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RARE-EARTH ELEMENT (REE) MINERALIZATION IN THE MISTASTIN LAKE AND SMALLWOOD RESERVOIR AREAS, LABRADOR: FIELD RELATIONSHIPS AND PRELIMINARY U–Pb ZIRCON AGES FROM HOST GRANITOID ROCKS

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ABSTRACT

In the large and poorly known area underlain by the Mesoproterozoic Mistastin batholith, geophysical and surficial geochemical data highlight two areas that are inferred to represent small, compositionally evolved plutonic complexes. Exploration shows that these both contain REE mineralization, including concentrations in satellite veins and dykes, and also diffuse disseminated mineralization associated with mafic mineral and oxide concentrations. In both areas, the surrounding (older?) rocks are rapakivi-textured granites, but the age relationships are not everywhere clear. The U–Pb geochronological data from the Ytterby 2 granite and Ytterby 3 syenite–granite indicate emplacement ages of 1423 ± 2 Ma and 1439 ± 3 Ma, respectively. These rule out correlation between these units, and with the well-known Strange Lake Intrusion (ca. 1240 Ma), which contains the best-known REE mineralization in the wider area. The data instead suggest that the mineralized granites are an integral part of the Mistastin batholith, and provide the first fully documented ages from this extensive body. Like other major Mesoproterozoic igneous complexes elsewhere in the region, it appears that the Mistastin batholith includes rocks formed over tens of millions of years. The dated samples have strongly negative ε_{Nd} (-9) at the time of their crystallization, suggesting significant input from older material; likely continental crust.

In the Michikamats Lake area, near the Smallwood Reservoir, a granite unit was previously dated at ca. *1459 Ma. A subsequent aeromagnetic survey defined prominent ring-like features within this unit, and reconnaissance exploration found anomalous REE values associated with syenites. A sample of syenite was investigated to determine its temporal relationship to the surrounding granite unit. The results indicate an identical age of 1459 ± 3 Ma, showing that it is not a discrete younger unit, but is instead likely related to the surrounding granite.*

Results from granites and syenites containing REE mineralization in adjacent Québec indicate age groupings of ca. *1410 Ma and* ca. *1480 Ma, distinct from those obtained in this study. However, the younger of these ages (from the Misery Lake ring complex) suggests that it could represent a young component of the greater Mistastin batholith, which surrounds it. The* ca. *1480 Ma ages come from the Smallwood Reservoir area, and with the* ca. *1459 Ma age from Michikamats Lake, may define a similarly protracted magmatic event associated with the* ca. *1469 Ma Michikamau anorthosite intrusion.*

INTRODUCTION

Exploration for rare-earth element (REE) mineralization across Labrador and adjacent Québec between 2009 and 2011 targeted several areas (Figure 1; summarized by Kerr, 2011). The largest exploration project was actually in Québec, adjacent to the previously known Strange Lake REE–Zr–Nb deposit, which currently sits within Exempt Mineral Lands (EML) in Labrador. This exploration effort defined a discrete REE deposit (the B-Zone) in Québec a few kilometres west of the original discovery, and pre-feasibility studies for its potential development are currently underway. The activity in the Strange Lake area awakened interest in a poorly known area south of Strange Lake, along the Québec-Labrador border (Figure 1), based on the idea that similar mineralized intrusions might exist there. In 2010 and 2011, the part of Labrador south and west of Mistastin Lake was explored for the first time, and REE mineralization was discovered in association with compositionally evolved granitoid rocks. The area is not mapped in detail, and its geology remains poorly known, particularly in Labrador. In adjacent Québec, the alkaline syenite ring com-

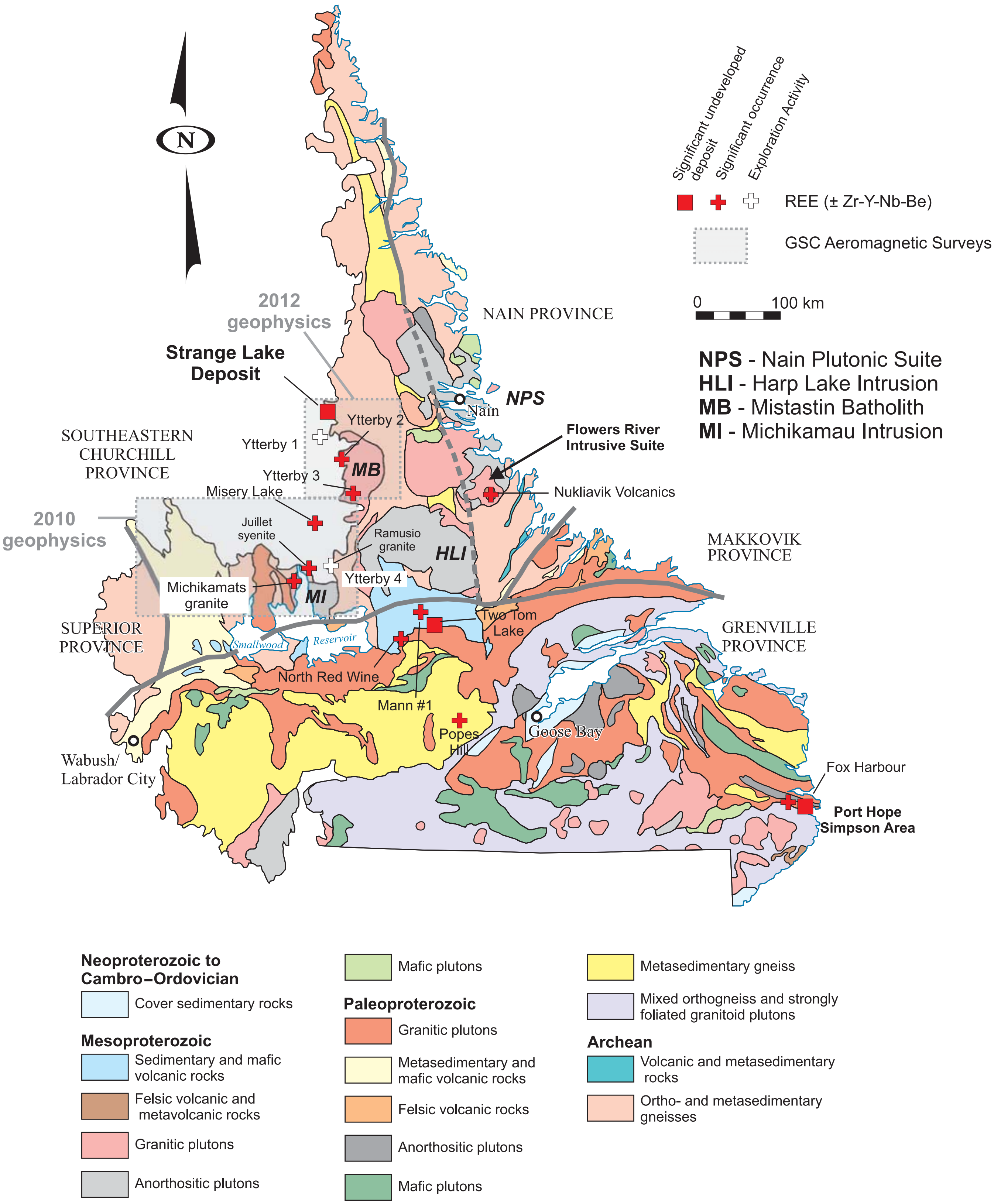


Figure 1. *Simplified geological map of Labrador showing areas of interest for REE exploration, and also relevant areas in Québec. The approximate boundaries of high-resolution aeromagnetic surveys completed in both provinces released in 2010 and 2012 are also indicated.*

plex at Misery Lake (Figure 1) was outlined *via* aeromagnetic surveys completed in 2009 by the Geological Survey of Canada (GSC, 2010). This is now an active exploration project for REE (Quest Rare Minerals, website information). In the Smallwood Reservoir area, this same survey revealed other ring-complex-like features in both Labrador and Québec, and initial exploration indicates local REE enrichment. Similar aeromagnetic surveys were completed along the border region north of Misery Lake in 2011 (GSC, 2012), largely in response to exploration developments. These latter data have yet to be interpreted in detail, but should prove invaluable to future mapping efforts. Should a mining operation eventually develop in Québec at Strange Lake, the challenges to exploration posed by the remote nature of the border region will diminish; thus, there is a new incentive to investigate and better understand its geology.

This article discusses the Mistastin Lake and Smallwood Reservoir areas, partly with reference to the new government geophysical data, and provides some descriptive information on rock types and mineralization. It is based on limited field work completed in 2010 and 2011, and detailed exploration results from these areas remain confidential as of publication. The report also presents results of U–Pb zircon geochronological work, and discusses the new ages in the context of results obtained from similar research in adjacent Québec.

REGIONAL GEOLOGICAL FRAMEWORK

The areas discussed in this report lie within the Churchill Province of the Canadian Shield (Figure 1). Much of the Churchill Province is a vast expanse of generally high-grade metamorphic rocks that includes reworked Archean basement (generally represented by complex orthogneisses) and remnants of Paleoproterozoic supracrustal rocks, largely of pelitic to psammitic composition, but also including calc-silicate rocks, amphibolites and mafic granulites. The gneisses are intruded by Paleoproterozoic granitoid rocks, which are syntectonic to posttectonic with respect to the regional deformation. The Paleoproterozoic history of the region is not discussed further in this report, but is summarized and discussed by van der Leeden *et al.* (1990) and Wardle *et al.* (1990), for Québec and Labrador, respectively.

Younger rocks in this part of the Churchill Province are undeformed gabbro, anorthosite and related intermediate and granitoid rocks of Mesoproterozoic age, overlain by terrestrial sedimentary rocks. The intrusive rocks are part of a large magmatic province that extends right across northern Labrador and Québec (Figure 1). Important examples are the 1340 Ma to 1290 Ma Nain Plutonic Suite in coastal Labrador (Ryan, 1998) and the *ca.* 1450 Ma Harp Lake Intrusive Suite in central Labrador (Emslie, 1980), both of which also intrude the Archean Nain Province. Within the Churchill Province, the largest Mesoproterozoic intrusive complex is termed the 'Mistastin batholith' (Emslie *et al.*, 1980). This is dominated at surface by granitoid rocks, with only scattered areas of anorthosite and gabbro (Figures 1 and 2), but mafic rocks are interpreted to be more abundant at depth. The geochronology of the Mistastin batholith is poorly known, but previously reported U–Pb data suggested an age of *ca.* 1420 Ma (J.C. Roddick, *in* Emslie and Stirling, 1993). In the Smallwood Reservoir area, the Michikamau Intrusion includes layered mafic rocks, anorthosite and lesser diorite and syenite (Emslie, 1968). Early investigations of these rocks suggested a U–Pb age of *ca.* 1460 Ma (Krogh and Davis, 1973), but Kerr and McNicoll (2010) subsequently obtained an older U–Pb baddeleyite age of 1469 ± 1 Ma from anorthosite. A granite body located to the west of the Michikamau Intrusion was reported to have an age of 1459 ± 2 Ma (Krogh, 1993; James *et al.*, 1994). This body is known as the Michikamats Intrusion, after Michikamats Lake (James *et al.*, 1994) and the syenitic unit dated as part of this study lies within its confines. Other transborder granitoid intrusions north and west of the Michikamau Intrusion, including the Ramusio granite and the Juillet syenite (Figure 1), were previously assumed to be of Mesoproterozoic age, and this inference is now confirmed by recent U–Pb geochronology in Québec (David *et al.*, 2012).

GEOLOGY AND REE MINERALIZATION IN THE MISTASTIN LAKE AREA

GENERAL INFORMATION

The geology of the Mistastin batholith in Labrador and around the Québec border (Figures 1 and 2A) is very poorly known. Mistastin Lake itself fills a Cenozoic meteorite crater, around which remnants of a impact melt sheet occur, and this is the only area that has received detailed study (Currie, 1971; Grieve, 1975; Marion and Sylvester, 2010). The batholith was mapped at a reconnaissance scale by Emslie *et al.* (1980), who defined two broad units, *i.e.*, an inner zone of older pyroxene- and pyroxene-bearing quartz monzonite, syenite and granite, surrounded by an outer zone of younger biotite–hornblende granite (Figure 2A). Both granitoid units are widely characterized by plagioclase mantles developed on K-feldspar phenocrysts (rapakivi texture) and also by deep weathering. Emslie *et al.* (1980) also noted texturally distinct monzonitic rocks belonging to what is now termed the Misery Lake ring complex in Québec. Anorthositic rocks were mapped mostly in the area around Mistastin Lake, and were suggested to represent a deeper seated component of the complex. Field work in 2010 and 2011, and exploration activity, suggest that gneissic rocks,

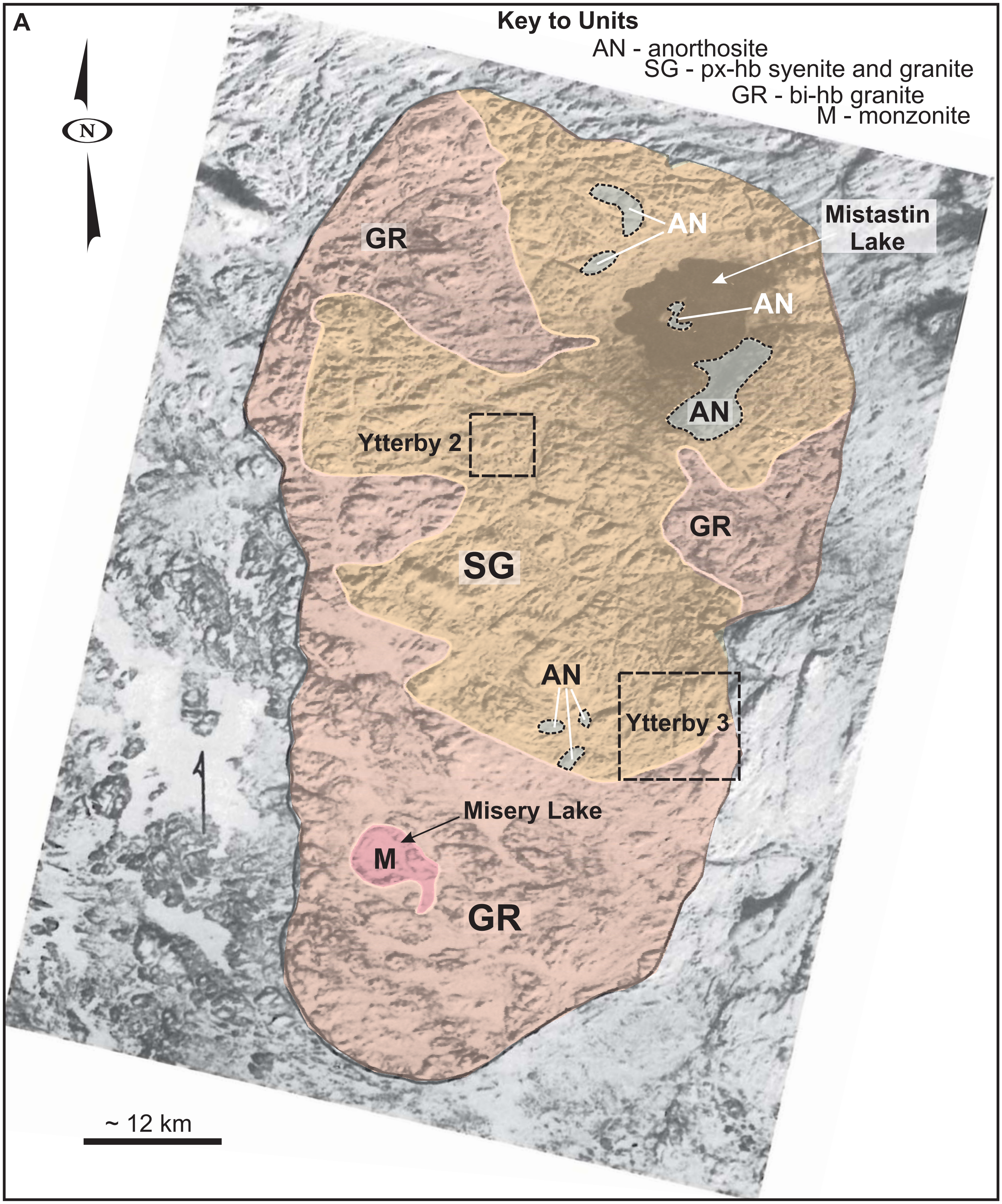
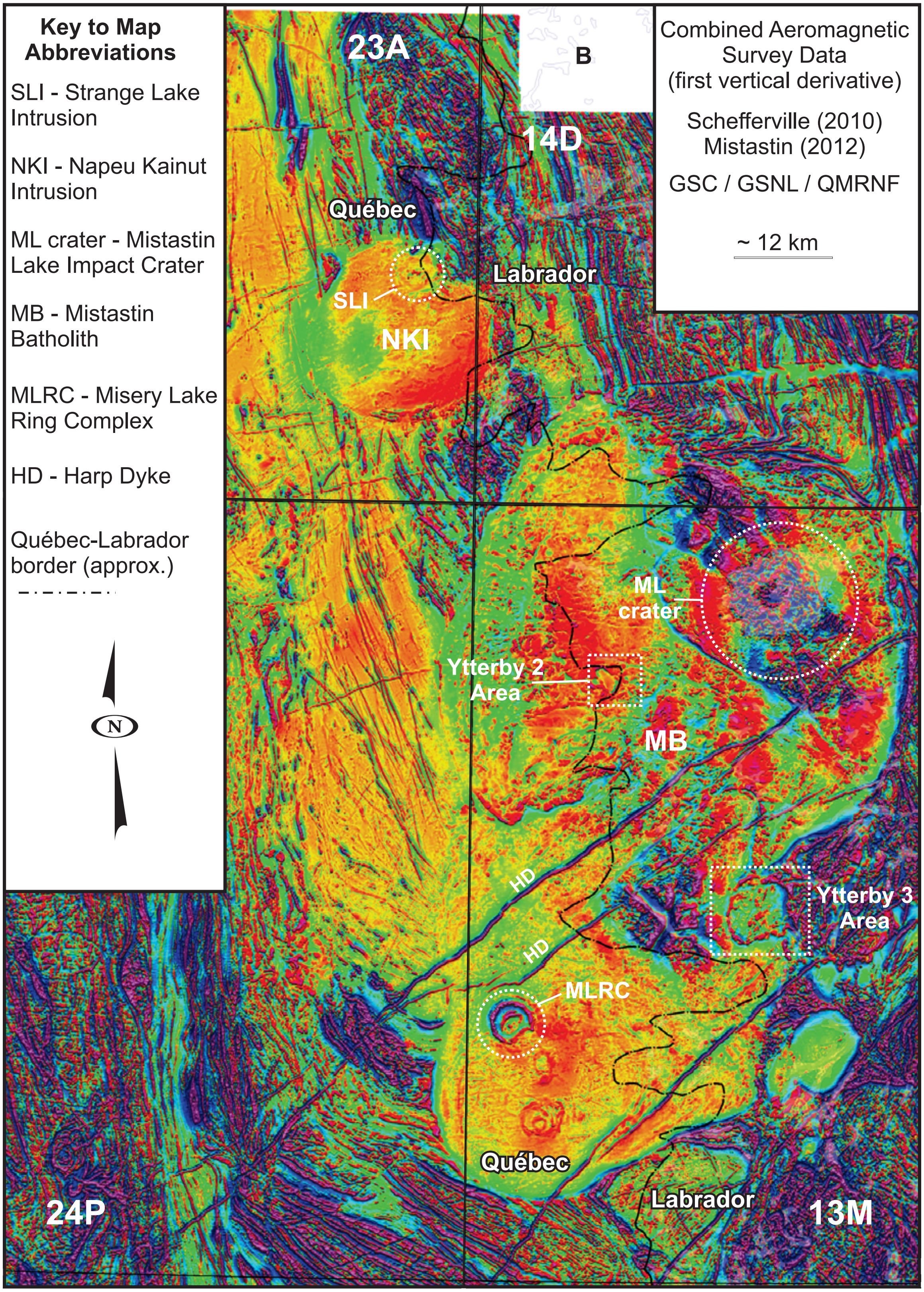


Figure 2. *A) Simplified geological map of the Mistastin batholith, and adjacent areas in Québec and Labrador also showing the locations of the Ytterby 2 and 3 exploration areas and the Misery Lake alkaline ring complex. Original map of the Mistastin batholith from Emslie* et al.*, 1980. B) Colour image showing combined and levelled data from parts of the Schefferville (2010) and Mistastin (2012) aeromagnetic surveys by the GSC, portrayed as the first vertical derivative rather than total field.*



Note the presence of multiple ring-complex features in the southern part of the Mistastin batholith, the clear definition of its intrusive contacts, and the crosscutting linear features interpreted as ca. *1270 Ma Harp dykes. For the outline of the batholith,* see *A.*

presumably remnants of older country rocks, are locally abundant. The combined aeromagnetic data from the GSC surveys provide a striking image of the batholith and its country rocks, and also adjacent plutonic complexes (Figure 2B). These results have yet to be interpreted in detail, but will obviously be invaluable in future investigations.

In addition to the general concept that evolved granitoid rocks with REE potential might occur south of Strange Lake, regional radiometric and aeromagnetic surveys completed prior to 2009, and surficial geochemical data from both provinces, provided first-order targets for exploration. Midland Exploration Ltd (Midland) acquired mineral rights in both provinces, and named their properties Ytterby 1, 2, 3 and 4 (Figures 1 and 2). The name is drawn from the town of Ytterby in Sweden, for which four of the REE are named (yttrium, ytterbium, terbium and erbium). Of these four exploration areas, Ytterby 1 is located mostly in Québec south and west of Strange Lake, and Ytterby 3 is located entirely in Labrador. The Ytterby 2 and Ytterby 4 areas sit on both sides of the interprovincial boundary (Figure 1). In addition to seeking bedrock mineralization, the company is currently assessing the well-defined glacial dispersion train from the Strange Lake deposit, but this work is not discussed here. The Ytterby 2 and Ytterby 3 areas are located within granitoid rocks of the Mistastin batholith (Figure 2), whereas the Ytterby 4 area is located within the Ramusio granite, a separate intrusion located to the south (Figure 1). Only the Ytterby 2, 3 and 4 areas are discussed in this report. The assessment reports for exploration work remain confidential as of publication, but information is provided *via* a presentation on the Midland Exploration website, and also by Banville (2011).

YTTERBY 2 EXPLORATION AREA

The Ytterby 2 area is a rugged, barren upland area located about 60 km southeast of the Strange Lake deposit, on the Québec-Labrador border (Figures 1 and 2). In Labrador, there are two main rock types. The most abundant is coarse-grained “rapakivi-textured” granite, characterized by large ovoidal K-feldspar crystals (up to 10 cm in diameter) that commonly have white plagioclase rims. The remainder of the rock consists of quartz, with hornblende, relict pyroxene and possibly biotite. The rapakivi-textured granite typically displays deep weathering, and many “outcrops” are little more than piles of K-feldspar gravel; it is very difficult to collect fresh samples and verify mineralogy. This rock type is also present in adjacent Québec, based on limited observations. The second rock type occurs in the centre of the area, straddling the border, and is an equigranular pink to orange or red, K-feldspar- and quartz-rich granite that typically lacks rapakivi textures, and does not exhibit the deep weathering. Biotite is the most obvious ferromagnesian mineral in this rock type. Hand-held scintillometer readings indicate that this red granite typically has a stronger radiometric response (300 to 500 cps) than that of the surrounding rapakivi-textured granite (typically < 150 cps). Dykes and sheets of this granite, and also composite aplite and pegmatite zones of similar appearance, cut the rapakivi-textured granite in the surrounding area in Labrador. This suggests that the pink to red granite is a younger unit that intruded the rapakivi-textured granite. Locally, alteration and reddening (hematization?) of the rapakivi-textured granite is observed adjacent to the contacts of such dykes and sheets, suggesting some associated hydrothermal alteration. A few outcrops of foliated gneissic rocks were observed on traverses, and these are most likely screens or xenoliths of older metamorphic rocks.

Airborne magnetic and radiometric surveys were completed by Midland in 2010; the area was also covered by the GSC aeromagnetic survey (Figure 3). The company surveys confirmed the anomalous radiometric response associated with the red granite. The aeromagnetic data suggest that the red granite is broadly associated with a magnetic low, which has some strong positive magnetic anomalies associated with its contact regions (Figure 3A, B). The latter seem to be associated with outcrops of gneissic material, based on mapping by the company (Figure 3B). Prospecting in 2010 returned a wide assortment of grab samples enriched in REE. The best values were over 13% TREO* (notation indicates total REE oxides including Y_2O_3) from the Pam showing (Figure 3B), although values in the range of 1-4% TREO* were more typical. The data given in press releases (and also summarized by Kerr, 2011) indicate that the mineralization is rich in light REE (La, Ce, Pr, Nd, Sm) rather than the more valuable and rare heavy REE (Gd to Lu). There are five main mineralized localities (Figure 3B), of which three are in Labrador. The Pam and Pam South showings are associated associated with dyke-like or sheet-like bodies of red granite, pegmatite and aplite that cut the rapakivi-textured granite. The Shark showing is also associated with veins and sheets of pink granite. Typically, the highest radiometric responses are associated with concentrations of ferromagnesian (mafic) minerals and/or oxides; and REE enrichment is associated with anomalous radioactivity. Little is presently known of the mineralogy, but the steep, light-REE-enriched patterns (illustrated by Kerr, 2011) are typical of minerals such as monazite and allanite. The Levin and Falls showings are located in Québec (Figure 3B), and have not been examined. Midland reported that these occurrences had somewhat higher proportions of heavy REE than the showings in Labrador. The main REE showings in the Ytterby 2 area were tested by reconnaissance drilling in 2011 and 2012, but no results have been released to date.

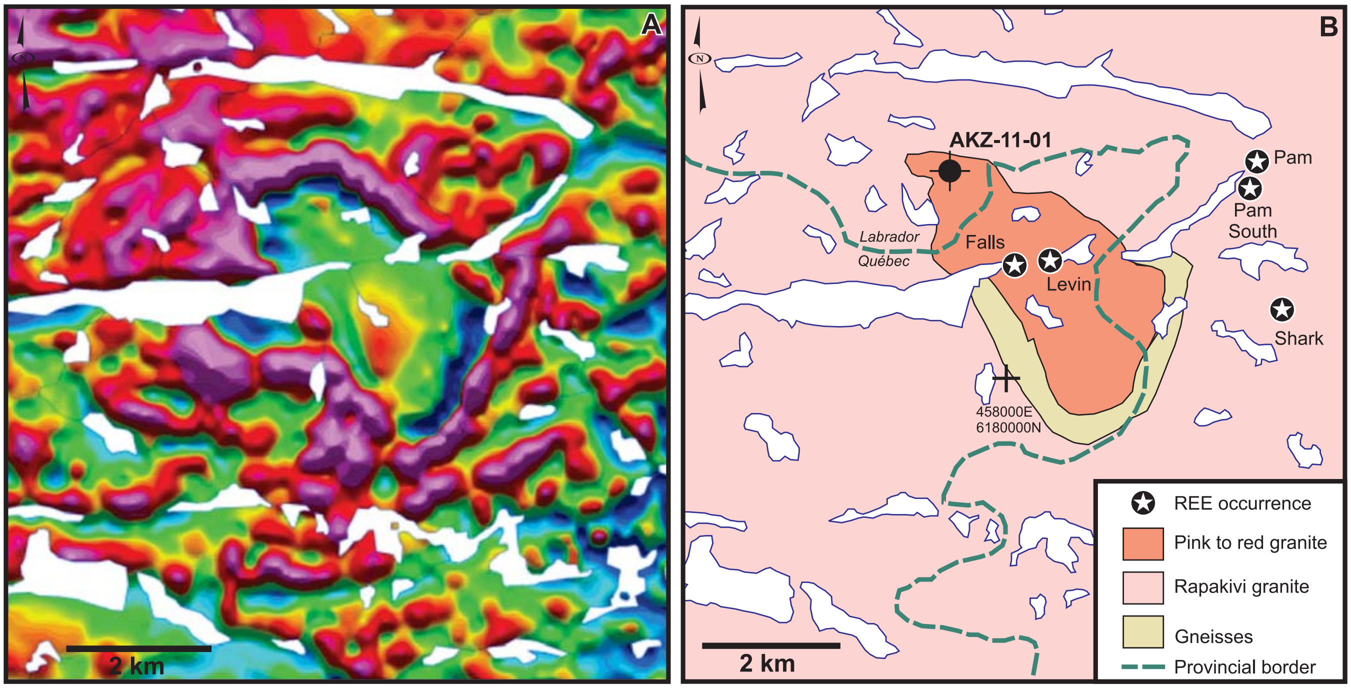


Figure 3. *Information from the Ytterby 2 exploration area. A) High-resolution aeromagnetic survey, first vertical derivative; B) simplified geological map, indicating the main locations of REE mineralization. Information from Midland Exploration website/presentations, and also Geological Survey of Canada data. The location of geochronology sample AKZ-11-01 is indicated.*

The red granite in the Ytterby 2 area was sampled for geochronological study on a hilltop located just a few hundred metres inside Labrador, roughly 4 km west of the Pam showing (Figure 3B), at UTM coordinates 455408E/6182632N (NAD 1927). The sampling locality for AKZ-11-01 is close to the contact between the red granite and the rapakivi-textured granite (Figure 3B), but the contact itself is not exposed.

YTTERBY 3 EXPLORATION AREA

The Ytterby 3 exploration area is located in Labrador, about 90 km southwest of Strange Lake, and 10 to 20 km north of the interprovincial border (Figures 1 and 2). It is a rugged area typified by high hills and deeply incised valleys. Upland areas are barren and rocky, but some of the lower elevations contain scrubby and obstructive vegetation. There are two main rock types in the area. The perimeter of the area consists of rapakivi-textured granite, locally very coarse grained, which is closely similar to equivalent rocks observed in the Ytterby 2 area. The central part of the Ytterby 3 area is also underlain by coarse-grained granitoid rocks, but these lack mantled-feldspar textures and are in general more homogeneous, and locally equigranular to seriate, rather than porphyritic. Diffuse veins, dykes and sheets of fine- to medium-grained pink granite are common in this central unit. In some areas, this central unit appears syenitic rather than granitic in composition, with little or no quartz. Contacts between the central syenite–granite unit and the surrounding rapakivi-textured granite were observed in a few locations, but these seem to be planar, and it was not possible to discern age relationships from vein-like offshoots or xenolith-host relationships. Foliated gneissic rocks dominated several outcrops and, according to Midland's mapping, these form a discrete unit in the northeast, in part coincident with the contact against surrounding rapakivi-textured granite.

As in the case of the Ytterby 2 area, the central syenite–granite unit is broadly associated with a magnetic low (Figure 4A), and this has a circular shape. The strongest positive magnetic anomalies are associated wih an arcuate zone of gneisses that seems to define the northeast side of the central syenite–granite unit (Figure 4B). Airborne radiometric surveys completed by the company suggest stronger local responses in parts of the central syenite–granite unit, which are interpreted a separate 'phase'; however, no clear textural or mineralogical differences between these and surrounding areas are evident. The central syenite–granite unit is interpreted by Midland as a younger intrusion emplaced into the rapakivi granite, but this relationship cannot be confirmed from the limited field observations, and other interpretations cannot be discounted (*see* later discussion).

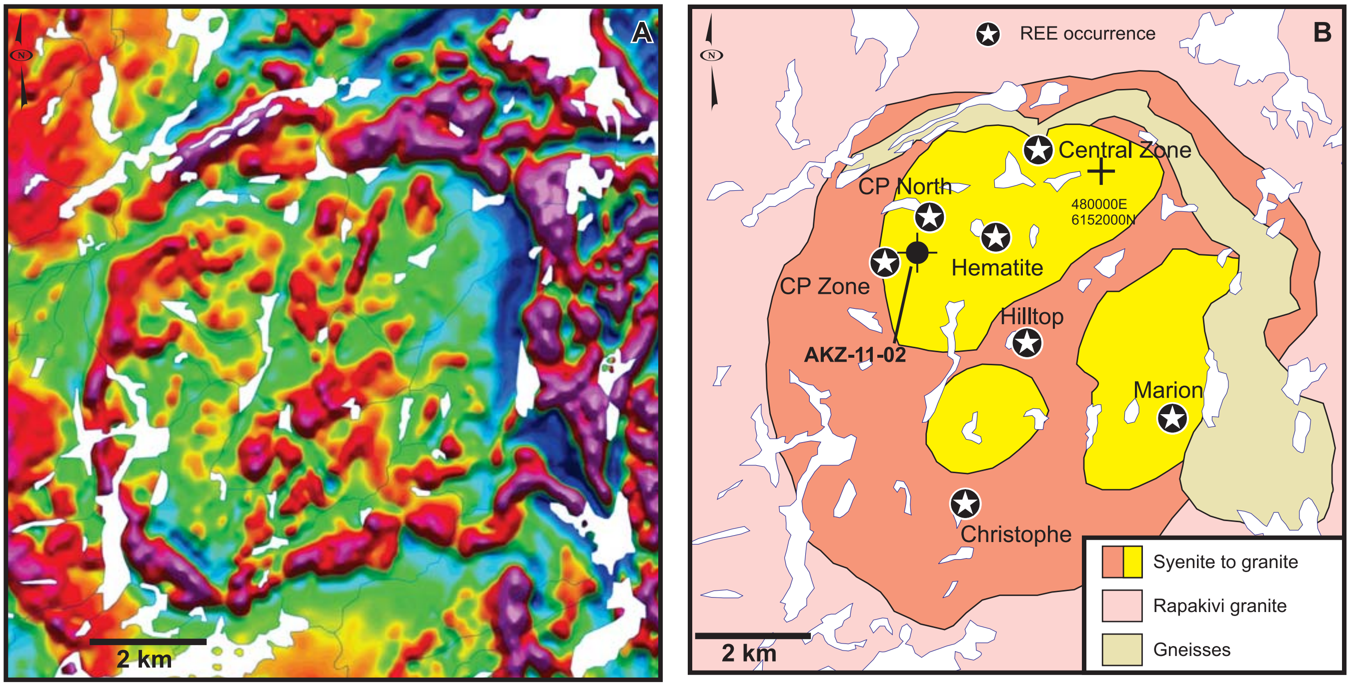


Figure 4. *Information from the Ytterby 3 exploration area. A) High-resolution aeromagnetic survey, first vertical derivative; B) simplified geological map, indicating the main locations of REE mineralization. Information from Midland Exploration website/presentations, and also Geological Survey of Canada data. The location of geochronology sample AKZ-11-02 is also indicated.*

There are seven main zones of REE-enriched mineralization in the central syenite–granite unit (Figure 4B). These are known as the Central showing, CP showing, CP North showing, Hilltop showing, Marion showing, Hematite showing and the Christophe showing (Figure 4b). All but the last-named were examined, and seem broadly similar in that they are associated with diffuse concentrations of ferromagnesian silicates (largely amphibole) and iron oxides in otherwise homogeneous syenite and granite. The TREO* contents of samples range up to several percent, but most examples contain between 0.5 and 2.0% TREO*. There is an association between TREO* values and the percentage of dark minerals in outcrops, and also with elevated radioactivity. The showings are enriched in light REE relative to heavy REE, and the REE patterns are broadly similar to those from Ytterby 2, as illustrated by Kerr (2011). The orientation of mafic mineral concentrations is variable, but in several stripped outcrops, they appear to be gently dipping or subhorizontal layers, suggestive of primary magmatic layering; however, in other areas their distribution is patchy and sporadic. In 2011, several drillholes were completed to test some of these showings, but results have not yet been released.

The central syenite–granite unit in the Ytterby 3 area was sampled for geochronological studies from outcrops adjacent to the CP zone mineralized area (Figure 4B). The sample location for AKZ-11-02 is at UTM 475514E/6150230N (NAD 1927).

YTTERBY 4 EXPLORATION AREA

The Ytterby 4 exploration area is located about 150 km south of Strange Lake, on the Québec-Labrador border (Figure 1). The area is located entirely within the Ramusio granite, a circular body some 12 km in diameter, mostly located in Québec. In Labrador, this unit was mapped by Nunn (1995), but is not described in detail. The outcrops in Labrador examined in 2010 consisted of coarse-grained, pink, biotite granite, with some localized pegmatite and aplite zones. The Ramusio granite is well-defined by a circular magnetic low, which clearly truncates the magnetic expression of structural trends within the older gneissic rocks (Figure 5). The Scintillometer prospecting of Ytterby 4 did not reveal any strongly anomalous radioactivity, and grab samples had generally low REE contents. No geochronology sampling was completed in Labrador, but the granite was sampled close to the border by the Québec Ministère des Ressources Naturelles et de la Faune (QMRNF; Figure 5). The U–Pb geochronological data from this location are reported by David *et al.* (2012).

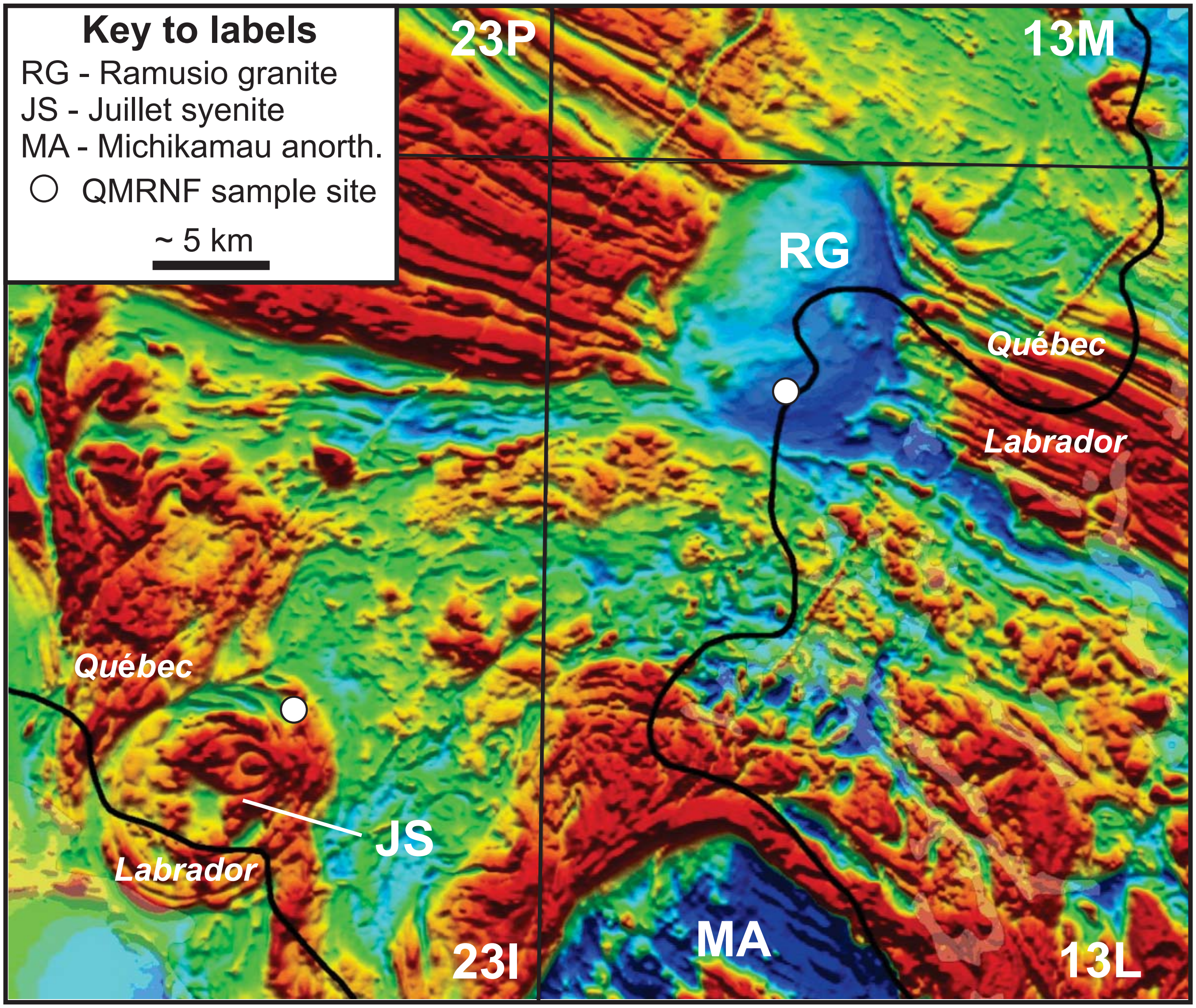


Figure 5. *High-resolution total field aeromagnetic image of the Ramusio granite (Ytterby 4 exploration area) on the Québec-Labrador border, on the north part of NTS sheet 13L. Note the clear truncation of structural trends in older Archean and Paleoproterozoic rocks by the prominent magnetic low. Data from the Geological Survey of Canada. The approximate location of the U–Pb geochronological sample discussed by David* et al. *(2012) is also indicated. The southwestern corner of this image overlaps with Figure 6B.*

GEOLOGY AND REE MINERALIZATION IN THE SMALLWOOD RESERVOIR AREA

This area of interest is located in central Labrador, at the northern edge of the Smallwood Reservoir, about 100 km north of Churchill Falls and about 200 km south of Strange Lake (Figure 1)**.** The regional geology of this area is described by James and Mahoney (1994) and more recently by Valley *et al.* (2011). The unit of most interest here was termed the Michikamats granite by James and Mahoney (1994), and forms an elongate body of some 20 km by 7 km, bounded on its west and north sides by older foliated granites of presumed Paleoproterozoic age**.** Contacts with the gabbroic and anorthositic rocks of the Michikamau Intrusion (to the east) are obscured by sedimentary rocks assigned to the Seal Lake Group or by faults (Figure 6A). James and Mahoney (1994) distinguished two units in the main body; an outer granitic unit, and an inner circular unit of syenite. Similar rock types exposed on islands in the reservoir to the south were correlated with the Michikamats intrusion by James and Mahoney (1994). The area has no history of mineral exploration, although the adjoining Michikamau Intrusion was explored for magmatic Ni–Cu sulphide deposits in the 1990s and from 2004 to 2006 (*see* Kerr and McNicoll, 2010, for a summary).

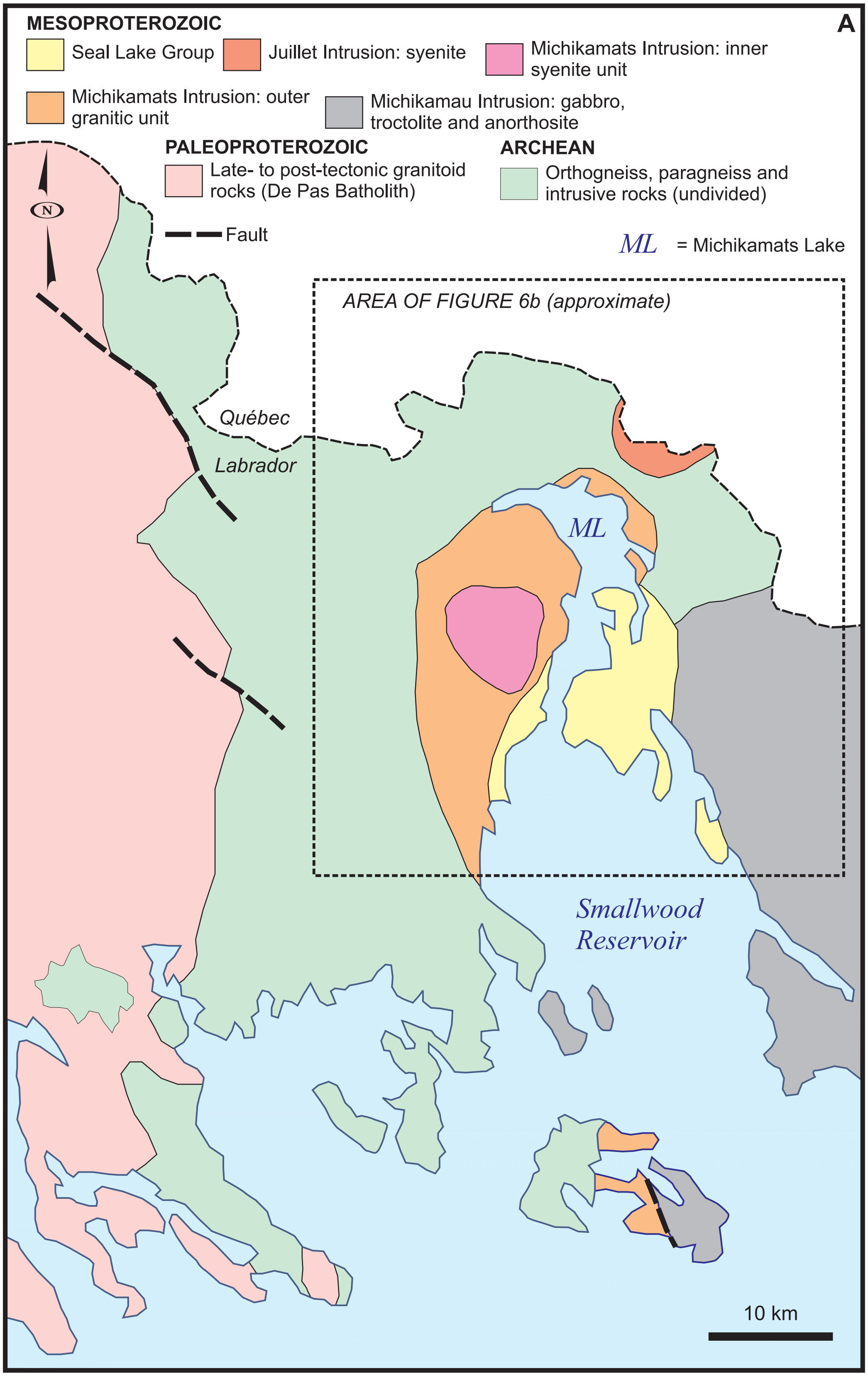
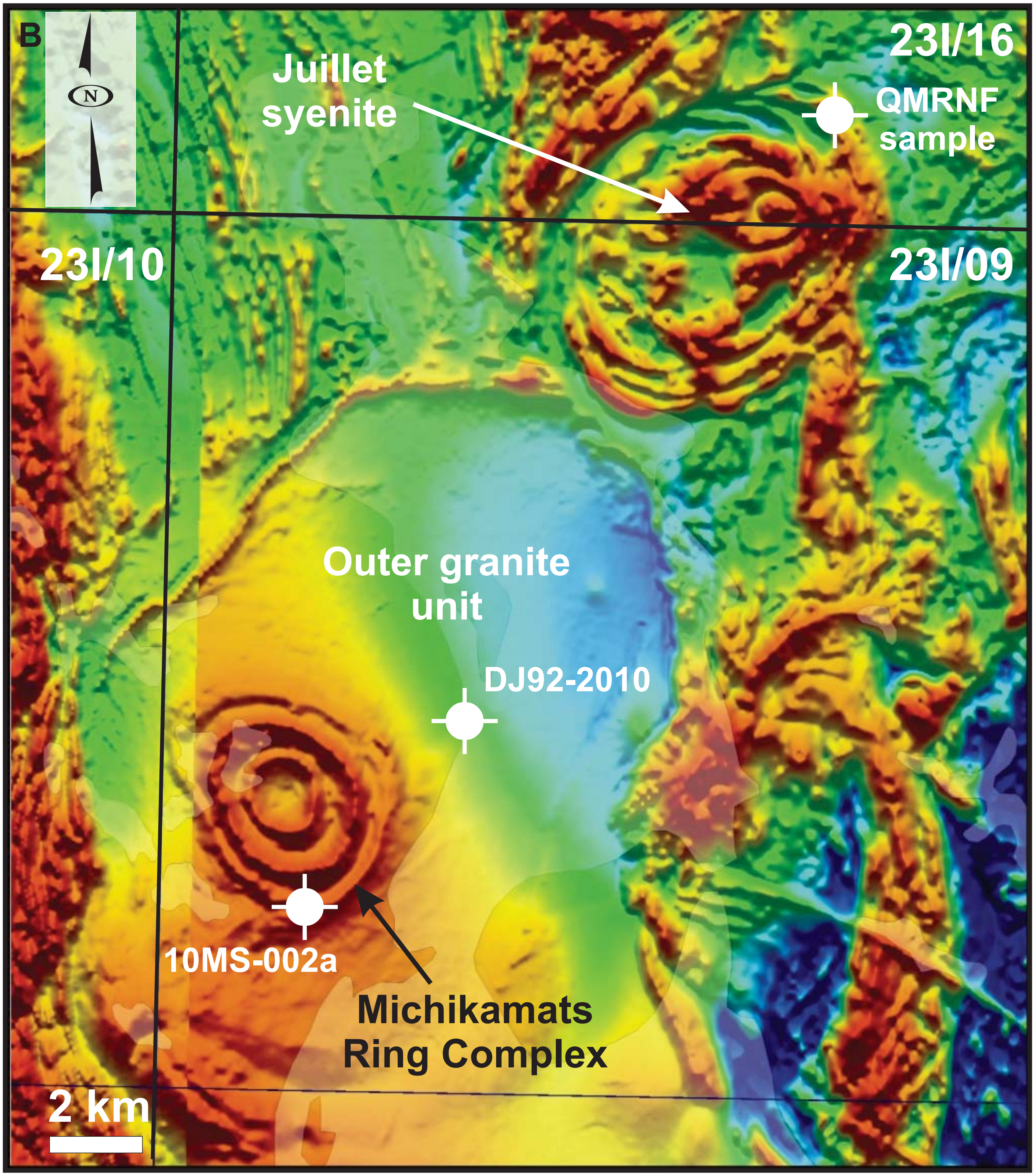


Figure 6. *Information from the Michikamats Lake area. A) Generalized geology, after James and Mahoney, 1994; B) high-resolution total field aeromagnetic data, defining ring-complex like structures that correspond to the syenite unit. Data from*



the Geological Survey of Canada. The image also shows the aeromagnetic features associated with the Juillet syenite, and the approximate location of the U–Pb geochronological sample discussed by David et al. *(2012).*

Exploration attention was focused on the Michikamats intrusion in 2009, following release of aeromagnetic surveys by the GSC (2010). These data indicated well-defined ring-like magnetic structures (Figure 6B) approximately coincident with the syenite unit mapped by James and Mahoney (1994). This pattern resembled a similar ring-complex structure identified at Misery Lake within the Mistastin batholith in Québec (*see* Figure 2B), which quickly became an exploration target. The aeromagnetic survey also defined some other ring-like structures in closely adjacent areas of Québec. One of these is associated with a unit termed the Juillet syenite, which also extends into Labrador, but does not appear to truncate the broader magnetic low associated with the Michikamats granite (Figure 6B).

In 2010, FieldEx Exploration completed reconnaissance exploration in the Michikamats Lake area. Some initial results from the work were placed on the company website, but no formal press releases were issued. In summary, prospecting returned grab samples with variably anomalous REE contents, with TREO* values ranging from 0.25% to 0.9%. Most of the anomalous samples were located in the central part of the ring structure, and were associated with elevated radioactivity (Figure 6B). In 2011, the area was mapped and sampled by GSNL (T. van Nostrand, unpublished data, 2014) but no analytical data are presently available from this work. However, the information released from exploration suggests that mineralized samples are enriched in the light REE. Valley *et al.* (2011) report elevated La and Ce values from routine analyses.

The Michikamats outer granite unit was previously sampled for geochronology in 1993, at a location on the Smallwood Reservoir (UTM 412309E / 6052830N, NAD 1927). The data were interpreted to give a crystallization age of 1459 ± 2 Ma (Krogh, 1993; James and Mahoney, 1994). The inner syenitic unit associated with the ring-like magnetic features was visited and sampled by the Québec Ministère des Ressources Naturelles et de la Faune (QMRNF) as part of a regional project in 2010 (Figure 6B), and this sample was donated to GSNL for analysis. The sample location coordinates are 407169E / 6047487N (NAD 1927), and the rock type is a homogeneous coarse-grained pale-brown syenite (J. Goutier**,** personal communication, 2010; hand sample observations)**.** Information from subsequent field work by GSNL (T. van Nostrand, personal communication, 2012) suggests that this rock type is typical of the 'outer rings' as defined by aeromagnetic data. The Juillet syenite was also sampled as part of the QMRNF project (Figure 6B). The rationale for completing a second U–Pb determination in the Michikamats Lake area was to ascertain if this central syenite, with its distinctive ring-complex features, represented a discrete unit with a younger age than the surrounding granite.

U–Pb GEOCHRONOLOGY

GENERAL INFORMATION

Data from four samples are reported here. Although the results from the outer unit of the Michikamats granite are available in an unpublished contract report (Krogh, 1993), these data are tabulated here in the interests of easier and wider access. The remaining samples were collected in 2010 (Michikamats inner unit) and 2011 (Ytterby 2 and Ytterby 3 areas); coordinates are listed in the preceding section. All samples were analyzed at the Jack Satterly Geochronology Laboratory, although the facility was located at the Royal Ontario Museum in the 1990s, rather than at the University of Toronto.

Sample processing and analytical techniques are not outlined in detail in this report. However, Krogh (1993) describes the methods employed at that time, and details of current techniques and U–Pb analytical protocols are provided in Kamo *et al.* (2011). The main differences between analyses in the 1990s and 2012 lie in the number of individual grains contained within analysis fractions (typically a single grain is analyzed today, rather than multigrain fractions) and in the modern use of chemical abrasion rather than physical abrasion techniques to remove areas of possible Pb loss from individual zircon grains (Mattinson, 2005). The complete U–Pb analytical and isotopic data are listed in Table 1. Data for the Michimakats outer granite are transcribed directly from Krogh (1993).

RESULTS FROM THE MISTASTIN BATHOLITH AREA

The samples from the Mistastin Lake area have fairly simple zircon populations dominated by high-quality, transparent, faceted grains. There are no obvious physical signs of inheritance in these grains, although they were not imaged through back-scattered electron or cathodoluminescence techniques. The U–Pb isotopic data show that the samples from Ytterby 2 and Ytterby 3 exploration areas have demonstrably different ages, but that one does contain some inheritance.

Three zircon fractions from the red granite at Ytterby 2 were analyzed; two single-grain fractions (Z1, Z2) are essentially concordant (0.3 to 0.4% discordant), and the third (Z3; two grains) lies very slightly below concordia (0.8% discordant). The calculated age for the sample is 1423.3 ± 1.8 Ma, with a 91% probability of fit (Figure 7A), and this is interpreted as an igneous crystallization age.

Four single-grain zircon fractions from the syenite–granite at Ytterby 3 were analyzed, and their pattern is

Table 1. Zircon U-Pb isotopic data for granites and syenites from the Mistastin batholith and Smallwood Reservoir area, Labrador and Quebec-Labrador border region

Fraction	Description	Weight (µg)	U (ppm)	Pb^T (pg)	Pb_C (pg)	Th/U	$^{206}Pb/^{204}Pb$	$^{206}Pb/^{238}U$	± 2σ	$^{207}Pb/^{235}U$	± 2σ	$^{207}Pb/^{206}Pb$	± 2σ	Ages (Ma) $^{206}Pb/^{238}U$	± 2σ	$^{207}Pb/^{235}U$	± 2σ	$^{207}Pb/^{206}Pb$	± 2σ	Disc. (%)
AKZ-11-01 Ytterby 2 Granite, Mistastin batholith area (sampled by A. Kerr)																				
Z1	n=1; 2:1 flat, clr, cls, euh pr	2.7	52	66.72	0.61	0.743	6249	0.246393	0.000462	3.05446	0.00787	0.089909	0.000117	1419.8	2.4	1421.4	2.0	1423.6	2.5	0.3
Z2	n=1; 2:1 clr, cls, euh pr, inc	2.3	43	33.84	0.82	0.769	2344	0.246141	0.000508	3.05114	0.01186	0.089904	0.000252	1418.5	2.6	1420.5	3.0	1423.5	5.4	0.4
Z3	n=2; 2:1 clr, cls, euh & brkn pr	3.1	123	107.32	0.80	0.685	7769	0.244961	0.000569	3.03543	0.00849	0.089872	0.000137	1412.4	2.9	1416.6	2.1	1422.8	2.9	0.8
AKZ-11-02 Ytterby 3 Syenogranite, Mistastin batholith area (sampled by A. Kerr)																				
Z1	n=1; 3:1 clr, cls, euh pr	2.5	57	32.60	0.80	0.697	2359	0.244235	0.000566	3.05476	0.01197	0.090713	0.000263	1408.7	2.9	1421.4	3.0	1440.6	5.5	2.5
Z2	n=1; eq, clr, cls, euh, pr	2.3	118	116.58	0.65	0.969	9652	0.246592	0.000465	3.11571	0.00747	0.091638	0.000098	1420.9	2.4	1436.6	1.8	1459.9	2.0	3.0
Z3	n=1; 2:1 clr, cls, euh, pr, inc	2.4	107	106.70	1.32	0.752	4623	0.247581	0.000465	3.09461	0.00845	0.090654	0.000148	1426.0	2.4	1431.4	2.1	1439.3	3.1	1.0
Z4	n=1; stubby clr, cls, euh, pr, inc	2.1	99	75.72	1.46	0.859	2895	0.249577	0.000467	3.11791	0.01041	0.090606	0.000208	1436.3	2.4	1437.1	2.6	1438.3	4.4	0.2
10MS-002a Coarse syenite, ring complex, Michikamats Lake area (provided by J. Goutier)																				
Z1	n=1; eq, clr, cls, euh pr	3.2	114	68.65	6.13	0.529	687	0.252635	0.000614	3.19118	0.03522	0.091613	0.000881	1452.1	3.2	1455.0	8.5	1459.4	18.3	0.6
Z2	n=1; eq, clr, cls, euh pr	2.6	138	76.28	1.24	0.487	3736	0.251910	0.000500	3.18155	0.00968	0.091599	0.000173	1448.3	2.6	1452.7	2.4	1459.1	3.6	0.8
Z3	n=2; 2:1 clr, cls, euh, pr	3.7	87	89.90	2.18	0.627	2425	0.252049	0.000488	3.18064	0.01176	0.091523	0.000246	1449.0	2.5	1452.5	2.9	1457.5	5.1	0.6
DJ92-2010 Granite, Michikamats Lake area (data transcribed from Krogh, 1993; sampled by D. James)																				
HW136	n=3, pr, abr, inc	20.0	72	392.00	7.90	0.480	70592	0.253540	0.000740	3.20341	0.01414	0.091630	0.000320	1456.7	3.8	1458.0	3.4	1459.8	7.4	0.2
HW137	n=20, pr, abr	50.0	63	892.50	5.62	0.569	14292	0.261060	0.000920	3.46063	0.01194	0.096140	0.000180	1495.2	4.8	1518.3	2.8	1550.6	4.4	4.0
HW134	Titanite, dark brown, frac	133.0	94	3473.00	203.80	0.391	1038	0.253250	0.000660	3.19408	0.01102	0.091470	0.000200	1455.2	3.4	1455.7	2.8	1456.5	4.8	0.1

Notes:
All analyzed fractions represent best quality, crack- and optically core-free zircon, pretreated via chemical abrasion methods (1000°C annealing and acid leaching, after Mattinson, 2005), except those of Krogh (1993), which were air-abraded.
Abbreviations: clr - clear; cls - colourless; euh - euhedral; eq - equant; pr - prism, brkn - broken; inc - minor fluid inclusions; frac - fractured; abr - received air-abrasion pretreatment.
Pb^T is total amount (in picograms) of Pb.
Pb_C is total measured common Pb (in picograms) assuming the isotopic composition of laboratory blank: 206/204 - 18.221; 207/204 - 15.612; 208/204 - 39.360 (errors of 2%).
Pb/U atomic ratios are corrected for spike, fractionation, blank, and, where necessary, initial common Pb; 206Pb/204Pb is corrected for spike and fractionation.
Th/U is model value calculated from radiogenic 208Pb/206Pb ratio and 207Pb/206Pb age, assuming concordance.
Disc. (%) - per cent discordance for the given 207Pb/206Pb age.
Uranium decay constants are from Jaffey et al. (1971).

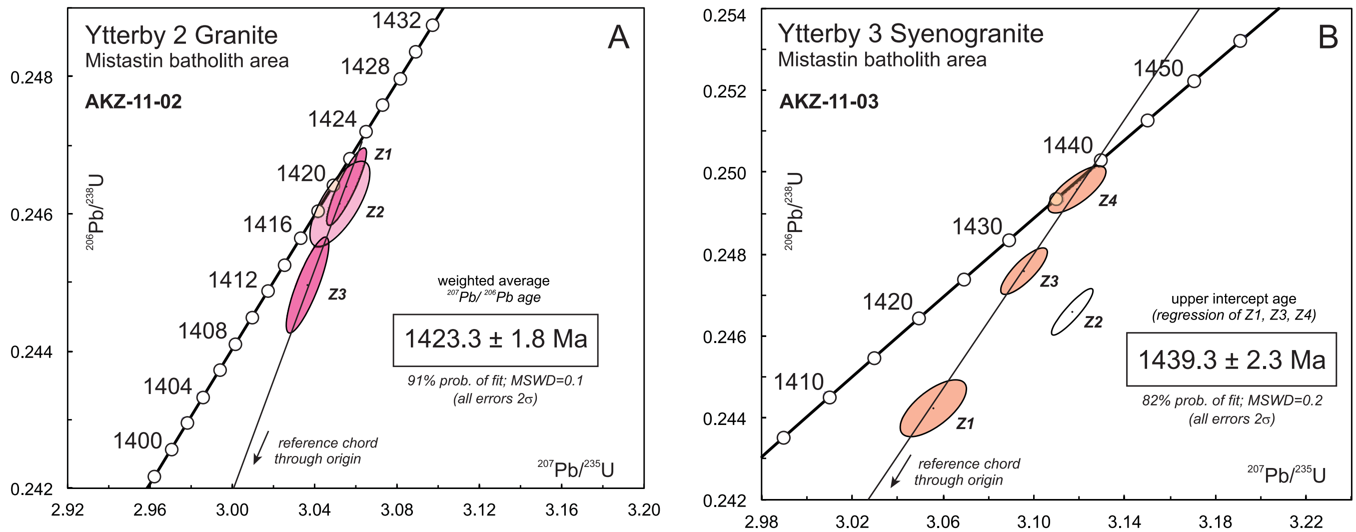


Figure 7. *U–Pb concordia diagrams for samples from the Mistastin batholith area. (A) Pink to red granite at the Ytterby 2 exploration area; (B) central syenite–granite unit at the Ytterby 3 exploration area.*

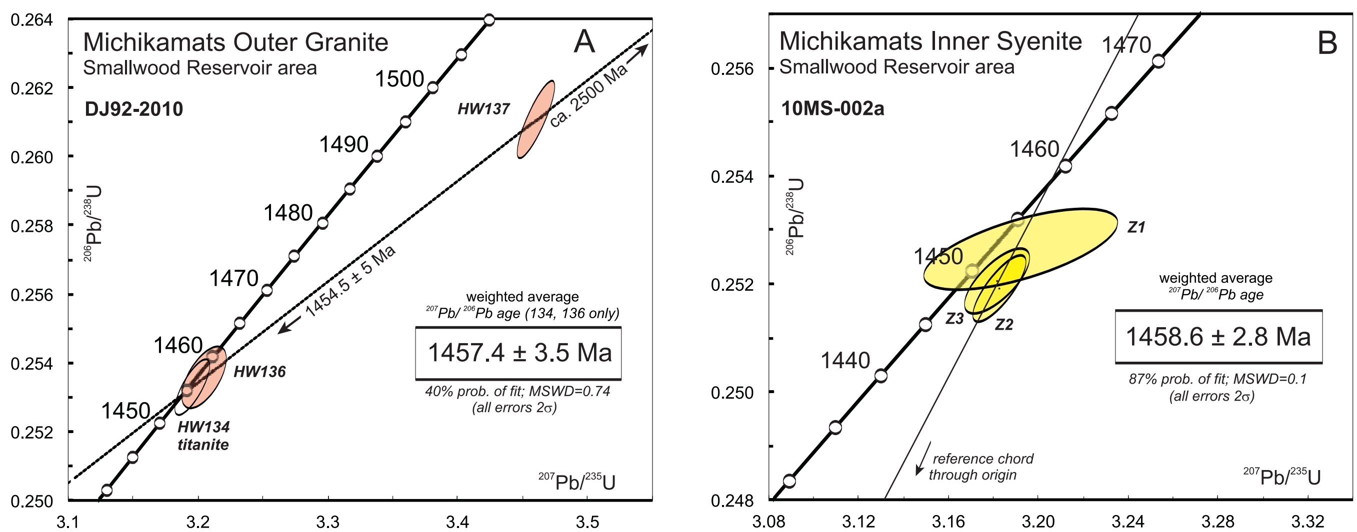


Figure 8. *U–Pb concordia diagrams for samples from the Michikamats Lake area. A) Michikamats granite, outer unit, data of Krogh (1993); B) inner syenite unit associated with ring-complex features.*

slightly more complex. Fraction Z4 is essentially concordant, are 2.5% and 1% discordant, respectively, and lie on a line projecting to the origin. Fraction Z2 lies off this discordia line and the concordia line, and its $^{207}Pb/^{206}Pb$ age is about 20 m.y. older than the other fractions, at *ca.* 1459 Ma. A linear regression of the data, through the three colinear points Z1, Z3 and Z4, and anchored at the origin yields an upper intercept age that is 1439.3 ± 2.3 Ma, with a 82% probability of fit (Figure 7B). This is also interpreted as an igneous crystallization age, and it is inferred that the Z2 grain must contain an inherited core. The true age of the inherited component cannot be determined from the data, because fraction Z2 has presumably also suffered Pb loss.

RESULTS FROM THE SMALLWOOD RESERVOIR AREA

Sample DJ-92-2010 from the outer granitic unit of the Michikamats intrusion was investigated by Krogh (1993). It was described as containing large amounts of high-quality zircon. Of the two zircon fractions, one consisting of three grains (HW136) is essentially concordant (0.24% discordant) and has a $^{207}Pb/^{206}Pb$ age of 1460 Ma. A second larger fraction of 20 grains (HW137) shows a significant degree of discordance, and projects from *ca.* 1460 Ma to a late Archean upper intercept age (Figure 8A). A titanite fraction from the same sample is also essentially concordant, and overlaps the concordant zircon fraction HW136 (Figure 8A). Krogh (1993) suggested a crystallization age of 1459 ± 2 Ma based on the zircon data, but using the weighted average of the $^{207}Pb/^{206}Pb$ ages for fractions HW134 and HW136 gives a slightly younger age of 1457.4 ± 3.5 Ma (Figure 8A). This is within uncertainty of the previous estimate, and has little impact upon interpretation.

Sample 10-MS-002a, from the inner syenite unit of the Michikamats intrusion, contained a simple zircon population of colourless, well-formed grains. The three analyzed fractions are very slightly discordant (~0.5%), and one fraction (Z1) has a significantly larger uncertainty than the others. All three near-concordant analyses define a narrow range of $^{207}Pb/^{206}Pb$ ages, and a weighted average of all fractions yields an age of 1458.6 ± 2.8 Ma (Figure 8B). This is interpreted as the time of igneous crystallization, and is essentially identical to the age previously obtained from the outer granite unit.

Sm–Nd ISOTOPE GEOCHEMISTRY

The samples from the Ytterby 2 and Ytterby 3 areas were also analyzed for Sm and Nd isotopic compositions at Memorial University. The preparation methods and analytical techniques correspond to those summarized by Kerr and Wardle (1997). Results are shown in Table 2. The two samples have closely similar ε_{Nd} signatures at the time of crystallization (-9.1 and -8.9), which are identical within uncertainties. This similarity is also reflected in their narrow range of calculated depleted-mantle model ages (2310 Ma–2343 Ma). These negative ε_{Nd} values are well below the expected range of mantle-derived magmas at *ca.* 1430 Ma (around +4.7) and indicate significant input from older material to these granitic magmas. The most likely source for such material is the continental crust of the Churchill Province, which contains Archean and Paleoproterozoic rocks.

Table 2. Sm–Nd isotopic data

Sample Number	AKZ-11-01	AKZ-11-02
Unit	Ytterby 2	Ytterby 3
Details	red granite	quartz syenite
Assumed Age (Ma)	1423	1439
Nd (ppm)	64.98	162.33
Sm (ppm)	9.96	26.06
$^{147}Sm/^{144}Nd$	0.0928	0.0971
$^{143}Nd/^{144}Nd$	0.511204	0.511245
ε_{Nd} (CHUR)	-9.1	-8.8
Model Age (Ma)	2310	2343

Notes:
Present-day CHUR values used in calculation of ε_{Nd} are as follows:
$^{147}Sm/^{144}Nd = 0.1966$; $^{143}Nd/^{144}Nd = 0.512638$.
Model age calculations use the model of DePaolo (1988), for depleted mantle evolution.

Analytical errors are < ± 0.00005 for $^{147}Sm/^{144}Nd$, and < ± .000025 for $^{143}Nd/^{144}Nd$ (2 sigma); error in ε_{Nd} is estimated at < ± 0.4 ε units.

DISCUSSION AND CONCLUSIONS

This report presents the first fully documented U–Pb zircon ages from the area of the Mistastin batholith in Labrador. The Ytterby 2 and Ytterby 3 granitoid units are almost 200 m.y. older than the Strange Lake Intrusion (1240 Ma; Miller *et al.*, 1997) and thus cannot be related to it. The Ytterby 2 and Ytterby 3 mineralized granitoid rocks appear instead to be an integral part of the Mistastin batholith, and suggest that this extensive and poorly known intrusive complex has potential for REE mineralization. The new data provide the best information on the age range of the Mistastin batholith, which was previously cited as '*ca.* 1.42 Ga'. (Emslie and Stirling, 1993), but without analytical or locational data. The new results from Ytterby 2 are broadly consistent with the earlier inference by Emslie and Stirling (1993) but the results from the Ytterby 3 area suggest that the batholith also includes significantly older rocks. Its age span is now defined as from at least *ca.* 1439 to 1423 Ma. The pink to red granite in the Ytterby 2 area clearly intrudes the surrounding rapakivi-textured granite, indicating that this unit must be older than 1423 Ma, but the relationship of the inner syenite–granite unit in the Ytterby 3 area to the surrounding rocks is less clear. If it *is* a younger intrusion, as suggested by Midland, this implies that the rapakivi-textured granites in that area are older than 1439 Ma. However, it is also possible that the syenite–granite unit could be an older inlier, perhaps protruding through a sheet-like upper (younger) rapakivi granite unit. Thus, we cannot be sure that the age provides a minimum constraint on the surrounding granitoid unit. The Sm–Nd isotopic data from Ytterby 2 and Ytterby 3 units indicate that both intrusions contain significant amounts of older crust. The Nd isotopic data reported by Emslie *et al.* (1994) from the Nain Plutonic Suite show that plutonic rocks in its western part (underlain by Churchill Province basement rocks) have broadly similar negative Nd isotopic signatures. However, these strongly negative ε_{Nd} values differ from the much more neutral values (-1 to -3) that characterize the younger Strange Lake

Intrusion (A. Kerr, unpublished data, 2014). Given that the older rocks of the Churchill Province are broadly similar in both areas, there must be important differences in the petrogenesis of the Strange Lake Intrusion and the Ytterby 2 and 3 granites.

Although the Michikamats granite had already provided a U–Pb zircon age of *ca.* 1459 Ma (Krogh, 1993), the absolute age of the inner syenite ring-complex unit was unknown, although it was inferred to be younger in a relative sense. The U–Pb age of the syenite unit is now shown to be identical to that of the outer granite, indicating that they are closely related. These *ca.* 1458 Ma intrusive rocks could have a broad genetic relationship to the nearby Michikamau Intrusion, although the anorthositic rocks in the complex are somewhat older at around 1469 Ma (Kerr and McNicoll, 2010).

Three U–Pb zircon dates were obtained from prospective granitoid rocks in adjacent Québec during the same time period as this study. The results are presented by David *et al.* (2012), and merit discussion in the context of new information presented here. Results from the ring complex at Misery Lake, represented by pegmatitic alkaline syenite, were interpreted to indicate a crystallization age of 1409.7 ± 1.7 Ma, based on a weighted average of the $^{207}Pb/^{206}Pb$ ages. This age is younger than that obtained from the Ytterby 2 granite, but it could still form part of the broad magmatic event represented by the Mistastin batholith, in the same way that the *ca.* 1290 Ma Flowers River ring complex forms the youngest component of the *ca.* 1330 to 1300 Ma Nain Plutonic Suite (Ryan, 1998). David *et al.* (2012) also present data from the Ramusio granite (Ytterby 4 area; *see* Figure 5 for location), which yielded an age of 1481.7 ± 4.3 Ma, based on concordant and slightly discordant zircon fractions. The Ramusio granite is thus significantly older than the Mistastin batholith, but only slightly older than the Michikamau Intrusion, located to its southwest. To date, no indications of REE mineralization are reported from the Ramusio granite, either by Midland Exploration or by the Québec MRNF (David *et al.*, 2012). The third age determination in the Québec study was from the Juillet intrusion, a syenitic body located on the Québec-Labrador border northeast of the Michikamats granite (Figures 1 and 6). There are some indications of REE mineralization in this unit, according to David *et al.* (2012), but no details are available. This provided discordant zircon fractions, indicating an upper intercept crystallization age of 1479.9 +12.6/- 5.4 Ma, closely similar to that obtained from the Ramusio granite, but older than the two ages from the Michikamats Lake area presented here.

The combined data from this study and that of David *et al.* (2012) suggest that the Mesoproterozoic magmatic history of this part of the Canadian Shield is complex and episodic, extending from *ca.* 1480 Ma (Juillet and Ramusio) to *ca.* 1240 Ma (Strange Lake), with the Mistastin batholith emplaced between 1439 Ma and 1410 Ma, if Misery Lake is included as part of it. Of these intrusions, only one (the Ramusio granite) seems to lack any indications of REE mineralization. On this basis, it would not appear that age is a fundamental control on prospectivity for REE in Mesoproterozoic intrusive rocks across the region, although age may influence the style and extent of mineralization. From the perspective of regional geology, the combined geochronological data define two temporal associations. The results from Ytterby 2, Ytterby 3 and Misery Lake (and earlier unpublished data quoted by Emslie and Stirling, 1993) imply that the Mistastin batholith formed over a protracted time interval (*ca.* 1439 to 1410 Ma), just like other better-known composite intrusive complexes such as the Nain Plutonic Suite (Ryan, 1998; Myers *et al.*, 2008). In the Smallwood Reservoir area, the ages from the Ramusio granite (Ytterby 4 area), Juillet syenite and the Michikamats intrusion may imply a similarly protracted period of magmatism broadly associated with the *ca.* 1469 Ma Michikamau Intrusion. More work is required to substantiate these patterns and to establish temporal links between granitoid rocks and mafic–anorthositic rocks in the Mistastin batholith. A sample of the rapakivi-textured granite from the Ytterby 2 area is currently under investigation, and it is possible that archived material held by M.A. Hamilton from the work of Emslie *et al.* (1980) may be of value in this context.

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REFERENCES

Banville, R.
2011: Midland's new rare-earth-elements (REE) discoveries at Ytterby 2 and 3 near the Québec-Labrador border. Geological Association of Canada, Newfoundland and Labrador Section, Annual technical meeting. Abstract published in Atlantic Geology, Volume 47.

Currie, K.L.
1971: Geology of the resurgent cryptoexplosion crater

at Mistastin Lake, Labrador. Geological Survey of Canada, Bulletin 207, 62 pages.

DePaolo, D.J.
1988: Neodymium Isotope Geochemistry: An Introduction. Springer Verlag, Berlin, 187 pages.

David, J., Simard, M., Bandayayera, D., Goutier, J, Hammouche, H., Pilote, P. and LeClerc, F.
2012: Datations U-Pb effectuées dans les provinces du Supérieur et de Churchill en 2010-11. Québec Ministère des Ressources Naturelles et de la Faune, Rapport 2012-01, 33 pages.

Emslie, R.F.
1968: The geology of the Michikamau Intrusion, Labrador (13L, 23I). Geological Survey of Canada, Paper 68-57, 85 pages.

1980: Geology and petrology of the Harp Lake Complex, central Labrador: an example of Elsonian magmatism. Geological Survey of Canada, Bulletin 293, 136 pages.

Emslie, R.F., Cousens, B., Hamblin, C. and Beilecki, J.
1980: The Mistastin Batholith, Labrador - Québec: An Elsonian composite rapakivi suite. Geological Survey of Canada, Paper 80-1A, pages 95-100.

Emslie, R.F., Hamilton, M.A. and Thériault, R.J.
1994: Petrogenesis of a mid-Proterozoic anorthosite-mangerite-charnockite-granite (AMCG) complex: Isotopic and chemical evidence from the Nain Plutonic Suite. Journal of Geology, Volume 102, pages 539-558.

Emslie, R.F. and Stirling, A.R.
1993: Rapakivi and related granitoids of the Nain Plutonic Suite: Geochemistry, mineral assemblages and fluid equilibria. Canadian Mineralogist, Volume 31, pages 821-847.

Geological Survey of Canada
2010: Geophysical series, parts of NTS 13L, 13M, 23I, 23J, 23O, 23P. Geological Survey of Canada, Open File 6532, scale 1:250 000. (Compilers Dumont, R., Fortin, R., Hefford, S. and Doshaler, F.)

2012: Aeromagnetic survey, Mistastin Batholith. Geological Survey of Canada, Open Files 7154 to 7168 inclusive, 1:50 000 scale. (Compilers Dumont, R. and Janes, A.)

Grieve, R.A.F.
1975: Petrology and chemistry of the impact melt at Mistastin Lake crater, Labrador. Geological Society of America Bulletin, Volume 86, pages 1617-1629.

Jaffey, A.M., Flynn, K.F., Glendenin, L.E., Bentley, W.C. and Essling, A.M.
1971: Precision measurements of half-lines and specific activities of ^{235}U and ^{238}U. Physical Review, Volume C4, pages 1889-1906.

James, D.T. and Mahoney, K.L.
1994: Structural, metamorphic and intrusive relations in the hinterland of the eastern Churchill Province, western Labrador. *In* Current Research. Newfoundland Department of Mines and Energy, Geological Survey Branch, Report 94-1, pages 375-385.

Kamo, S.L., Heaman, L.M. and Gover, C.F.
2011: Evidence for post-1200 Ma - pre-Grenvillian supracrustal rocks in the Pinware terrane, eastern Grenville Province at Battle Harbour, Labrador. Canadian Journal of Earth Sciences, Volume 48, pages 371-387.

Kerr, A.
2011: Rare-earth element (REE) mineralization in Labrador: A review of known environments and the geological context of current exploration activity. *In* Current Research. Newfoundland and Labrador Department of Natural Resources, Geological Survey Branch, Report 11-1, pages 109-145.

Kerr, A. and McNicoll, V.
2010: U-Pb ages from mafic rocks associated with orthomagmatic Ni–Cu–Co sulphide mineralization in west-central Labrador. *In* Current Research. Newfoundland Department of Natural Resources, Geological Survey Branch, Report 10-1, pages 23-41.

Kerr, A. and Wardle, R.J.
1997: Definition of an Archean–Proterozoic crustal suture by isotopic studies of basement intersections from offshore wells in the southern Labrador Sea. Canadian Journal of Earth Sciences, Volume 34, pages 209-214.

Krogh, T.E.
1993: Report on Labrador geochronology, 1992-93. Newfoundland and Labrador Department of Mines and Energy, File [LAB/0977].

Krogh, T.E. and Davis, D.W.
1973: The significance of the inherited zircons on the age and origin of igneous rocks - an investigation of the age of the Labrador adamellites. Carnegie Institute of Washington Yearbook, Volume 72, pages 610-613.

Marion, C. and Sylvester, P.J.
2010: Composition and heterogeneity of anorthositic impact melt at Mistastin Lake crater, Labrador. Planetary and Space Science, Volume 58, pages 552-573.

Mattinson, J.M.
2005: Zircon U-Pb chemical abrasion (CA-TIMS) method: Combined annealing and multi-step partial dissolution analysis for improved precision and accuracy and of zircon ages. Chemical Geology, Volume 220, pages 47-66.

Miller, R.R., Heaman, L.M. and Birkett, T.C.
1997: U-Pb zircon age of the Strange Lake peralkaline complex: implications for Mesoproterozoic peralkaline magmatism in north-central Labrador. Precambrian Research, Volume 81, pages 67-82.

Myers, J.S., Voordouw, R.J. and Tettelaar, T.A.
2008: Proterozoic anorthosite-granite Nain batholith: Structure and intrusion processes in an active lithosphere-scale fault zone, northern Labrador. Canadian Journal of Earth Sciences, Volume 45, pages 909-946.

Nunn, G.A.
1995: Bedrock geology of the Kanairiktok River headwaters area, NTS area 13L/NW, Labrador. Newfoundland and Labrador Department of Mines and Energy, Map 94-122. File Number [13L/0078]

Ryan, B.
1998: The Mesoproterozoic Nain Plutonic Suite in eastern Canada, and the setting of the Voisey's Bay Ni-Cu-Co sulphide deposit. Geoscience Canada, Volume 74, pages 173-188.

Valley, P., Bulle, F. and Skipton, D.
2011: Geology of the southeastern Churchill Province, western Labrador. *In* Current Research. Newfoundland Department of Natural Resources, Geological Survey Branch, Report 11-1, pages 295-313.

van der Leeden, J., Belanger, M., Danis, D., Gerard, R. and Martelin, J.
1990: Lithotectonic domains in the high-grade terrain east of the Labrador Trough (Québec). Geological Association of Canada, Special Paper 37, pages 371-386.

Wardle, R.J., Ryan, B. and Ermanovics, I.
1990: The eastern Churchill Province, Torngat and New Québec orogens: An overview. Geoscience Canada, Volume 17, pages 217-222.