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PB AND O ISOTOPIC CONSTRAINTS ON THE SOURCE OF GRANITIC ROCKS FROM CAPE BRETON ISLAND, NOVA SCOTIA, CANADA

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ABSTRACT. Pb isotopic compositions of leached feldspars from twenty-three plutons in Cape Breton Island can be divided into two groups: anorthosite, syenite, and granite in the Blair River Complex, which have the least radiogenic compositions on the Island, and granitic rocks from terranes (Aspy, Bras d'Or, and Mira) to the south. Pb isotopic data for the Blair River Complex ($^{206}Pb/^{204}Pb$ = 17.399-18.107; $^{207}Pb/^{204}Pb$ = 15.505-15.560; $^{208}Pb/^{204}Pb$ = 36.689-37.733) are consistent with an old source region ultimately derived from the mantle and contaminated by sialic crust. Oxygen isotopic compositions of syenite in the Blair River Complex ($\delta^{18}O$ = +8.0 to +8.5 permil) are slightly higher than anorthosite (+7.0 to +8.3 permil); a Silurian granite in the Blair River Complex has $\delta^{18}O$ = +7.5 permil. Cambrian to Devonian plutons in the Aspy, Bras d'Or, and Mira terranes are more radiogenic ($^{206}Pb/^{204}Pb$ = 18.192-18.981; $^{207}Pb/^{204}Pb$ = 15.574-15.712; $^{208}Pb/^{204}Pb$ =37.815-38.936) than the Blair River Complex and were generated from source regions having a predominant crustal Pb signature (high μ). The $\delta^{18}O$ values of granites and granodiorites in the Aspy terrane (+7.5 to +9.2 permil; avg = +8.6 permil) and Bras d'Or (+3.7 to +11.3 permil; avg = +9.4 permil) are also consistent with involvement of sialic crust. Many Late Proterozoic granites from the Mira terrane have anomalously low $\delta^{18}O$ values (+0.2 to +5.9 permil), perhaps produced from protoliths that had undergone hydrothermal alteration prior to melting. Paleozoic granitic rocks from the Aspy, Bras d'Or, and Mira terranes cannot be uniquely distinguished on the basis of their Pb and O isotopic compositions. The granitic rocks could have been generated during terrane amalgamation from combinations of unradiogenic (Grenville-like) and more radiogenic (Avalon-like) sources.

INTRODUCTION

The geochemical nature of the lower continental crust is difficult to determine directly because generally these rocks are not exposed. However, indirect information regarding the composition and age of the crust may be obtained by establishing the isotopic compositions of felsic igneous rocks (Zartman, 1974; Farmer and DePaolo, 1983; Ayuso, 1986; Aleinikoff and others, 1987; James and Henry, 1993). The use of such geochemical data for characterizing igneous source regions in the northern Appalachian orogen is complicated by tectonic events that resulted in superposition and juxtaposition of numerous crustal blocks (Williams and Hatcher, 1982). As a result, magmatic rocks exposed at the surface

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may be part of thrust slices or dismembered blocks that have separated them from their source regions (Ayuso and Bevier, 1991). Even in this case, however, isotopic and other geochemical information can help to identify igneous rocks that had a common source region and, conversely, can assist in characterizing plutonic rocks within now adjacent slices that originally belonged to separate crustal blocks.

The purpose of the present study is to investigate the source regions of magmas under Cape Breton Island, using Pb and O isotopic data from felsic plutons. Because Pb isotopic compositions commonly reflect the time-integrated and average composition of large segments of the crust (Zartman, 1974; Doe and Zartman, 1979), they provide a way to infer the nature of the source region of granitic magmas and of large portions of the crust. Variations among $\delta^{18}O$ values of Mesozoic and Cenozoic granitic plutons in the western U.S. (Solomon and Taylor, 1989) closely follow the regional definition of Pb-isotope crustal domains (Zartman, 1974), and thus $\delta^{18}O$ values provide additional constraints on the nature of the source regions. The plutons in the present study range in age from Middle Proterozoic to middle Paleozoic, and represent the four tectonostratigraphic blocks proposed by Barr and Raeside (1989) (fig. 1). The Pb and O isotopic data complement results of a Nd isotopic study on plutons from Cape Breton Island (Barr and Hegner, 1992) and provide additional constraints on the nature of the source regions of these granitic rocks. In addition, the isotopic compositions are compared to those of plutons in New Brunswick (Bevier, 1987) and elsewhere in the northern mainland portion of the Appalachian orogen (Ayuso, 1986; Ayuso and Bevier, 1991) to further constrain postulated terrane correlations.

GEOLOGICAL SETTING AND SAMPLE DISTRIBUTION

According to the tectonic framework of Barr and Raeside (1986, 1989), the northernmost part of Cape Breton Island (fig. 1) contains exposures of North American Middle Proterozoic (Grenville) basement (designated as the Blair River Complex), similar to those in the Humber zone of western Newfoundland (Williams and Hatcher, 1982). The Aspy terrane, located south of the Blair River Complex (fig. 1), is correlated with parts of southwestern Newfoundland commonly included in the Gander terrane (Williams and Hatcher, 1982) and with the Miramichi and St. Croix terranes in central New Brunswick (Fyffe and Fricker, 1987). The Bras d'Or terrane, located south of the Aspy terrane, is correlated with areas in southern Newfoundland previously included in the Gander terrane but recently recognized to be older than typical Gander terrane and of postulated Avalonian affinity (Dunning and O'Brien 1989; Dunning and others, 1990). The Bras d'Or terrane also has been correlated with the Brookville terrane in southern New Brunswick (Bevier and others, 1990). Like central Newfoundland, both the Bras d'Or and Aspy terranes have been interpreted on the basis of seismic reflection data to be underlain by crust of the Central block (Marillier, Keen, and Stockmal, 1989). Only the southeastern part of Cape Breton Island—the Mira terrane of Barr and Raeside (1989)—is interpreted to be equivalent to the classical Avalon terrane of eastern Newfoundland. This terrane subdivision is in contrast to suggestions that all of Cape Breton Island is part of the Avalon terrane (Williams and Hatcher, 1992), and that the proposed divisions represent different levels of exposure of a single Avalon Composite Terrane, to which the Blair River Complex may be the basement (Keppie, Dallmeyer, and Murphy, 1990; Keppie, Dallmeyer, and Krogh, 1992; Murphy and others, 1989a,b).

The Blair River Complex consists of a distinctive assemblage of quartzofeldspathic and amphibolitic gneiss and minor calcareous rocks, intruded by anorthosite, monzodiorite, syenite, and granite (Barr and others, 1987; Raeside and Barr, 1992). Both the syenite and anorthosite, as well as associated orthogneissic units, have igneous and metamorphic ages in the range 980 to 1200 Ma with a younger igneous and metamorphic overprint at about 430 Ma (Barr, Raeside, and van Breemen, 1987; Miller and others, 1993). Samples from three units in the Blair River Complex (about 1080 Ma Lowland Brook syenite and Delaney Brook anorthosite and an unnamed Silurian granite) were analyzed as part of the present study (table 1).

The Aspy terrane is characterized by low- to high-grade metamorphic rocks intruded by extensive suites of mainly Silurian to Devonian granitic rocks (fig. 1). The metamorphic rocks include greenschist and amphibolite facies phyllite and schist derived from mafic and felsic volcanic and clastic protoliths, upper amphibolite-facies gneiss of similar composition, and tonalitic to granitic orthogneiss (Jamieson and others, 1986; Macdonald and Smith, 1980; Barr and Jamieson, 1991). Felsic volcanic units and tonalitic orthogneiss have given ages of about 430 Ma (Dunning and others, 1990; Keppie and others, 1992; Jamieson and others, 1986). Therefore, protoliths of both the low- and high-grade metamorphic rocks of the Aspy terrane are inferred to be mainly Ordovician to Silurian in age, with peak metamorphism during the Devonian attributed to docking with the Bras d'Or terrane to the south and possibly the Blair River Complex to the north (Reynolds and others, 1989; Dunning and others, 1990; Barr and Jamieson, 1991). Plutonic rocks in the Aspy terrane are massive to strongly foliated and range widely in composition from tonalite, monzogranite, granodiorite, and granite formed in arc, collisional, and post-orogenic settings (see Barr, 1990; Barr and Jamieson, 1991 for a summary of the petrography and major- and trace-element compositions). Four Devonian plutons were sampled for Pb and O isotopic analysis: Cameron Brook granodiorite (about 402 Ma; Dunning and others, 1990), West Branch North River granite (about 400 Ma; O'Beirne-Ryan and Jamieson, 1986), Black Brook granitic suite (about 375 Ma; Dunning and others, 1990), and Margaree granite (about 365 Ma; Reynolds and others, 1989). In addition, samples were analysed from the Cheticamp granodiorite, a pluton with an age of about 550 Ma which has been variously interpreted to be an allocthonous

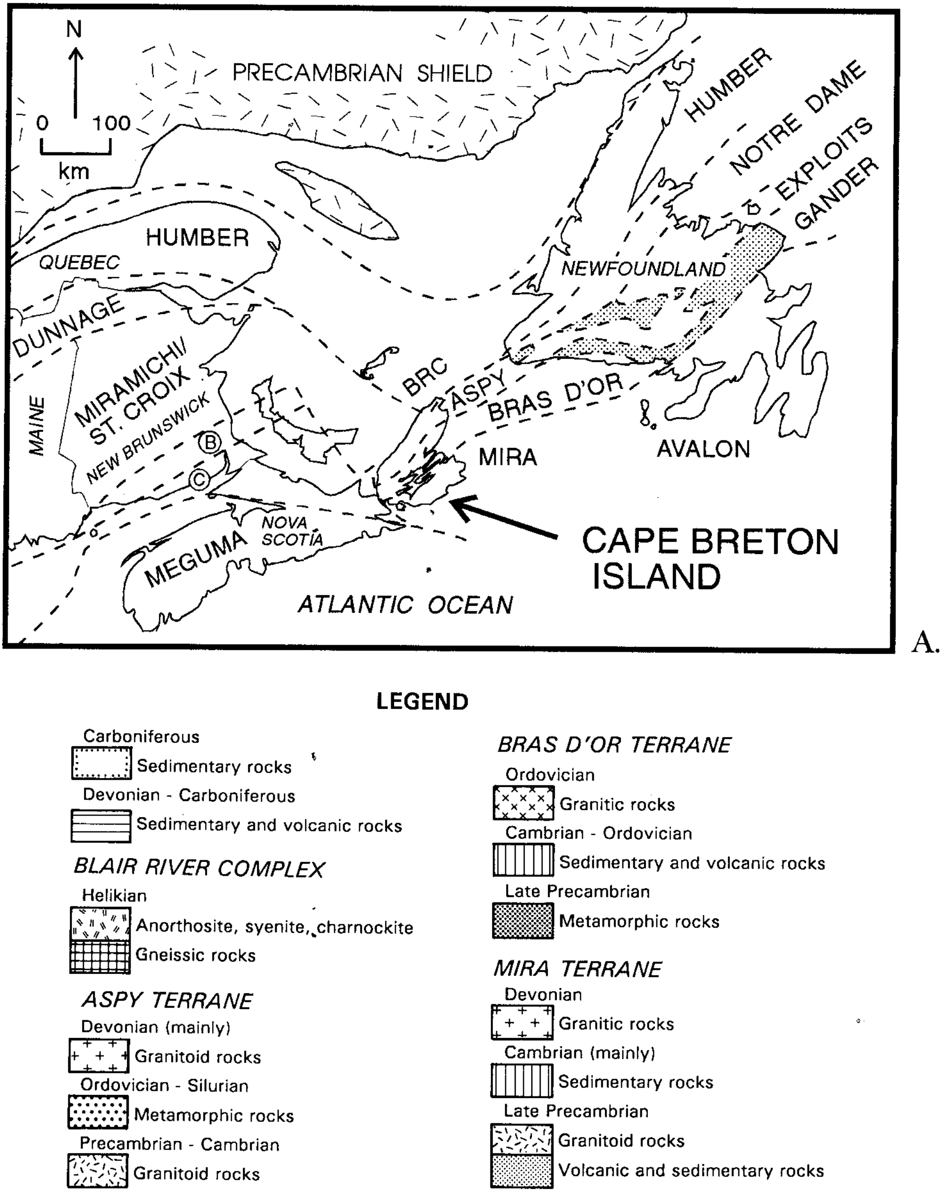
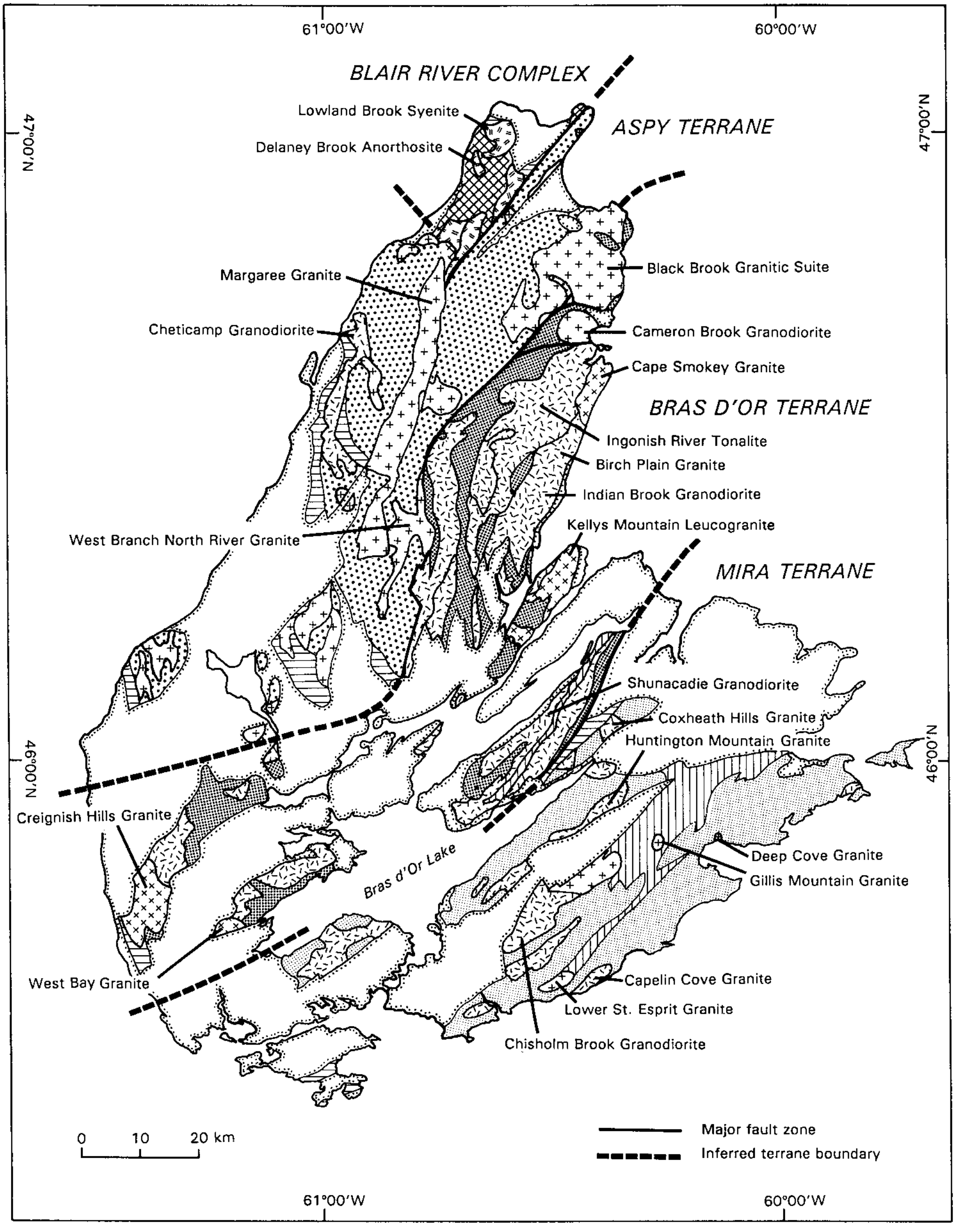


Fig. 1(A) Regional map shows inferred correlation of terranes in the northern Appalachian orogen after Barr and Raeside (1989). (B) Simplified geological map of Cape Breton Island shows terrane boundaries, granite locations, and analyzed samples. Abbreviations are as follows: BRC, Blair River Complex; B, Brookville terrane in southern New Brunswick; C, Caledonia terrane in southern New Brunswick.



B.

Fig. 1 (continued)

TABLE 1

Pb and O isotopic compositions of granitic rocks from Cape Breton Island, Nova Scotia

Sample	Age (Ga)	$^{206}Pb/^{204}Pb$	$^{207}Pb/^{204}Pb$	$^{208}Pb/^{204}Pb$	$^{238}U/^{204}Pb$ (μ)	δ18O*	Nd**	Nd (.4Ga)	Rock Unit
									BLAIR RIVER COMPLEX
BVM132	0.43	18.107	15.560	37.733	9.58	7.5	—	—	Granite in Blair River Complex
CW085	1.08	17.408	15.513	36.731	9.59	8.2	—	—	Lowland Brook Syenite
SB1024	1.08	17.423	15.522	36.771	9.63	8.0	0.4	-6	Lowland Brook Syenite
SB1112	1.08	17.399	15.507	36.689	9.57	8.5	—	—	Lowland Brook Syenite
SB1030	1.08	17.536	15.517	36.937	9.56	—	—	—	Lowland Brook Syenite
SB1113	1.08	17.850	15.516	37.329	9.45	8.3	—	—	Delaney Brook Anorthosite
SB1070	1.08	17.853	15.505	37.254	9.40	7.0	—	—	Delaney Brook Anorthosite
						ASPY			
SB3043	0.365	18.331	15.618	38.174	9.78	8.5	-1.2	-0.8	Margaree Granite
CW3724	0.365	18.379	15.625	38.262	9.8	9.2	—	—	Margaree Granite
SB3212	0.365	18.407	15.596	38.189	9.66	—	—	—	Margaree Granite
SB3209	0.365	18.444	15.602	38.300	9.68	—	—	—	Margaree Granite
WY4046	0.375	18.644	15.701	38.495	10.06	8.8	-1.2	-1.8	Black Brook Granitic Suite
CW3587	0.375	18.406	15.643	38.183	9.87	9.1	—	—	Black Brook Granitic Suite
SB3090	0.375	18.469	15.638	38.256	9.83	—	—	—	Black Brook Granitic Suite
SB8498	0.400	18.459	15.630	38.202	9.8	7.5	0.5	0.5	West Branch North River Granite
SB3079	0.402	18.355	15.632	38.215	9.83	8.5	—	—	Cameron Brook Granodiorite
RR2554	0.402	18.325	15.606	38.123	9.73	8.4	—	—	Cameron Brook Granodiorite
K1110	0.555	18.369	15.653	38.161	9.92	—	—	—	Cheticamp Granodiorite
K1112	0.550	18.306	15.626	38.045	9.82	8.8	—	—	Cheticamp Granodiorite
K1082	0.550	18.399	15.681	38.191	10.04	—	-0.7	-2.9	Cheticamp Granodiorite
K1093	0.550	—	—	—		9.0	—	—	Cheticamp Granodiorite

					BRAS D'OR				
SB3207	0.498	18.397	15.635	38.219	9.84	8.1	0.8	-0.5	Kellys Mountain Leucogranite
K71131	0.498	18.419	15.683	38.357	10.04	–	–	–	Kellys Mountain Leucogranite
SB3208	0.493	18.397	15.620	38.181	9.77	8.3	–	–	Cape Smokey Granite
CH8727	0.495	18.402	15.685	38.181	10.06	8.9	–	–	Creignish Hills Granite
MJ85257	0.495	18.426	15.712	38.287	10.17	10.0	–	–	West Bay Granite
MJ85267	0.495	18.444	15.707	38.295	10.14	11.3	–	–	West Bay Granite
K10S09	0.555	18.417	15.702	38.243	10.13	7.2	–	–	Ingonish River Tonalite
K1512	0.564	18.403	15.663	38.128	9.96	10.1	1.4	0	Shunacadie Granodiorite
F1523	0.564	18.302	15.632	38.001	9.85	–	–	–	Shunacadie Granodiorite
K1505	0.564	18.192	15.584	37.815	9.66	9.1	–	–	Shunacadie Granodiorite
CBH887	0.565	18.249	15.586	37.876	9.66	4.3 (4.5)	–	–	Birch Plain Granite
IBG1	0.565	18.371	15.630	38.143	9.82	7.2	-0.1	-1.6	Indian Brook Granodiorite
K9A28	0.565	18.294	15.613	37.977	9.76	6.4	–	–	Indian Brook Granodiorite
AM8414	0.565	18.422	15.617	38.249	9.75	3.7	–	–	Indian Brook Granodiorite
					MIRA				
FD120B	0.380	18.351	15.640	38.174	9.87	9.5	1.5	1.8	Deep Cove Granite
FS87514	0.378	18.248	15.574	37.880	9.60	–	–	–	Lower St. Esprit Granite
FS87507	0.378	18.232	15.587	37.890	9.66	–	–	–	Lower St. Esprit Granite
FS87563	0.378	18.243	15.587	37.922	9.66	6.6 (7.1)	–	–	Lower St. Esprit Granite
F1116C	0.384	18.460	15.599	38.155	9.66	7.9	–	–	Gillis Mountain Granite
FS526	0.574	18.874	15.608	38.199	9.62	5.9	–	–	Capelin Cove Granite
FS557	0.574	18.832	15.590	38.170	9.55	2.3 (3.9)	5	3.5	Capelin Cove Granite
GD8745	0.620	18.981	15.674	38.936	9.88	4.2 (5.0)	1.5	-0.9	Chisholm Brook Granodiorite
CHMDE-35	0.620	18.377	15.664	38.172	9.97	–	–	–	Coxheath Hills Granite
EB-91-14#	0.620	18.283	15.668	38.437	10.01	0.2	2.9	0.4	Huntington Mountain Granite

* Whole rock and feldspar (parenthesis) oxygen isotopic compositions in permil.
** Nd isotopic compositions from Barr and Hegner (1992)
\# Pb, Nd and Sr isotopic compositions determined on samples from same field location

part of the Bras d'Or terrane (Barr and Raeside, 1989) or as evidence that Bras d'Or and Aspy are not separate terranes (Keppie, Dallmeyer, and Murphy, 1990; Lynch and Tremblay, 1992; Lynch, Tremblay, and Rose, 1993).

The Bras d'Or terrane is characterized by low-pressure cordierite-andalusite gneiss, low- to high-grade metasedimentary and minor metavolcanic rocks, and abundant weakly to strongly foliated plutonic rocks (Raeside and Barr, 1990). Many of the plutons have U-Pb (zircon) ages between 565 and 555 Ma, but widespread plutonism also occurred at ~495 Ma (Dunning and others, 1990; Barr and others, 1990). The older plutons (565-555 Ma) include diorite, tonalite, granodiorite, and granite and are interpreted to have formed in a continental margin subduction zone, whereas the about 495 Ma plutons are mostly granites and may have been a result of crustal melting during post-orogenic uplift (Raeside and Barr, 1992). Both the 565 to 555 Ma plutons (Ingonish River, Shunacadie, Birch Plain, and Indian Brook) and the about 495 Ma plutons (Kellys Mountain, Cape Smokey, Creignish Hills, and West Bay) were sampled for this study (table 1).

The Mira terrane consists of several dominantly volcaniclastic sequences in separate northeast trending, fault-bounded belts. The oldest sequence forms the Stirling belt and has been dated at about 680 Ma; younger belts dated at about 620 Ma occur to the northwest in the East Bay Hills, Coxheath Hills, and Sporting Mountain belts, and the youngest sequence, dated at about 575 to 560 Ma, forms the Coastal belt (Bevier and others, 1993). Regional metamorphic grade is low in the region (subgreenschist or lower greenschist facies) (Barr, 1993). The Stirling belt and the volcanogenic sequences dated at about 620 Ma to the northwest were intruded by dioritic, granodioritic, and granitic plutons at about 620 Ma, whereas the Stirling and Coastal belts were intruded by granitic plutons at about 575 Ma and about 380 Ma (Farrow and Barr, 1992; Barr and others, 1990; Barr and Macdonald, 1992; Bevier and others, 1993). The Late Proterozoic volcanic, sedimentary, and plutonic rocks of the Mira terrane correlate very closely with similar units in the Avalon terrane (sensu stricto) of eastern Newfoundland (Bevier and others, 1993; Barr and others, 1994). For the present study, the analyzed samples included three plutons dated at about 620 Ma (Chisholm Brook, Huntington Mountain, and Coxheath Hills), one pluton dated at about 574 Ma (Capelin Cove), and three Devonian plutons (Deep Cove, Lower St. Esprit, and Gillis Mountain) (table 1).

ANALYTICAL METHODS

About 100 to 500 mg of handpicked K-feldspar and labradorite separates were leached to remove labile radiogenic lead (Ludwig and Silver, 1977; Housh and Bowring, 1991) in warm HF-HBr and HCl solutions, prior to dissolution using HF and HNO_3 in closed Teflon containers heated in a microwave. Pb was concentrated using HBr chemistry on AG1 × 8 exchange resin. Procedural blanks during the course of this study decreased from 500 pg to less than 200 pg and thus are of no consequence to the measured values. Pb isotopic analyses were obtained using three mass spectrometers: Finnigan MAT 261 and Finnigan MAT 262 multicollector mass spectrometers and a 12-inch NBS-type mass spectrometer at the U.S. Geological Survey, Reston, Virginia. Isotope ratios were corrected for thermal fractionation relative to accepted values for NBS 981 and NBS 982 Pb standards ($\sim$0.12 $\pm$ .02 percent per mass unit). On the basis of repeated runs of NBS standards and control samples, the Pb isotopic data are reproducible and have a total uncertainty of about 0.1 percent (2σ).

To facilitate comparisons among plutons having a wide range of crystallization ages, measured Pb isotopic values of granitoid plutons (table 1) were recalculated to 400 Ma. For granitoid samples, it was assumed that $\mu = {}^{238}U/{}^{204}Pb = 12$ and $\kappa = {}^{232}Th/{}^{238}U = 3.5$ (both ratios characteristic of crustal rocks). Data for the anorthosite and syenite in the Blair River Complex were recalculated assuming $\mu = 8.4$ and $\kappa = 3.5$ (values that are similar to those thought to be characteristic of mantle reservoirs, for example, plumbotectonics model of Doe and Zartman, 1979). Pb-isotope model ages and estimates of μ were determined using the method of Ludwig (1991).

Oxygen was extracted from whole-rock powders and four K-feldspar mineral separates using the BrF_5 method of Clayton and Mayeda (1963) and quantitatively converted to CO_2 using red-hot graphite. The O isotope data are presented in the normal δ notation relative to Vienna Standard Mean Ocean Water (V-SMOW) (Craig, 1961; Baertschi, 1976). An oxygen-isotope CO_2-H_2O fractionation factor of 1.0412 at 25°C has been employed in these calculations to calibrate the mass spectrometer reference gas. An average $\delta^{18}O$ value of 9.66 $\pm$ 0.18 permil was obtained for eight samples of silica standard NBS-28 analyzed during this study. Variation in results of duplicate or triplicate analyses performed on eight of the whole rock samples of this study averaged $\pm$0.17 permil.

PB ISOTOPIC DATA

Partial melting processes in the crust or mantle and fractional crystallization of granitic magmas do not affect the initial Pb isotopic values inherited by feldspars in equilibrium with the magma. Moreover, because feldspars are U and Th poor, initial Pb isotopic values do not evolve significantly, and the values do not change drastically with time if the system remains closed. The initial Pb isotopic values may, however, reflect the extent of melting and age of the source, distribution (for example, monazite versus zircon), and composition (μ and κ) of the accessory minerals in the crust undergoing anatexis, extent of isotopic homogeneization of the melt (Hogan and Sinha, 1991), and the effects of multiple metamorphisms on the original isotopic compositions. Thus, Pb isotopic variability can exist in otherwise geochemically identical plutons (Ayuso, 1986; Hogan and Sinha, 1991; Miller and others, 1991) and may not reflect only regional source differences. However, in Cape Breton

Island, monazite is rare in the granitic rocks, and Pb isotopic variations in each terrane are independent of lithology—leucogranites to granodiorites in each group encompass similar isotopic ranges. Thus, we think that regional differences established on the basis of feldspar isotopic compositions broadly reflect the composition and age of the source in each terrane. Initial Pb isotopic values of the original magmas, however, can also be severely disturbed by country rock assimilation during magma ascent and pluton emplacement, isotopic redistribution as a result of hydrothermal alteration, or mixing of crust- and mantle-derived magmas of different isotopic compositions at different levels in the crust. In fact, the possibility that granitic melts reflect an average Pb isotopic composition between the composition of hydrothermal fluids and large volumes of crust undergoing melting enhances the use of Pb as a regional probe of unexposed crustal sections (Zartman, 1974). In the following sections we further discuss these possibilities in terms of the Pb and O data.

Anorthosite, syenite, and granite samples from the Blair River Complex have the lowest values for $^{206}Pb/^{204}Pb$, $^{207}Pb/^{204}Pb$, and $^{208}Pb/^{204}Pb$ compared to samples from the other terranes (fig. 2; table 1). Pb isotopic compositions of Paleozoic plutons grouped by terrane and/or age fall in scattered fields with broadly positive slopes (fig. 2). The majority of these samples straddle or plot at higher values than the model Pb-isotope evolution curve of Stacey and Kramers (1975) which is thought to represent the average Pb evolution of the crust. Most samples from Paleozoic plutons of the Aspy and Bras d'Or terranes and most samples from the Mira terrane display a relatively narrow range in $^{206}Pb/^{204}Pb$ values ($\sim$ 18.19-18.47 except for one sample at 18.64). Samples from the Cape in Cove granite (about 575 Ma) and from the Chisholm Brook granodiorite (about 620 Ma) in the Mira terrane have distinctly higher $^{206}Pb/^{204}Pb$ ratios and plot to the right of the Pb evolution curve (fig. 2). No systematic variation of Pb isotopic compositions with major- and trace-element abundances is evident in any of the groups, except that the Late Proterozoic and Paleozoic granitic plutons are more radiogenic and more silicic than the Middle Proterozoic syenite and anorthosiste in the Blair River Complex.

Fine-scale isotopic differences are notable in the Blair River Complex. Although the syenite and anorthosite have similar $^{207}Pb/^{204}Pb$ values ($\sim$ 15.51-15.52), their $^{206}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$ values are distinct (fig. 2); the anorthosite is more radiogenic in $^{206}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$ than the syenite. However, both the syenite and the anorthosite are less radiogenic than the Silurian granite. The syenite and anorthosite samples also display a distinctive compositional trend on age-corrected (400 Ma) diagrams (fig. 3), plotting well below the Pb evolution curve. This feature supports the uniqueness of the source region in the Blair River Complex relative to the terranes to the south which are more radiogenic (fig. 3A,B) and hints at a source region containing components with at least some affinites to those in the mantle.

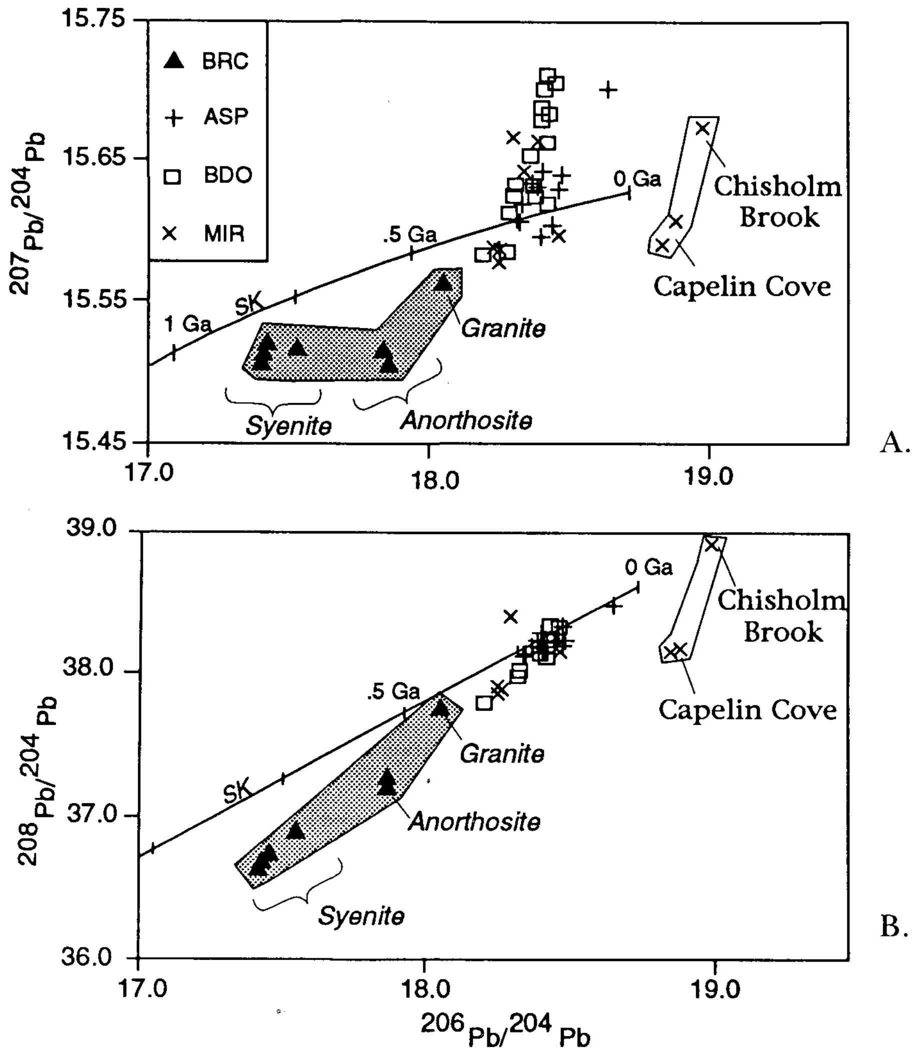


Fig. 2. Plots of present-day (A) $^{206}Pb/^{204}Pb$-$^{207}Pb/^{204}Pb$ and (B) $^{206}Pb/^{204}Pb$-$^{208}Pb/^{204}Pb$ measured values for leached feldspar fractions from granitic rocks of Cape Breton Island. The Pb-isotope evolution curve (Stacey and Kramers, 1975) is divided at intervals of 0.25 Ga. Symbols and abbreviations are as follows: Blair River Complex, BRC; Late Proterozoic to Paleozoic samples from the Aspy (ASP), Bras d'Or (BDO) and Mira (MIR) terranes. Note the radiogenic composition of the Chisholm Brook (620 Ma) and Capelin Cove (575 Ma) granites from the Mira terrane.

Plutons from the Aspy and Bras d'Or terranes have a relatively narrow range of Pb isotopic compositions (table 1; fig. 2), and the two terranes cannot be distinguished. As a group, the Pb isotopic compositions have ranges comparable on the basis of Pb isotopes to those in felsic

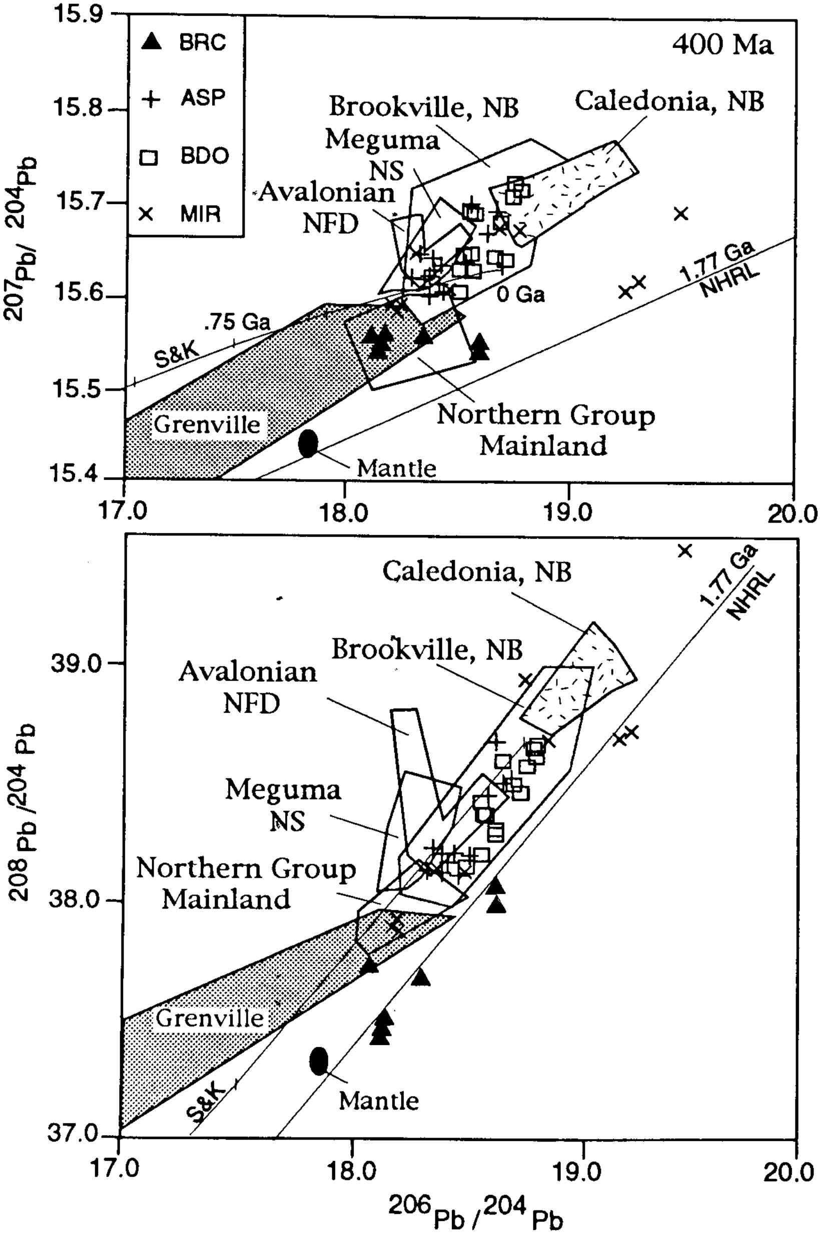


Fig. 3. Plots of age-corrected data at 400 Ma (A) $^{206}Pb/^{204}Pb$-$^{207}Pb/^{204}Pb$ and (B) $^{206}Pb/^{204}Pb$-$^{208}Pb/^{204}Pb$ for feldspars from granitic rocks of Cape Breton Island. Data sources: Northern group of plutons in New England are from Ayuso and Bevier (1991); granitic rocks from the Caledonian and Brookville terranes in New Brunswick are from Bevier (1987); Ackley City granite in the Avalon terrane from Newfoundland from R. Ayuso, D. Strong, and D. Kontak (unpublished data, 1994); granitic rocks in the Meguma terrane from Canso from R. Ayuso and J. D. Hill (unpublished data, 1994). Grenville data from Ayuso and Ratcliffe (unpublished data, 1994). Devonian (depleted-mantle-type) mantle data are from Doe, Delevaux, and Albers (1985). The 1.77 Ga Northern Hemisphere Regression Line for oceanic ridge basalts (Hart, 1984) is shown for reference. Symbols and abbreviations as in figure 2.

igneous rocks generated at active continental margins (for example, Peninsular Ranges batholith in the western United States: Silver and Chappell, 1988; Andes: Hildreth and Moorbath, 1988). Pb isotopic compositions of plutons dated at 565 to 555 Ma and about 495 Ma in the Bras d'Or terrane are virtually indistinguishable (table 1; fig. 2). Moreover, the Cheticamp granodiorite (550 Ma), a possible outlier of the Bras d'Or terrane (Reynolds and others, 1989; Dunning and others, 1990), matches the Pb isotopic compositions of the majority of the intrusions in both the Aspy and Bras d'Or terranes.

In the Mira terrane, granites from Deep Cove, Lower St. Esprit, and Gillis Mountain (all about 380 Ma) and the about 620 Ma granites from the Huntington Mountain and Coxheath Hills plutons overlap the field of plutons from the Aspy and Bras d'Or terranes (fig. 2). The Devonian plutons as a group, however, have lower $^{206}Pb/^{204}Pb$, $^{207}Pb/^{204}Pb$, and $^{208}Pb/^{204}Pb$ values compared to about 620 Ma plutons.

The radiogenic compositions of the granitic rocks and the variable values of $^{207}Pb/^{204}Pb$ (except in the Blair River Complex) are consistent with the predominance of a crustal source region. They indicate that the magmas were generated from sources containing a major contribution of sialic continental crust that evolved with an integrated history of relatively higher U/Pb and Th/Pb ratios than sources in the Blair River Complex. The $^{207}Pb/^{204}Pb$ data are also high enough to imply an earlier, relatively high μ stage for the source rocks in the Aspy, Bras d'Or, and Mira terranes. In addition, we note that the about 365 Ma Margaree granite, one of the youngest intrusions in the Aspy terrane, has Pb similar to those in the older plutons (table 1).

OXYGEN ISOTOPIC DATA

Granitic rocks can show wide variability in oxygen-isotope composition, as illustrated by Taylor (1968, 1978), who recognized three main categories. In the simplest scenario, the $\delta^{18}O$ values of "normal" granitic rocks (+6.0 to +10.0 permil) generally indicate an origin by partial melting or fractional crystallization of a dominantly igneous protolith. For values less than +8 permil, it is generally assumed that the involvement of sediments or weathered rocks has been insignificant, but as the whole rock $\delta^{18}O$ values rise above +8 permil, the contribution to the magma of materials formed or modified in a low-temperature environment becomes more significant. "High" $\delta^{18}O$ values in granitic rocks (more than +10 permil) are generally considered to indicate extensive contribution to a granitic magma from protoliths formed or modified in a low temperature environment (that is, high ^{18}O supracrustal rocks), but low temperature alteration of a granitic rock can also produce such a result (Wenner and Taylor, 1976). "Low" $\delta^{18}O$ values (< +6 permil) most commonly suggest large-scale hydrothermal interaction between granitic rocks and water following crystallization, but the possibility of crystallization at high temperatures from low-^{18}O magmas also exists (Taylor, 1977). In the former case, feldspars are generally more reactive and commonly become more depleted in ^{18}O than other minerals. This behavior produces abnormally large oxygen-isotope fractionations between quartz and feldspar/and small or even negative feldspar-mica and/or felspar-amphibole fractionations (Taylor, 1968, 1977). In the latter case, oxygen-isotope fractionations between minerals should reflect high temperature conditions (Taylor and Sheppard, 1986), given that subsequent alteration has not occurred.

In the Blair River Complex, the $\delta^{18}O$ values (table 1; fig. 4) obtained for the Lowland Brook syenite (+8.0 to +8.5 permil) range to slightly higher values than the Delaney Brook anorthosite (+7.0 to +8.3 permil), corresponding broadly with silica content. All these values lie within the range known for plutonic rocks derived from igneous protoliths, with little or no apparent contribution from, or contamination by, supracrustal materials (Taylor, 1968, 1978).

The nine samples analyzed from Devonian plutons in the Aspy terrane have slightly higher $\delta^{18}O$ values (+7.5 to +9.2 permil; avg = +8.6 permil; Table 1; fig. 4) than the syenite and anorthosite samples from the Blair River Complex (avg $\delta^{18}O$ = +8.0 permil), a result consistent with some involvement of sialic crust in the formation of Aspy terrane magmas. The two samples from the older about 550 Ma Cheticamp pluton have $\delta^{18}O$ values ($\delta^{18}O$ = +8.8 to +9.0 permil) similar to those of the younger plutons. Twelve samples from plutons in the Bras d'Or show a much wider range in $\delta^{18}O$ values (fig. 4), and the general resemblance in

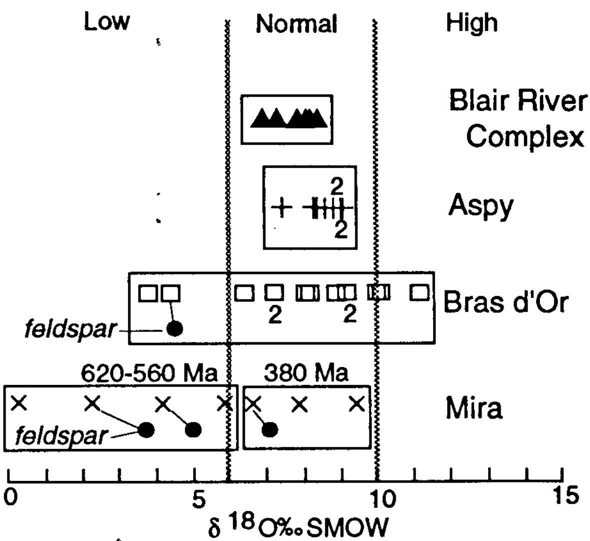


Fig. 4. Whole-rock and K-feldspar oxygen isotopic compositions of Cape Breton Island granitic rocks. Low, normal, and high fields indicate the ranges defined for granitoid rocks by Taylor (1978). Number "2" means that two samples have the same isotopic composition and cannot be differentiated on this plot.

isotopic composition observed for Pb between the Aspy and Bras d'Or granitic rocks does not exist for oxygen (fig. 5). The seven samples with higher values (+8.1 to 11.3 permil; avg +9.4 permil) include all of the about 495 Ma plutons, as well as the about 564 Ma Shunacadie granodiorite. The five samples with lowest $\delta^{18}O$ values (+3.7 to +7.2 permil) are from the about 565 to 555 Ma plutonic complex in the northeastern portion of the terrane (fig. 4). Three of these samples have oxygen-isotope compositions typical of granitic rocks that had igneous protoliths, but two have lower values of +3.7 to +4.3 permil, results generally considered to indicate significant post-crystallization, hydrothermal alteration. However, petrographic examination does not reveal any obvious difference in degree of alteration among the samples. Furthermore, a K-feldspar separate from one of these samples has a $\delta^{18}O$ value higher than the whole-rock value (table 1; fig. 4). Hence, preferential ^{18}O depletion of feldspar alone probably is not responsible for the low ^{18}O character of these samples.

Like the Pb-isotope data, O-isotope results for the Mira terrane divide into two distinct groups. The about 380 Ma granitic rocks range in $\delta^{18}O$ from +6.6 to +9.5 permil, within the range of "normal" granitic rocks (fig. 4). Two of the three samples have oxygen-isotope compositions typical of most calc-alkaline magmas, but some supracrustal involvement or low temperature alteration is indicated by the more ^{18}O-rich nature of the Deep Cove granite. In contrast, the Late Proterozoic granitic rocks from the Mira terrane all have anomalously low values

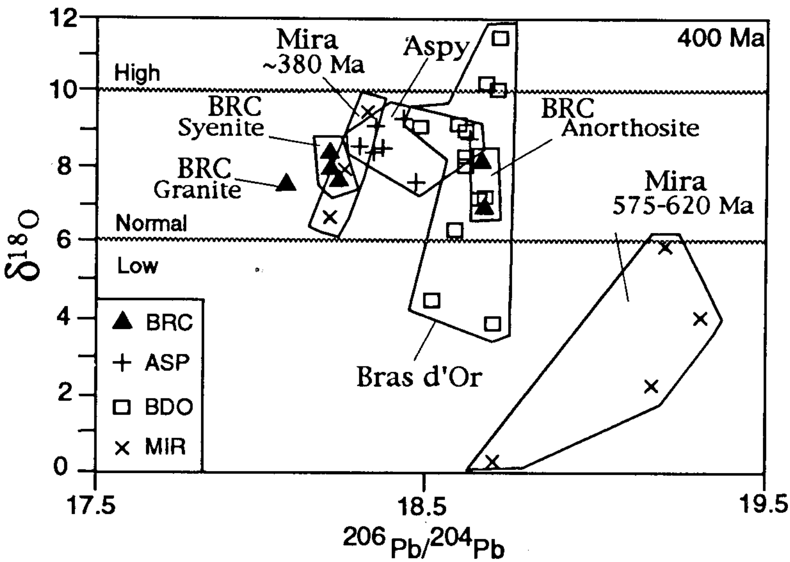


Fig. 5. Plot of $\delta^{18}O$ (‰) versus $^{206}Pb/^{204}Pb$. Abbreviations and symbols as in figure 2.

(+0.2 to +5.9 permil; fig. 4). Commonly, such results do not reflect magmatic processes and instead indicate interaction with hot water (generally of meteoric origin). However, the granitic rocks in this study have no obvious petrographic evidence for hydrothermal alteration. K-feldspars from two of these samples have $\delta^{18}O$ values up to 1.6 permil higher than the whole rock values, behavior similar to that of the K-feldspar separated from the "normal"-^{18}O Lower St. Esprit granite sample (table 1). Hence, the low ^{18}O character of these granitic samples need not result from hydrothermal alteration of feldspar alone. Another explanation consistent with the feldspar data is that the protoliths of these granitic magmas had undergone hydrothermal alteration prior to melting—an alternative that we favor at this time. However, this possibility cannot be suitably tested from the data currently available to us.

DISCUSSION

Pb and O isotopic variations in Cape Breton Island.—Plotted on $^{207}Pb/^{204}Pb$-$^{206}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$-$^{206}Pb/^{204}Pb$ diagrams (fig. 3A,B), the age-corrected data do not clearly distinguish the granitic plutons according to the pre-Carboniferous terrane subdivisions of Barr and Raeside (1989) with the exception of the samples from the Blair River Complex. The anorthosite, syenite, and granite in the Blair River Complex form the least radiogenic part of a broad trend, and granitic rocks from terranes to the south of the Blair River Complex form the radiogenic end (fig. 2). The wide spectrum of Pb-isotope values in each group is also shown by oxygen isotopic compositions, except that the widest range in $\delta^{18}O$ values was obtained for the Early Cambrian granites of the Bras d'Or terrane (fig. 5). The variations in ϵ_{Nd} (at 400 Ma) are also large for Cape Breton Island as a whole, ranging from −6.0 to +3.7 (fig. 6); values generally increase from the Blair River Complex to the Mira terrane (Barr and Hegner, 1992).

Regional comparisons.—Regional comparison of the Pb-isotope data from Cape Breton Island and in mainland North America indicate that the relatively unradiogenic range of values from the Blair River Complex generally resembles that of granites from the Northern group of plutons from northern Maine and Vermont (Ayuso, 1986; Ayuso and Bevier, 1991) and granites from the Dunnage and Humber terranes in New Brunswick and Quebec (Bevier, 1987; Whalen, 1993) (fig. 3). The oxygen-isotope values also overlap the range obtained for granites from Vermont and Maine (for example, Andrew, Loiselle, and Wones, 1983; Ayuso, Horan, and Kriss, 1988; Arth and Ayuso, 1993) which range in $\delta^{18}O$ from +6 to +14 permil and do not distinguish among the granite goups established on the basis of Pb isotopic compositions. In contrast, ϵ_{Nd} values of granites from New Brunswick and Quebec illustrate a broad decreasing trend from the Humber (~+5 to 0) to the Dunnage and Gander terranes (~0 to −6); the Avalon terrane (includes the Brookville and Caledonian terranes in New Brunswick) has the widest ϵ_{Nd} range (~−5.5 to +4) (Whalen and others, 1989; Whalen, 1993). Also, the range of ϵ_{Nd} values in

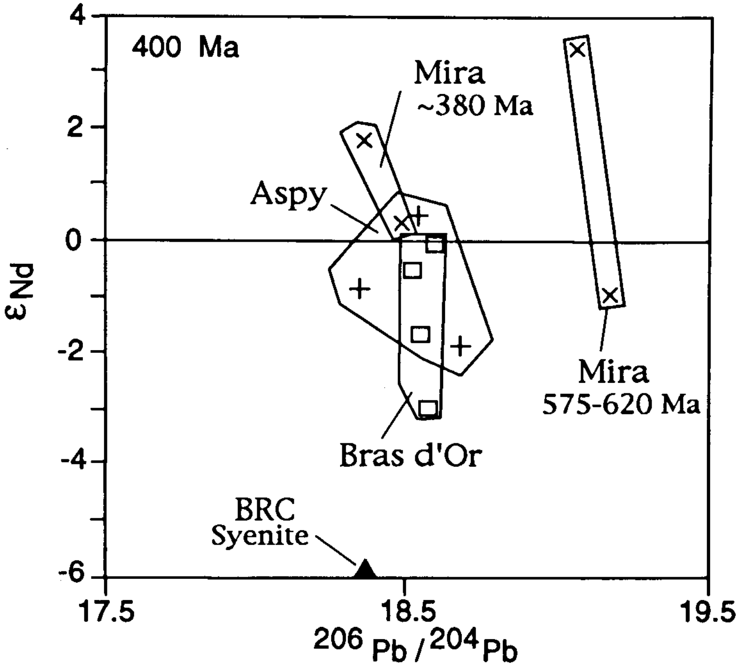


Fig. 6. Plot of ϵ_{Nd} versus $^{206}Pb/^{204}Pb$ and ϵ_{Nd} (from Barr and Hegner, 1992). Abbreviations and symbols as in Fig 2.

the Mira terrane is generally similar to that of granitic rocks from the Avalon terrane in Newfoundland (Fryer and others, 1992), further substantiating correlation of these areas based on overall geological similarity.

The Pb and O isotopic data in New England were used to infer that the granitic plutons in the Northern group are underlain by and derived from mafic source regions in Grenville-type rocks (Ayuso, Horan, and Kriss, 1988; Arth and Ayuso, 1993) (fig. 3). Syenite from the Blair River Complex in Cape Breton Island has considerably lower $^{208}Pb/^{204}Pb$ than the plutons of the Northern group (Ayuso and Bevier, 1991) (fig. 3); this difference could indicate a major contribution of mantle-derived material in the source region. The range of Pb isotopic compositions in the Blair River Complex broadly resembles values found in about 1.45 to 1.65 Ga anorthosites from the Grenville Front in Labrador (Ashwal, Wooden, and Emslie, 1986) which have been interpreted as mantle-derived and crust-contaminated magmas. Moreover, as indicated earlier, Pb-isotope data from the Blair River Complex closely match the range obtained for metatonalite, amphibolite, and metatrondhjemite dated at 1.31 to 1.35 Ga (Ratcliffe and others, 1991) in the Mount Holly Complex of the Green Mountains massif in Vermont (R. Ayuso and N. Ratcliffe, unpublished data, 1993), again supporting a Grenville affinity for the Blair River Complex. The $\delta^{18}O$ values in the Blair River Complex plutons generally match the range of $\delta^{18}O$ in various monzonite to quartz monzonite plutons in the Grenville Province (+8 to +11‰, Shieh, 1985) as well as Grenville basement gneisses (+6 to +12 permil, Shieh and Schwarcz, 1974).

In the $^{206}Pb/^{204}Pb$-$^{207}Pb/^{204}Pb$ diagram (fig. 3), granites from the Aspy, Bras d'Or, terranes extensively overlap the field of granites from the Brookville and Caledonia terranes of New Brunswick. The isotopic fields for terranes in New Brunswick virtually coincide with the field for plutons in the Southern group of mainland North America (from Maine and Rhode Island) (Ayuso and Bevier, 1991). However, granites in the Aspy and Bras d'Or terranes have lower values of $^{208}Pb/^{204}Pb$ relative to the Caledonia terrane (fig. 3). Granites from the Mira terrane overlap but are generally less radiogenic than the granites from the Caledonia terrane. Available Pb-isotope data for granitic rocks of the Avalon terrane in Newfoundland (for example, Ackley City, R. Ayuso, D. Strong, and D. Kontak, unpublished data, 1994) and for the Meguma terrane (granitic rocks from the Canso area, R. Ayuso and J. Hill, unpublished data, 1994) overlap; the granitic rocks from the Meguma terrane, however, display a wider variation and higher values of $^{206}Pb/^{204}Pb$ than rocks from Cape Breton Island.

Pb isotopic compositions of galenas from mineral occurrences in Cape Breton Island generally indicate a pattern similar to the regional isotopic variations in the granitic rocks—the Aspy and Bras d'Or units are substantially more radiogenic than the Blair River Complex (Sangster, Thorpe, and Chatterjee, 1990). Such results imply that the compositions reflect the regional control of crustally-derived Pb from large segments of the crust. Galena isotopic data, however, define finer-scale isotopic differences than the granitic rocks, apparently distinguishing between the Bras d'Or and Aspy terranes and even various parts of the Bras d'Or terrane itself.

Granite source constraints.—The Pb and O isotopic results underscore the complex genesis and crustal predominance of the source regions of granites in Cape Breton Island (figs. 5 and 6). Nd depleted-mantle model ages and ranges in ϵ_{Nd} values were inferred to suggest similar crustal sources for granites in the Aspy and Bras d'Or terranes but different from those of the Mira terrane (Barr and Hegner, 1992). In contrast to the Nd model ages, Pb-Pb model ages (relative to Stacey and Kramers, 1975) are not thought to represent meaningful mantle-separation ages or estimates of crust formation in the region, as these estimates differ greatly from the crystallization ages and range from 754 Ma (Blair River Complex) to future ages (Mira). Moreover, we do not think that the granite sources were homogeneous, as emphasized by the range in $^{207}Pb/^{204}Pb$ values (15.505 to 15.712) and by the large spread in O isotopic compositions (fig. 5). In addition, calculated μ values, which we assume to be estimates of the average composition of the source rocks involved in the production of these granitic magmas, range from 9.40 (mantle-like value) to 9.63 (average crustal value) in the Blair River Complex and between 9.66 to 10.17 (dominantly upper crustal-like) in the Aspy and Bras d'Or terranes. In the Mira terrane, the Devonian Lower St. Esprit granite has a $\mu = \sim 9.60$, slightly lower than the average crustal Pb evolution curve, again consistent with mixtures of mantle and crustal components; for the plutons dated at about 620 Ma in the Mira terrane, μ ranges from 9.55 to 9.88. The relatively high μ values imply that the source regions in Cape Breton Island evolved through an older stage in a high μ environment.

Syenite in the Blair River Complex has the most primitive Pb (μ as low as 9.4), generally low and narrowest range of $\delta^{18}O$ values (+7.0 to +8.5 permil), and a distinctive Nd isotopic composition (figs. 5 and 6). The $^{207}Pb/^{204}Pb$ values are the most mantle-like yet found in Cape Breton Island (fig. 2). The data suggest that low μ values (<9.4?) were present in the source region. The range of μ values in the Blair River Complex could well have originated if the source included the subcontinental lithospheric mantle (Sun, McDonough, and Ewart, 1989), as this material typically has evolved with low μ (Menzies, 1989; Zartman and others, 1991). Our Pb and O isotopic data, however, are not extensive enough to confidently select the type of mantle involved in the generation of the Blair River Complex. Mantle contributions are difficult to distinguish in terms of Pb isotopic compositions because of the high Pb abundances in the continental crust and low abundances in the mantle; mixing schemes will thus be dominated by the crust. On the basis of Nd isotopic variations (Barr and Hegner, 1992) only granites from the Mira terrane are thought to have a substantial component of juvenile mafic crust.

Although the Pb and Nd isotopic values in the Blair River Complex are also consistent with a source region including some older sialic crust, it is not known whether this crust is of lower or upper crustal affinities, except that the generally low values of $^{208}Pb/^{204}Pb$ (fig. 2) do not support the presence of an old crustal source region (lower crust) that experienced long-lived depletion of U. This kind of depletion results in higher κ and low μ values and consequently produces increased values of $^{208}Pb/^{204}Pb$ (Th-derived Pb) relative to $^{206}Pb/^{204}Pb$ (U-derived Pb). As neither mantle-derived nor crustal sources appear to be sole components in the source region of the Blair River Complex, we suggest that the generally low Pb-isotope values represent mantle-derived, hybridized, crust-contaminated magmas (high μ).

The spectrum of Pb and O isotopic values in the Mira terrane is broad; some of the Late Proterozoic granites (Capelin Cove granite and Chisholm Brook granodiorite) are significantly more radiogenic (high $^{206}Pb/^{204}Pb$) than granitic rocks from the Brookville and Caledonia terranes, perhaps because their source regions were altered or metamorphosed prior to the production of granitic magma in the Paleozoic or even because of post-crystallization incorporation of radiogenic Pb. Recent studies have shown that Sr and O isotopic disturbances can take place in the source regions of granitic rocks during prograde subsolidus metamorphic reactions, and that the effect of hydrothermal fluids on large volumes of crust can be drastic (Wickham, 1990). It is thus feasible that similar metamorphic and hydrothermal reactions could have affected the O and Pb isotopic compositions of the source region of the granites of the Mira terrane before or concurrent with magma generation, as well as during the closing stages of crystallization and in the post-solidus environment (Taylor, 1978, Wenner and Taylor, 1976). In addition, because Pb is mobile in S and Cl-rich environments in hydrothermal systems (Helgeson, 1969), the potential for Pb isotopic modification during the closing stages of crystallization could also have been significant. In the event that the source rocks in the Mira terrane were modified as a result of hydrothermal events prior to and during melting, the resulting melt could have inherited an average Pb isotopic composition intermediate between the composition of the hydrothermal fluids and the large volume of crustal rocks undergoing anatexis. If hydrothermal alteration in fact occurred long after crystallization, and if the isotopic compositions of the fluids were different relative to the initial Pb compositions (open system), the resulting feldspar values could have been drastically disturbed as a result of mixing. For example, feldspars from plutons associated with porphyry Cu mineralization typically point to post-crystallization isotopic disturbance—thus, their Pb isotopic values are not necessarily primary. In the case of the Mira terrane, the granites show no petrographic evidence of significant hydrothermal alteration so that this possibility can be discounted; however, we cannot preclude that the source was hydrothermally altered prior to melting.

The 380-Ma Lower St. Esprit granite is among the least radiogenic of the Paleozoic granites in Cape Breton Island; in fact, this granite even overlaps the field of the Northern group of plutons, a feature we interpret as indicating an important component of relatively unradiogenic, mantle-derived materials in its source. The Pb isotopic range of these approx 380 Ma granites, however, does not match that of normal ocean-ridge basalts (depleted mantle-type, Doe, Delevaux, and Albers, 1985; Zindler and Hart, 1986) or magmas generated from mantle derived from the continental keel which tend to have low $^{206}Pb/^{204}Pb$ values (Hawkesworth and others, 1990). The slightly higher $^{207}Pb/^{204}Pb$ values in the Mira granites better resemble those characteristic of arc magmas (Hawkesworth and others, 1991), consistent with the suggestion on the basis of trace element variations that these rocks originated in a volcanic arc setting (Barr, 1990). The Pb-isotope results in the case of the 380 Ma Mira granites are consistent with the positive ϵ_{Nd} values (range from -1.1 to $+3.7$ at 400 Ma) found in most intrusions of the Mira terrane, again consistent with a source region that had an important juvenile component (Barr and Hegner, 1992).

Mixing.—Granite sources in Cape Breton Island could have been part of different blocks or terranes, or they could be represented by crust underlying the Grenvillian Blair River Complex and the Avalonian Mira terrane. If, as we infer, basement rocks from the Blair River Complex and from the Avalonian blocks have distinct Pb and O (and Nd) isotopic compositions reflecting different evolutionary paths (μ and κ), an assessment can be made of whether granite source regions represented by unradiogenic (Grenville-like) and radiogenic rocks (Avalon-like) could have been the predominant contributors to the younger granitic magmas (fig. 7A).

That there is a significant variation in $^{207}Pb/^{204}Pb$ ($\sim$15.59-15.71) from north to south, for example, does not support a process of homogenization for the entire region during crustal melting or provide strong evidence for homogenization caused by fluid flow before melting of the source rocks. An alternative favored at this time is that mixing of source rocks is responsible for the regional isotopic variations. However, despite the fact that the majority of the granites are intermediate between unradiogenic (Grenville-like) and radiogenic (Avalon-like) endmembers (fig. 7), there is no unique mixing scheme to explain the total spectrum of compositions, particularly the broad north-south trend. This lack of consistency in the Pb and O isotopic data relative to the geographic position of the granites signifies that if mixing is the correct process, then it must have occurred in a complex fashion, probably including variable amounts of these endmembers.

Although Grenville-type rocks in the Blair River Complex can be broadly assumed as suitable endmembers of the least radiogenic component, the wide variability in the approx 620 Ma rocks in the Avalonian Mira terrane precludes confident selection of a radiogenic source rock. Source rocks represented entirely by the compositions of the Chisholm Brook granodiorite (about 620 Ma) can be eliminated as the radiogenic endmember—the $^{206}Pb/^{204}Pb$ values are too high. It is also notable that the Late Proterozoic granite of Capelin Cove (about 575 Ma) in the Mira terrane also has much higher $^{206}Pb/^{204}Pb$ values than the Early Cambrian plutons (about 565-555 Ma) in the Bras d'Or terrane. The absence of an isotopic match between the Late Proterozoic (about 620 Ma) granites from the Mira and the Early Cambrian (about 565 to 555 Ma) granites in the Bras d'Or terrane suggests that these granites could not have been wholly generated from the same source region. Figure 8 shows the relative position of a Central block, as indicated by seismic studies (Marillier and others, 1989; Loncarevic and others, 1989), which underlies the Bras d'Or and Aspy terranes. Such a separate crustal type underlying these two terranes is thought to be consistent with Nd isotope data indicating that old crust like that under the Blair River Complex (Grenville-type) is not present (Barr and Hegner, 1992). Furthermore, the Pb isotopic data are also consistent with the inference that the Paleozoic crustal source regions in the Bras d'Or terrane are akin to those of the Aspy terrane. Thus, although the tectonic subdivision of Cape Breton Island between the Aspy and Bras d'Or terranes may be warranted on the basis of stratigraphy, contrasts in metamorphic grade, style of plutonism, and ages of associated igneous rocks, the isotopic variations

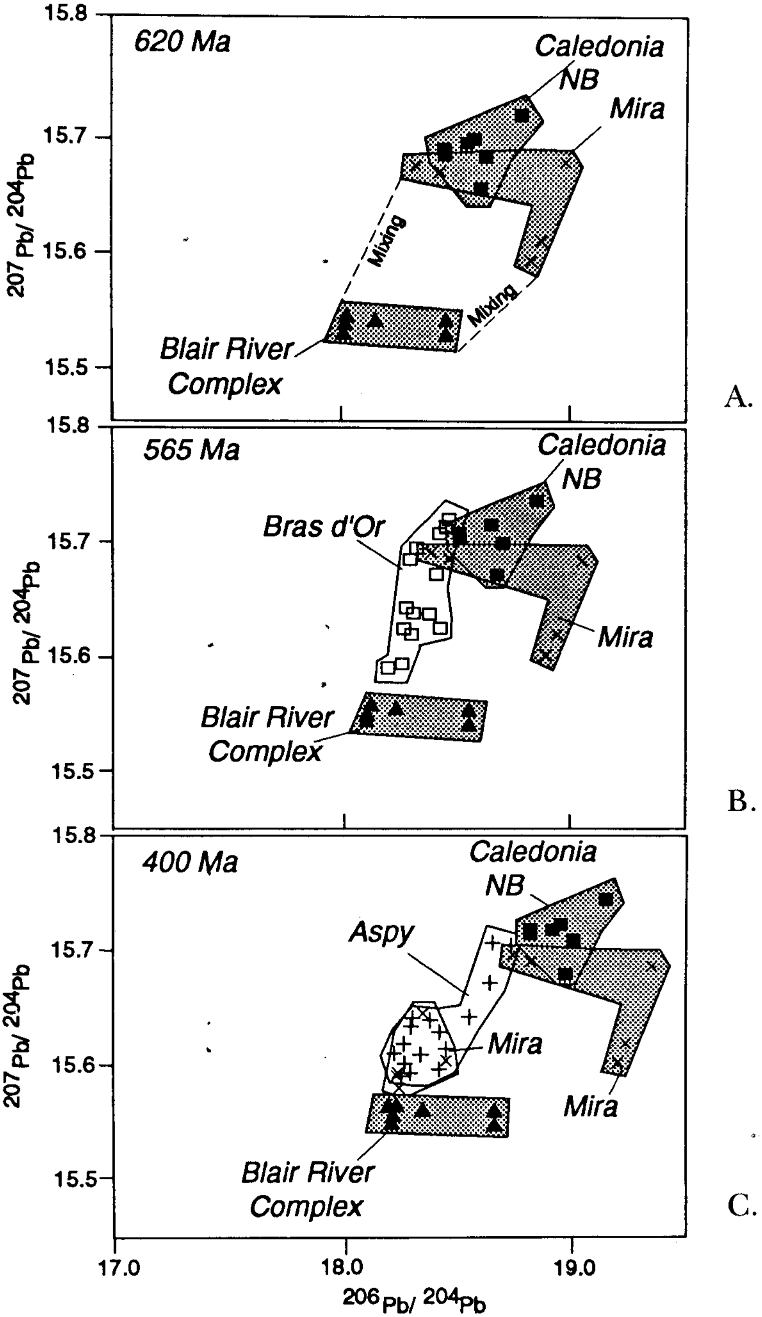


Fig. 7. Pb-isotope variations in granitic rocks at 620, 565, and 400 Ma in a simple mixing scheme between relatively unradiogenic and radiogenic endmembers. (A) Pb isotope values at 620 Ma show at least two isotope reservoirs: unradiogenic (Grenville-like) and more radiogenic (Avalon-like). Mixing lines between the hypothetical end members are shown for reference. (B) Granitic rocks generated at ~565 Ma in the Bras d'Or terrane have intermediate compositions between the Caledonia-Mira field and an unradiogenic endmember represented by the Blair River Complex. (C) Devonian granitic magmas produced at ~400 to 360 Ma in the Aspy terrane and at ~380 Ma in the Mira terrane also have isotopic compositions between the radiogenic and unradiogenic endmembers and are broadly similar to magmas generated at 565 Ma. This behavior is consistent with a process involving melting of similar source materials as those producing the 565 Ma magmas from sedimentary debris derived from those granites, or even by remelting of the 565 Ma rocks themselves.

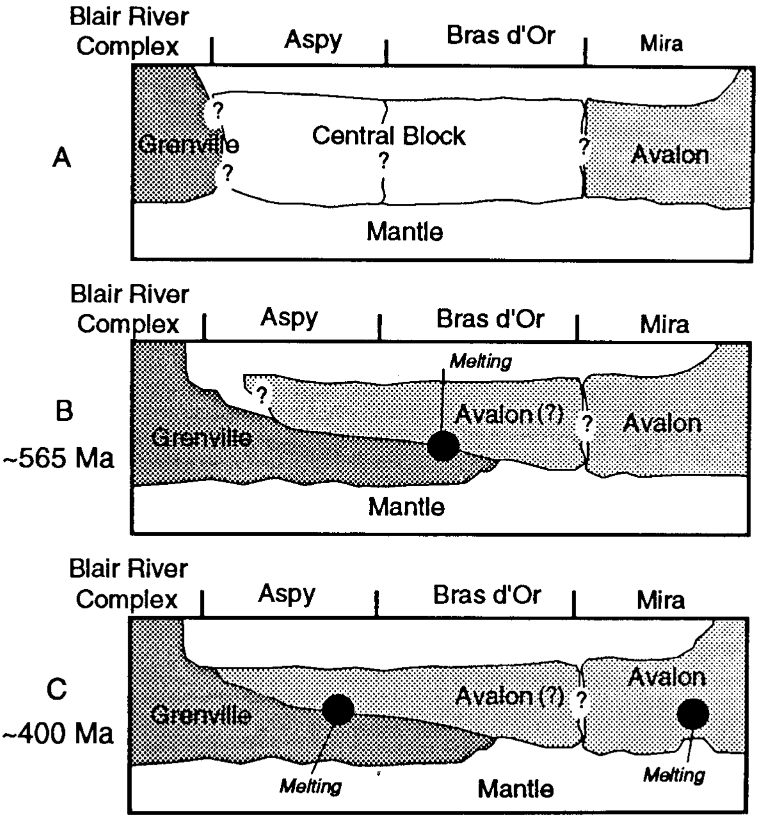


Fig. 8. Schematic diagram showing: (A) three blocks identified by seismic methods: Avalonian, Central, and Grenville; the blocks are thought to be separated by faults (Marillier, Keen, and Stockmal, 1989; Loncarevic, and others, 1989); (B) possible scenario to account for the broad Pb isotopic spectrum of the granitic magmas. For the Bras d'Or, a region of melting is invoked at ~565 Ma that involved relatively unradiogenic (Grenville-like) and radiogenic (Avalon-like) endmembers. The two blocks were amalgamated as a result of thrusting Avalonian-like basement on Grenville; (C) region of melting at ~400 Ma required to generate the Devonian granites in the Aspy and Mira terranes.

do not provide unequivocal proof that the source region of the granitic rocks in these two terranes also exhibited major differences in age or composition.

A hypothetical radiogenic Pb endmember can be represented by combining plutons in the Mira terrane (approx 620 Ma and 575 Ma) and plutons from the Caledonia terrane (approx 620-550 Ma) in southern New Brunswick. This is a feasible combination as the Caledonia terrane on the mainland has been correlated to the Mira terrane in Cape Breton Island (Bevier, White, and Barr, 1990; Barr and others, 1994) (fig. 7A). This combined field significantly overlaps the compositions of the late

Early Cambrian plutons in the Bras d'Or terrane (fig. 7B). Hence, the whole spectrum of compositions in the Bras d'Or granites could have resulted from mixing protoliths or sedimentary debris represented by these hypothetical components—Grenville-like (relatively non-radiogenic) and Avalon-like (radiogenic). A similar scenario could apply to the generation of the Devonian plutons of the Aspy and Mira terranes (fig. 7C). In contrast, it is also notable that Devonian granite in the Blair River Complex has unradiogenic compositions, as predicted if the magma was generated dominantly from the unradiogenic endmember. If our regional interpretation is correct, it implies that melting occurred after terrane amalgamation, perhaps as a result of thrusting of a relatively more radiogenic block (Avalon-like) onto a less radiogenic block (Grenville-like) (fig. 8) and that the various terranes were joined by ~565 to 555 Ma. Alternatively, complete terrane amalgamation need not have taken place as long as the granitic source rocks included sedimentary debris derived from a radiogenic component (Avalon-like) and a less radiogenic component (Grenville-like).

Our Pb and O isotope data suggest that Grenville-like rocks, as analyzed in our study, could not have been the sole source rocks of the granitic magmas in the Aspy and Bras d'Or terranes. The data also do not prove that Avalon-like basement, as indicated by our isotopic compositions, extends to the north of the Mira terrane. Furthermore, the isotopic data demonstrate that the known Late Proterozoic rocks in the Mira terrane could not have been the only source rocks that produced the entire spectrum of granitic compositions in Cape Breton Island. The isotopic data, however, can be interpreted consistently if the entire range of compositions in Cape Breton Island resulted from mixing sources akin to hypothetical nonradiogenic (Grenville-like) and radiogenic (Avalon-like) components.

CONCLUSIONS

Paleozoic granitic rocks from the Mira, Bras d'Or, and Aspy terrane cannot be uniquely distinguished on the basis of their Pb and O isotopic compositions. The Pb isotopic data suggest the presence in the Blair River Complex of a source region similar to that identified in northern New England (Grenville-like). The Blair River Complex differs from terranes to the south in that the rocks have the most primitive Pb, generally low and narrow range of $\delta^{18}O$ values (+7.0 to +8.5 permil), and a distinctive Nd isotopic composition. The isotopic values probably represent mantle-derived, hybridized, crust-contaminated magmas (high μ). In the Aspy and Bras d'Or terranes, the granitic magmas share the radiogenic character of plutons from New Brunswick and coastal New England. The implied high μ values for the granitic tocks from the Aspy and Bras d'Or terranes suggest that the sources evolved through an older stage in a high μ environment. The Pb isotopic data are in agreement with Nd model ages and ranges in ϵ_{Nd} values that suggested the presence of crustal sources in the Aspy and Bras d'Or terranes. In the Mira terrane, the about 620 Ma granites overlap the Pb isotopic field of plutons from the Aspy and Bras d'Or terranes. The Devonian plutons in the Mira terrane, however, have relatively low $^{206}Pb/^{204}Pb$, $^{207}Pb/^{204}Pb$, and $^{208}Pb/^{204}Pb$ values as a group, consistent with a source that included mixtures of mantle and crustal components. Paleozoic granitic rocks from Cape Breton Island could have been generated during terrane amalgamation from combinations of Grenville-like and Avalon-like sources, perhaps as a result of thrusting of the Avalonian (Gondwanan) block on the Grenville craton.

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