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Article abstract

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U-Pb dating of the Musquodoboit Batholith, southern Nova Scotia: evidence for a protracted magmatic-hydrothermal event in a Devonian intrusion

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ABSTRACT

The first high-temperature geochronometric data are presented for the peraluminous, multiple phase Musquodoboit Batholith, the second largest intrusion in the Meguma terrane of Nova Scotia. Previous geochronology includes $^{40}Ar/^{39}Ar$ mica (i.e., muscovite and biotite, 363 to 370 Ma) and Rb-Sr whole-rock (266 Ma) and mineral (biotite, 370 Ma) ages. These earlier ages contrast with new data for zircon and monazite which together define an age of 378 ± 1 Ma for the high-temperature crystallization (i.e., ca. >650–800°C) and, therefore, provide a more reliable time for emplacement and solidification of the batholith. Integration of the new data with previous work is reconciled in the context of a protracted cooling history for the intrusion that reflects the depth of emplacement (i.e., 10–12 km) and potentially high geothermal gradient due to the radioelement-rich nature of parts of the complex. This study suggests that absolute dating of large intrusive bodies emplaced at moderate crustal levels (i.e., ≥3–4 kbars) should employ high-temperature geochronometers rather than the commonly used $^{40}Ar/^{39}Ar$ mica technique, which is limited due to the relatively lower blocking temperatures of ≤350°C.

RÉSUMÉ

Les premières données géochronométriques à haute température visent le batholite hyperalumineux à phases multiples de Musquodoboit, deuxième intrusion en importance dans le terrane de Meguma, en Nouvelle-Écosse. Les données géochronologiques antérieures comprennent des datations $^{40}Ar/^{39}Ar$ de mica (c.-à-d. muscovite et biotite, de 363 à 370 Ma), une datation Rb-Sr de roche totale (266 Ma) et une datation minérale (biotite, 370 Ma). Ces âges plus précoces contrastent avec les nouvelles données du zircon et de la monazite, qui confèrent ensemble un âge de 378 ± 1 Ma par cristallisation à haute température (c.-à-d. à environ > 650 à 800 °C) et qui fournissent par conséquent une datation plus fiable de la mise en place et de la solidification du batholite. L'intégration des nouvelles données concordent avec les travaux antérieurs compte tenu du refroidissement passé prolongé de l'intrusion correspondant à la profondeur de l'enfouissement (c.-à-d. 10 à 12 kilomètres) et du gradient géothermique potentiellement élevé en raison de la nature riche en radioéléments de certaines parties du complexe. Cette étude permet de supposer qu'il faut employer des géochronomètres à température élevée plutôt que la technique couramment utilisée de la datation $^{40}Ar/^{39}Ar$ au mica, qui est limitée par des températures de fermeture relativement plus faibles de ≥ 350 °C, pour réaliser une datation absolue des masses intrusives importantes enfouies à des niveaux crustaux moyens (c.-à-d. ≥ 3–4 kilobars).

[*Traduit par la redaction.*]

INTRODUCTION

Granite batholiths form a large part of tectonic terranes (e.g., Cordillera of North and South America, Appalachian Orogen) and, therefore, constitute an important part of their geological history. Consequently, it is important to document precisely the age of intrusion and longevity of the magmatism and related hydrothermal systems in order to understand the geological evolution of areas underlain by these intrusions. In the case of the larger intrusions, such as batholiths of thousands of km², it is even more important to constrain their time of emplacement and duration of cooling, as they constitute a large component of the thermal flux of an orogen. In this paper, we present the first high-temperature (i.e., >500°C) geochronometric data for the Musquodoboit Batholith (MB, MacDonald and Clarke 1985; Fig. 1), the second largest intrusion (800 km²) in the Meguma terrane , and one of the larger intrusions in the Canadian Appalachians. Until now the emplacement of the

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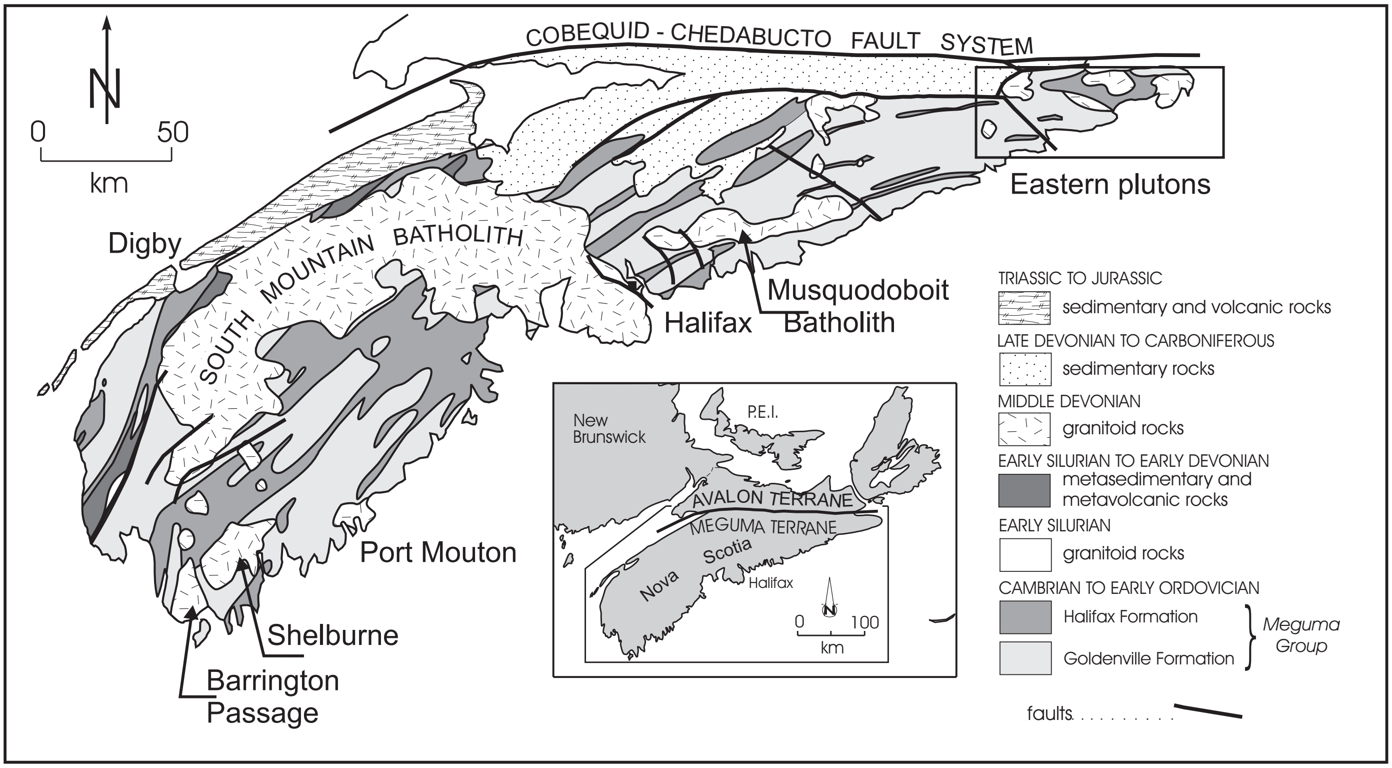

Fig. 1 Geological map of southern Nova Scotia showing the general geology of the Meguma terrane and the location of the Musquodoboit Batholith and other intrusions referred to in the text. Area indicated as Eastern plutons is referred to in the text and some of these intrusions along with their ages (U-Pb) are summarized in Table 1.

MB has been constrained to ca. 370 Ma based on $^{40}Ar/^{39}Ar$ mica ages, which provide the time of cooling through 350–300°C, that being the time at which argon diffusion in mica ceases (McDougall and Harrison 1988). This age is significantly younger than ages from other granite bodies of the Meguma terrane as constrained by U-Pb dating of zircon and monazite (see Clarke *et al.* 1997 for review). Therefore, in order to better define the time of high-temperature crystallization for the MB, the intrusion was sampled for high precision U-Pb zircon and monazite dating. The results presented here indicate an age significantly older than the $^{40}Ar/^{39}Ar$ mica dates and are discussed in the context of the cooling history of the MB.

REGIONAL GEOLOGY

Meguma terrane

The Meguma terrane of southern Nova Scotia is the most outboard terrane of the Canadian Appalachian Orogen. The terrane is bounded to the north by the east-trending Cobequid-Chedabucto Fault Zone (CCFZ) that separates this terrane from the Neoproterozoic-Cambrian composite Avalon terrane (Fig. 1). The Meguma terrane consists predominantly of Lower Paleozoic metasedimentary and volcanic rocks that are intruded by Late Devonian metaluminous and peraluminous granite (Clarke *et al.* 1997). The Lower Paleozoic rocks consists of the older Cambrian-Ordovician Meguma Group, a sequence of deep water distal turbidites that includes a metawacke-dominant lower part, the Goldenville Formation, and slate-rich upper part, the Halifax Formation. The Meguma Group is overlain by mixed sedimentary and mafic-felsic volcanic rocks of the Silurian to Devonian White Rock, Kentville, New Canaan and Torbrook formations, all of which were deposited in shallow water continental settings. This mixed package of rocks was regionally deformed into northeast-trending, open to close, upright folds, and metamorphosed to mainly greenschist facies during the Acadian Orogeny at ~400 ± 10 Ma (Keppie and Dallmeyer 1987; Kontak *et al.* 1998; Hicks *et al.* 1999). Subsequently the area was intruded by minor mafic rocks (e.g., Liscomb gabbro; Clarke *et al.* 1993) and large volumes of metaluminous to peraluminous granite, of which the South Mountain and Musquodoboit batholiths are the largest. The South Mountain Batholith intruded deformed rocks of the Lower to Middle Devonian (i.e., Lochovian to Emsian) Torbrook Formation, but Benn *et al.* (1997) ascribed a late tectonic rather than post-tectonic (Clarke and Clarke 1998) origin with respect to the Acadian Orogeny. Recently, Culshaw and Bhatnagar (2001) showed that emplacement of the SMB overlapped some ductile deformation of the Meguma Group and that fold development, although in an advanced stage, was not over at the time of batholith intrusion. The presence of coarse clastic rocks of the Fammenian Horton Group (Martel *et al.* 1993), representing the basal part of the overlying Carboniferous stratigraphy, resting on granitic rocks of the SMB indicate that uplift, denudation, and unroofing of the granite intrusions of the Meguma terrane occurred by ~360 Ma.

Musquodoboit Batholith

The Musquodoboit Batholith (MB) intrudes metasedimentary rocks of the Meguma Group, and a narrow contact metamorphic aureole containing cordierite porphyroblasts in finer grained biotite and andalusite hornfels is developed within a few hundred metres of the contact (MacDonald and Clarke 1985; Ham 1993; Horne *et al.* 1998). A composite map of the MB (Fig. 2), based on several years of field work (Ham 1993, 1994, 1998, 1999, 2000), shows that the oldest unit, occurring mostly along the southern contact, is medium- to coarse-grained biotite monzogranite with trace muscovite and cordierite. However, the predominant phase in the batholith is medium- to coarse-grained biotite leucomonzogranite with minor muscovite and cordierite (trace to 1%). Underlying the west-central part of the batholith, a similar unit is characterized by the presence of more cordierite (to 4%) compared to the areas flanking it (<1%; see also MacDonald and Clarke 1985). Fine-grained, texturally and mineralogically variable leucomonzogranite bodies occur locally throughout the batholith. Dyke rocks and pegmatite are also present, some of which are associated with mineralization, such as the Dunbrack occurrence (Kontak *et al.* 1999a) and the numerous tungsten showings in the MB (Ham 1993). Airborne radiometric surveys indicate that areas underlain by fine-grained and/or texturally variable phases have elevated U/Th ratios and that such phases extend along the southern and northern parts of the batholith in the western half, and occur as small bodies scattered within the southern part of the eastern half such as near the Tangier Grand Lake area (Ford 1993; Ham 1994, 1998). Faults strongly influence the shape of the MB and, by analogy to the structure of the South Mountain Batholith (Horne *et al.* 1992), these faults probably pre-dated intrusion and were active at the time of emplacement, and consequently controlled the nature of the contacts and the present day outline of the granite. No penetrative structures occur in the MB that might suggest a late tectonic overprint.

PREVIOUS GEOCHRONOLOGY OF THE MUSQUODOBOIT BATHOLITH

The earliest radiometric ages for the MB were reported by Fairbairn *et al.* (1964), who obtained a whole-rock Rb-Sr isochron date of 266 ± 17 Ma and a Rb-Sr biotite age of ca. 370 Ma for a monzogranite sample (both recalculated with new constants; Keppie and Smith 1978). Subsequently, several authors have obtained ages for micas using the ^{40}Ar/^{39}Ar step-wise heating technique: (1) MacMichael (1975) calculated an age of 368.7 ± 3.2 Ma for biotite from monzogranite; (2) Reynolds *et al.* (1981) obtained a 363 Ma biotite age and a 302 Ma white mica age (integrated age for a discordant pattern) for altered rock adjacent to a mineralized vein at the Dunbrack mineral deposit; (3) Keppie and Dallmeyer (1987) reported an age of 370.4 ± 1.5 Ma for biotite from the northeastern part of the MB; and (4) Kontak *et al.* (1999a) obtained a plateau age of 368.5 ± 2.5 Ma and laser spot ages of 369 to 376 Ma (n=17) for individual muscovite grains from a mineralized vein sample from the Dunbrack deposit. The seventeen spot dates on the mineral separate gave integrated and correlation ages of 370 ± 2 Ma and 370 ± 2 Ma, respectively.

Given that the nearby Kinsac pluton is considered to show subsurface continuity with the northwestern extremity of the MB based on geological and geophysical arguments (Creasar 1996; Horne *et al.* 1998), the ^{40}Ar/^{39}Ar ages obtained for that intrusion are also relevant to the present study. Reynolds *et al.* (1981) reported plateau ages of 373 and 363 Ma for biotite and muscovite, respectively, and 363 Ma for biotite from two monzogranite samples from this intrusion. More recently, Kontak *et al.* (1999b) reported a 354 Ma plateau age for K-feldspar in monzogranite from the same area.

In summary, the mica ages for the MB and related Kinsac pluton indicate that the dated samples had cooled to below their blocking temperatures of ca. 300–350°C (McDougall and Harrison 1988) by 370–363 Ma. However, we emphasize that these ages represent the time at which argon diffusion in the dated samples ceased. The crystallization of minerals and the solidification of the batholith occurred earlier and at higher temperatures.

ANALYTICAL TECHNIQUES AND SAMPLING

The sample used for dating in the present study was collected from the north end of Porters Lake (lat. 63° 23', long. 44° 48') following a road off highway 107 (exit 19) east of Halifax (Figs. 1, 2). The sample is from the dominant phase of the MB, the medium- to coarse-grained, K-feldspar megacrystic two-mica leucomonzogranite. In thin section, large perthitic K-feldspar megacrysts are in a hypidiomorphic granular matrix of normal to oscillatory zoned oligoclase, perthitic orthoclase-microcline, quartz, dark brown to orange-brown biotite, pinitized cordierite, and minor muscovite. The K-feldspar has local development of mottled texture due to variable inversion to triclinic microcline, and quartz has rare subgrain development. Both features reflect post-crystallization ductile deformation.

U-Pb (zircon, monazite) dating was carried out in the geochronology laboratory of Memorial University, St. John's, Newfoundland using analytical procedures modified after Krogh (1973). Complete details of the methods have recently been summarized in Dubé *et al.* (1996). Regression lines were calculated using the program of Davis (1982), and uncertainties are reported at the 95% confidence level.

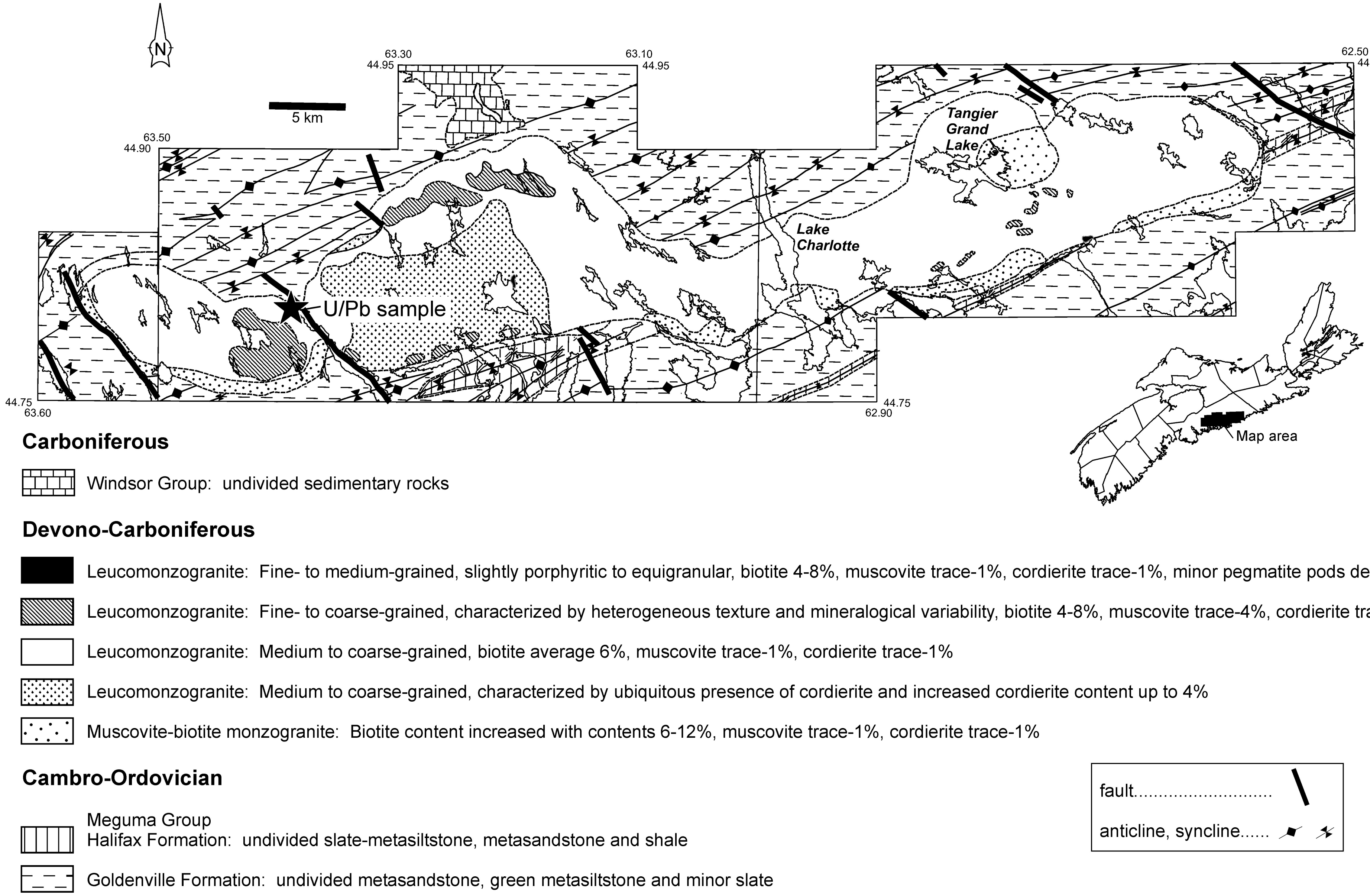

Fig. 2 Geology of the Musquodoboit Batholith with location of the sample used for U-Pb dating.

RESULTS

In the present study, six zircon and two monazite fractions were separated, but zircon fractions Z1 to Z4 are discordant due to a component of inheritance and hence the data are not reported. The data for the remaining two zircon fractions (Z5, Z6) and the two monazite fractions (M1, M2), which represent duplicate analyses of the same abraded monazite separate, are given in Table 1 and the data are plotted on a conventional concordia diagram (Fig. 3). The monazite fractions fall just above the chord, but are concordant within uncertainties and overlie the two zircon fractions. Collectively the data indicate an age of 378 ± 1 Ma for this sample, which is taken as the time of crystallization of the minerals.

DISCUSSION AND CONCLUSIONS

Significance for Age Interpretation of Granitic Intrusions

The new U-Pb age for the MB is compared to other U-Pb ages of granitic intrusions for the Meguma terrane in Table 2. The MB data are bracketed by data for other intrusions, which collectively indicate a span from 384 to 370 Ma for emplacement of granite, and more importantly the 378 Ma age is more consistent with the timing of magmatism across the terrane rather than the previous ages of 363–370 Ma. Importantly, these ages of intrusion indicate that there was continuous injection of felsic magma into the Meguma terrane for some 14 Ma, but this is reduced to 9 Ma if the anomalously old monazite age of 384 Ma for the South Mountain batholith is excluded.

The interpretation of a radiometric age as a geologically meaningful event relates in part to the recognition of when the chronometer of interest is activated, i.e., when the daughter nuclide generated from decay of the parent nuclide accumulates within the crystal being dated (i.e., Ar, Sr, Pb in the case of K, Rb, and U, respectively, for these chronometers). This parent-daughter relationship, which is diffusion dependent, is referred to as the blocking or closing temperature and varies not only for the different chronometers, but also for different minerals (i.e., biotite versus muscovite for K-Ar). Thus, relevant to this study is the fact that closure temperatures for the U-Pb chronometer in zircon and monazite have been estimated at ~650 to >800°C and 550–750°C, respectively (Gebauer and Grunenfelder 1979; Cliff 1985; Parrish 1990; Heaman and Parrish 1991). These temperatures are well in excess of the ~350 to <300°C blocking temperatures estimated for muscovite and biotite, respectively (Jager 1979; Hames and Bowring 1994; Harrison *et al.* 1985).

An added complexity to the blocking temperature is the rate of cooling, which for purposes of this paper is a function mostly of depth of emplacement of the intrusions of the Meguma terrane. Although there have been no detailed studies of the contact aureole about the MB, the assemblage of biotite-andalusite-cordierite in Meguma Group metasedimentary rocks (MacDonald and Clarke 1985; Williams and Hy 1990) is similar to that in the contact metamorphic aureole observed around the South Mountain Batholith for which

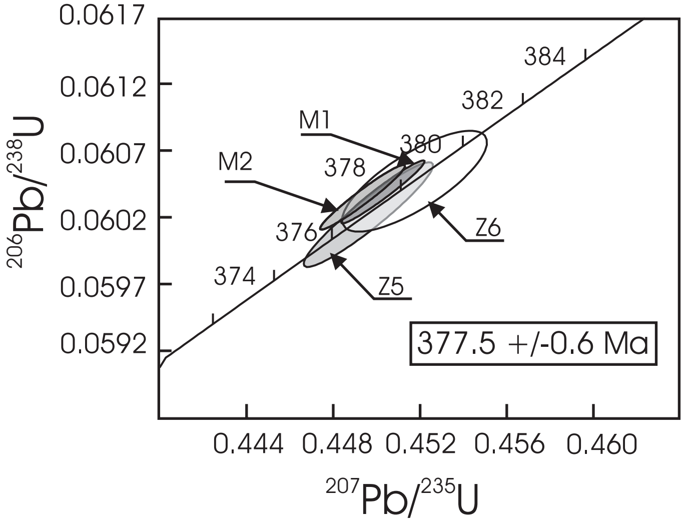

Fig. 3 Concordia diagram with data from the Musquodoboit Batholith. Analysis for monazite (M) and zircon (Z) are shown. The best estimate of the age is 377.5 ± 0.6 Ma based on averaging the zircon and monazite data.

Table 1. U/Pb data for Musquodoboit Batholith

Fraction	Weight (mg)	Concentration		Measured		Corrected Atomic Ratios*							Age (Ma)		
		U	Pb (rad)	Total comm. Pb (pg)	^{206}Pb/^{204}Pb	^{208}Pb/^{206}Pb	^{206}Pb/^{238}U	±	^{207}Pb/^{235}U	±	^{207}Pb/^{206}Pb	±	^{206}Pb/^{238}U	^{207}Pb/^{235}U	^{207}Pb/^{206}Pb
		(ppm)													
Z5 11 lrg needles abr	0.024	299	51.1	12	2294	2.2215	0.06022	32	0.4496	24	0.05415	10	377	377	377
Z6 50 tiny needles abr	0.018	181	10.8	24	536	0.0955	0.06047	30	0.4517	28	0.05418	20	378	379	379
M1 med yel clr abr	0.078	1897	936.5	39	14255	8.3784	0.06039	20	0.4503	16	0.05408	4	378	377	374
M2 med yel clr abr	0.088	1926	907.4	46	13868	7.9538	0.06035	20	0.4493	16	0.05400	6	378	377	371

Notes: Z = zircon, M = monazite. Z1 – Z4 contained significant inherited zircon and do not constrain the age of the sample. Lrg = large, abr = abraded, Yel = yellow, clr = clear. *Atomic ratios corrected for fractionation, spike, laboratory blank of 2- 10 picograms total common lead at the age of the sample calculated from the model of Stacey and Kramers (1975) and 1 picogram U blank. Two sigma uncertainties are reported after the ratios and refer to the final digits.

Table 2. Summary of U-Pb dates from plutonic rocks of the Meguma terrane, Nova Scotia.

Intrusion	Mineral	Age (Ma)	Reference
South Mountain	Monazite	374 ± 2, 371 ± 1	Harper (1988)
	Zircon (grd)	377 ± 4	Keppie *et al.* (1993)
	Monazite (lcmzgr)	384 ± 4	Keppie *et al.* (1993)
Port Mouton	Monazite (ton to	373 ± 1	Clarke *et al.* (2000)
	Monazite (ton ms gr)	377.7 ± 3	Currie *et al.* (1998)
Shelburne	Zircon	372 ± 3	Keppie & Krogh (1999)
	Monazite	372 ± 2	
	Monazite	373 ± 1	Currie *et al.* (1998)
	Zircon (diorite)	376 ± 2	Tate (1997)
Barrington Passage	Monazite	372 ± 2	Keppie & Krogh (1999)
	Zircon	373 ± 2	
	Titanite	361	Currie *et al*. (1998)
Musquodoboit	Zircon, Monazite	378 ± 1	This study
Canso	Zircon	370 ± 3	Keppie & Krogh (1999)
	Zircon	378 ± 5	Hill (1991)
	Monazite	370 ± 3	Hill (1991)
Halfway Cove	Monazite	372 ± 2	Keppie & Krogh (1999)
	Zircon	379 ± 2	
Larrys River	Monazite	371 ± 2	Keppie & Krogh (1999)
Queensport	Monazite	376 ± 2	Keppie & Krogh (1999)
Sangster Lake	Monazite	375 ± 2	Keppie & Krogh (1999)

Raeside and Mahoney (1996) estimated a depth of emplacement of ~3.5 kbars. Equivalent to slightly deeper depths of emplacement have been estimated for the Port Mouton and Barrington-Shelburne plutons (Currie *et al.* 1998). Using fluid inclusion thermometry, Kontak *et al.* (1999a) estimated emplacement pressures of 3–3.5 kbars during vein mineralization at the Dunbrack occurrence in the MB, which is similar to pressures suggested for greisen and vein mineralization at the East Kemptville tin deposit in the western part of the South Mountain Batholith (Halter and Williams-Jones 1999; Kontak *et al.* 2001). Thus, a pressure equivalent to ca. 3.5 kbars is considered the best estimate of the emplacement of the MB, which equates to a lithostatic load of ca. 12 km. Using a geothermal gradient of 25°C/km, which has been suggested for the Meguma terrane by Keppie and Dallmeyer (1995) during the Acadian Orogeny, a temperature of 300°C is indicated for the wall rocks. This temperature is similar to that of the blocking temperature of argon in biotite and only just below that for muscovite (350°C). Also relevant here is the recent suggestion that the present-day geothermal gradient in the western part of the South Mountain Batholith is in the order of 45°C/km (Chatterjee and Dostal 2003). Given that the MB is similar to the South Mountain Batholith in terms of its radioelement abundances (Ford *et al.* 1992; Ford 1993), a similarly elevated geotherm may have existed for the MB.

The above discussion indicates that dating of the MB using relatively low-temperature geochronometers (i.e., ^{40}Ar/^{39}Ar mica ages) may not provide a reliable estimate of the timing of intrusion if the intrusion cooled slowly. Thus, the apparent discrepancy in ages of zircon and monazite (i.e., ca. 378 Ma) versus muscovite and biotite (i.e., ca. 370 Ma) may simply be a function of cooling rate, itself related to the depth of emplacement and the elevated temperature of the wall rock (i.e., 300°C). Based on our U-Pb results, we suggest that dating of similarly emplaced intrusions using ^{40}Ar/^{39}Ar mica be done with caution as cooling rate is an important factor to consider and one which is difficult to assess in the absence of higher temperature geochronometric data. We also note the apparent discrepancy for recent Re/Os molybdenite and U-Pb zircon ages (376–380 Ma; Kontak *et al.* 2003) versus younger conventional ^{40}Ar/^{39}Ar mica ages (ca. 370 Ma; Reynolds *et al.* 1981, 1987) for the South Mountain Batholith. However, recent laser ^{40}Ar/^{39}Ar dating of white mica phases from the batholith has yielded ages to 380 Ma (Carruzzo 2003; Reynolds *et al.* 2004).

Integration of new U-Pb ages and previous ^{40}Ar/^{39}Ar dating

The age of the MB is herein redefined as 378 ± 1 Ma based on concordant zircon and monazite ages. The coincidence of these ages indicates that inheritance is not a concern for the zircon ages and, similarly, that the monazite age is not related to a post-crystallization event. The 378 Ma age for crystallization and, by inference, batholith emplacement is some 8–15 Ma older than previously interpreted based on published ^{40}Ar/^{39}Ar mica ages for the MB (Reynolds *et al.* 1981; Keppie and Dallmeyer 1987; Kontak *et al.* 1999a). The ^{40}Ar/^{39}Ar ages are now interpreted to indicate that the MB remained above the 300–350°C blocking temperature of mica for nearly 10 Ma, a significant time interval and one that may have implications for mineralization in the batholith.

The age data for the MB are plotted on a time-temperature plot in Fig. 4 with a proposed cooling curve for the intrusion, which is used as a means to account for the age discrepancy among the different dating techniques. In this diagram the intrusion age is defined by the higher blocking temperature minerals (zircon, monazite), whereas the lower temperature part of the cooling curve is constrained by mica ages. The curve is extrapolated to lower temperatures based on the K-feldspar age for the Kinsac intrusion which, as noted above, is inferred to connect to the MB at depth. The plateau age of 354 ± 3 Ma for K-feldspar probably records the final stage of uplift and denudation of the MB prior to deposition of the Famenian Horton Group (Martel *et al.* 1993). Thus, the age discrepancy noted herein for the MB relates to the depth of emplacement of the batholith (i.e., 12 km), which consequently resulted in a protracted cooling history from the time of crystallization to cooling to 300–350°C. It is tempting to speculate, therefore, that the steep cooling path is related to sudden uplift of the area and is tectonically significant with respect to the geological evolution of the Meguma terrane.

Implications of age data for uplift rates in the Meguma terrane

The results of the high-temperature chronometry provide a well constrained point for assessing the nature of uplift rates in the Meguma terrane during the waning stages of the Acadian Orogeny. The integration of the age data and pressure constraints for the MB and other intrusions suggest denudation of ca. 12 km of overlying Lower Paleozoic stratigraphy during a span of no less than 18 Ma, as constrained by the emplacement ages of granite and time of deposition of the unconformably overlying Horton Group. It is unlikely that the rate of uplift was uniform and two values are used to bracket it. Firstly, the age of vein mineralization is estimated at 370 Ma with pressures constrained to 3.5 kbars based on fluid inclusion thermometry (Kontak *et al.* 1999a), which indicates that most uplift occurred after this time at a rate of 1.2 mm/yr. In contrast, assuming a steady state rate from the time of emplacement at 378 Ma, a more conservative rate of 0.6 mm/yr is estimated. These uplift rates are averaged over considerable time periods, which contrast with variable rates that typify most orogens (e.g, Andean Orogen; Kennan, in press) due in part to the fact that a steady state or equilibrium between accretion, uplift, and denudation is not always attained and maintained because tectonic processes (e.g., convergence rates, magma production) may vary (Willet & Brandon 2002). In addition, proximity to major faults, in this case the Cobequid-Chedabucto Fault, may also affect uplift rates such that higher rates occur proximal to such structures (e.g, Alpine Fault; Koons 1989). However, despite the simplistic approach used for estimating uplift, we note that the rates are comparable to those documented during the Cenozoic evolution of the Andes (ca. 0.05–0.5 mm/a; summaries in Kennan, in press), an area that may have some parallels to the evolution of the Meguma terrane during the relevant time period when granite of the terrane was generated due to tectonic thickening of the continent (Clarke *et al.* 1993). In contrast, these uplift rates are much lower than rates documented in high-grade metamorphic terranes where rates of 5–7 mm/a have been documented during the Variscan Orogen in granulite-eclogite rocks of the Erzgebirge (Germany; Werner & Lippolt 1999) and similar grade, but much younger (i.e., 40 Ma) rocks in northern Greece (Liati & Gebauer 1999).

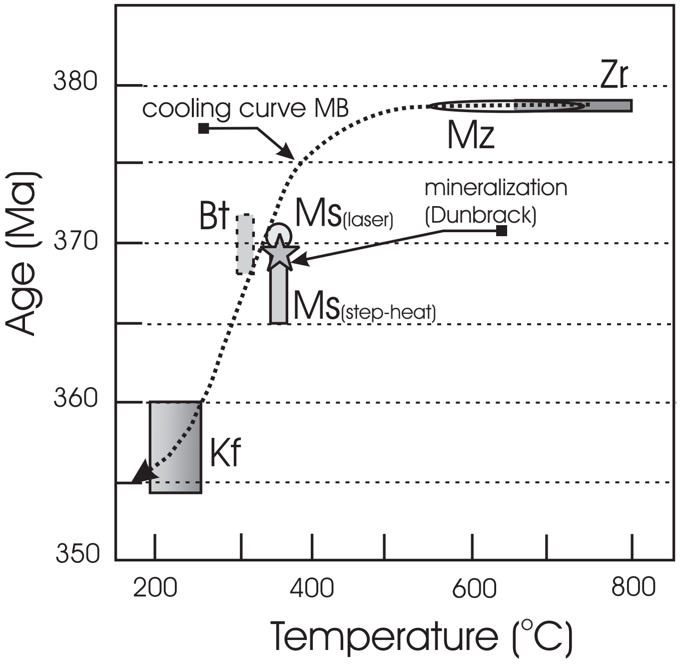

Fig. 4 Time (Ma) and temperature (°C) plot for the Musquodoboit Batholith with inferred cooling curve based on the blocking temperatures (see text for discussion) of the zircon (U-Pb), monazite (U-Pb), mica (^{40}Ar/^{39}Ar) and K-feldspar (^{40}Ar/^{39}Ar) ages. The size of the geometrical shapes relate to the error for the age and blocking temperature, but for K-feldspar it may extend to a much lower temperature (i.e, 150°C; McDougall and Harrison 1988). Note that the K-feldspar age is for a sample from the adjacent Kinsac pluton (Kontak *et al.* 1999b).

Thus, the inferred uplift rates for the Meguma terrane following emplacement of the MB and other intrusions of similar age are considered realistic for the style of deformation and metamorphism during the Acadian Orogeny. Further work and better constraints on the uplift rates after granite emplacement may provide an independent means of more rigorously assessing the varied models proposed for the tectonic environment that generated the Late Devonian granite of the Meguma terrane (cf. Clarke *et al.* 1993; Keppie & Dallmeyer 1995; Keppie & Krogh 1999; Murphy *et al.* 2000).

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