

PRELIMINARY U–Pb GEOCHRONOLOGICAL DATA FROM MESOPROTEROZOIC ROCKS, GRENVILLE PROVINCE, SOUTHERN LABRADOR

D.T. James, S. Kamo¹, T. Krogh¹, and L. Nadeau²
Regional Geology Section

ABSTRACT

Preliminary geochronological studies of samples of deformed and recrystallized quartz monzonite and K-feldspar porphyritic granite, occurring within the Mecatina terrane (MECT), Grenville Province, indicate igneous emplacement ages of 1500 ± 4 Ma and 1493 ± 3 Ma, respectively, based on U–Pb data from zircons. The widespread occurrence of these types of rocks suggests the MECT is dominated by Mesoproterozoic (Pinwarian-age) intrusions. The data also constrain the depositional age of included supracrustal gneisses to be older than 1500 Ma, consistent with a proposed correlation between the supracrustal rocks and the Wakeham Group. Titanite, within the porphyritic granite, gives an age of 1043 ± 6 Ma, which is interpreted to represent the time of upper amphibolite-facies Grenvillian metamorphism and attendant deformation in the MECT.

Zircons taken from an undeformed and unrecrystallized biotite granite give an age of 964 ± 3 Ma. The granite intrudes Labradorian-age rocks that make up the Mealy Mountains terrane. The age is interpreted as the time of igneous emplacement and confirms that the intrusion is late- to post-Grenvillian. The same rock contains titanite yielding ages between 957 and 935 Ma, and possibly signifying a post-Grenvillian thermal event.

INTRODUCTION

Precise age dating of rocks using U–Pb geochronological methods is an essential supplement to reconnaissance-scale bedrock mapping in areas where intrusive and metamorphic ages are inadequately known and unequivocal contact relationships between rock units are unexposed. As part of the ongoing 1:100 000-scale mapping of the Grenville Province in NTS map area 13/C (Minipi Lake map area; Figure 1), southern Labrador, (*see* James, 1999; James and Lawlor, 1999; James and Nadeau, 2000a, b; James *et al.*, 2000; Wardle *et al.*, 2000; James and Nadeau, *this volume*), samples were collected from regionally important intrusive units that make up the Mecatina terrane (MECT), and from an undeformed granite pluton that intrudes the Mealy Mountains terrane (MMT). The samples collected from the MECT are significant because rocks from this terrane in Labrador have never been dated.

Fractions of zircon and titanite from the samples were analyzed at the Jack Satterley Geochronology Laboratory, Royal Ontario Museum, Toronto. The results, as well as a brief discussion of their implications, are presented in this report. The ages should be considered as preliminary. It may be necessary in the future to collect additional mineral fractions from the same samples or to re-analyse certain fractions in order to refine the ages.

REGIONAL SETTING

The study area is situated in the northeastern Grenville Province and includes parts of the Mealy Mountains and Mecatina terranes (Figure 2). These terranes are Grenvillian tectonic divisions, although they consist primarily of late Paleoproterozoic (MMT) and Mesoproterozoic (MECT) crust.

¹ Jack Satterley Geochronology Laboratory, Royal Ontario Museum, Toronto, Ontario

² Earth Sciences Sector, Geological Survey of Canada, GSC-Québec

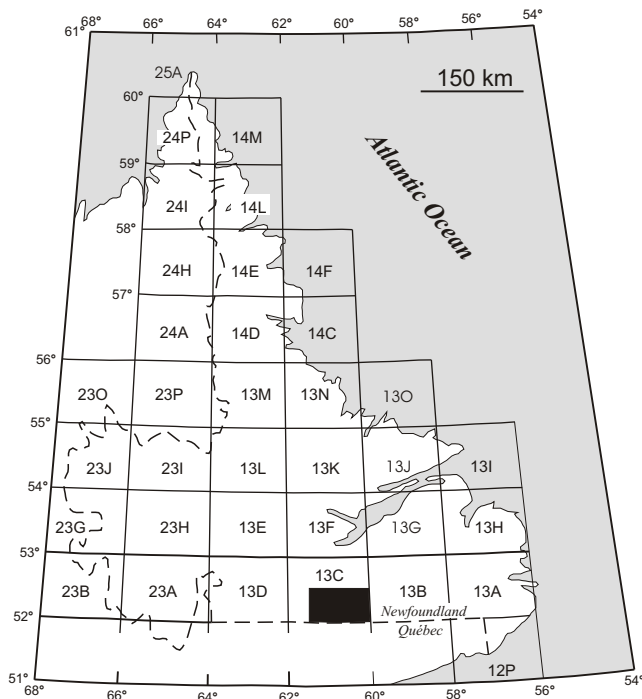


Figure 1. NTS index map for Labrador showing location of the study area.

The MMT (Gower and Owen, 1984) consists primarily of late Paleoproterozoic (Labradorian-age) crust of the Mealy Mountains intrusive suite (MMIS) (*see* Emslie, 1976; Emslie and Hunt, 1990; Krogh *et al.*, 1996), minor amounts of Paleoproterozoic pre-Labradorian crust, and Pinwarian (1510 to 1450 Ma) and late- to post-Grenvillian intrusions (Gower, 1996). The MMIS consists mainly of an older group of anorthositic, leucogabbroic and leucotroctolitic rocks, and a younger group of pyroxene-bearing monzonite and quartz monzonite intrusions. Emplacement ages for units of MMIS monzodiorite orthogneiss, porphyritic quartz monzodiorite and pyroxene-bearing monzonite, occurring in the Kenamu River area (NTS map area 13C/NE) and determined by U–Pb geochronology of zircon, are 1659 ± 5 Ma, 1650 ± 1 Ma, and 1643 ± 2 Ma, respectively (James *et al.*, 2000). In addition, pyroxene monzonite and pyroxene granite, inferred to be from the younger group of MMIS rocks and occurring in the northeastern part of the MMIS, have emplacement ages of 1646 ± 2 Ma and $1635 \pm 22/8$ Ma (Emslie and Hunt, 1990), respectively. Emplacement ages of MMIS rocks overlap with the regionally significant tectonothermal and magmatic events of the Labradorian Orogeny, which occurred in northeastern Laurentia in the interval between 1720 and 1600 Ma (*see* Gower, 1996).

Rocks in the western part of the MMT are variably foliated and locally gneissic; in general, they have northeast- to east-northeast-striking planar fabrics that are inferred to be Labradorian (James and Nadeau, 2000a). However, the local

occurrence of deformed Pinwarian-age (ca. 1514 Ma) granite in the Kenamu River area (James *et al.*, 2000) demonstrates the western part of the terrane has also been affected by Pinwarian and/or Grenvillian deformation.

The MECT in Labrador has not been studied in much detail. The oldest rocks, which make up a very minor amount of the MECT, are inferred to be upper amphibolite-facies supracrustal rocks provisionally correlated with the >1500 Ma Wakeham Group in Québec. The supracrustal rocks are intruded by granitoid orthogneiss, deformed granitic and monzonitic rocks, gabbro, anorthosite and local troctolite. The igneous rocks are part of the Petit Mecatina anorthosite–monzonite–charnockite granite (AMCG) suite. However, geochronological data are lacking and the MECT may include igneous rocks having significantly different emplacement ages. The principal foliation and gneissosity in MECT rocks are mainly west-southwest- to west-northwest-striking. On the basis of U–Pb geochronological data (*discussed below*), metamorphism and attendant deformation of the MECT are interpreted to be Grenvillian.

The location and nature of the boundary between the MMT and the MECT terrane are uncertain (James and Nadeau, *this volume*). In the Fourmont Lake area (Figure 3), rare occurrences of mylonitic rocks having an undetermined kinematic history suggest the boundary is a south-dipping high-strain zone, possibly Grenvillian in age. However, the area inferred to contain the terrane boundary is very poorly exposed and reliable field data are lacking.

The MMT and the MECT are intruded by plutons consisting of unmetamorphosed, massive to weakly foliated granite. These plutons are interpreted to be part of a widespread suite of 966 to 956 Ma granitoid intrusions occurring in the Pinware terrane and the southeastern MMT (*see* Gower, 1996).

GENERAL GEOLOGY

In the study area (Figure 3; *see* James and Nadeau, 2000a, b), the MECT consists of units of foliated to augen-textured and locally gneissic K-feldspar porphyritic granite (M_{MC} kpg), foliated quartz monzonite (M_{MC} qmm) and metamorphosed gabbro (M_{MC} gbr). These units are tentatively interpreted to be part of the Petit Mecatina AMCG suite. The granite and quartz monzonite units contain inclusions of upper amphibolite-facies quartzite and pelitic migmatite. The M_{MC} gbr gabbro forms small, locally layered intrusions south and west of Fourmont Lake, and occurs as minor dykes in the M_{MC} kpg porphyritic granite. The quartz monzonite is intruded by unmetamorphosed, northeast- and northwest-striking mafic dykes.

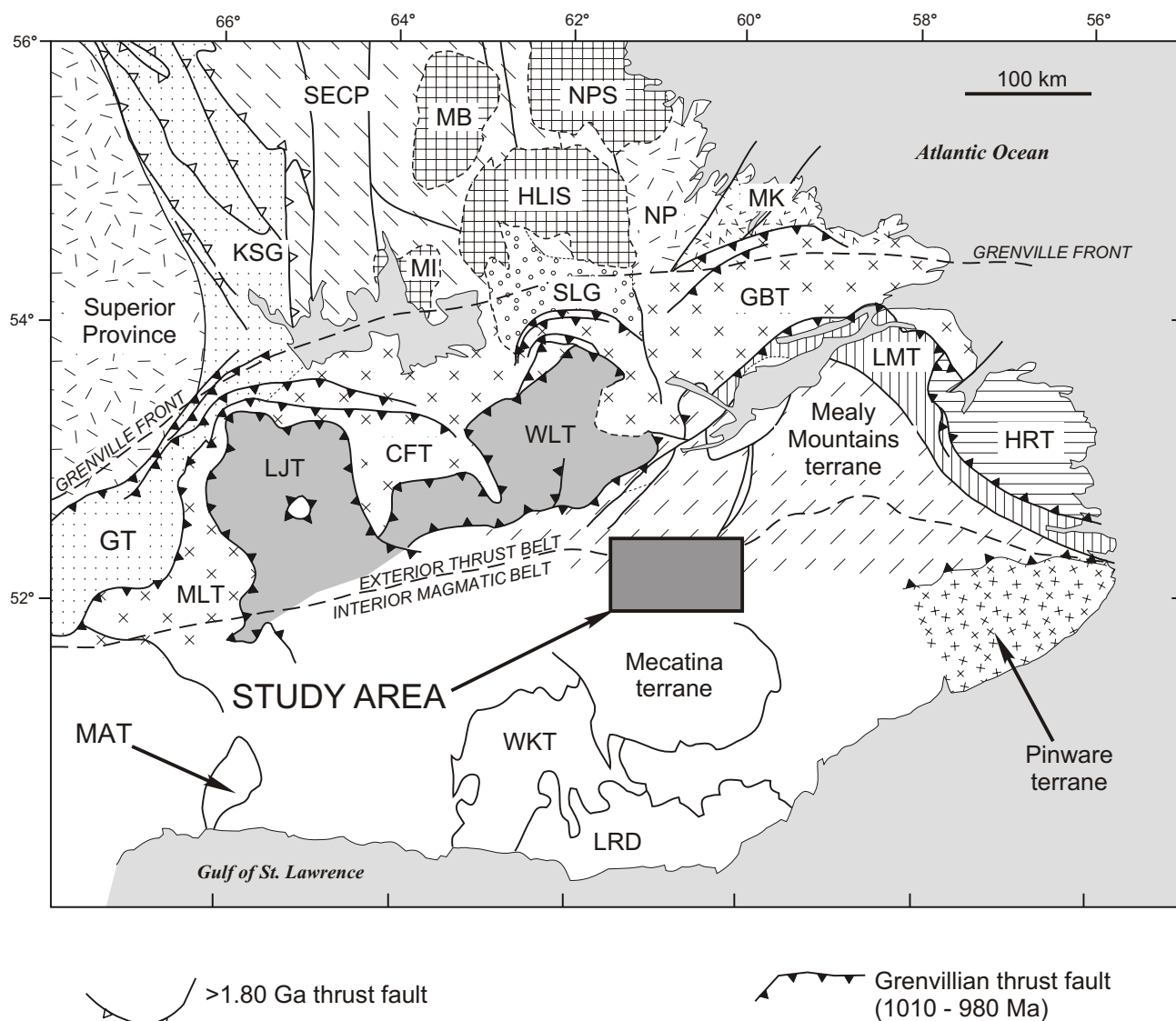


Figure 2. Location of the Minipi Lake (NTS map area 13C/S) study area in relation to the tectonic and major lithotectonic units of northeastern Laurentia. Grenville Province: HRT - Hawke River terrane, LMT - Lake Melville terrane, GBT - Groswater Bay terrane, WLT - Wilson Lake terrane, CFT - Churchill Falls terrane, LJT - Lac Joseph terrane, MLT - Molson Lake terrane, GT - Gagnon terrane, MAT - Matamec terrane, WKT - Wakeham terrane, LRD - La Romaine domain. Archean divisions: SP - Superior Province, NP - Nain Province (Hopedale Block). Archean and Paleoproterozoic divisions: MK - Makkovik Province, SECP - Southeastern Churchill Province (core zone), KSG - Kaniapiskau Supergroup (2.25 to 1.86 Ga). Mesoproterozoic units: NPS - Nain Plutonic Suite, HLIS - Harp Lake intrusive suite, MB - Mistastin batholith, MI - Michikamau Intrusion, SLG - Seal Lake Group.

Labradorian-age units of deformed and variably recrystallized monzodiorite and monzonite gneiss (P_{MM} mdq), monzonite (P_{MM} mzt), gabbro and gabbro-norite (P_{MM} gbr), belonging to the MMIS, dominate the MMT. The terrane also includes a unit of granitoid orthogneiss (P_1 ggn), containing abundant rafts of amphibolite. Emplacement age(s) of igneous protoliths of P_1 ggn rocks are undetermined.

Plutons consisting of medium- to coarse-grained granite (M_{LG} grn) and K-feldspar porphyritic granite (M_{LG} kpg) intrude the MECT and MMT. They are interpreted to be late- to post-Grenvillian in age. The rocks are unmetamorphosed and mainly undeformed, although local occurrences of weakly foliated granite demonstrate that pluton emplacement slightly overlaps and postdates the late stages of

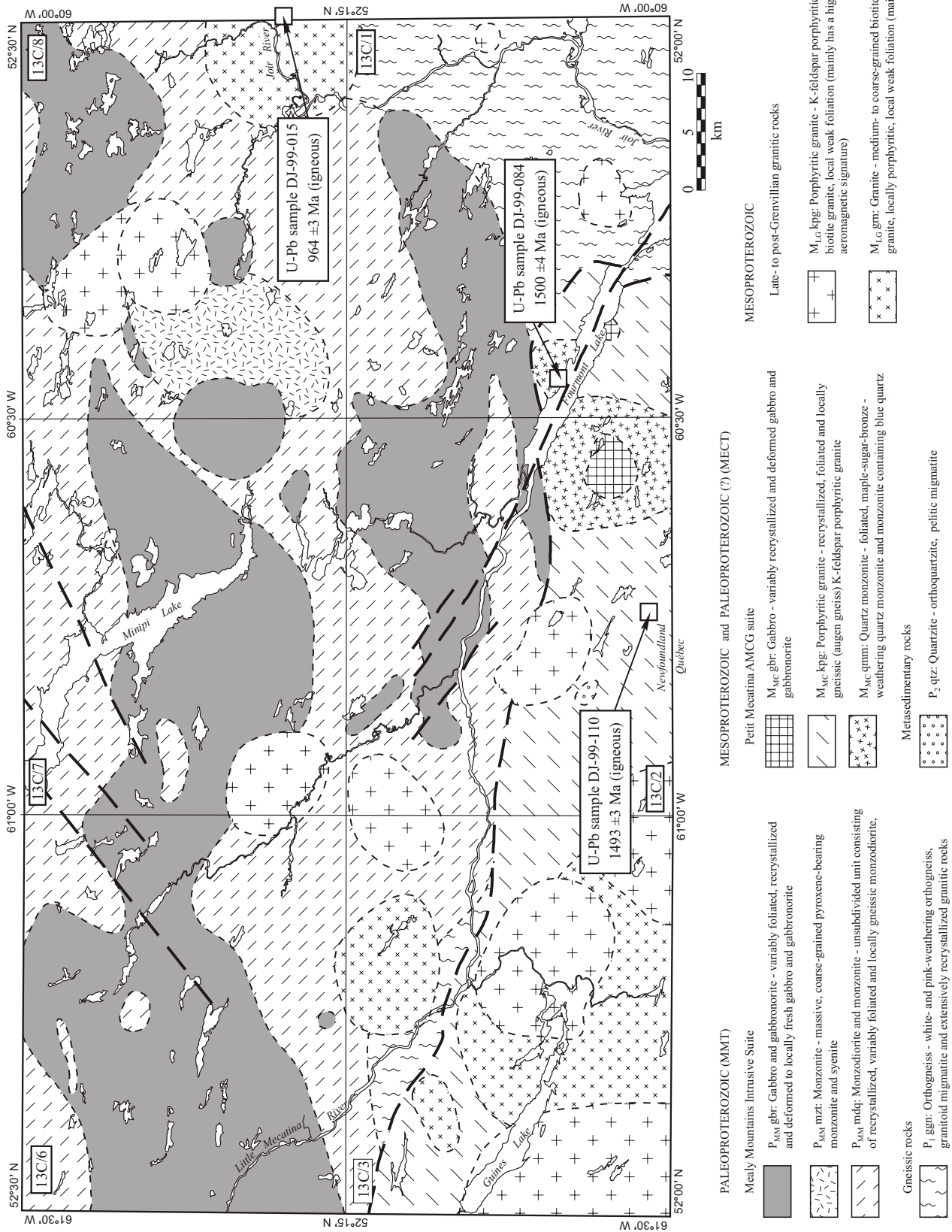


Figure 3. General geology of the Miripi Lake study area. Modified from James and Nadeau (2000b). MMT - Mealy Mountains terrane. MECT - Meccatina terrane.

Grenvillian orogenesis. The magnetic expression of these intrusions is varied, although they are commonly marked by prominent circular or elliptical, magnetic highs.

ANALYTICAL PROCEDURES

Zircon and titanite were separated from the rock samples using standard heavy liquid and magnetic separation techniques. All zircon fractions had an air abrasion treatment (see Krogh, 1982). Mineral dissolution and isolation of U and Pb from zircon follow the procedure of Krogh (1973), modified by using small anion exchange columns (0.05 mL of resin) that permit the use of reduced acid reagent volumes. Zircon fractions weighing less than 0.005 mg had no chemical separation procedures. The HBr method was used to extract U and Pb from titanite (see Corfu and Stott, 1986).

Lead and U were loaded together with silica gel onto outgassed rhenium filaments. The isotopic compositions of Pb and U were measured using a single collector with a Faraday or Daly detector in a solid source VG354 mass spectrometer. A mass fractionation correction of 0.1% per AMU for both Pb and U was used. The laboratory blanks for Pb and U were usually 1 to 3 pg and 0.2 pg, respectively, for zircon, and 10 and 2 pg, respectively, for titanite, which required larger anion exchange columns. In some cases the laboratory blank was higher due to common Pb introduced by a contaminated HCl bottle; in these cases the isotopic composition was corrected. Error estimates were calculated by propagating known sources of analytical uncertainty for each analysis including ratio variability (within run), uncertainty in the fractionation correction (0.015% and 0.038% (1 sigma) for Pb and U, respectively, based on long-term replicate measurements of the standards NBS981 and U-500), and uncertainties in the isotopic composition and amount of laboratory blank and initial Pb. Initial common Pb in excess of blank was corrected using the Stacey and Kramers (1975) Pb evolution model. Decay constants are those of Jaffey *et al.* (1971). All age errors quoted in the text and error ellipses on the concordia diagrams are given at the 95% confidence interval. Discordia lines and intercept ages were calculated using the regression program of Davis (1982).

SAMPLE DESCRIPTIONS

QUARTZ MONZONITE (M_{MC} qmm)

A sample (DJ-99-084) of quartz monzonite (M_{MC} qmm) was collected from an outcrop on the north shore of Fourmont Lake (UTM 674127m. E, 5773188m. N, Grid Zone 20, NAD 1927 projection, NTS map area 13C/1). The outcrop consists mainly of quartz monzonite, although it also contains common, small (< 30 cm), grey, fine-grained mafic inclusions, and unmetamorphosed, 045°- and 320°-striking

diabase dykes. The quartz monzonite is foliated and deformed by very thin (<10 cm), west-southwest-striking ductile shear zones containing protomylonitic and mylonitic rocks (Plate 1).



Plate 1. M_{MC} qmm quartz monzonite (DJ-99-084 sample location) containing minor west-southwest-striking Grenvillian shear zones.

The sample is pink- and black-weathering and is a light bronze on the fresh surface; quartz is bluish-grey. The rock is medium to coarse grained, weakly foliated, and contains abundant coarse-grained K-feldspar. It also contains <10 percent, fine-grained relicts of igneous clinopyroxene that are mainly replaced by hornblende and biotite. The rock has accessory magnetite and zircon.

Abundant, euhedral, clear, pale-brown zircons containing numerous melt inclusions were recovered from the sample. Three concordant data points (fractions 1 to 3; see Figure 4 and Table 1), comprising two fractions of two grains and one single-grain fraction, gave $^{207}\text{Pb}/^{206}\text{Pb}$ ages of 1499.9 ± 7.0 , 1499.9 ± 6.4 and 1500.9 ± 6.0 Ma. These ages are 0.3%, 0.7% and 0.6% discordant toward a zero-age (0 Ma) lower intercept, respectively. The weighted mean Pb/Pb age is 1500.3 ± 3.7 Ma and is considered the time of zircon crystallization and the best estimate for the time of igneous emplacement of M_{MC} qmm quartz monzonite.

K-FELDSPAR PORPHYRITIC GRANITE (M_{MC} kpg)

K-feldspar porphyritic granite (DJ-99-110) was collected from the M_{MC} kpg unit, approximately 15 km southwest of Fourmont Lake (UTM 654046m. E, 5765078m. N, Grid Zone 20, NTS map area 13C/2). The outcrop is very homogeneous; it consists of well-foliated K-feldspar porphyritic granite and is lacking in inclusions or younger dykes. The sample is light pink and white on the fresh and weathered surfaces. It is fine to coarse grained, containing abundant,

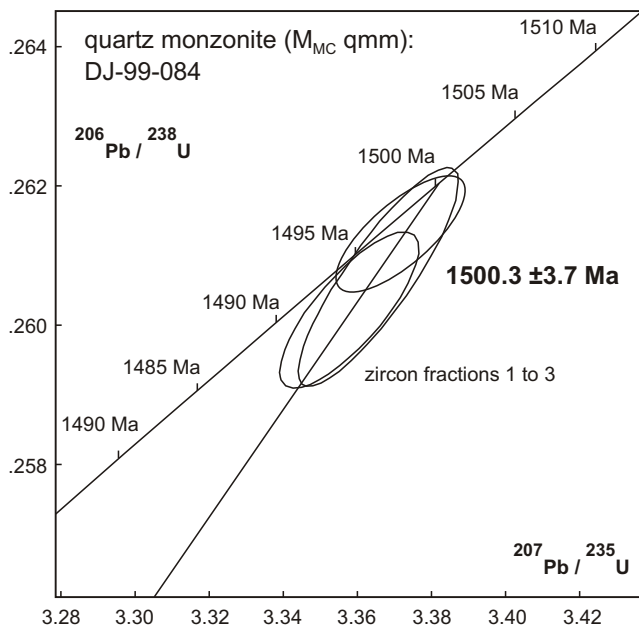


Figure 4. *U-Pb concordia diagram for sample DJ-99-084.*

coarse-grained K-feldspar phenocrysts (Plate 2) surrounded by fine-grained, recrystallized K-feldspar (microcline), plagioclase and quartz. The sample contains less than 10 percent, pleochroic-green biotite, accessory titanite and zircon.

One concordant data point was obtained from a single zircon fraction (Fraction 4; Figure 5) and three near-concordant data points were obtained from three fractions consisting of three zircons each (fractions 5 to 7). The ²⁰⁷Pb/²⁰⁶Pb ages for fractions 4 to 7 are 1492.7 ± 4.2, 1490.6 ± 2.6, 1490.8 ± 3.8 and 1489.1 ± 8.4 Ma, and are 0.1%, 0.5%, 0.6% and 1.0% discordant, respectively. The ²⁰⁷Pb/²⁰⁶Pb weighted mean age is 1491.1 ± 2.1 Ma, slightly younger and within error of the upper intercept age of 1492.9 ± 2.5 Ma



Plate 2. *Foliated M_{MC} kpg K-feldspar porphyritic granite (DJ-99-110 sample location).*

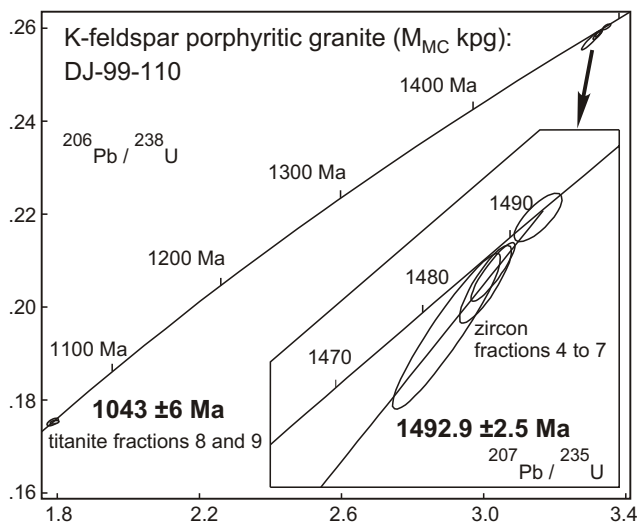


Figure 5. *U-Pb concordia diagram for sample DJ-99-110. Inset (lower right) shows enlarged plots of zircon fractions 4 to 7.*

(97% probability of fit). The latter age is the best estimate for the time of zircon crystallization and M_{MC} kpg granite emplacement.

Two fractions of brown titanite fragments from the same sample (fractions 8 and 9) gave distinctly younger ²⁰⁷Pb/²⁰⁶Pb ages of 1040.1 ± 14.4 Ma and 1046.3 ± 12.6 Ma, that are -0.1% and 0.6% discordant, respectively (Figure 5). The mean Pb/Pb age of these two points is 1043 ± 6 Ma. This age is interpreted to represent the time of new titanite crystallization, as opposed to isotopic resetting of existing titanite, because the gem-like habit of the crystals suggests they are newly formed.

BIOTITE GRANITE (M_{LG} grn)

A sample of granite (DJ-99-015) was collected from an M_{LG} grn pluton occurring on the Joir River (UTM 704629m. E, 5798187m. N, Grid Zone 20, NTS map area 13B/5). The pluton was correlated in the field, with late- to post-Grenvillian intrusions, based on correlation of rock types and because the rocks are undeformed. However, the sample comes from an intrusion not marked by a magnetic high, which is in marked contrast with many of the known late- to post-Grenvillian intrusions. Thus, the field designation is uncertain.

The sample is medium pink on the fresh and weathered surfaces. It is a medium- to coarse-grained granite to quartz monzonite containing coarse-grained K-feldspar (microcline), <10 percent pleochroic-green biotite, several percent titanite, a very minor amount of magnetite and accessory zircon (Plate 3). Rocks are massive and have a consistent

Table 1. U–Pb isotopic data for zircon and titanite

No.	Fraction	Weight (mg)	U (ppm)	Th/U	Pb/U (ppm)	²⁰⁶ Pb/ ²⁰⁸ Pb	²⁰⁶ Pb/ ²³⁸ U	²⁰⁷ Pb/ ²³⁸ U	2 sigma	²⁰⁶ Pb/ ²³⁸ U	2 sigma	Age (Ma)/2 sigma	%Disc.	2 sigma
<i>DJ99-084 monzonite</i>														
1	2 Ab Zr, 2:1 pr, euh, pale brown gem	0.008	41	0.60	1.4	382.4	0.26129	0.00083	3.3716	0.0173	1499.8	7.0	0.2	0.3
2	1 Ab Zr, 3:1 pr, euh, pale brown gem, no chemistry	0.004	93	0.65	1.6	371.5	0.26069	0.00138	3.3657	0.0217	1500.8	6.1	0.6	0.4
3	2 Ab Zr, 2:1 pr, euh, pale brown gem, no chemistry	0.005	77	0.60	1.3	491.2	0.26022	0.00112	3.3379	0.0188	1499.8	6.4	0.7	0.3
<i>DJ99-110 foliated, megacrystic granite</i>														
4	1 Ab Zr, equant, euh, pale brown gem	0.009	43	0.48	1.7	369.2	0.26030	0.00063	3.3460	0.0116	1492.5	4.2	0.1	0.2
5	3 Ab Zr, equant, euh, pale brown gem	0.009	154	0.46	1.5	1407.0	0.25888	0.00076	3.3241	0.0106	1490.5	2.6	0.5	0.2
6	3 Ab Zr, no chemistry	0.004	217	0.54	1.0	1335.5	0.25857	0.00102	3.3205	0.0126	1490.7	3.8	0.6	0.3
7	3 Ab Zr, no chemistry	0.002	219	0.51	0.7	995.1	0.25734	0.00203	3.3018	0.0262	1489.0	5.2	1	0.5
8	3 titanite fragm ents, brown, clear	0.015	129	0.14	24.0	79.2	0.17527	0.00083	1.7869	0.0162	1039.9	14.4	-0.1	0.8
9	15 titanite fragments, brown, clear	0.109	156	0.05	139.8	109.6	0.17526	0.00040	1.7923	0.0120	1046.2	12.6	0.5	0.7
<i>DJ99-015 massive, discord granite</i>														
10	11 Ab Zr, euh, pale brown, 2:1 pr, many melt inclusions	0.032	67	1.07	8.1	211.4	0.16112	0.00047	1.3819	0.0072	963.4	7.0		0.4
11	12 Ab Zr, euh, pale brown, 2:1 pr, few melt inclusions	0.025	102	0.97	5.2	376.6	0.16109	0.00036	1.3823	0.0048	964.3	4.1	0.2	0.3
12	4 Ab Zr, re edies 4:1 pr, euh, pale brown, many melt inclusions	0.034	28	1.35	4.3	175.2	0.16095	0.00044	1.3789	0.0079	961.6	7.9	-0.1	0.4
13	multi-titanite, clear, high quality fragments	0.130	38	7.02	400.5	28.4	0.16001	0.00044	1.5559	0.0372	943.6	49.1	-1.5	2.9
14	23 titanite fragments, clear, brown	0.267	47	7.08	695.2	28.7	0.15913	0.00049	1.5574	0.0374	948.7	49.5	-0.4	2.9
15	1 titanite fragm ent, clear, brown	0.020	50	7.30	39.0	27.6	0.15880	0.00049	1.5394	0.0368	937.4	48.4	-1.5	2.9
16	multi-titanite fragments, clear, very pale brown	0.146	19	1.95	375.2	20.4	0.15615	0.00083	1.4810	0.0930	892.4	132.2	-5.2	9

Ab is abraded; Zr is zircon; euh is euhedral; pr is prismatic.

Th/U is calculated from radiogenic ²⁰⁶Pb/²³⁸U ratio and ²⁰⁷Pb/²³⁸U age.²⁰⁶Pb/²³⁸U is corrected for fractionation and spike.²⁰⁷Pb/²³⁸U ratios are corrected for fractionation, spike, blank, and common Pb.

composition and texture. The outcrop contains rare, cognate inclusions of finer grained granite.

Three multigrain zircon fractions (fractions 10 to 12; Figure 6) consisting of euhedral, pale-brown, prismatic (2:1 aspect ratio), clear grains, and elongate (4:1 aspect ratio) grains gave overlapping and concordant data having a weighted mean ²⁰⁷Pb/²⁰⁶Pb age of 963.8 ± 3.2 Ma. This age is interpreted to be the time of zircon crystallization and igneous emplacement.

Three fractions of clear, brown titanite fragments, including two multi-fragment fractions (fractions 13 and 14) and a single fragment (Fraction 15), are concordant and within error of each other and yield ²⁰⁶Pb/²³⁸U ages of 956.9 ± 2.4 Ma, 952.0 ± 2.8 Ma and 950.2 ± 2.8 Ma. A fourth multi-fragment titanite fraction consisting of very pale-brown grains (Fraction 16) gave a ²⁰⁶Pb/²³⁸U age of 935.3 ± 4.6 Ma. The significance of the titanite ages is uncertain but may represent a late Grenvillian thermal event that caused varying degrees of recrystallization, or two discrete growth episodes resulting in the brown and pale-brown titanite.

DISCUSSION

The 1500 ± 4 Ma and 1493 ± 3 Ma ages for M_{MC} qmm quartz monzonite and M_{MC} kpg porphyritic granite units, interpreted to be the time of igneous emplacement for each, represent the first geochronological data from rocks of the MECT in Labrador. The widespread occurrence of these units, especially the porphyritic granite, suggests the MECT is dominated by Mesoproterozoic (Pinwarian-age) intrusive rocks. These ages are similar to emplacement ages for granitoid rocks reported from the Pinware terrane (e.g., Tucker and Gower, 1994; Gower, 1996), the Wakeham and La Romaine terranes (J. David, *unpublished data*). The ages for these MECT intrusive units constrain the depositional age of included supracrustal gneisses to be older than 1500 Ma, consistent with a model proposing a correlation between the MECT supracrustal rocks and the Wakeham Group (James and Nadeau, 2000a). The ages of M_{MC} qmm and M_{MC} kpg units are only slightly younger than the emplacement age of a 1514 ± 10 Ma foliated granite (James *et al.*, 2000), which occurs in the MMT, 60 km north of Fourmont Lake. Pinwarian-age intrusive rocks make up a very minor part of the MMT, although the similarity in intrusive ages may suggest a Pinwarian-age linkage between MMT and MECT crust. Nevertheless, the pre-Grenvillian tectonic relationships between Labradorian-age and Pinwarian-age crust remain an outstanding problem.

The M_{MC} qmm quartz monzonite and M_{MC} kpg porphyritic granite units are considered to be part of the Petit

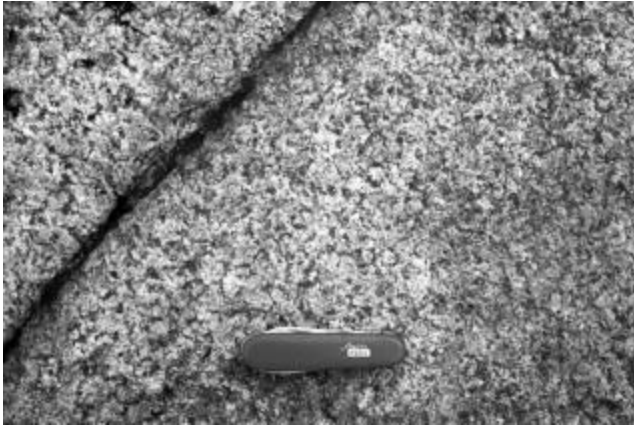


Plate 3. Typical field aspects of medium-grained, massive M_{LG} grn biotite granite (DJ-99-015 sample location). Mecatina AMCG suite, which also includes gabbro and anorthosite. However, the anorthosite intrusions have not been dated and the possibility exists that the MECT includes unrelated AMCG suite rocks having significantly different ages.

The 1043 ± 6 Ma age determined from titanite, contained in the sample of porphyritic granite, is interpreted to represent the time of upper amphibolite-facies Grenvillian metamorphism in the MECT. The foliation in this rock is interpreted as a Grenvillian fabric. There are no field nor geochronological data to indicate that MECT rocks have a Pinwarian history of metamorphism and deformation. A lower intercept age of ca. 1050 Ma (U–Pb analyses on zircon), obtained from the Pinwarian-age granite in the MMT (*discussed previously*) and interpreted as the time of Grenvillian overprinting of the MMT, may suggest that the MMT and MECT were joined by that time.

The 964 ± 3 Ma age determined from the sample of M_{LG} grn granite, and interpreted as the time of igneous emplacement, confirms the intrusion is late- to post-Grenvillian in age. The age is consistent with emplacement ages between 966 and 956 Ma for similar granitoid intrusions occurring in the northeastern Grenville Province. The significance of titanite ages between 957 and 935 Ma, from the same sample of M_{LG} grn granite, is unknown. These ages may represent a thermal event resulting in resetting or growth of new titanite. A poorly constrained lower intercept age of ca. 940 Ma (U–Pb analyses on zircon) determined from a Labradorian-age monzodiorite gneiss (James *et al.*, 2000) in the MMT, may suggest effects of this late thermal event are relatively widespread in this part of the Grenville Province.

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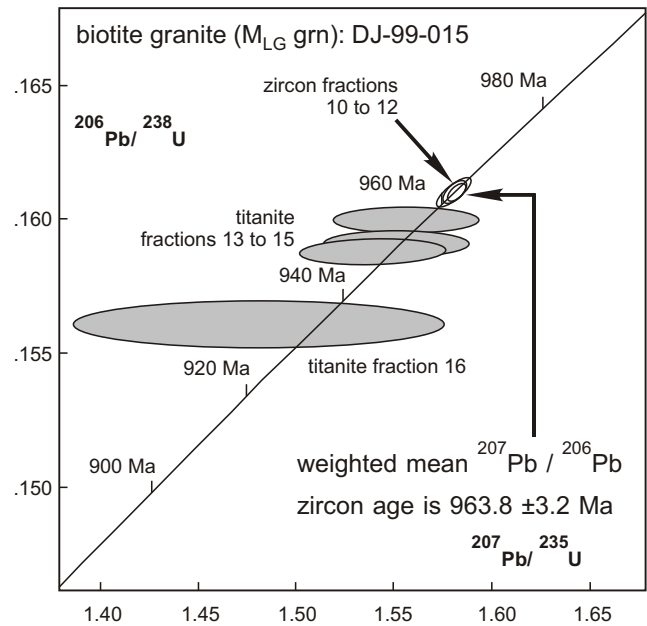


Figure 6. U–Pb concordia diagram for sample DJ-99-015 (zircon data - open ellipses; titanite data - shaded ellipses).

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