5.08	6.28	NA
MnO	0.22	0.16	0.19	0.46	0.47	0.23	0.48	0.13
MgO	7.4	6.23	7.07	6.31	6.17	5.13	13.73	5.81
CaO	12.36	11.45	8.28	4.82	5.15	2.65	3.32	10.71
Na_2O	2.71	2.78	3.48	5.54	4.12	5.67	1.79	4.05
K_2O	0.14	3.97	2.13	1.94	4.21	3.48	4.9	1.59
P_2O_5	0.17	0.21	0.26	0.21	0.21	0.24	0.15	0.1
LOI	6.37	10.77	8.09	6.69	4.53	4.54	7.56	9.16
Mg #	57.29	60.73	53.09	56.01	62.92	59.47	75.96	51.84
Cr	334	371	67	180	107	ND	249	488
Ni	159	117	48	110	71	49	123	274
Sc	40	48	42	44	35	29	42	44
V	289	349	360	298	235	208	295	234
Cu	94	80	59	121	85	76	117	9
Zn	86	94	98	90	71	106	62	58
Rb	NA	NA	NA	NA	NA	NA	NA	30
Ba	39	1211	826	433	2564	968	1651	97
Sr	209	360	263	93	241	101	129	253
Ga	25	24	28	25	21	21	21	NA
Nb	9.3	3.5	7.6	3.1	4	4.5	1.9	0.7
Hf	2.98	1.99	3.28	3.03	2.97	3.54	1.55	1.58
Zr	107	74	133	115	122	145	53	82
Y	28	20	23	24	22	23	18	33
Th	0.7	2.12	2.34	4.68	6.28	8.61	1.48	0.05
La	6.83	11.52	15.55	15.02	17.21	18.67	6.88	1.87
Ce	16.94	24.51	35.58	31.48	37.73	43.02	15.01	5.75
Pr	2.53	3.15	4.68	4.2	4.97	5.33	2.05	1.3
Nd	12.13	13.95	20.45	18.24	20.95	22.37	9.48	7.79
Sm	3.85	3.41	4.96	4.31	4.73	4.84	2.78	2.87
Eu	1.47	1.05	1.53	1.37	1.29	1.21	0.95	1.15
Gd	4.87	3.71	4.98	4.69	4.56	4.76	3.37	4.24
Tb	0.77	0.55	0.71	0.69	0.67	0.68	0.5	0.77
Dy	5.76	3.76	4.85	4.6	4.47	4.55	3.61	5.14
Ho	1.16	0.76	0.97	0.95	0.89	0.89	0.74	1.12
Er	3.26	2.3	2.67	2.7	2.59	2.63	2.07	2.77
Tm	0.48	0.32	0.37	0.39	0.38	0.37	0.3	0.4
Yb	3.1	2.19	2.43	2.43	2.62	2.56	1.94	2.55
Lu	0.46	0.32	0.36	0.37	0.37	0.37	0.29	0.36

sedimentary packages as well as on the geochemical subdivision of the mafic lavas.

The Fortune Harbour Formation forms the lower unit of the Cottrells Cove Group (O'Brien, 1990, 1991a,b), not the upper one as previously indicated (Dean, 1978; Swinden *et al.*, 1985; see also Helwig, 1967 and Lafrance and Williams, 1992). A probable conformable contact between pillow lavas and diabase of the Moretons Harbour Group and pillow lavas of the Fortune Harbour Formation is exposed in Tom Wall Harbour (Figure 2). The southeast-younging pillow basalts contain characteristic Fortune Harbour Formation rafts of greyish red chert (see also Strong and Payne, 1973; p. 1371) as well as abundant volcaniclastic intercalations.

Table 1. *Continued*

Sample	86SS-0260	86SS-0263	86SS-0264	86SS-0267	86SS-0268A	86SS-0269	86SS-0273	86SS-0284
SiO_2	49.93	50.17	52.19	50.85	45.04	49.4	54.67	48.64
TiO_2	1.18	0.69	1.05	1.04	0.77	1.63	0.57	1.02
Al_2O_3	18.91	13.91	18.1	17.05	14.68	15.18	13.21	15.19
Fe_2O_3	11.31	6.52	8.82	12.08	10.21	11.23	7.24	8.06
FeO	NA	NA	NA	NA	NA	NA	NA	NA
MnO	0.19	0.14	0.67	0.13	0.19	0.23	0.15	0.32
MgO	7.52	8.41	1.14	9.36	10.05	8.23	8.09	7.54
CaO	6.08	16.24	15.26	3.11	16.01	10.71	14.82	14.05
Na_2O	3.06	2.68	2.18	3.56	2.39	3.14	1.01	4.23
K_2O	1.73	1.05	0.25	2.63	0.6	0.12	0.12	0.82
P_2O_5	0.09	0.19	0.34	0.18	0.07	0.12	0.12	0.14
LOI	9.05	9.23	4	5.23	8.77	2.23	6.23	11.2
Mg #	56.84	71.87	20.38	60.54	66.09	59.21	68.88	64.94
Cr	348	429	ND	ND	671	146	192	242
Ni	209	196	14	30	356	75	99	108
Sc	39	31	32	40	36	45	32	38
V	301	206	108	378	185	363	190	290
Cu	72	47	3	35	26	61	35	43
Zn	52	32	52	66	43	63	32	51
Rb	37	14	3	35	15	1	1	11
Ba	132	285	125	214	106	35	28	169
Sr	229	358	592	197	189	134	65	226
Ga	NA	NA	NA	NA	NA	NA	NA	NA
Nb	4.7	3.5	3	2.3	0.6	5.2	1.1	3.6
Hf	0.95	1.67	1.83	1.44	1.44	2.44	0.94	1.26
Zr	72	71	84	53	53	110	33	59
Y	15	17	25	24	20	36	14	16
Th	0.1	2.69	1.82	1.29	0.11	0.23	0.86	0.7
La	2.24	10.25	8.51	6.56	1.68	4.12	3.98	4.11
Ce	7.34	21.96	18.91	16.15	4.82	12.86	8.85	9.6
Pr	1.29	2.9	2.77	2.29	0.98	2.1	1.3	1.45
Nd	6.37	12.22	12.88	10.88	4.88	11.03	5.63	7.03
Sm	2.46	2.83	3.46	3.18	1.73	3.93	1.79	2.14
Eu	0.89	1	1.52	1.09	0.78	1.54	0.71	0.76
Gd	2.74	3.43	4.23	4.23	2.73	4.8	2.12	2.82
Tb	0.52	0.53	0.7	0.71	0.5	0.96	0.37	0.48
Dy	2.9	3.07	4.59	4.42	3.41	6.16	2.4	3.09
Ho	0.6	0.67	0.98	0.94	0.75	1.37	0.5	0.66
Er	1.67	1.77	2.61	2.47	2.26	3.7	1.37	1.68
Tm	0.21	0.24	0.39	0.32	0.31	0.51	0.18	0.24
Yb	1.4	1.57	2.41	2.13	2.12	3.62	1.32	1.62
Lu	0.2	0.24	0.35	0.32	0.32	0.54	0.19	0.22

Strong and Payne (1973) tentatively proposed that the Moretons Harbour Group consists prodominatly of island-arc volcanic rocks. No further studies have been carried out in the Moretons Harbour Group and the geochemistry of the pillow lavas in Tom Wall Harbour has not yet been determined. It is inferred, however, that they represent the same basal horizon of the Fortune Harbour Formation as the Type II (N-MORB) pillow lavas in the area of Little North Harbour and North Harbour Head (Figures 2 and 3). Although the relationship between the Moretons Harbour and Cottrells Cove groups remains unclear, contrary to the previous opinions of Dean and Strong (1977) (see also van der Pluijm *et al.*, 1990, 1993; and Van der Voo *et al.*, 1991) it is certain that the pillow lavas of the Fortune Harbour Formation extend northward beyond Little North Harbour and there is no definite structural discontinuity between them and

Table 1. *Continued*

Sample	86SS-0285A	86SS-0285B	86SS-0286	86SS-0287	86SS-0288A	86SS-0288B	86SS-0289	86SS-0290
SiO_2	49.64	51.26	44.12	49.15	45.72	47.09	47.43	48.16
TiO_2	1.19	1.09	0.84	0.66	0.6	0.74	0.64	0.89
Al_2O_3	16.19	15.72	15.21	14.01	13.95	14.95	13.16	15.98
Fe_2O_3	9.84	7.36	9.7	7.22	6.7	8.1	7.89	9.23
FeO	NA	NA	NA	NA	NA	NA	NA	NA
MnO	0.23	0.25	0.18	0.13	0.16	0.16	0.18	0.14
MgO	5.46	6.23	6.11	9.45	8.03	10.87	10.52	13.24
CaO	12.65	12.71	19.19	16.97	20.19	13.05	16.52	7.21
Na_2O	4.04	4.66	4.27	2.09	3.65	3.47	3.38	2.17
K_2O	0.6	0.58	0.25	0.16	0.87	1.45	0.16	2.7
P_2O_5	0.16	0.14	0.13	0.16	0.12	0.12	0.12	0.27
LOI	5.54	6	13.8	7.93	11.2	9.47	8.85	6.54
Mg #	52.36	62.64	55.51	72.16	70.36	72.66	72.52	73.96
Cr	248	235	613	661	340	1100	1492	310
Ni	112	141	267	313	218	305	566	142
Sc	43	41	36	29	30	34	31	43
V	273	253	231	200	221	221	194	281
Cu	3	57	23	41	52	41	55	69
Zn	68	47	48	35	29	39	47	55
Rb	18	11	4	2	13	15	2	48
Ba	32	ND	48	39	153	194	33	413
Sr	126	282	169	235	242	135	88	251
Ga	NA	NA	NA	NA	NA	NA	NA	NA
Nb	3.1	4.3	2	3.5	2.2	2.3	2.3	7.3
Hf	1.94	NA	1.12	1.27	1.04	1.21	1.17	1.84
Zr	70	72	57	61	40	45	41	78
Y	29	23	21	15	14	15	14	19
Th	0.66	NA	0.8	1.62	1.39	1.49	1.54	2.04
La	5.37	NA	5.17	8.35	6.56	4.74	6.09	9.16
Ce	14.54	NA	11.61	18.16	14.11	11.23	13.64	20.43
Pr	2.11	NA	1.79	2.68	1.92	1.7	1.89	2.79
Nd	10.41	NA	7.8	10.01	7.98	7.33	8.6	11.84
Sm	3.3	NA	2.48	2.66	2.24	2.14	2.12	3.25
Eu	1.32	NA	0.91	0.9	0.7	0.72	0.73	1.18
Gd	4.5	NA	3.05	2.81	2.5	2.56	2.45	3.95
Tb	0.78	NA	0.53	0.46	0.41	0.41	0.37	0.61
Dy	5.13	NA	3.39	2.85	2.55	2.72	2.43	3.73
Ho	1.15	NA	0.73	0.56	0.56	0.58	0.52	0.79
Er	2.95	NA	1.95	1.52	1.49	1.48	1.37	2
Tm	0.4	NA	0.26	0.19	0.2	0.2	0.19	0.26
Yb	2.68	NA	1.76	1.27	1.41	1.33	1.28	1.85
Lu	0.42	NA	0.24	0.2	0.2	0.19	0.2	0.26

the Moretons Harbour Group (Figure 2). This suggests that the 'Chanceport Fault' outcrops merely as a minor structure, restricted to the N-MORB lavas of the Fortune Harbour Formation.

Thrust faults bound the main sedimentary member of the Fortune Harbour Formation (Figure 5). The succession of radiolarites and volcaniclastics is underlain by Type I (island-arc) mafic lavas. Basalt rafts of similar, calc-alkalic affinity are present in the olistostrome unit (Figure 8d).

Given the petrogenetic discordance between the calc-alkalic rocks on the one hand and the N-MORB and E-MORB lavas on the other hand, it can be reasonably suggested that the former are not petrogenetically related to the latter and furthermore, that they represent very different tectonic

Table 1. *Continued*

Sample	86SS-0291A	86SS-0291B	86SS-0291C	86SS-0291D
SiO_2	51.07	49.57	49.47	50.04
TiO_2	1.19	1.55	1.43	1.35
Al_2O_3	15.49	17.66	15.8	16.23
Fe_2O_3	8.71	9.5	9.04	6.53
FeO	NA	NA	NA	NA
MnO	0.16	0.19	0.16	0.11
MgO	9.72	7.32	9.6	7.18
CaO	9	9.01	9.92	12.99
Na_2O	4.39	4.68	4.24	5.14
K_2O	0.16	0.36	0.19	0.27
P_2O_5	0.12	0.17	0.15	0.16
LOI	4.85	7.16	6.85	9.08
Mg #	68.85	60.41	67.77	68.53
Cr	607	522	552	451
Ni	313	274	323	280
Sc	39	47	34	39
V	255	320	262	262
Cu	49	55	47	50
Zn	41	57	56	43
Rb	1	5	2	4
Ba	92	ND	81	7
Sr	217	252	263	348
Ga	NA	NA	NA	NA
Nb	2.1	6.4	5	5.7
Hf	2.59	NA	2.33	NA
Zr	94	122	107	119
Y	28	32	28	30
Th	0.16	NA	0.27	NA
La	2.47	NA	3.27	NA
Ce	9.07	NA	10.14	NA
Pr	1.69	NA	1.74	NA
Nd	9.52	NA	9.07	NA
Sm	3.26	NA	3.03	NA
Eu	1.18	NA	1.12	NA
Gd	4.1	NA	4.05	NA
Tb	0.75	NA	0.72	NA
Dy	5.09	NA	4.8	NA
Ho	1.14	NA	0.98	NA
Er	3.06	NA	2.58	NA
Tm	0.43	NA	0.37	NA
Yb	2.98	NA	2.41	NA
Lu	0.43	NA	0.37	NA

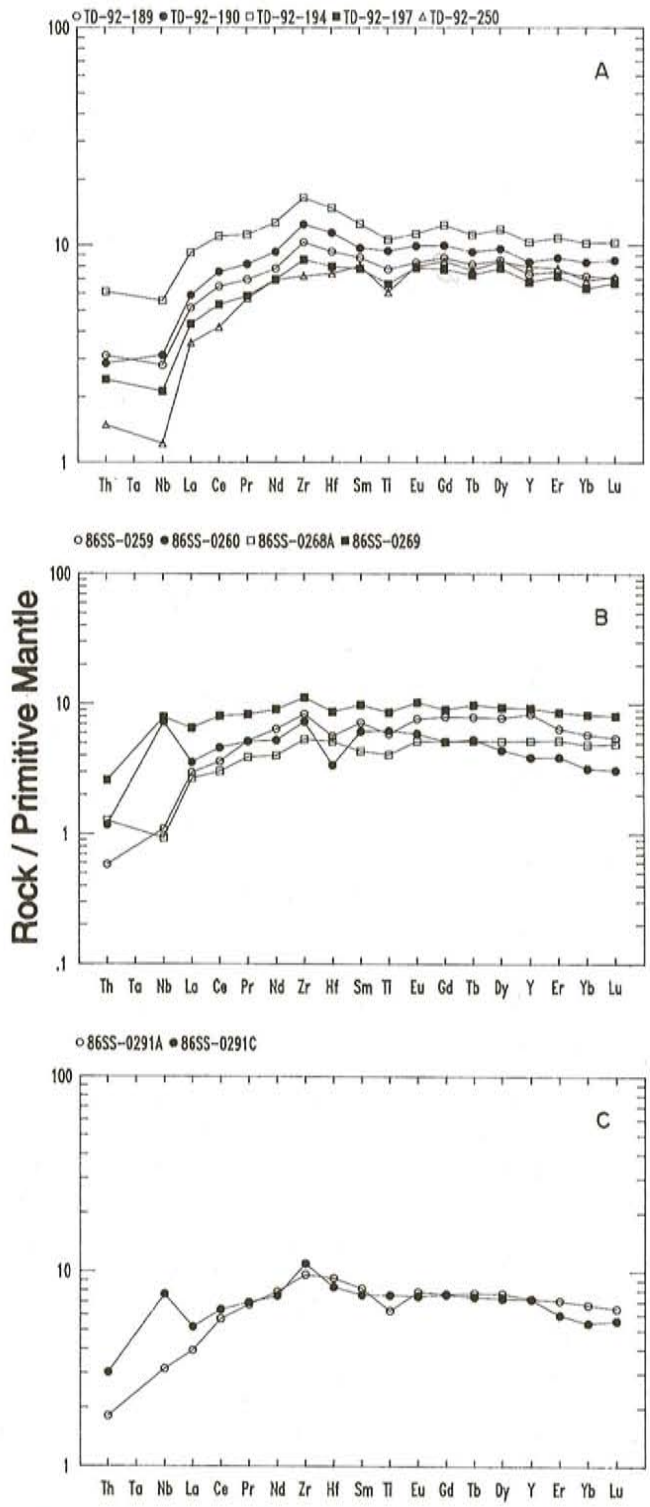

Figure 9. *Extended REE patterns for Type II volcanic rocks. Primitive mantle normalization after Swinden* et al. *(1990). A—mafic volcanic flows from the east shore of the Fortune Harbour Peninsula; B—mafic volcanic rocks from the Chanceport Group; C—mafic volcanic clasts from the Boones Point Complex at Yates Point.*

environments. The calc-alkalic rocks are unlikely to be stratigraphically related to the others and significant faults between sequences containing these contrasting rock types can be postulated (see Figures 2 to 4). However, the relationships between N-MORB and E-MORB lavas in the study area is equivocal. Such lavas are known to erupt together in modern tectonic settings (e.g. the mid-Atlantic Ridge; Schilling *et al.*, 1983). A stratigraphic relationship between the N-MORB and E-MORB lavas is possible, although not demanded by the geochemical data. It is equally possible that

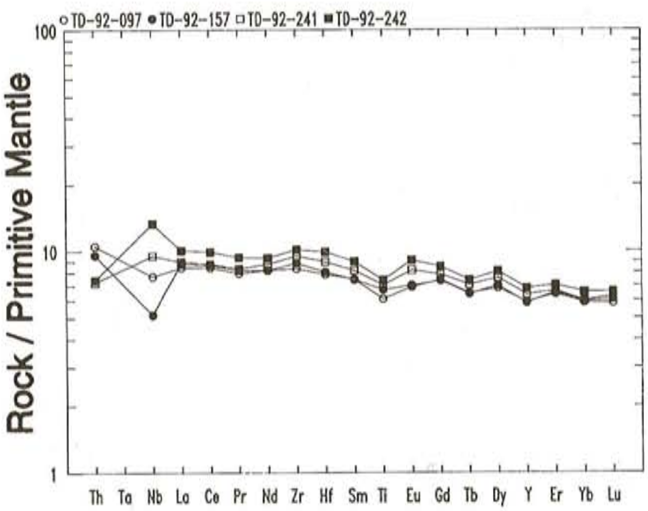

Figure 10. *Extended REE patterns for Type III volcanic rocks. Primitive mantle normalization after Swinden* et al. *(1990).*

they represent different, stratigraphically unrelated, volcanic episodes. The proposed stratigraphic model for the Cottrells Cove Group favours the latter scenario as it requires the Type III (E-MORB) lavas to be the youngest. In the continuous succession on Grassy Island (Figure 4), the E-MORB pillow lavas are conformably overlain by radiolarian cherts with volcaniclastic intercalations that in turn pass upward into the turbiditic deposits of the Moores Cove Formation.

REGIONAL CORRELATIONS

Most workers in recent years have correlated the Cottrells Cove and Chanceport groups with the Roberts Arm and Buchans groups to the west and southwest, suggesting that the rocks between the Chanceport and Lukes Arm faults are part of the Buchans–Roberts Arm volcanic belt (Dean, 1978; Williams *et al.*, 1988). Our geochemical data are consistent with this correlation.

Bostock (1988) and Swinden (1992) have shown that the Roberts Arm Group is geochemically bipartite, consisting of: i) an eastern tholeiitic sequence containing rocks of N-MORB, E-MORB, oceanic-island basalt (OIB) and island-arc tholeiite (IAT) affinities, and ii) an eastern sequence consisting of calc-alkalic andesites and basalts and rhyolite. Similar subdivisions can be recognized to the south in the Buchans Group. Swinden (1991) suggested that the tholeiitic rocks might be related to an ocean-floor sequence to the west (the Hall Hill, Mansfield Cove, Hungry Mountain and Annieopsquotch complexes) and have been structurally imbricated with the calc-alkalic rocks during accretion to the Laurentian margin. However, definitive evidence for this relationship is still lacking.

Calc-alkalic rocks in the Cottrells Cove and Chanceport groups are geochemically similar to calc-alkalic rocks in the Roberts Arm Group. Although not definitive, this similarity is consistent with their correlation with the Roberts Arm

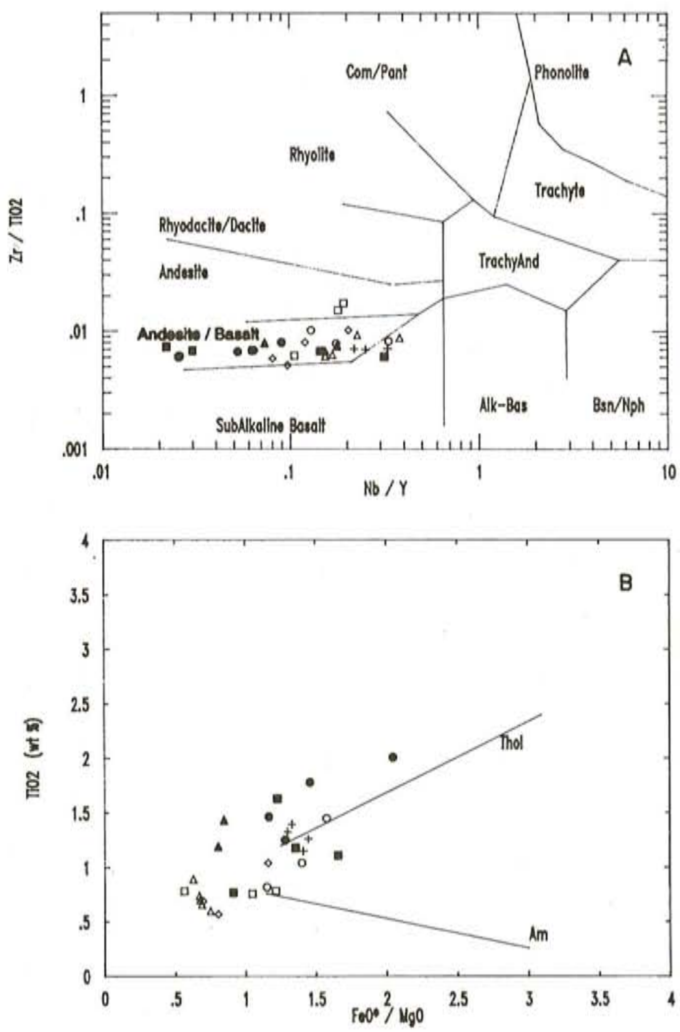

Figure 11. *Magma series of mafic volcanic rocks in the Cottrells Cove and Chanceport groups. A–discrimination of alkalic and subalkalic rocks after Winchester and Floyd (1975); B–discrimination of tholeiitic and calc-alkalic magma series after Miyashiro (1974). Open symbols are arc-related rocks: circles–boulders from Moores Cove Formation conglomerate and Fortune Harbour Formation olistostrome; squares–North Harbour area lavas; triangles–Cottrells Cove Group lavas in Highway 352 roadcuts between Cottrell's Cove and Fortune Harbour; diamonds–Chanceport Group lavas. Closed symbols are N-MORB-like basalts: circles–from the Boones Point Complex. Crosses represent E-MORB-type lavas from the east coast of the Fortune Harbour Peninsula and from Grassy Island.*

Group. Tholeiitic rocks in the study area, although not as geochemically varied as those in the Buchans and Roberts Arm groups, nonetheless have clear analogs in these sequences. Their presence in the Cottrells Cove Group is again consistent with but does not prove the correlation with the Roberts Arm Group.

There is presently no clear-cut evidence for the stratigraphic relationship of tholeiitic and calc-alkalic rocks

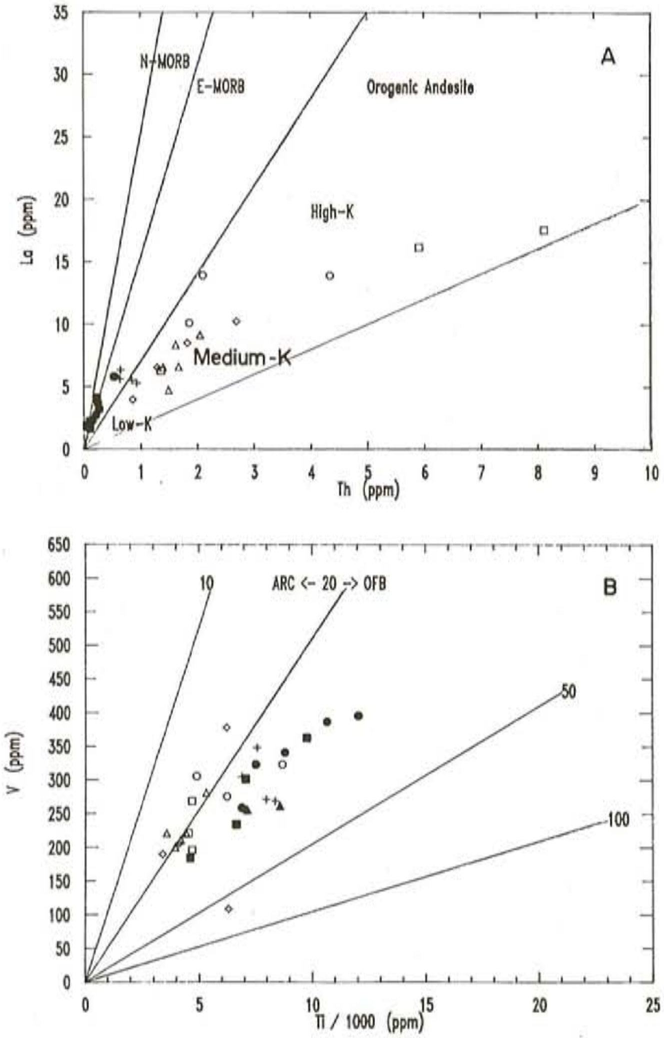

Figure 12. *Trace-element ratio plots. A—discrimination of orogenic andesite from MORB after Gill (1981); B—discrimination of arc from non-arc (OFB) rocks after Shervais (1982).*

in the Buchans—Roberts Arm volcanic belt. If tholeiitic rocks are correlative with those in the Hall Hill—Mansfield Cove complexes, then they must be slightly older than the calc-alkalic rocks (Dunning *et al.*, 1987). However, it is equally possible that there is more that one volcanic episode represented by the geochemically diverse tholeiitic volcanic rocks. In such a case it may be that at least some of these rocks are, in fact, younger than the calc-alkalic rocks as shown in Figure 5. This being true, there are no clear relationships in the Roberts Arm Group that can be used to infer stratigraphy in the present study area.

The main assemblage of sedimentary rocks in the Roberts Arm Group is represented by the Crescent Lake Formation (Bostock, 1988), which broadly resembles the deposits of the Cottrells Cove Group. However, Bostock's (1988) Units A and B do not reflect the significant differences between the sedimentary rocks in the Fortune Harbour and Moores Cove formations. Furthermore, the Crescent Lake Formation constitutes the lowest unit of the Roberts Arm Group (Bostock, 1988, p. 69). Such a lithostratigraphic position reflects the earlier, erroneous interpretations of the Cottrells Cove Group (Dean, 1978; Swinden *et al.*, 1985; see also Helwig, 1967 and Lafrance and Williams, 1992). These earlier interpretations are contrary to the order of events proposed by O'Brien (1990, 1991) which are confirmed in our model (Figure 5).

Both, the volcanic and the sedimentary rocks of the Chanceport Group strongly resemble those in the Cottrells Cove Group. However, our lithostratigraphic model is at odds with the Lafrance and Williams's (1992, p. 1903) threefold subdivision of the 'Chanceport Terrane'.

METALLOGENY

Calc-alkalic andesites and basalts in the Buchans and Roberts Arm groups host a number of important volcanogenic massive sulphide deposits including the Buchans camp, Gullbridge and Pilley's Island. The calc-alkalic sequences in these groups are widely regarded as excellent targets for volcanogenic massive sulphide deposits. If their correlation with the Cottrells Cove and Chanceport groups is correct, then calc-alkalic rocks in these groups must also be considered as having a good exploration potential. The existing data are not sufficient to precisely outline all of the calc-alkalic rocks in these groups. However, based on the distribution of available samples, there would seem to be at least one belt of calc-alkalic rocks traversing the north and central parts of the Cottrells Cove Group between North Harbour and Cottrell's Cove. In the Chanceport Group, the data suggest that there may be at least two belts of calc-alkalic rocks separated by a belt of N-MORB lavas. More detailed sampling in both areas would allow better definition of the extent of prospective volcanic rocks.

CONCLUSIONS

The stratigraphy of the Cottrells Cove Group has been provisionally established on the basis of newly recognized field relationships, supported by sedimentological studies and geochemistry of mafic volcanic rocks.

1. The lower part of the Cottrells Cove Group is represented by the Fortune Harbour Formation, whose lowest N-MORB lavas, and associated radiolarites and volcaniclastic intercalations, are in a possible conformable relationship with the underlying island-arc(?) pillow lavas of the Moretons Harbour Group.

2. The remaining, thrust-bound sections of the Fortune Harbour Formation consist of island-arc, calc-alkalic andesites and basalts, followed by a 1250-m-thick succession of radiolarian cherts and pelagic mudstones, intrebedded with volcaniclastic turbidites and debrites. This main sedimentary member of the Fortune Harbour Formation is interpreted as a basin plain, which was oversupplied with contemporaneously produced volcanogenic detritus.

3. The E-MORB lavas and the overlying radiolarites represent the youngest volcano-sedimentary event of the Fortune Harbour Formation and pass gradationally into the pelagic and turbiditic deposits of the Moores Cove Formation.

4. The Moores Cove Formation is over 1200 m thick and constitutes the upper part of the Cottrells Cove Group. It is represented by a coarsening-upward succession of mudstones sandstones and conglomerates, deposited in lower-slope/basin-plain and submarine-fan environments. Plutonic, volcanic, sedimentary and ophiolitic detritus in the upper, turbiditic portion of the formation is reminiscent of the Upper Ordovician–Lower Silurian deep-sea turbidites in the Exploits Subzone. A possible correlation of the Moores Cove Formation across the Red Indian Line with the turbiditic deposits of the Point Leamington and the Milliners Arm formations undermines the fundamental stratigraphic rationale for the existing subdivision of the Dunnage Zone into suspect terranes of the Notre Dame and Exploits subzones.

5. Despite similarities between volcano-sedimentary successions of the Cottrells Cove and Roberts Arm groups there are no clear relationships in the Roberts Arm Group that would correspond to our lithostratigraphic model.

6. The Chanceport Group succession strongly resembles that of the Cottrells Cove Group.

7. The Chanceport Fault is restricted to the rocks of the Cottrells Cove Group and does not separate distinct geological units or terranes.

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