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TECTONOTHERMAL HISTORY AND ^{40}AR/^{39}AR GEOCHRONOLOGY OF NORTHEASTERN GANDER ZONE, WEIR'S POND AREA (2E/1)

Pat O'Neill and Dan Lux[1]
Newfoundland Mapping Section

ABSTRACT

Two phases of deformation, manifested by mesoscopic, isoclinal and later upright, open folds, were identified in the map area. The affects of three types of metamorphism, apparently developed after the initial phase of deformation, are described.

Biotite, garnet, staurolite, andalusite, sillimanite and locally cordierite isograds, are defined for the northeastern part of the map area, near Ocean Pond. Microfabric–porphyroblast relationships imply overlap of metamorphic mineral growth and open upright folding. The sequence of metamorphic mineral assemblages developed, suggest low pressure–high temperature regional metamorphism.

In the southeastern part of the map area, near Wing Pond, a series of isograds, which are at least locally telescoped, occur within a structural high-strain zone. Kyanite-bearing assemblages are present and imply higher pressure metamorphism (deeper level?) than that at Ocean Pond.

Coarse-grained muscovite, overprinting all earlier structures and minerals, occurs in a narrow zone, in the northeast, peripheral to the Deadman's Bay Granite. Near Moccasin Pond, cordierite–andalusite–K-feldspar assemblages are developed within 2 km of the Deadman's Bay Granite. These assemblages define a zone of hornfelsing associated with this granite.

^{40}Ar/^{39}Ar ages on muscovite and biotite concentrates from pelitic rocks near Ocean Pond, range between 400 and 385 Ma, and define a cooling age for the regional metamorphism in the northeast. The time frame for this thermal event suggests a correlation between metamorphism and plutonism in northeastern Newfoundland, and a Late Silurian orogeny in southern Newfoundland.

INTRODUCTION

Regional tectonic and stratigraphic relationships of the rocks discussed in this paper are described elsewhere (O'Neill and Blackwood, *this volume*). This paper presents an account of microfabric–porphyroblastesis relationships in metasedimentary rocks of the Gander Group and ^{40}Ar/^{39}Ar cooling ages from muscovite and biotite mineral separates, which can be used to infer the approximate timing of the development of some of these relationships.

TECTONOTHERMAL HISTORY

General Description

Gander Group rocks in the Weir's Pond map area exhibit the effects of three types of metamorphism. To facilitate the description of these metamorphic events, the part of the map area underlain by rocks at biotite and higher grades is divided into three areas, the Ocean Pond, Moccasin Pond and Wing Pond areas. However, this report primarily describes the tectonothermal history of the rocks in the Ocean Pond area, since most of the ^{40}Ar/^{39}Ar data presented here, relate to the area (Figure 1). A hornfelsed aureole, peripheral to the Deadman's Bay Granite, is also described.

Two phases of deformation were recognized on a mesoscopic scale in the map area. The earliest phase of deformation produced isoclinal folds having a predominantly steep, westerly to southwesterly plunge and a north–northeast-trending axial planar fabric. These early-phase folds are overprinted by a later phase of open, upright folds having a northeast-trending subhorizontal plunge and a typically steep crenulation cleavage.

Ocean Pond Area

In the Ocean Pond area, biotite, garnet, staurolite, andalusite and sillimanite isograds are defined in rocks of the Jonathans Pond formation. Pelitic and semipelitic rocks are coarse-grained and schistose throughout much of the zone. The sillimanite isograd defines a localized, metamorphic culmination near Ocean Pond. Farther east and northeast,

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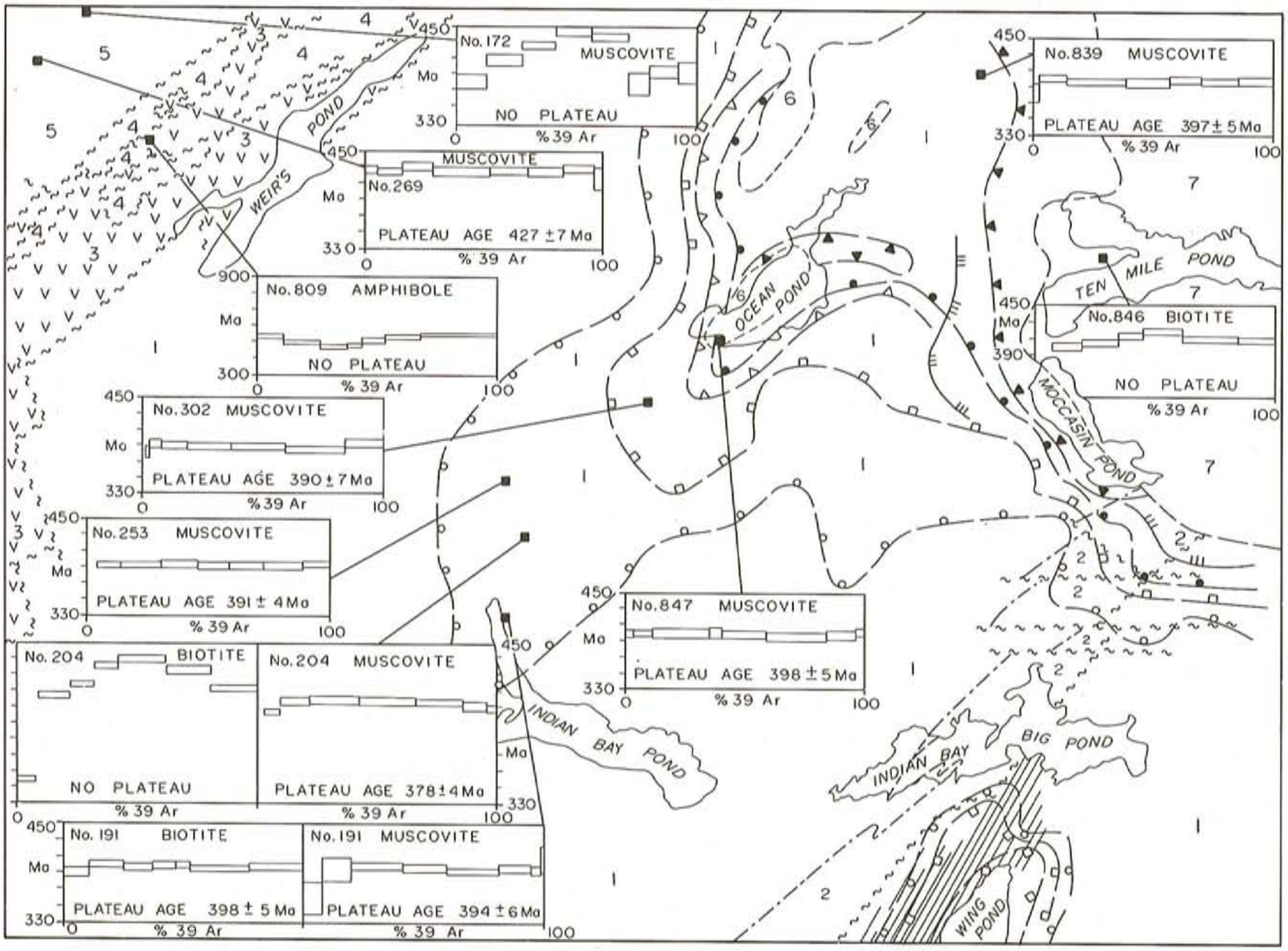
[1] Department of Geology, University of Maine, Orono, Maine, U.S.A.



LEGEND

SILURO – DEVONIAN

7 Deadman's Bay Granite: *Undeformed, megacrystic, biotite granite*

6 Ocean Pond granite: *Foliated, muscovite – garnet – tourmaline granite*

ORDOVICIAN

Davidsville Group

5 Hunts Cove formation

4 Weir's Pond formation

ORDOVICIAN OR OLDER

3 **Gander River complex**

Gander Group

2 Indian Bay Big Pond formation

1 Jonathans Pond formation

SYMBOLS

INTRUSIVE
GRADATIONAL
FAULT INFERRED
ASSUMED
UNKNOWN
BIOTITE
GARNET

STAUROLITE
ANDALUSITE
SILLIMANITE
CORDIERITE
TELESCOPED ISOGRAD SERIES (STAUROLITE, KYANITE, SILLIMANITE, ANDALUSITE
HIGH STRAIN ZONE

Figure 1. *Geology and $^{40}Ar/^{39}Ar$ mineral age spectra for the Weir's Pond map area, northeastern Gander Zone, Newfoundland.*

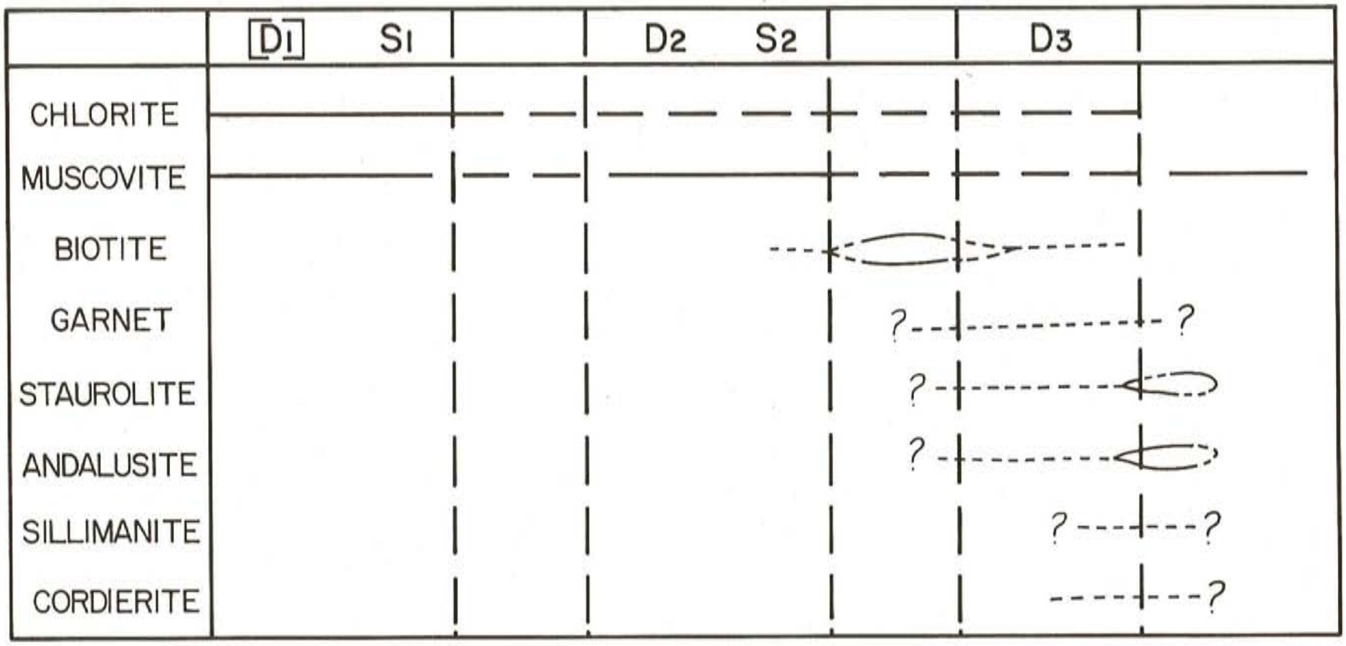


Figure 2. *Relative timing of metamorphic mineral growth and relationship to deformational phases; Ocean Pond area, Weir's Pond map area.*

the sillimanite isograd approximately parallels the margin of the Deadmans Bay Granite, from the northern edge of the map area, southward to Moccasin Pond, where the granite intrudes across the isograd.

The leucocratic, muscovite-, garnet- and tourmaline-bearing Ocean Pond granite is best exposed near Ocean and Little Ocean ponds, in the higher grade parts of the Ocean Pond area. Although the granite appears to cut across some of the isograds, it does not have an associated aureole.

Definition of fabrics. In most of the metasedimentary rocks, the principal tectonic fabric is a penetrative foliation and is axial planar to isoclinal folds. This fabric is manifested as a solution seam cleavage in psammite and as a slatey cleavage in pelite. However, microfabric studies, particularly on pelitic and semipelitic rocks, show that this principal fabric is almost invariably a crenulation of an older fabric, which is the oldest recognized and therefore designated S_1. No major deformational phase has been associated with S_1 and it may be a bedding-parallel layering. The principal fabric, S_2, is therefore S_1 incompletely transposed. S_2 is axial planar to the isoclinal folds that occur in most exposures. In most semipelitic and pelitic samples, S_2 is gently to moderately crenulated by a later folding, designated F_3. These late microscopic crenulations correlate with the ubiquitous, open folds and crenulations on a mesoscopic scale. These folds are northeast-trending and typically display a subhorizontal plunge.

Fabric development and porphyroblastesis. Both S_1 and S_2 fabrics are defined by fine- to medium-grained chlorite and muscovite, which gradually increase in grain size with increasing grade. Biotite poikiloblasts overprint S_1 and S_2 and contain inclusions of these fabrics. The relationship between biotite growth and S_3 is more subtle. Biotite never clearly overprints the F_3 folds, however, toward the margin, of approximately 20 percent of the biotite examined, Si (internal fabric) in biotite, (which is typically S_2) is bent and parallels a corresponding curvature of the S_2 fabric in the matrix, caused by F_3 folds. Elsewhere, biotite is bent around F_3 folds. Thus, biotite is post-D_2 but grew before, and synchronously with, the early stages of D_3 (Figure 2).

Almanditic garnets overprint biotite and typically contain a poorly developed Si (typically S_2), which is generally straight but locally gently curved.

Most staurolite and andalusite porphyroblasts contain an Si defined by quartz, opaque minerals and muscovite. They also contain random biotite, garnet and occasionally coarse grained muscovite. Inclusion trails in staurolite and andalusite are straight, curved or crenulated. As in the case of biotite, staurolite and andalusite clearly overprint the S_1 and S_2 fabrics. However, unlike biotite, staurolite and andalusite overprint F_3 crenulations locally. The crenulations preserved in the staurolite and andalusite are continuous with F_3 crenulations defined in the matrix. There is no apparent flattening of the fabrics around the porphyroblasts and, therefore, andalusite and staurolite grew after D_3. Although porphyroblast growth may have been partly synchronous with the development of D_3, there is no conclusive evidence for this.

Fibrolite–sillimanite developed after and replaces andalusite and, therefore, probably has similar timing relationships to D_3 as andalusite. However, a high-strain fabric involving sillimanite is developed in several samples collected northwest of Ten Mile Pond. This high-strain fabric is not readily correlated with any of the previously defined fabrics. Both fibrolite and sillimanite are aligned in foliae that are evident in hand specimen and are clearly crenulated. The sillimanite foliae are variable in width, up to a maximum of 1 mm; the thicker foliae split and anastomose around single or aggregate quartz grains and biotite. Some of the quartz grains enveloped by sillimanite have aspect ratios of 10:1 to 15:1, and are en echelon and strained. Biotite enveloped by the aluminosilicate is locally fish-shaped, suggesting a non-coaxial deformation. In contrast to the strong morphology exhibited by the sillimanite within the foliae, sillimanite within quartz grains away from the foliae are randomly oriented. Textures involving sillimanite, which are similar to those described above, have been described by Vernon (1987), who attributes their development to the ability of sillimanite to undergo non-coaxial deformation.

Moccasin Pond Area

The textural characteristics of the metasediments, from the northern end of Moccasin Pond southward, contrast with those exhibited by the rocks in the Ocean Pond area. In the Moccasin Pond area, biotite, garnet, andalusite and cordierite isograds are defined in pelitic and semipelitic rocks of the Jonathans Pond and Indian Bay Big Pond formations. The isograds approximately parallel the margins of the Deadman's Bay Granite. The principal differences between rocks of the Ocean Pond and Moccasin Pond areas are in grain size and in their microfabric–porphyroblastesis relationships. Texturally, the rocks in the Moccasin Pond area, which are biotite and garnet grades, are fine grained. At higher grades, andalusite and cordierite porphyroblasts, up to 4 mm across, occur in a fine grained matrix. Andalusite and cordierite porphyroblasts have, locally, survived the extensive retrogression affecting these rocks, although most are partly sericitized.

Fabric development and porphyroblastesis. The earliest fabric in pelitic and semipelitic rocks of the Moccasin Pond area, is poorly developed and defined by very fine grained, chlorite and muscovite. In those rocks where this early tectonic? fabric is preserved, fine biotite randomly overprints it, and the biotite is in turn overprinted by pseudomorphs of fine grained white mica and chlorite after cordierite and/or andalusite(?). After the porphyroblast growth, the rocks are affected by a second deformation, which crenulated the early fabric and aligned the biotite. The new crenulation fabric is particularly strong around pseudomorphs and porphyroblasts of andalusite and cordierite, which form augen. However, locally, the Si in the pseudomorphs curve at their margins and become parallel with the external matrix fabric. Elsewhere the Si is moderately crenulated, thus implying growth of these porphyroblasts early in the crenulation deformation. This deformation later affected the augening of the porphyroblasts. The biotite fabric is locally overprinted by garnet and a late crenulation gently folds the biotite fabric in some sections.

Wing Pond Area

Near Wing Pond, a rapid increase in metamorphic grade occurs several kilometres southeast of the southeastern margin of the Indian Bay Big Pond formation. In the lower grade parts of the zone, the rocks are coarse grained and muscovite-rich. The biotite zone is based on rare and sporadic occurrences of this mineral. Similarly, the garnet ± biotite zone, is based on several scattered occurrences of this assemblage. On the northeast side of the pond, the metastable assemblage kyanite–staurolite–sillimanite–andalusite–biotite ± garnet occur within several hundred metres of rocks containing biotite and garnet. The kyanite and staurolite commonly occur as inclusions in andalusite porphyroblasts and form a relict, metastable assemblage. It is not clear whether the sillimanite is associated with the older, kyanite–staurolite assemblage or the andalusite-bearing assemblage.

The close spatial proximity of the lower and higher grade rocks suggest that several isograds, including staurolite, andalusite and sillimanite are telescoped together. The surface traces of all the isograds in the Wing Pond area, lie within a steep high-strain zone. Rocks in this zone, containing the assemblages described above, all exhibit the effects of non coaxial deformation.

Kyanite-bearing rocks indicate a higher pressure type of metamorphism than that in the Ocean Pond area; however, this may represent a deeper level but equivalent metamorphism. The timing of the development of the high-strain zone and its relationship to the regional metamorphism of the Ocean Pond area is not known. The tectonothermal history of the Wing Pond area will be described in detail (O'Neill, *in preparation).*

Deadman's Bay Granite Aureole

In the Ocean Pond area, sillimanite-bearing rocks, in the northeast, within 3 km of the margin of the Deadman's Bay Granite, are characterized by coarse porphyroblastic muscovite, up to 3 mm across. Elsewhere, in the Ocean Pond area, away from the granite, muscovite is typically fine to medium grained ($\leq$ 0.5 mm across) and is the main fabric-forming element in S_1 and S_2 fabrics. The coarse grained muscovite in rocks adjacent to the Deadman's Bay Granite, contain inclusions of sillimanite and biotite and, therefore, grew late with respect to the regional metamorphism. Tectonic fabrics are only vaguely defined or, are totally absent from these hornfelsed rocks.

West of Ten Mile Pond, four samples, two within sillimanite and two in andalusite grade rocks, contain cordierite. In all the samples, andalusite and biotite are associated with the cordierite, but are enclosed within cordierite in some samples. In one sample, a fibrolite rim around the andalusite and the biotite is included within the

Table 1: $^{40}Ar/^{39}Ar$ analytical data on muscovites and biotites from the Weirs Pond area, northeastern Gander Zone.

Release Temp C	$(^{40}Ar/^{39}Ar)^*$	$^{37}Ar/^{39}Ar$	$(^{36}Ar/^{39}Ar)^*$	Moles ^{39}Ar	^{39}Ar % of Total	$\%^{40}Ar$ Radiogenic	K/Ca	Apparent Age(Ma)
				MUSCOVITE				
Sample #191; Pelite; Gander Group; J = .006113								
825	51.45	0.4392	0.0531	16.3	7.0	69.5	1.12	356.7 +/-19.6
890	43.32	0.4218	0.0117	29.3	12.6	92.0	1.16	393.5 +/-13.7
950	41.22	0.2877	0.0033	49.4	21.3	97.6	1.70	396.7 +/-4.0
1025	40.53	0.2581	0.0018	43.6	18.8	98.6	1.90	394.5 +/-5.2
1115	40.23	0.2332	0.0020	50.1	21.6	98.5	2.10	391.3 +/-4.3
1170	40.15	0.4186	0.0004	29.3	12.6	99.7	1.17	395.0 +/-4.0
1220	40.43	0.8757	0.0024	10.4	4.5	98.3	0.56	392.6 +/-4.9
Fusion	42.46	1.1932	0.0039	3.3	1.4	97.4	0.41	406.9 +/-16.3
Total				231.4	100.0		Total Gas Age	391.6 +/-6.8
Sample #204; Pelite; Gander Group; J = .005926								
825	34.62	0.0147	0.0120	40.3	2.8	89.7	33.27	304.6 +/-8.1
890	39.10	0.0300	0.0040	91.6	6.5	96.9	16.35	365.3 +/-3.6
950	39.95	0.0204	0.0020	168.4	11.9	98.4	24.07	377.9 +/-4.0
1025	39.98	0.0101	0.0015	296.4	21.0	98.8	48.47	379.5 +/-3.8
1115	39.85	0.0144	0.0015	334.8	23.7	98.8	33.93	378.3 +/-3.8
1170	39.68	0.0204	0.0013	270.4	19.1	98.9	24.03	377.4 +/-3.9
1220	39.22	0.0495	0.0016	148.2	10.5	98.7	9.90	372.6 +/-3.7
Fusion	38.88	0.0630	0.0016	64.4	4.5	98.7	7.77	369.7 +/-4.5
Total				1414.4	100.0		Total Gas Age	374.4 +/-4.0
Sample #253; Pelite; Gander Group; J = .005992								
725	38.690	0.0065	0.0107	44.2	2.5	91.7	75.84	347.86 +/-3.69
825	41.400	0.0019	0.0030	175.5	9.9	97.8	261.33	391.72 +/-4.01
890	40.970	0.0014	0.0015	295.8	16.7	98.8	354.56	391.80 +/-3.96
950	40.850	0.0011	0.0010	284.7	16.0	99.2	428.32	392.23 +/-5.03
1025	40.760	0.0037	0.0013	235.3	13.3	99.0	132.08	390.53 +/-3.98
1115	40.660	0.0039	0.0013	249.6	14.1	99.0	126.61	389.74 +/-3.95
1170	40.670	0.0040	0.0012	295.8	16.7	99.1	110.63	390.16 +/-3.93
Fusion	41.200	0.0015	0.0019	195.0	11.0	98.6	336.31	392.99 +/-3.98
Total				1775.8	100.0		Total Gas Age	390.17 +/-4.13

cordierite; however, timing relationships between the cordierite and sillimanite blastesis are equivocal.

K-feldspar is present in stable coexistence with the cordierite–sillimanite assemblage.

Southwest of Big Bear Cove Pond, andalusite–biotite assemblages also contain K-feldspar. The presence of K-feldspar implies that the stability field of muscovite + quartz has been exceeded and the rocks are high grade.

The spatial distribution of these assemblages in hornfelsed rocks, peripheral to this granite, indicates that the zone represents the granite aureole.

$^{40}AR/^{39}AR$ GEOCHRONOLOGY

$^{40}Ar/^{39}Ar$ incremental release ages were determined for 8 muscovite, 3 biotite and 1 hornblende mineral concentrate, from metasedimentary and igneous rocks in the Weir's Pond area. The analytical data are presented in Table 1 and the

Table 1: *(Continued)*

Release Temp C	$(^{40}Ar/^{39}Ar)^*$	$^{37}Ar/^{39}Ar$	$(^{36}Ar/^{39}Ar)^*$	Moles ^{39}Ar	^{39}Ar % of Total	% ^{40}Ar Radiogenic	K/Ca	Apparent Age(Ma)
Sample #839; Sillimanite Schist; Gander Group; J = .006172								
825	51.97	0.0115	0.0469	28.0	1.8	73.3	42.57	380.8 +/-11.3
890	42.19	0.0060	0.0069	182.0	11.6	95.1	81.26	399.2 +/- 4.3
950	40.76	0.0071	0.0034	392.6	25.1	97.5	69.47	395.6 +/- 4.1
1025	40.68	0.0021	0.0032	286.0	18.3	97.6	239.02	395.3 +/- 5.3
1120	40.98	0.0036	0.0033	201.5	12.9	97.6	136.68	397.9 +/- 4.3
1170	40.68	0.0084	0.0027	244.4	15.6	98.0	58.66	396.8 +/- 4.0
1220	40.67	0.0035	0.0024	144.3	9.2	98.2	141.70	397.4 +/- 5.2
Fusion	40.83	0.0963	0.0030	83.9	5.4	97.7	5.09	397.2 +/- 4.4
Total				1562.6	100.0		Total Gas Age	396.4 +/- 4.6
Sample #302; Pegmatite; Ocean Pond Granite; J = .006054								
750	45.04	0.0032	0.0197	28.6	0.8	87.0	152.74	384.0 +/-20.8
825	41.23	0.0085	0.0076	54.6	1.5	94.5	57.49	382.0 +/- 8.1
890	41.14	0.0008	0.0033	187.2	5.2	97.5	652.64	392.3 +/- 4.9
950	40.81	0.0050	0.0030	400.4	11.1	97.7	98.75	390.2 +/- 4.3
1025	40.38	0.0003	0.0020	655.2	18.2	98.4	1938.29	389.1 +/- 4.2
1115	40.24	0.0004	0.0017	821.6	22.8	98.7	1366.04	388.7 +/- 4.1
1170	40.04	0.0012	0.0019	895.7	24.8	98.5	419.52	386.2 +/- 4.1
Fusion	40.80	0.0007	0.0018	561.6	15.6	98.6	703.11	393.2 +/- 4.5
Total				3604.9	100.0		Total Gas Age	389.1 +/- 4.4
Samples #847; Ocean Pond Granite; J = .006168								
825	45.28	0.0026	0.0180	52.7	3.2	88.2	188.90	397.3 +/- 4.2
890	42.92	0.0007	0.0095	138.5	8.4	93.4	716.37	398.5 +/- 4.0
950	41.85	0.0018	0.0061	387.4	23.4	95.6	274.36	398.1 +/- 5.0
1025	41.53	0.0006	0.0048	83.9	5.1	96.5	866.49	398.6 +/- 5.5
1120	41.43	0.0010	0.0049	312.7	18.9	96.4	491.38	397.4 +/- 4.6
1170	40.88	0.0027	0.0040	411.5	24.8	97.0	184.07	394.8 +/- 4.4
1220	41.26	0.0023	0.0045	204.1	12.3	96.7	214.07	396.9 +/- 5.3
Fusion	41.40	0.0057	0.0039	67.0	4.0	97.1	86.16	399.6 +/- 4.7
Total				1657.5	100.0		Total Gas Age	397.1 +/- 4.7

technique is described briefly here. Age spectra and their locations are shown in Figure 1 for most of the muscovite and biotite separates; the remainder of the spectra for muscovite and hornblende will be discussed in O'Neill *(in preparation)*.

$^{40}Ar/^{39}Ar$ incremental release spectra allow cooling ages to be determined for various K-bearing minerals. These ages date the approximate time the minerals passed through their closure temperatures i.e., the temperature Ar ceased to diffuse through the crystal lattice. However, in the case of rapidly cooled rocks, the crystallization and cooling ages converge. Two types of ages, plateau and total gas, are derived from the incremental release spectra. A plateau age is the mean value of all increments, which are concordant, based on 2 sigma analytical uncertainties, excluding any uncertainty in the J factor. A total gas age is determined by weighting each age and associated uncertainty, based on the amount of $^{39}Ar_K$ present, in each increment and averaging.

Method

Samples were crushed and sieved in order to isolate size fractions that contained the mica or amphibole as individual rather than composite grains. Standard density, magnetic and hand-picking techniques were used to purify mineral separates. In all cases, purity was estimated to be greater than 99 percent. The samples were encapsulated in aluminium foil,

Table 1: *(Concluded)*

Release Temp C	$(^{40}Ar/^{39}Ar)^*$	$^{37}Ar/^{39}Ar$	$(^{36}Ar/^{39}Ar)^*$	Moles ^{39}Ar	^{39}Ar % of Total	% ^{40}Ar Radiogenic	K/Ca	Apparent Age(Ma)
				BIOTITE				
Sample #191; Pelite; Gander Group; J = .005989								
750	42.87	0.0107	0.0086	102.7	11.1	94.0	45.67	390.1 +/- 4.9
890	42.35	0.0054	0.0034	133.3	14.1	97.6	91.04	398.9 +/- 4.1
925	41.91	0.0089	0.0027	109.2	11.8	98.0	55.21	396.8 +/- 4.2
950	41.96	0.0206	0.0022	87.8	9.5	98.4	23.80	398.5 +/- 4.2
1025	42.01	0.0159	0.0022	53.9	5.8	98.4	30.76	398.9 +/- 4.0
1130	41.55	0.0131	0.0019	229.5	24.8	98.6	37.52	395.8 +/- 4.1
Fusion	41.39	0.0158	0.0011	209.3	22.6	99.1	30.97	396.5 +/- 3.9
Total				925.6	100.0		Total Gas Age	396.3 +/- 4.2
Sample #204; Pelite; Gander Group; J = .006053								
750	32.17	0.0684	0.0148	61.8	8.2	86.3	7.16	280.2 +/- 3.1
825	40.88	0.0216	0.0052	106.6	14.1	96.1	22.70	385.0 +/- 3.9
900	42.02	0.0160	0.0038	75.4	10.0	97.3	30.55	398.8 +/- 3.9
975	44.35	0.0265	0.0026	72.8	9.6	98.2	18.50	422.0 +/- 4.2
1050	45.14	0.0281	0.0020	152.1	20.1	98.6	17.44	430.4 +/- 4.3
1130	43.68	0.0312	0.0020	139.1	18.4	98.5	15.71	417.8 +/- 5.3
Fusion	41.08	0.0523	0.0023	147.6	19.5	98.3	9.37	394.5 +/- 4.1
Total				755.3	100.0		Total Gas Age	398.4 +/- 4.2
Sample #846; Deadmans Bay Granite; J = .006196								
750	37.46	0.0466	0.0094	80.0	6.9	92.5	10.51	351.0 +/- 3.7
825	40.77	0.0158	0.0023	146.3	12.6	98.2	31.04	399.8 +/- 4.4
900	41.36	0.0120	0.0025	175.5	15.1	98.1	40.94	404.8 +/- 4.1
975	42.04	0.0279	0.0020	118.3	10.2	98.5	17.58	412.2 +/- 4.0
1050	42.56	0.0327	0.0014	188.5	16.2	98.9	15.00	418.3 +/- 4.1
1130	41.41	0.0324	0.0014	269.8	23.2	98.9	15.11	408.2 +/- 4.1
Fusion	41.36	0.0566	0.0017	184.6	15.9	98.7	8.66	406.9 +/- 4.0
Total				1162.9	100.0		Total Gas Age	404.5 +/- 4.1

weighed and loaded into silica glass vials, which were then sealed. Samples were irradiated in the H5 facility of the Phoenix Memorial Laboratory at the University of Michigan. Correction factors for Ca and K-derived isotopes were determined through the analysis of irradiated K and Ca salts and are as follows: $(^{40}Ar/^{39}Ar)_K = 0.0347$; $(^{36}Ar/^{37}Ar)_{Ca} = 0.0002572$; $(^{39}Ar/^{37}Ar)_{Ca} = 0.0007494$. The primary flux monitor was MMhb-1 (Alexander *et al.*, 1978).

The irradiated samples were heated in a molybdenum crucible within an ultra-high vacuum extraction system using R induction heating. Extraction temperatures are estimated to be accurate to ± 50°C. Standard gettering techniques were used to purify the inert gases. The isotopic composition of Ar was determined using a 15 cm Nier type mass spectrometer. Ages were calculated using the equations of Dalrymple *et al.* (1981).

Results

The muscovite and biotite cooling ages discussed here, are for those samples collected in the Ocean Pond area only.

Muscovite. $^{40}Ar/^{39}Ar$ age spectra were determined on muscovite separates from 3 samples from the biotite zone, (pelite, samples 86-191, 86-204 and 86-253) and one sillimanite zone hornfels (sample 87-839), in the Jonathans Pond formation, Gander Group. All have well defined plateaus after initial increments that suggest some loss of Ar (not necessarily through natural means), but which is less than 10 percent of total Ar liberated. Samples 86-191 and 86-253 have total gas ages of 391.6 ± 6.8 and 390.17 ± 4.13 Ma respectively, and plateau ages of 394 ± 6 and 391 ± 4 Ma respectively. However, although sample 86-204 has a reasonable plateau, it is approximately 20 Ma younger than the others (and is also the youngest dated rock). The muscovite in this sample is very fine grained, < 0.1 mm, defines the main fabric and is strongly crenulated by F_3. Although the very fine grain size in the sample 86-204 may have effectively lowered the closure temperature, sample 86-253 has muscovite of similar grain size, but its age is similar to that defined by other samples. Also, the late microfolding is not as well developed in sample 86-253.

Sample 87-839 is a sillimanite-bearing semipelitic rock, approximately 4 km northeast of the Deadman's Bay Granite. The rock is a hornfels and comprises granoblastic quartz, plagioclase, muscovite and sillimanite needles, preserved in quartz. A fine grained equigranular, muscovite, biotite granite, which is slightly foliated, intrudes the semipelite. The muscovite is coarse grained and is located within the thermal aureole of the Deadman's Bay Granite. The age spectrum for sample 87-839 has a plateau age of 397 ± 5 Ma and a total gas age of 396.4 ± 4.6 Ma.

Samples 87-847 and 86-302 represent the Ocean Pond granite and a muscovite-rich pegmatite, spatially and mineralogically related to the granite. The age spectrum for the granite (87-847) is quite flat with a plateau age of 398 ± 5 Ma and a total gas age of 397.1 ± 4.7 Ma. The pegmatite sample (87-302) was collected 3 km southwest of the granite, intrudes the garnet zone and has a slightly younger age of 389 ± 4 (total gas age) and a plateau age of 390 ± 7 Ma.

Biotite. $^{40}Ar/^{39}Ar$ age spectra were determined for two biotite concentrates from pelitic samples 86-191 and 86-204, collected from the biotite zone of the Gander Group Jonathans Pond formation and one concentrate, sample 87-846, from the Deadman's Bay Granite; age spectra are shown on Figure 1.

The spectrum for sample 86-191, already mentioned, has a plateau age of 398 ± 5 and a total gas age of 396.3 ± 4.2 Ma.

Sample 86-204 has a discordant hump-shaped spectrum and gives a total gas age of 398 ± 4 Ma. The low temperature part of the spectrum records an anomalously young age, however, the initial gas fraction represents only 8 percent of the total gas liberated and thus the young age has little, if any, significance. The total gas age is similar to both plateau and total gas ages (biotite) of sample 86-191 and is also similar to plateau ages given by muscovite spectra of pelites from the same area. Sample 87-846, collected from the Deadman's Bay Granite, is a K-feldspar rich, megacrystic biotite granite, which contains 15 to 20 modal percent biotite and < 5 percent muscovite. The age spectrum is hump shaped and the first gas fraction represents 7 percent of the total Ar liberated. The remaining increments are slightly discordant and a plateau is absent; the total gas age is 404 ± 4 Ma.

DISCUSSION

$^{40}Ar/^{39}Ar$ incremental release spectra on muscovite and biotite from metasedimentary and igneous rocks from the northeastern part of the Weir's Pond map area, generally exhibit reasonable plateaus, and when combined with microfabric and porphyroblastesis relationships, suggest that a single regional thermal event affected most of these rocks.

Most muscovite plateau ages fall in the range between 404 and 388 Ma and are similar to the total gas ages, which range from approximately 400 to 385 Ma. Muscovite cooling ages on the Ocean Pond granite and an associated pegmatite, fall within this range. It is not clear whether the granite and metamorphism are two separate effects of a crustal heating event or whether the metamorphism reflects a regional aureole associated with a massive granite at depth; the Ocean Pond granite being a surface manifestation of this larger granitic body. Lux *et al.* (1986) in a study of New England granites and low pressure−high temperature metamorphic belts, concluded that the plutons provided the source of heat for the regional metamorphism. The relationship between the Ocean Pond granite and the regional metamorphism in the Weir's Pond area is very similar to that displayed by granites and metamorphic belts in New England.

Biotite cooling ages are similar to those of muscovite, and range from 402 to 393 Ma, implying that both minerals passed through their closure temperatures, of between 350°C and 250°C respectively.

Muscovite and biotite $^{40}Ar/^{39}Ar$ cooling ages suggest that these metasediments and the Ocean Pond granite cooled through greenschist facies conditions between approximately 400 and 385 Ma. The partial overlap of biotite growth and F_3 development, suggest that these cooling ages constrain the D_3 event, which was a phase of upright folding.

Although the Deadman's Bay Granite is clearly posttectonic, cutting all structures in the metasediments, its biotite age suggests that it cooled slightly earlier than the metasediments and the synkinematic Ocean Pond granite. The similarity between this biotite age and the coarse muscovite from the hornfelsed aureole, and the remaining muscovite and biotite from the Ocean Pond area and southwestward, suggest that the Deadman's Bay Granite intruded very soon after the main thermal event. As reference to Figure 1 will show, some of the muscovite and biotite samples were taken up to 20 km from the Deadman's Bay Granite and thus have not been affected by any localized thermal resetting due to this granite. The 404 Ma biotite age on the Deadman's Bay Granite is similar to a K/Ar age of 400 ± 13 Ma, obtained from the granite by Currie (*in* Stevens *et al.*, 1981).

Sericitic metavolcanic rocks from the western part of the Avalon Zone, yielded whole rock $^{40}Ar/^{39}Ar$ spectra with plateau ages in the range 370 to 390 Ma (Dallmeyer *et al.*, 1983), which were interpreted to closely date the regional metamorphism and associated deformation in the western Avalon Zone. $^{40}Ar/^{39}Ar$ age spectra on biotite from the Hare Bay Gneiss in the northeastern Gander Zone, record plateau ages ranging from 365 to 383 Ma (Dallmeyer *et al.*, 1981) and were interpreted to date the regional post-metamorphic cooling and also reflect a minimum date for initial tectonic activity along the Dover Fault. The older ages within the range of dates described by Dallmeyer *et al.* (1983) are similar to those presented in this paper, and imply a synchroneity in post-metamorphic cooling throughout the northern Gander and western Avalon zones.

In southern Newfoundland, Dunning *et al.* (1988) argue for a major Late Silurian orogeny with medium to high grade, regional metamorphism and deformation, combined with plutonism and volcanism. The North Bay Granite is posttectonic, dated by U–Pb at 396 $^{+5}_{-3}$ and provides a younger age limit for the orogenic event in the south. Cooling ages on biotite and muscovite from the Weir's Pond area in the northeastern Gander Zone, are approximately 20 Ma younger than U–Pb peak metamorphic ages for the southern Newfoundland event and suggest that plutonism and metamorphism in the northeastern Gander Zone may have occurred synchronously with the Late Silurian orogeny as defined for southern Newfoundland.

The overlap between biotite porphyroblastesis (and recrystallization of muscovite) and the D_3 deformational phase, allows this phase to be somewhat constrained to a Late Silurian–Early Devonian time frame. The early, main phase of deformation, which had quite a different style and was pre-metamorphic, is therefore an older event, probably Early Silurian at the youngest, based on correlations with southern Newfoundland.

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