$^{40}Ar/^{39}Ar$ Ages for the St. Anthony Complex Dynamothermal Aureole, Northwestern Newfoundland

by

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ABSTRACT

A study of $^{40}Ar/^{39}Ar$ age relationships of various structural levels of the St. Anthony Complex dynamothermal aureole was undertaken. Units of the aureole dated include a small jacupirangite suite metamorphosed with the base of the peridotite, the Long Ridge Metagabbro below the peridotite contact and the Green Ridge Amphibolite structurally below the metagabbro and furthest from the peridotite contact.

Only the jacupirangite suite gives a geologically reasonable age of 495 $\pm$ 6 Ma. Excess argon effects and low potassium contents of the Long Ridge Metagabbro and the Green Ridge Amphibolite preclude a geologically consistent interpretation of their apparent ages (450 $\pm$ 10 Ma and 900 Ma respectively).

A date of 495 Ma is a minimum age for the formation of the dynamothermal aureole. It is, at least, 5 Ma older than Dallmeyer's (1977) $^{40}Ar/^{39}Ar$ ages (480 $\pm$ 10) for amphibolites lower in the aureole. An age discrepancy between the top of the aureole and lower structural levels may be implied. Such a pattern is also recognized in the Bay of Islands and Samail ophiolites.

An emplacement model to account for an age difference suggests that successively shallower crustal rocks were accreted onto the base of an overriding peridotite tectonite. The progressive displacement of the zone of the shear heating to the base of each new slab allowed the cooling of structurally higher and earlier incorporated units. A previously hot peridotite is therefore not necessary

INTRODUCTION

Since ophiolites are now generally believed to be tectonically emplaced fragments of oceanic crust (eg. Coleman, 1977), the significance of high grade metamorphic aureoles associated with some of them is being reconsidered.

Specifically, ophiolite metamorphic aureoles display a combination of dynamic and thermal metamorphic effects and have thus been labelled dynamothermal aureoles (Malpas et al, 1973; Karamata, 1974). These aureoles are invariably developed at the base of the ophiolite sequence. They are structurally overlain by ultramafic rocks and underlain by volcanic and sedimentary units. A reversed metamorphic grade is characteristic, grading from upper amphibolite facies quickly downward into greenschists and unaltered rocks (Williams and Smyth, 1973; Coleman, 1977; Jamieson, 1980).

The origin of dynamothermal aureoles has been variously attributed to:

i) frictional heating during overthrusting associated with ophiolite obduction (Malpas et al, 1973; Woodcock and Robertson, 1977).

ii) Conduction of heat from a still hot mantle peridotite into rocks caught up with the moving ophiolite (Church, 1972; Williams and Smyth, 1973; Malpas et al, 1973).

iii) A combination of frictional and conductive heating during the juxtaposition of progressively shallower units during the emplacement episode (Jamieson, 1979).

iv) The accretion of previously amphibolitized ocean floor rocks onto the base of the ophiolite (Coleman *et al*, 1976; Karamata, 1974).

The understanding of relative age relationships between the ophiolite and the underlying aureole is of particular importance in resolving the mechanism by which ophiolites may have been emplaced. $^{40}Ar/^{39}/Ar$ dating of the Bay of Islands metamorphic aureole by Dallmeyer (1975) gave ages of 477 ± 10 Ma and 468 ± 10 Ma for the base of the peridotite and the underlying metamorphic aureole respectively. $^{40}Ar/^{39}Ar$ dating of the Samail ophiolite by Lanphere (1980) revealed a similar pattern, with an older age for the base of the peridotite (90.0 ± 3.0 Ma) than the underlying metamorphic aureole (79.5 ± 3.0 Ma).

It is the object of this thesis to date successively lower slices of the St. Anthony Complex metamorphic aureole in an attempt to determine whether a similar pattern of age discrepancy between ophiolite and aureole can be recognized. The relationship between the peridotite-aureole age and ophiolite emplacement mechanisms will also be speculated on.

Three units were dated by $^{40}Ar/^{39}Ar$ techniques. They include a jacupirangite unit deformed and metamorphosed with the base of the ophiolite, the Long Ridge Metagabbro representing the upper part of the dynamothermal aureole, and the Green Ridge Amphibolite structurally below the metagabbro and further away from the peridotite contact.

REGIONAL GEOLOGY

Ophiolitic rocks of the St. Anthony Complex comprise the structurally highest transported unit of the Hare Bay Allochthon. The Hare Bay Allochthon overlies autochthonous miogeosynclinal and eugeosynclinal successions of the Lower Paleozoic eastern margin of North America (Figure 1). Placed in the Humber Zone of Williams' (1978) interpretation of the Appalachian Orogen,these rocks display the effects of the Taconic Orogeny in Newfoundland. They also mark the western limit of Appalachian deformation.

Development of the stable eastern shelf platform of North America ceased at the Cambro-Ordovician boundary (Klappa, et al, 1980) in response to the closure of the Iapetus Ocean (Williams, 1975) (Figure 2). This break in continental development is signified by the deposition of deep-water limestones (Table Head fm) and eastern derived flysch containing ophiolite debris (Goose Tickel fm). This clastic flysch unit contains Llanvirnian to Arenigian fossils (Tuke, 1968). Allochthon movement must therefore have commenced at least by Arenig time. The age of final emplacement of the St. Anthony Complex is less well defined. However, the Humber Arm Allochthon to the south is overlain by neoautochthonous sedimentary rocks of Llandeilian age (Long Point fm). This implies emplacement was complete by the latest Middle-Ordovician.

Ophiolite obduction is believed to have been initiated in response to an island-arc collision with North America

Fig. 1 Regional Geology of Western Newfoundland

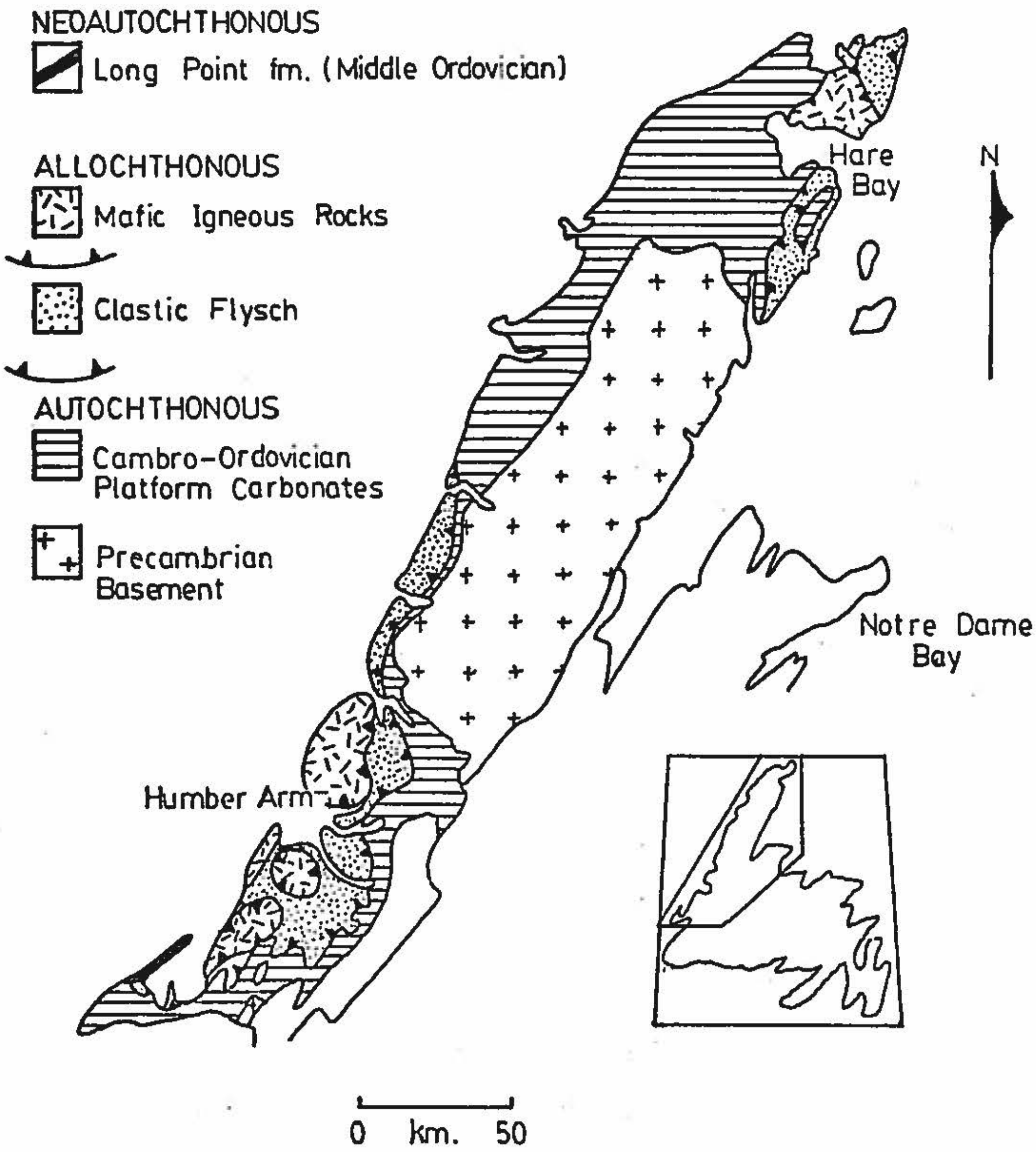
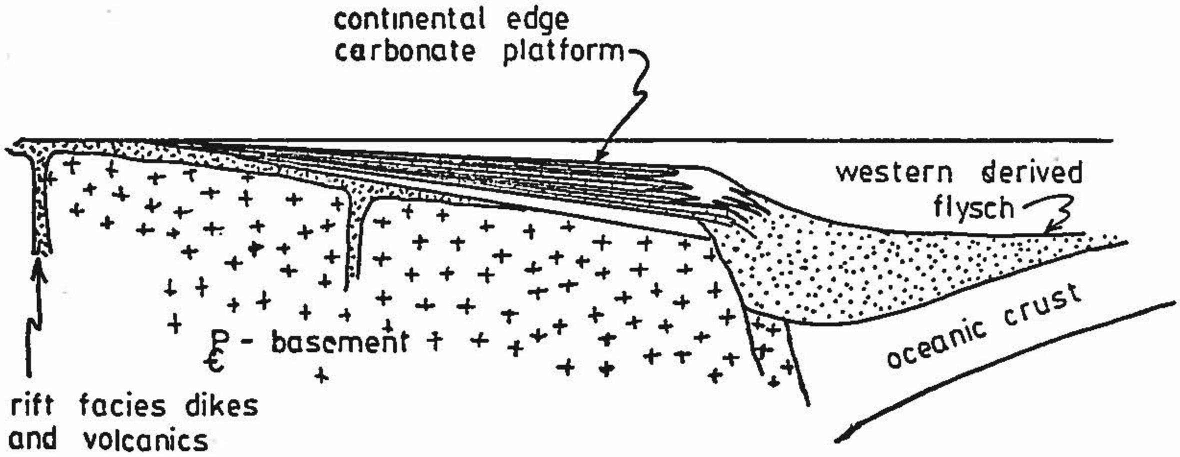
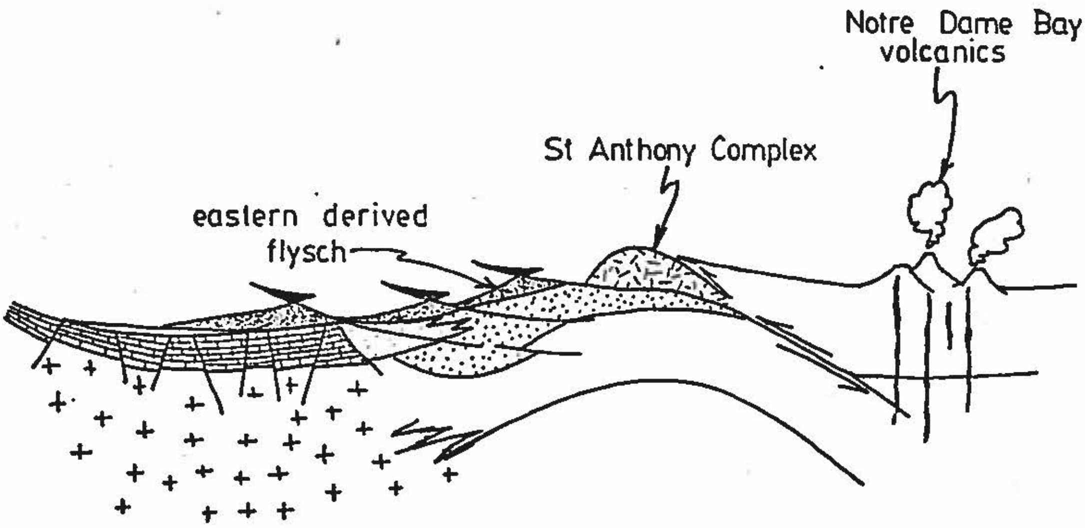


Fig. 2 Generalized stratigraphic and tectonic evolution of western Newfoundland.

PRE – ARENIG



LATE – ARENIG



(Church and Stevens, 1971; Malpas and Strong, 1975; Williams, 1975). The Bay of Islands and St. Anthony Complexes are the remnants of this episode of ocean closure and ophiolite obduction, generally regarded as the Taconic event.

THE ST. ANTHONY COMPLEX

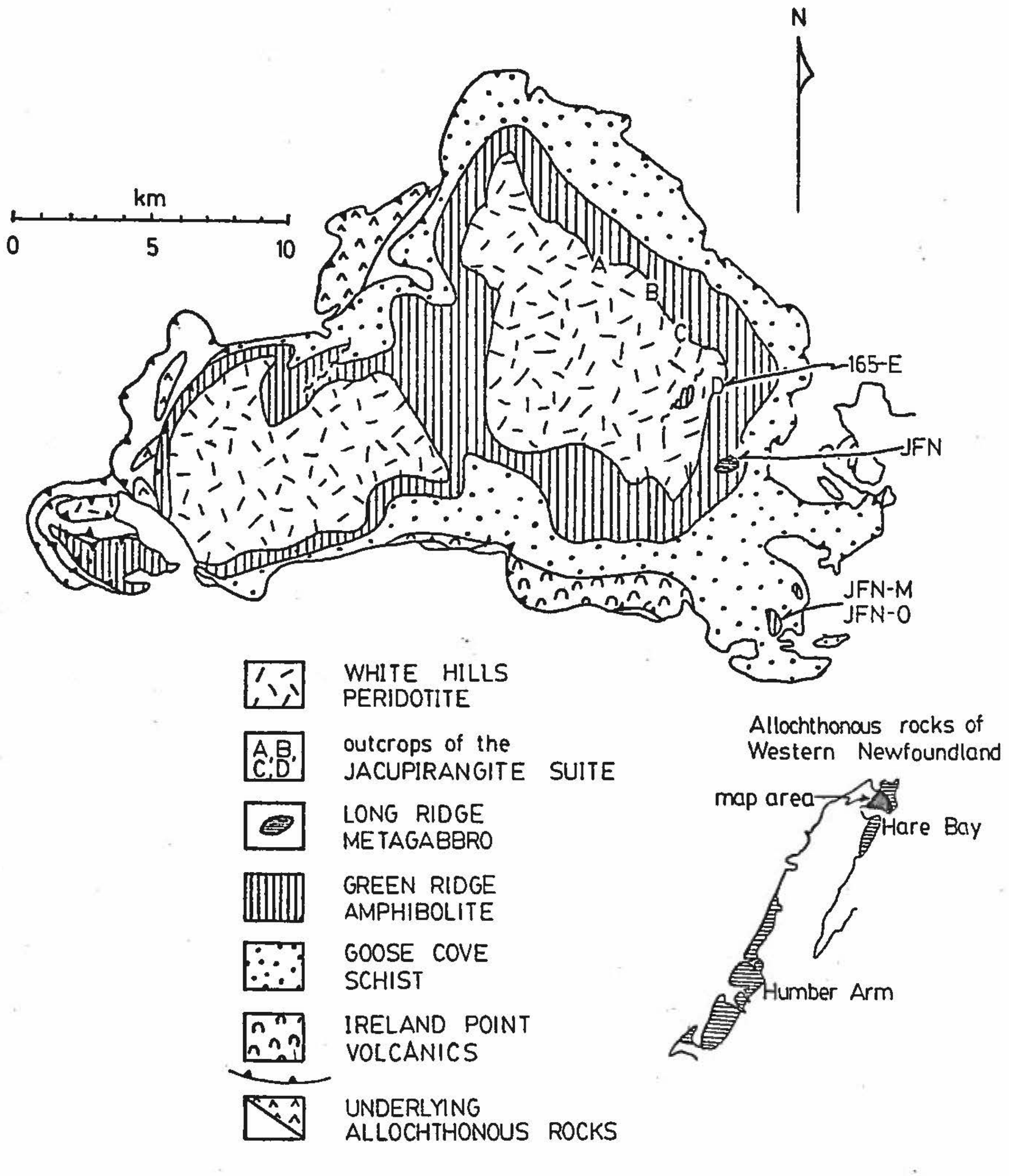
The St. Anthony Complex of northwestern Newfoundland forms the uppermost tectonic slice of the Hare Bay Allochthon. Papers by Tuke (1968) and Williams (1975) outline in detail the geology of the allochthon.

A detailed description of the St. Anthony Complex is given by Jamieson (1979). A peridotite tectonite and an underlying dynamothermal aureole comprise the complex. Five distinct lithological units are recognized. These are, from top to bottom, the White Hills Peridotite, the Long Ridge Metagabbro, the Green Ridge Amphibolite, the Goose Cove Schist and the Ireland Point Volcanics (Figure 3). Elevated topography of the White Hills Peridotite unit creates a concentric outcrop pattern of lower units around upper units.

The White Hills Peridotite: The White Hills Peridotite is the structural and topographically highest unit of the St. Anthony Complex. It rises in two discrete massifs separated by a glacial valley within which amphibolites of the underlying metamorphic aureole outcrop.

The White Hills Peridotite is dominated by porphyroclastic harzburgites with large porphyroclasts of enstatite. Chromite-olivine dunites, lherzolites and diopside - enstatite pyroxenites

Fig. 3 ST ANTHONY COMPLEX (with $^{40}Ar/^{39}Ar$ sample locations)



occur to a lesser degree. Serpentinization is localized along fault zones and within the basal shear zone.

The lower 50 metres of the peridotite is characterized by an ultramafic mylonite zone. Isoclinal folds with flat lying axial planes and a subhorizontal foliation are extensively developed. Sheets of brown amphibole (pargasite) occur in the plane of the foliation. Geochemical data suggest the basal mylonites were originally lherzolites. The localization of the pargasite to the mylonites and the base of the ophiolite suggests a syntectonic origin.

A narrow ten metre zone of jacupirangite, hornblende gneiss and syenitic mylonite outcrops intermittently along the structural base of the White Hills Peridotite. The jacupirangite is relatively unaltered and comprises titanaugite, titaniferous biotite, titanian amphibole (Kaersutite)ilmenite and apatite (Jamieson and Talkington, 1980). In contrast to the strongly foliated overlying peridotites, the jacupirangite lacks a tectonic fabric. Its contact with the peridotites is sharp, planar, and displays no evidence of being igneous (i.e., chilled margins, crosscutting dikes) (Jamieson and Talkington, 1980).

The jacupirangite grades downward into a hornblende gneiss. The change is signified by the increased replacement of titanaugite by kaersutite. A penetrative fabric which trends parallel to the base of the peridotite is also developed.

Syenitic mylonite comprises the base of the unit. It consists of roughly 75 percent sodic plagioclase. Granular augite, biotite, Fe-olivine and Ti-hornblende comprise the remainder of the zone. A well-developed horizontal foliation and a north-west - southeast trending mineral lineation are defined by the mafic minerals.

The origin of the unit is certainly an enigma. Jamieson and Talkington (1980) concluded that an alkaline ultrabasic liquid was generated in the upper mantle by partial melting in the presence of a CO_2 rich vapor phase. Subsequent accretion onto the base of the peridotite early in the ophiolites history resulted in the jacupirangites present structural position. It is particularly important to note that the hornblendes are the result of pyroxene recrystallization associated with peridotite emplacement (Jamieson and Talkington, 1980).

The Long Ridge Metagabbro: This unit, of limited areal extent, comprises variably deformed and metamorphosed gabbros. Minor coronitic troctolites, dunites and anorthosite lithologies are also recognized. Gabbroic rocks are pervasively amphibolitized, however; unlike rocks of the Green Ridge Amphibolite, coarse grained amphibole and a penetrative foliation are not developed. Ultrabasic rocks are generally completely serpentinized and are compositionally similar to ultrabasic rocks of the White Hills peridotite.

Deformation is highly inhomogenous within the unit, which ranges from undeformed to strongly sheared. At the western edge of the complex, intensely foliated metagabbro appears texturally and mineralogically similar to underlying plagioclase amphibolites.

The sequence of rocks represented by the Long Ridge Metagabbro is the same as that described by Malpas (1976) as typical of the "Critical Zone" of many ophiolite complexes. These rocks correspond to the "seismic Moho", and thus mark the transition from upper mantle to lower crust.

The Green Ridge Amphibolite: Up to 100 metres of medium to coarse grained plagioclase and quartz-amphibolite characterizes this unit. Immediately below the tectonic contact with the White Hills Peridotite, pyroxene amphibolites are prevelant.

Coarse compositional banding resulting from variations in the proportions of hornblende and plagioclase is common, but no partially melted rocks are seen (Jamieson, 1979). A strong subhorizontal foliation and a northwest trending lineation are invariably developed. A basal mylonite zone (biotite amphibolite) separates the Green Ridge Amphibolite from underlying rocks of the Goose Cove Schist.

Protoliths for the unit are basic igneous rocks. Some of the amphibolites may have originated from layered gabbros (Jamieson, 1979).

The Goose Cove Schist: The Goose Cove Schist includes polydeformed greenschist and epidote-amphibolite facies mafic pillow basalts, green tuffs and minor agglomerates. Interbedded greywackes, psammites and pyritic pelites are common near the base of the unit.

Primary volcanic and sedimentary features, and a gradational contact with the underlying unmetamorphosed Ireland Point Volcanics are preserved. This implies that the Goose Cove Schist was derived from the Ireland Point Volcanics and the Maiden Point Sandstones (Williams and Smyth, 1973; Jamieson, 1979).

The Ireland Point Volcanics: Approximately 1000 metres of relatively undeformed alkali pillow basalts, agglomerates, and pyroclastics comprise the Ireland Point Volcanics. The unit is bounded by the underlying Hare Bay thrust fault and by an upward gradation into greenschists of the Goose Cove Schist.

$^{40}Ar/^{39}Ar$ THEORY

The $^{40}Ar/^{39}Ar$ dating technique was first developed by Siguigeirson (1962). Detailed derivation of the $^{40}Ar/^{39}Ar$ dating equation and methods are described by Merrihue and Turner (1966) and Mitchell (1968).

The theory of the $^{40}Ar/^{39}Ar$ method is essentially similar to that of conventional $^{40}K/^{40}Ar$ dating. Both techniques depend on the assumption that a sample contained no argon at the time of its crystallization. In the case of hornblende, ^{40}Ar produced by the natural radioactive decay of ^{40}K diffuses out of the crystal at temperatures above 450-550 degrees C. Below this "blocking" temperature ^{40}Ar is retained within the crystal lattice. Using the known decay rate of ^{40}K to ^{40}Ar and the amount of ^{40}Ar and ^{40}K in the sample today, one can calculate the age of a specimen.

The $^{40}Ar/^{39}Ar$ method necessitates the conversion of ^{39}K (93.08% natural K) to ^{39}Ar by irradiation with fast neutrons within a nuclear reactor. In effect ^{39}Ar is a measure of the potassium within a sample. Subsequently the age of a sample can be calculated by the following equation.

1. $t = 1/\lambda \cdot \ln(1 + D/P)$ D = daughter isotopes (^{40}Ar)
   P = parent isotope today

Substituting:

2. $t = 1/\lambda \cdot \ln\left[1 + (^{40}Ar/^{39}Ar)J\right]$

J is a dimensionless parameter which is a function of the age of a mineral monitor (irradiated together with the unknowns) and the integrated fast neutron flux.

Specifically, by the equation:

$$3. \quad J = \frac{e^{\lambda tm} - 1}{(^{40}Ar/^{39}Ar)m}$$

where tm is the known age of the mineral monitor, and $(^{40}Ar/^{39}Ar)m$ is the measured ratio of radiogenic ^{40}Ar to ^{39}Ar in the mineral monitor. Therefore, using the monitor of known age, quantity J can easily be calculated and substituted into equation 2.

Correction factors for undesirable irradiation products must be employed. These reactions include the production of ^{40}Ar, ^{36}Ar and ^{39}Ar from ^{40}K, ^{40}Ca, and ^{42}Ca respectively.

Furthermore, ^{40}Ar measured in the samples must be corrected for atmospheric contamination (^{40} Ar atmos) by the equation:

$$4. \quad ^{40}Ar\ atmos = 295.5\ (^{36}Ar)total$$

SAMPLE LOCATION AND DESCRIPTION

Samples were collected from units within the metamorphic aureole to give a profile normal to the structural layering of the complex.

One large hornblende crystal (165-E) was collected from the hornblende gneiss of the jacupirangite suite (figure 3). This sample represents the top of the metamorphic aureole closest to the peridotite contact. Hornblende defines a sub-horizontal foliation which commonly wraps around relict augite augen (Jamieson and Talkington, 1980).

Sample JFN was collected from the Long Ridge Metagabbro approximately 200 metres east of Western Long Pond (figure 3). Coarse pargasitic hornblendes and sausseritized plagioclase are separated into distinct bands. No primary pyroxene grains were recognized in thin section analysis. Potassium content of hornblendes was extremely low (0-.01%) as determined from preliminary microprobe analysis.

Samples JFN-M and JFN-Q were separated from quartz amphibolites of the Green Ridge Amphibolite. Both were collected from the crest of Three Mountain Summit where an amphibolite outlier is gradational downward into surrounding greenschists (figure 3). Medium grained (1-2mm) pargasite hornblendes comprise 50 to 70 percent of the samples. A well defined compositional segregation between plagioclase and hornblende is developed on a fine scale.

METHODS

Rock samples for analysis were microscopically analyzed to ensure that the hornblendes were coarse enough to separate and that no high potassium phases were included. Two samples from the Green Ridge Amphibolite (JFN-M, JFN-O), one from the Long Ridge Metagabbro (JFN) and a sample from the Jacupirangite suite (165-E) were determined to be suitable for dating. Specimens were crushed to retain the 40-480 sieve fraction. Hornblende was separated from feldspar using a Frantz Magnetic Separator.

500 mg hornblende concentrates of each sample were loaded in an alumunim canister along with four South Mountain Batholith biotite standards of known age. Irradiation by fast neutrons for 60 hours within the McMaster University Nuclear Reactor was then carried out. A ten-week cooling period ensued before low radiation levels allowed safe handling of samples.

Individual samples were heated in an internal tantalum resistance furnace in step-wise temperature increments within a vacuum system. The first step was 250-650 degrees C and successive steps generally increased by 100 degrees C until fusion of the specimen occurred. Monitor samples of known age were heated in a single step to their fusion point.

Gas evolved from each temperature interval was purified by means of a titanium getter and analyzed in a modified MS10 mass-spectrometer. Atomic masses 40,39,37, and 36 were recorded and the ratios 36/39, 37/39/ and 40/39 calculated.

Corrections for undesired irradiation products, the atmospheric Ar contamination, and the actual age dating of the sample were accomplished by the $^{40}Ar/^{39}Ar$ age computer program at Dalhousie University.

RESULTS

The $^{40}Ar/^{39}Ar$ analytical data are presented in Table 1, and are plotted as age spectra in figures 4 to 7 .

Sample JFN-M and JFN-0 (Green Ridge Amphibolite) have total gas ages of 717 Ma and 589 Ma respectively. However, low temperature steps give high apparent ages (figure 4 and 5) which are suggestive of excess argon loosely bound within the hornblende (Stukas, 1973). A concordant 'plateau' defined by 92 percent of the total ^{39}Ar gives an apparent age of 546 Ma and 562 Ma for samples JFN-M and JFN-0 respectively (figure 4 and 5).

The total ^{39}Ar released during heating of JFN (Long Ridge Metagabbro) was only 8.mV. In comparison, total ^{39}Ar released from samples JFN-M, JFN-0, and 165-E was 27.4 mV, 32.7mV, and 291.4 mV respectively. The effect of a small volume of excess argon on such a low total ^{39}Ar content is reflected in the anomalously high and geologically unreasonable age of 900 My for sample JFN (figure 6).

Sample 165-E (Hornblende Gneiss) yielded a large volume of ^{39}Ar (291.4 mV). Excess argon effects can be recognized in the low temperature intervals resulting in anomalously old ages (figure 7). However, the large volume of total ^{39}Ar released buffers the effect of the small volume of excess argon. Consequently, 80 percent of the total ^{39}Ar defines a concordant 'plateau' with a combined gas age of 495 Ma (figure 7).

Harris and MacDougall (1980) concluded from experimental work that three distinct types of $^{40}Ar/^{39}Ar$ release spectra could be recognized. The first is the normal spectrum where the $^{40}Ar/^{39}Ar$ ratio is the same for all temperature steps (Figure 8a). This results in equivalent apparent ages for all the temperature intervals. The second type of age spectra displays low apparent ages for the low temperature steps (Figure 8b). This conforms to a diffussive model where hornblende has suffered post-crystallization argon loss. Finally, impossibly high apparent ages in the low temperature steps is the result of post crystallization diffusive gain of ^{40}Ar (Figure 8c).

Furthermore, Harrison and McDougall (1980) realized that both post crystallization argon loss and diffusive argon gain could be recognized in some $^{40}Ar/^{39}Ar$ spectra (Figure 8d). Samples JFN-M, JFN-0, and 165-E display age spectra which conform to patterns of samples which have suffered post-crystallization argon loss and enrichment (figure 9).

Such a pattern is of particular significance in interpretting the age of sample 165-E. It is apparent that the low temperature ages are geologically unreasonable due to the excess argon effect. However, at the 20 percent Ar released point, the excess argon curve intersects the Ar diffussive loss curve. The effect of the diffussive loss of Ar can be recognized up to the fussion point of the sample. This implies that the true $^{40}Ar/^{39}Ar$ age may be older than that determined.

TABLE 1

$^{40}Ar/^{39}Ar$ Analytical Data

SAMPLE	TEMPERATURE (C)	% ^{39}Ar	% ATMOSPHERIC Ar	APPARENT AGE (Ma) (± 2σ)
JFN-M	650- 750	2	63	1086 ± 34
	750- 850	2	67	1099 ± 47
	925-1000	2	89	568 ± 147
	1000-1075	18	52	541 ± 8
	1075-1150	13	32	533 ± 8
	1150-1250	62	24	564 ± 8
JFN-O	925-1000	4	79	666 ± 42
	1000-1075	13	28	554 ± 12
	1075-1150	35	30	556 ± 8
	1150-1225	44	33	577 ± 8
	1225-1275	3	65	594 ± 18
JFN	925-1000	16	78	1021 ± 24
	1000-1075	52	32	922 ± 14
	1075-1150	24	45	853 ± 12
	1150-1225	7	55	840 ± 24
165-E	200- 650	1.5	47	896 ± 32
	650- 750	2.9	24	599 ± 9
	750- 850	1.8	21	529 ± 9
	850- 900	3.2	18	531 ± 7
	900- 950	5.7	9	533 ± 7
	950-1000	4.4	9.8	516 ± 6
	1000-1050	16.5	5.5	493 ± 6
	1050-1100	23.0	3.6	489 ± 6
	1100-1150	29.5	4.8	501 ± 6
	1150-1225	11.7	8.4	511 ± 6

Fig. 4 JFN-M

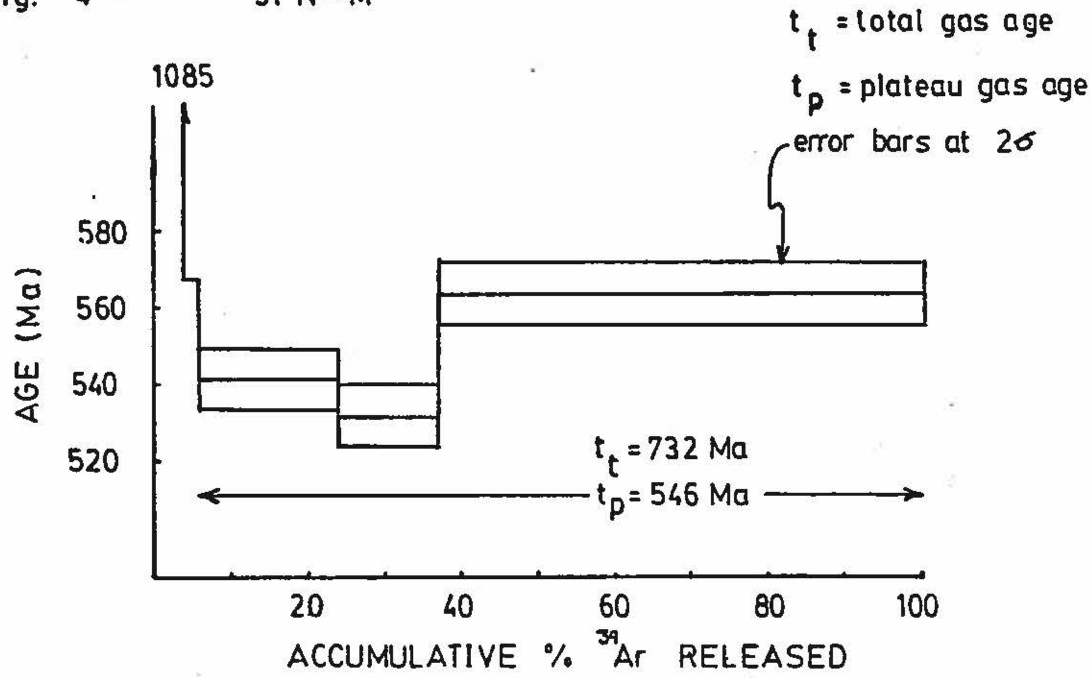


Fig. 5 JFN-O

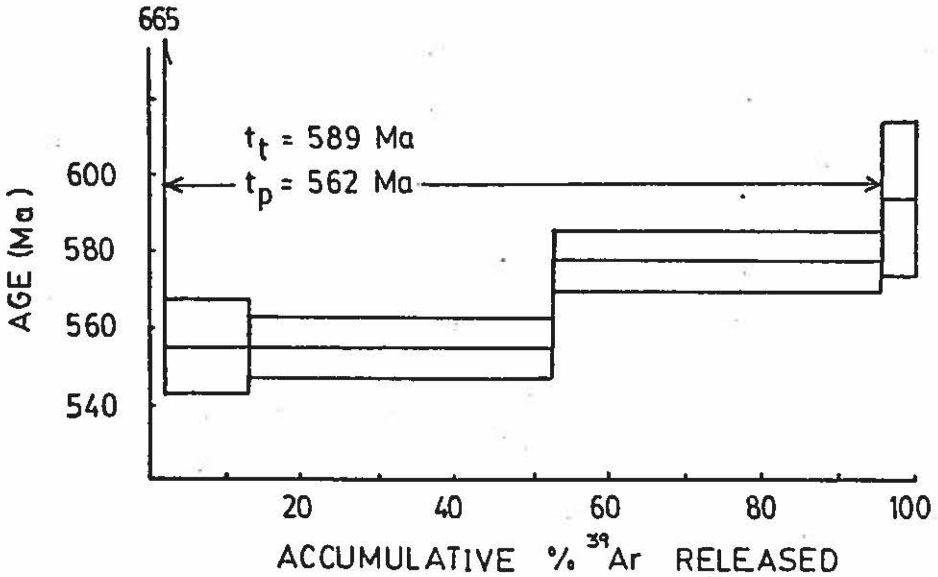


Fig. 6 JFN

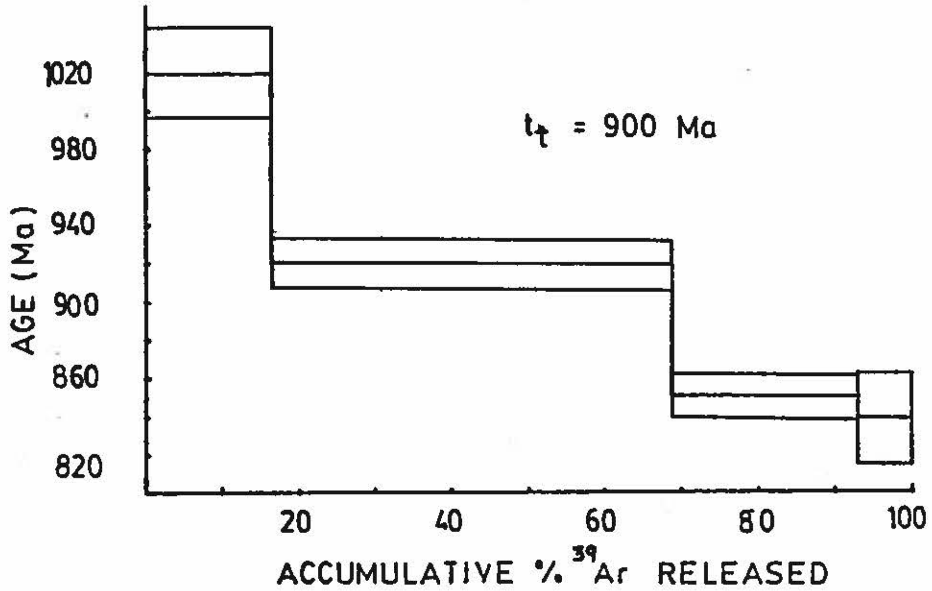
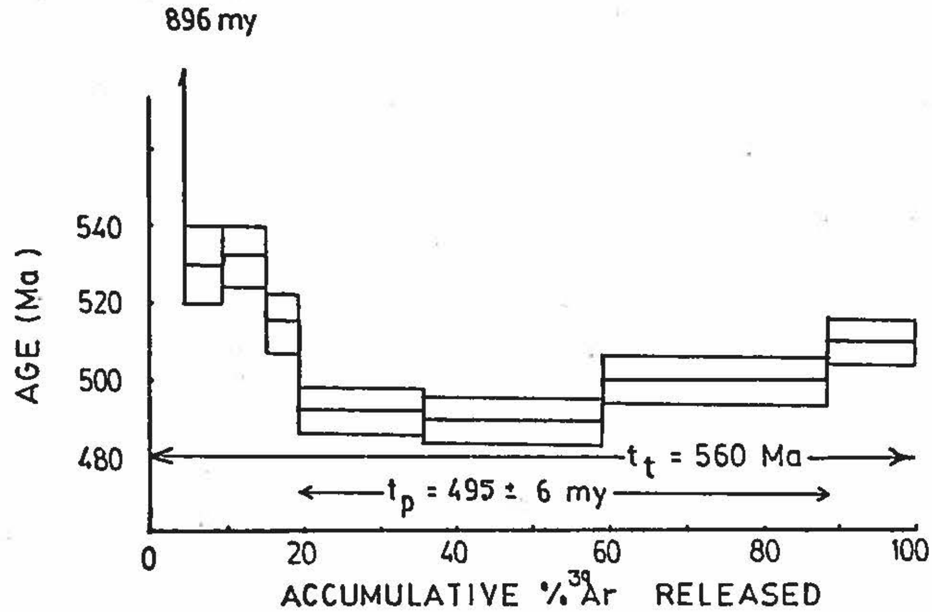


Fig. 7 165-E



DISCUSSION

Excess argon effects preclude the interpretation of the experimentally derived age of 900 Ma for sample JFN. Age spectra for amphibolites JFN-M and JFN-0 also appear to have been affected by excess argon (see results). Apparent ages of 545 Ma and 560 Ma for samples, JFN-M and JFN-0 respectively, are probably older than their true ages and are thus of dubious quality.

The large volume of $^{39}Ar_{total}$ outgassed by 165-E and the concordant plateau defined by 80 percent of the total ^{39}Ar released, suggests that the apparent age of 495 Ma for the hornblende gneiss is real. The age represents the time when metamorphic hornblendes of the jacupirangite suite cooled below their argon blocking temperature of 450-550 degrees C. Furthermore, the metamorphic mineralogy of the jacupirangite suite formed during the deformation of the basal level of the peridotite; this was accompanied by temperatures of about 950 degrees C during the early stages of the dynamothermal aureole formation (Jamieson, 1989). The age of 490 Ma therefore represents the minimum age of ophiolite obduction, and is in agreement with stratigraphic and paleontological control in Northwestern Newfoundland.

An age of 545-560 Ma for amphibolite (JFN-M, JFN-0) lower in the dynamothermal aureole is more difficult to justify. Such an age implies that the Green Ridge Amphibolite formed prior to its accretion into the aureole beneath the peridotite. A lower Middle-Cambrian age for the Green Ridge

Fig. 8a Ideal ^{39}Ar release spectrum

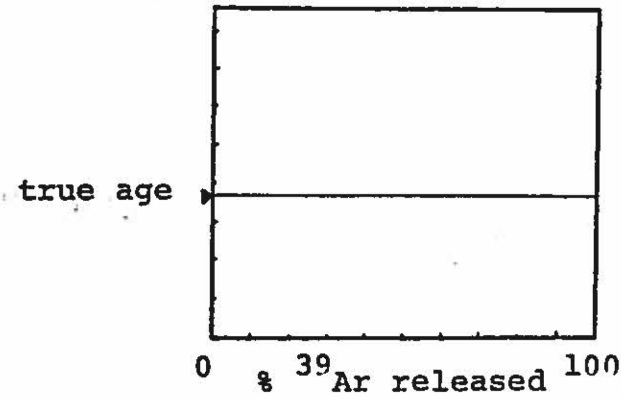


Fig. 8b Argon release spectra displaying the effect of post-crystallization argon loss (Harrison and McDougal,1980)

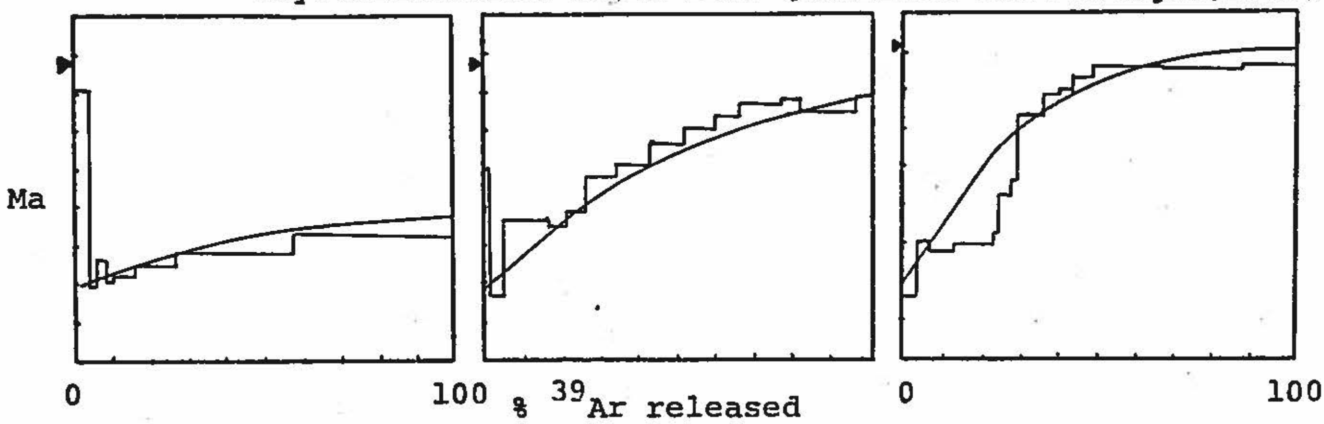


Fig. 8c Argon release spectra displaying the effect of loosely bound excess argon (Harrison and McDougal,1980).

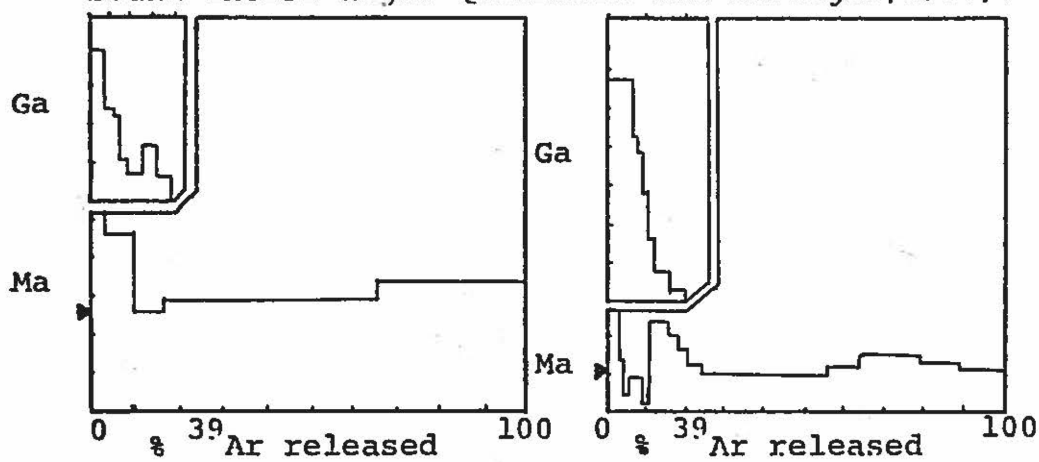


Fig. 8d Argon release spectra displaying the combined effects of post-crystallization argon loss and diffussive argon gain (Harrison and McDougal,1980).

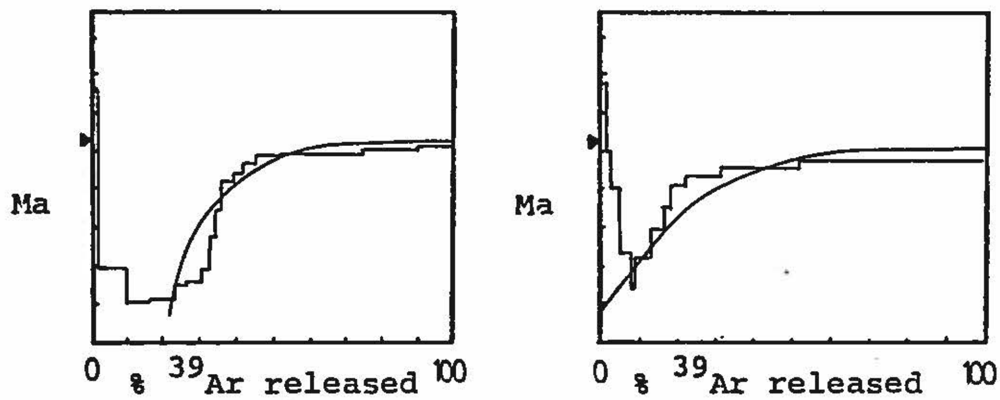
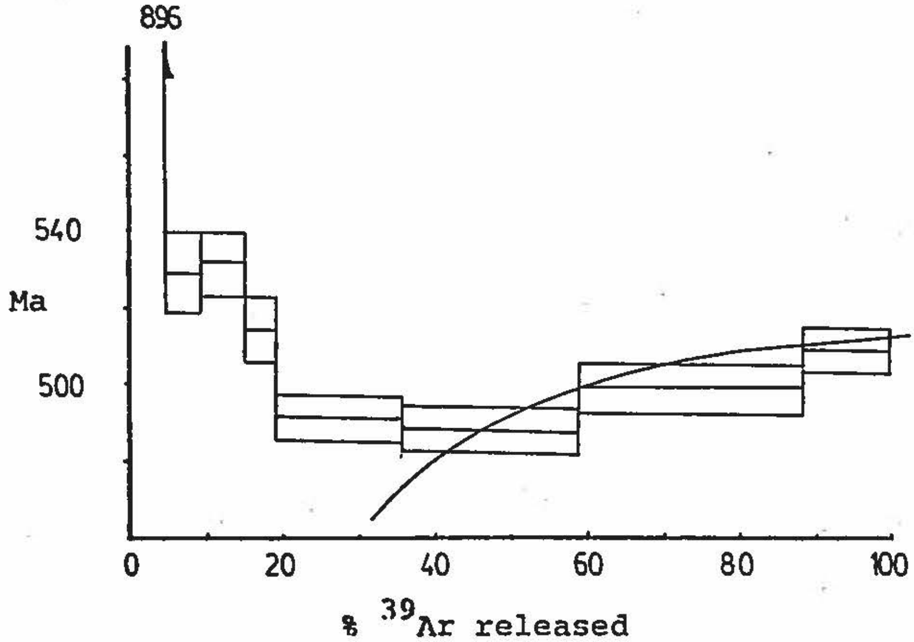


Fig. 9 Argon release spectra for sample 165-E with a diffussive argon loss curve superimposed.



Amphibolite corresponds to the oldest fossils associated with Cambrian island-arc volcanics in the Notre Dame Bay area of central Newfoundland (Kean and Strong, 1975). If a subduction zone was responsible for these volcanics, it could also have supplied the mechanism to amphibolitize oceanic crust prior to its incorporation onto a westward transgressing ophiolite. However, amphibolite compositional layering and foliation display a remarkable parallelism with the subhorizontal peridotite contact. This strongly suggests that the deformation fabric was developed during the transport and emplacement episode of the ophiolite. The metamorphic mineralogy, particularly amphibole, is completely consistent with the deformation fabric. There is no evidence to suggest that the emplacement fabric and the metamorphic mineralogy represent an earlier metamorphism. It therefore appears that the 550 Ma experimentally determined age for the amphibolites is geologically unreasonable. This discrepancy may be attributed to the effects of excess argon on the relatively low concentrations of radiogenic ^{40}Ar within the hornblendes.

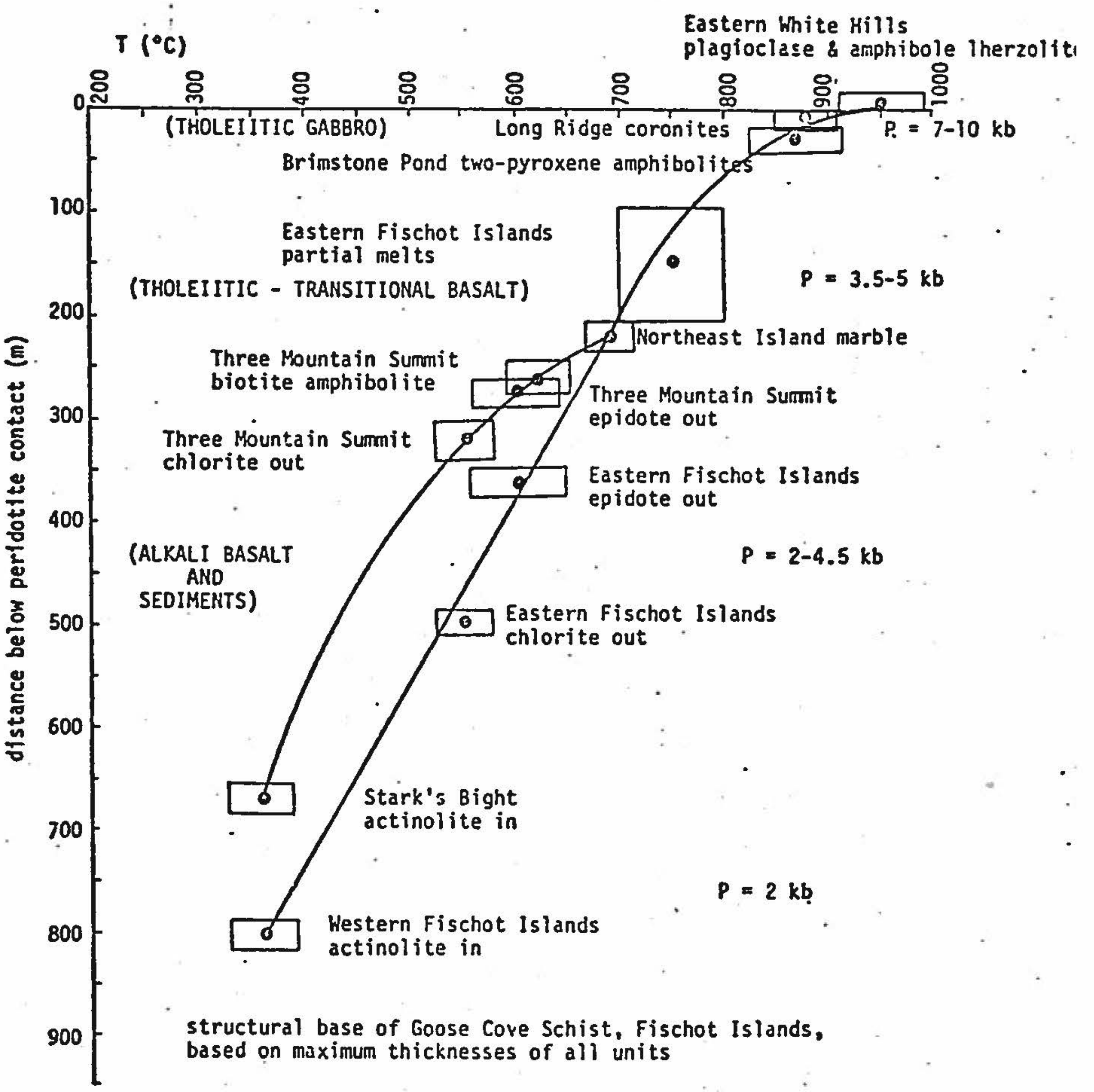
A minimum age of 495 $\pm$ 6 Ma for the initiation of obduction of the White Hills Peridotite agrees remarkably well with Dallmeyer's (1977) age of 480 $\pm$ 6 Ma for ophiolite obduction. Up to two percent of this difference can be reconciled in Dallmeyer's (1977) use of a pre-1977 potassium decay constant. Recalculation using the decay constant established by Steiger and Jäger (1977) raises Dallmeyer's minimum age for ophiolite obduction up to 490 ± 10 Ma. A 5 Ma age difference between the jacupirangite suite and the underlying amphibolites may be insignificant. However, the ^{39}Ar release spectra for sample 165-E is suggestive of post-crystallization argon loss (Harrison and McDougall, 1980). This implies that the true age of the jacupirangite suite is actually older than its apparent age of 495 ± 6 Ma. It is therefore possible than an age difference between the base of the peridotite and the underlying metamorphic aureole exists.

The tendency for the base of the peridotite to be slightly older than the underlying amphibolites lower in the dynamothermal aureole is also recognized in the Bay of Islands (Dallmeyer, 1975) and the Samail ophiolite (Lamphere, 1980). Therefore, if one considers the 5-10 Ma age difference between the base of the White Hills Peridotite (this study) and the amphibolites of the dynamothermal aureole (Dallmeyer, 1977) to be significant, the implications with respect to ophiolite emplacement models is of great consequence. Age differences between rocks at varying structural levels implies a composite origin for these dynamothermal aureoles.

Structural and lithologic discontinuities have been recognized in the metamorphic aureole underlying the White Hills Peridotite. Structural breaks include subhorizontal mylonite zones separating the White Hills Peridotite, upper amphibolite facies rocks, epidote amphibolites and greenschist facies rocks (Jamieson and Strong, 1981). Peridotites, quartz amphibolites, plagioclase amphibolites, metasediments, and basic metavolcanics all represent pre-metamorphic compositionally distinct units (Jamieson, 1979).

Based on pressure-temperature studies of the metamorphic mineral assemblage within the aureole, Jamieson (1979) reached the conclusion that the aureole was composite in origin. Applying conductive and frictional models as a heat source, and a peridotite-aureole contact temperature of 900-950 degrees C, Jamieson (1979) concluded that the units of the aureole were progressively metamorphosed at conditions depicted in figure 10 . A conductive model could not explain the high temperatures observed at the peridotite aureole contact. Therefore, as successive slabs were welded onto the transgressing peridotite they underwent metamorphism partly due to conductive heating from the overlying hot peridotite mass, but mainly the result of frictional heating along the peridotite-aureole contact (Jamieson, 1979). In summary, Jamieson (1979) proves the composite nature of the aureole and demonstrates the necessity of a frictional heat source. However, cessation of shearing along the base of the peridotite would result in the contemporaneous cooling of both the peridotite and the underlying dynamothermal aureole. Consequently, $^{40}Ar/^{39}Ar$ cooling ages would be similar for the jacupirangite suite

Fig. 10 Composite thermal and metamorphic profile through the St Anthony Complex, based on metamorphic reactions and mineral geothermometers (after Jamieson, 1979)



and the Green Ridge Amphibolite.

Juxtaposition of a thickness of rock onto the base of the over-riding peridotite could, instead, shift the frictional heat source to the new base of the ophiolite. Isolation of the peridotite and the first incorporated units of the aureole from the active heating zone would allow the cooling of metamorphic hornblendes below their argon blocking temperatures. Therefore, $^{40}Ar/^{39}Ar$ cooling ages for metamorphic hornblendes would be greater for the first incorporated lithologies than ages determined from hornblendes lower in the aureoles. The model implies that cooling of the White Hills Peridotite was quick, and complete, before the progressive accretion of units lower in the aureole occurred. Rapid ascent of the peridotite along high angle thrust faults during the initial stages of ophiolite formation could possibly explain quick cooling. The reversed metamorphic gradient of the aureole could be the result of the juxtaposition of successively shallower and cooler oceanic crustal lithologies onto the peridotite. Evidence for this is suggested by the existence of oceanic crust-mantle transition rocks (Long Ridge Metagabbro) near the top of the aureole , and basic volcanics and metapelites at the base of the aureole (Goose Cove Schist, Ireland Point Volcanics). The reversed metamorphic grade could also be due to the slowing and cessation of ophiolite movement. This would result in a decrease in heat generated along the basal shear planes, and a subsequent decrease in the metamorphic grade.

CONCLUSIONS

Although it was the original intention of this thesis to date successively lower slices of the St. Anthony Complex metamorphic aureole, only one sample (165-E) provided a geologically reasonable age. The jacupirangite suite has an apparent metamorphic $^{40}Ar/^{39}Ar$ age of 495 ± 6 Ma. Argon release spectra not unlike those presented by Harrison and McDougall (1980) suggest that 495 ± 6 Ma is a minimum age for sample 165-E.

Samples JFN-M and JFN-0 of the Green Ridge Amphibolite have apparent metamorphic ages of 545 ± 10 Ma, and 560 ± 10 Ma respectively. However, stratigraphic control and structural implications within the aureole suggest such dates are geologically unreasonable.

A metamorphic age of 900 ± Ma for sample JFN is geologically impossible. The extremely low potassium content of the sample was apparently insufficient to allow dating by $^{40}Ar/^{39}Ar$ technique.

However, it is apparent that the top of the metamorphic aureole (165-E) may be older than amphibolites lower in the aureole. $^{40}Ar/^{39}Ar$ dating by Dallmeyer (1977) of the Green Ridge Amphibolite gave an age of 480 ± 6 Ma. When corrected using the potassium decay constant of Steiger and Jäger (1977), this age is 5 - 10 Ma younger than rocks of the overlying Jacupirangite suite also metamorphosed during the emplacement episode. Such a trend is also recognized in the Bay of Islands (Dallmeyer, 1975) and the Samail ophiolite (Lamphere, 1980).

An emplacement model to explain such an age difference implies the metamorphic aureole is composite in origin. The initial transport of the ophiolite from depth resulted in the juxtaposition of progressively shallower slabs of oceanic crust onto the base of the ophiolite.

The zone of shear heating along the base of the ophiolite was also successively displaced to each new slice of the aureole. Cooling of the first incorporated slices of the aureole resulted in older ages than units lower in the aureole. An inversed metamorphic grade resulted either from the incorporation of cooler (shallower) crustal rocks or from the waning of ophiolite transport.

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