Fractionation trends in the Bay of Islands ophiolite of Newfoundland: polycyclic cumulate sequences in ophiolites and their classification

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The fractionation range of the cumulate sequence of the allochthonous Bay of Islands ophiolite of the Western Platform of Newfoundland, measured in terms of the FeO(total)/MgO ratios of the liquids from which they were derived, encompasses entirely the range of known values exhibited by the overlying dikes and pillow lavas. Cryptic variations within the cumulate sequences are irregular, often inverse, and the crystallization sequences found in the cumulates suggest that they were formed from at least three different basaltic magma types, one of which is unusual in having given rise to co-existing highly aluminous clinopyroxenes and spinels. These features suggest that crystallization of the Bay of Islands plutonic rocks took place in an '*open system*' magma chamber that was tapped repeatedly during fractionation to form dike rocks and lavas. Most of the cumulate rocks of the Bay of Islands ophiolite formed according to the crystallization sequence ol–cpx–(opx) or the sequence ol–plag–cpx–(opx). In contrast, the cumulate rocks of the Betts Cove ophiolite, located within the Fleur de Lys orthotectonic zone of the Newfoundland Appalachians, crystallized according to the sequences ol–opx–cpx and ol–cpx–plag. This difference in the nature of the cumulate sequences within the Bay of Islands and Betts Cove ophiolites is also reflected in the Ti characteristics of the basaltic rocks of the ophiolites, and in the morphology of the gabbroic units. Comparison with Mesozoic ophiolites suggests, as a general rule, that within ophiolite cumulate successions there is a tendency for ol–opx sequences to be followed by ol–cpx sequences, and for ol–cpx sequences to be followed by ol–plag sequences. Such a relationship may be related to processes involving remelting of lower-temperature crystallization products in a system open to either continuous or periodic additions of high temperature basaltic liquid. In terms of oceanic structures the Bay of Islands ophiolite corresponds to sonobouy model 2 of Christensen and Salisbury: the basal high velocity layer corresponding to the olivine-gabbro cumulate rocks, and the lower velocity 'gabbroic' layer to the upper part of the olivine-free cumulate sequence and overlying massive uralitized roof gabbro and dike rocks.

Le domaine de fractionnement de la séquence cumulative d'ophiolite allochthone de Bay of Islands dans la plateforme ouest de Terre-Neuve, mesuré en terme du rapport FeO(total)/MgO des liquides desquels ils dérivent, recouvre tout le domaine des valeurs connues qu'on rencontre dans les dykes et les laves en coussins susjacents. Les variations occultes à l'intérieur des séquences cumulatives sont irrégulières, souvent inverses, et les séquences de cristallisation observées dans les accumulations suggèrent qu'elles se sont formées à partir d'au moins trois types différents de magmas basaltiques, un de ceux-ci se distingue pour avoir donné naissance à des clinopyroxènes et des spinelles coexistants très riches en alumine. Ces caractères suggèrent que la cristallisation des roches plutoniques de Bay of Islands s'est produite dans une chambre magmatique en "système ouvert" qui a été sollicité à plusieurs reprises durant le fractionnement pour former des dykes et des laves. La plupart des roches accumulées de l'ophiolite de Bay of Islands se sont formées selon la séquence de cristallisation ol–cpx–(opx) ou la séquence ol–plag–cpx–(opx). En contraste, les roches cumulatives de l'ophiolite de Betts Cover, située dans la zone orthotectonique de Fleur de Lys dans les Appalaches de Terre-Neuve, ont cristallisé selon la séquence ol–plag–cpx et ol–cpx–plag. Cette différence dans la nature des séquences cumulatives des ophiolites de Bay of Islands et de Betts Cove se reflète aussi dans le comportement de Ti dans les roches basaltiques des ophiolites et dans la morphologie des unités gabbroïques. La comparaison avec les ophiolites du Mésozoïque suggère, en règle générale, qu'à l'intérieur des successions cumulatives de l'ophiolite, les séquences ol–opx tendent à être suivies par des séquences ol–cpx et les séquences ol–cpx à être suivies par des séquences ol–plag. Une telle relation peut se rattacher aux processus impliquant une nouvelle fusion des produits de cristallisation de basse température dans un système ouvert aux additions soit continues soit périodiques de liquide basaltique à haute température. En termes de structures océaniques, l'ophiolite de Bay of Islands correspond au modèle de bouée sonore no 2 de Christensen et Salisbury: la couche basale à haute vitesse correspondant aux roches accumulées de gabbro à olivine et la couche "gabbroïque" à faible vitesse, à la partie supérieure de la séquence cumulative sans olivine, au gabbro ouralitisé massif susjacent et aux dykes.

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Introduction

The Bay of Islands ophiolitic complex of Newfoundland (Fig. 1) is the largest and best preserved example of Paleozoic oceanic lithosphere in the Appalachian system (Church and Stevens 1971). It forms the uppermost structural unit of the Humber Arm allochthon and is therefore, according to Stevens (1970) probably the most easterly or 'oceanward' derived of the various tectonic slices of the allochthon. The chemical characteristics of the basaltic rocks of the complex are similar to those of present-day oceanic basalts; of all the ophiolites of the Appalachian system, the Bay of Islands complex is the most likely to represent oceanic lithosphere of the Proto-Atlantic ocean. In this paper, we draw attention to certain features of the cumulate sequences of the Bay of Islands complex that appear to bear on the genesis of oceanic crust and the tectonic significance of ophiolites. Specifically, we attempt to make three points: (*1*) the fractionation range of the cumulate rocks of the Bay of Islands complex encompasses entirely the compositional range of the overlying dike and lava units; thus attempts to define fractionation trends in ophiolites by combining plots of compositional variation in both cumulate (ultramafic and gabbroic) and non-cumulate (massive gabbro, dikes, and lavas) rocks on an AFM diagram may lead to erroneous conclusions concerning the genetic relationship of these rocks in ophiolites; (*2*) the cumulate sequences are both polycyclic and polygenetic, and would therefore appear to have formed by fractional crystallization in an *open system* magma chamber; and (*3*) previously noted differences in composition between the basaltic dike and flow rocks of the Bay of Islands complex and those of the Betts Cove and Thetford ophiolites of the more internal zones of the Appalachians (Church and Coish 1976; Church 1977) are reflected in the nature of the cumulate sequences, hence the cumulate variations may serve as a useful basis for the classification of ophiolites.

Fractionation Trends in the Bay of Islands Ophiolite

Most of the gabbroic component of the Bay of Islands ophiolite is of cumulate origin. The bulk composition of the gabbros cannot therefore directly represent the composition of the liquids from which they crystallized. Certain features of the composition of the liquids can (however) be calculated from the composition of the cumulus phases and known values of solid–liquid partition coefficients. The FeO^+/MgO weight ratio of olivines in the ultramafic and gabbroic cumulates of the Bay of Islands ophiolite ranges from 0.16 to 0.73, and the FeO^+/MgO weight ratio of the clinopyroxenes from 0.14 to 0.51 (Fig. 1); thus the FeO/MgO weight ratio of the liquids from which the cumulate phases crystallized is indicated to range from 0.53 to 2.54 (Fig. 2). In comparison the FeO^+/MgO ratios of the pillow lavas and dikes from the Bay of Islands ranges from 0.55 to 1.8. (FeO^+ = total iron) (Strong and Malpas 1975; R. A. Coish, personal communication, 1976). The fractionation range of the cumulate sequence encompasses entirely, therefore, the spread of values exhibited by the dikes and pillow lavas (Fig. 2). The compositional fields of pillow lavas and dikes plotted on AFM diagrams show only a limited overlap with those of ultramafic and gabbroic cumulates not because the pillow lavas and dikes are more differentiated than the plutonic rocks but because the latter consist largely of minerals whose FeO/MgO ratios are lower than the FeO/MgO ratios of the liquids from which they crystallized. (Exceptionally, however, gabbroic rocks that form during the late stages of fractionation of tholeiitic magma—and which may therefore contain abundant cumulus or intercumulus magnetite—may have FeO^+/MgO ratios equal to or greater than the parental liquids from which they crystallized.) Accordingly, the suggestion by Strong and Malpas (1975) based on AFM compositional plots, that ophiolitic lavas are erupted only after cooling and differentiation of the magma chambers, is debateable. It seems unlikely that dike injection and lava eruption take place only during the ultimate stages of fractionation after formation of the cumulate sequences. Most dikes and lavas of the Bay of Islands complex tend to have FeO/MgO ratios (estimated on the basis of Fe_2O_3 = 1.5 wt.%) between 0.8 and 1.5 (Strong and Malpas 1975; R. A. Coish, personal communication, 1976) a range of values that falls within the range of the liquids which gave rise to the troctolite, anorthosite, olivine–gabbro cumulates of unit 5 of the Bay of Islands ophiolite (Fig. 3) that is, liquids that crystallized olivine in the range Fo_{87}–Fo_{80}. However, some of the dike rocks with FeO/MgO ratios in this range have relatively low An/cpx normative

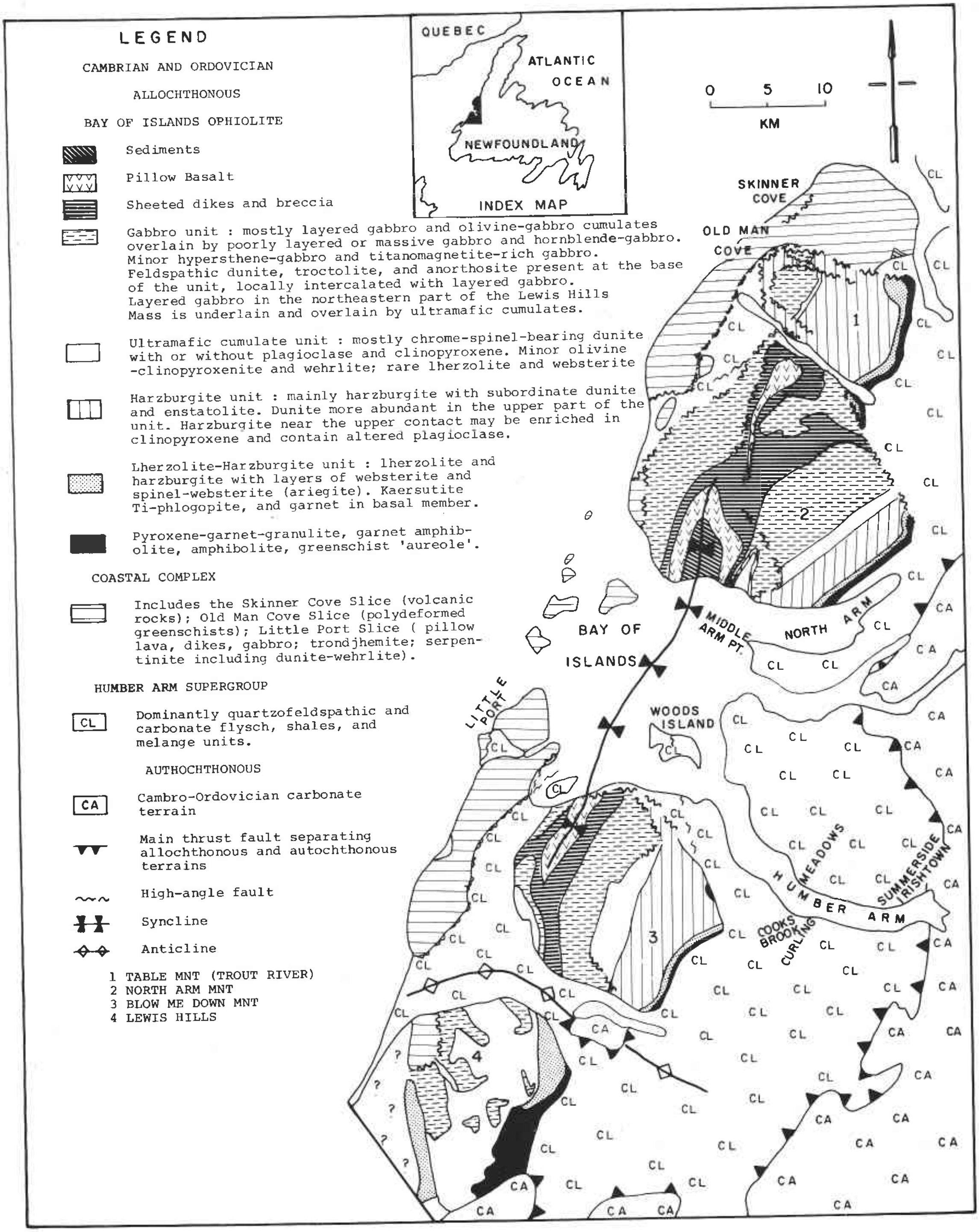

FIG. 1. Geology of the Bay of Islands region.

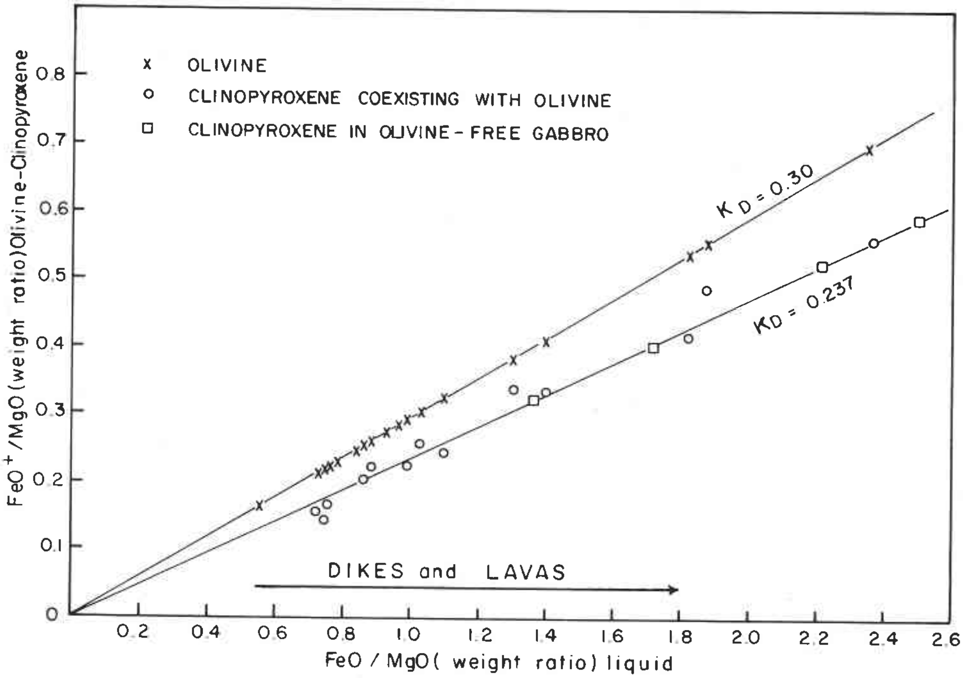

FIG. 2. Diagram illustrating the range in FeO/MgO weight ratios of the liquids that gave rise to the olivine and clinopyroxene-bearing ultramafic and gabbroic rocks of the Bay of Islands ophiolite, compared with the range of FeO$^+$ (total iron)/MgO ratios exhibited by the overlying dikes and pillow lavas. Note: (*1*) the FeO/MgO ratios of the liquids were calculated assuming a K_D coefficient of 0.3 for olivine–liquid (Roeder and Emslie 1970); (*2*) the K_D value (FeO$^+$/MgO cpx : FeO/MgO liquid) of 0.24 for clinopyroxene–liquid is estimated using the FeO/MgO ratio of the liquids calculated from the composition of coexisting olivine; (*3*) the ferric-iron content of the olivines is assumed to be very low since the ferric-iron content of coexisting spinel phases is also very low (Riccio 1976); (*4*) the ratio of iron to magnesium in the dikes and lavas is given as FeO (total iron)/MgO because the initial oxidation state is not known; the FeO/MgO values of the dikes and lavas are therefore maximum values. (Data from Strong and Malpas 1975; Riccio 1976; R. A. Coish, personal communication, 1976).

ratios (Duke and Hutchinson 1974; Williams and Malpas 1972) and may therefore have crystallized from the same kind of basaltic magma as that which gave rise to the olivine–clinopyroxene–orthopyroxene cumulate sequence of unit 4 of the Bay of Islands ophiolite (Fig. 3). The extent to which frequency of dike injection varied during the evolution of the Bay of Islands magma chamber is not determinable with the currently available data. However, liquids which gave rise to the most magnesian (Fo_{90-91}) cumulates of unit 4 of the cumulate sequence seem to be poorly represented in the overlying dike and lava units. (This is in contrast to the Betts Cove ophiolite; see Church and Coish 1976.) The cumulate minerals of the lower ultramafic sequence may therefore have been introduced into the magma chamber in suspension, and settled out relatively near to the ridge axis (Church and Riccio 1974). Alternatively, given that the liquids from which the cumulates of unit 4 formed were the earliest introduced into the magma chamber, it is also possible that their presence in the dike unit has been obscured by the intrusion of the later dikes.

'Open' *Versus* 'Closed' System Fractionation

A thorough petrogenetic study of the plutonic component of the Bay of Islands ophiolite would require detailed examination of many dozens of cross sections through the ophiolite and many years of intensive analytical work. We can hardly pretend therefore to have more than scratched, both literally and metaphorically, the surface of this massive complex. Nevertheless, the data available are sufficient to demonstrate that the crystallization of the plutonic rocks of the Bay of Islands complex most likely took

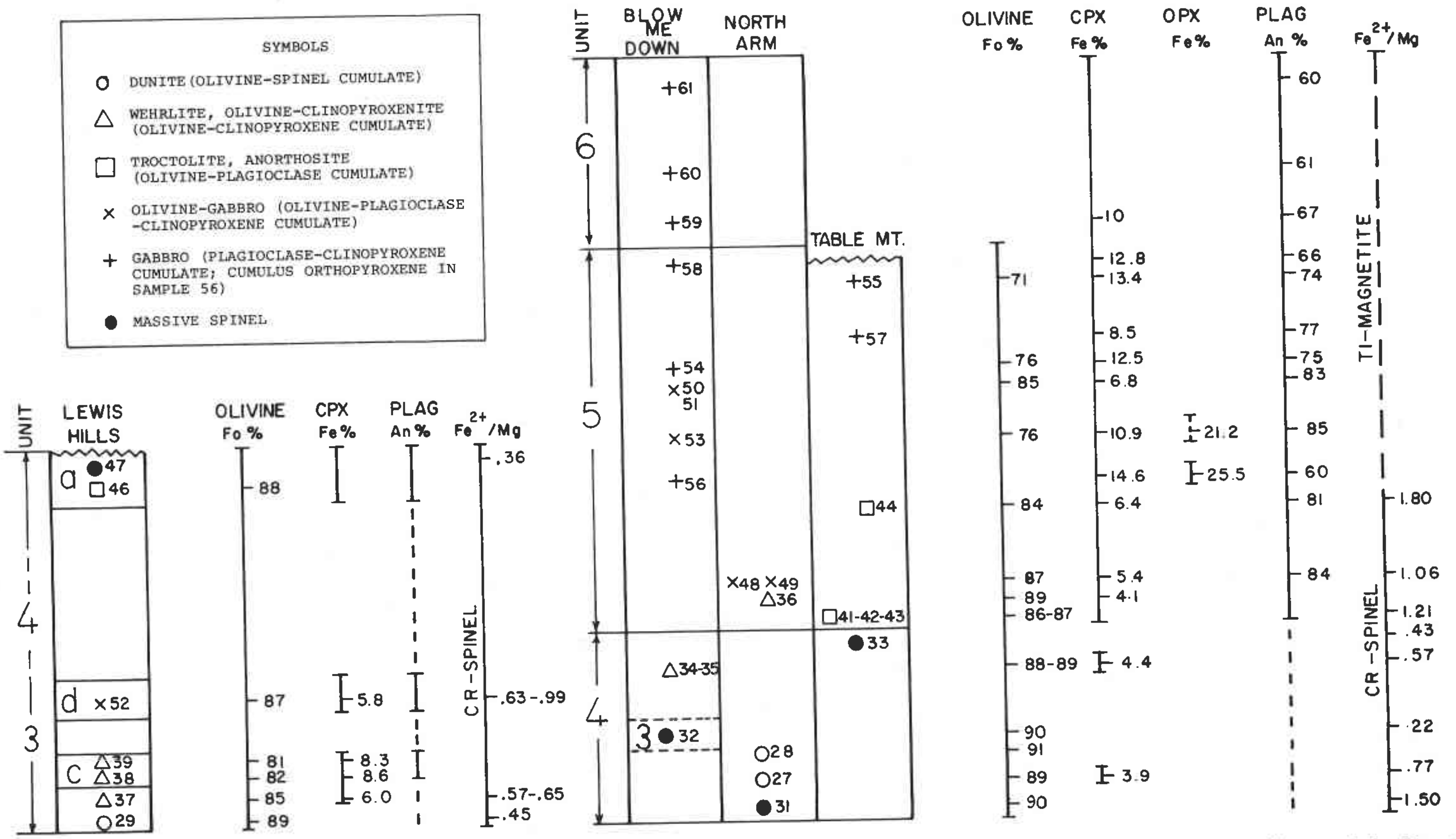

FIG. 3. Compositional variation of olivine, clinopyroxene, orthopyroxene, plagioclase, and spinel within the various cumulate assemblages of the Bay of Islands ophiolite. Broken lines refer to intercumulus minerals. Unit 4 is largely composed of cumulate rocks formed according to the crystallization sequence olivine–clinopyroxene–orthopyroxene–plagioclase; unit 5 is composed of cumulate rocks crystallized in the order olivine–plagioclase–clinopyroxene–orthopyroxene; and unit 6 is made up of massive fine-grained to pegmatoid, uralitized gabbro which may form the roof zone of the plutonic sequence. The Lewis Hills cumulate rocks of unit 3 crystallized in the order olivine–clinopyroxene–plagioclase, a sequence possibly matched elsewhere in the Bay of Islands only in certain spinel layers in the lower part of the Blow Me Down section. Note: (*1*) numbers next to lithologic symbols are sample numbers (Riccio 1976); (*2*) Fo% = percent forsterite in olivine; (*3*) An% = percent anorthite; (*4*) Fe% = 100 Fe/Fe + Mg + Ca (atomic); (*5*) Fe^{2+}/Mg = atomic ratio of ferrous iron to magnesium.

place in an 'open system' magma chamber that received fresh batches of high temperature magma on a continuous or semi-continuous basis.

Cryptic Variation

Although there is a general trend towards increased fractionation with stratigraphic height within the cumulate sequences of the Bay of Islands (Fig. 3) the trends are irregular and, as noted by Irvine and Findlay (1972) are commonly inverse. In the Blow Me Down section the most differentiated cumulate rocks, with clinopyroxenes containing 9 wt.% FeO^+ (14.5 cation percent Fe in Ca–Mg–Fe) occur less than 1 km above the ultramafic cumulate – gabbro cumulate contact, whereas more primitive cumulates containing olivine of composition Fo_{85} and clinopyroxenes with only 4.24 wt.% FeO^+ occur at stratigraphically higher levels. Moreover the range of FeO^+/MgO values exhibited by the cumulates of the Bay of Islands overlaps only the lowermost part of the range of the rocks of the Skaergaard intrusion. In both these respects the Bay of Islands layered sequence would seem to represent an 'open' system of the Rhum type rather than a 'closed' system of the Skaergaard type (Wager and Brown 1968). The overall stratigraphy and cryptic layering in the cumulate sequences of the Bay of Islands ophiolite closely resembles that of the Cuillin intrusion (Wager and Brown 1968, Fig. 224) as well as that of the more mafic portion of the Kap Edvard Holm intrusion (Deer and Abbot 1965). In these three bodies, Ca-poor pyroxene is rarely found as a cumulus phase, and crystallization of iron-ore minerals begins immediately after cessation of crystallization of Cr-spinel. In contrast, the Bushveld and Skaergaard complexes contain abundant cumulus orthopyroxene, and magnetite appears as a cumulus phase much later than the cessation of the crystallization of Cr-spinel.

Variation in Magma Type

Cumulus minerals in the Bay of Islands plutonic units were deposited in this order: (*1*) olivine (spinel)–clinopyroxene–(orthopyroxene); and (*2*) olivine (spinel)–plagioclase–clinopyroxene–(orthopyroxene). Orthopyroxene, although rare, has been observed towards the top of the dunite–wehrlite unit and occasionally as rare large cumulus grains in olivine-free gabbro of the upper part of the gabbro sequence.

Such variations in type of mineral association suggest that the magma that gave rise to the Bay of Islands cumulate sequence must have changed composition with time in a manner more radical than can be accounted for by simple fractionation in a closed system. Also, there are indications that lateral facies variations are represented even within the lower ultramafic cumulate sequence. In the Lewis Hills region of the Bay of Islands, clinopyroxenes and spinels in wehrlites of the dunite–wehrlite cumulate sequence are much richer in Al_2O_3 (cpx — 5–6 wt.%; sp — 41–53 wt.%) than those in wehrlites of the North Arm, Table Mountain, or the upper part of the Blow Me Down regions (cpx — 2.5–4 wt.%; sp — 6–30 wt.%). The olivines in wehrlites of the Lewis Hills cumulates are also richer in iron (ranging in composition from Fo_{89} to Fo_{81}) than olivines in wehrlites of the North Arm, Table Mountain, and Blow Me Down regions (usually not less than Fo_{88}, Fig. 2). Cumulates of the Lewis Hills type also appear to be represented in the lower part of the Blow Me Down cumulate section where spinels forming massive layers within dunite contain 66 wt.% Al_2O_3 (Riccio 1976). If the lower part of the Blow Me Down section is correlative with the Lewis Hills sequence, the cumulate sequences may be transgressive from southwest to northeast with the Lewis Hills cumulates representing the oldest rocks formed in the Bay of Islands magma chamber. Berger *et al.* (1975) have suggested that the Lewis Hills wehrlite and gabbro units represent *in situ* partial melts trapped within upper mantle material. This interpretation seems unlikely however, in view of the evolved nature of the mineral phases.[1] The considerable variation in composition of the basaltic magma that gave

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[1] We would not rule out the possibility that some dunite units within the lower part of the ultramafic cumulate sequences represent tectonically intercalated mantle rocks. We have observed mantle-type harzburgite units within the cumulate dunite unit at North Arm; tectonite harzburgite wedges are known to occur within feldspathic-dunite sequences in the Kizil Dag ophiolite of Turkey (Parrot 1973). We note also that it is difficult to decide in the field whether deformed feldspar-free dunite is of mantle or cumulate origin. The identification of the mantle–cumulate boundary is also rendered difficult by the presence of harzburgites in the upper part of the mantle sequence containing clinopyroxene and plagioclase. Although such rocks in the Troodos complex are considered by Menzies and Allen (1974) to represent partial melt products of mantle lherzolite, the chemistry of the rocks in the Bay of Islands complex (Riccio 1976) suggests that they are of injection or metasomatic origin.

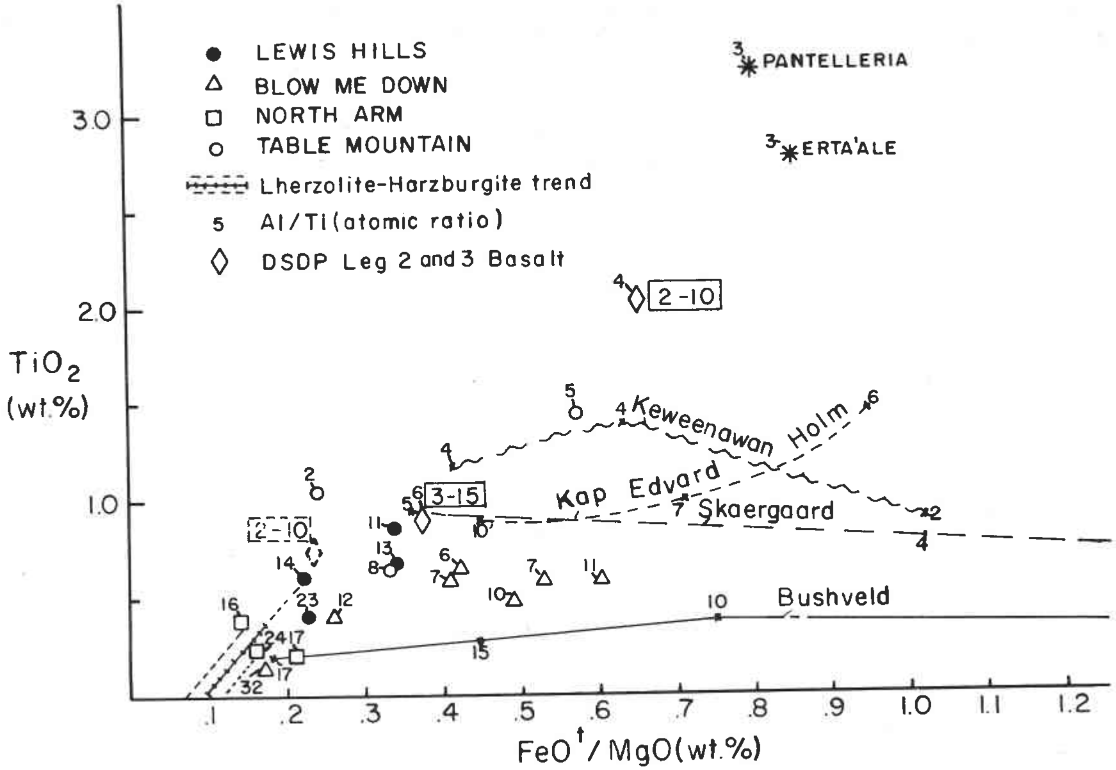

FIG. 4. Variation in TiO_2 versus FeO^{+}/MgO of clinopyroxenes from the cumulate sequence of the Bay of Islands ophiolite in comparison with pyroxenes from the Bushveld (Atkins 1969) Skaergaard (Brown 1957) and Kap Edvard Holm (Deer and Abbot 1965) layered intrusions, and the Keweenawan (Church, unpublished data) Pantelleria (Bryan 1969) and Erta'Ala (Barberi *et al.* 1971) continental basaltic series. The trend of variation in clinopyroxenes of the lherzolite–harzburgite sequence is based on data from the lherzolite–harzburgite unit of the Bay of Islands and Hare Bay ophiolites of Newfoundland (Riccio 1976). The composition represented by the broken diamond symbol is the estimated composition of the liquidus clinopyroxene in DSDP basalt 2–10 (Frey *et al.* 1974) assuming K_D (Ti) clinopyroxene–liquid has an approximate value of 0.5.

rise to the Bay of Islands cumulates is also clearly reflected in the composition of the cumulus clinopyroxenes. For example, the TiO_2 content of the clinopyroxenes ranges from less than 0.5 wt.% to more than 1.0 wt.% at $FeO^{+}/MgO = 0.25$ (wt. ratio) (Fig. 4) and there are no clearly discernable trends either in titanium content or Al/Ti ratio.

Major changes in the nature of cumulate assemblages with stratigraphic position in ophiolitic plutonic assemblages are also found in many other ophiolites (Table 1). In most of the ophiolite cumulate sequences cumulus minerals are deposited according to the following crystallization orders: (*A*) ol (chrom)–opx–cpx–(plag); (*B*) ol (chrom)–cpx–plag–(opx); (*C*) ol (chrom–cpx–opx–(plag); (*D*) ol (chrom)–plag–cpx–(opx).

Where more than one crystallization sequence is represented in the ophiolite, the sequences tend to form sets composed of (*A* + *B*), (*B* + *C*) or (*C* + *D*). On this basis ophiolites can be classified as Papuan – Betts Cove type (*A* + *B*) Vourinos type (*B* + *C*), or Pindos – Bay of Islands type (*C* + *D*) (Table 1). The reasons for such variations are poorly understood but must in part reflect the degree of partial melting in the source region from which the liquids were derived, the nature of the mantle material undergoing melting, and possibly the open-system nature of the crystallization process, involving, perhaps, the re-melting of mineral phases such as plagioclase, crystallized at lower temperature levels within the magma chamber, as they sank into the hotter reaches of the magma pool, or were circulated by convection currents. (Both

TABLE 1. Crystallization sequences *interpreted* to occur in cumulate units of various Mesozoic and Paleozoic ophiolites. Data from: Davies 1969 (Papua); Riccio 1972 (Betts Cove); Riccio 1976 (Lewis Hills, Bay of Islands); Church 1976 (Thetford); Mesorian 1973 (Antalaya); Jackson *et al.* 1975 (Vourinos); Greenbaum 1972 (Troodos); Parrot 1973 (Hatay); Terry 1974 (Pindos); Ohnenstetter, M. *et al.* 1975; Ohnenstetter, D. *et al.* 1975 (Inzecca)

Class	A	A*	B	C	D
Type sequence					
Mesozoic	Papua	(Inzecca)?	Vourinos	Troodos	Pindos
Paleozoic	Betts Cove		Lewis Hills		Bay of Islands
Order of crystallization	ol-opx-cpx-plag	ol-opx-plag-cpx	ol-cpx-plag-opx	ol-cpx-opx-plag	ol-plag-cpx-opx
Cyclic sequence	(4) opx-cpx-plag (3) opx-cpx (2) opx (1) ol-(chr)	(4) opx-plag-cpx (3) opx-plag (2) opx (1) ol-(chr)	(4) cpx-plag-opx (3) ol-cpx-plag (2) ol-cpx (1) ol-(chr)	(4) cpx-opx-plag (3) cpx-opx (2) ol-cpx (1) ol-(chr)	(4) plag-cpx-opx (3) ol-plag-cpx (2) ol-plag (1) ol-(chr)
Ophiolites:					
Papua	A1, A2, A3, A4				
Betts Cove	A1, A2, A3				
Thetford	A1, A2, A3				
Inzecca	A1, A2, A3	(A*1, A*2)?			D1, D2, D3
Lewis Hills			B1, B2, B3		D1, D2, D3
Vourinos			B1, B2, B4	C3, C4	
Troodos				C1, C2, C3, C4	
Hatay				C1, C2, C3, C4	
Antalaya				C1, C2, C3, C4	
Pindos				C1, C2, C3	D1, D2, D3
Bay of Islands				C1, C2, C3	D1, D2, D3, D4

planar and lineate lamination is well developed in the well layered cumulate sequences of the Bay of Islands ophiolite.)

Conclusions

We have tried to show that (*1*) in terms of FeO/MgO ratios the fractionation range of the liquids that gave rise to the cumulate rocks of the Bay of Islands ophiolite is comparable to that exhibited by the overlying dike and pillow lava units; and (*2*) the plutonic rocks are likely to have crystallized in an *open system* magma chamber. It seems improbable therefore that the formation of ophiolite plutonic sequences like that of the Bay of Islands takes place within small ocean rift magma chambers during periods of non-spreading such that the lavas are erupted only after cooling and differentiation of the magma chambers (Strong and Malpas 1975). The complexity of the variation exhibited by the cumulate sequences in ophiolites can only be explained in terms of a dynamic model involving differential rates of spreading and influx of magma. Where the rate of introduction of melt into the magma chamber exceeds the rate of spreading, the volume of the magma chamber would tend to increase, causing the distal part of the wedge-shaped magma chamber to migrate laterally away from the rift. These circumstances may be reflected by the presence in the distal parts of the chamber of unconformable sheets of gabbro injected into previously crystallized cumulate rocks, as is perhaps represented by the gabbro unit unconformably overlying the cumulate ultramafic rocks of the Betts Cove ophiolite (Church and Riccio 1974). Inasmuch as there is likely to be a correlation between rate of spreading and degree of partial melting in the mantle source regions of the ophiolite basaltic rocks, the presence in the Betts Cove complex of orthopyroxene as a common cumulus mineral within the ultramafic sequence, and of highly magnesian, low titanium basalts within the dike and pillow lava units (Church and Coish 1976) indicates that the Betts Cove ophiolite formed under conditions of high rates of spreading. In contrast, the Bay of Islands plutonic rocks may have crystallized during a cycle of decreasing rate of spreading and magma injection, and of magma injection relative to spreading. (This interpretation is corroborated by the contrasted nature of the cumulates in the Bay of Islands and Betts Cove ophiolites (Piccardo and Riccio 1975) in that the cumulate of the Bay of Islands ophiolite are predominantly adcumulates whereas those at Betts Cove contain abundant intercumulus material.) A later return to conditions of faster spreading and magma injection in the Bay of Islands ophiolite is possibly reflected by the presence of sheets of leucogabbro injected along the interface of the ultramafic and gabbroic units. The upper massive pegmatoid gabbro unit, although in part composed of recrystallized cumulate rocks, may also represent laterally injected gabbroic liquid emplaced between or within the roof gabbro – dolerite and the cumulate gabbro units.

Christensen and Salisbury (1975) have recently pointed out that the anomolous geophysical features characteristic of mid-ocean rift zones persist for large distances in directions normal to the rifts, and that there is a commensurate tendency for gabbroic layer 3 to thicken in the same direction. Christensen and Salisbury suggest that the thickening of the gabbroic layer is accomplished by repeated injection of small bodies of magma into the already crystalline 'gabbroic' layer, this magma having been derived by segregation of melt from the underlying partially molten anomalous mantle. However, in the mantle and cumulate units of ophiolites, injection sheets, dikes, and veins appear invariably to be propagated laterally or downwards rather than upwards (Kacira 1972; Riccio 1972; Alleman and Peters 1972; Parrot 1973; Mesorian 1973). Although in general, therefore, the two layer seismic structure of oceanic crust layer 3 (sonobouy model 2 of Christensen and Salisbury 1975) is likely to reflect the tendency of olivine gabbros to be located in the lower part, and of olivine-free gabbros, leucogabbros, fine-grained to pegmatoid metagabbro, trondjhemites, and dike rocks in its upper part, it is improbable that seismic experiments are capable of delineating in detail the actual structural and lithologic complexity of oceanic crust of the type found in most ophiolites. Christensen and Salisbury (1975) have pointed out that ultramafic cumulates with intercumulus plagioclase will be indistinguishable seismically from upper mantle harzburgite, and that the high veolocity basal layer of oceanic crust layer 3 cannot be represented by unaltered ultramafic cumulates such as are found in ophiolites. It would seem rather that the Mohorovicic Discontinuity must reflect either the incoming of plagioclase as a major cumulus phase in the cumulate sequence, or less likely, a level within the ultramafic cumulate sequence demarcating the high temperature breakdown of orthopyroxene to talc and olivine. While there is little reason to doubt that cumulate sequences of ophiolites formed in magma chambers located beneath mid-ocean ridges (*cf.* Rosendahl 1976) the tectonic significance of the considerable variation in lithology, geochemistry, and morphology of ophiolites remains to be resolved. In this respect the heterogeneity displayed by the ophiolite complexes of the Appalachian orogen (Church 1977) should caution us to treat with circumspection plate tectonic rationalizations that lean heavily on specific tectonic interpretations of Appalachian ophiolite complexes.

Acknowledgements

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