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THE BAIE VERTE LINEAMENT, NEWFOUNDLAND: OPHIOLITE COMPLEX FLOOR AND MAFIC VOLCANIC FILL OF A SMALL ORDOVICIAN MARGINAL BASIN

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Abstract. The Baie Verte Lineament, located in the Burlington Peninsula, northwest Newfoundland, is a steeply-dipping linear belt 90 km long by 1 to 5 km wide containing a variably disrupted ophiolite suite and other mainly mafic volcaniclastic and volcanic rocks that originally overlay the ophiolite complex. The ophiolite complex closely resembles others interpreted as samples of oceanic crust and upper mantle, although the thickness of the gabbro layer is less than 1 km. The overlying mafic volcaniclastic sediments show evidence of deposition close to (and locally at) the base of a steep scarp bounding the east side of the basin. Minor silicic tuffs are found near the top of the preserved sequence. Mafic pillow lavas comprise from 0 to 80% of the sediment section whose total preserved thickness before deformation is estimated as 5 km. Lavas within the sediment section have a chemistry closely resembling samples dredged from the Marianas Basin, while the pillow lavas and dykes of the ophiolite complex are of a distinctly different composition and include some komatiites.

The rocks of the Lineament are tectonically bounded on both sides by polyphase-deformed metasediments, metavolcanics and metaplutonic rocks, generally of coarse-grained epidote-amphibolite metamorphic facies. These rocks were metamorphosed and deformed prior to formation of the ophiolite complex and supplied some clearly identifiable detritus to the lowest sediments to prove it. They behaved as rigid bounding blocks to the Lineament. The local and regional structural, stratigraphic and detrital derivation evidence shows that the Lineament is best interpreted as the remains of a small marginal basin. Its width was probably not more than 50 km (and probably less), after spreading in it ceased. It lay in the basement to an Early Ordovician island arc, on the side remote from the trench, on the American side of the Appalachian-Caledonian (Iapetus) Ocean. The basin remained undeformed until Middle Devonian time, when it closed as a consequence of the Acadian continental collision that shut the Northern Appalachian Ocean. Closure of the Baie Verte basin did not, it appears, involve subduction, but occurred by initial formation of a large syncline with subsequent moderate-angle overturning and eastward thrusting, followed by oversteepening of the main zone of the Lineament due to continued convergence of the two rigid bounding blocks. This behavior, rather than subduction, was probably due to the small width of the basin. The best present-day analogues to the Baie Verte basin can be found in the small basins in the rear of the southern New Hebrides arc. It is suggested that the rocks exposed in the Baie Verte Lineament provide useful information about parts of present-day marginal basins that are mostly inaccessible to direct observation.

Introduction

Wilson's [1966] suggestion that the Appalachian-Caledonian orogenic belt was the site of opening and subsequent closing of a major ocean basin has been very fruitful both in the reinterpretation of its geology in terms of the effects of plate tectonics [Dewey, 1969; Bird and Dewey, 1970; Dewey and Bird, 1971; Stevens, 1970; Church and Stevens, 1971] and for the interpretation of the geological corollaries of plate tectonics in general [Dewey and Bird, 1970, 1971]. Although the quantitative plate motions responsible for the geology of Paleozoic and older orogenic belts will almost certainly never be known, this situation is also true for many Mesozoic and Tertiary belts [Dewey et al., 1973]. Therefore, even though the relative plate motions responsible for parts of orogenic belts are unlikely to be more precisely definable than having been convergent or divergent, useful information about the geological effects of plate tectonics may be obtained from any orogenic belt if the rocks concerned are well exposed and were not severely disrupted and deformed during final closure of the ocean. In particular, information may be obtained on features not readily accessible to sampling in the same tectonic environment near present plate and continental margins.

The northwestern Newfoundland Appalachians have superb coastal exposures in a section across strike and are in an area that was relatively little deformed during the Acadian collision that closed this sector of the ocean [Dewey and Kidd, 1974]. They possess three sharply defined belts of rocks containing well-preserved ophiolite complexes (Fig. 1) that are of interest both as samples of oceanic crust and mantle and for the nature of their type of origin and mode of emplacement. This paper deals with one of these ophiolitic belts, the Baie Verte Lineament (Fig. 1). This is a steeply-dipping, linear belt 90 km long by 1 to 5 km wide containing a variably disrupted ophiolite suite and other mostly mafic volcaniclastic and volcanic rocks that originally overlay the ophiolite complex. Several more or less plausible and comprehensive evolutionary schemes, seen in terms of the geologic corollaries of plate tectonics, have been proposed for the development of the northwest Newfoundland Appalachians. Although these schemes differ considerably in various respects, most workers now appear to agree with the view of Dewey and Bird [1971] that the ophiolite complexes and associated rocks were formed as the crust and fill to one or more early Ordovician marginal basins. There is disagreement, however, over the site or sites of origin of the basins with their ophiolite complex floor, and hence on the 'root zone" for the now allochthonous sheets of the Bay of Islands and Hare Bay ophiolite complexes (Fig. 1). Evidence detailed below bears on this problem and is discussed in a regional context; however, the main purpose of this paper is to illustrate the evolution of a particular marginal basin and to draw some conclusions from it about marginal basins in general.

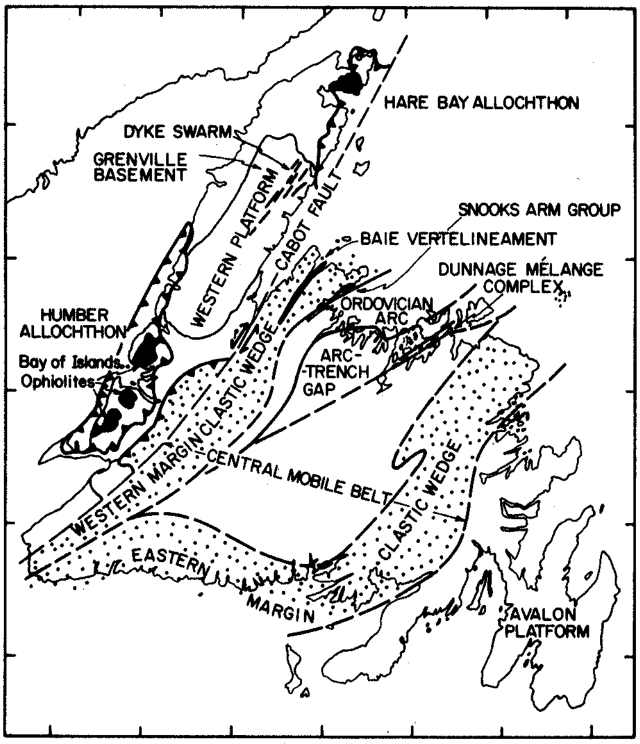

Fig. 1. Major tectonic zones of the Newfoundland Appalachians (black - ophiolites and related rocks; stippled - medium T/P metamorphic belts).

The rocks adjoining the western side and the northern part of the eastern side of the Baie Verte Lineament are polyphase deformed, thoroughly recrystallized, generally epidote-amphibolite facies metasedimentary and metavolcanic schists, the Fleur de Lys Supergroup [Church, 1969], part of the western margin clastic wedge of the Newfoundland Appalachians (Fig. 1). These rocks, which include some gneissic granitic basement to the west [deWit, 1974] are lithologically correlated with the lower part of the autochthonous Cambro-Ordovician miogeocline of the Western Platform, and with the Cambrian and older part of the allochthonous sedimentary rocks of the Humber Arm and Hare Bay allochthons (Fig. 1). The latter and most of the Fleur de Lys Supergroup are interpreted as early graben fill and overlying continental rise sediments developed on this margin of the opening Appalachian ocean [Dewey, 1969; Stevens, 1970; Bird and Dewey, 1970]. Along most of its eastern side, the Baie Verte Lineament is bounded by an extensive granodiorite, the Burlington Granodiorite. This intruded rocks of the Fleur de Lys Supergroup early in, or prior to, their complex deformation [Kidd, 1974], and therefore belongs with the Fleur de Lys structural assemblage. The rocks it intrudes are mafic metavolcaniclastic and metavolcanic schists, which pass to the east conformably and transitionally upwards into an assemblage of silicic metavolcanic and metavolcaniclastic schists and subjacent plutonic rocks, the Grand Cove Group and Cape Brule porphyry [Church, 1969]. A suggestion [DeGrace et al., 1975] that the Grand Cove Group is equivalent to the late Ordovician or younger Cape St. John Group (also silicic volcanics and related rocks) has not yet, in the author's view, been satisfactorily demonstrated. The ophiolitic Baie Verte Lineament thus lies within a zone of complexly deformed and medium-grade metamorphic rocks while itself containing rocks that, although moderately to strongly deformed, are not metamorphosed beyond greenschist facies. The Baie Verte Group has not been directly dated, but is presumed to be Arenigian (early Ordovician) in age due to its very close lithological and stratigraphic resemblance to the fossil-dated Snooks Arm Group. The latter is found 30 km from the Baie Verte Lineament on the east cost of the Burlington Peninsula (Fig. 1). During the early and middle Ordovician, the rock assemblages found to the southeast of the Burlington Peninsula in the Notre Dame Bay region are interpreted [Dewey and Bird, 1971] as representing a volcanic island arc succeded to the southeast by an arc-trench gap, in turn adjoined by an extensive melange (Dunnage) interpreted as a trench-wall assemblage (Fig. 1). The spreading age of the Bay of Island ophiolites is probably Tremadocian (earliest Ordovician), and their obduction into their present allochthonous position, in an exogeosyncline developed on the previous carbonate miogeocline, occurred during medial Ordovician time [Stevens, 1970].

Several conflicting hypotheses have been proposed for the occurrence of the Baie Verte Lineament, a belt of ophiolite-bearing low-grade rocks within a higher grade metamorphic terrain. Church and Stevens [1971] suggested that it is a downfaulted part of a once more extensive obducted ophiolite sheet of which the Bay of Islands ophiolites are also a remnant; Neale and Kennedy [1967] suggested that it is the root zone for obduction of the Bay of Islands ophiolites; while Dewey and Bird [1971], and Kidd [1974] suggested that it is the remains of a marginal basin in the sense of Karig [1971], developed by spreading to the immediate rear of an active island arc. They suggested that the Bay of Islands complex also originated in a marginal basin, but to the west of, and separated by a piece of remnant arc from the Baie Verte basin. On this hypothesis the Baie Verte Lineament cannot have been the root zone for the obduction of the Bay of Islands complex. Evidence detailed below shows that only the latter hypothesis is tenable. The stratigraphic sequence, the structure, and the chemistry of the basalts all show some interesting and distinctive features that may aid in understanding some features of present day marginal basins and assist in the recognition of similar features in orogenic belts.

Stratigraphy and Sediment Provenance

The ophiolite complex is best exposed and preserved in the Mings Bight area at the northern end of the Lineament. Although it occurs in two inverted and one upright thrust slices the ophiolitic plutonic rocks within each slice are internally undeformed. The slices are cut by some high-angle normal faults, but a reconstruction can be made by matching distinct lithological boundaries across these faults.
The thicknesses shown for the ophiolite complex units (Fig. 2) are therefore minimum thicknesses for most of the units. The rocks of the ophiolite complex consist of the full sequence of units seen in, and closely resemble, others interpreted as oceanic crust and upper mantle. The minimum thicknesses obtained are comparable to other complexes with the exception of the gabbro unit, which is apparently less than 1 km thick. In this aspect the complex resembles that of Betts Cove, the intact complex found at the base of the Snooks Arm Group [Upadhyay et al., 1971].

The structurally inverted contact between the top of the pillow lavas of the ophiolite complex and the stratigraphically overlying sediment section is fully exposed on the west coast of Mings Bight. About 300 m thickness of little-deformed sediments are preserved between the ophiolite complex pillow lavas stratigraphically below, and a further section of about 1 km (probably at least 2 km before deformation) of pillow lava above (Fig. 2). A bed of maroon chert 30 cm thick lies directly on the ophiolite

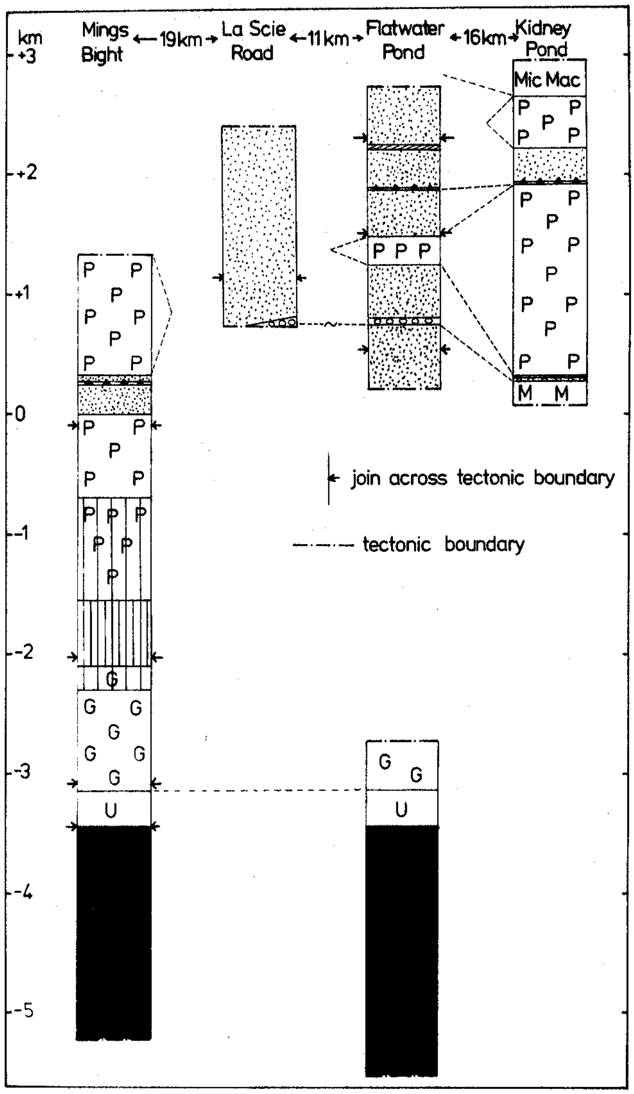

Fig. 2. Stratigraphic sections of the Baie Verte Lineament (black - non-cumulate harzburgite; U - ultramafic cumulates; G - gabbro; vertical lines - diabase dike complex; P - pillow lava; wide-spaced vertical lines with either G or P - diabase dikes with screens of gabbro or pillow lava; stipple mafic volcaniclastics; black triangles - clinopyroxene-rich volcaniclastics; circles - black slate conglomerate; M - gabbro megabreccia; oblique lines - pink silicic tuff). Thicknesses shown for sediment and upper volcanic units are for present deformed state; these should be at least doubled for original thicknesses. Ophiolite complex
rocks are internally undeformed.

complex pillow lava; however, the remainder of the section consists entirely of sandy, silty and conglomeratic mafic volcaniclastic sediments with minor interbedded mudstone to cherty mudstone laminae in places. Some of the beds are graded, but most are not; the conglomeratic beds mainly show large, mostly distinctly rounded cobbles to pebbles dispersed and supported in a sandy to silty matrix. Small-scale channeling is seen at the base of some sandy beds and larger channels can be seen in some places filled by the conglomeratic beds. These sediments thus show evidence of deposition mainly by a mud- or sand-flow (grain flow) mechanism although a minority may be turbidite deposited. None show any definite evidence of being directly deposited tuffs, settled through water or otherwise. The occurrence of medium-scale channels and this mode of deposition suggest that the depositional environment was near the base of a relatively steep submarine slope [Stanley and Unrug, 1970). Rare slump folds consistently show a paleoslope from the northeast/east when the beds are unfolded by a strike rotation. The identifiable clastic components of the sandy and silty beds are albitised plagioclase grains, most commonly rounded, suggesting a shallow water transit; the mafic components appear to have been much finer grained and have mostly been recrystallized and obliterated in the low greenschist facies alteration affecting the rocks. Quartz is universally and conspicuously absent. Near the base of the section, the conglomeratic clasts are mainly large flakes of yellowish cherty mudstone very similar to beds within the section; upward, mafic lava clasts predominate, accompanied by rare ophiolite gabbro and diabase clasts. Near the top of the section, there is a sequence of conglomeratic beds dominantly containing very porphyritic mafic lava clasts with large oscillatory zoned phenocrysts of (altered) clinopyroxene, which also occur abundantly in the coarse sandy matrix. Such a rock type suggests derivation from an island arc, and a very similar rock is illustrated by Mitchell [1966] from Neogene arc deposits in the New Hebrides. The overlying lavas, which are in large part strongly deformed, contain two thick sills of abundantly and coarsely porphyritic plagioclase porphyry dolerite; wide feeder dikes of identical aspect are found cutting all members of the ophiolite suite including the non-cumulate harzburgite. This demonstrates that the lavas above the sediments are not, in the strict sense, part of the ophiolite suite.

Such a thick section consisting entirely of mafic volcaniclastic rocks is not expected to immediately overlie oceanic crust formed in a major ocean, except possibly near a "hot spot"type volcanic chain originating very near the spreading axis. However, the upper lavas should then show alkaline affinities, which they do not, and the progressive erosion of the inactive part of the migrating volcanic chain should result in a rapid return to pelagic sedimentation, which is not seen. Sections developed near fracture zones should mainly show scree breccias and pelagic sediments without sandy mafic deposits.

Inland, the stratigraphic succession is, in part, different. Although the lower part of the ophiolite complex stratigraphy is preserved in one place and large ultramafic bodies are found discontinuously along the western side of the Lineament, the contact between the ophiolite complex and the overlying mafic sediments and volcanics has everywhere been removed by tectonic sliding. However, the nature of the exposed basal sediments suggests that they were deposited not far above the ophiolite complex base. The section forms an eastward-facing homocline across the Lineament. The sediments and lavas in the inland area are deformed and appropriate lithologies possess a steep cleavage. Estimates of shortening from rare suitable lithologies show that original stratigraphic thicknesses were probably at least double present thicknesses and therefore that the total thickness of 2.5 km in the southern (Kidney Pond) section (Fig. 2) was probably at least 5 km before deformation. The two southern sections show (Fig. 2), above the two basal units, sandy to silty and conglomeratic mafic volcaniclastic rocks, essentially identical to those in the Mings Bight section, intercalated on a large scale with pillow lava containing a relatively few thin horizons of mafic sediments. The pillow lava comprises about 80% of the southern section (Kidney Pond) and mapping shows that it thins northward, being entirely replaced by volcaniclastic rocks in the La Scie Road section. Dolerite sills are common throughout the Kidney Pond section and also become less common northward. Two distinctive horizons near the base and top of the stratigraphic sequence in the Flatwater and Kidney Pond sections provide control for the demonstration of this facies change. The upper of these horizons consists of conglomeratic mafic sediment containing abundant large zoned clinopyroxene phenocrysts in the matrix and in the clasts; this horizon is very similar to that in the Mings Bight section, but they cannot be proven to be equivalents. Above this horizon in the Flatwater Pond section, there are fairly abundant beds of pink, silicic, albite-phenocryst-bearing tuffs. Both these lithologies suggest the presence of a nearby island arc. Rare slump structures in the lower part of the sediment section all indicate an east to west paleoslope when rotated to horizontal about strike.

The lowest two units in the Kidney Pond section show some distinctive characteristics. The upper of the two, a black slate matrix pebbly conglomerate, has been equated with a melange [St. Julien et al.,1976]. The term is inappropriate for this unit that is contained within a regular stratigraphic sequence, that nowhere exceeds 60 meters in thickness, that does not show any signs of disruptive post-depositional deformation, and that possesses a restricted range of clast types.

This conglomerate is merely a submarine mudflow deposit, just as the conglomeratic mafic volcaniclastics above are sandflow deposits; it differs only in the distinctive nature of its matrix and clast assemblage. This assemblage consists of 1) argillaceous clasts similar to the matrix; 2) clasts of distinctive ophiolite-derived gabbro, diabase and basalt; and 3) exotic, quartz-bearing clasts. Most of the clasts, because they are somewhat rounded, were probably worked through shallow water before incorporation in the mudflow. This observation also applies to the mafic volcanic clasts elsewhere in the succession. The restricted assemblage of ophiolitic clasts is noteworthy; apart from a few rare and small clinopyroxenite clasts, there are no ultramafic clasts present and no chromite has been detected. These ophiolite-derived clasts form the bulk (90% +) of the total assemblage. Most are pebble to cobble size, but one block of ophiolite gabbro 40 X 20 meters in section is present. The exotic clasts never comprise more than 10% of the assemblage and are usually much less abundant. The most common type are of granodiorite, ranging in size up to 1 meter across. These, as has previously been pointed out [Church, 1969; Neale and Kennedy, 1967] very closely resemble the Burlington Granodiorite, which is a large syn- or pre-kinematic intrusion into the metamorphic terrain and which immediately adjoins the eastern side of the Baie Verte Lineament. These clasts confirm the paleoslope direction of provenance, and demonstrate that the Baie Verte Lineament rocks, including the conformably underlying ophiolite complex base, are not allochthonous, on a large scale, with respect to the eastern bounding block. Other rare clasts within this conglomerate include pieces of silicic tuff with a strong pre-depositional foliation; these range in size from pebbles to a slab 1 meter across. They can also be matched with rocks (probably Grand Cove Group) in the metamorphic block to the east of the Baie Verte Lineament. Also matchable with the Grand Cove rocks to the east is one large block (1 X 2 meters exposed) of silicic meta-siltstone possessing a well-developed, pre-depositional muscovite schistosity axial surface to tight folds, both refolded by open angular folds that are also predepositional. In addition, a boulder conglomerate, which probably occupies a large channel, and is on strike but not directly connected with the black slate conglomerate, occurs towards the La Scie Road section. It mostly contains quartzite and quartz pebble conglomerate boulders, the latter very closely resembling metasediments found in the area previously mapped as Cape Brule Porphyry, but which are probably in the Grand Cove Group. It also contains some small serpentinized and chloritized chromite-bearing ultramafic clasts.

The lower of the two lower units in the Kidney Pond section is a megabreccia. This consists entirely of large (10-100 meters across), closely packed slabs of ophiolite gabbro, with or without diabase dikes. Thin accumulations of silty mafic volcaniclastic and mudstone beds conformable to the section above the unit occur between blocks showing that it accumulated block by block as a submarine scree breccia, not as a disrupted tectonic melange or olistostrome. Several characteristics of some of the gabbros, distinct from normal ophiolite gabbros, suggest that they were deformed on a fault zone before incorporation in the megabreccia. Gabbro blocks containing diabase dikes parallel to a sheet jointing have their long dimensions parallel to the sheet jointing and lie flat in the bedding orientation so that the dike segments are also coplanar with bedding. Toward Flatwater Pond this unit is replaced along strike by a unit of sandy and silty mafic volcaniclastics with minor argillaceous laminae and very rare calcareous turbidites. In places this unit also contains large blocks, for example one of cumulate clinopyroxenite and one of recrystallized limestone both about 10 meters across. Areas of ophiolite gabbro at its base mayor may not be accumulations of blocks or large single blocks several hundred meters across.

The clast types and occurrences are more fully documented and discussed in Kidd [1974].

Composition of the Basalts

Three separate units of basalt are present in the area; 1) the ophiolite complex pillow lavas and dikes; 2) the upper pillow lavas above the sediment section in Mings Bight; and 3) the upper pillow lavas in the Kidney and Flatwater Pond sections. Major element analyses of mafic lavas in low greenschist facies have been shown to give highly variable and hence unreliable results by Smith [1968]; this variability affects all of the major elements and is not merely spilitization affecting Na and K. Whether the variability (in some cases extreme) found in the major element analyses of the Baie Verte lavas is due to such migration during alteration and low greenschist facies metamorphism is an open question, but appears likely from the less mobile minor element data. An average of 6 of the more consistent analyses of the ophiolite lavas and one analysis of the Kidney Pond section upper pillow lavas are given for information in Table IA. These analyses appear to be a reasonably normal spilitized basalts, but a few within the ophiolite lavas have the characteristics of basaltic komatiites (Table lA, Sample T2). This is of interest because of the more common occurrence of such rocks in Archean greenstone belt sequences.

The less mobile minor element analyses (Table IB) show much more consistency than the major element analyses and give a clear discrimination between the ophiolite lavas and dikes, and the upper pillow lavas in the Kidney Pond section. The upper pillow lavas in the Mings Bight section appear to be very similar to the ophiolite lavas.

TABLE I

Selected Analyses of Baie Verte Lineament Basalts

Major Elements	Ophiolite Pillow Lavas (average of 6 samples)	Sample T2	Upper Pillow Lavas Kidney Pond Section
SiO_2	49.58	47.11	48.24
TiO_2	0.46	0.40	1.46
Al_2O_3	14.16	12.63	14.58
FeO*	8.52	8.94	11. 93
MgO	11.59	12.80	7.79
CaO	9.30	13.81	9.37
Na_2O	3.07	0.95	3.55
K_2O	0.04	0.34	0.31

Minor Elements (ppm)	Number of Samples	Ti	Zr	Y	Nb	Sr	Cr
Mings Bight							
Ophiolite Dikes	8	2240	18	12	0.5	105	115
Ophiolite Pillow Lavas	11	2790	21	12	0.4	93	418
Upper Pillow Lavas	5	1900	19	8	0.6	101	572
Kidney Pond							
Upper Pillow Lavas	5	8760	104	29	4.4	190	nd
Marianas Trough[a]	6	8940	101	25	6	186	231
Niua Fo'ou[b]	14	8760	131	36	nd	160	282
Average Ocean Ridge Basalt[c]	33	8340	100	43	nd	123	296

a - Hart et al. 1972 b - Reay et al. 1974 c - Melson and Thompson 1971

XRF analyses by E. Nesbit and R.G.W. Kidd at the University of East Anglia

For comparison, averages of analyses of the same minor elements for samples obtained from the active Marianas Trough marginal basin [Hart et al., 1972], from the volcano Niua Fo'ou in the northern Lau active marginal basin [Reay et al., 1974] and ocean ridge basalts [Melson and Thompson, 1971] are given. It can be seen that the ophiolite lavas and dikes from the Baie Verte Lineament are quite distinct from the present active marginal basin samples and from ocean ridge basalts, but that the Kidney Pond section upper pillow lavas are very similar to all three types given for comparison, especially to the Mariana Trough samples.

Plotting of Ti, Y, Zr, and Sr values on Pearce and Cann's [1973] revised discrimination diagrams reveals the unfortunate fact that the ophiolite lavas and dikes and the Mings Bight upper pillow lavas plot in the island arc low-K tholeiite field while the upper lavas within the Kidney Pond sediment section plot in the ocean ridge basalt field. A minor but mappable horizon of dark pillow lava within the Kidney Pond upper lavas yields analyses with alkaline affinities (not shown in Table I) and that plot in the alkaline (hot-spot) field on Pearce and Cann's diagrams. It is suggested that the environment of formation of rocks from marginal basins may not always be correctly discriminated by Pearce and Cann's method.

Structure and Deformation

The structure of the Baie Verte Lineament is a tightly folded syncline severely disrupted by thrust faults, which developed synchronously with the severe horizontal shortening deformation responsible for the single steep penetrative cleavage. It can be argued from a sequence of thrust faults and cleavage development in the thrust zones exposed in the Mings Bight area (Fig. 3), that the initial stages of development involved a syncline with an axial surface dipping moderately west. This was disrupted by moderately west-dipping thrust faults as it tightened and cleavage developed. Subsequent oversteepening of the rocks caught in the main part of the Lineament occurred, together with high-angle thrust-faulting (tectonic sliding) on both east and west boundaries of this steep zone, which is essentially the whole of the width of the Baie Verte Lineament south of the Mings Bight area. During all this deformation, the bounding blocks to the Lineament (the western and eastern Fleur de Lys metamorphic terrain) behaved in an essentially rigid manner. Very little evidence of local deformation or retrograde metamorphism can be seen in most places even within 100 meters of the tectonic contacts on either side of the Baie Verte Lineament, both in the mostly epidote-amphibolite facies schists on the western, and northern part of the eastern, sides, and in the Burlington Granodiorite on the eastern side. The only exceptions to this statement are in a zone of thin thrust slivers of retrograded and deformed Burlington Granodiorite on the east side of the Lineament north from Flatwater Pond, and very close to local sympathetic thrust zones in the Fleur de Lys schists on the eastern margin in the Mings Bight area (Fig. 3).

The structural situation in the Advocate mine area at the west of the Mings Bight section appears to be more complex, but the affinities of the ophiolitic rocks in this area are not yet entirely clear [Bursnall and deWit, 1975]. Some belong to the older, polypnase deformed and metamorphosed Fleur De Lys terrain while others, although complexly deformed, may belong to the Baie Verte assemblage, perhaps having been deformed on a fault zone, possibly a transform fault, and

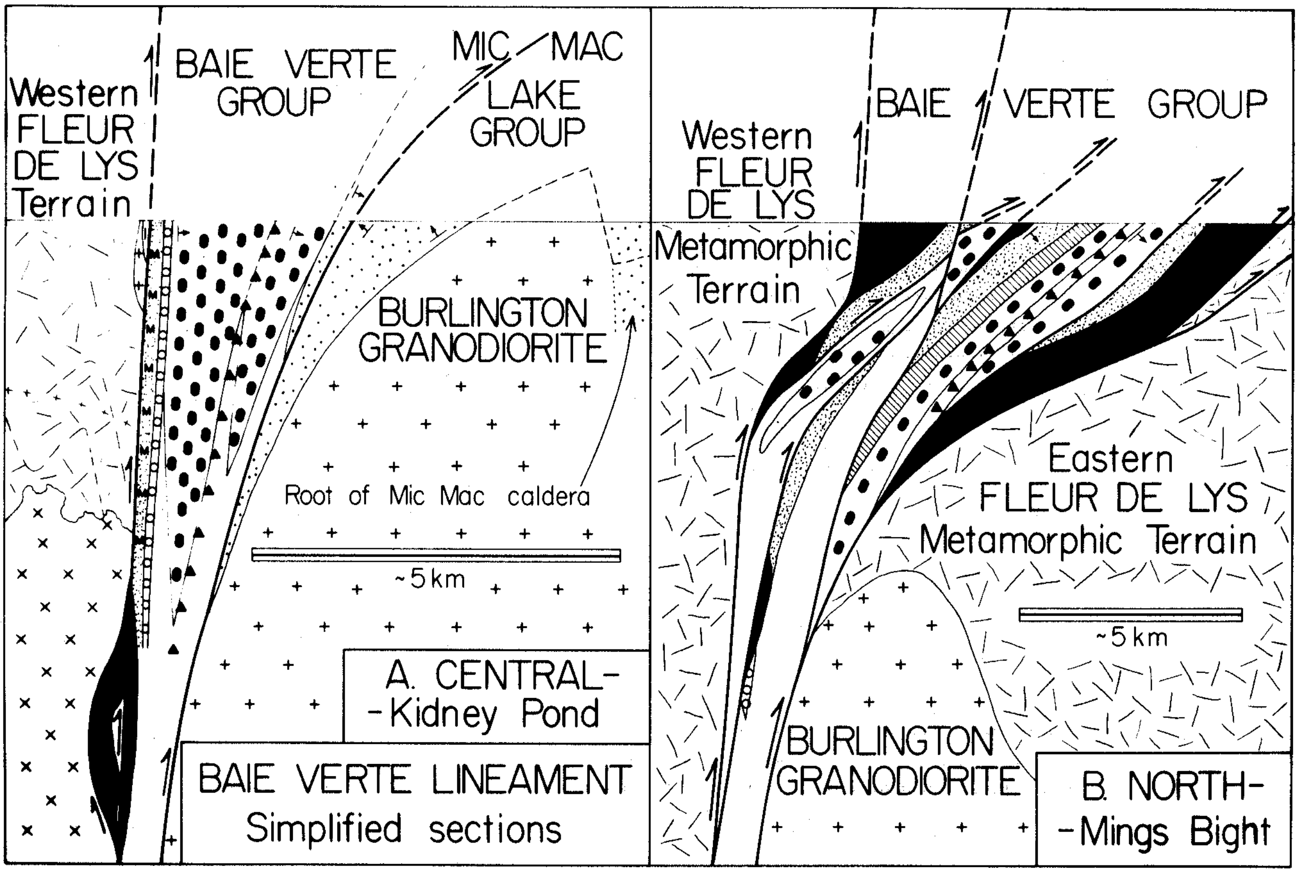

Fig. 3. Simplified and extrapolated cross-sections of the Baie Verte Lineament. (a) Bounding blocks: random dashes - schists of the Fleur de Lys terrain; +-Burlington Granodiorite; x - post-kinematic granite in the Fleur de Lys. (b) Baie Verte Lineament: black - ultramafic rocks; fine dots - ophiolite gabbro; lines - sheeted dikes; black ovals - pillow lava; M - gabbro megabreccia; circles - black slate matrix conglomerate; black triangles - mafic volcaniclastics containing some beds with abundant clinopyroxene-porphyry clasts; blank - mafic volcaniclastics; coarse dots - Mic Mac Lake Group; arrows with bar - younging direction.

perhaps the same fault zone responsible for the gabbro megabreccia and the highly strained gabbros found in places within it.

Two partially simplified and extrapolated cross-sections of the Baie Verte Lineament are shown in Fig. 3. In the Mings Bight area, two somewhat disrupted, inverted thrust slices overlie a slice containing a partial ophiolit~ section that, is upright, defining a disrupted synclinal structure. In the Kidney Pond area, the structure is also a disrupted syncline, although another group of rocks is also involved besides the ophiolitic Baie Verte Group. This is the early Devonian Mic Mac Lake Group, a subaerial bimodal basalt-rhyolite sequence containing much proximally-derived alluvial fan sediment. In the section in the Kidney Pond area, a thin strip of east-facing Mic Mac Lake Group rocks rests with very slight, unfaulted, angular unconformity on the east-facing homocline of Baie Verte Group'volcanics and sediments (Fig. 3, Fig. 2). This same contact has been suggested to be a fault [Church, 1969], and conformable with the Baie Verte Group overlying west-facing Mic Mac Lake Group [Neale and Kennedy, 1967]. Neither of these hypotheses is correct. Most of the Mic Mac Lake Group in this area faces west from a spectacular unconformity on the Burlington Granodiorite. The west and east facing sections of the Mic Mac Lake Group are separated by a major thrust fault (tectonic slide zone), which has been removed in most places by a late high angle fault with considerable westward down throw (for clarity, not shown on Fig. 3). In the Flatwater Pond area, the east-facing Baie Verte is separated from a narrow belt of west-facing Mic Mac Lake Group by this same thrust fault, with thin thrust slices of Burlington Granodiorite intervening in places. As suggested by Neale and Kennedy [1967], the Mic Mac Lake Group shares the same single regional cleavage as is found in the Baie Verte Group. The overall structure in this area is therefore also a thrust-modified syncline, just as it is in the Mings Bight area.

Considering the east-moving thrusts, the relatively intact nature of the Baie Verte sequence, the very low angle unconformity with which the Mic Mac Lake Group (early Devonian) overlies the Baie Verte Group (probably Arenigian), and their shared single cleavage, there is no evidence of significant regional deformation of the ophiolitic Baie Verte Group until after early Devonian times. It is suggested that there is no evidence of subduction having occurred during the deformation of this belt, although some of the oceanic mantle underlying the-Baie Verte Lineament must have been displaced downwards during the convergence of the two rigid bounding blocks and the resulting compressive, fundamentally horizontally directed, deformation. In addition, all the post-early Devonian thrust deformation is towards the east, and it is therefore in the wrong direction, let alone the wrong age, for the Baie Verte Lineament to be a source or root zone for the Bay of Islands ophiolites. The source along White Bay and Deer Lake thrust belt (at the western side of the Grand Lake Group schists) proposed by Dewey and Bird [1971] seems a more likely proposition.

Reconstruction and Present Day Analogues

Assuming the conclusion that there was no subduction involved during the deformation of the Baie Verte Lineament is correct, then the width of the oceanic crust that floored the Baie Verte basin can be estimated by unstacking the thrust sheets and unfolding the syncline, allowing a generous estimate for the width of material at depth and that eroded. Such an estimate for, the Mings Bight section (Fig. 3) gives a width of about 30 km; it is extremely difficult to imagine that it could be more than 50 km. An approximately scale cross-section reconstructing the Baie Verte basin given a 30 km width of oceanic crust is shown as Fig. 4. This incorporates the arc volcanic source for the mafic volcaniclastic rocks and silicic tuffs, the fault zone and scarp source for the megabreccia and black slate conglomerate, and indicates the renewed vulcanism in the basin responsible for the upper pillow lavas. Data from the Mid-Atlantic Ridge [Ballard et al., 1975] shows that pillow lavas do not flow great distances and therefore that the source must have been within the basin, and is not likely to be overflow from the arc. This is also likely to be true because of the chemistry of the upper lavas, which resemble ocean ridge basalts.

The overall length of the Baie Verte Lineament can also be approximately determined. The Canadian 1:63,360 aeromagnetic maps show that the pronounced anomalies associated with the ultramafic bodies and the weak trend along the Lineament do not continue to the NNE beyond the seaward end of Burlington Peninsula. To the SSW, the Lineament proper is cut off by the Green Bay Fault, which has 20 km dextral displacement [Upadhyay et al., 1971]. However, a small ultramafic body occurs about this distance to the west of the appearent end of the Lineament near Sandy Lake [Neale and Nash, 1963] and mafic rocks like those in the Lineament are found on and around Glover Island in Grand Lake [Riley, 1957]. However, no further occurrences are found south of this area. The Baie Verte Lineament proper is about 90 km long; with the extension proposed above, it becomes 220 km long. St. Julien et al., [1976] speculate that the Baie Verte Lineament is the same structure as that around Thetford in Quebec, a distance of about 1500 km. This seems unlikely to be true, because of the absence of any direct evidence that there is a continuous structure between the two localities, because the Baie Verte Lineament was not deformed until post-early Devonian times, whereas the Quebec structure developed in early to medial Ordovician

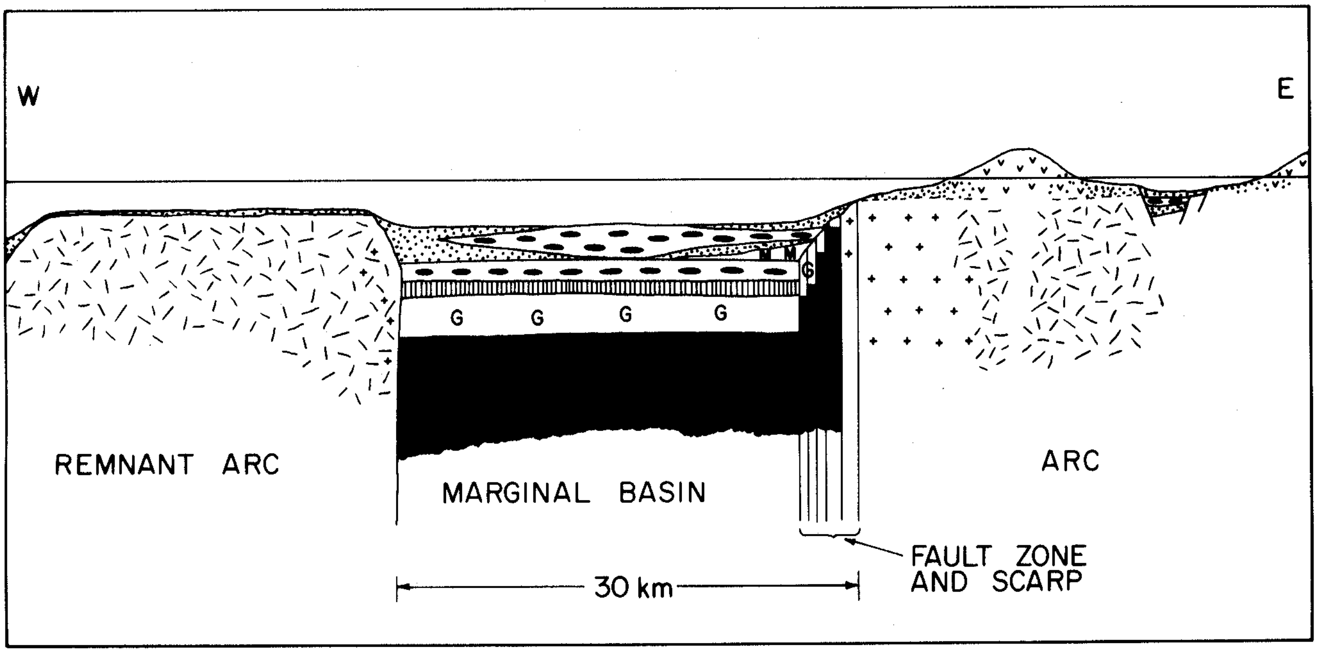

Fig. 4. Reconstructed cross-section (approx. to scale, V=H) of the Baie Verte marginal basin in Ordovician time. Ornament as for Fig. 3 except: fine dots - mafic volcaniclastics; G - ophiolite gabbro, V - arc volcanics.

time, and because of the evidence presented here and in Dewey and Bird [1971] that the western Newfoundland ophiolitic belts developed in separate marginal basins. Thus a present day analogue for the basin floored by oceanic crust that became the Baie Verte Lineament must have dimensions about 30-50 km wide and 100-200 km long and be developed behind an active island arc. Such a process is represented today in areas like the Marianas Trough and Lau-Havre Trough [Karig, 1971], but these basins are about ten times too wide and long to be precise analogues to the Baie Verte basin. However, precise analogues for size can be found behind the southern half of the New Hebrides arc (Fig. 5) [Karig and Mammerickx, 1972]. These basins have been demonstrated to be relatively free of sediment given the available supply from the arc and are clearly active extensional structures [Karig and Mammerickx, op. cit.]. The narrower ones have not yet been demonstrated to be floored by oceanic crust, but a wider basin in the central part of the arc is highly likely to be so floored. To further the analogy with the Baie Verte sequence, this basin has the volcano Aoba sited within it. This [Warden, 1970] currently erupts plagioclase-phyric basalt, perhaps resembling a possible source similar to that which supplied the porphyritic dikes and sills in the Mings Bight section. It has also erupted ankaramitic lavas, and may perhaps be similar to the source of the coarse clinopyroxene porphyry conglomeratic horizons in the Baie Verte. Most of the other volcanoes in the New Hebrides erupt plagiophyric lavas [Mitchell and Warden, 1971]; this resemblance to the source of the volcaniclastics in the Baie Verte is perhaps also noteworthy. Karig and Mammerickx (op. cit.) emphasized the en echelon nature of the smaller New Hebrides basins oblique to the general trend of the arc. This obliquity to the arc is also true of the Baie Verte Lineament (Fig. 1). The Baie Verte structure is also not an isolated example; the Snooks Arm Group 30 km to the east has a very similar sequence of rocks conformably resting on an ophiolite complex base [Upadhyay et al., 1971]. These are also in a fault-founded syncline, and are rather less deformed than the Baie Verte Group. This has also been proposed to have formed in a small marginal basin [Upadhyay et al., 1971].

Discussion and Conclusions

Regional Geology

The fact that the sediments immediately and conformably above the ophiolite complex base to the Baie Verte Group contain clasts of material closely matching rocks in the eastern Burlington Peninsula shows that it and its ophiolite base are not allochthonous with respect to that area. The Snooks Arm Group is also not allochthonous with respect to the same area for the same reason [Church, 1969; Dewey and Bird, 1971]. The fact that clasts of this material in the Baie Verte

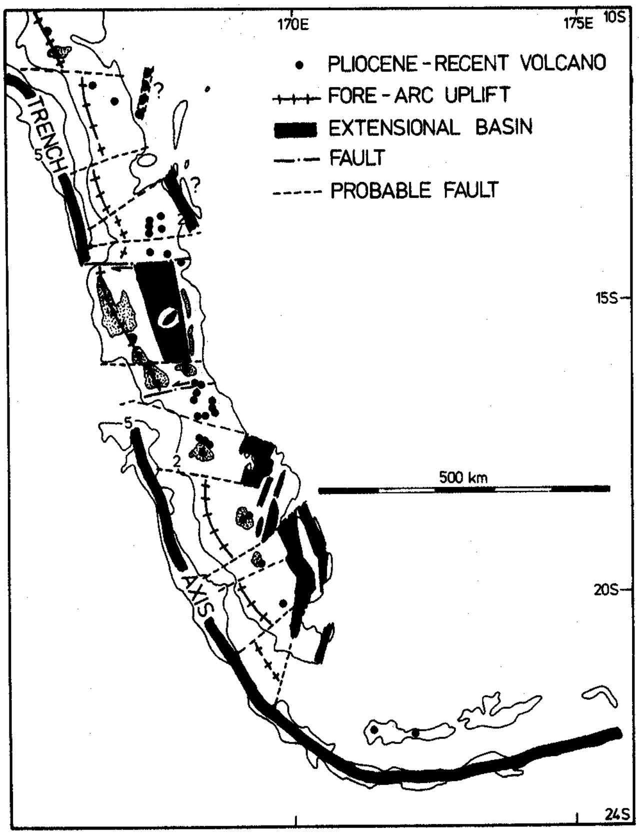

Fig. 5. Sketch map of the New Hebrides island arc. Slightly modified from Karig and Mammerickx (1972). 2 and 5 km. submarine contours shown.

Group show significant predepositional deformation fabrics demonstrates that they had undergone that compressive deformation and metamorphism not only prior to the deposition of the sediments but also prior to the formation of the ophiolite complex (oceanic crust and mantle) base. The latter must have developed in a structural environment of regional brittle tension, not the plastic, compressive behavior represented by the pervasive deformation of the metamorphic rocks. The Baie Verte Group did not undergo any regional penetrative deformation until after the deposition of the early Devonian Mic Mac Lake Group, and therefore does not show any detectable effects of the medial Ordovician obduction of the Bay of Islands ophiolites and Humber Arm allochthon. In addition, all the thrusting in the Baie Verte Lineament moved eastward. The rocks of the Fleur de Lys metamorphic terrain that form the two blocks bounding the Lineament were not internally penetratively deformed in any significant way during the compressive, horizontally directed, deformation that affected the rocks of the Baie Verte Lineament.

General

The occurrence of a coherent ophiolite complex base to the sequence in the Baie Verte Lineament (and the Snooks Arm Basin) shows that, even in such small marginal basins, the spreading results in the successive injection of coplanar dikes into the accreting oceanic crust. The fact that these dikes are coplanar and do not penetrate the cumulate and non-cumulate ultramafic rocks shows that this process is coherent at least on the scale of a few kilometers, and, therefore, that at least short segments of spreading ridge should be present in actively distending marginal basins. Whether these segments are connected in a single, orderly ridge-transform boundary in large marginal basins is not predictable from this data, but in narrow New Hebrides-type basins there.is not likely to be room for more than one such boundary. There are two sets of orientations of ophiolite diabase dikes at right angles to one another (each is in a different thrust sheet) in the Mings Bight ophiolite complex. The restored original orientations of these dikes in the Baie Verte basin are near parallel and at a high angle to its length. The dikes in the Snooks Arm basin are at a high angle to its long dimension and those in the allochthonous Bay of Islands ophiolites are oblique to the long axis of the allochthon and the presumed trend of the basin they originally lay in. These data suggest that spreading axes in marginal basins are rarely parallel to their long dimension and also that radical changes of spreading direction and consequent ridge axis jumping may commonly occur.

The chemistry, particularly of some of the minor elements, of the mafic lavas of the ophiolite complex does not resemble that of lavas dredged from the larger, active marginal basins like the Marianas Trough [Hart et al., 1972] and the Lau-Havre Trough [Hawkins, 1976], and presumed to be representative of their upper oceanic crust. Perhaps smaller basins like those in the New Hebrides will yield lavas more similar to those of the Baie Verte ophiolites; their different compositions might be due to their emplacement in a narrower basin with thicker adjacent lithosphere. However, the occurrence of lavas, very closely similar to those from the Marianas Trough, within the sediments filling the Baie Verte Basin suggests an alternative possibility. If vulcanism occurs in marginal basins not only at the spreading ridge segment axes, forming the upper oceanic crust, but also in a relatively widespread manner in other parts of the basins, then some hitherto puzzling features of active marginal basins might be at least partially explicable. The relatively rough -topography within the basins, and the difficulty or impossibility of identifying coherent or symmetrically disposed spreading magnetic anomaly patterns could both be, at least in part, accounted for. It can be pointed out that in a narrow basin with a high rate of volcaniclastic sediment supply, such off-axis volcanics might be separated from the oceanic crustal lavas by a significant, seismically detectable, thickness of sediments, but that in wider basins with a low rate of pelagic sedimentation such volcanics would likely be indistinguishable by such means from the oceanic crustal lavas below them.

It is suggested that the closure of the Baie Verte basin did not involve subduction because of the small width of oceanic crust in it, just as in the case of the Cretaceous marginal basin of Southern Chile [Dalziel et al., 1974].

The occurrence of basalts resembling basaltic komatiites within the ophiolite lavas suggests that many of the narrow greenstone belts in Archean terrains may be the closed remains of marginal basins, rather than cores of island arcs, a suggestion made on this and other grounds by Burke et al. [1976]. The Baie Verte Lineament in many respects closely resembles such Archean greenstone belts, particularly in its steep, pinched structure and its steep penetrative cleavage indicating severe horizontal compression and shortening.

It is not clear whether such a zone of small, en echelon extensional basins as is found in the New Hebrides represent the initial state in the formation of a large marginal basin or whether they represent the rear-arc distentional process occurring at a slower rate than that forming large marginal basins. It could perhaps be suggested that it is confusing to apply the term marginal basin to structures of such smaller size. However, the fundamental process and effects seem to be the same, merely being applied on a different scale. Their possible role in producing narrow ophiolitic lineaments in orogenic belts that may not directly mark ancient subduction zone sites or sutures of major consequence may perhaps be more important than previously realized. Small basins closing without subduction, like the Baie Verte Lineament, appear to preserve more of their contents on the site of closure than are preserved at sites where larger oceanicfloored basins, for example the Bay of Islands basin, or the main Appalachian ocean in Newfoundland, are proposed to have vanished by subduction.

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