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# VOLCANIC STRATIGRAPHY NORTHWEST OF NEW BAY POND, CENTRAL NEWFOUNDLAND, AND THE STRIKE–EXTENT OF THE POINT LEAMINGTON MASSIVE SULPHIDE HORIZON

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## ABSTRACT

*Geological mapping in the area west and north of New Bay Pond, central Newfoundland, suggests that submarine volcanic and epiclastic rocks informally assigned to the New Bay Pond sequence may be correlated with the Wild Bight Group immediately to the north. Whole-rock geochemical data support this correlation and allow the New Bay Pond sequence lavas to be interpreted in the context of the chemostratigraphy of the Wild Bight Group. Pillow lavas that form the northeastern unit of the New Bay Pond sequence consist mainly of incompatible element-depleted rocks with unusual REE-patterns. These rocks are similar to those found in the central part of the Wild Bight Group stratigraphic section where they are invariably associated with volcanogenic sulphide deposits. In contrast, the southwestern volcanic unit in the New Bay Pond sequence consists of light REE-enriched tholeiitic and mildly alkalic rocks. They are similar to rocks at the top of the Wild Bight Group, which are not known to be associated with mineralization.*

*Interpretation of geochemical and geophysical (electromagnetic and vertical gradient magnetometer) data suggest that the highly incompatible element-depleted rocks in the New Bay Pond sequence form part of a geological unit that can be traced continuously northward to the area of the Point Leamington massive sulphide deposit. The data indicate that this unit and its contained massive sulphide deposit are separated from volcanic and sedimentary rocks to the east by a thrust fault that predates regional folding. Numerous northeast-striking faults in the area have small displacements and do not significantly disrupt the stratigraphic succession.*

## INTRODUCTION

Submarine mafic and felsic volcanic rocks and volcaniclastic turbidites between New Bay Pond and Frozen Ocean Lake (Figures 1 and 2) were assigned by Dean (1978) to the Frozen Ocean Group, which he considered to be of probable Silurian age. Kusky (1985) and Swinden (1988a) independently mapped this area and reinterpreted these rocks as pre-Middle Ordovician correlatives of the Wild Bight Group, a thick sequence of dominantly volcanic-derived turbidites interbedded with mafic and minor felsic volcanic rocks immediately to the north and northeast (Figure 2). Swinden (1988a) suggested that the stratigraphic name 'Frozen Ocean Group' be abandoned, and informally coined the term 'New Bay Pond sequence' for the marine volcanic and sedimentary rocks northwest of New Bay Pond.

Although the overall lithological similarity between the New Bay Pond sequence and the Wild Bight Group suggest that the two might be correlative, this interpretation is equivocal. There are many other marine mafic volcanic–volcaniclastic sequences in central Newfoundland, which are lithologically similar to, and thereby also potentially correlative with, the New Bay Pond sequence, although none are so closely associated. One way of testing the correlation is through study of the whole-rock geochemistry of the mafic volcanic rocks. Such an approach is feasible because the chemostratigraphy of the Wild Bight Group has been particularly well-documented and it has been shown that geochemically distinct mafic volcanic rocks are characteristic of particular intervals within the stratigraphic sequence (Swinden, 1987; Swinden *et al.*, 1990). Therefore, it is likely that if the mafic volcanic rocks in the New Bay Pond sequence do correlate with parts of the Wild Bight Group, their chemostratigraphic association can be recognized. Of particular interest, in the context of this study, is whether the stratigraphic interval that hosts the large Point Leamington massive sulphide deposit immediately to the northwest of the New Bay Pond area could be traced to, or recognized in, the New Bay Pond sequence, thereby enhancing the exploration potential of this area.

Ten samples of mafic volcanic rocks were collected from the New Bay Pond sequence and analyzed for a

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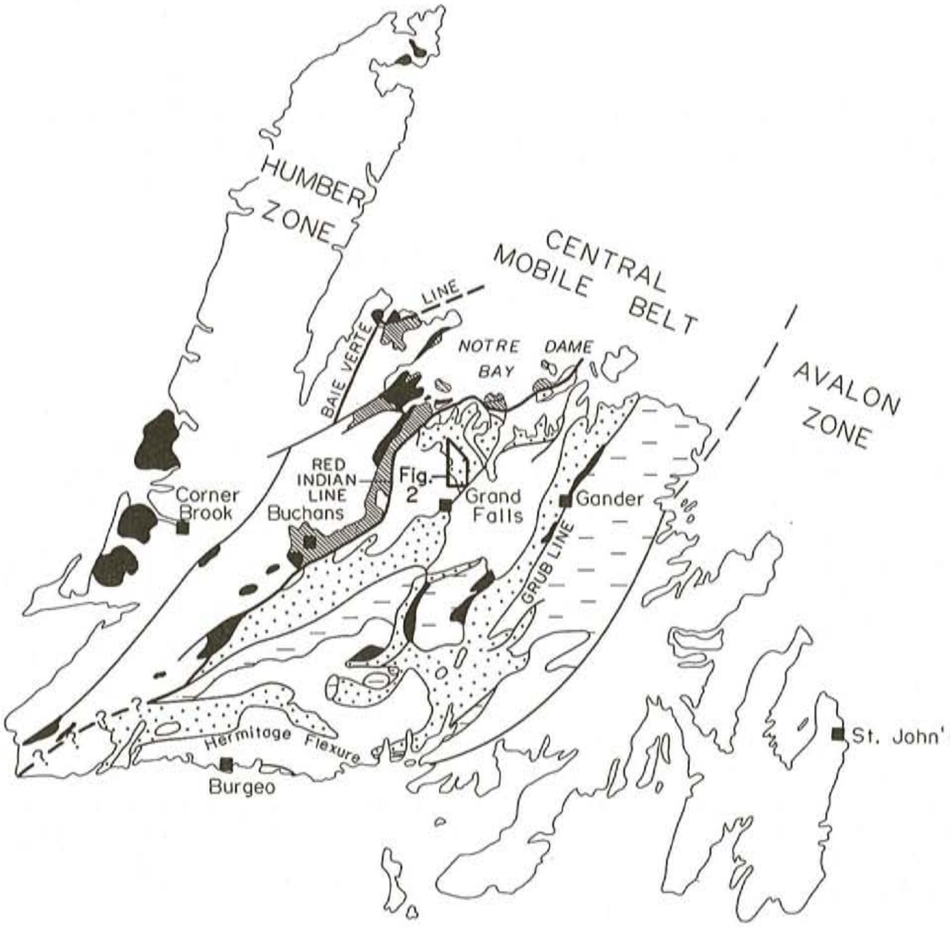


**Figure 1.** *Location map showing vestiges of Iapetus in central Newfoundland (after Swinden* et al., *1988). Ophiolites are in black. Hatched and stippled areas are volcanic and epiclastic rocks in the Notre Dame and Exploits subzones (Williams* et al., *1988), respectively. Solid box outlines area of Figure 2.*

comprehensive suite of major and trace elements (Figure 2; Table 1). These data are herein used to examine the proposed lithostratigraphic correlations between the New Bay Pond sequence and the Wild Bight Group and, coupled with results from gradiometer (Geological Survey of Canada data) and industrial airborne electromagnetic surveys, to revise the geological map of the area between the Point Leamington deposit and New Bay Pond. New interpretations resulting from these data suggest that the productive Point Leamington stratigraphic interval can be traced intact from the deposit southward to the area of New Bay Pond and that a structural model involving early, south-directed thrusting can explain previously unresolved stratigraphic problems in the area of the massive sulphide deposit.

## GENERAL GEOLOGY

The early Paleozoic geological history of the central part of Notre Dame Bay is recorded by a structurally disrupted sequence of Cambrian to Ordovician volcanic and volcaniclastic rocks, which record events in a number of island arcs and back-arc basins. The Wild Bight and adjacent Exploits groups preserve the youngest arc and back-arc sequences in Newfoundland (Swinden *et al.*, 1989a; 1990) and are regionally overlain by a Middle Ordovician chert and carbonaceous argillite unit (the 'Caradocian Interval' of Dean, 1978), which passes gradationally and conformably into Upper Ordovician and Lower Silurian volcanic-derived turbidites (the Sansom and Point Leamington greywackes and the Goldson Conglomerate).

The geology of the Wild Bight Group has been most recently described by Dean (1978) and Swinden (1987). It is disposed about a major, north-trending fold, the Seal Bay anticline. Rocks in the core of the Seal Bay anticline represent the stratigraphically lowest units in the Wild Bight Group and the stratigraphic succession progresses more or less continuously upward across the limbs of this fold (although with local reversals resulting from folding and faulting) until passing into the overlying Shoal Arm Formation ('Caradocian interval'). Rocks in the Wild Bight Group comprise about 25 percent volcanic rocks, of which aqpproximately 90 percent are mafic pillow lavas and lesser massive basalts. There are four volcanogenic sulphide deposits or occurrences in the central part of the Wild Bight Group, the Point Leamington and Lockport deposits and the Indian Cove and Long Pond

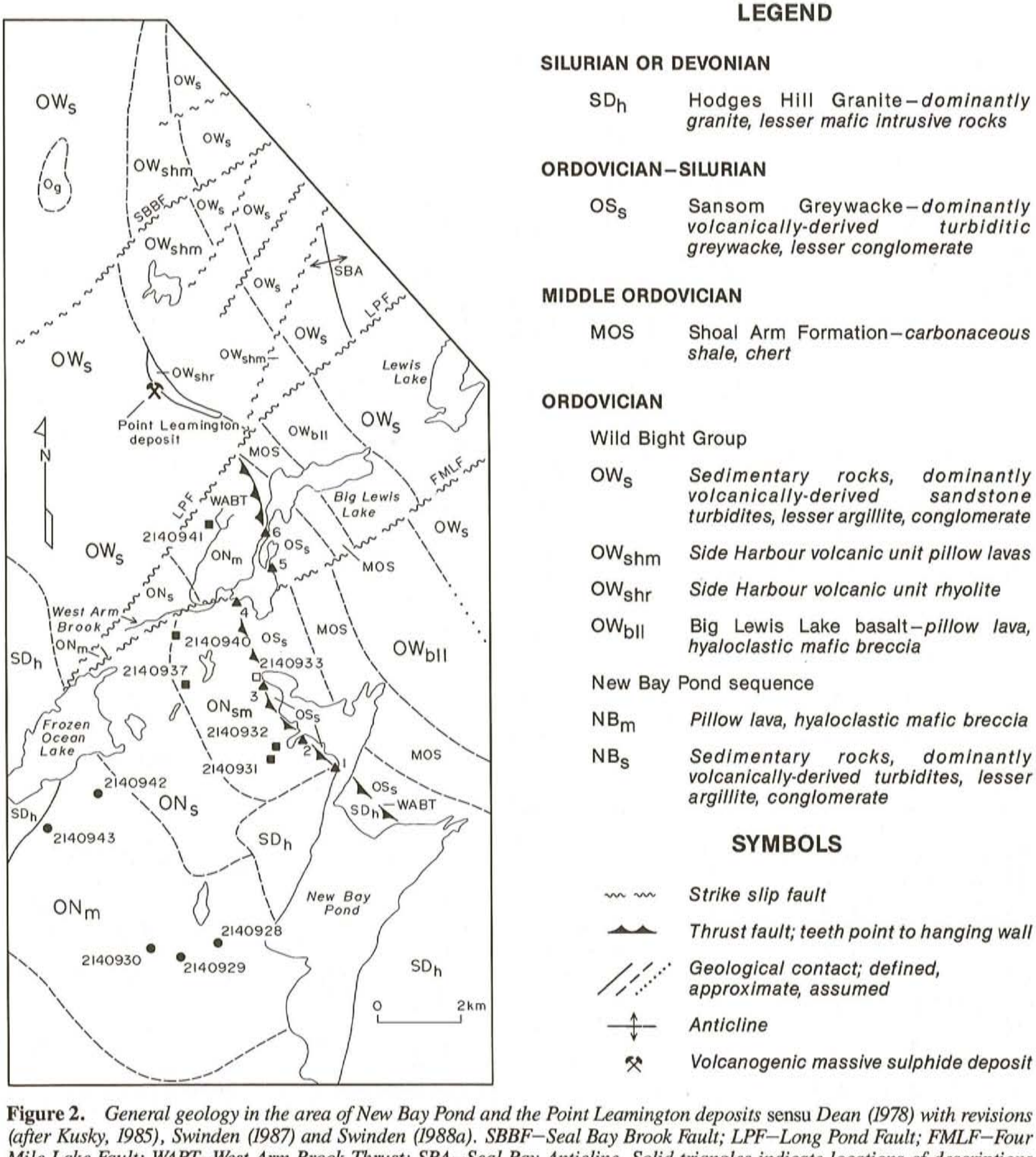


**Figure 2.** *General geology in the area of New Bay Pond and the Point Leamington deposits* sensu *Dean (1978) with revisions (after Kusky, 1985), Swinden (1987) and Swinden (1988a). SBBF–Seal Bay Brook Fault; LPF–Long Pond Fault; FMLF–Four Mile Lake Fault; WABT–West Arm Brook Thrust; SBA–Seal Bay Anticline. Solid triangles indicate locations of descriptions of the West Arm Brook Thrust (Kusky, 1985). Analyzed sample locations with sample numbers are keyed to geochemical type (see text): solid squares–Type I; open squares–Type II; solid dots–Type III.*

deposits (Swinden, 1988b). The largest of these, the Point Leamington deposit, contains about 13.8 million tonnes of massive sulphide grading 0.48 percent Cu, 1.92 percent Zn, 18.1 g/t Ag and 0.9 g/t Au (Walker and Collins, 1988). The Lockport deposit is a small, massive-sulphide lens having an extensive footwall alteration zone, whereas the Indian Cove and Long Pond occurrences are stockworks.

In the New Bay Pond area, the top of the Wild Bight Group consists of a thick unit of pillow lava and pillow breccia

**Table 1.** Geochemical analyses of New Bay Pond Sequence mafic volcanic rock

| Sample | 2140928 | 2140929 | 2140930 | 2140931 | 2140932 | 2140933 | 2140940 | 2140941 | 9140942 | 9140943 |
|---|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 51.65 | 49.05 | 48.90 | 49.30 | 52.40 | 51.25 | 55.40 | 62.30 | 48.30 | 50.25 |
| $TiO_2$ | 1.72 | 1.97 | 1.50 | 0.16 | 0.32 | 0.68 | 0.48 | 0.33 | 1.34 | 1.81 |
| $Al_2O_3$ | 17.29 | 15.15 | 14.30 | 12.92 | 17.68 | 14.86 | 14.35 | 12.62 | 12.04 | 13.77 |
| $Fe_2O_3$ | 5.06 | 4.96 | 6.13 | 0.78 | 1.63 | 4.52 | 5.01 | 1.67 | 2.12 | 2.74 |
| FeO | 3.25 | 6.46 | 4.62 | 7.96 | 8.04 | 9.03 | 7.00 | 6.39 | 8.19 | 7.82 |
| MnO | 0.21 | 0.18 | 0.19 | 0.15 | 0.11 | 0.19 | 0.13 | 0.13 | 0.20 | 0.16 |
| MgO | 5.07 | 7.02 | 6.45 | 8.68 | 6.99 | 4.89 | 3.69 | 4.06 | 12.47 | 9.78 |
| CaO | 9.82 | 9.67 | 14.01 | 9.62 | 3.78 | 8.77 | 10.25 | 5.21 | 10.66 | 8.47 |
| $Na_2O$ | 4.11 | 3.41 | 2.65 | 0.85 | 5.54 | 2.81 | 0.47 | 4.02 | 2.26 | 3.80 |
| $K_2O$ | 0.73 | 1.09 | 0.13 | 1.01 | 0.07 | 0.20 | 0.07 | 0.11 | 0.17 | 0.35 |
| $P_2O_5$ | 0.36 | 0.25 | 0.19 | 0.01 | 0.01 | 0.05 | ND | ND | 0.18 | 0.21 |
| Total | 100.66 | 100.52 | 100.60 | 99.53 | 100.20 | 99.78 | 99.65 | 100.69 | 100.18 | 100.13 |
| LOI | 1.39 | 1.31 | 1.53 | 8.09 | 3.63 | 2.50 | 2.81 | 3.12 | 2.25 | 0.97 |
| Mg # | 54 | 53 | 53 | 64 | 57 | 40 | 36 | 48 | 69 | 63 |
| Cr | 71 | 114 | 366 | 729 | 101 | 7 | 7 | 25 | 805 | 463 |
| Ni | 35 | 56 | 113 | 118 | 34 | 8 | 14 | 14 | 374 | 196 |
| Sc | NA | 29 | 25 | NA | 51 | 41 | 58 | NA | 30 | 31 |
| V | 205 | 268 | 260 | 252 | 306 | 424 | 425 | 271 | 213 | 230 |
| Cu | 9 | 32 | 55 | 127 | 102 | 58 | 106 | 154 | 80 | 89 |
| Zn | 81 | 97 | 80 | 75 | 77 | 97 | 86 | 69 | 79 | 91 |
| Rb | 15 | 23 | ND | 14 | 6 | 7 | ND | ND | ND | 7 |
| Sr | 550 | 315 | 215 | 108 | 73 | 62 | 122 | 28 | 313 | 220 |
| Ta | NA | 0.74 | 0.56 | NA | ND | 0.03 | ND | NA | 0.53 | 0.73 |
| Nb | NA | 13.9 | 10.1 | NA | 0.2 | 0.4 | 0.2 | NA | 9.2 | 13.1 |
| Hf | NA | 3.10 | 2.48 | NA | 0.13 | 0.65 | 0.21 | NA | 2.58 | – |
| Zr | 172 | 117 | 81 | NA | 4 | 18 | 5 | 1 | 98 | 125 |
| Y | NA | 20 | 17 | NA | 3 | 15 | 4 | NA | 17 | 20 |
| Th | NA | 2.11 | 1.11 | NA | 0.04 | 0.25 | 0.09 | NA | 1.50 | 1.57 |
| La | NA | 12.60 | 9.86 | NA | 0.28 | 1.51 | 0.51 | NA | 9.71 | 11.50 |
| Ce | NA | 28.60 | 21.80 | NA | 0.54 | 3.56 | 0.79 | NA | 21.70 | 26.70 |
| Pr | NA | 3.90 | 2.90 | NA | 0.11 | 0.64 | 0.20 | NA | 3.06 | 3.93 |
| Nd | NA | 17.40 | 12.60 | NA | 0.65 | 3.17 | 0.88 | NA | 13.60 | 17.00 |
| Sm | NA | 4.61 | 3.34 | NA | 0.28 | 1.21 | 0.32 | NA | 3.55 | 4.37 |
| Eu | NA | 1.52 | 1.20 | NA | 0.11 | 0.52 | 0.18 | NA | 1.07 | 1.57 |
| Gd | NA | 4.74 | 3.90 | NA | 0.39 | 1.75 | 0.50 | NA | 3.96 | 4.82 |
| Tb | NA | 0.72 | 0.56 | NA | 0.08 | 0.33 | 0.09 | NA | 0.57 | 0.69 |
| Dy | NA | 4.20 | 3.34 | NA | 0.61 | 2.49 | 0.74 | NA | 3.54 | 4.02 |
| Ho | NA | 0.82 | 0.65 | NA | 0.13 | 0.56 | 0.17 | NA | 0.68 | 0.74 |
| Er | NA | 2.17 | 1.81 | NA | 0.46 | 1.79 | 0.50 | NA | 1.84 | 2.03 |
| Tm | NA | 0.30 | 0.24 | NA | 0.06 | 0.26 | 0.08 | NA | 0.25 | 0.31 |
| Yb | NA | 1.82 | 1.52 | NA | 0.40 | 1.78 | 0.50 | NA | 0.63 | 1.64 |
| Lu | NA | 0.25 | 0.21 | NA | 0.08 | 0.28 | 0.08 | NA | 0.24 | 0.25 |

NA–not analyzed; ND– not detected; major elements in wt. %; trace elements in ppm

informally termed the Big Lewis Lake basalt by Swinden (1987). The Big Lewis Lake basalt is overlain, apparently conformably although the contact has not been observed, by the fossiliferous Caradocian Shoal Harbour Formation. Although there are no direct data as to the age of the Wild Bight Group, its relationship with the Shoal Arm Formation and correlations with the fossiliferous Exploits Group to the east suggest that the top is probably Llanvirn–Llandeilo in age. The Shoal Arm Formation is stratigraphically overlain by Middle Ordovician to Silurian volcanic-derived turbidites of the Sansom Greywacke.

In the area between New Bay Pond and Big Lewis Lake (Figure 2), the Sansom Greywacke is structurally overlain by pillow lavas of the New Bay Pond sequence (Kusky, 1985).

The geology of the New Bay Pond sequence (Figure 2) has been previously described in some detail by Kusky (1985) and Swinden (1988a). The sequence consists of a northwest-striking succession of marine, dominantly mafic, volcanic and volcanic-derived sedimentary rocks. Three lithostratigraphic units are recognized (Figure 2):

1) a basal (southwestern) mafic volcanic unit consisting predominantly of massive basalt and mafic volcanic breccia;

2) an intermediate epiclastic turbidite unit consisting predominantly of greywacke and pebbly conglomerate with lesser argillite and coarse, polylithic conglomerate; and

3) an upper (northeastern) mafic volcanic unit consisting dominantly of pillow lava and recognizable pillow breccia containing minor silicic volcanic rocks. Red, ferruginous chert having interbedded magnetite are present locally.

Facing directions in the epiclastic unit are dominantly to the northeast but contacts between lithostratigraphic units were not observed and it is not known whether the lithological succession is stratigraphic or structural.

Kusky (1985) was the first to recognize that the contact between the New Bay Pond sequence and the Sansom Greywacke to the northeast is a fault, which he informally named the FOG fault. Because this name has not been formally published and does not correspond to accepted practice in structural nomenclature, the fault is herein renamed the West Arm Brook Thrust. Kusky (1985) made detailed structural observations, including measurement of stretching lineations, C–S fabrics, rotated clasts and sheath folds, at 6 localities between New Bay Pond and Big Lewis Lake (Figure 2). From these, he interpreted the kinematic sense of movement on the fault, when rotated to account for later folding, to be consistent with thrusting from north to south. Kusky (1985) suggested that this may have occurred during back thrusting associated with continued convergence of outboard terranes against the Laurentian margin following the Taconian orogenic event.

Dean's (1978) interpretation of stratigraphic and structural relationships northwest of New Bay Pond require a major structural discontinuity in the area north of Big Lewis Lake. This is because the sequence exposed on the shores and south of Big Lewis Lake exhibits a continuous stratigraphic section from the Big Lewis Lake basalt into the Shoal Arm Formation and thence, the Sansom Greywacke, with the Big Lewis Lake basalt representing the stratigraphic top of the Wild Bight Group. Northwest of Big Lewis Lake, however, volcanic rocks that are more or less along strike with the Big Lewis Lake basalt (the Side Harbour volcanic unit of Swinden, 1987 and Swinden *et al.*, 1990) were interpreted to pass stratigraphically upward into a continuing thick section of Wild Bight Group turbidites (Figure 2). In this interpretation, these volcanic rocks must have originated substantially below the Big Lewis Lake basalt, the Side Harbour and Big Lewis Lake basalts could not be stratigraphically correlative, and the fact that they are more or less along strike would be considered to be fortuitous. Such an interpretation necessitates a major structural break between the two volcanic units; Dean (1978) postulated that this break was the northeast-striking Long Pond Fault (Figure 2), requiring a major left-lateral offset on this structure.

## GEOCHEMISTRY

### THE WILD BIGHT GROUP

Swinden (1987) and Swinden *et al.* (1990) showed through a detailed geochemical and isotopic study that that volcanic rocks in the Wild Bight Group record a transition from island-arc-related volcanism (lower and middle stratigraphic levels) to dominantly non-arc-related volcanism (upper stratigraphic levels). Mafic volcanic rocks with island-arc geochemical signatures (positive Th and negative Nb, Ta anomalies on extended rare-earth plots; see Swinden *et al.*, 1989a, 1990, for discussions of arc and non-arc geochemical signatures) occupy the lower two-thirds of the stratigraphic section, overlain by rocks in the upper third of the section that lack island-arc signatures (Figure 3). Swinden *et al.* (1990) recognized six types of mafic volcanic rocks based on their geochemical characteristics. The lowermost mafic volcanic rocks in the Wild Bight Group consist mainly of light rare-earth-element (LREE)-enriched arc tholeiites and calc-alkalic basalts (Type A-I; this and subsequent references to geochemical type follow the nomenclature of Swinden *et al.*, 1990). They pass upward in the intermediate stratigraphic levels of the group into an interval marked by the eruption of LREE-depleted arc tholeiites (Type A-II), refractory tholeiites of highly distinctive chemical character (Type A-II), and LREE-depleted rhyolites. These pass upward into successions in the upper part of the Wild Bight Group, in which the volcanic rocks are characterized by alkalic basalts (Type N-I), high-$TiO_2$ tholeiites of oceanic island character (Type N-II) and basalts typical of tholeiites found on mid-ocean ridges (Type N-III).

Swinden *et al.* (1990) proposed a tectonic model for the Wild Bight Group, whereby an early episode of arc volcanism (recorded by arc tholeiites in the lower part of the group) was succeeded by a rifting of the arc (recorded by arc tholeiites, refractory arc tholeiites and rhyolites) in the central part of the group. Following rifting of the arc, a back-arc basin was established, recorded by non-arc rocks in the upper part of the group. The four volcanogenic sulphide deposits in the Wild Bight Group occur in the central part of the stratigraphy and are closely associated with Type A-III refractory tholeiites and rhyolite. Swinden *et al.* (1989a,b) have proposed that this association of massive sulphides with refractory mafic volcanic rocks is characteristic of many of the ancient island-

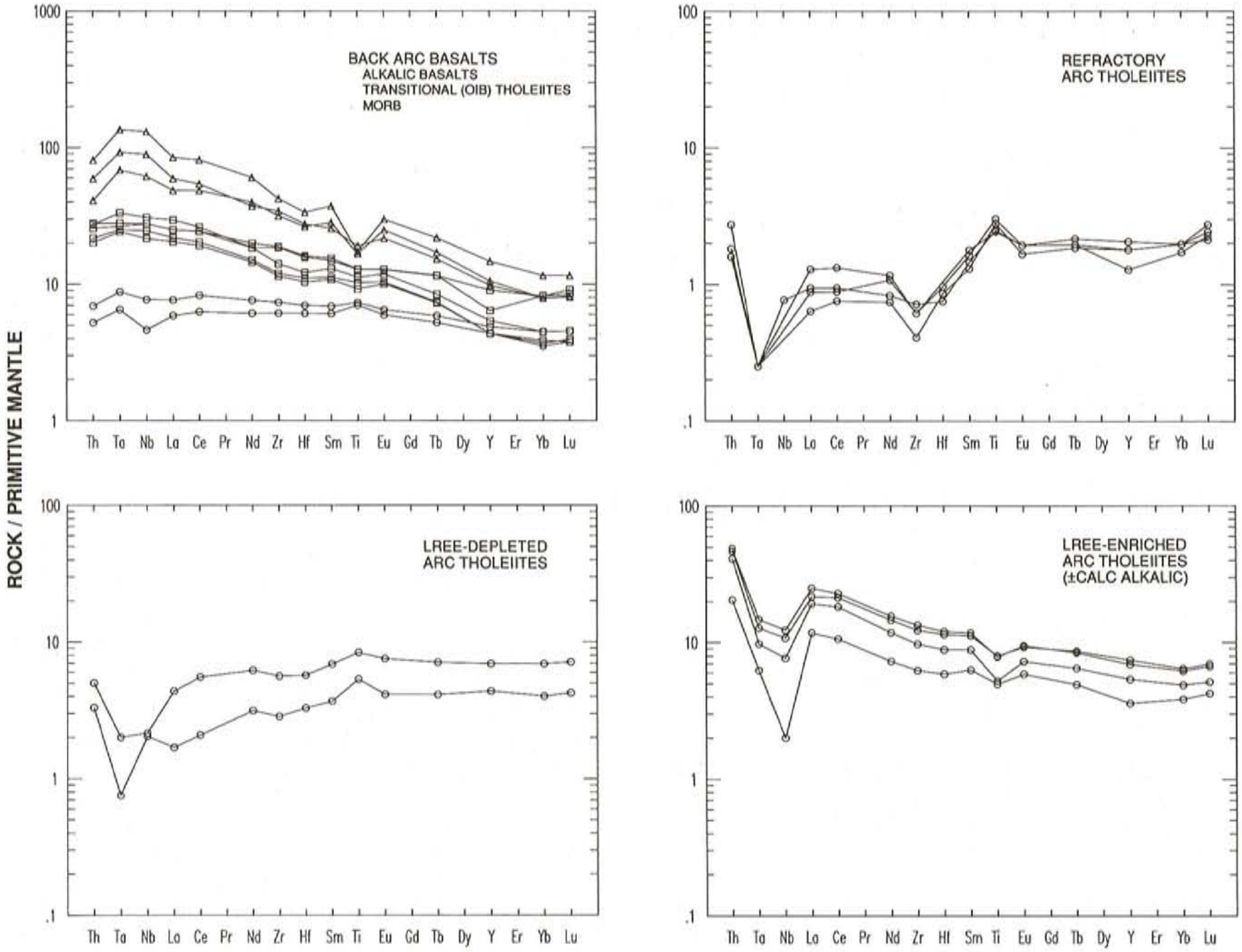


**Figure 3.** *Chemostratigraphy of the Wild Bight Group (after Swinden* et al., *1990). LREE-enriched arc tholeiites (Type A-I) are found in approximately the lower third of the sequence and are joined by LREE-depleted arc tholeiites (Type A-II) and refractory arc tholeiites (Type A-III) as well as rhyolites (not shown) in the intermediate part of the sequence. Back-arc basalts (triangles—Type N-I; squares—Type N-II; circles—Type N-III) dominate the upper part of the sequence.*

arc environments in central Newfoundland (e.g., Rambler, the Lushs Bight Group, the Betts Cove Ophiolite Complex; Swinden *et al.*, 1989a,b).

Swinden (1987) pointed out that there is a stratigraphic problem in the area of the Point Leamington deposit, if island-arc rocks are supposed to stratigraphically underlie non-arc rocks in the Wild Bight Group. In this area (Figure 2), the Side Harbour volcanic unit appears to be chemically bipartite. The Point Leamington massive sulphide deposit and its associated rhyolite form the western edge of the volcanic unit and are associated with arc-related refractory tholeiites in the immediate footwall. However, pillow lavas less than 1 km to the east and northeast of the deposit, and apparently stratigraphically below by virtue of their relative positions on the west limb of the Seal Bay anticline, are high-$TiO_2$ non-arc tholeiites and alkalic basalts. Swinden (1987) recognized this apparent anomaly in the stratigraphic relationships and suggested that it might be explained by repetition of stratigraphy along a roughly bedding-parallel fault between the Point Leamington deposit and the volcanic rocks to the east. However, exposure is very poor in the area and there were no geological observations to support or refute this suggestion.

## THE NEW BAY POND SEQUENCE

New analyses of mafic volcanic rocks from the New Bay Pond sequence are summarized in Table 1 and illustrated in Figures 4 to 6. Samples were taken from the interior of pillows or the relatively fresh interiors of massive flows. Data for the major elements and the trace elements Cu, Pb, Zn, Co, Ni, V, Ba, Sr and Rb were acquired by inductively coupled plasma—emission spectrometry (ICP-ES) in the Geological Survey Branch Laboratory using a HF, $HClO_4$ and HCl digestion. Analyses for the REE, certain high-field strength elements (HFSE; Ta, Nb, Zr, Hf, Y) and Th were analyzed by inductively coupled plasma—mass spectrometry (ICP-MS) at the Department of Earth Sciences, Memorial University; analytical techniques for ICP-MS with accuracy and precision are reported by Jenner *et al.* (1990).

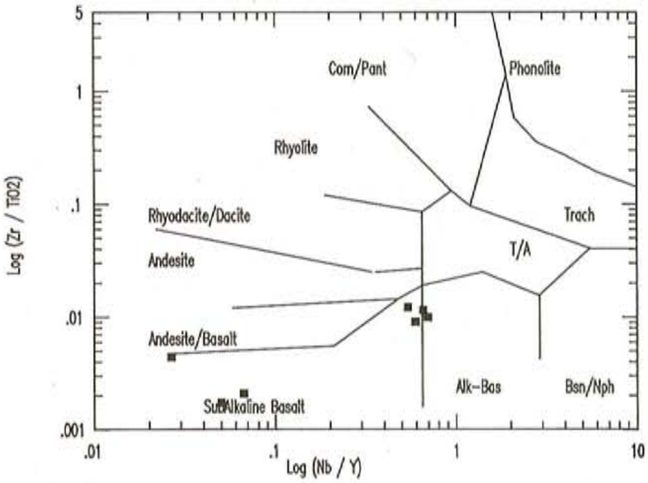


**Figure 4.** *Discrimination of volcanic magma types for old altered rocks after Winchester and Floyd (1977). New Bay Pond sequence basalts form two groups with affinities to subalkalic basalts and transitional alkalic basalts; respectively.*

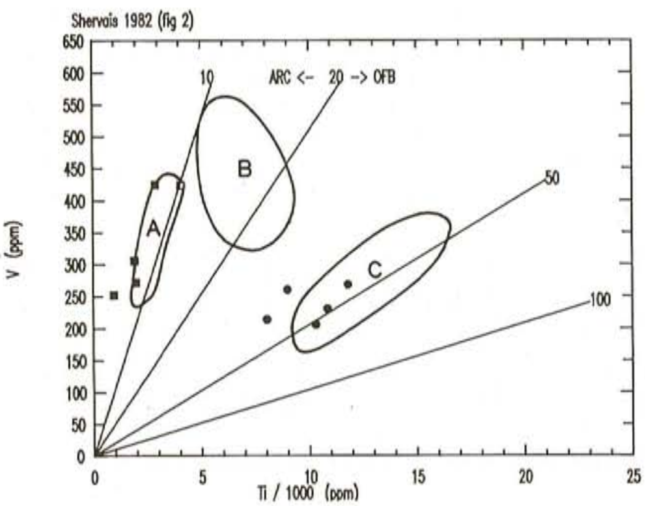


**Figure 5.** *Ti:V plot for New Bay Pond sequence mafic volcanic rocks after Shervais (1982). Solid squares–Type I; open squares–Type II; solid dots–Type III. Field A–Type A-III refractory tholeiites in the Wild Bight Group; Field B–Type A-II LREE-depleted arc tholeiites in the Wild Bight Group; Field C–Type N-II tholeiites of oceanic island affinity from the Wild Bight Group.*

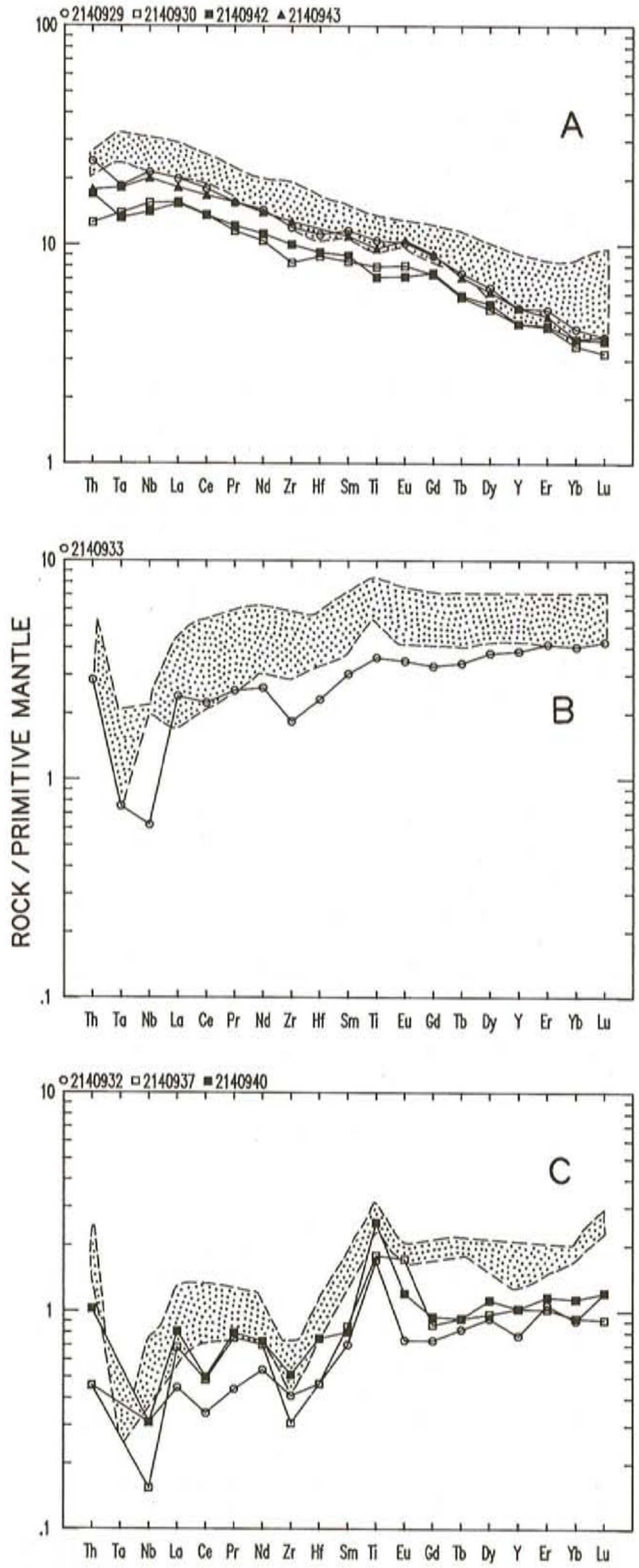


**Figure 6.** *Extended rare-earth plots for the New Bay Pond mafic volcanic rocks. A–Type I. Stippled field is the Type A-III refractory tholeiites in the Wild Bight Group; B–Type II. Stippled field is Type A-II LREE-depleted arc tholeiites in the Wild Bight Group; C–Type III. Stippled field is Type N-II tholeiites of oceanic island affinity from the Wild Bight Group.*

Mafic volcanic rocks in the New Bay Pond sequence clearly fall into two distinct magma types (Figure 4), a set of subalkalic basalts (Nb/Y <.08) and a set of subalkalic to transitional alkalic basalts (Nb/Y ~ 0.4 to 0.8). Incompatible-element contents and trace-element ratios (illustrated by the Ti:V ratio, Figure 5) support this subdivision and extended REE plots suggest that the subalkalic basalts can be further subdivided into two groups containing lower and higher incompatible-element contents, respectively. The geochemistry of these samples is described below in terms of these three geochemical types.

### Type I

Type I mafic volcanic rocks are subalkalic and highly depleted in the incompatible elements (e.g., <0.5 percent $TiO_2$). They have ratios of more incompatible to less incompatible elements similar to some arc tholeiites (Figure 5). The extended REE patterns (Figure 6a) are distinctive with a flat LREE pattern at <1 x primitive mantle, a flat HREE pattern at ~1 x primitive mantle, and a distinctive 'step up' between Nd and Eu. These patterns closely resemble those of the Type A-III refractory island-arc tholeiites in the Wild Bight Group (Figure 6a). As noted above, such rocks are associated with most of the volcanogenic sulphide deposits in the Wild Bight Group and are known to occur in the footwall to the Point Leamington deposit.

### Type II

Type II volcanic rocks are represented by a single sample, a subalkalic, low-$TiO_2$ (0.68 percent), LREE-depleted rock with characteristic arc-geochemical signature (Figure 6b). This rock has a Ti:V ratio characteristic of island-arc rocks (Figure 5) and is very similar, geochemically, to Type A-II LREE depleted arc tholeiites that occur in the Nanny Bag Lake area in the southern part of the Wild Bight Group. Such rocks in the Wild Bight Group occur in the intermediate part of the stratigraphy and are roughly stratigraphically equivalent to the refractory tholeiites and rhyolites.

### Type III

Type III rocks are transitional tholeiitic to alkalic, high $TiO_2$ (~1.3 to 2 percent), LREE-enriched rocks. They have Ti:V ratios typical of rocks generated in non-arc environments and lack the arc-geochemical signature on the extended REE plots (Figure 6c). They are similar to 'transitional tholeiites' Type N-II) of oceanic island affinity that form part of the back-arc succession in the upper part of the Wild Bight Group.

There is a clear stratigraphic regularity to the occurrence of the geochemically different types of mafic volcanic rocks in the New Bay Pond sequence (Figure 2). The rocks of island-arc origin (Types I and II) occur only in the northeastern volcanic unit (i.e., adjacent to the West Arm Brook Thrust), whereas the non-arc (Type III) rocks are all in the southwestern volcanic unit. The geochemical data provide clear evidence that volcanic rocks in the New Bay Pond sequence have close analogues in the adjacent Wild Bight Group. In particular, the refractory arc tholeiites are a unique rock type that has previously only been recognized in the Wild Bight Group. These data strongly suggest that the northeastern volcanic belt in the New Bay Pond sequence can confidently be correlated with the central part of the Wild Bight Group and probably records part of the arc-rifting event. In contrast, the southeastern volcanic belt can be correlated with the upper parts of the Wild Bight Group, and records volcanism in the same back-arc basin (cf. Swinden *et al.*, 1990). The fact that most facing directions in the intermediate turbidite unit are toward the northeast suggests that there is further internal faulting within the sequence. It is herein informally proposed that rocks of the New Bay Pond sequence, as defined by Swinden (1988a), be included in the Wild Bight Group. Formal stratigraphic subdivision at the formation level awaits detailed mapping now in progress in central Notre Dame Bay.

## GEOPHYSICS

The presence of refractory tholeiites in the New Bay Pond sequence that are almost identical to those found in close association with the Point Leamington deposit more or less along strike and only 7 km away, suggests that there may be a geological connection between the two areas. The strike extent of the refractory tholeiites and, in particular, their disposition between New Bay Pond and the Point Leamington deposit, is of obvious interest to explorationists. However, a straightforward along-strike correlation of favourable massive sulphide environments between the two areas is difficult to reconcile with previous interpretations of the local stratigraphy and structure that require a major discontinuity along the Long Pond Fault (Figure 2). Unfortunately, exposure is very poor in the critical area. In order to further investigate the possible geological connection between the Point Leamington deposit and the New Bay Pond area, an examination was made of: i) data from industry airborne electromagnetic (AEM) and ground electromagnetic surveys from the Geological Survey Branch assessment files; and ii) recent vertical gradient magnetic (gradiometer) surveys published by the Geological Survey of Canada.

### ELECTROMAGNETIC SURVEYS

An AEM survey of the area between Big Lewis Lake and Seal Bay was carried out by Questor Surveys Limited (1972) using the INPUT system. Carbonaceous shales of the Shoal Arm Formation are highly conductive, and their surface extent is marked by prominent AEM anomalies that can be traced from northeast of New Bay Pond, northwestward across the western end of Big Lewis Lake to an area east of the Point Leamington deposit. The conductors correspond precisely to the mapped extent of the Shoal Arm Formation (Figure 2). The anomalies do not stop at the Long Pond Fault, as they should if this structure has a major offset, but appear to continue for some distance to the northwest of its mapped surface trace. More detailed electromagnetic information is provided by a Max-Min survey undertaken by Noranda Exploration Company Limited. The survey was carried out on 100-m lines and results are summarized in Figure 7, taken

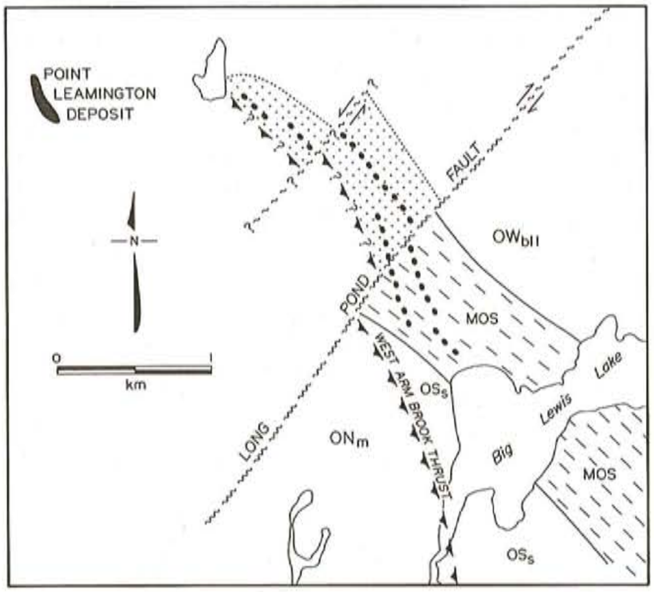


**Figure 7.** *Electromagnetic (Max-Min) anomalies (black ellipses) associated with carbonaceous shales of the Shoal Arm Formation northwest of Big Lewis Lake; legend as for Figure 2. The mapped extent of the Shoal Arm Formation and its previously supposed termination against the Long Pond Fault are shown by the dashed pattern. The Max-Min conductors strongly suggest the continuation of the Shoal Arm Formation northwest of the Long Pond Fault (dotted lines) with only minor dextral offset. The anomalies (and presumably the shales) terminate near a small pond east of the Point Leamington deposit.*

from a compilation map by Graves (1984). The EM anomalies on the Shoal Arm Formation clearly continue across the Long Pond Fault with only minor dextral offset. About 800 m to the northwest of the Long Pond Fault, they are again offset slightly in a sinistral sense and then terminate near a small pond, 1300 m east of the Point Leamington deposit.

The EM data lead to two principal conclusions. First, there is no geophysical evidence for a major offset along the Long Pond Fault; second, they strongly suggest that the Shoal Arm Formation shales (and presumably the West Arm Brook Thrust, which forms their western boundary in this area) can be traced continuously to a point where they are only 1300 m across strike from the Point Leamington deposit.

## GRADIOMETER

Gradiometer data for the New Bay Pond area have recently been published by the Geological Survey of Canada (1988a,b) and show a good correspondence with known geology (Figure 8). Mafic volcanic and intrusive rocks are characterized by high magnetic relief, whereas sedimentary rocks generally have low relief.

The Big Lewis Lake basalt in the Wild Bight Group is a strongly magnetic unit marked by a strong, northwest-striking magnetic anomaly (Figure 8). Magnetic data indicate that this unit is slightly offset by several northeast-striking faults, including a sinistral offset on a previously unrecognized fault north of New Bay Pond and dextral offsets on the Four Mile Lake and Long Pond faults (consistent with EM data, see above). The Big Lewis Lake basalt can be traced continuously to the area northeast of the Point Leamington deposit where it forms part of a large, roughly elliptical 'bullseye' of high magnetic relief (Figure 8).

The Shoal Arm Formation and Sansom Greywacke overlying the Big Lewis Lake basalt have low magnetic relief, in sharp contrast to the adjacent volcanic rocks. The magnetic low that marks their outcrop extent can be traced continuously although with minor offsets along northeast-striking faults, to the area immediately east of the Point Leamington deposit. The disappearance of this magnetic low is coincident with the disappearance of the EM anomaly associated with the Shoal Arm Formation shales (Figures 7 and 8).

In the New Bay Pond sequence, the Type I and Type II mafic volcanic rocks in the northeastern volcanic belt are characterized by moderate magnetic relief, less pronounced than that associated with the Big Lewis Lake basalt. The fault contact between the volcanic rocks and the low-relief Sansom Greywacke and Shoal Arm Formation is sharply delineated. The linear magnetic high, associated with these volcanic rocks near New Bay Pond, can be traced northerly to the area of the Point Leamington deposit, where it converges and eventually merges with the Big Lewis Lake basalt anomaly to form the magnetic 'bullseye' northwest of Big Lewis Lake. Slight offsets along northeast-striking faults (e.g., the Four Mile Lake Fault) are consistent with offsets of other magnetic anomalies.

The turbidites in the central part of the New Bay Pond sequence are marked by generally lower magnetic relief, but contain two northwest-striking linear magnetic anomalies that are interpreted, on the basis of outcrop information, to reflect gabbroic sills (Figure 8). These anomalies are of some interest for the regional geological interpretations because they show the same dextral offset on the Four Mile Lake Fault as do the volcanic units, little or no offset on the Long Pond Fault and a minor dextral offset along the Seal Bay Brook Fault (Figure 8).

The Side Harbour volcanic unit is also marked by a prominent magnetic trend of moderate to high relief. Trending down from the north, it is slightly offset in a dextral sense along the Seal Bay Brook Fault (consistent with previous mapping); south of this fault, it abruptly terminates against a prominent, northeast-trending, magnetic low on the north side of the magnetic 'bullseye' that is transverse to the regional magnetic grain. Acrosss this magnetic low, the Side Harbour volcanic unit is approximately along strike with the Big Lewis Lake and New Bay Pond sequence basalts.

## INTERPRETATION OF THE GEOLOGY BETWEEN NEW BAY POND AND THE POINT LEAMINGTON DEPOSIT

This paper proposes new interpretations of the nature and extent of the fault boundary between the New Bay Pond sequence and the Wild Bight Group—Shoal Arm Formation—

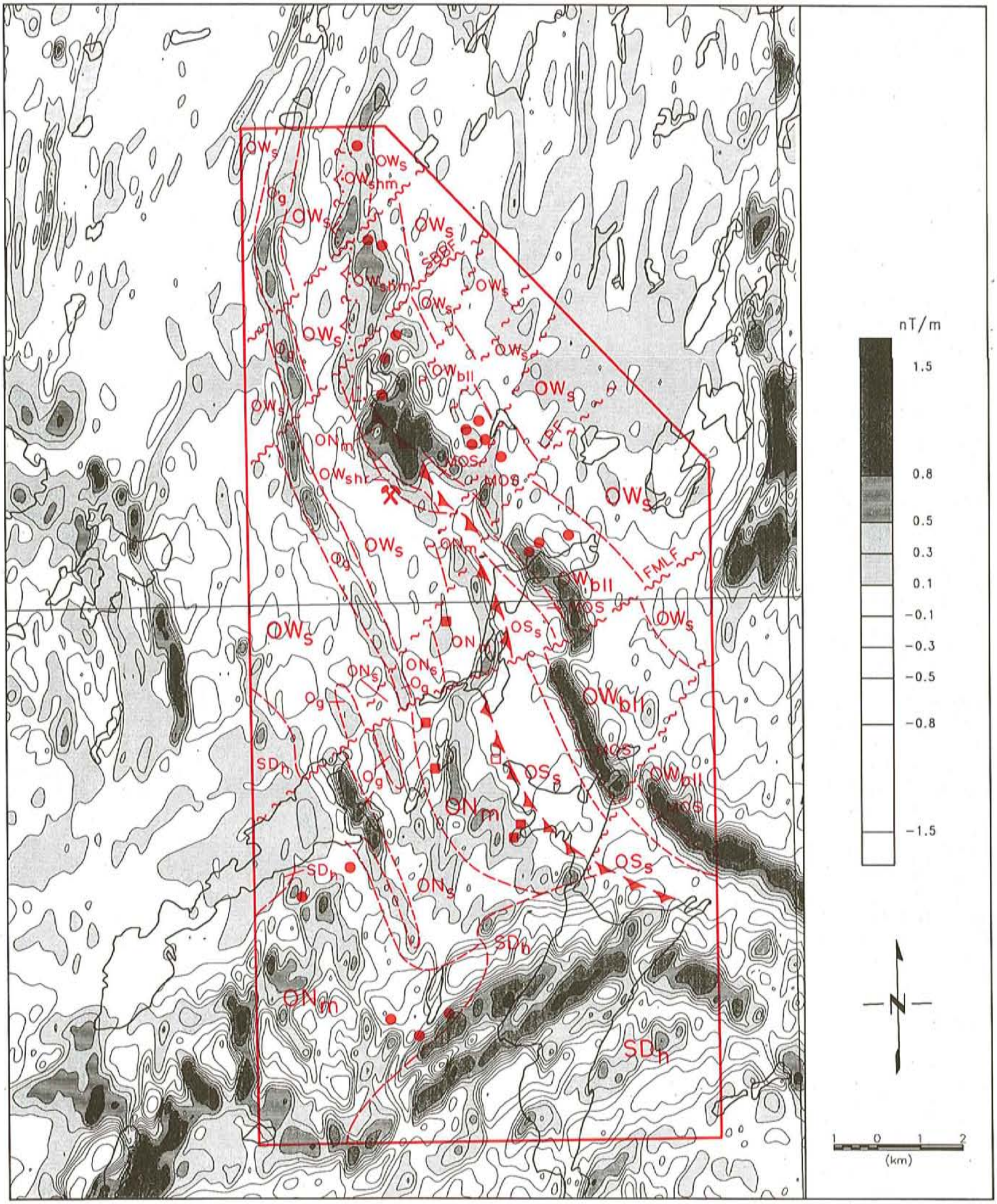


**Figure 8.** *Simplified gradiometer map for the same area as Figure 2 with geochemical information and newly interpreted geology in red. Legend and symbols as for Figure 2. Geochemical samples shown by squares and dots, as in Figure 5.*

Sansom Greywacke, the extent of volcanic rocks that are highly prospective for massive sulphides of the Point Leamington type, and the effect of late strike-slip faulting on stratigraphic reconstruction in central Notre Dame Bay.

## THE WEST ARM BROOK THRUST

Kusky (1985) traced this fault from New Bay Pond northwestward to the north end of Big Lewis Lake. His observations led to two significant conclusions about its nature: i) it is a pre-folding thrust fault along which rocks of the New Bay Pond sequence were emplaced in a generally southerly direction over the Sansom Greywacke; and ii) in the area south of Big Lewis Lake, the fault ramps upward in the hanging wall, bringing New Bay Pond sequence rocks against increasingly higher stratigraphic levels of the Sansom Greywacke.

Data presented in this paper supports these conclusions and shows that they can be extended northwestward for some distance where they help to explain apparent anomalies in the succession in the area of the Point Leamington deposit. The ramping of the fault can be traced to the northwest (i.e., toward the source of the thrusting) on the gradiometer maps by the convergence of the high-relief anomalies associated with the mafic volcanic rocks at the top of the New Bay Pond sequence and the Big Lewis Lake basalt (Figure 8), with the concomitant thinning of the area of flat magnetic relief that marks the sediments above the Big Lewis Lake basalt. Although outcrop is extremely sparse northwest of Big Lewis Lake, the continued convergence of the two magnetic anomalies in this area indicates that structurally lower ramps originate in the Shoal Arm Formation and the New Bay Pond basalt is juxtaposed with successively lower carbonaceous shale strata toward the northwest. Immediately east of the Point Leamington deposit, the fault juxtaposes New Bay Pond sequence basalts with the Big Lewis Lake basalts. The West Arm Brook Thrust cannot be confidently traced north of the magnetic 'bullseye' formed by the structural juxtaposition of the two volcanic units. Detailed examination of shaded-relief maps of gradiometer data for this area (not shown) indicate that the fault continues in a northwesterly direction through the magnetic high (indicated by the extension of the West Arm Brook Thrust on Figure 8), and strikes into the transverse magnetic low that separates the 'bullseye' from the magnetic high over the Side Harbour volcanic unit.

## RECOGNITION AND EXTENT OF MAFIC VOLCANIC UNITS

As previously recognized by Swinden *et al.* (1990), there are three mafic volcanic units in the immediate area of the Point Leamington deposit that can be distinguished on the basis of stratigraphic setting and geochemistry (Figure 8):

i) The Big Lewis Lake basalt—this consists of non-arc rocks of MORB and alkali basalt affinity. It is underlain by Wild Bight Group volcaniclastic turbidites but, except immediately northeast of the Point Leamington deposit, stratigraphically overlain by the Shoal Arm Formation. It is interpreted to lie at the top of the Wild Bight Group;

ii) The Side Harbour basalt (excluding rocks in the immediate footwall of the Point Leamington deposit)—this unit comprises a linear belt of transitional tholeiites and alkalic basalts of non-arc affinity. The volcanic rocks are underlain and overlain by Wild Bight Group volcaniclastic turbidites along contacts that have been considered to be stratigraphic (Dean, 1978; Swinden, 1987). On this basis, they have previously been interpreted to occupy a lower stratigraphic level in the Wild Bight Group than the Big Lewis Lake basalt;

iii) The refractory tholeiites in the Point Leamington deposit footwall are geochemically distinct from the Big Lewis Lake basalt and the rest of the Side Harbour volcanic unit, but identical to rocks that are interpreted to be stratigraphically lower in the Wild Bight Group then the Big Lewis Lake and Side Harbour mafic volcanic rocks.

Geochemical data show that refractory tholeiites in the footwall of the Point Leamington deposit are similar to those in the New Bay Pond sequence. Gradiometer data indicate that the volcanic unit is continuous between the two areas and can be traced with some precision, providing a good estimate of the extent of highly prospective ground south-southeast of the Point Leamington deposit. The recognition that this prospective volcanic unit sits immediately above an early thrust fault in the New Bay Pond area (the West Arm Brook Thrust), and the geophysical evidence that this fault continues northward to the area of the Point Leamington deposit, confirms previous suspicions (Swinden,1987) that the sequence hosting the Point Leamington deposit must be separated by a fault (or faults) from mafic volcanic rocks to the east and north.

The extent of prospective stratigraphy north of the Point Leamington deposit is still problematic, and interpretation of the extent of prospective stratigraphy north of the deposit depends in part on how one chooses to interpret the structure from geochemical and relatively inconclusive geophysical evidence. The West Arm Brook Thrust can be traced north of the deposit for about 1000 m; it eventually strikes into a northeast-striking linear, transverse magnetic low of uncertain origin (Figure 8). This magnetic low does not appear to represent a fault with major displacement as the gradiometer map shows, at most, only a slight sinistral offset on a mafic dyke about 2 km to the southwest along its trend. Therefore, it seems most likely that the West Arm Brook Thrust continues northward within or along the west side of the Side Harbour volcanic unit. This model is attractive because it provides a mechanism by which the along-strike, geochemically similar, and more or less geophysically continuous mafic volcanic rocks of the Side Harbour and Big Lewis Lake volcanic units can be be continuous with each other. In this model, the extensive turbidite sequence west of the Side Harbour unit would be structurally, not stratigraphically, above the volcanic rocks, thereby resolving the apparent dichotomy in the hanging-wall stratigraphy of the two volcanic units. Furthermore, it would obviate the necessity for a major structural dislocation transverse to stratigraphy in the area of the Point Leamington deposit that would otherwise be necessary to explain the apparently diverse stratigraphic relationships. The principal objection to this model is that no rocks with island-arc geochemical signatures have been identified north of the Point Leamington deposit on the west side of the Side Harbour volcanic unit (Figure 8). In fact, rocks immediately north of this feature and along strike with the Point Leamington deposit are geochemically characterized as transitional tholeiites of clear non-arc affinity (Swinden, 1987). Nonetheless, it is possible that the West Arm Brook Thrust continues in this direction, and that volcanic rocks with arc-geochemical signatures either are present and have not been sampled, have pinched out, or have been excised by another, as yet unrecognized thrust fault subparallel to the bedding. Clearly, if rocks with arc signatures are present west of the non-arc rocks of the Side Harbour volcanic unit north of the Point Leamington deposit, they would be highly prospective for base-metal exploration. Detailed geochemical studies along the western margin of the Side Harbour volcanic unit might go a long way toward resolving this question.

## CONCLUSIONS

Application of new geological and whole-rock geochemical information, coupled with analysis of available gradiometer and electromagnetic data provide new interpretations of the geological relationships in the area between New Bay Pond and the Point Leamington massive sulphide deposit.

The New Bay Pond sequence contains two, northwest-striking volcanic belts. Geochemical data show that mafic volcanic rocks in the two belts are geochemically and tectonically distinct and correlate well with volcanic rocks in the adjacent Wild Bight Group. The northeasterly belt contains mafic volcanic rocks with island-arc geochemical signatures, including refractory tholeiites similar to those universally associated with volcanogenic sulphide deposits in the Wild Bight Group, and includes minor amounts of rhyolite. This unit can be traced northward by geochemistry and geophysics to the area of the Point Leamington deposit. The strike extent of this volcanic unit between the Point Leamington deposit and New Bay Pond is considered to be highly prospective for massive sulphide deposits, because it is along the strike extension of a horizon already demonstrated to be prospective and because it contains distinctive refractory basaltic rocks that are found to be closely associated with volcanogenic mineralization both in the Wild Bight Group and throughout central Newfoundland.

The southeastern volcanic belt of the New Bay Pond sequence has mafic volcanic rocks with non-arc geochemical signatures and is not considered to have potential for Point Leamington-type massive sulphide deposits.

The data show that a previously recognized early thrust fault (herein termed the West Arm Brook Thrust) separating the New Bay Pond sequence from the Sansom Greywacke can be traced northward to the area of the Point Leamington deposit. This provides good evidence that the Point Leamington deposit is structurally rather than stratigraphically above the non-arc rocks to the east, resolving a previously recognized stratigraphic enigma. The West Arm Brook Thrust (and hence, the prospective stratigraphy) can presently be traced with confidence for about 1 km northward from the Point Leamington deposit. However, geological modeling constrained by gradiometer data suggests that it may continue for some distance north of this along the western side of the Side Harbour volcanic unit. Detailed geochemical testing is required to determine whether volcanic rocks with arc signatures can be identified in the Side Harbour volcanic unit. Recognition of such rocks would provide evidence that the Point Leamington deposit stratigraphy continues to the north and would provide a good rationale for detailed base-metal exploration in this area.

The gradiometer data clearly show that the prominent set of northeast-striking faults in this part of Notre Dame Bay invariably have minor, variously dextral or sisistral, offsets. They do not appreciably disrupt the stratigraphy in the area between New Bay Pond and Seal Bay and cannot be called upon to explain apparent major discontinuities in the stratigraphy in this area.

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