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PILLOW LAVAS IN THE DEAD ISLANDS AREA, GRENVILLE PROVINCE, SOUTHEAST LABRADOR

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ABSTRACT

Pillow lavas have been recognized in dominantly amphibolite-facies mafic rocks, in the Dead Islands area, southeast Labrador. This occurrence is the first unequivocal example of pillow lavas in pre-Labradorian supracrustal rocks in the eastern Grenville Province. The pillow lavas occur with a dominantly pelitic supracrustal sequence that includes minor quartz- and calc-silicate-rich rocks, interpreted to be derived from metamorphosed banded chert and calcareous sedimentary protoliths, respectively.

Regionally, this sequence is part of the Paradise metasedimentary gneiss belt. The recognition of these pillow lavas strengthens the interpretation of more deformed and metamorphosed analogues elsewhere in the same metasedimentary belt as probably having a similar origin. The whole-rock geochemical compositions indicate that the volcanic rocks were not generated in an island-arc setting. Coupled with the sedimentary association, they might be interpreted as having formed in an intra-oceanic environment in which the magmatism had oceanic island affinities (either major ocean or back-arc), or in a passive margin or intra-continental rift. Analogies can be drawn in terms of sedimentary and magmatic character with the Aldridge Formation of southern British Columbia, which hosts the Sullivan SEDEX deposit, and with the environments of some Besshi-type deposits. The presence of abundant sulphide-rich gossans, in association with distal clastic sediments and banded chert, suggests a grassroots-exploration potential for sediment-hosted exhalative sulphide deposits in the Paradise metasedimentary gneiss belt and, by analogy, in other paragneiss successions in the Grenville Province of Labrador.

INTRODUCTION

The purpose of this paper is to report on an occurrence of unequivocal mafic pillow lavas in the Grenville Province in southeast Labrador. There are three reasons for doing this: (i) to provide indirect supporting evidence for the submarine, extrusive origin of other mafic rocks in pre-Labradorian supracrustal sequences in the area; (ii) to use the presence and geochemical characteristics of the mafic pillow lavas to infer the depositional and tectonic setting; and iii) to suggest the possibility of a hitherto unrecognized mineral-exploration potential for sediment-hosted massive sulphide deposits of either SEDEX (Morganti, 1988; Goodfellow *et al.*, 1990) or Besshi (Mitchell and Bell, 1973; Slack and Shanks, 1989) types in the Grenville Province of Labrador.

Supracrustal rocks predating Labradorian orogenesis are widespread in the eastern Grenville Province (defined here as that part of the Grenville Province shown in the inset to Figure 1). The most widespread pre-Labradorian supracrustal rock type is pelitic to semipelitic gneiss, which is locally interlayered with quartz-rich sediments (interpreted as quartzite and/or banded metachert), calcareous sediments, and banded mafic rocks. In sequences of quartzofeldspathic rocks that lack aluminosilicate or other minerals characteristic of a pelitic protolith, quartzite and calcareous metasediments are invaluable in confirming the sedimentary protolith of the overall sequence.

The use of mafic meta-igneous rocks to interpret the protolith of strongly deformed and metamorphosed sequences is more difficult however, as such rocks could be either extrusive or intrusive. If they are mafic intrusions, they clearly cannot be used to suggest whether a given package of quartzofeldspathic gneisses is orthogneiss or paragneiss. One criterion that is commonly interpreted as indicating a probable supracrustal origin for strongly deformed and metamorphosed rocks is compositional banding. Rocks that lack such banding (in the absence of more definitive evidence such as crosscutting contacts against an older compositional layering) are commonly interpreted as mafic dykes. Although this method of discrimination must suffice in the absence of better evidence, it is inherently unsatisfactory, as metamorphism and deformation may either obliterate or create compositional layering.

Therefore, the recognition of unequivocal mafic pillow lavas in the eastern Grenville Province is of considerable significance as it provides proof of a subaqueous, extrusive origin. Furthermore, preservation of pillows is evidence of comparatively moderate deformation and metamorphism,

[1] Mineral Deposits Section

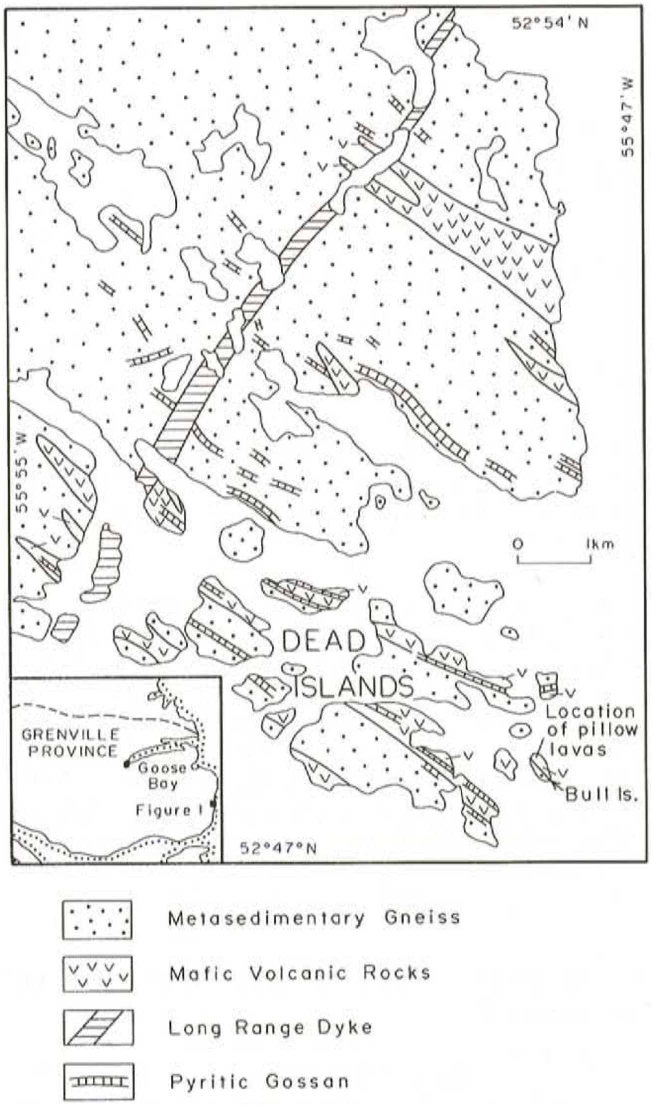

Figure 1. *Geology of the Dead Islands area, southeast Labrador. The location of the area within the eastern Grenville Province is shown in the inset. Location of pillow-lava locality on Bull Island is also shown.*

which provides an incentive to carry out geochemical studies in order to interpret the tectonic setting of volcanism. Because interpretations of predictive metallogeny are commonly closely tied to interpretations of tectonic environments (at least in the case of syngenetic deposit types), such interpretations may suggest exploration potential for specific deposit types.

GEOLOGICAL SETTING

The pillow-lava locality is on Bull Island at the southeastern end of the Dead Islands group. The distribution of rock types in the surrounding area is shown in Figure 1 (adapted from Gower *et al.*, 1988). Apart from mafic dykes and minor granitoid intrusions (neither of which are shown in Figure 1) and a northeast-trending Long Range dyke, the area is underlain entirely by supracrustal rocks. In the area shown in Figure 1, the pelitic gneisses are pink-, black-, grey- or buff-weathering, medium- to coarse-grained, quartz–K-feldspar–biotite–magnetite ± cordierite ± sillimanite ± garnet ± retrograde muscovite rocks. These gneisses are intimately associated with white-, grey- or creamy-weathering metasedimentary diatexites. Calc-silicate rocks and quartzite are interlayered with the pelitic rocks, although they are rarely extensive enough to be shown as separate units at the scale of mapping (1:100,000). Pyritic gossan, which may be metamorphosed banded chert, is a particularly characteristic rock type in the Dead Islands area.

Mafic rocks, comprising green to black, homogeneous to well-banded, fine- to medium-grained amphibolites, are interlayered with the metasedimentary rocks. The characteristic mineral assemblage in the amphibolite is hornblende and plagioclase, and they commonly contain lenses or pods of calc-silicate minerals, such as grossularite and diopside. Gower *et al.* (1987) suggested that some of the amphibolite was derived from mafic pillow lavas and included a photograph of part of an outcrop showing an example of pillows. It was during a subsequent excursion that included re-examination of this outcrop, that the mafic pillow lavas described here were discovered.

Geological features of the Bull Island mafic pillow lava locality are illustrated on Plates 1 to 4. The outcrop is composed of both pillowed and unpillowed flows. In Plate 1, the irregular-surfaced area on the right and centre rear is composed of pillow lava, in contrast to the front left area, which is composed of unpillowed mafic lava. The sequence has been intruded by a prominent mafic dyke. Details of the pillows are shown in Plates 2 and 3. Individual pillows are moderately flattened, generally less than 40 cm in diameter, and have thick margins and locally an internal radial structure which may have originally been defined by vesicles (Plate 3). Quartzofeldspathic mobilizate is locally present between the pillows. Thin layers of siliceous, laminated sediment are locally preserved between unpillowed flows (Plate 4).

Plate 1. *Overview of outcrop at the Bull Island pillow-lava locality. Pillow lavas are at the right and centre rear. Unpillowed flows are in the left foreground.*

Plate 2. *Ellipsoidal, moderately flattened pillows with clearly defined pillow margins and white quartzofeldspathic leucosome material.*

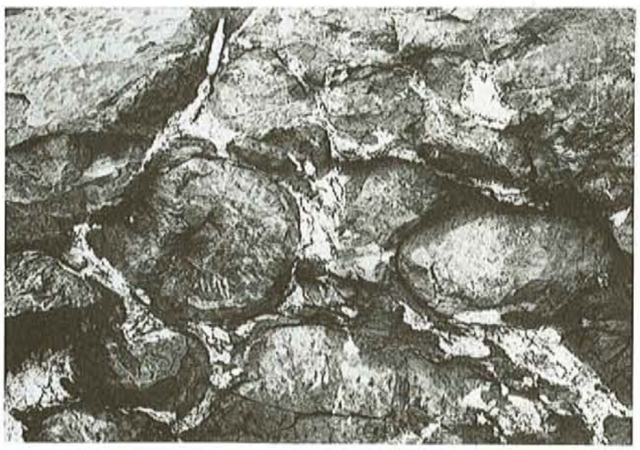

Plate 3. *Close-up of pillows with thick pillow margins and radial vesicles(?) in pillow interiors. White quartzofeldspathic leucosome between pillows. Felt-tipped marker in upper left for scale.*

Plate 4. *Laminated siliceous clastic sediment between unpillowed flows, width of area shown in foreground is 3 m.*

GEOCHEMISTRY OF THE PILLOW LAVAS

ANALYTICAL METHODS

Major-element oxides and the trace elements Ba, Zr and Cr were determined by lithium metaborate fusion followed by analysis by inductively coupled plasma–optical emission spectrophotometry (ICP-OES), and the trace elements Ni, V, Rb, Sr, Cu, Pb and Zn, by total, multi-acid digestion and ICP-OES determination, all in the Newfoundland Department of Mines and Energy laboratory. The rare-earth elements (REE), the trace elements Sc, Th, Ta, Nb and Y were analyzed at Memorial University of Newfoundland using inductively coupled plasma–mass spectrometry (ICP-MS), according to analytical techniques described by Jenner *et al.* (1990). Precision for Th and the REE (excluding Eu and Lu) is better than 3 percent, for Eu and Lu it is 4 percent, and for Nb 7 percent.

Results

Whole-rock analyses of 3 samples taken from the Bull Island pillow-lava locality are presented in Table 1. Silica contents (44.05 to 45.20 percent) are in the basalt range and the rocks contain variable but high concentrations of TiO_2 (1.58 to 3.16 percent) and other incompatible elements. The Nb/Y ratios are approximately 0.8, and the rocks are mildly alkalic basalts according to the Winchester and Floyd (1977) discrimination diagram (Figure 2), consistent with silica concentrations. Other high-field-strength relationships also indicate a mildly alkalic or transitional tholeiitic composition for these rocks as displayed, for example, on the Nb–Zr–Y diagram (Figure 3). In this diagram, the samples plot in the field of overlap between within-plate tholeiitic and alkalic basalts.

The Mg# (defined as the molecular ratio [100*MgO]/[MgO+FeO]) ranges from 65 to 40, indicating that the samples have experienced variable low pressure fractional crystallization and that, collectively, they represent a considerable range of fractionation.There are considerable variations in the absolute concentrations of many compatible (e.g., Ni, Cr) and incompatible (e.g., Ti, Zr) elements, but incompatible element ratios for all three samples are constant and typical of within-plate tholeiitic and alkalic basalts (e.g., Zr/Y–Zr, Figure 4; Ti-Zr-Y, Figure 5), suggesting that they all represent the same source area, and probably the same parent magma.

Extended REE patterns (Figure 6) show a pronounced light rare-earth-element (LREE) enrichment and decrease smoothly to the heavy rare-earth elements (HREE). Thorium is negative with respect to La on a normalized basis and there is no negative Nb or Ta anomaly; both are important considerations in interpretations of tectonic setting (see below). There is no evidence that the magma sources might have been influenced by a subducting slab, nor the magmas contaminated by continental crust during ascent (cf. Wood *et al.*, 1979; Sun, 1980; Swinden *et al.*, 1990).

Table 1. Analyses of pillow lavas from the Dead Islands locality

Sample	2141074	2141075	2141076
SiO_2	45.20	44.35	44.05
TiO_2	3.16	1.58	1.99
Al_2O_3	14.21	9.93	11.63
Fe_2O_3	17.30	11.28	12.32
MnO	0.23	0.16	0.17
MgO	5.17	9.44	8.46
CaO	9.83	19.48	16.42
Na_2O	2.77	1.42	2.14
K_2O	0.69	0.23	0.16
P_2O_5	0.37	0.18	0.23
Total	98.93	98.05	97.57
Cr	17	1441	883
Ni	45	548	383
Sc	32	27	30
V	403	238	287
Cu	224	45	30
Pb	3	2	2
Zn	153	83	95
Rb	20	4	3
Ba	306	80	54
Sr	407	357	411
Ta		0.68	0.93
Nb	27	12	15
Zr	248	105	140
Y	33	15	20
Th		1.04	1.71
La	22.7	9.9	14.43
Ce	54.3	24.6	34.58
Pr	7.4	3.5	4.71
Nd	32.4	14.8	20.09
Sm	7.6	3.7	4.75
Eu	2.3	1.2	1.54
Gd	8.1	4.0	5.38
Tb	1.2	0.6	0.73
Dy	6.8	3.3	4.29
Ho	1.3	0.6	0.8
Er	3.4	1.7	2.2
Ta	0.5	0.2	0.28
Yb	2.9	1.4	1.78
Lu	0.4	0.2	0.25
Mg#	40	65	60

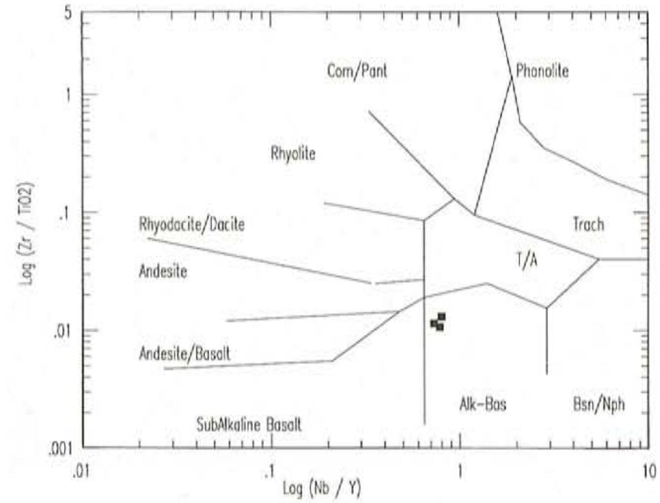

Figure 2. *Classification of the Dead Islands pillow lavas (solid squares) using immobile elements after Winchester and Floyd (1977). According to this diagram, they are mildly alkalic basalts.*

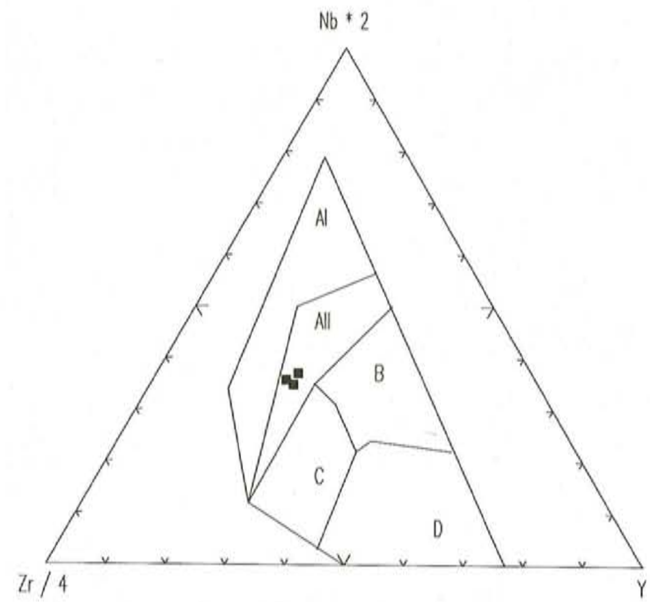

Figure 3. *Tectonic setting of the Dead Islands basalts (solid squares), using the trace-element diagram of Meschede (1986). Samples plot in field AII, the field of overlap between within-plate tholeiitic and alkalic basalts. Field AI is within-plate alkalic basalt, fields B, C, and D are MORB and volcanic-arc basalts. E-MORB and T-MORB (see text) would plot in field B.*

The range of absolute concentrations of some elements is readily interpreted in terms of low pressure fractional crystallization of a single magma. Incompatible elements including Ti, V, Zr, Y and the REE all increase regularly with decreasing Mg# (used here as an indicator of fractionation) (Table 1) and the extended REE patterns are parallel with regularly increasing total abundances corresponding to decreasing Mg# (Figure 6). The Cr and Ni decrease regularly with Mg#, while Sc and the ratio Al_2O_3/TiO_2 decrease only slightly, suggesting that fractionating phases were dominantly olivine and Cr spinel. Minimal clinopyroxene and plagioclase crystallization may account for slight decreases in Sc and Al_2O_3/TiO_2 ratios with decreasing Mg#.

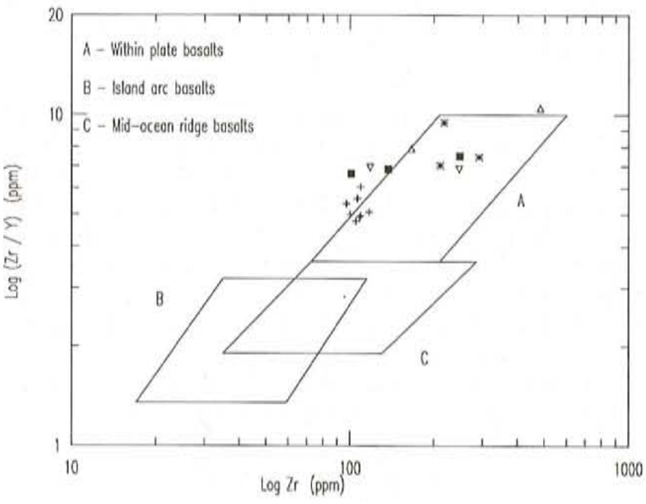

Figure 4. *Tectonic setting discrimination of the Dead Islands basalts (solid squares) according to the Zr–Zr/Y diagram of Pearce and Norry (1979). Shown for comparison are endmember Hawaiian alkalic basalts (upright triangles) and Hawaiian (Kilauean) tholeiites (inverted triangles) from the Basaltic Volcanism Study Project (1981) reference suite, Tibbett Hill formation basalts (asterisks) and alkalic sills from the Aldridge Formation (crosses). All plot in the field of within-plate basalts. See text for discussion.*

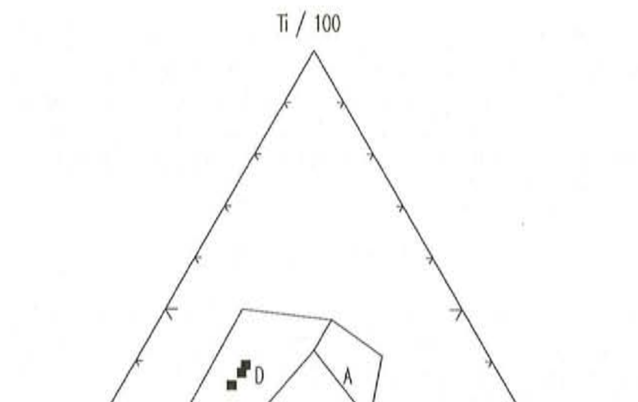

Figure 5. *Further illustration of the within-plate setting (Field D) of the Dead Island basalts (solid squares) according to the Pearce and Cann (1973) triangular diagram. Fields A, B, and C are MORB and volcanic-arc basalts.*

The dramatic increase in Ti, V and Fe with fractionation is characteristic of tholeiitic trends and suggests that neither hornblende nor iron–titanium oxides was present on the liquidus. The rocks are best interpreted as variably

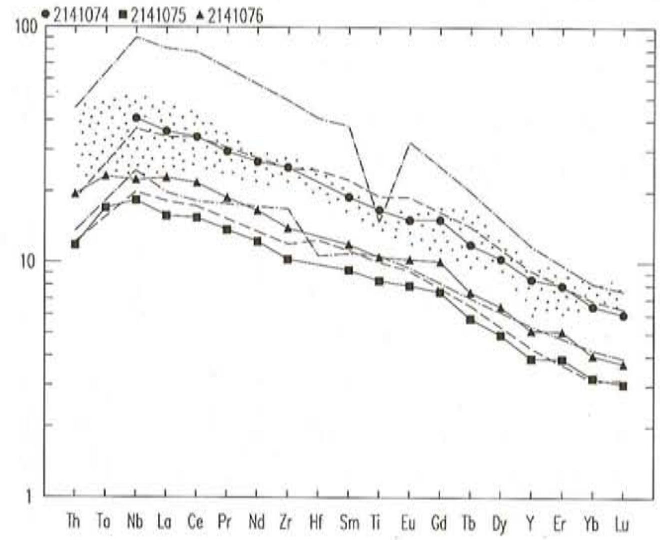

Figure 6. *Extended REE plot of the Dead Island basalts. The stippled field is the Tibbett Hill volcanics (passive margin rift sequence) from the data of Coish et al. (1985). Broken lines encompass the range of Kilauean tholeiites, broken lines with dots encompass the range of Hawaiian alkalic basalts in the Basaltic Volcanism Study Project (1981) reference suite.*

fractionated transitional tholeiites to mildly alkalic basalts, erupted in a within-plate tectonic setting.

DISCUSSION

REGIONAL EXTRAPOLATIONS

The supracrustal rocks underlying the area of Figure 1 are part of the Paradise metasedimentary gneiss belt (Gower *et al.*, 1987), which extends without break to the northwest side of Sandwich Bay, a distance of about 175 km (Figure 7). Discontinuous zones of metasedimentary gneiss also occur farther northwest (between Sandwich Bay and Rigolet), but as some of these occur in different tectonic terranes it is uncertain whether they are regionally correlative with the Paradise metasedimentary gneiss belt. The age of the metasedimentary gneiss in this belt is not known precisely. Schärer and Gower (1988) reported a U–Pb zircon date of 1654^{+29}_{-28} Ma for a sillimanite-bearing metasedimentary gneiss at the southern end of Sandwich Bay, and suggested that the date was either the average age for detrital zircon in the metasediment or that it is related to Labradorian metamorphism. Indirect age constraints based on ages obtained from other units in the area imply that the sequence is almost certainly older than ca. 1675 Ma and unlikely to predate ca. 1750 Ma.

Mafic rocks, inferred to be of supracrustal origin have been reported from various places in the Paradise metasedimentary gneiss belt and its discontinuous extensions north of Sandwich Bay (Gower *et al.*, 1983, 1985, 1986). Gower *et al.* (1985) drew attention to an outcrop of fine-

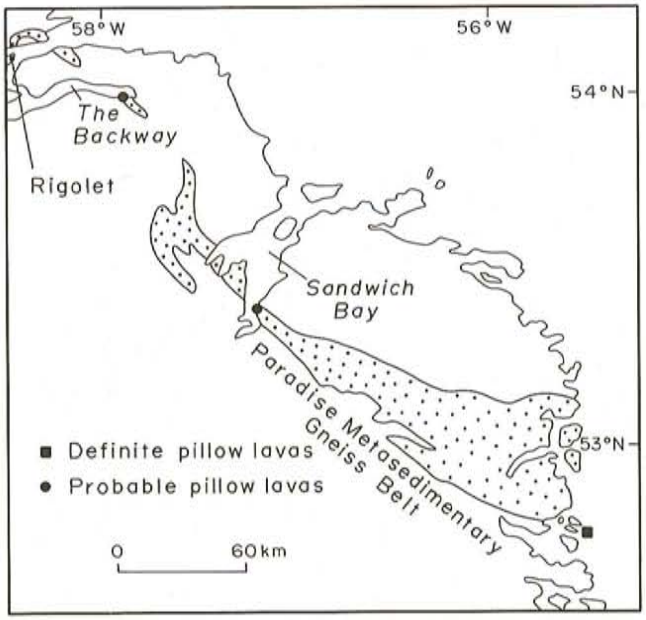

Figure 7. *Location of definite and probable pillow lavas in the Paradise metasedimentary gneiss belt and metasedimentary rocks farther northwest, southeast Labrador.*

grained amphibolite characterized by melanocratic seams and pods bearing calc-silicate minerals on the shoreline of Sandwich Bay, 4 km north of Paradise River, and compared it with similar rocks on the southeast shore of The Backway (Figure 7). As in the case of the Dead Islands pillow lavas, the calc-silicate pods were interpreted to represent calcareous interpillow material, and the melanocratic seams were suggested to be derived from pillow margins. With the recognition of unequivocal pillows at the Dead Islands locality, it now seems probable that these other occurrences are indeed derived from pillowed mafic volcanic rocks. Interpretation of the depositional and tectonic environment of the Paradise metasedimentary gneiss belt as a whole, should ideally consider all occurrences. It is worth reiterating the observation of Gower *et al.* (1985) that all three localities noted above are on the coast where exposure is very good. It is likely that similar mafic meta-igneous rocks (which are recessive-weathering) are more common inland than current maps would indicate.

Although rocks interpreted as pillowed mafic volcanics have not been found in other metasedimentary belts in eastern Labrador, minor occurrences of mafic rock, interlayered with other supracrustal rocks, have been described from other parts of Labrador. For example, Ryan *et al.* (1982) described finely layered amphibolite with narrow sulphide-rich zones along the southern edge of a thrust sheet south of the Red Wine River. This unit is probably correlative with the Beaver gneiss farther west, described by Emslie *et al.* (1978) as a metasedimentary gneiss having a relatively mafic appearance, but with local quartzofeldspathic interbeds and thin quartzite layers. In western Labrador, Nunn *et al.* (1984, 1986) and Connelly and Scowen (1987) have described banded, supracrustal mafic rocks as minor intercalations within metasedimentary gneiss. None of the occurrences outside eastern Labrador have been identified as having pillowform character.

Occurrences of mafic pillow lavas that may be pertinent to the late lower Proterozoic tectonic framework are found in the Stora Le-Marstrand Formation within the Sveconorwegian Orogenic Belt in coastal southwest Sweden (Ahäll, 1984; Hageskov, 1990), an area that is interpreted to have been relatively close to southern Labrador at that time (Gower and Owen, 1984). The pillowed mafic volcanic rocks identified by Ahäll (1984) were subsequently dated by Ahäll and Daly (1989) at 1758 $\pm$ 78 Ma (Nd–Sm, whole-rock), an age which is consistent with evidence for the age of the pillow lavas in southeast Labrador.

Depositional Setting

Aside from inferences of a pelitic sedimentary protolith (implying a distal clastic environment), little attempt has been made to characterize the depositional setting(s) of pre-Labradorian supracrustal rocks. Arima *et al.* (1986) noted that the metasedimentary gneiss in central Labrador is characterized by hematite as the dominant Fe-oxide. These authors suggested that the protolith was derived from two end-member components, one characterized by high SiO_2 and low REE, and the other by enhanced Al_2O_3, Fe_2O_3 and REE. They noted that the latter features are characteristic of weathering products of volcanic rocks.

The presence of pillow lavas in the Paradise metasedimentary belt shows that the depositional environment was at least locally subaqueous. The predominance of pelitic and cherty protoliths coupled with the absence of coarse clastic material suggests a relatively distal sedimentary environment.

Tectonic Setting

The tectonic setting of supracrustal rocks deposited prior to, or during the early stages of the Labradorian orogenic cycle, has not been established unequivocally. Two models have been favoured: (i) that the sediments were deposited as a Lower Proterozoic continental wedge that developed adjacent to the passive southern margin of proto-Laurentia; (ii) that the sediments were deposited in some form of island-arc environment, with which the subsequent (Labradorian) granitoid rocks were also associated (cf. Gower, 1990 for references). The latter model has gained some favour recently due to the absence of inherited zircons from early Lower Proterozoic or older crust in most samples of metasedimentary gneiss analyzed to date (Shärer and Gower, 1988; Currie and Loveridge, 1985; although see Thomas *et al.*, 1986 for the single exception).

The whole-rock compositions of the pillow lavas from southeast Labrador show that volcanic rocks, at this locality at least, probably did not form in an island-arc environment. The lack of positive Th and negative Ta and Nb with respect to La on the extended REE plots are diagnostic of magmatism that has not been influenced by a subducting slab (Wood *et al.*, 1979; Sun, 1980; Arculus and Powell, 1986; Swinden *et al.*, 1990). The geochemical data do not conclusively discriminate between the various non-arc environments that are permitted by the general geological relations, particularly as there are only three samples from a single outcrop. However, they do suggest a number of possibilities.

1) Passive margin rift

Tholeiitic to mildly alkalic mafic magmatism is characteristic of rifting of passive continental margins. An example of such rocks in the Appalachian Orogen is the Cambrian early rift volcanics of the northern Appalachians formed during rifting that eventually lead to formation of the Iapetus Ocean. The mafic magmatism ranges from tholeiitic to alkalic. Examples of mildly alkalic volcanic rocks from the Tibbett Hill Formation in Vermont (Coish *et al.*, 1985) are plotted on Figure 6 and show that volcanic rocks similar to those at the Dead Islands locality are represented in such an environment.

The possibility that these sequences represent a passive rift environment may be supported by recent geochronological data. Inherited zircons having ages of >1750 and 1735 Ma have been identified in a 1631 Ma hornblende granodiorite from the Mealy Mountains terrane (Schärer and Gower, 1988). This tends to support the idea that Pre-Labradorian crust was present on the southern flank of the Labrador Orogen, and was temporarily separated from proto-Laurentia prior to being accreted to the Laurentian margin during Laradorian orogenesis. Deposition of pre-Labradorian pelitic sediments and associated volcanic rocks in this rift basin would be consistent with such a tectonic scenario.

2) Epicontinental rift

Large epicontinental rift basins, formed through rifting of continental crust, are characteristic of the Proterozoic world-wide. Although generally sediment-dominated, these rifts are characterized by minor amounts of mafic magmatism, dominantly tholeiitic to alkalic in character. An example of such a sequence in the ancient record is the Purcell Supergroup of the Cordillera, in which the Aldridge Formation hosts the Sullivan massive sulphide deposit. Synsedimentary magmatism in this sequence is recorded by the Moyie diabase and gabbro sills, ranging from tholeiitic to mildly alkalic in character (Höy, 1989). Alkalic sills in the Aldridge Formation are geochemically similar to the Dead Island basalts (e.g., Figure 4).

Such a tectonic setting would also be consistent with the geochronological data noted above.

3) Within-plate oceanic magmatism (oceanic or back-arc basin)

Within-plate oceanic magmatism resulting, for example, from passage of an oceanic plate over a hotspot, commonly produces tholeiitic and alkalic basalt of oceanic island affinity (Basaltic Volcanism Study Project, 1981). This type of magmatism is characteristic of both major ocean and back-arc basins and may produce isolated seamounts or strings of seamounts (e.g., Hawaii). The Dead Islands basalts have clear affinities to this type of volcanism, as seen by comparison with both tholeiitic and alkalic eruptive rocks from Hawaii (Figure 6). The Dead Islands basalts plot in the field of overlap between Hawaiian tholeiitic and alkalic basalts.

4) Enriched spreading centre

Geochemically and isotopically enriched (or 'plume-type') volcanism characterizes many major oceanic and back-arc spreading centres (e.g., parts of the Mid-Atlantic Ridge, Schilling, 1973; Schilling *et al.*, 1983). The resulting rocks are commonly termed T-MORB or E-MORB (Transitional or Enriched Mid-Ocean-Ridge-Basalt), respectively, depending on the degree of enrichment. Although plume-type ridge volcanism typically produces rocks having geochemical characteristics similar to the Dead Islands pillow lavas, such rocks commonly plot in MORB fields on the Ti–Zr–Y diagram. Furthermore, the overwhelming dominance of sedimentary rocks is not supportive of such an environment and present evidence suggests this model is perhaps the least likely of those possible for the Paradise belt.

METALLOGENY

Known Mineralization

Sulphide occurrences are common and can be easily located in well-exposed coastal regions in the Paradise metasedimentary gneiss belt. In the Dead Islands and Occasional Harbour areas (cf. Gower *et al.*, 1987 and references therein), spectacular ocherous-weathering gossans are widespread and similar occurrences are known in the Sandwich Bay area, 150 km to the northwest (Gower *et al.*, 1985) as well as at The Backway and near Rigolet (Gower and Erdmer, 1984). Although gossans are uncommon in areas mostly covered by surficial deposits in the intervening area, the apparent continuity of the geological units between these areas provides a good reason to believe that sulphide occurrences are present throughout the whole belt. The main sulphide present is pyrite but minor chalcopyrite is also present locally. Douglas (1953) reported a grab sample containing 2.8 percent Cu from the Eagle River showing in the Sandwich Bay area and this area was also the focus of considerable geochemical and geophysical surveys by Brinex Limited (Sutton, 1965, 1966). Gower *et al.* (1987) reported Au assay values up to 37 ppb from grab samples in coastal outcrops.

Disseminated mineralization (magnetite, pyrite and pyrrhotite) is also associated with metasedimentary gneiss in interior parts of Labrador (Pyke, 1956).

Metallogenic Models

Syngenetic sulphide deposits occur widely in sediment-dominated environments where minor magmatism or rising geotherms related to rifting apparently provide the heat source to drive hydrothermal systems. Deposits of this type are variously called 'Besshi-type' or sedimentary exhalative ('SEDEX'), depending on the specific geological characteristics of the deposit, particularly the metal associations and the extent of volcanic activity (Sawkins, 1976; Slack and Shanks, 1989; Goodfellow *et al.*, 1990).

Besshi-type deposits (Mitchell and Bell, 1973; Sawkins, 1976; Slack and Shanks, 1989) are dominantly sediment-hosted, but are spatially and stratigraphically associated with significant volcanic activity. They commonly contain significant copper and locally zinc, silver, gold and/or cobalt. Most are Proterozoic or Paleozoic in age and the largest deposits of this type are in the 100- to 300-million tonnes range (e.g., Ducktown, Windy Craggy). The host sedimentary sequence is dominantly pelitic and the associated volcanic rocks range form MORB-like tholeiites to mildly alkalic basalt (Gair, 1988; Smith and Fox, 1989).

SEDEX deposits are dominantly Zn, Pb, barite deposits, with lesser Cu, Ag and Au. Most occur in Proterozoic and Paleozoic epicontinental rifts (e.g., Sullivan, Selwyn Basin) and are hosted by fine-grained deep-water clastic sedimentary rocks. Mafic magmatism is locally associated with these deposits. In the Selwyn Basin, as an example, it is dominantly alkalic basaltic. Syn-sedimentary sills in the Aldridge Formation stratigraphically associated with the Sullivan deposits range from tholeiitic to mildly alkalic (Höy, 1989). The alkalic sills are geochemically similar to the Dead Islands basalts (Figure 4).

The nature of the sedimentary succession in the Paradise metasedimentary gneiss belt and the geochemical character of the associated volcanic rocks would appear to be supportive of deposit models for either Besshi-type or giant SEDEX deposits. Interpretations of the sequence as either a passive margin rift or an epicontinental rift sequence allows for the formation of Besshi-type mineralization; an epicontinental rift interpretation supports SEDEX models. Interpretation of the sequence as a within-plate oceanic island or plume-type spreading centre would be less supportive of these metallogenic models. However, in the relatively unlikely event that we are dealing with a ridge crest, cupriferous massive sulphides might be expected to have formed at sites of hydrothermal discharge (e.g., the TAG and Snakepit fields, Mid-Atlantic Ridge; Rona *et al.*, 1986; Thompson *et al.*, 1988). Any of these would be worthy targets for regional grassroots exploration in a relatively unprospected environment such as the Paradise metasedimentary gneiss belt.

CONCLUSIONS

Amphibolite-facies mafic rocks from the Dead Islands area, southeast Labrador, are unequivocally identified as pillow lavas. This occurrence is the first to be reported from pre-Labradorian supracrustal rocks in the eastern Grenville Province. The pillow lavas occur within a dominantly pelitic supracrustal sequence that, regionally, is termed the Paradise metasedimentary gneiss belt. This occurrence lends support for a similar interpretation of more deformed and metamorphosed analogues that occur elsewhere in the same metasedimentary belt. The whole-rock compositions indicate that the pillow lavas are mildly alkalic basalts and indicate that these rocks were not erupted in an island-arc environment. The geochemical evidence, coupled with the geological relationships, suggests a number of alternatives for the tectonic environment including epicontinental rift, passive margin rift, within-plate oceanic islands, or plume-type spreading ridge. However, although the data are consistent with these environments, it would be unwise to extrapolate too far from such a small database. Further geological and geochemical work is needed to fully document the range of magmatism that occurred in this belt. Isotopic studies may be required to discriminate between intra-oceanic and continentally influenced environments.

Given the present state of knowledge, there would appear to be a good grassroots potential for exploration for sediment-hosted Besshi-type and SEDEX deposits in the Paradise belt.

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