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THE TRANS-LABRADOR GRANITOID BELT IN THE MAKKOVIK PROVINCE: NEW GEOCHRONOLOGICAL AND ISOTOPIC DATA AND THEIR GEOLOGICAL IMPLICATIONS

Andrew Kerr and Tom Krogh[1]
Labrador Mapping Section

ABSTRACT

U–Pb and Rb–Sr geochronological data show that, contrary to previous supposition, most plutonic rocks in the Makkovik Province are probably related to the ca. 1800 Ma Makkovikian Orogeny, rather than to the ca. 1650 Ma Labradorian Orogeny. Makkovikian plutonic rocks mostly have ages of 1800 Ma or older, and include both syntectonic (foliated) and posttectonic (massive) associations. It is suggested that both are part of a single magmatic pulse, which outlasted final deformational episodes associated with the Makkovikian Orogeny. High-silica, fluorite-bearing granites of the Strawberry intrusive suite have been dated (at one locality) at 1719 ± 3 Ma. These have a strong geochemical similarity to ca. 1800 Ma granitoid rocks, and probably represent the final expression of Makkovikian magmatism; they may be analogous to late high-silica granites of the Newfoundland Appalachians. Subordinate Labradorian plutonic rocks include gabbro–diorite–monzonite–syenite suites (Adlavik and Mount Benedict intrusive suites), which appear to have been derived by fractionation of mafic parent magmas, and a variety of granitic rocks, including slightly peraluminous leucogranites. U–Pb zircon dates from Labradorian plutons cluster between 1650 and 1640 Ma.

Neodymium isotopic studies of Makkovikian plutonic rocks reveal the existence of a fundamental crustal boundary within the Makkovik Province. In the west, Nd isotopic signatures indicate the presence of older (probably Archean) crustal source materials, whereas plutons in the east appear to have had juvenile (Proterozoic) sources. The eastern half of the Makkovik Province represents a Proterozoic crustal province that was juxtaposed with (accreted to?) to the Archean Nain Province during or prior to the Makkovikian Orogeny. The geographic variations of Nd isotopic signatures imply that Makkovikian magmas were probably formed as mixtures of new material (derived from the mantle) and older polycyclic Archean (western domain) or recently generated Proterozoic (eastern domain) sialic crust. A possible mechanism for this process involves the emplacement of mafic magmas into the lower crust, followed by generation and assimilation of anatectic melts. Mechanisms of this type are increasingly popular as models for granitoid magmatism in a variety of environments.

The geochronological data presented force some reappraisal of ideas and terminology. In particular, it is suggested that the term 'Trans-Labrador Batholith' be abandoned as, in the Makkovik Province at least, this feature is a composite belt including rocks of ca. 1800, ca. 1720 and ca. 1650 Ma age.

INTRODUCTION

General Review

This project was initiated in 1984 to assess the mineral potential of granitoid rocks in east-central Labrador, and to gain an understanding of the anatomy and petrogenesis of rocks grouped under the general heading of 'Trans-Labrador Batholith' (Figure 1). Previous publications by Kerr (1986, 1987, 1988) dealt with general geology and the identification and characteristics of potential specialized granitoid rocks in the project area.

This article summarizes the results of geochronological studies by the second author, and also some aspects of Kerr's (1989a) Ph.D. thesis work, notably trace-element geochemistry and Nd isotopic studies. The geological implications of this new information are discussed briefly. Full details of U–Pb zircon geochronology will be presented elsewhere in a publication to be co-authored with T. Krogh. Other aspects are discussed by Kerr (1989a), and will be dealt with in more detail in planned external publications, and a final project report.

This project is a contribution to the Canada–Newfoundland Mineral Development Agreement, 1984–1989

[1] Department of Geology and Mineralogy, Royal Ontario Museum, Toronto, Ontario, M5S 2C6

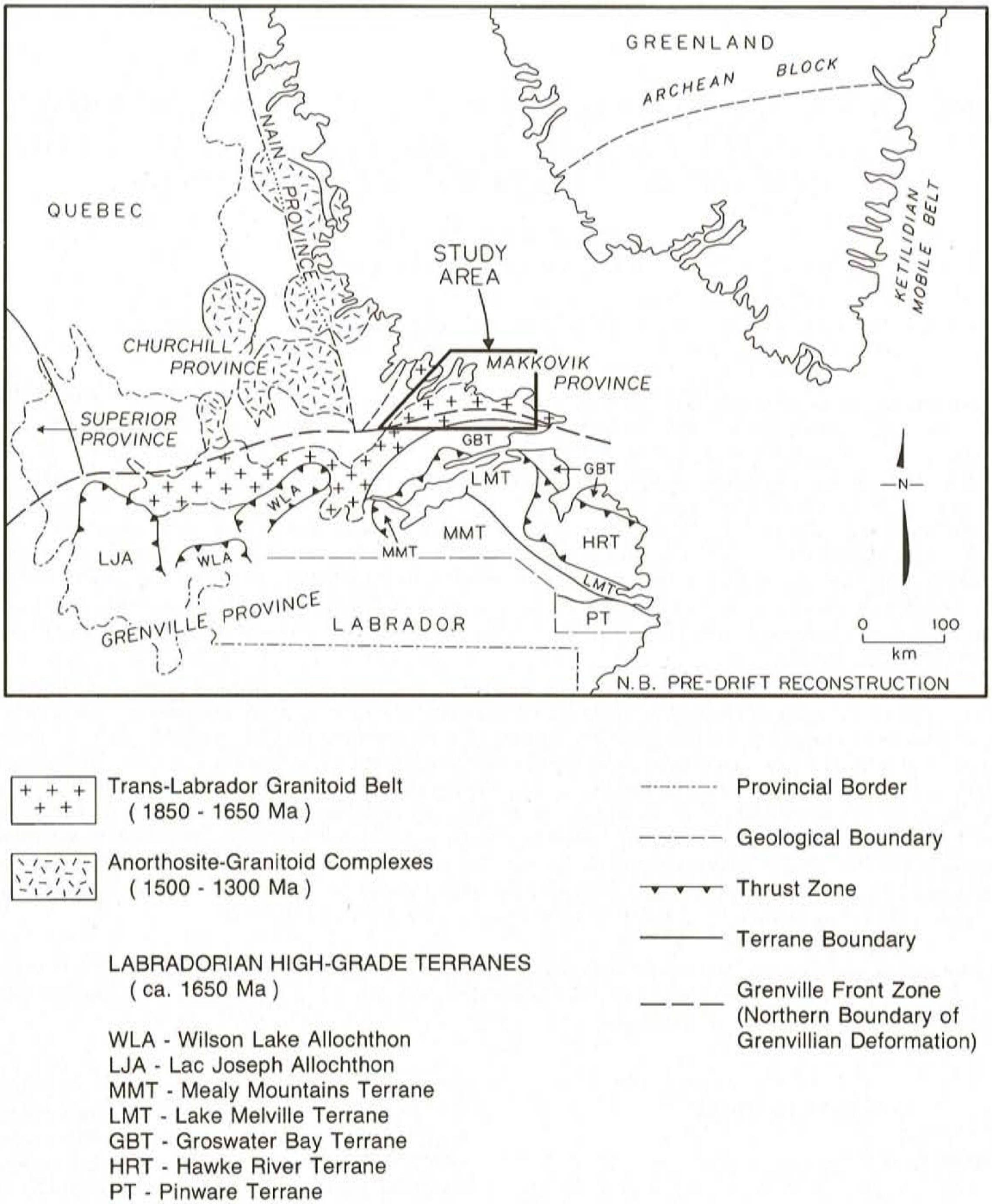
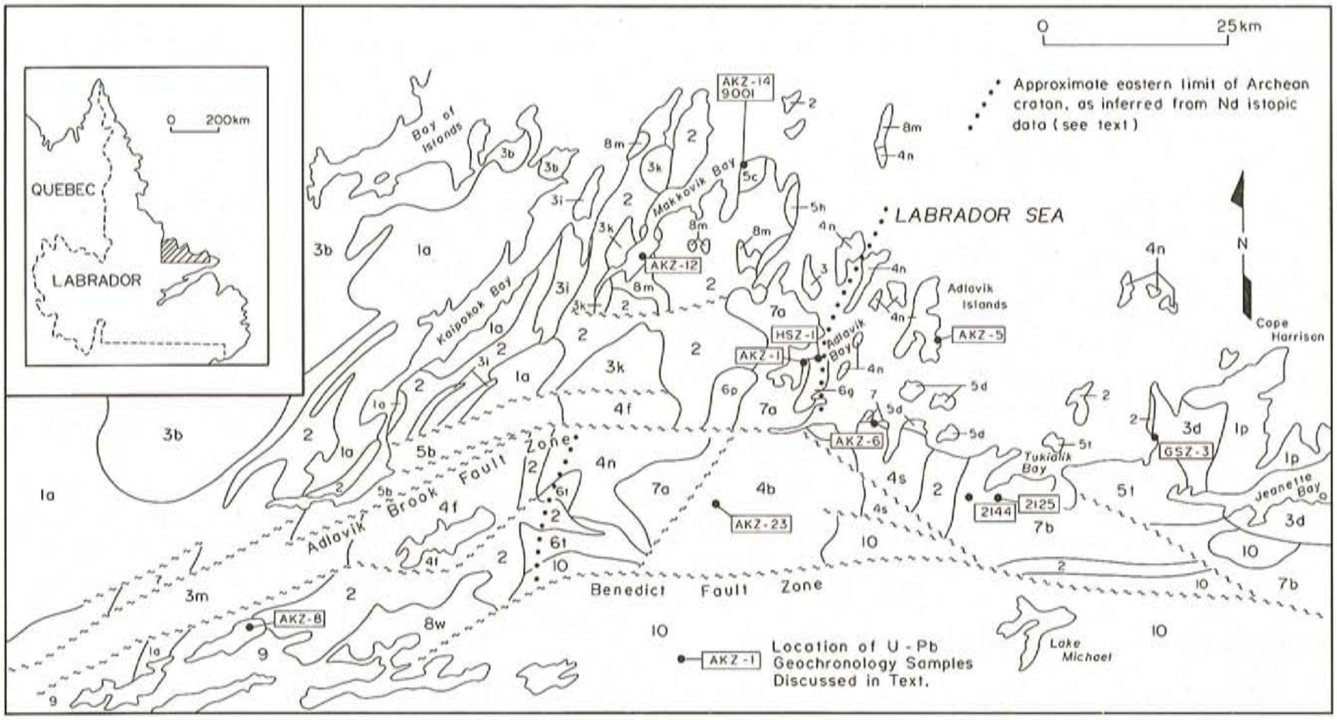


Figure 1. *Major geotectonic elements of Labrador, showing the location of the Trans-Labrador Granitoid Belt and the study area. Adapted from Gower and Ryan (1986), with modifications to show recent work in the Grenville Province.*

Igneous Assemblages

The study area (Figures 1 and 2) is dominated by plutonic igneous rocks, which intrude felsic metavolcanic and other supracrustal rocks of the Aillik Group and/or basement gneisses. It has been recognized for some time (e.g., Gower, 1981; Gower and Owen, 1984; Gower and Ryan, 1986) that there are two groups of intrusive rocks. Most are massive, and generally undeformed, but a subordinate group of foliated granitoid rocks have north- or northeast-trending fabrics that are parallel to those in Aillik Group country rocks. The deformational event that affected the Aillik Group at ca. 1800 Ma is termed the Makkovikian Orogeny (Gower and Ryan, 1986), and these foliated granitoid rocks were termed 'Makkovikian Batholith' by Kerr (1987). Undeformed intrusive rocks have traditionally been assigned to the 'Trans-Labrador Batholith' and (mostly by analogy with central Labrador) were presumed to be of ca. 1650 Ma age. Until



UNCLASSIFIED PLUTONIC ROCKS

10 *Assorted, massive to foliated granitoid rocks. Includes undivided granitoid gneisses south of the Benedict fault zone that were strongly affected by Grenvillian events*

LABRADORIAN PLUTONIC ROCKS (ca. 1650 Ma)

9 Otter Lake–Walker Lake granitoid. *Coarse grained, seriate to porphyritic biotite–hornblende quartz monzonite to granite*

8 *Leucogranite suites;* **8m,** Monkey Hill intrusive suite; **8w,** Witchdoctor and Burnt Lake granites. *Fine- to medium-grained leucocratic to alaskitic biotite–chlorite and biotite–muscovite granite*

7 *Gabbro–diorite (± monzonite–syenite) suites derived from mafic parent magmas;* **7a,** Adlavik Intrusive Suite; *Gabbro, gabbronorite, leucogabbro and diorite;* **7b,** Mount Benedict intrusive suite; *monzonite, syenite and quartz syenite, minor gabbro and diorite*

POSTTECTONIC MAKKOVIKIAN PLUTONIC ROCKS (ca. 1800 to 1720 Ma)

6 Lanceground intrusive suite; **6g,** *Lanceground granite;* **6p,** *Pistol Lake granite;* **6t,** *Tarun granite. Coarse grained, porphyritic, locally hypersolvus biotite–hornblende syenite to alkali-feldspar granite*

5 Strawberry intrusive suite; **5b,** *Bayhead granite;* **5c,** *Cape Strawberry granite;* **5h,** *October Harbour granite;* **5d,** *Dog Islands granite;* **5t,** *Tukialik granite. Coarse grained, porphyritic, fluorite-bearing biotite granite*

4 *Other Units;* **4b,** Big River granite; *coarse grained, porphyritic biotite–hornblende granite.* **4n,** Numok intrusive suite; *coarse grained hornblende–biotite–pyroxene monzonite to quartz syenite, locally fayalite-bearing.* **4s,** *Stag Bay granitoid; porphyritic biotite granodiorite.* **4f,** *Freshsteak and Noarse Lake granitoids; medium grained, melanocratic, biotite–hornblende quartz monzonite to granite*

SYNTECTONIC MAKKOVIKIAN PLUTONIC ROCKS (ca. 1800 Ma or older)

3 **3i,** Long Island quartz monzonite; *medium grained, melanocratic, plagioclase–porphyritic quartz monzonite.* **3k,** Kennedy Mountain intrusive suite; *dominantly coarse grained, fluorite-bearing, biotite granite.* **3m,** *Melody granite; strongly-deformed, porphyritic granite.* **3d,** Deus Cape granitoid; *foliated granodiorite.* **3b,** Island Harbour Bay intrusive suite; *includes tonalite, hornblende diorite and biotite granite with minor fluorite*

COUNTRY AND BASEMENT ROCK UNITS

2 *Lower and upper Aillik group and probable equivalents; lower Aillik Group includes metasedimentary and mafic metavolcanic rocks, upper Aillik Group is dominated by felsic metavolcanic rocks*

1 *Quartzofeldspathic orthogneisses;* **1a,** *Archean gneisses equivalent to Nain Province;* **1p,** *Proterozoic gneisses of the Cape Harrison area (Cape Harrison metamorphic suite)*

NOTE *Geological map is partly based on Gower (1981),* Gower et al. *(1982) and Ryan (1984).*

Figure 2. *Simplified geological map summarizing the distribution of plutonic, volcanic and basement rock assemblages in the study area, and locations of U–Pb geochronology samples. The boundary between western and eastern domains is defined using Nd isotopic patterns (see text).*

1986, very few U–Pb or Rb–Sr age determinations were available from either assemblage in the study area.

Geochronological data summarized here show that there are at least four discrete igneous assemblages. In contrast to previous views (e.g., Gower and Ryan, 1986; Kerr, 1987), the dominant group is of Makkovikian, rather than Labradorian age, and it includes both syn- and post-tectonic associations. Figure 2 illustrates the general distribution of these assemblages, and names proposed for component suites and units. Names used for suites and units were introduced by Kerr (1988, 1989a). Individual units were described lithologically in earlier reports (Kerr, 1986, 1987, 1988) and no detailed descriptions are given here.

GEOCHRONOLOGICAL RESULTS

Table 1 lists results of U–Pb and Rb–Sr geochronological work conducted as part of this project. Locations of U–Pb zircon samples are shown in Figure 2.

Syntectonic Makkovikian Plutonic Rocks

This name is used here for foliated intrusive rocks that have north- or northeast-trending foliations. Most of these are located within the western part of the area, around Kaipokok and Makkovik bays (Figure 2). However, Gower and Owen (1984) and Gower and Ryan (1986) also noted the presence of this 'Makkovik Trend' in granitoid rocks in the east of the area. One such unit, here termed Deus Cape granitoid, yielded a U–Pb zircon age of 1837^{+6}_{-4} Ma (Sample GSZ-3; Table 1) that confirms its Makkovikian affinity. In comparison to other foliated units in the Makkovik Province, it is slightly older than the Island Harbour intrusive suite (1805 ± 5 Ma; Loveridge *et al.*, 1987) or the Long Island quartz monzonite (1802^{+13}_{-7}; Gandhi *et al.*, 1988).

The 1800 Ma Posttectonic Makkovikian Assemblages

The most interesting geochronological development is the identification of widespread posttectonic Makkovikian plutonic rocks. These are generally massive and undeformed, except in the south of the area where east-trending (but locally variable) foliations are probably related to Grenvillian events. There are no reliable field criteria to discriminate between these and younger Labradorian plutonic rocks.

Numok intrusive suite. Undeformed intrusive rocks of ca. 1800 Ma age were identified initially in the Adlavik Islands area, where a fayalite–pyroxene syenite (sample AKZ-5) gave a concordant age of 1801 ± 2 Ma (Table 1). A quartz monzonite from the locally deformed margin of an adjacent unit (sample HSZ-1) yielded slightly discordant zircons that indicate a closely similar crystallization age (Table 1). A genetic link between these rocks and gabbro–diorite of the nearby Adlavik Intrusive Suite, suggested by Kerr (1986, 1987) is precluded by these data, in conjunction with the 1650 Ma age obtained from the latter. Trace-element abundances also indicate that derivation of these rocks by fractionation of an Adlavik-like parent magma would be difficult (Kerr, 1989a). The name 'Numok intrusive suite' (derived from the local name for the largest of the Adlavik Islands) is used here for the monzonite to quartz syenite of the Adlavik Islands, and their equivalents south of the Adlavik Brook fault zone (Figure 2).

Other Units. The Big River granite (Figure 2) is a coarse grained granite unit, characterized by mantled-plagioclase ('pseudo rapakivi') textures. A Rb–Sr whole-rock isochron suggests an age of 1798 ± 28 Ma (Kerr, 1989a; Table 1). A subsequent U–Pb investigation gave a precise age of 1802 ± 2 Ma (sample AKZ-23; Table 1). This illustrates that Rb–Sr methods can yield useful information in the area; however, this is certainly not the case in all examples, and Rb–Sr data must be treated with caution.

Rb–Sr data from the Stag Bay granitoid (Figure 2) gave an ambiguous age of 1714 ± 44 Ma (Kerr, 1989a; Table 1). Preliminary U–Pb zircon data are discordant, but indicate a Makkovikian age of ca. 1800 Ma (sample AKZ-6; Table 1).

In the case of the Freshsteak granitoid (Figure 2), a Rb–Sr whole-rock isochron suggests an age of 1798 ± 48 Ma (Kerr, 1989a; Table 1). The results are very similar to those obtained from the Big River granite, and indicate a Makkovikian age. No U–Pb data presently exist for confirmation; however, the generally low Rb/Sr ratios of this unit suggest that it is probably not susceptible to disturbance by loss of radiogenic Sr, and the isochron is regarded as a reasonable, although imprecise, estimate of age.

Discussion. These data indicate that a number of generally undeformed plutonic rocks are posttectonic intrusions related to Makkovikian, rather than Labradorian, events. The ages obtained from these rocks are within error of U–Pb ages listed above for syntectonic units such as the Island Harbour intrusive suite and Long Island quartz monzonite. They are also very close to the 1807 ± 3 Ma U–Pb zircon age obtained from a porphyry within the upper Aillik Group (Schärer *et al.*, 1988).

The data suggest that syn- and post-tectonic Makkovikian assemblages form part of a single magmatic pulse that outlasted final deformational events associated with the Makkovikian orogeny. Alternatively, it could be argued that this late deformation was heterogeneous in intensity and/or timing. Plutons such as the Island Harbour (as described by Ryan *et al.*, 1983) and Numok intrusive suites, which have deformed margins but massive interiors, could result from either process. Schärer *et al.* (1988) obtained sphene and monazite ages of 1794 ± 2 Ma to 1761 ± 2 Ma from anatectic granitoids in the reworked Archean basement of the Kaipokok Bay area, suggesting that deformation and metamorphism continued well beyond 1800 Ma in some parts of the area. A close relationship between syn- and post-tectonic Makkovikian assemblages is also indicated by their geochemical affinities (Kerr, 1989a; see also below).

Table 1. Summary of U–Pb zircon and Rb–Sr whole-rock age determinations referenced and discussed in this report

Sample	Unit and description	Age information	Comments
U–Pb ZIRCON AGES			
	Syntectonic Makkovikian Plutonic Rocks		
GSZ-3	Deus Cape granitoid; coarse grained foliated granodiorite	1837^{+6}_{-4} Ma	Three fractions, 5 to 8% discordant; sphene (1 fraction) gave 1782 Ma
	Posttectonic Makkovikian Plutonic Rocks		
AKZ-5	Numok intrusive suite; coarse grained pyroxene-fayalite syenite, undeformed	1801 ± 2 Ma	Euhedral, colourless, gem-quality zircons up to 2 mm in length
HSZ-1	Numok intrusive suite; quartz monzonite from locally deformed marginal zone, Adlavik Bay	ca. 1801 Ma	Two fractions are 4% and 6% discordant along a line from 1801 (concordia) to ca. 1000 Ma (lower intercept)
AKZ-23	Big River granite; coarse grained, K-feldspar porphyritic pseudo-rapakivi granite	1802 ± 2 Ma	Two fractions are almost concordant
AKZ-6	Stag Bay granitoid; coarse grained, massive biotite-granite	ca. 1800 Ma	One fraction only is 2.6% discordant, but sits on a line from 1800 to 1000 Ma.
AKZ-14, 9001	Cape Strawberry granite; AKZ-14 is a coarse grained granite, 9001 is a biotite-rich cumulate zone with enhedral zircons	1719 ± 3 Ma	Initial discordant data suggested 1800-1760 Ma; two fractions from 9001 are < 1% discordant
	Labradorian Plutonic Rocks		
AKZ-1	Adlavik Intrusive Suite; monzodiorite to syenodiorite from Adlavik Bay area	1649 ± 1 Ma	Five fractions analyzed in 1987 and 1988 are concordant or slightly discordant
AKZ-8	Otter Lake–Walker Lake granitoid; coarse grained, two-feldspar porphyritic granodiorite	1647 ± 2 Ma	One fraction concordant, one fraction is 1.2% discordant
2144, 2125	Mount Benedict intrusive suite; 2144 is a syenite; 2125 is a less evolved syenomonzonite from a nearby locality	1650 ± 10 Ma	2144 gave discordant data indicating a *ca.* 1650 age; 2125 gave two slightly discordant fractions; age preliminary
AKZ-12	Monkey hill granite; fine grained, biotite-chlorite leucogranite	1640 ± 10 Ma	Contained very little zircon; two fractions are 4 and 7% discordant; age is preliminary
Rb–Sr WHOLE-ROCK AGES			
	Big River granite; 7 samples from north-west of unit	1798 ± 28 Ma Sr(i)=0.7017 ± 9	Agrees well with subsequent U–Pb zircon age
	Freshsteak granitoid; 6 samples from north of unit	1798 ± 48 Ma Sr(i)=0.7029 ± 6	Unit has generally low Rb/Sr ratios and is less susceptible to isotopic disturbance than other granites
	Stag Bay granitoid; 5 samples only, including AKZ-6	1714 ± 44 Ma Sr(i)=0.7035 ± 5	Age is probably disturbed, as U–Pb gives *ca.* 1800 Ma
	Strawberry intrusive suite; 5 samples from discrete plutons	1694 ± 56 Ma Sr(i)=0.6974 ± 64	High Rb/Sr ratios; age is probably disturbed; may also reflect variation in Sr(i) between plutons
	Lanceground intrusive suite; 4 samples from Lanceground granite, 1 from Pistol Lake granite	1692 ± 32 Ma Sr(i)=0.6991 ± 63	Very high Rb/Sr ratios; age is probably a minimum only; geochemically akin to other posttectonic Makkovikian units

NOTES: All Rb–Sr ages utilize a decay constant value of 1.42×10^{-11}.
Errors are quoted to the last significant digit.
U–Pb techniques and procedures correspond to those of Schärer *et al.* (1988).

The 1720 Ma Posttectonic Makkovikian Assemblage

The Cape Strawberry granite. The Strawberry intrusive suite (Kerr, 1988) comprises several plutons of closely similar, totally undeformed, fluorite-bearing, biotite granite scattered in an east–west array over 100 km in length (Figure 2).

Initial U–Pb zircon studies, of the Cape Strawberry granite (sample AKZ-14; Table 1) did not give a precise age, as the data were highly discordant. It was clear, however, that a ca. 1650 Ma age was very unlikely. In order to improve precision, a nearby mafic mineral accumulation layer (sample 9001; Table 1) containing euhedral 'cumulus' zircons was examined. This gave a precise age of 1719 ± 3 Ma.

Discussion. The close petrological similarity between all members of the Strawberry intrusive suite suggests that the Bayhead, October Harbour, Dog Islands and Tukialik granites (Figure 2) are also of similar age. At present, it is not clear if other 1720 Ma granites are present in the study area. However, the Lanceground intrusive suite (Kerr, 1988; Figure 2), comprising coarse grained, variably hypersolvus granites and alkali-feldspar granites, is a possible suspect for such. The Rb–Sr whole-rock age of 1692 ± 32 Ma for the Lanceground granite (Kerr, 1989a; Table 1) is considered a minimum only, as there is evidence of radiogenic Sr loss, common in low-Sr granites of this type (e.g., Faure, 1978). This age is also suspiciously similar to a 1694 ± 56 Ma composite Rb–Sr isochron from the Strawberry intrusive suite (Kerr, 1989a; Table 1). The very imprecise initial Sr isotopic ratios of both isochrons are a function of the high Rb/Sr ratios of these granites. However, it should also be pointed out that there are some petrographic and geochemical similarities between the Lanceground intrusive suite and syenite to quartz syenite of the Numok intrusive suite, dated precisely at 1801 Ma (see above).

The 1720 Ma Strawberry intrusive suite falls almost halfway between the 1800 Ma and 1650 Ma assemblages in chronological terms. In terms of geochemistry, the Strawberry intrusive suite is an evolved, high-silica, granite suite of metaluminous to peralkaline affinity, that is enriched in fluorine, Zr, Nb, Y and REE (Kerr, 1988, 1989a; see also below). In these respects, it is comparable to posttectonic Makkovikian units such as the Numok intrusive suite and Big River granite, and to undated syntectonic (i.e., foliated) Makkovikian units such as the Kennedy Mountain intrusive suite (Figure 2). It does not resemble known 1650 Ma granitoid rocks. The Strawberry intrusive suite is thus regarded as a posttectonic Makkovikian association emplaced some 80 Ma after the metamorphic and deformational events of the Makkovikian orogeny. It falls into the grey area between 'postorogenic' and 'anorogenic' magmatism, and is perhaps analogous to late high-silica granites in the Appalachians such as the François, Ackley and St. Lawrence granites in Newfoundland, which bear a similar temporal relationship to deformational events. As noted above, U–Pb data from anatectic granites (Schärer *et al.*, 1988) indicates that Makkovikian thermal events continued well beyond 1800 Ma.

Labradorian Plutonic Rocks

It is clear from the above that plutonic suites of ca. 1650 Ma age are much rarer in the Makkovik Province than previously supposed. However, several units of this age have been identified by U–Pb geochronology. In general, Labradorian plutonic rocks fall into two categories. Compositionally expanded gabbro–diorite (± monzonite–syenite) assemblages, which appear to be derived by fractionation of mafic parental magmas, are present in the form of the Adlavik and Mount Benedict intrusive suites (Figure 2). Labradorian granites *(ss.)* include weakly peraluminous leucogranites (e.g., Monkey Hill intrusive suite), and quartz–monzonite to granite units of regional extent (Figure 2).

Adlavik Intrusive Suite. This spectacular cumulate-layered mafic intrusion at Adlavik Bay area gave a precise U–Pb age of 1649 ± 1 Ma (sample AKZ-1; Table 1) for a potassic diorite. The term Adlavik Intrusive Suite is now once more restricted to these mafic and intermediate rocks, as the adjacent monzonite to quartz syenite is now known to be a posttectonic Makkovikian pluton.

Mount Benedict intrusive suite. This term is introduced for fresh monzonite, syenite, quartz syenite and granite in the Benedict Mountains area, corresponding generally to Unit 21 of Gower (1981). This exhibits crude stratification; the most evolved rocks occur at highest elevations. The least evolved rocks are olivine-bearing plagioclase cumulates that resemble parts of the Adlavik Intrusive Suite. The suite is regarded as a complement to the mafic mineral and plagioclase cumulates of the Adlavik Intrusive Suite, i.e., it is a residual liquid derived from a mafic parental magma. Trace-element modelling indicates that a link of this type is feasible (Kerr, 1989a), and it is consistent with the strong enrichment of lithophile trace elements (e.g., Rb, U, Th) in the Mount Benedict intrusive suite. A syenite from the Mount Benedict area was previously dated by Brooks (1982) at 1625 ± 50 Ma (Rb–Sr whole-rock). U–Pb zircon data from two nearby sites (samples 2125, 2144; Table 1) are variably discordant; a preliminary age of 1650 ± 10 Ma is suggested, which is very close to that obtained from the Adlavik Intrusive Suite. Error limits may be revised slightly when additional data become available.

Monkey Hill intrusive suite. This suite includes several small, compositionally identical, leucogranite plutons in the Makkovik Bay area. The Monkey Hill granite gave discordant U–Pb data that indicate a preliminary age of 1640 ± 10 Ma (sample AKZ-12; Table 1; subject to minor revision when additional data are available). This is very close to the 1632 ± 9 Ma U–Pb zircon age (Brooks, 1983) from the compositionally similar Witchdoctor granite, in the southwest of the area (Figure 2). It is also consistent with field observations indicating that the Monkey Hill intrusive suite cuts the Adlavik Intrusive Suite north of Adlavik Bay (Kerr, 1989a).

Otter Lake–Walker Lake granitoid unit. This regionally extensive, biotite–hornblende quartz monzonite to granite unit was defined by Ryan (1984). It has previously given Rb–Sr whole-rock ages of 1548 ± 73 Ma and 1498 ± 46 Ma (Kontak, *in* Ryan, 1984). U–Pb zircon data indicate a precise age of 1647 ± 2 Ma (sample AKZ-8; Table 1). This is very similar to the age of the Adlavik and Mount Benedict intrusive suites, and also to the 1649 ± 1 Ma age obtained by Schärer *et al.* (1988) from a rhyolite in the Bruce River Group. It confirms the possibility of a comagmatic volcanic–plutonic relationship, proposed initially by Ryan (1984).

GEOCHEMICAL ASSOCIATIONS

Previous geochemical assessments of the Trans-Labrador granitoid belt (TLGB) (e.g., Kerr, 1988; 1989b) have drawn attention to its transitional character; it has affinity both to calc-alkaline (e.g., continental margin batholiths) and alkaline (e.g., within-plate granite) associations. It is now evident that these conclusions were based on a mixed assemblage of 1800, 1720 and 1650 Ma igneous suites. Most of the 'alkaline' or 'within-plate' features are characteristic of the Makkovikian assemblage. Information presented below is from a systematic regional geochemical database collected using a 2 by 2 km grid system.

Makkovikian *vs* Labradorian

Within the new geochronological framework, geochemical patterns appear more systematic. Detailed discussion is beyond the scope of this short note, but the relationship between geochronological and geochemical associations is well illustrated by three trace-element variation plots (Figure 3).

In the Rb–(Y + Nb) discrimination diagram (Figure 3a) of Pearce *et al.* (1984), Makkovikian (ca. 1800 Ma and older) granitoid rocks mostly plot in the within-plate granite (WPG) field, whereas the 1650 Ma Labradorian assemblage is mostly confined to the volcanic-arc granite (VAG) field. The 1720 Ma Strawberry intrusive suite also falls within the WPG field, and has a similar distribution to the undated Lanceground intrusive suite. Note that the Adlavik and Mount Benedict intrusive suites include gabbroic and dioritic rocks that are not (strictly speaking) granitoid rocks; consequently, the tectonic implications of the diagram may not be valid for these.

In the Zr–(Ga/Al x 10,000) discrimination diagram (Figure 3b) of Whalen *et al.* (1987), which separates so-called 'A-type' granites from other granitoid associations, a similar separation between Makkovikian and Labradorian assemblages is evident, and it is clear that the Strawberry intrusive suite corresponds well to the 1800 Ma assemblage. Note that reanalysis of Zr (using digestion of fused material) has increased absolute Zr levels beyond those reported by Kerr (1987, 1988, 1989b) for some units.

The F–SiO_2 diagram (Figure 3c) illustrates the fluorine-rich character of Makkovikian granitoid rocks compared to their Labradorian counterparts, particularly above 65 percent SiO_2. The Strawberry intrusive suite shows the highest fluorine content.

A number of other major- and trace-element contrasts exist between Makkovikian and Labradorian assemblages, and are discussed by Kerr (1989a). As in the examples shown here, separation is incomplete, and any attempts to classify single samples or small sample suites using geochemical methods are intrinsically hazardous. For example, if considered on a unit level, the ca. 1800 Ma Stag Bay granitoid and the ca. 1650 Ma Otter Lake–Walker Lake granitoid have fairly similar major- and trace-element compositions. This emphasizes the importance of good geochronological control in regional lithogeochemical studies of granitoid rocks.

Plutonic *vs* Volcanic

There is, without question, a strong geochemical affinity between the felsic metavolcanic rocks of the upper Aillik Group and the ca. 1800 Ma Makkovikian assemblage. Volcanic rocks generally lack the strong fluorine enrichment of Makkovikian granites, but this is probably a function of volatile loss in the surface environment; in other respects, they are similar at all SiO_2 contents. Previous geochemical studies of the Aillik Group (e.g., White and Martin, 1980) have drawn attention to alkali-metasomatism as a modifier of original compositions. A closely similar pattern of Na-metasomatism is present in the syntectonic Kennedy Mountain intrusive suite (Kerr, 1989a), suggesting a genetic relationship to parts of the upper Aillik Group. These foliated high-silica granites are logical candidates for plutonic equivalents of upper Aillik Group rhyolites. Ryan (1984) suggested that the Bruce River Group and the Otter Lake–Walker Lake granitoid were comagmatic, a suggestion supported by geochronological data (Schärer *et al.*, 1988; *this report).* Geochemical contrasts between the Bruce River Group and the upper Aillik Group are broadly analogous to those observed between Labradorian and Makkovikian granitoid rocks of equivalent major-element compositions.

NEODYMIUM ISOTOPES AND THE NATURE OF THE CRUST IN THE MAKKOVIK PROVINCE

Nd isotopic studies can yield powerful constraints concerning the sources of igneous suites and the timing of crust formation events. A regional study of this type is summarized below.

Background

The Sm–Nd isotopic system is broadly analogous to the more familiar Rb–Sr system; the ratio of interest from a petrogenetic viewpoint is the initial $^{143}Nd/^{144}Nd$ ratio. This is usually expressed as ϵ_{Nd} CHUR, a convenient integer measure that gives the isotopic composition of a sample, at the time it crystallized, relative to the isotopic composition

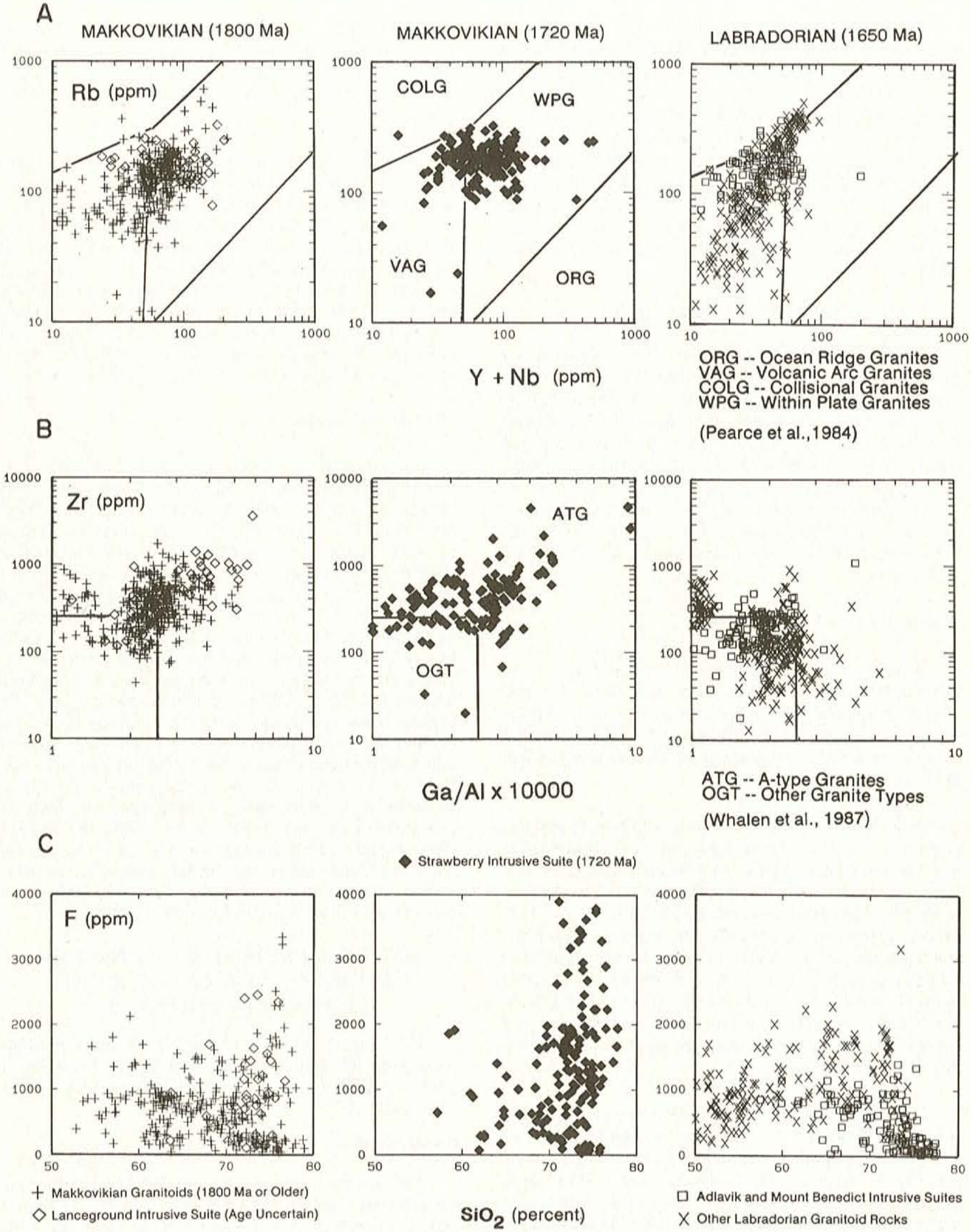


Figure 3. *Summary of some trace-element geochemical contrasts between Makkovikian and Labradorian plutonic assemblages. (a) Rb–(Y + Nb) diagram; (b) Zr–(Ga/Al x 10,000) diagram; (c) F-SiO_2 diagram. See text for discussion.*

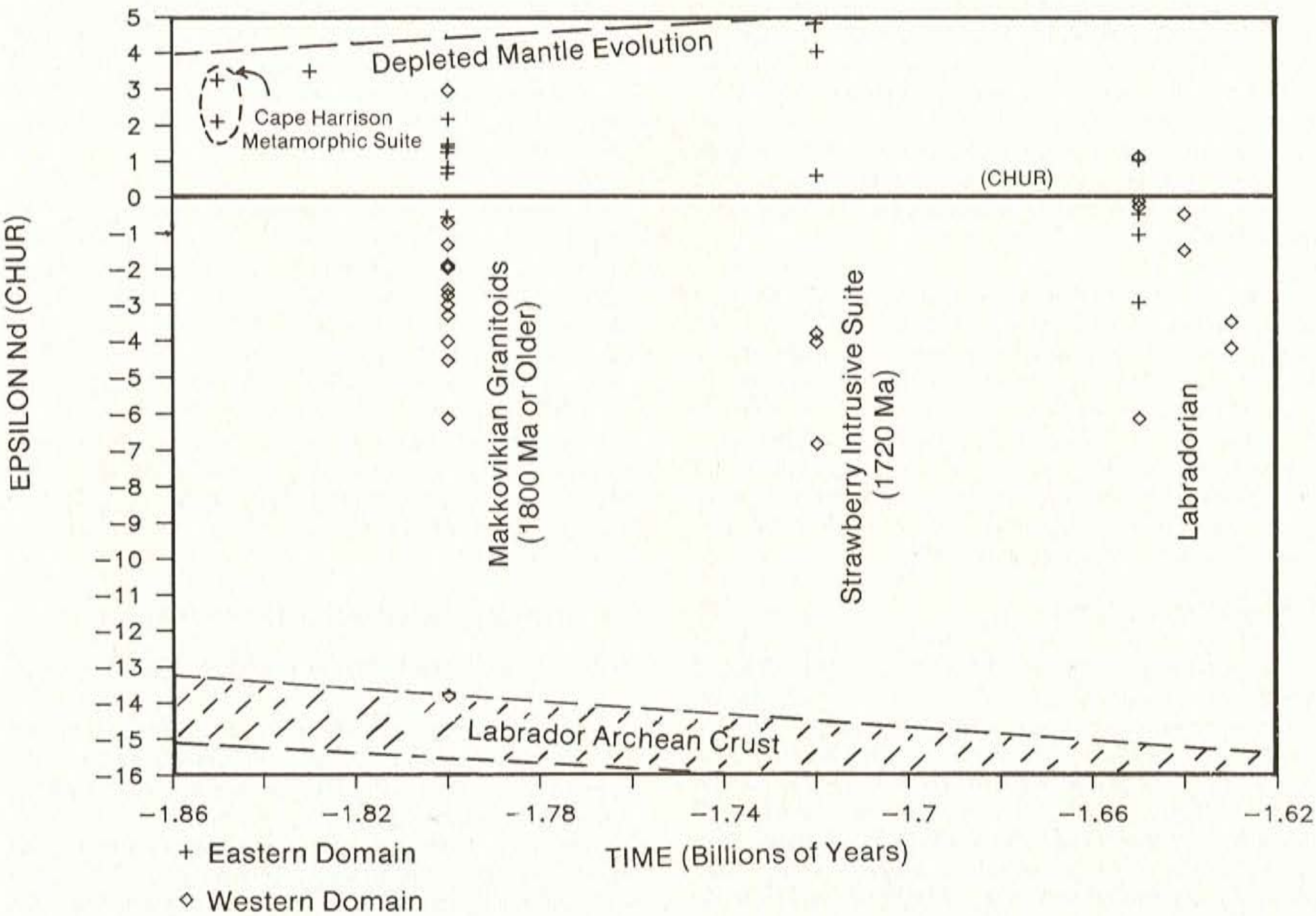


Figure 4. *Nd isotopic evolution diagram for plutonic rocks of the Trans-Labrador Granitoid Belt in the Makkovik Province. See text for explanation of diagram, and discussion of results.*

of a 'chondritic' composition at that time (see, e.g., DePaolo, 1981). Crustal rocks have lower Sm/Nd ratios than chondrites, so (once separated from the mantle) they evolve toward negative ϵ_{Nd} CHUR. The upper mantle has higher Sm/Nd ratios than chondrites, because Nd has been removed by crust formation. Consequently, the 'depleted mantle', as it is conventionally termed, evolves toward positive ϵ_{Nd} CHUR. The most important difference between the Sm/Nd and Rb/Sr systems is that Sm and Nd are not fractionated during most crustal processes. Consequently, the ϵ_{Nd} CHUR of a sample gives information about its source materials, regardless of the number of and duration of steps involved in generating the sample from that source. These fundamental tenets of Nd geochemistry do not apply in all cases, as garnet fractionation or hydrothermal processes can affect Sm/Nd ratios, but the very small range of Sm/Nd observed in crustal rocks indicates that they are generally correct.

Representation of Results

Nd isotopic data from the TLGB are discussed in detail by Kerr (1989a). Figure 4 is a Nd evolution diagram, on which the horizontal line at ϵ_{Nd} CHUR = 0 represents the evolution of a hypothetical chondritic Earth. The ϵ_{Nd} CHUR values of samples are shown at their respective times of formation. For reference purposes, the evolution of the Archean crust of the Nain Province, and the depleted mantle reservoir are also shown. The latter is based on data from mafic volcanic rocks through geological time. For the sake of simplicity, a few volcanic samples, and granitoid rocks of uncertain age, are omitted from the diagram.

Makkovikian Assemblage

It is clear that ca. 1800 Ma Makkovikian plutonic rocks fall into two groups, which respectively have negative and positive ϵ_{Nd} CHUR values. This contrast is geographically systematic; most of the negative group lie west of a line passing through the Adlavik Islands and west of Big River (Figure 2), whereas the positive group lie east of this line. This line defines the western and eastern domains shown in Figure 4 as different symbols.

Western domain samples (with one exception, which is a small nebulitic granite body) lie above the evolution of the local Archean crust (based on Nd data obtained by Brooks, 1983), and cannot therefore be derived entirely by anatexis of such material. However, it is clear that their sources included significant amounts of older crust. In contrast, eastern domain samples lie closer to the depleted mantle line, indicating that they had 'juvenile' sources. Two samples from the Cape Harrison Metamorphic Suite, which is the only significant remnant of gneissic material in the east, also have positive $\in_{Nd}$ CHUR, which precludes an Archean age for this 'basement'.

The ca. 1720 Ma Strawberry intrusive suite shows a similar pattern to the 1800 Ma rocks, but there is an even greater contrast between eastern and western domains (Figure 4). In the east, two samples have isotopic signatures that are almost identical to postulated mantle evolution, which is problematic in view of their strongly evolved geochemistry. It must be stressed at this point that the various plutons within the Strawberry intrusive suite show a remarkable continuity in elemental geochemistry from east to west, which indicates a gross similarity in their petrogenesis.

Labradorian Assemblage

Plutonic rocks dated at ca. 1650 Ma have a quite different pattern of variation (Figure 4). There is no systematic variation between eastern and western domains, and also little correlated variation between $\in_{Nd}$ CHUR and bulk composition. For example, olivine-gabbro from the Adlavik Intrusive Suite and leucogranite from the Monkey Hill intrusive suite have essentially identical $\in_{Nd}$ CHUR. With the exception of three (negative) samples, Labradorian plutonic rocks cluster around $\in_{Nd}$ CHUR values of 0 to -2, regardless of composition or location.

Discussion

The east-west isotopic contrasts amongst Makkovikian granitoid rocks probably have a very simple cause. The domain boundary shown in Figure 2 is interpreted as the eastern edge of the Archean North Atlantic Craton. To the east of this, the Makkovik Province is composed entirely of juvenile Proterozoic crust, some of which may be preserved in the gneisses of the Cape Harrison Metamorphic Suite. It is interesting to note that the edge of the craton appears to be offset by the Adlavik Brook fault zone; the dextral offset of ca. 20 km corresponds to that deduced by Gower *et al.* (1982) based on matching of Aillik Group units. This may indicate that the fault zone is a major structure that extends through the lower crust; however, it may simply be an upper crustal displacement of the granite plutons themselves, which does not involve their lower crustal source rocks. Makkovikian plutonic rocks are best explained as mixtures of juvenile mantle-derived material and pre-existing crustal rocks. In the west, the crustal component was polycyclic Archean material; in the east, Proterozoic sialic crust had only a short crustal residence time, and therefore exerted little isotopic leverage. The strongly positive values from the eastern Strawberry intrusive suite demand a crustal component that had a negligible crustal residence period; this could perhaps represent material added to the crust during earlier (ca. 1800 Ma) magmatism. The striking local variation in Nd isotopic composition indicates that mixing of mantle and crust took place via direct melting and assimilation of the latter, probably as a result of 'underplating' of sialic crust by mantle-derived magmas. Mechanisms of this type are now widely proposed for silicic magmatism in a variety of settings (e.g., Fyfe, 1988).

Labradorian plutonic rocks do not show this type of variation, and even mafic compositions are displaced below the mantle evolution line (Figure 4). This, and the relative constancy of $\in_{Nd}$ CHUR across their compositional spectrum, may indicate that crust-mantle mixing took place in a subcrustal environment, perhaps as a consequence of continent-derived sediment being introduced to the mantle via subduction. Models of this type have been proposed for a number of Proterozoic igneous suites that have comparable isotopic characteristics (e.g., Patchett and Bridgwater, 1984). The lack of geographic contrast may also reflect the 'dilution' of Archean lower crust in the western domain by Makkovikian magmatism.

SUMMARY AND DISCUSSION

Will The Real Trans-Labrador Batholith Please Stand Up?

The original usage of the term Trans-Labrador Batholith (Wardle *et al.*, 1982) was as a geographic (rather than chronostratigraphic) label for a major pre-Grenvillian magmatic province. Definition as a ca. 1650 Ma feature (e.g., Wardle *et al.*, 1986) was largely based on geochronological work in central Labrador (e.g., Thomas *et al.*, 1986). If a strict chronostratigraphic definition is employed, the 'batholith' in the Makkovik Province is now reduced to scattered plutons.

It is therefore recommended that the term be abandoned, and replaced with 'Trans-Labrador granitoid belt', which avoids the implication of common age or origin. This new definition should include syntectonic Makkovikian, posttectonic Makkovikian, and Labradorian plutonic assemblages and is, in some senses, a return to the original geographic definition. Such a step may be viewed as retrogressive by some workers, in that it combines rock units whose age is known to differ by as much as 150 Ma. It should rather be viewed as an acknowledgment that the geological entity to which we have applied the moniker 'Trans-Labrador......' is probably a composite magmatic province developed during a continuum of Early and Middle Proterozoic events along the southern margin of the Laurentian–Greenland Shield complex. There is plenty of room within this general heading to define specific assemblages based on geochronological and/or geochemical grounds, as has been done here.

As a side issue, the term 'Benedict Mountains intrusive suite' should also be abandoned, as it includes at least three discrete age groupings, and can no longer be considered a 'suite'. This will also eliminate confusion with the more specific term 'Mount Benedict intrusive suite' informally introduced here.

Makkovikian plutonic rocks may also occur in the central and western parts of the TLGB; the present absence of older U–Pb ages by no means precludes their occurrence in these complex and poorly exposed areas. It is also likely that there is a gross transverse variation across the TLGB, reflecting partial superposition of Makkovikian and Labradorian batholiths, with the younger assemblage becoming dominant in the south (e.g., Groswater Bay and Lake Melville terranes; Figure 1). Labradorian rocks in the Makkovik Province are probably a distal manifestation of events that occurred within the present Grenville Province.

It is important also to note that the Makkovikian plutonic rocks discussed here were all developed at late stages in the Makkovikian orogenic cycle, and represent its late- to post-kinematic magmatic development. Gandhi *et al.* (1988) report a U–Pb zircon age of 1910 Ma from a poorly known foliated granite to the west of the study area, and other examples of 'older' Makkovikian plutonic rocks are likely to be revealed by further dating. However, patterns observed in younger belts such as the Appalachian Orogen imply that late- to post-kinematic granitoid rocks are vastly dominant over those related to earlier events, and the Makkovik Province may exhibit the same features.

Relationships Between TLGB Plutonism and Volcanism

There is little doubt that the Bruce River Group consists of Labradorian volcanic rocks (Schärer *et al.*, 1988). Similarly, there is now good evidence that Makkovikian magmatism had its surface expression in parts of the upper Aillik Group. This latter sequence has a number of internal lithological and structural contradictions that led Gower and Ryan (1987) to propose that it was a two-stage sequence, consisting of an 1800 Ma or older sequence overlain by 1650 Ma volcanic rocks. This hypothesis was invalidated by Schärer *et al.* (1988), who dated parts of the 'later' sequence at ca. 1860 and 1810 Ma.

However, this general concept of a two-stage or multistage sequence may still be valid if the upper Aillik Group includes equivalents of both syn- and post-tectonic Makkovikian plutonic rocks. A model of this type would account for the fact that parts of the upper Aillik Group appear only weakly deformed, whereas other parts are strongly foliated. The 1807 $\pm$ 3 Ma age reported by Schärer *et al.* (1988) from part of the upper Aillik Group overlaps ages from both syn- and post-tectonic Makkovikian plutonic rocks. However, plutonic rocks that are chronologically equivalent to the ca. 1860 Ma components of the upper Aillik Group are not evident; the oldest syntectonic plutonic unit yet recognized is the ca. 1837 Ma Deus Cape granitoid. There is clearly a need for precise dating of more foliated granitoid units but, more importantly, a pressing need for an improved understanding of upper Aillik Group stratigraphy.

Another problem concerns the possible existence of ca. 1720 Ma volcanic rocks. There is as yet no geochronological evidence of such, but circumstantial Nd isotopic evidence points to one possible candidate. A subvolcanic feldspar porphyry from a fresh sequence of volcanic rocks east of the Stag Bay granitoid (Figure 2) has strongly positive ϵ_{Nd} CHUR (+4 to +5; it is not plotted in Figure 4), and a high-silica granitic composition. The only plutonic rocks that share this unique signature are the eastern plutons of the Strawberry intrusive suite. This possibility also needs to be tested, preferably by dating a rhyolite from the belt. If 1720 Ma volcanic rocks are identified, it will introduce yet another problem in understanding the upper Aillik Group.

Crustal Anatomy of the Makkovik Province

The Nd isotopic data reveal a fundamental boundary within the Makkovik Province that represents an interface between an ancient Archean Craton and a juvenile Proterozoic domain. The boundary indicated on Figure 2 also corresponds with the eastern limit of extensive supracrustal sequences in the Makkovik Province. East of this line, the geology is dominated by plutonic rocks.

It is possible that this reflects a restriction of Aillik Group felsic volcanism to areas underlain by Archean crust. However, plutonic rocks of similar age and composition appear to be abundant in the eastern domain. It is more likely that this contrast reflects greater uplift and erosion of the eastern domain in response to substantial thickening of its thinner, juvenile crust during Makkovikian magmatism. This probably took place by underplating of mantle-derived material to the base of the crust. The mantle-like isotopic signatures of the eastern Strawberry intrusive suite may indicate partial reprocessing of this recently added material at ca. 1720 Ma, whereas, in the western domain, the zone of magma generation remained fixed in Archean crust.

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