Current Research (2011) Newfoundland and Labrador Department of Natural Resources
Geological Survey, Report 11-1, pages 109-143

RARE-EARTH-ELEMENT (REE) MINERALIZATION IN LABRADOR: A REVIEW OF KNOWN ENVIRONMENTS AND THE GEOLOGICAL CONTEXT OF CURRENT EXPLORATION ACTIVITY

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ABSTRACT

Labrador contains several areas of rare-metal (RM) and rare-earth-element (REE) mineralization, including a potentially large deposit at Strange Lake. Although the main deposit at this site is presently exempt mineral land (EML), recent exploration in adjacent Québec has nearly tripled inferred REE resources within the ~1240 Ma Strange Lake Intrusion. Defined RM–REE deposits elsewhere in Labrador are now being reassessed, and other early stage exploration projects have revealed mineralization and/or favourable environments in unexplored areas. This article reviews defined RM–REE deposits and potential environments, and assesses new results from active exploration programs in their wider geological and metallogenic context.

Mineralization of this type in Labrador is associated with peralkaline igneous suites of known or presumed Mesoproterozoic age, but subsequent deformation obscures original relationships south of the Grenville Front. Strange Lake is, by far, the most significant resource, and is relatively enriched in the more valuable heavy REE (Gd to Lu). The ~1330 Ma Letitia Lake Group of south-central Labrador contains significant Be–Nb–REE deposits, and these resources are likely larger than originally estimated in the 1960s. These deposits are dominated by light REE (La to Sm), and have high Nd contents. They also represent significant resources of Be, which may be important in the future. The associated ~1330 Ma Red Wine Intrusive Suite contains orthomagmatic accumulations of the Na–Zr–REE-silicate eudialyte, which is enriched in the heavy REE, and also an important potential source of Zr. The extent and continuity of such mineralization remain to be established, but deposits of this type elsewhere are attracting industry interest, in part, because they lack deleterious radioactive elements such as U and Th. Another high-potential environment for RM–REE in Labrador are the peralkaline felsic volcanic rocks and subvolcanic intrusions of the Nuiklavik caldera, within the ~1290 Ma Flowers River Igneous Suite. Such potential has long been recognized, but this area has yet to be systematically explored. An early stage exploration project in the Grenville Province of southeastern Labrador has now discovered widespread mineralization that includes light REE- and heavy REE-enriched subtypes, and another such project in a remote stretch of the Québec–Labrador border region illustrates the potential of areas that were last mapped in the 1960s. This diverse RM–REE mineralization presents numerous interesting scientific problems, ranging from fundamental mineralogical questions to wider genetic issues. Renewed exploration work across Labrador provides many opportunities for future research to better document these unusual deposits and guide exploration for their undiscovered counterparts.

INTRODUCTION

Exploration for deposits of rare-earth elements (REE), and associated rare metals (RM; *e.g.*, Zr, Nb, Be, Ta) has grown rapidly since 2008. This reflects increasing usage of REE in modern technology, coupled with restrictions on supply from China, which presently accounts for >97% of world REE production (*e.g.*, Walters *et al.*, 2010). These combined factors led to sustained price increases for most REE in the last few years. In this Province, exploration for REE is intense in Labrador, where there is a large potential resource at the Strange Lake deposit, 125 km west of Nain (Figure 1). However, this was not the first such deposit to be unearthed in Labrador, because E.L. Mann and J.J. Brummer discovered Nb- and Be-bearing minerals near Letitia Lake (Figure 1) in 1956, and noted the presence of associated REE. Regional-mapping projects discovered other REE- and RM-enriched zones, notably in the Flowers River area and southeastern Labrador (Figure 1). Exploration since 2008 provided new information on all of these areas, and led also to the discovery of new zones of mineralization. Exploration in adjacent Québec led to definition of new resources at Strange Lake, but the deposit in Labrador remains closed to exploration pending land-use decisions by the Province

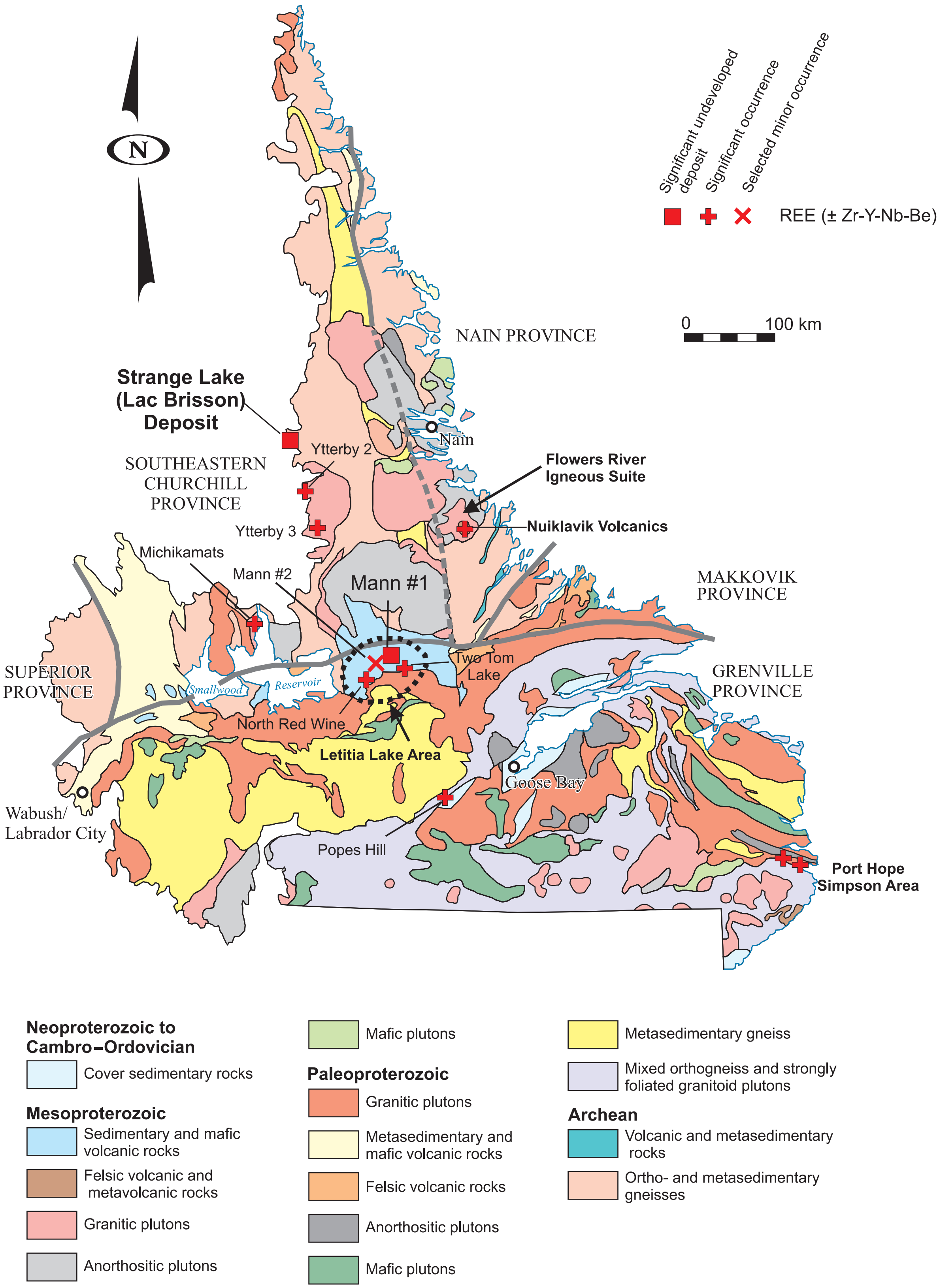

Figure 1. *Simplified geological map of Labrador, showing the locations of the main areas of rare-metal (RM) and rare-earth-element (REE) mineralization discussed in this article. Note that some minor showings and indications of mineralization are omitted for the sake of clarity.*

and Nunatsiavut. This report summarizes geological knowledge about REE mineralization in Labrador, and discusses the implications of new data from active exploration programs. It is intended to provide an update of and expansion from reports from an earlier GSNL project aimed mostly at Zr–Y–Nb deposits (Miller, 1986, 1987, 1988, 1993).

RARE-EARTH ELEMENTS: CHARACTERISTICS AND REPRESENTATION

The REE include 14 elements known technically as the 'lanthanide series', plus the chemically similar elements yttrium (Y) and scandium (Sc). In order of atomic number, the lanthanides consist of lanthanum (La), cerium (Ce) praseodymium (Pr), neodymium (Nd), samarium (Sm), europium (Eu), gadolinium (Gd), terbium (Tb), dysprosium (Dy), holmium (Ho), erbium (Er), thulium (Tm), ytterbium (Yb) and lutetium (Lu). The REE are generally divided into the light REE (LREE; La to Sm), and the heavy REE (HREE; Gd to Lu). The element europium (Eu) sits between these groups, but has geochemical behaviour distinct from both. Yttrium (Y) resembles the heavy REE in behaviour, and is commonly included with them. The abbreviations TREE (total rare-earth elements) or TREO (total rare-earth oxides) are commonly used in reporting concentrations, but there is some ambiguity in which elements are included in totals. In this report, the notation TREE* or TREO* is used wherever Y or Y_2O_3 is included in the total, which is the current practice in exploration reports. The REE are incompatible elements, aside from Eu, which substitutes for Ca, notably in feldspars. The light REE are generally more incompatible than the heavy REE, due to larger ionic radii. A wide variety of minerals contain REE in rocks and mineral deposits. The most familiar are zircon, allanite, titanite (all silicates), apatite, monazite and xenotime (all phosphates), but several much rarer minerals are economically important, notably bastnaesite (a REE-bearing carbonate). The mineralogy of REE–RM deposits is critical, as it may dictate the feasibility of processing and recovery, and individual deposits tend to have distinct (or endemic) mineral assemblages.

In exploration, the current practice is to report total REE oxides (including Y_2O_3), and individual REE may not be reported in absolute form. In research, REE are commonly reported as elemental values, as ppm (g/t), but displayed in 'normalized' form, in which concentrations are divided by accepted values for chondritic meteorites. This avoids the zigzag pattern imparted by the greater abundances of elements that have even atomic numbers, and the shapes of normalized REE patterns can distinguish geological units or provide insight into geological processes. Individual REE abundances are important in assessing exploration results, because their prices vary widely, but this

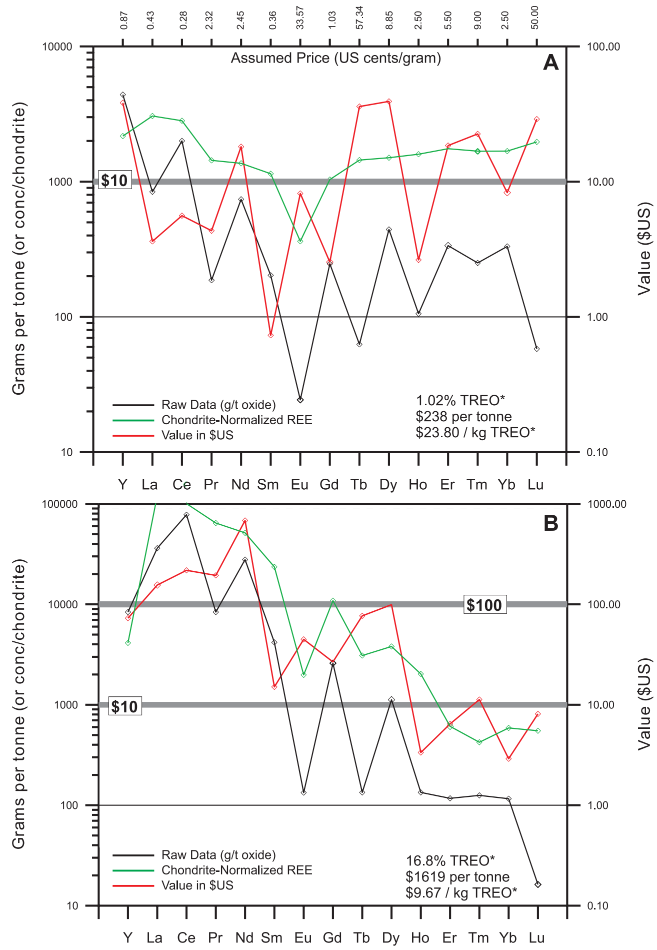

Figure 2. *Examples of contrasting REE distributions in two deposits, illustrating the methods of representing such data and the impact of REE distribution upon* in-situ *value. A) Average of historical data from the Strange Lake deposit, having a TREO* content slightly higher than estimated for the bulk resource in 1984; data from Miller (1985a). B) Average REE data from the high-grade Steenskampskraal deposit in South Africa; data from the Great Western Minerals website. Chondrite normalization values from Taylor and McLennan (1985). Note that valuation uses 2007 3-year trailing average from the economic analysis of Ramsey* et al. *(2010) rather than current spot prices. The assumed prices for individual REE (in US cents per gram) are indicated on the top axis of the charts. The valuation may differ significantly if the price assumptions are changed, and also does not account for the impact of recoveries for individual REE, if indeed they are recoverable. In summary, this is for illustrative purposes only.*

information is not always provided. For purposes of comparison, this article uses modified REE profiles that indicate abundances, chrondrite-normalized data and calculated monetary values on the same vertical scales (Figure 2). Valuation is based on the 2007 3-year trailing averages used in economic analysis of the Quest Minerals B-Zone deposit on the Québec side at Strange Lake, and the Nechalacho deposit in the NWT (Ramsey *et al.*, 2010). These assumptions are conservative compared to current prices, notably for the LREE. Value is assigned to all REE, assuming 100% recovery, even where abundances are low. This simplistic method allows a visual representation of where potential value lies, and allows calculation of the dollar value of the bulk TREO*. Figure 2A illustrates the average of historical REE analyses from the Strange Lake deposit (Miller, 1985a). The chondrite-normalized pattern is relatively flat, and most value is contributed by Y, some heavy REE (Tb, Dy, Er and Lu) and the light REE Nd. Figure 2B illustrates high-grade, vein-type REE mineralization from Steenkampskraal in South Africa (Great Western Minerals, website information). This has very high TREO* (~17%) compared to Strange Lake (~1%), but has a distinctly different REE distribution. The chondrite-normalized pattern is steep, and most of the potential value resides with light REE, notably La, Ce, Pr and Nd. The value per kg of TREO* for this deposit is less than half of the equivalent value for Strange Lake. Similar calculations for several REE deposits in Canada and elsewhere (not illustrated) show that the value per kg of TREO* varies by a factor of 3, from <US$ 10/kg to almost US$ 30/kg. Any such analysis depends on the price assumptions, but it has value for first-order comparisons.

METALLOGENY OF RARE-EARTH-ELEMENT DEPOSITS

Overviews of this topic are presented by Castor and Hedrick (2006) and Walters *et al.* (2010), and more detailed treatments by Richardson and Birkett (1995a, b) with an emphasis on Canada. The REE deposits are subdivided into primary and secondary classes, and both contribute to global production. Primary deposits are mostly hosted by igneous rocks or their metamorphosed equivalents, and are mostly derived through magmatic processes. However, there are also some vein-style deposits whose origins are less clear. The most important REE deposits are associated with carbonatites and peralkaline igneous rocks; there is commonly a spatial association between these two rock groups and a link to continental rift-related magmatism. The REE are also potential by-products of so-called 'iron oxide copper gold' (IOCG) deposits, of which Olympic Dam in Australia is the largest. Current and recent primary REE production comes mostly from deposits associated with carbonatites, notably Mountain Pass in California, and Bayan Obo in China; however, the origin of the latter is controversial (*e.g.*, Reguir *et al.*, 2010), and some workers suggest a link to the IOCG clan. Secondary REE deposits include placers, paleoplacers and residual weathering deposits with affinities to laterites, all derived from various primary deposits or igneous–metamorphic source terranes. Residual deposits called 'ion-adsorption clays', are important heavy REE sources, but are presently mined only in China. Known REE deposits in Labrador (Figure 1) are associated with peralkaline igneous suites or their derivatives, although there may be potential for carbonatites and IOCG-related occurrences.

Peralkaline igneous rocks are a tiny part of the spectrum of igneous rocks, but they are very distinctive. The high molecular values of (K_2O + Na_2O)/Al_2O_3) in these magmas favours crystallization of Na-bearing amphiboles (arfvedsonite, reibeckite) or pyroxenes (aegirine), and they may also be silica-undersaturated, containing nepheline or other feldspathoid minerals. Peralkaline magmas are commonly enriched in REE, Y, Zr, Nb, Hf, Ta, and in fluorine (F); they may also be enriched in incompatible elements, such as U, Th, Rb, Cs, Pb, and Be. Deposits associated with peralkaline suites tend to be enriched in Y and heavy REE compared to those linked to carbonatites (Richardson and Birkett, 1995a, b; Castor and Hedrick, 2006). The settings of deposits in peralkaline suites are varied, and they include a complete spectrum from orthomagmatic to hydrothermal−metasomatic. Orthomagmatic types include cumulate-like layered accumulations of REE-bearing minerals such as apatite or eudialyte (a Na−Zr−REE silicate) in syenites, and disseminated mineralization in evolved peralkaline granites, aplites and pegmatites. Deposits in these high-level plutonic to subvolcanic settings are influenced also by hydrothermal processes, but opinions on the importance and role of the latter diverge. There is a general consensus that magmatic fractionation processes provide the main mechanism for REE concentration (Richardson and Birkett, 1995a, b), although fluid interactions and hydrothermal processes may be important in promoting deposition of the REE and controlling mineral assemblages (*e.g.*, Williams-Jones, 2010).

RARE-EARTH-ELEMENT MINERALIZATION

REGIONAL SETTINGS

In Labrador, Precambrian rocks range in age from Paleoarchean (>3600 Ma) to late Neoproterozoic (~600 Ma), and are disposed in five major structural provinces (Figure 1). Archean rocks occur in the Superior Province (western Labrador) and the Nain Province (eastern Labrador). These cratonic regions are separated by the Paleoproterozoic Churchill Province, and the Nain Province is bounded to the south by the Paleoproterozoic Makkovik Province. Most of southern Labrador lies within the younger Grenville Province, in which discrete fault-bounded terranes are dominated by rocks of late Paleoproterozoic and Mesoproterozoic ages. Mesoproterozoic 'anorogenic' magmatism was widespread from ~1460 to ~1240 Ma. This magmatism was

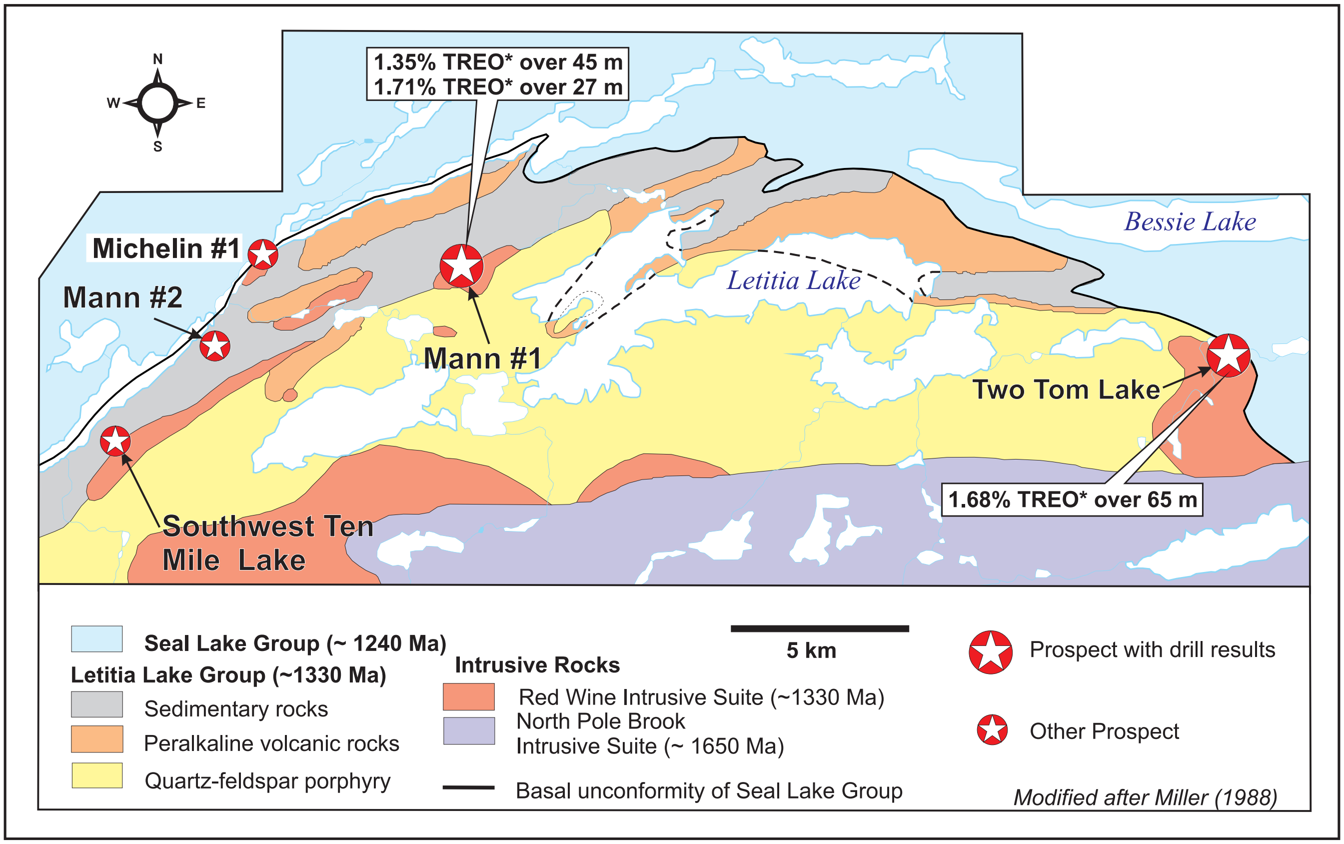

Figure 3. *Simplified geological map of the Letitia Lake area, adapted from Miller (1987) and Thomas (1981), showing the locations of the main prospects discussed in this article discovered since 2008.*

contemporaneous with development of sedimentary basins and associated volcanism, such as the Letitia Lake Group (~1330 Ma) and the Seal Lake Group (~1240 Ma) of central Labrador. Mesoproterozoic igneous suites include peralkaline rocks of the Letitia Lake Group and Red Wine Intrusive Suite (both of ~1330 Ma age), the Flowers River Intrusive Suite (~1290 Ma) and the Strange Lake Granite (~1240 Ma), all of which host REE−RM mineralization. Newer discoveries in the Québec−Labrador border region are associated with undeformed evolved granitoid rocks of probable Mesoproterozoic age. Mesoproterozoic igneous rocks, including peralkaline suites, are variably affected by younger deformation in areas south of the Grenville Front, such as the Letitia Lake area (Figure 1). The ages of metamorphic and pegmatitic rocks that host REE in the Grenville Province of southeastern Labrador are unknown, and these could be late Paleoproterozoic or Mesoproterozoic.

LETITIA LAKE AREA

Location and Exploration History

E.L. Mann found radioactive zones between Letitia Lake and Ten Mile Lake in 1956, and two of these (Mann #1, Mann #2) were found also to contain Nb and Be (Brummer, 1957; Brummer and Mann, 1961; Figure 3). Exploration at Mann #1 in the early 1960s provided a crude resource estimate of ~2 million tonnes at 0.35 to 0.40 percent BeO, with associated Nb, Zn and REE (Brummer, 1957; Evans and Dujardin, 1961). Metallurgical tests indicated that the Be-bearing minerals could not easily be concentrated due to fine grain size, and that Nb is mostly hosted by niobophyllite, which has <10% Nb (Nickel *et al.*, 1964). A subsequent airborne radiometric survey detected the Two Tom Lake prospect, defined by mineralized boulder fields and outcrops that resemble the Mann #1 zone, with up to 2% TREO (Westoll, 1971). This was also deemed uneconomic and short-duration exploration programs in subsequent years did not progress beyond cursory examination and dismissal. High Y and Ce values were reported by Miller (1985b), and also by Mitchell (1996). Claims covering the known occurrences were eventually acquired by Rare Earth Metals Inc., who completed exploration work in 2009 and 2010. This work has now documented REE mineralization of significant extent and grade at Mann #1 and Two Tom Lake, and also indicated new REE-enriched zones in several areas.

Overview of Geology

The Letitia Lake area lies at the northern edge of the Grenville Province, where it adjoins metamorphic rocks and igneous intrusions of the Churchill Province (Figures 1 and 3; Marten, 1975; Thomas, 1981 and Miller, 1987). The Letitia Lake Group consists of deformed and metamorphosed felsic volcanic and pyroclastic rocks, quartz-feldspar porphyry and lesser volcaniclastic sedimentary rocks. These are in tectonic contact with older (~1650 Ma) metaplutonic rocks to the south, and are overlain unconformably by the ~1240 Ma Seal Lake Group to the north. The age of the Letitia Lake Group is defined by a 1327 ± 4 Ma U−Pb zircon age from a volcanic unit (Fryer, *in* Hill and Thomas, 1991). The Letitia Lake and Seal Lake groups are affected by northward-verging overturned folds and related thrust faults, but the intensity of this deformation diminishes to the north. Several syenitic bodies occur within the Letitia Lake Group (Figure 3) and share its deformational history; these are grouped with the Red Wine Intrusive Suite (Thomas, 1981; Curtis and Currie, 1981; Miller, 1987; *see* later discussion). The structural complexity is not always emphasized in previous descriptions of the mineralized areas (*e.g.*, Miller, 1987), but it obscures many original relationships and confounds interpretation. Deformation is particularly intense at Mann #1, where a significant part of the deposit is hosted by mylonitic rocks, but similar features are seen at the other prospects.

Mineralization

The Mann #1 prospect (Figure 3) is the best known and most extensive zone of mineralization, with a potential strike length of some 1.6 km. Evans and Dujardin (1961) defined four discrete mineralized zones, termed A to D, which vary in character. Miller (1987) defined five 'styles' of mineralization, termed M1 to M5, and extended this classification to other areas (*see* below). The prospect sits in a strongly deformed zone that separates felsic metavolcanic rocks from metasedimentary rocks of the Letitia Lake Group (Figure 3), but is, in part, hosted with metasyenite. The main mineralized zone (B-Zone of Evans and Dujardin, 1961) is a banded, mylonitized 'syenitic gneiss' (Plate 1A, B) that is bounded on both sides by less-deformed syenites, which retain some relict igneous textures. Miller (1987) designated this as type M1 mineralization, and described it as "sheared, lineated and gneissic syenite and amphibolite". The rock has alternating feldspar-rich and amphibole (reibeckite)-rich bands, and contains wider concordant veins dominated by feldspar and aegirine (M2 mineralization of Miller, 1987; Plate 1B), cut by rarer discordant veins (M3 or M4 mineralization of Miller, 1987). The other mineralized zones defined within Mann #1 are less extensive, but important in terms of interpretation. Of particular note are the C-Zone and the D-Zone, located south of, and along strike from, the B-Zone. These consist of less-deformed metasyenite, dissected by complex mineralized veins that have aegirine-rich and feldspar-rich sections (Plate 1C, D). The random, locally stockwork-like pattern of veins in these zones suggests that they were originally intrusive into their host (M3 and M4 mineralization of Miller, 1987). The B-Zone dips steeply to the south, concordant with the regional fabric and lithological contacts in the host rocks.

Niobium occurs mostly in niobophyllite (a mica-like mineral), with lesser amounts in pyrochlore. Beryllium is hosted by two rare minerals, namely barylite (a Ba−Be silicate) and eudidymite (a Na–Be silicate). Phosphate minerals, dominated by apatite, were also noted, and there is mention of possible gadolinite, which is a Be–Ca–REE silicate (Evans and Dujardin, 1961). These minerals are disseminated in the gneiss-like rocks of the B-Zone, but are invisible due to their fine grain size. Little is known about the mineralogical distribution of the REE, or the characteristics of the more vein-like mineralization in the C- and D-zones.

Renewed exploration work commenced with re-sampling of pre-existing trenches in late 2009, which confirmed previously reported BeO and Nb_2O_5 values, and indicated high TREO* values from 0.47 to 4.99 percent. New trenching and channel sampling yielded similar results, and showed the light REE (notably La, Ce and Nd) to be dominant (Rare Earth Metals Inc., Press Release, August 4, 2010). Initial drilling indicated wide mineralized intersections, including 1.35% TREO*, 0.38% Nb_2O_5 and 0.31% BeO over 45 m in hole Mann1-04. Some of the holes encountered two discrete mineralized zones representing the C-Zone and the main B-Zone (Rare Earth Metals Inc., Press Release, October 14, 2010), and the highest-grade result to date is 1.71% TREO*, 0.24% Nb_2O_5 and 0.2% BeO over 27 m in hole Mann1-06 (Press Release, Oct 19, 2010). These results confirm the lateral continuity of mineralization over about 600 m, and at depths up to 100 m. The REE distributions from Mann #1 (Figure 4) show the dominance of LREE, with the most value being contributed by Nd. The chondrite-normalized REE patterns are steep, indicating strong HREE depletion. Grab samples collected by the GSNL in 2010 show closely similar patterns to these averages from drilling results.

The Two Tom Lake prospect is located some 12 km east of Mann #1, and is also hosted by the Letitia Lake Group metavolcanic rocks and associated metasyenites (Westoll, 1971; Miller, 1987). Most of the mineralization is within extensive fields of angular boulders, dominated by radioactive "syenitic gneiss" similar to the host rocks at Mann #1 (Westoll, 1971). Miller (1987) assigned most examples to his types M1 and M2 mineralization, *i.e.*, sheared to lineated 'gneissic' syenite, and foliated aegirine-feldspar rocks, respectively. Examination of new trenches in 2010 con-

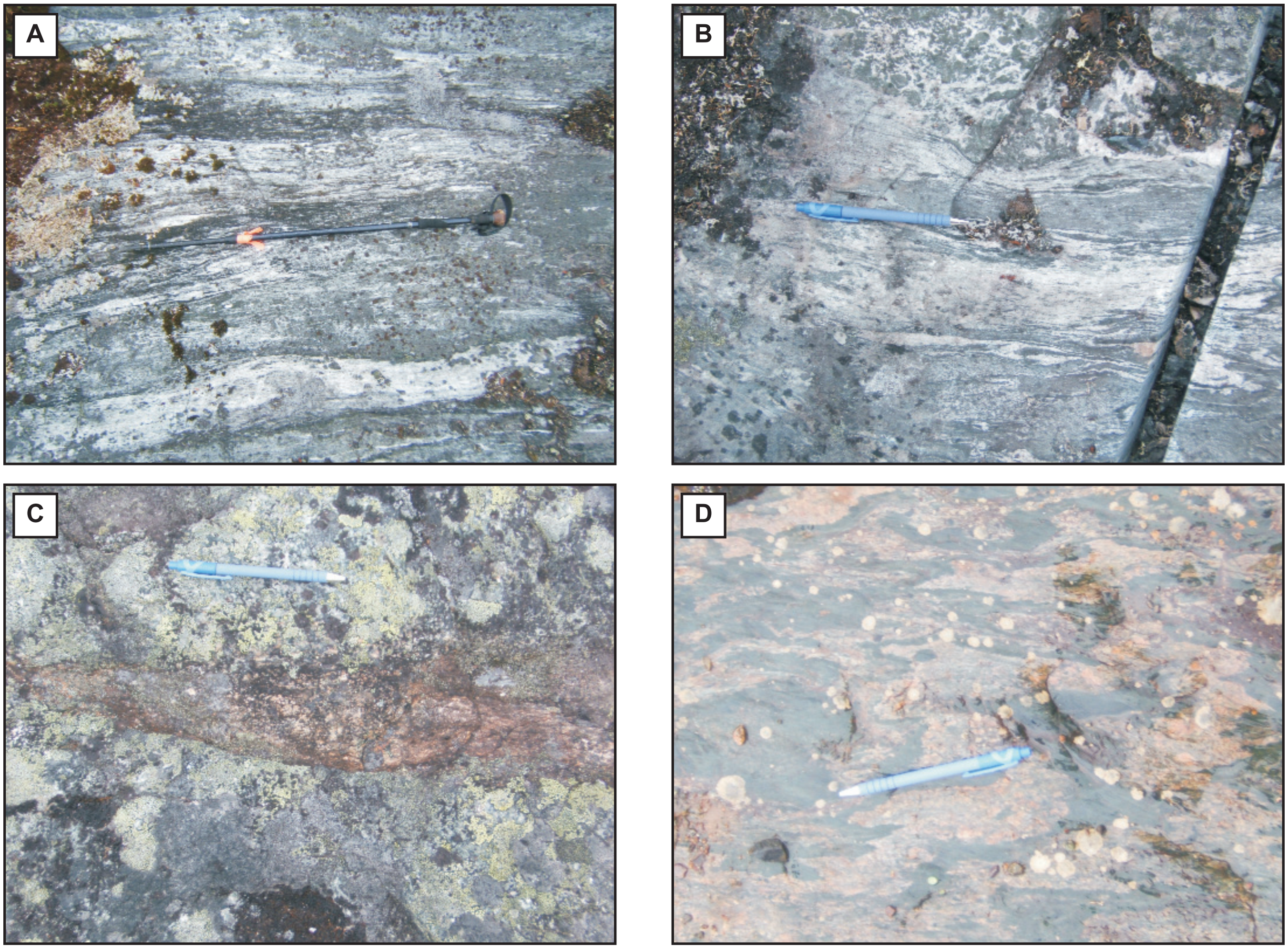

Plate 1. *Rock types and mineralization at the Mann #1 prospect, Letitia Lake area. A) Strongly foliated, banded, mylonitic "syenite gneiss" host rock to the Mann #1 B-Zone, which contains most of the known resources. B) More detailed view, showing concordant and slightly discordant veins, note coarse aegirine-feldspar vein at top left. C) Mineralized feldspar-rich vein cutting foliated (but non-mylonitic) syenite at the Mann #1 C-Zone, located about 100 m across strike from the B-Zone. D) Complex network of mineralized aegirine-feldspar veins dissecting foliated metasyenite at the Mann #1 D-Zone, located several hundred metres along strike from the B-Zone.*

firmed the strong similarities in rock types and mineralization to Mann #1 (Plate 2). Trenching also reveals examples of discordant vein-style mineralization that more closely resemble the C-Zone at Mann #1 (Plate 2). These correspond to mineralization styles M3 and M4 of Miller (1987). Metallurgical studies indicated the presence of barylite, eudidymite, niobophyllite and pyrochlore, as at Mann #1, and other 'exotic' minerals such as catapleite and rosenbuschite, which were suggested as possible REE hosts (Westoll, 1971).

Re-sampling of pre-existing trenches and new trenching in 2009 and 2010 confirmed Be, Nb and REE values reported in previous studies (Rare Earth Metals Inc, Press Release, August 31, 2010), but thick overburden obstructed trenching in many areas. Drilling completed in late 2010 suggests that mineralization is extensive. The initial hole returned 105.7 m at 1.35% TREO*, 0.31% Nb_2O_5 and 0.32% BeO, including a 65-m higher grade zone grading 1.68% TREO* (Rare Earth Metals Inc., Press Release, October 25, 2010). Results from three subsequent holes have also intersected significant widths of mineralization, including 88.5 m grading 1.32% TREO*, 0.37% Nb_2O_5 and 0.18% BeO, and 81.1 m grading 1.11% TREO*, 0.29% Nb_2O_5 and 0.23% BeO (Rare Earth Metals Inc., Press Release, November 17, 2010). Results from three more holes now suggest that mineralization of comparable width and grade extends over 1 km along strike (Rare Earth Metals Inc., Press Release, January 7, 2011). The REE profiles from Two Tom Lake are illustrated in Figure 5, and closely resemble those from Mann #1 (Fig-

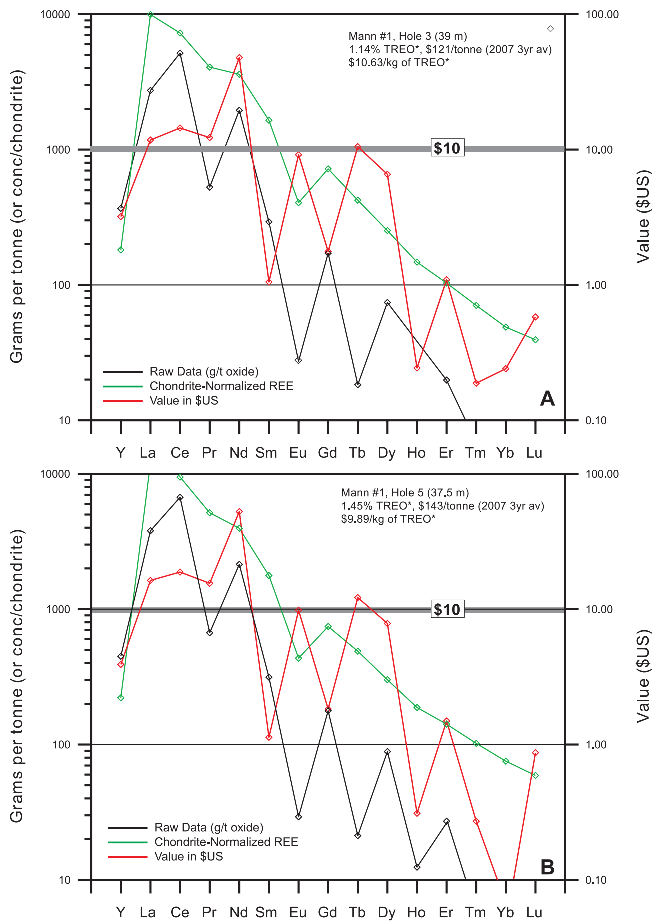

Figure 4. *(A, B). Average REE contents and valuations of two recent drill intersections from the Mann #1 prospect, Letitia Lake area, data from Rare Earth Metals Inc. (press releases and unpublished information for selected heavy REE). Chondritic normalization and REE price assumptions are the same as for Figure 2.*

ure 4). The REE data from grab samples collected by the GSNL in 2010 are consistent with these averages from the drilling results.

Other zones of mineralization around Letitia Lake (Figure 3) include the Mann #2 showing, the Michelin #1 showing, and other zones, some of which were discovered in 2010. The Mann #2 prospect is reported to be similar to Mann #1, albeit smaller; exploration work here since 2008 is of limited extent. Miller (1987) reported nepheline-bearing syenites in the area of the mineralization. Re-sampling in 2010 suggests local concentrations up to 4.1% TREO*, 0.78% Nb_2O_5 and 0.34% BeO (Rare Earth Metals Inc., Press Release, August 4, 2010). Miller (1987) described the Michelin #1 zone as disseminated mineralization in syenite, and discordant felsic veins (his M4 type). A brief visit to a new exploration trench in 2010 suggested the presence of sub-concordant to weakly discordant, mineralized aegirine-feldspar veins (Plate 3). Grab sampling by Rare Earth Metals Inc. returned values up to 5.29% TREO*, 2.18% Nb_2O_5, and 0.56% BeO, with mostly light REE (Rare Earth Metals Inc., Press Release, August 4, 2010). The Dory Pond showing (Figure 3) is currently defined by zones of mineralized boulders, but these are reported to be enriched in HREE compared to Mann #1 and Two Tom Lake (Rare Earth Metals Inc., Press Release, January 7, 2011).

Discussion

Half a century has elapsed since E.L. Mann's discoveries, but many questions from that era remain unanswered. However, the new work completed in 2010, particularly at Two Tom Lake, suggests that mineralization is more extensive than the early work indicated, and that there is significant REE enrichment in all these zones.

The widths of the mineralized zone at these prospects are encouraging, and at Mann #1 these are approximate true widths for the zone. The wider intersections at Two Tom Lake may not necessarily be true widths, but this is less important than the fact that there is a wide zone of near-surface mineralization. This prospect has evolved rapidly from a series of mineralized boulder fields and a few small outcrops to a zone with a strike length of over 1 km, within which grade seems to be consistent. The TREO* contents are relatively low at Mann #1 and Two Tom Lake, and the per-kg value of TREO* is at the lower end of the value spectrum, but both zones have promising *in-situ* value, notably in their high Nd contents. The high BeO contents of both deposits are also notable; Two Tom Lake was not previously known as a beryllium deposit, but new information suggests that it also hosts resources of this strategic element. Beryllium and BeO are high-value commodities, but the present market for them is small, and supplied by existing production in the USA. The mineralogical distribution of the REE at Letitia Lake is largely unknown, as it is for most deposits in Labrador. Previous work identified the host minerals for Be and Nb, but also suggested that the separation of these minerals would present a challenge in processing. If the REE are hosted with Be and Nb, or in equally fine-grained material, this issue remains to be addressed through mineralogical research and metallurgical studies.

The Be–Nb–REE mineralization in the Letitia Lake Group does not readily fit into prevailing models, and there are different interpretations of its genesis. The spatial association between mineralization and peralkaline rocks suggests an original genetic link to such magmatism, as proposed by Miller (1987). However, the host rocks at Mann #1 and Two Tom Lake can only be described as mylonitic, and genetic links to regional deformation and metamorphism were also proposed (*e.g.*, Thomas, 1981). Evans and Dujardin (1961) suggested metasomatic replacement of a

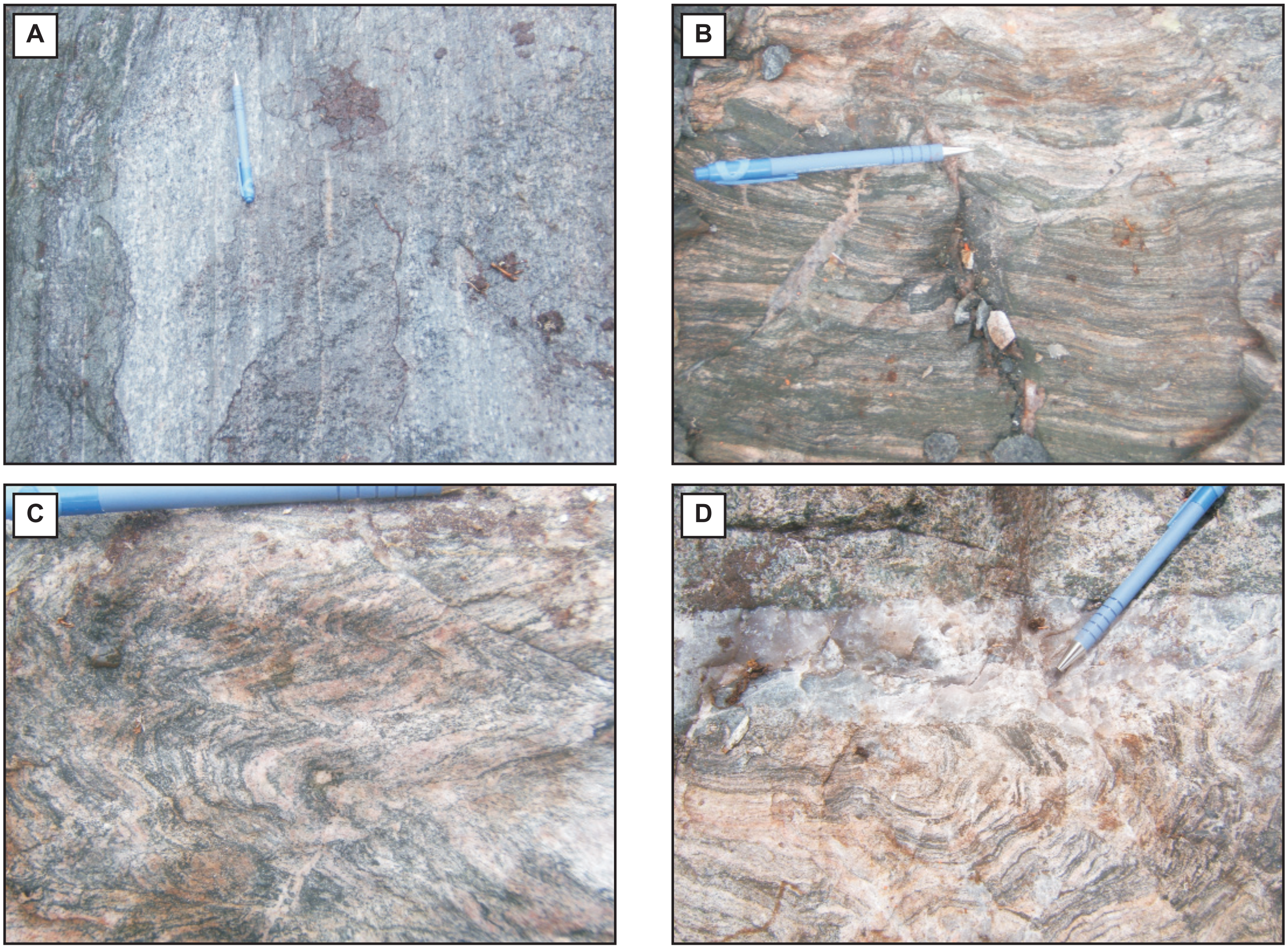

Plate 2. *Rock types and mineralization at the Two Tom Lake prospect, Letitia Lake area. A) Strongly foliated, banded 'syenitic gneiss' hosting mineralization. B) detailed view, showing concordant feldspar-rich veins and discordant quartz veins. Note similarities to equivalent photos from the Mann #1 prospect (Plate 1). C) Complex folding of a coarser grained, foliated, aegirine-feldspar-rich zone within the strongly foliated gneiss. D) Crosscutting relationship between a late quartz vein and folding in the mineralized zone, foliated syenite host rock in upper part of photo.*

sheared sedimentary protolith following emplacement of the syenite and quartz syenite, and Miller (1987) alluded to similar processes as part of his model.

Two end-member models seem possible. The first model interprets the deposits as syngenetic magmatic or magmatic−hydrothermal concentrations that later became sites of Grenvillian ductile deformation, such that most original relationships were destroyed. The mylonitic host rocks are severely transposed and straightened vein networks, and deformation was preferentially focused by alteration. The second model interprets peralkaline igneous rocks as source regions from which Be, Nb and REE were mobilized and concentrated into the shear zone, which is the primary control on mineralization, rather than a superimposed feature. It is also possible that both processes played a role, because element mobility would likely accompany transposition of pre-existing mineralization under metamorphic conditions. Whichever interpretation is preferred, there is no denying that there is a strong structural control at Mann #1, and probably also at Two Tom Lake. These models have contrasting exploration implications. The epigenetic shear-zone model suggests that the zone of ductile deformation associated with the boundary between volcanic and sedimentary rocks in the Letitia Lake Group represents a regional exploration target. Conversely, a syngenetic magmatic model implies that only specific areas (associated with syenites?) within such a zone have such potential. The presence of variably deformed vein-style mineralization adjacent to the main shear zone at Mann #1 broadly supports the magmatic model, and similar features are also present at Two Tom Lake and Michelin #1; however, such evidence is not definitive. The new information provided from drillcore in all these areas should help in interpreting the detailed relation-

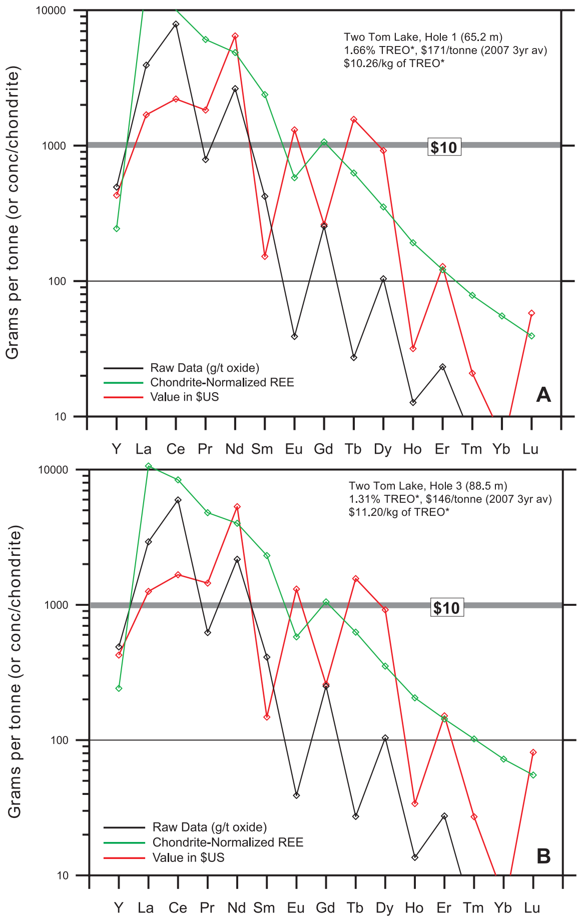

Figure 5. *(A, B). Average REE contents and valuations of two recent drill intersections from the Two Tom Lake prospect, Letitia Lake area, data from Rare Earth Metals Inc. (press releases and unpublished information for selected heavy REE). Chondritic normalization and REE price assumptions are the same as for Figure 2.*

ships between discordant veins and their possibly transposed equivalents.

RED WINE INTRUSIVE SUITE

Location and Exploration History

The Red Wine Intrusive Suite lies southwest of Letitia Lake, in two main areas, termed the North Red Wine pluton and South Red Wine pluton (Figure 6; Curtis and Currie, 1981; Thomas, 1981). As discussed above, several smaller bodies of syenitic rocks associated with mineralization in the Letitia Lake Group may be higher level counterparts of the suite (Figure 3). The distinctive pink mineral eudialyte (a Na–Zr-silicate) was recognized in the North Red Wine pluton during prospecting (Smith, 1968). Petrographic and geochemical studies confirmed the presence of significant Zr and REE, thought to be in eudialyte, and analyses showed that the eudialyte contained up to 13% Zr, 1.85% Y and 0.52% Ce (Smith, 1969). The mineral potential of the suite was noted by Smith (1968), Westoll (1971) and Marten (1975), but there was no systematic exploration until 2009. Search Minerals has completed most of the work in the North Red Wine pluton, aside from work at North Red Wine #1 and #2 (Figure 6b), which are held by Rare Earth Metals Inc. The latter company has also completed exploration work in the South Red Wine pluton, in association with Playfair Mining.

Overview of Geology

The Red Wine Intrusive Suite consists of metamorphosed peralkaline igneous rocks including both quartz-bearing and undersaturated (quartz-free) variants (Curtis and Currie, 1981; Thomas, 1981). The map pattern of these

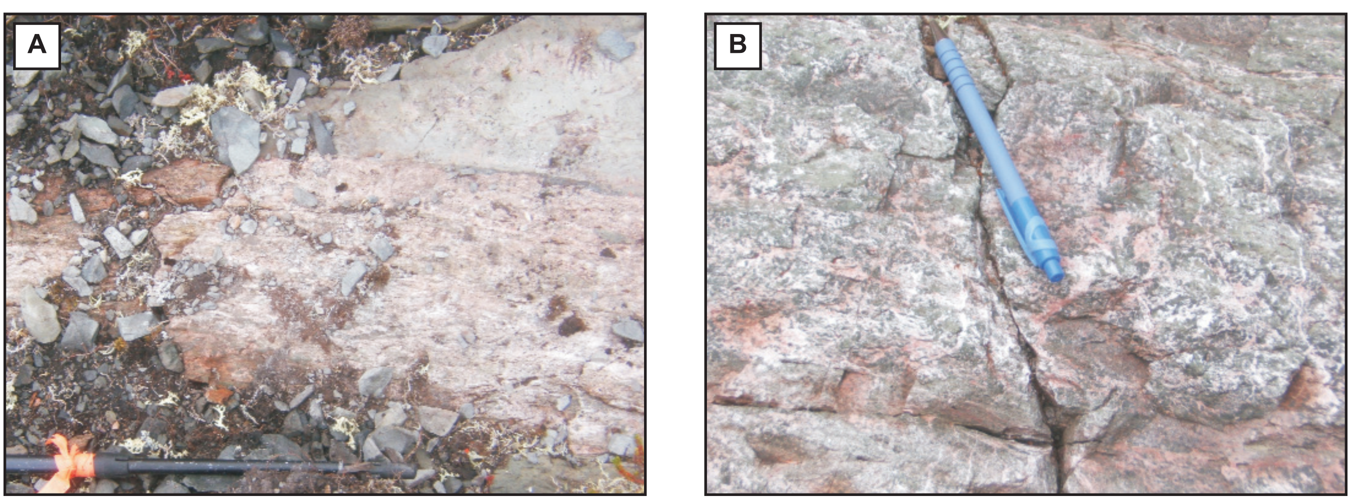

Plate 3. *Rock types and mineralization at the Michelin #1 showing, Letitia Lake area. A) Contact between mineralized aegirine-feldspar-rich vein and metavolcanic (?) host rocks. B) Coarse-grained pegmatitic texture preserved in the central part of a vein, with increasing intensity of foliation toward the contact zone, near top of photo.*

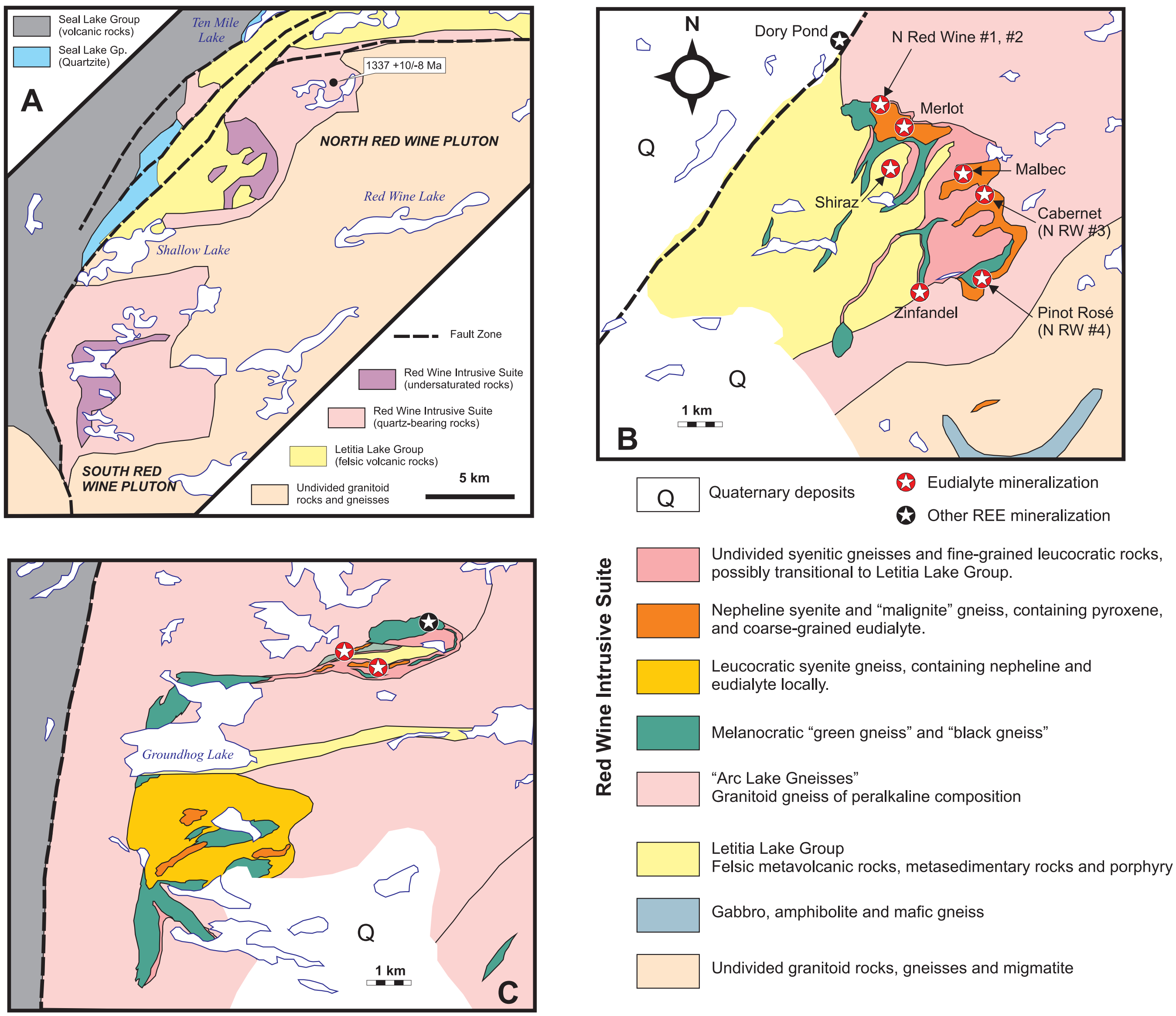

Figure 6. *Simplified geological map of the Red Wine Intrusive Suite and surrounding area, adapted from Thomas (1981) and Curtis and Currie (1981), showing the locations of eudialyte-bearing zones and other REE-enriched zones. A) General map showing locations of the North and South intrusions. B) Detailed map of the North Intrusion. C) Detailed map of the South Intrusion. Locations of additional eudialyte-bearing zones from R. Miller, Search Minerals.*

units is complex, and the undersaturated rocks form isolated lenticles within a wider envelope of quartz-rich peralkaline gneiss, derived from granitic rocks, which is termed the ‘Arc Lake gneiss’ (Figure 6). The feldspar- and nepheline-rich undersaturated rocks were converted into banded gneiss-like rocks in which original igneous textures are only locally preserved. Structural complexity abounds on an outcrop scale, but the regional structural pattern remains largely unknown. The undersaturated peralkaline rocks consist of albite, microcline, aegirine and soda-rich amphibole (arfvedsonite), with variable amounts of nepheline, pectolite and eudialyte. Several unusual accessory minerals are also reported by Curtis and Currie (1981). The quartz-rich peralkaline gneisses consist of quartz, albite, and microcline, with smaller amounts of sodic amphibole, pyroxene and accessory minerals. Curtis and Currie (1981) report a Rb–Sr isochron age of 1345 ± 75 Ma from the undersaturated rocks, and Gandhi *et al.* (1988) reported a U–Pb age of 1330 +13/-11 Ma from the quartz-rich peralkaline rocks of the suite (*see* Figure 6A for location). The latter is generally taken as the age of the suite as a whole, but the details remain unpublished.

Mineralization

Disseminated to semi-massive eudialyte occurs mostly within nepheline-bearing metasyenite and syenitic gneiss (nepheline syenite and malignite unit of Curtis and Currie, 1981; Figure 6B, C) in both the North and South Red Wine plutons. Eudialyte also occurs in lesser amounts within other rock types as tiny dispersed grains but is not always obvious at first sight (Curtis and Currie, 1981). Coarse-grained eudialyte is easily recognized by its vibrant pink and red, as befits its colloquial name *almandine spar* (Plate 4).

Four main occurrences in the North Red Wine pluton are termed North Red Wine #1 to #4 (MODS information), but #3 and #4 have now been assigned more inventive names (*i.e.*, Cabernet and Pinot Rosé prospects). Additional zones in this area are now termed Malbec, Zinfandel, Merlot and Shiraz zones (Search Minerals, Press Release, September 29, 2010). Previously unreported eudialyte mineralization was discovered in the South Red Wine pluton (Rare Earth Metals Inc, Press Release, August 10, 2010). The locations indicated in Figure 6 represent the most extensive prospects, but eudialyte is widespread as a minor constituent in surrounding and intervening areas. The mineralization occurs in two contrasting forms (Plate 4). Disseminated eudialyte is dispersed in syenitic gneiss (Plate 4A), and also forms discrete layers containing larger crystals up to 2 cm in diameter (Plate 4B). Such layers locally contain up to 50% eudialyte, and are concordant with the fabric and layering in surrounding rocks. Individual eudialyte crystals show signs of rotation within the fabric, implying that they are pre-deformation phenocrysts or porphyroblasts. The larger prospects contain multiple eudialyte-rich layers of this type, and disseminated eudialyte in the intervening syenitic gneiss. The second mode of occurrence is as irregular leucocratic pegmatite zones; these consist of albite, arfvedsonite and massive eudialyte, with crystals up to several centimetres in size. Locally, monomineralic eudialyte veins are present (Plate 4D, E). These pegmatitic zones are also concordant with the fabric in surrounding gneisses, and resemble migmatitic sweats (Curtis and Currie, 1981). Both styles of mineralization are locally affected by tight folding, which demonstrates their pre- or syn-tectonic timing (Plate 4C). The extent of such mineralization is not easy to assess, but where eudialyte-rich bands are gently dipping, continuity can be demonstrated over areas up to 1000 m^2. Individual eudialyte-rich zones were reported to extend over lateral distances of several hundred metres (Search Minerals, Press Release, September 29, 2010).

Recent exploration work by Search Minerals consisted of grab and channel sampling, and trenching, followed by diamond drilling at the Pinot Rosé, Cabernet and Malbec prospects. No drilling results are available, but several zones

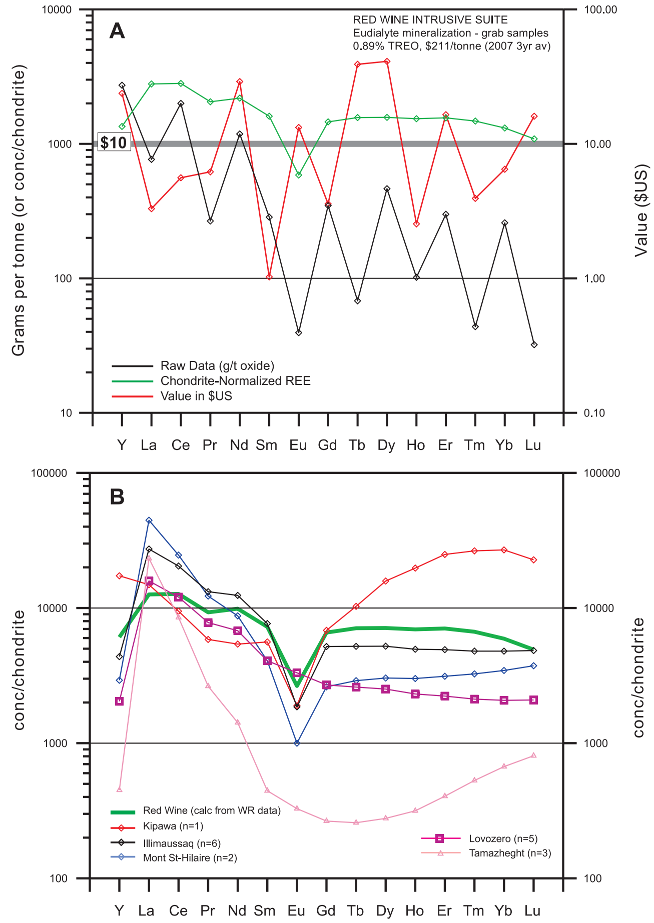

Figure 7. *A) Average REE content and valuation of five grab samples from eudialyte-rich mineralized zones in the Red Wine Intrusive Suite; data from Search Minerals website. Chondritic normalization and REE price assumptions are the same as for Figure 2. B) Comparison of chondrite-normalized REE profiles from Red Wine Intrusive Suite and the REE profiles of eudialytes from other peralkaline suites, including Ilimaussaq (Greenland), Mont St-Hilaire (Québec), Kipawa (Québec), Lovozero (Russia) and Tamazheght (Morocco). Note that the Redwine Intrusive Suite whole-rock data were recalculated to approximate eudialyte composition using the ZrO_2 content of whole-rock samples, assuming that eudialyte contains 12.5% ZrO_2, and that all Zr and REE in samples reside in eudialyte. Comparative REE data from other localities from Wu* et al. *(2010) and F-Y Wu (personal communication, 2011).*

of mineralization were intersected by four holes at the Pinot Rosé prospect, where mineralization extends to depths of at least 200 m (Search Minerals, Press Release, September 29, 2010. The average of samples collected in 2009 (Search Minerals, website information) indicates a grade of 0.89% TREO*, and a flat chondrite-normalized REE pattern indicative of HREE enrichment (Figure 7A). The eudialyte mineralization has no associated anomalous radioactivity,

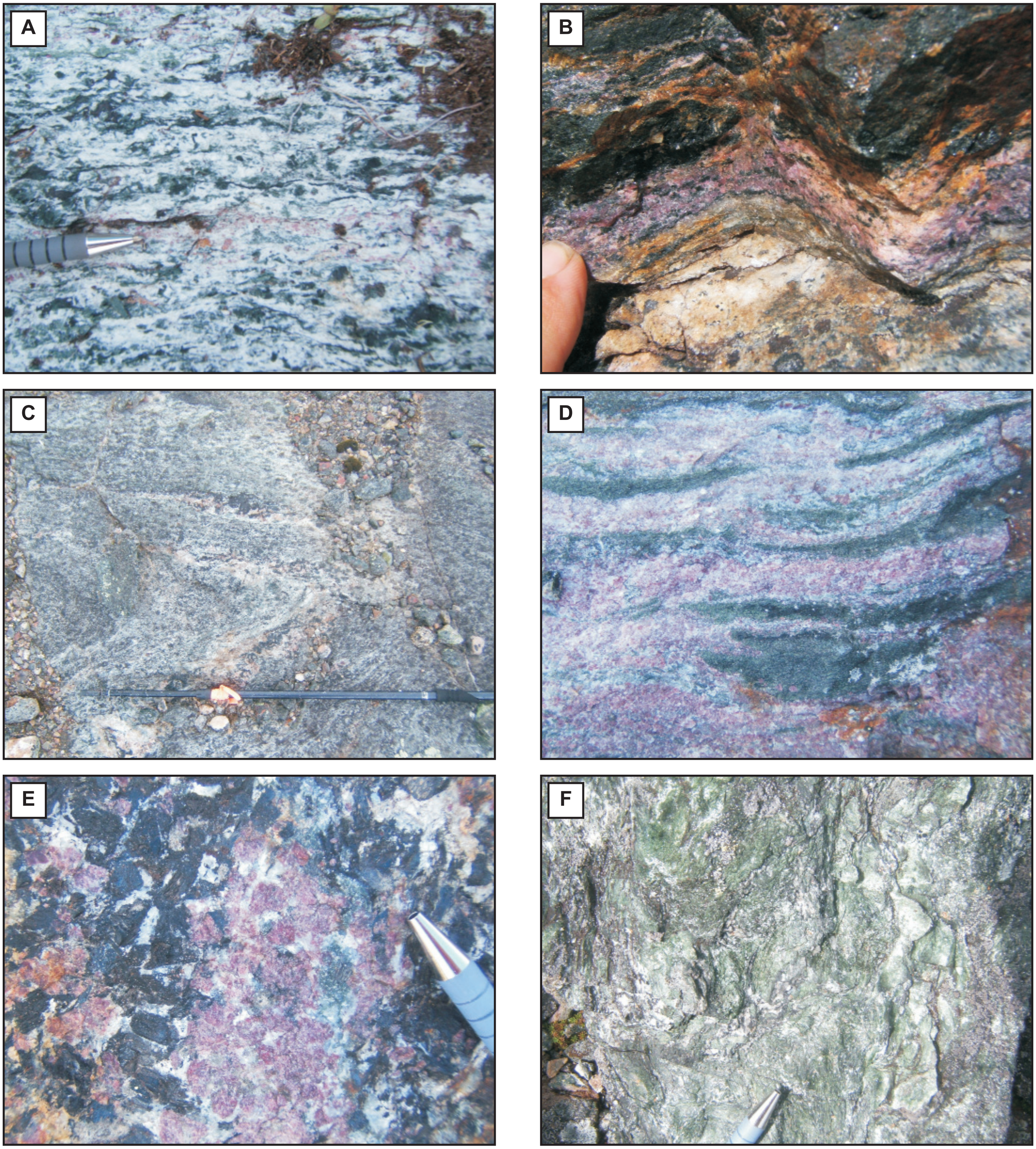

Plate 4. *Rock types and mineralization in the Red Wine Intrusive Suite. A) Gneiss-like rock of nepheline-syenite composition containing disseminated eudialyte (pink), which is most abundant near the pen, but disseminated elsewhere. B) Eudialyte-rich zone associated with amphibole and pyroxene, containing a strong fabric, but affected by later folding. C) Tight fold closure in syenitic gneiss, which affects both disseminated eudialyte layers in the rock, and a leucocratic pegmatite-like zone containing eudialyte, just above the hiking stick. D) Near-monomineralic eudialyte-rich layers, associated with coarse-grained amphibole, possibly formed from deformation of a pegmatitic zone. E) Massive eudialyte and amphibole (black) in relatively undeformed pegmatite, possibly parental to D). F) Bright-green amphibole-rich rock type associated with REE mineralization and elevated radioactivity. A) to E) are from the North Redwine pluton, and F) is from the South Red Wine pluton.*

suggesting no U or Th enrichment, but grab samples contain >3% ZrO_2. Several of the HREE contribute significant potential value, as shown by the high per-kg value for TREO*. The average REE profile is compared with laser-ablation ICP-MS REE analyses of eudialyte from elsewhere (Figure 7B; data from Wu *et al.*, 2010; *see* caption for assumptions about recalculation of Red Wine data). The Red Wine Intrusive Suite data resemble analyses from Illimaussaq (Greenland) and Kipawa (Québec), which are similarly enriched in HREE, but the Kipawa eudialytes show the strongest overall HREE enrichment. The profiles differ from those of eudialytes representing other peralkaline suites such as Lovozero (Russia) and Tamazheght (Morocco), which are depleted in HREE and lack Eu anomalies (Wu *et al.*, 2010).

In the South Red Wine pluton, REE enrichment is also associated with pyroxene- and amphibole-rich zones (Plate 4F) that also display elevated radioactivity (Rare Earth Metals Inc., Press Release, August 10, 2010) but little information is available. Grab samples contained 0.5 to 2.4% TREO*, but appear to be richer in LREE than the eudialyte-dominated mineralization. Grades of 2.6 to 3.0% ZrO_2 suggest that eudialyte-bearing zones resemble those from the North Red Wine pluton, consistent with field observations.

Discussion

Eudialyte mineralization is unusual, but it is attracting considerable exploration interest in several areas, as a promising source of Y and HREE that is free of processing and environmental complications associated with associated radioactive elements, notably Th. The name eudialyte comes from a Greek phrase meaning *easily dissolved* (World Minerals Database, website information). It is readily broken down by acids, but dissolution is accompanied by formation of silica gels that have proved obstacles in processing. Recent work on deposits in Kipawa, Québec, may now potentially resolve some of these problems (Matamec Inc., website information). On this basis, the Red Wine Intrusive Suite will continue to attract exploration attention if drilling shows that acceptable grades are sustained over significant depths and surface areas.

Mineralization of this type occurs in the famous Ilimmaussaq Intrusion of south Greenland (Sorenson, 2006), in the Lovozero Complex in Russia (*e.g.*, Kogarko *et al.*, 2010) and at an active exploration project near Kipawa, Québec (Currie and van Breemen, 1996; Matamec Inc., website information). In these areas, eudialyte is considered to be a cumulus mineral that crystallized with other silicates, or in isolation, perhaps as a result of magma-mixing processes (*e.g.*, Williams-Jones, 2010). Its origins in the Red Wine Intrusive Suite are less clear, due to metamorphism and deformation, and some zones may be pegmatitic 'sweats'. Curtis and Currie (1981) also noted these possible interpretations. Recent exploration suggests that eudialyte-rich zones may be extensive, as noted originally by Smith (1968), but only systematic drilling can truly define their distribution and character. The estimation of grade from drillcore may also be more complex than for other types of deposits, because the distribution of eudialyte may be irregular. Initial information from sampling suggests that the Red Wine eudialytes are HREE enriched, like those at Ilimmaussaq and Kipawa. Eudialyte is also amenable to *in-situ* U–Pb dating and analysis of Sr, Nd and Hf isotopic compositions (*e.g.*, Wu *et al.*, 2010), and this is also a topic of interest for future research. The current geochronological data on the Red Wine Intrusive Suite are inadequate but suggest a possible correlation with the Letitia Lake Group (Gandhi *et al.*, 1988). If this link is real, is it possible that LREE enrichment in the Letitia Lake Group records removal of HREE-enriched eudialyte from cogenetic magmas in a deeper plutonic setting?

STRANGE LAKE (LAC BRISSON) AREA

The Strange Lake (Lac Brisson) area contains potentially large deposits of Zr, Nb and REE on both sides of the Québec–Labrador border. Current exploration activity is mostly in Québec, because adjacent parts of Labrador are exempt mineral lands (EML). The deposits are described and discussed in government reports (*e.g.*, Currie, 1985; Miller, 1986, 1988, 1990) and several journal papers (*e.g.*, Birkett and Miller, 1991; Birkett *et al.*, 1992; Salvi and Williams-Jones, 1990, 1992; Boily and Williams-Jones, 1994; Miller, 1996; Miller *et al.*, 1997). Detailed information is provided in assessment reports submitted to the respective governments, and in a feasibility study (Iron Ore Company of Canada (IOC), 1985). The most recent information from Québec is in company Press Releases and related documents issued by Quest Rare Minerals Ltd. Although the future of deposits on the Labrador side remains to be decided, Strange Lake is important from the perspective of exploration models for REE deposits in peralkaline suites. This section summarizes several critical aspects of these deposits, and discusses new information available from Québec and limited work by the GSNL in Labrador and from archived samples.

Location and Exploration History

The Strange Lake deposit is located on the Labrador–Québec border about 125 km west of Nain, and 250 km northeast of Schefferville (Figure 1). This is a high-elevation, barren tundra region, having little natural outcrop, to which access is difficult. The deposit was discovered in 1979 by Iron Ore Company of Canada (IOC) by ground prospecting of U, Th, F and Mo lake-sediment anomalies. Radioactive boulder fields were located, and found to have high Zr, Y, and Nb contents, associated with elevated Be, Th, and fluorine. Subsequent drilling intersected the Main Zone deposit, which is located mostly in Labrador (Hlava and Krishnan, 1980; Figure 8). Intensive exploration from 1980 to 1983 defined a near-surface resource of ~57 Mt of 2.93% ZrO_2, 0.38% Y_2O_3, 0.31% Nb_2O_5, 0.08% BeO and 0.54% TREO (Venkateswaran, 1983a, b; IOC, 1985; not compliant with NI 43-101 standards). The REE were not the focus for exploration, and REE contents were mostly estimated from Y_2O_3 data, based on results from selective complete REE analyses. Including Y with the REE implies that this overall resource should have a TREO* content of ~0.9%, which approaches the average of historical REE analyses (*see* Figure 2). However, any such extrapolation requires direct confirmation. Development proposals (IOC, 1985) focused mostly upon a small near-surface high-grade zone termed the Zone 1 lens, estimated to contain a 'reserve' of some 5 Mt at 3.25% ZrO_2, 0.66% Y_2O_3, 0.56% Nb_2O_5 and 1.3% TREO (equivalent to ~2% TREO*). [Note that some papers (*e.g.*, Salvi and Williams-Jones, 1990) and other summary documents (*e.g.*, Walters *et al.*, 2010) misquote the resource at Strange Lake by combining the bulk tonnage with grades from the much smaller Zone 1 lens.] Development plans in the 1980s faltered in the face of poor market conditions, metallurgical obstacles and the remote location. Some additional metallurgical research was reportedly completed by Mitsui Inc., in the early 1990s, but this information is not present in the GSNL archives. The mining lease eventually lapsed, and the lands reverted to the Province as EML; the deposit area was subsequently negotiated as Labrador Inuit Lands (LIL) as part of a land-claims settlement. The Québec exploration leases also lapsed in the 1990s, but exploration resumed when the area was staked by Quest Uranium (now Quest Rare Minerals). This project commenced with drilling on the extension of the Main Zone located in Québec, but soon shifted to Lac Brisson (Figure 8), where previous IOC drilling had indicated the presence of unevaluated mineralization. Quest Rare Minerals has now defined a potentially large, near-surface deposit adjacent to Lac Brisson that is known as the 'B-Zone' (Figure 8). In early 2010, the company released resource estimates ranging from 11.8 Mt at 1.35% TREO* (cutoff of 1.2% TREO*) to 138 Mt at 0.97% TREO* (cutoff of 0.7% TREO*) with associated ZrO_2, Nb_2O_5 and BeO mineralization. A preliminary economic analysis and a conceptual development plan for mining some 43 Mt of this resource followed in September 2010 (Ramsey *et al.*, 2010). The estimated TREO* grades for the B-Zone resemble those inferred for the larger resource in the main Main Zone at equivalent tonnages, but the B-Zone ZrO_2 and Nb_2O_5 grades are lower at ~2.05% and 0.24%, respectively. Metallurgical studies of the B-Zone material built upon earlier IOC work, and the results are considered favourable, indicating high recoveries for elements of interest (Quest Rare Minerals, Press Release, August 12, 2010; Ramsey *et al.*, 2010). The B-Zone deposit is located entirely in Québec, but current conceptual development proposals (Ramsey *et al.*, 2010) envisage transport of ore for processing at Anaktalak Bay, Labrador (port site for the Voisey's Bay mine).

Since 2008, exploration in Labrador is limited by the EML status of the Main Zone deposit, but nearby areas outside the EML contain IOC drillholes that contain some mineralization (Figure 8). Quest Rare Minerals and Midland Exploration completed some limited work in these areas in 2010. Recent GSNL work consisted of data compilation, examination of archived drillcore, and short-duration field work focused on sampling. Selective re-analysis of archived IOC assay samples for the complete REE spectrum was also initiated to facilitate estimation of the Main Zone REE resource and a better understanding of REE behaviour. This work is in progress, but some of these data are highlighted in the following section.

Overview of Geology

The Strange Lake Intrusion (SLI) is a small circular body of peralkaline granite, about 8 km in diameter that intrudes metamorphic rocks of the Churchill Province and Mesoproterozoic quartz monzonite (Figure 8). The body straddles the provincial border, and appears to be a ring-complex, bounded by a fluorite-rich brecciated fault zone (Figure 8). The SLI is very poorly exposed and the distribution of internal units is interpreted largely from drilling results and angular boulder fields. U−Pb zircon data from an outcrop in Québec (Figure 8) indicate emplacement of the oldest phase at 1240 ± 2 Ma (Miller *et al.*, 1997); the older K−Ar (~1270 Ma) and younger (~1190 Ma) Rb−Sr results reported by Currie (1985) and Pillet *et al.* (1989) are likely disturbed. The SLI granites range from fresh and massive to altered and friable; a generalized chronology of intrusion is provided by rare outcrop field relationships and patterns inferred from drilling results. On this basis, the SLI is divided into three units (Miller, 1985a; 1986) distinguished on the basis of their modal mineralogy, texture and accessory mineral abundance (Figure 8). The oldest, termed the *exotic-poor granite*, is hypersolvus aegirine-arfvedsonite granite of varied texture that is generally fresh; it is locally charged with numerous aphanitic to felsdpar-porphyritic inclusions (Plate 5B). This unit contains zircon but only minor amounts of 'exotic' accessory minerals (*see* below). A younger subsolvus granite, termed the *exotic granite*, forms a border zone mostly within Québec, and is distinguished by strong enrichment in Zr, Y, Nb, and REE. This enrichment results in unusual minor minerals, including elpidite (Na−Zr-silicate), vlasovite (Na−Zr-silicate), armstrongite (Ca−Zr-silicate), gittinsite (Ca−Zr-silicate), gadolinite (Be−Ca−REE-

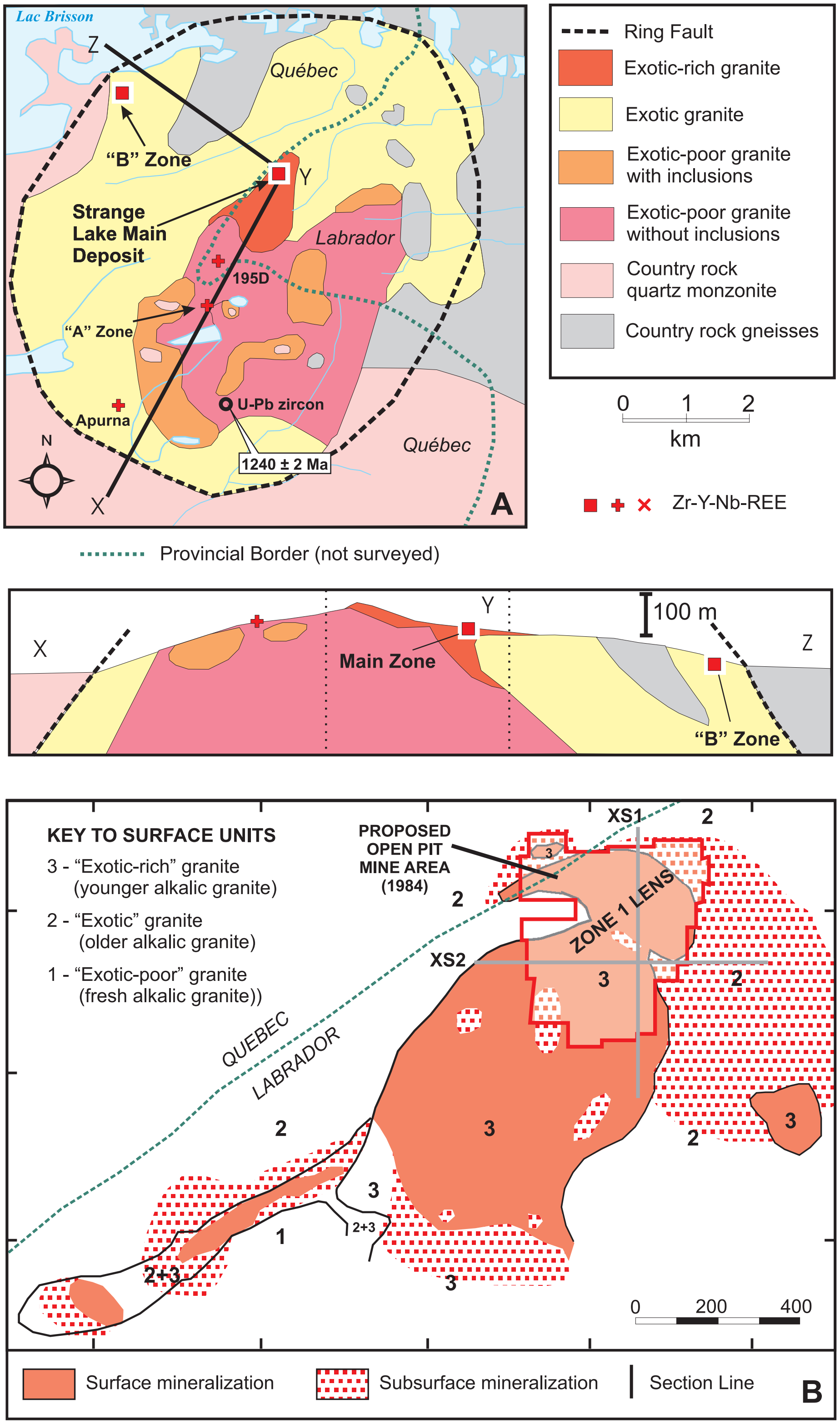

Figure 8. *A) Simplified geological map and schematic cross-section of the Strange Lake Intrusion, Québec–Labrador border area, showing the locations of the Main Zone, B-Zone and several other zones of interest for REE mineralization. Adapted from Miller (1986), Miller* et al. *(1997) and Quest Rare Minerals information. B) More detailed view of the area of the Main Zone deposit, showing the location of the Zone 1 lens and cross-sections illustrated in Figure 9. Adapted from IOC (1985).*

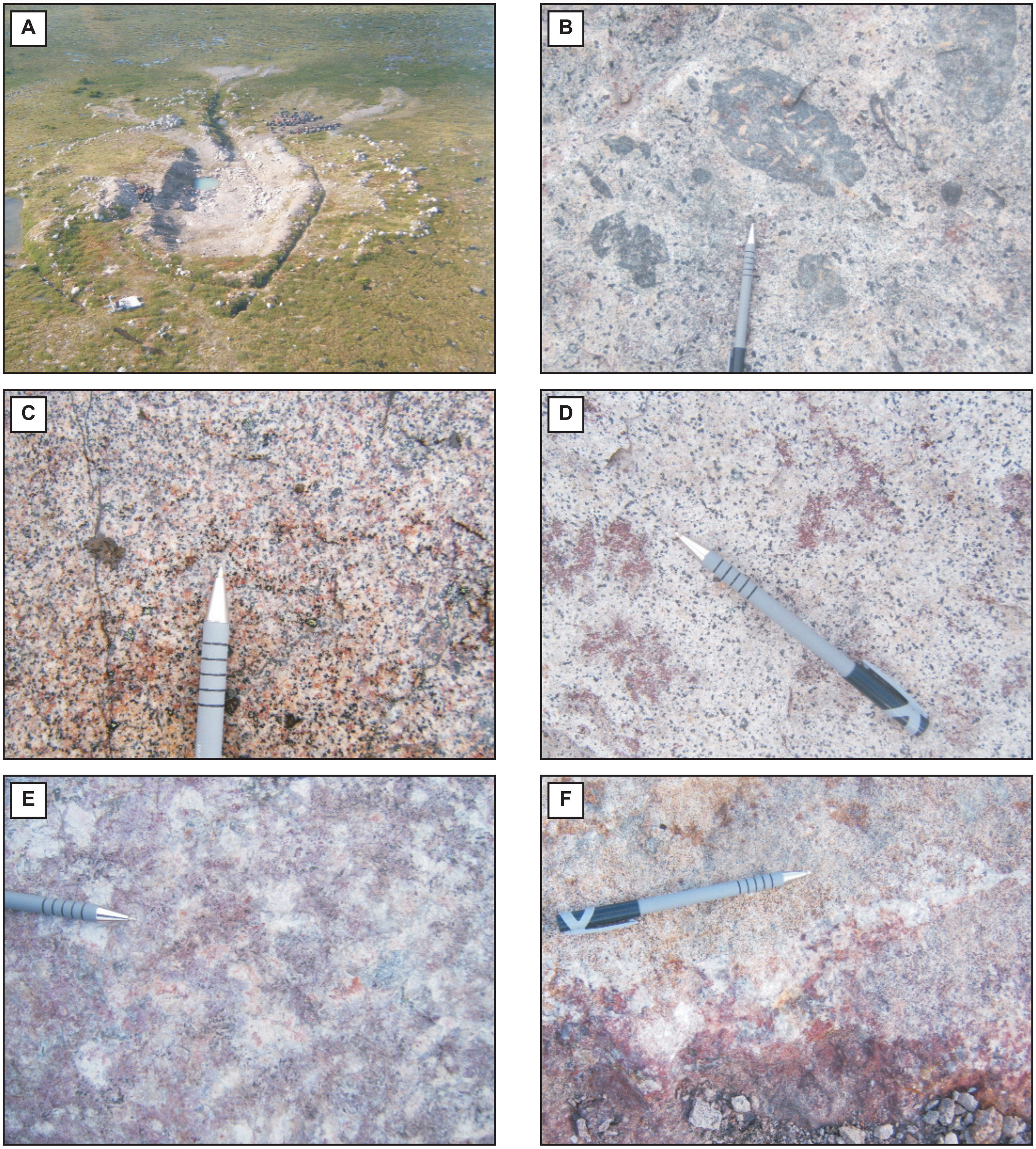

Plate 5. R*ock types and mineralization from the Strange Lake deposit. A) Bulk sample trench, located on the Québec–Labrador border, where the Zone 1 lens comes to surface. Note 45-gallon oil drums for scale. B) Inclusion-bearing 'exotic-poor' peralkaline granite; note the tabular feldspar phenocrysts in some inclusions suggesting their subvolcanic origin C) The fine-grained 'exotic-rich' peralkaline granite that constitutes a large segment of the bulk REE resource at Strange Lake. D) White 'aplitic' mineralized unit from the Zone 1 lens, containing large poikilitic (?) masses of exotic Zr- and REE-bearing minerals, mostly hematite-altered gittinsite (Ca-Zr-silicate); TREO* content of about 1.7%. E) Coarse-grained pegmatite facies from the Zone 1 lens, containing high-grade mineralization (>4% TREO*). F) Contact zone between aplitic and pegmatitic facies in the Zone 1 lens, showing veinlets of pegmatite cutting previously-crystallized aplite. Aside from C) all photos come from the area of the bulk sample trench. C) is from an outcrop in Labrador southwest of the Main Zone deposit.*

silicate), gagarinite (Na−Y−Ca−REE-fluoride), narsarsukite (Na−Ti−Fe-silicate), pyrochlore (Na−Ca−Nb-oxide), kainosite (Ca−REE-silicate) and a still-unnamed Ca−Y−REE-silicate (Miller, 1986; Salvi and Williams-Jones, 1990; IOC, 1985). The youngest unit in the SLI, termed the *exotic-rich granite*, is a variably altered subsolvus granite of limited extent, which intruded along the contact between the two older units, and forms isolated patches elsewhere in the complex (Figure 8). As its name suggests, this unit contains larger amounts of the exotic minerals, and is very strongly enriched in Zr, Y, Nb and REE. This is an equigranular to porphyritic arfvedsonite granite containing patches rich in these exotic minerals (Plate 5C, D). Parts of the exotic-rich granite unit represent potential low-grade disseminated ore (IOC, 1985; Miller, 1986, 1990). This unit also includes complex aplitic and pegmatitic variants that commonly occur together as sheet-like, dyke-like or irregular masses (Plate 5D, E, F). These pegmatites and aplites show extreme enrichment in incompatible elements, are strongly radioactive, and constitute much of the high-grade material in the Zone 1 lens. Strongly enriched pegmatitic material of similar aspect is also important within the B-Zone deposit outlined near Lac Brisson (Quest Rare Minerals, website information; Collins, 2010). Hydrothermal alteration of the host granites is relatively minor in the Main Zone, and was described as calcium metasomatism, manifested by the transformation of Na−Zr-silicates to Ca−Zr silicates (Salvi and Williams-Jones, 1990; Boily and Williams-Jones, 1994). These authors also suggested that the exotic-rich granite unit was simply an altered variant of the adjacent subsolvus exotic granite, and that mineralization was dominantly hydrothermal. This viewpoint was disputed by Birkett and Miller (1991) and Miller *et al.* (1997), who regarded much of the texture and mineralogy in all these units as original. The host rocks to pegmatite−aplite zones at the Zone 1 lens include all three granites of the SLI, and the older units are here generally fresh and unaltered (Plate 5B). The host rock to pegmatite units at the B-Zone is an inclusion-rich granite, but this shows more intense hematite alteration and calcium metasomatism than equivalent rocks at the Main Zone (Collins, 2010).

Mineralization

Several mineralized zones are defined within the SLI, on both sides of the Québec−Labrador border (Figure 8), but the most significant are the Main Zone and the B-Zone, upon which this discussion is largely focused. These mineralized zones are completely covered by overburden, and interpretations depend on drillcore data, aside from part of the Zone 1 lens, which is exposed in a bulk sample trench, located on the Québec–Labrador border (Figure 8; Plate 5A). There are two main types of mineralization, *i.e.*, low-grade, orthomagmatic, disseminated mineralization hosted by the exotic-rich granite unit, and high-grade mineralization hosted by complex pegmatite and pegmatite–aplite zones that intrude this and other units. The Main Zone deposit contains both styles of mineralization, and the high-grade component is interpreted to sit within and above the roof zone of the exotic-rich granite (IOC, 1985; Miller, 1986, 1992). The B-Zone deposit consists of several pegmatite sheets contained within altered granite; in this respect, it resembles parts of the Zone 1 lens. The exotic-rich granite is not explicitly described from the B-Zone, but recent reports of a ‘new deep REE zone’ that gave assays of ~1% TREO* over wide intervals (Quest Rare Minerals, Press Release, December 9, 2010) suggest that it may be present in the subsurface. At the very least, these new results from Québec resemble those from the deeper drillholes previously completed on the Main Zone deposit by IOC.

The Main Zone deposit includes a large area of mineralized exotic-rich granite (Figure 8) assessed only by widely spaced shallow drilling. This occupies a total area of some 1 km^2, but its subsurface geometry is not well defined, as most drillholes are probe only a few tens of metres. However, the longest drillholes that were only completed in this area (SL-178) terminated in mineralization at 281 m, so it extends to at least this depth. The geometry was described as resembling an inverted cone (Miller, 1985a, 1986) but a trumpet-shaped flower might provide a better analogue, and the upper surface of this intrusion likely lay just above the present erosion surface. Data from hole SL-178 indicate that its uppermost region has higher relative Y_2O_3 grades, implying that REE and other elements may have accumulated in the roof zone as a consequence of fractional crystallization, convective fractionation or volatile transport (Miller, 1985a, 1986, 1990, 1992). Pegmatitic and aplitic zones are most abundant in the upper section of this unit, and extend upward and outward into the adjoining older units of the SLI. The Zone 1 lens includes numerous individual zones of this type, which have complex and partly unresolved geometry, separated by variably mineralized wallrocks. The general geometry of the Main Zone mineralization is illustrated in Figure 9 (*after* IOC, 1985; Miller, 1986, 1990), which also shows the large potential resource contained at depth within the exotic-rich granite. Examples of the mineralized rock types are illustrated in Plate 5 C-F, mostly from the bulk-sample excavation. The REE contents of low-grade disseminated mineralization cannot be estimated accurately, but historical data and preliminary assessment of new data suggest TREO* values in the range of 0.6 to 0.9%. The average REE pattern of historical data (averaging ~1% TREO*) was previously indicated in Figure 2. Figure 10 illustrates the REE profiles of lower grade mineralization in the exotic-rich granite, and pegmatites and aplites representing the Zone 1 lens. The pegmatites and aplites have high TREO*, and high calculated *in-situ* value, to which the HREE make

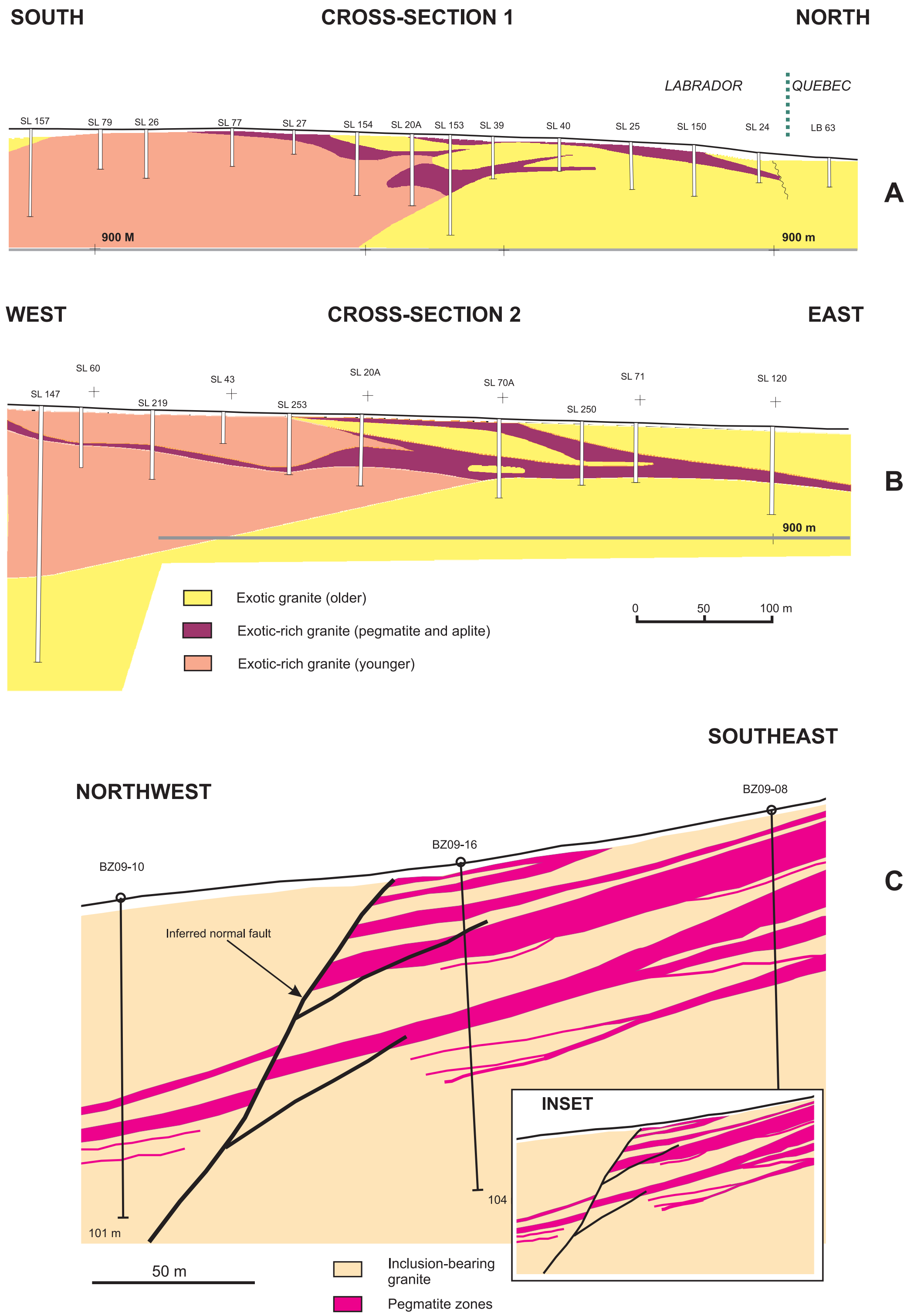

Figure 9. *A) True-scale cross-sectional view through the centre of the Main Zone deposit at Strange Lake, oriented in a north-south direction, with northern extremity located in Québec. Note the location of the pegmatite–aplite zones that defined the Zone 1 lens, and the larger near-surface resource indicated in the exotic-rich granite unit in the south. B) True-scale cross-section in an east-west direction. Adapted from the IOC (1985) feasibility study; see Figure 8 for section line locations. C) Cross-section of part of the B-Zone deposit in Québec, showing the pegmatite sheets within inclusion-bearing peralkaline granite. Adapted from information on the Quest Rare Minerals website; inset shows this section at the same scale as parts (A) and (B).*

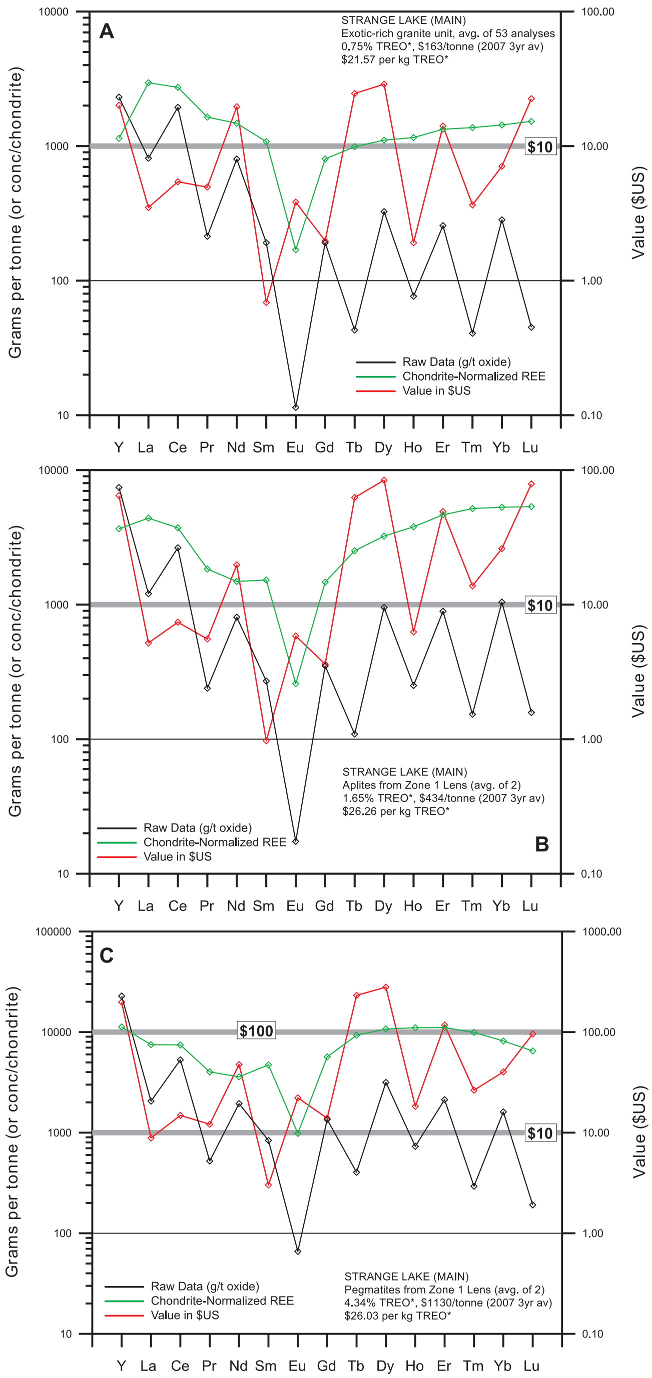

Figure 10. *Average REE contents and valuations of rock types within the Main Zone deposit at Strange Lake, data from recent GSNL reanalysis of archived drillcore samples. A) Average for the exotic-rich granite unit that constitutes much of the bulk resource. B) Analyses from aplitic (fine-grained granite) unit associated with pegmatites in the Zone 1 lens. C) Analyses from pegmatite units within the Zone 1 lens. Note the slightly different HREE-dominated pattern shown by the pegmatites. Chondritic normalization and REE price assumptions are the same as for Figure 2.*

the largest contribution. The average chondrite-normalized REE profiles for various mineralization types in the Main Zone deposit are broadly similar, although there is some variation in the relative abundances of LREE and HREE. Specifically, the aplites and pegmatites contain higher proportions of the HREE, with the degree of such enrichment proportional to the TREO* content.

General information concerning the B-Zone mineralization is available from corporate presentations (Quest Rare Minerals, website information), in Ramsey *et al.* (2010) and also in earlier assessment reports for this area (*e.g.*, Miller, 1984). Maps and cross-sections suggest that the B-Zone consists of multiple flat to gently dipping pegmatite sheets hosted by inclusion-bearing peralkaline granite (Figure 9C), but aplitic zones are reportedly less abundant than in the Main Zone (Collins, 2010). Examination of drillcores made available for public display suggests that the pegmatite units resemble those from the Zone 1 Lens (Plate 5E), albeit more altered. The overall grades of the B-Zone deposit represent various mixtures of high-grade pegmatitic material and wallrocks. In this respect, it resembles parts of the Zone 1 lens in the Main Zone. REE profiles for the B-Zone deposit are illustrated in Figure 11 (data extracted from Ramsey *et al.*, 2010 and Quest Rare Minerals Press Releases), and show a strong similarity to equivalent results from the Main Zone (Figure 10).

Mineralogical research sponsored by IOC in the 1980s and 1990s focused for the most part on the zirconium-bearing minerals (*e.g.*, Birkett *et al.*, 1992), but several potential REE-bearing minerals were identified, notably gadolinite, kainosite, gagarinite and an unnamed Ca–Y–REE-silicate (IOC, 1985; Miller, 1986; Salvi and Williams-Jones, 1990). However, the distribution of REE amongst these and other minerals, and the abundance of REE in Na–Zr and Ca–Zr-silicates was not documented in detail. Historical and newly acquired trace-element and REE data from the Main Zone deposit indicate strong correlations between the HREE and Y, suggesting a mineralogical link. The LREE are not as well correlated with Y, suggesting an independent LREE host mineral, or preferential mobilization of LREE during alteration. There is little correlation between the REE as a group and Zr or Nb, suggesting that minerals that host the latter (gittinsite and pyrochlore, respectively) do not contain significant REE. This aspect is very important in terms of economic evaluation, and research work aimed at better understanding mineralogy in the context of REE distribution is an obvious priority from both scientific and economic perspectives.

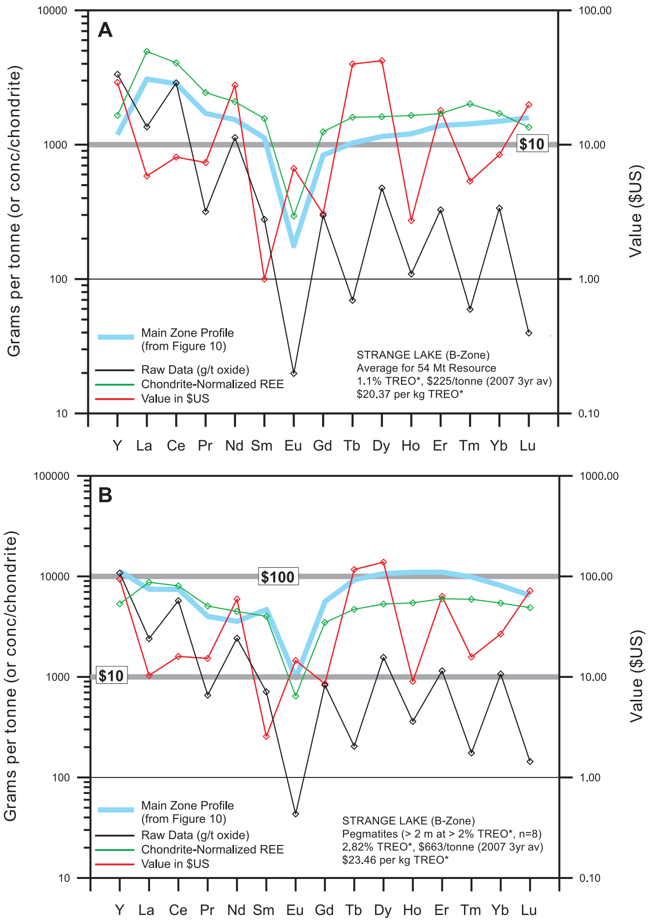

Figure 11. *Average REE contents and valuations of rock types within the B-Zone deposit at Strange Lake, data from Quest Rare Minerals (website information) and Ramsey* et al. *(2010). A) Average values for bulk resource at a tonnage of approximately 50 Mt. B) Average of several analyses from pegmatite sheets >2 m in thickness and containing >2% TREO* within the B-Zone. Equivalent chondrite-normalized data from the Main Zone deposit are illustrated for comparative purposes. Chondritic normalization and REE price assumptions are the same as for Figure 2.*

Discussion

Strange Lake was once described as *the largest deposit of yttrium in the world* (IOC, 1985). Given the Y–HREE association, it follows that it should also contain a large resource of the latter. Exploration by Quest Rare Minerals in adjacent Québec has amply demonstrated this potential. Although detailed information on REE in the Main Zone deposit remains to be gathered, recent findings approximately triple the total REE resource in the Strange Lake Intrusion. There is also a potentially large low-grade resource represented by the exotic-rich granite unit itself, which has so far only been defined within a few tens of metres of the surface, but extends to at least 300 m below the surface. There may be subtle differences between the Main Zone deposit and the B-Zone deposit, but their REE profiles are remarkably similar, and they are obviously closely related ore-forming systems. The REE mineralization at Strange Lake is relatively enriched in HREE, and in this respect stands out amongst Canadian REE deposits, including Nechalacho in the NWT, with which it has often been compared. Its HREE inventory is also significant amongst its global analogues. The distribution of Zr, Y and Nb amongst various minerals at Strange Lake is well-established from the 1980s IOC work, but there is far less information concerning the distribution of the REE. The strong Y-HREE correlation suggests that the still unnamed Ca–Y-silicate that carries most of the Y also hosts significant HREE. However, the LREE may have a much more complex distribution that may vary from place to place. Nevertheless, metallurgical research initiated by Quest Rare Minerals is reported to be successful, with acceptable recoveries for most of the REE. Mineralization at Strange Lake contains associated radioactive elements (up to 0.18% ThO_2 and 0.02% U_3O_8 in the Zone 1 lens; IOC, 1985) and these were recognized as potentially problematic in previous processing investigations. There is presently only limited information on the U and Th contents of bulk resources, or on the size of any potential U resource.

The preliminary economic analysis completed for Quest Rare Minerals (Ramsey *et al.*, 2010) for the B-Zone deposit also gave favourable conceptual results, and there is no reason to suppose that these would not also apply to the Main Zone deposit, given its similar size and grade. The Zone 1 lens, which probably has double the TREO* grade of bulk resources in either deposit, remains the most valuable component within this larger system, and the definition of a similar high-grade, near-surface ‘nugget’ within the B-Zone was stated as the next objective in the exploration program in Québec (Quest Rare Minerals, Press Release, September 16, 2010).

There are many interesting geological issues to consider, aside from those related to mineralogy. These include the potential for other near-surface deposits, or for high-grade mineralization at depth. The distribution of the exotic-rich granite, which could represent a large bulk resource, is particularly important. This granite comes to surface mostly in the area of the Main Zone deposit, but may be at depth elsewhere, perhaps including regions beneath the B-Zone. Models suggest that this phase of the Strange Lake Intrusion was the ultimate source for high-grade pegmatite and aplite zones that constitute the Zone 1 lens and parts of the B-Zone. These could be present in many areas of the subsurface, and there are presently no reliable geophysical techniques that could detect them in such situations. For example, could there be a physical connection between pegmatite

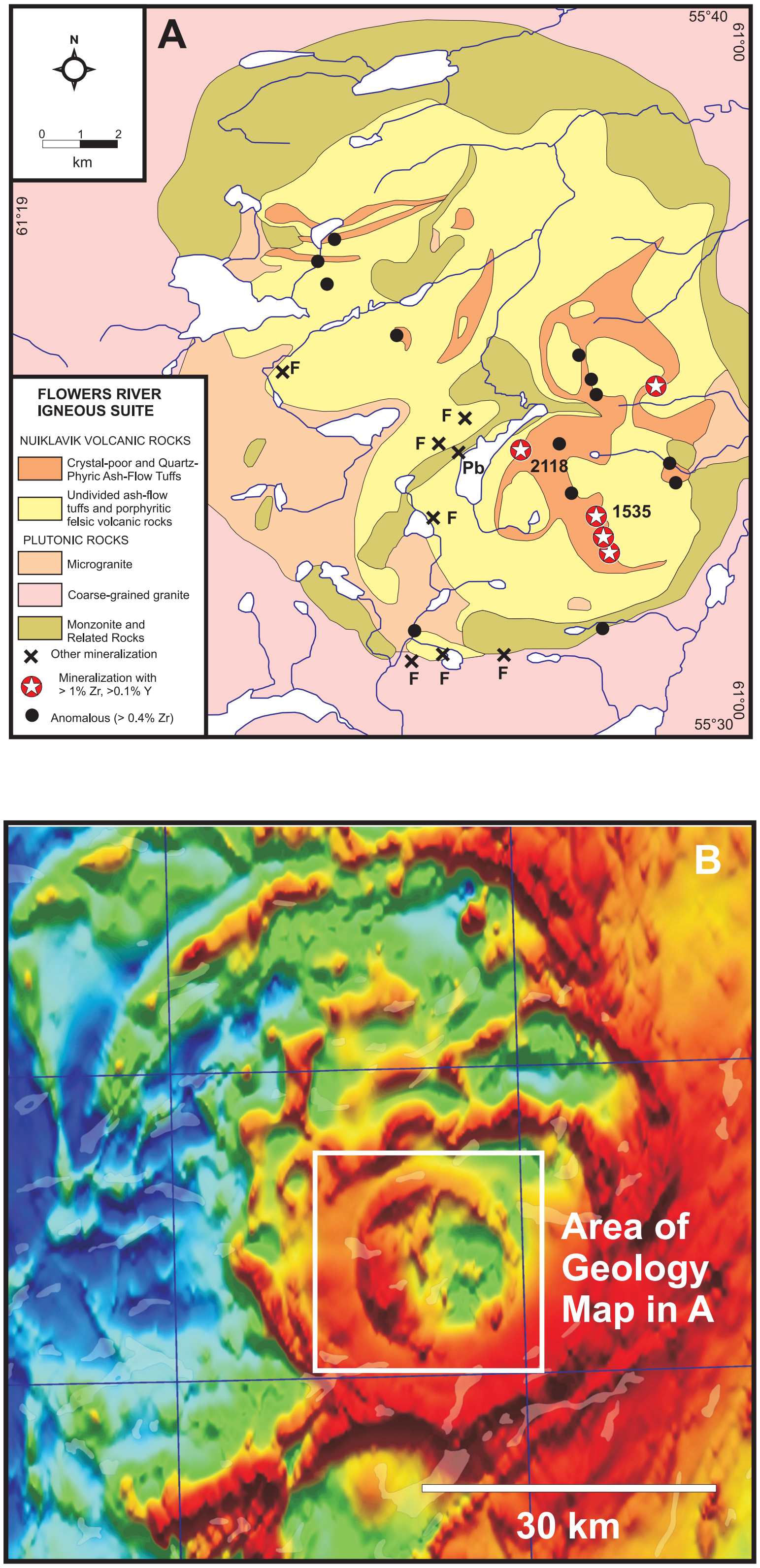

Figure 12. *A) Simplified geological map of the Flowers River Igneous Suite, and the volcanic rocks of the Nuiklavik area, showing the locations of zones containing Zr-Y-Nb-REE mineralization. Adapted from Hill (1982), and Miller (1988, 1992). B) Aeromagnetic map for the volcanic rocks and surrounding area, showing the striking annular anomalies suggestive of ring-complexes. Image prepared by G. Kilfoil at GSNL.*

sheets at the B-Zone in Québec and those in the Zone 1 lens in Labrador? Although REE deposits are generally considered best amenable to open-pit mining, underground mining is proposed for some, including Nechalacho, and the very high *in-situ* value of some pegmatite-hosted mineralization, places it in the same league as gold ores containing > 1 ounce per tonne.

FLOWERS RIVER IGNEOUS SUITE

Location and Exploration History

The Flowers River Igneous Suite is the most extensive tract of peralkaline igneous rocks in Labrador (Figure 1), and includes plutonic rocks (mostly granites and syenites) with related peralkaline volcanic rocks. The area was examined briefly in the 1950s by Brinex, but saw no further exploration until 2006, when it attracted interest for uranium. Minor base-metals, fluorite and radioactivity were noted during regional mapping in the late 1970s (Hill, 1982). Altius Minerals completed some initial exploration work in the area from 2006 to 2008, and located several new zones of radioactivity. In 2010, the claims covering the volcanic rocks, which host most known mineral occurrences, were sold to Rare Element Resources. Corporate information suggests that new REE showings were investigated by Altius, containing up to 1.3% Y_2O_3 and 1.1% TREO, associated with up to 2.3% ZrO_2 and 1.1% Nb_2O_5 (Altius Minerals, website information). Rare Element Resources has not released additional information, and there was no exploration program in 2010. The area was not visited by the author in 2010, and discussion here is based on published information, notably Miller (1992, 1993, 1994).

Overview of Geology and Mineralization

The Flowers River Igneous Suite is described by Hill (1982), and discussed by Collerson (1982), Hill and Miller (1990) and Hill (1991). The most extensive rock types are granites and syenites, including both subalkaline and peralkaline compositional types. Early U–Pb geochronological data (discussed by Hill, 1991) suggest their emplacement at ~1270 Ma. The granitoid rocks are enriched in Zr, Y, Nb and REE (Hill, 1982) and are potential targets for REE mineralization that still remain largely unexplored. They were emplaced as overlapping ring-complexes, and give rise to prominent circular magnetic anomalies (Figure 12). The Nuiklavik volcanic rocks are preserved in an area of high topographic and magnetic relief interpreted to represent a caldera structure (Hill, 1982, 1991; Miller, 1992; Figure 12). The volcanic rocks are dominated by ash-flow tuffs and other pyroclastic rocks, rather than flows, and have a well-defined stratigraphy (Miller, 1992, 1993). The U–Pb data from quartz-feldspar porphyry within the sequence provided ages of 1289 ± 2 Ma and 1293 ± 3 Ma (Krogh, 1993). Hill (1982) and McConnell (1984) reported minor mineral occurrences, including Pb–Zn sulphides, pyrite, molybdenite and fluorite, and also zones of anomalous radioactivity. Miller (1993) described several zones enriched in Zr, Y, Nb and REE, hosted by crystal-poor and quartz-phyric ash-flow tuff units in the upper part of the volcanic sequence (Figure 12). Mineralization is closely associated with anomalous radioactivity, and appears to be stratabound, although some is reported to be in dykes, rather than bedded rocks (Rare Element Resources, website information, 2010). Several samples from previous GSNL work (Miller, 1993) contained >1% Zr, associated with anomalous Y (1000-2000 ppm) and enrichment in the LREE La and Ce (up to 2500 ppm Ce). The La and Ce enrichment is also present in other samples that have lower (<0.5%) Zr contents. The mineralization was suggested to be broadly synvolcanic and magmatic in origin, although related hydrothermal processes may be important (Miller, 1993). There is evidence for Na-depletion in the felsic volcanic rocks, but the link between this process and REE mineralization is not clear (Miller, 1994). The REE patterns for selected mineralized samples (archived GSNL data) show moderate TREO* values (~0.4 to 1%), but samples are relatively enriched in HREE, with relatively high values per kg of TREO* (Figure 13). This valuation suggests that material containing closer to 1% TREO* would approach the per-tonne value of the bulk Strange Lake resource. Interest in this area was initially driven by the potential for volcanic-hosted U deposits, but there is presently no direct information on U contents of mineralized zones; they contain up to 400 ppm Th (Miller, 1993).

Discussion

The Flowers River Igneous Suite is one of the most obvious targets for REE mineralization in Labrador, but has not received exploration attention commensurate with its potential. Miller (1993, 1994) ranked it highly, and the Nuiklavik Caldera can perhaps be visualized as a less-eroded version of a high-level ring-complex akin to that represented by the Strange Lake Intrusion. The REE profiles for known mineralization also suggest the potential for relative enrichment in the HREE, although not quite to the extent seen at Strange Lake. Detailed work on the volcanological evolution of the complex was outlined by Miller (1994) but never published in an integrated fashion. This information could be very important in assessing the REE potential of other peralkaline volcanic suites, such as late Precambrian rocks in the Avalon Zone of Newfoundland. As in the case of most sites of REE mineralization, there is little information on the mineralogical aspects, but Miller (1993) suggested that REE-bearing minerals were very fine grained and distributed in the matrix of ash-flow tuffs, implying a syngenetic origin.

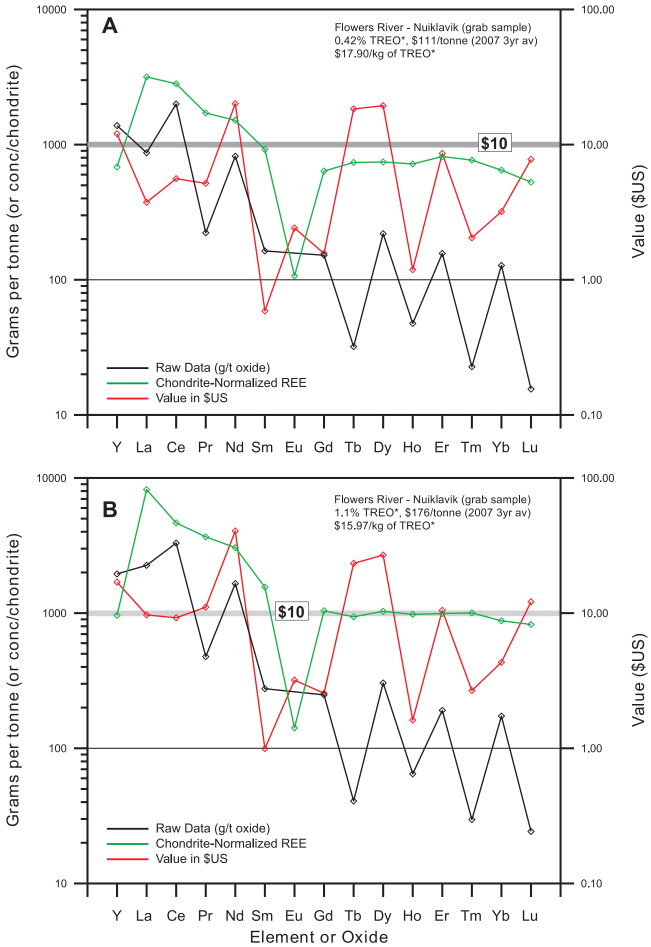

Figure 13. *Average REE content and valuation of samples from two mineralized zones in the Nuiklavik volcanic rocks, Flowers River Igneous Suite, archived GSNL data. A) Sample 1535 (*see *Figure 12 for location). B) Sample 2118 (*see *Figure 12 for location). Chondritic normalization and REE price assumptions are the same as for Figure 2.*

SOUTHEASTERN LABRADOR (PORT HOPE SIMPSON AREA)

Location and Exploration History

This area is the site of an early stage exploration project that has given interesting initial results in an area not previously known for REE or RM mineralization. In contrast to other areas discussed earlier, there is good infrastructure, including a road network. The area is underlain by largely metamorphic rocks of the southeastern Grenville Province. As noted in a recent review by Gower (2010), this region is *unexplored, rather than merely underexplored*. However, there was interest in its uranium potential from 2005 to 2008, and some drilling was completed in the area northwest of Port Hope Simpson (Figure 1). Other radioactive zones discovered by local prospectors during that period later attracted interest for REE–Zr–Nb mineralization. Meyer and Dean (1988) noted a radioactive mylonite zone on the coast near Fox Harbour (Figure 14), and reported high Zr (3.4%) combined with anomalous Ce, Yb, Th and U. A sample collected from a nearby location during mapping in 2003 contained 1.6% Zr, 1100 ppm Y, 1270 ppm La and 2170 ppm Ce (Gower, 2010; Figure 14). Exploration by Search Minerals commenced with the assembly of a large land package in 2009 covering regional lake-sediment anomalies for several incompatible elements. Subsequent airborne geophysical surveys and prospecting in 2009 revealed numerous radiometric anomalies. Evaluation continued in 2010, culminating in a drilling program that is still in progress as of writing. The results suggest the presence of at least two types of REE mineralization.

Overview of Geology

This area sits along the boundary between two fundamental lithotectonic blocks within the southeastern Grenville Province, namely the Lake Melville Terrane in the north, and the Pinware Terrane in the south (Figure 14). In this area, the Lake Melville Terrane is a narrow belt of strongly deformed rocks (Gilbert River Belt), characterized by dextral shear zones and strong deformation (Gower *et al.*, 1987, 1988; Gower, 1996). The rock types are dominated by ~1680 to ~1640 Ma orthogneisses (mostly derived from K-feldspar megacrystic granodiorite and granite), and lesser amounts of (older?) paragneisses, and strongly deformed mafic to anorthositic rocks (Gower, 1996; Figure 14). The Pinware Terrane also includes some metasedimentary gneisses, but is dominated by ~1500 to ~1470 Ma igneous rocks, some of which have transitional alkali-calcic to alkaline compositional traits, and lesser layered mafic intrusions (Gower, 1996; Figure 1). Posttectonic plutonic suites (~970 to ~950 Ma) form prominent circular intrusions within the Pinware Terrane, but are absent from the Lake Melville Terrane. However, syenitic rocks of ~1300 Ma age occur within the latter, and minor intrusive rocks with ages of ~1100 Ma to 1000 Ma are also documented (Gower, 1996). The detailed geology of the area is very complex, and beyond the scope of this review; readers are referred to recently released geological maps (Gower, 2010) and Gower (1996) for more complete discussions.

Two minor geological units are of interest in the context of REE mineralization. The first consists of fine-grained, strongly foliated, banded quartzofeldspathic gneisses that form several narrow belts extending inland from the Fox Harbour–St. Lewis area, close to the southern edge of the Lake Melville Terrane (Figure 14). These units are surrounded by the foliated porphyritic granite to augen gneiss that dominates the area and are interpreted to be metamorphosed peralkaline volcanic rocks (Search Minerals, Press

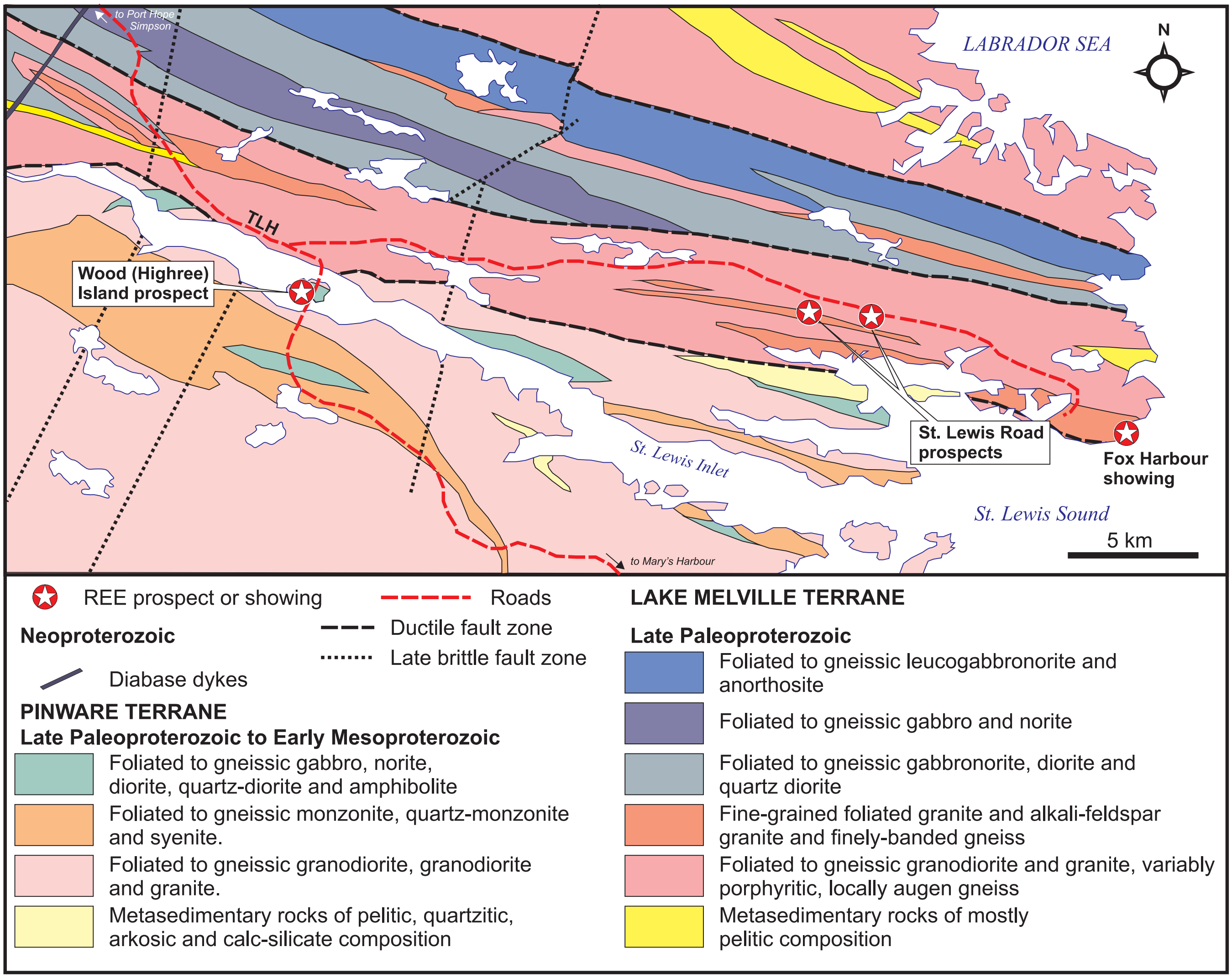

Figure 14. *Simplified geological map of the area St. Lewis Inlet, located between Port Hope Simpson and Mary's Harbour in southeastern Labrador, showing the locations of newly defined REE mineralization. Geology adapted from Gower (2010).*

Release, July 27, 2010). However, they could also represent intrusive sheets or dykes that have been rotated to lie parallel with the prominent shear zone trend (C. Gower, personal communication, 2010). The fine-grained gneisses have not been dated, although they have generally been assumed to be of ~1650 Ma age. The other rock unit of interest consists of pegmatites, which are abundant throughout the region, but have not been studied in detail. Several generations of pegmatites exist, and some host minor sulphides, including molybdenite, whereas others contain fluorite, amazonite feldspar and the REE-bearing mineral allanite (Gower, 2010). Various ages of pegmatites are known in eastern Labrador, including those of Grenvillian (1085–985 Ma) age. Pre-syn and late-tectonic ages (with respect to Grenvillian orogenesis) have been noted.

Mineralization

Two main types of REE mineralization are reported by Search Minerals in this area, but these are spatially associated on a regional scale (Figure 14) and hosted by the strongly deformed metamorphic rocks along the Lake Melville Terrane–Pinware Terrane boundary. These types are referred to by the company as the 'Fox Harbour type' and 'Island type', respectively.

The fine-grained, strongly foliated, banded quartzofeldspathic gneisses located in the area west of St. Lewis show regional enrichment in Zr, Nb and Y, and locally host significant mineralization, including REE (Gower, 2010; Search Minerals, Press Release, July 27, 2010). The rocks are anomalously radioactive, but high grades do not correspond with the strongest individual responses. Individual prospects are now defined in an area not far from where Gower (2010) reports anomalous Zr, La and Ce from roadside outcrops (Figure 14). Superficially, these mineralized rocks are unremarkable (Plate 6A, B), and show no signs of hydrothermal alteration, implying that Zr- and REE-bearing minerals are an integral component of their host rocks and thus likely syngenetic. The radioactive 'mylonite' of Meyer and Dean (1988) near Fox Harbour likely also represents this unit although this exact location proved difficult to relocate during exploration. Some of the mineralized zones are associated with prominent magnetic anomalies that may provide an additional prospecting tool. The grades of grab samples are variable, but locally exceed 1% TREO*, associated with high Zr (>1.3%). The REE profiles for averages of several samples reflect this general pattern, with La, Ce and Nd contributing most of the potential value (Figure 15A; data from Search Minerals, Press Release, July 27, 2010). Although the *in-situ* value of mineralized samples is modest, these grades are of interest, especially as prospecting work suggests that mineralization has significant strike extent and predictable geometry. Channel sampling and drilling to better define these zones were completed in late 2010, but results have yet to be released. Some of the zones remain untested by drilling.

The REE mineralization associated with pegmatites has distinctly different characteristics. The main location for this style of mineralization is on Wood Island in St. Lewis Inlet (known by the company as Highree Island), closely adjacent to the Trans-Labrador Highway (TLH, Figure 14). The bedrock geology of the island is complex, including several types of granitoid orthogneiss, and also amphibolitic rocks of mafic to intermediate composition. These are cut by several generations of pegmatite, including radioactive types and spectacular coarse-grained rocks that contain green amazonite feldspar, pyrite and molybdenite. The roadcut on the island is documented as a pyrite–molybdenite showing and is described by Gower (2010). Quartz-rich, and locally magnetite-bearing, pegmatites (Plate 6C, D) that are radioactive generally return high REE contents upon assay, but not all radioactive pegmatites are associated with elevated REE. The REE-bearing pegmatites contain a dark mineral that shows distinctive yellow-green weathering (Plate 6D), and this is as yet unidentified. However, visible/infrared reflectance spectrometry data show distinct absorption features related to the presence of REE (Kerr *et al.*, *this volume*). Locally, dense swarms of REE-bearing pegmatites dissect the country rocks. Mineralization of this type is difficult to assess by sampling, but grab samples of pegmatites (by Search Minerals) indicated high TREO*, up to 5%, and high abundances of Y and HREE (Search Minerals, Press Release, July 27, 2010). The REE patterns defined by these samples indicate strong enrichment in HREE, such that the chondrite-normalized patterns are almost flat in shape, and this material has a high value per-kg of TREO* (Figure 15C). However, such analyses are likely not representative of bulk materials. Channel samples from the island (Search Minerals, Press Release, October 21, 2010) have lower TREO* values (0.4 to 0.9%) but retain high *in-situ* valuation (Figure 15B); the REE patterns are similar to those from isolated pegmatite veins, suggesting that the wallrocks do not contribute significant REE. High Zr (up to 1.7%) and Nb (up to 0.7%) are associated with some channel samples, but the distribution of these elements is more erratic than for the REE. A drilling program was completed on Wood (Highree) Island in late 2010, but results have yet to be released. Search Minerals has also reported the discovery of similar HREE-enriched mineralization at other locations in the project area, including adjacent parts of the Pinware Terrane (Search Minerals, Press Release, November 2, 2010), but full details of these findings or locations have yet to be released.

Discussion

Exploration in this area remains at an early stage, but the findings are significant because they draw attention to the Grenville Province, and highlight its potential, despite lack of exploration. The combination of spatially associated LREE and HREE-enriched mineralization subtypes is also interesting, and the grades encountered in both are noteworthy. The pegmatite zones and masses discovered on Wood (Highree) Island and at other locations have some of the highest grades and per-kg TREO* values of any mineralization discussed in this article, and material of this kind can sustain significant dilution by barren wallrocks. The detailed results of drilling will document the extent and continuity of such mineralization, but grade estimation in this setting may be a challenge, as pegmatite distribution may be irregular. As for other areas, there is presently no information on the mineralogical controls of REE abundance or their distribution in either type of mineralization. The LREE-enriched mineralization encountered in the St. Lewis area is generally low in grade, but its probable syngenetic nature implies that documenting its extent and bulk characteristics will be easier. Associated radioactivity suggests high Th contents in the HREE-enriched pegmatite material, but the radiometric response of LREE-enriched rock types is muted, which is the opposite of the usual pattern.

The age and affinity of the host rocks to both types of REE mineralization remain unclear. The REE-rich pegmatites at Wood (Highree) Island and elsewhere are clearly late- to posttectonic, and are perhaps linked to Pinwarian (1520–1460 Ma) granites or younger posttectonic Grenvillian plutonic rocks that abound in the adjacent Pinware Ter-

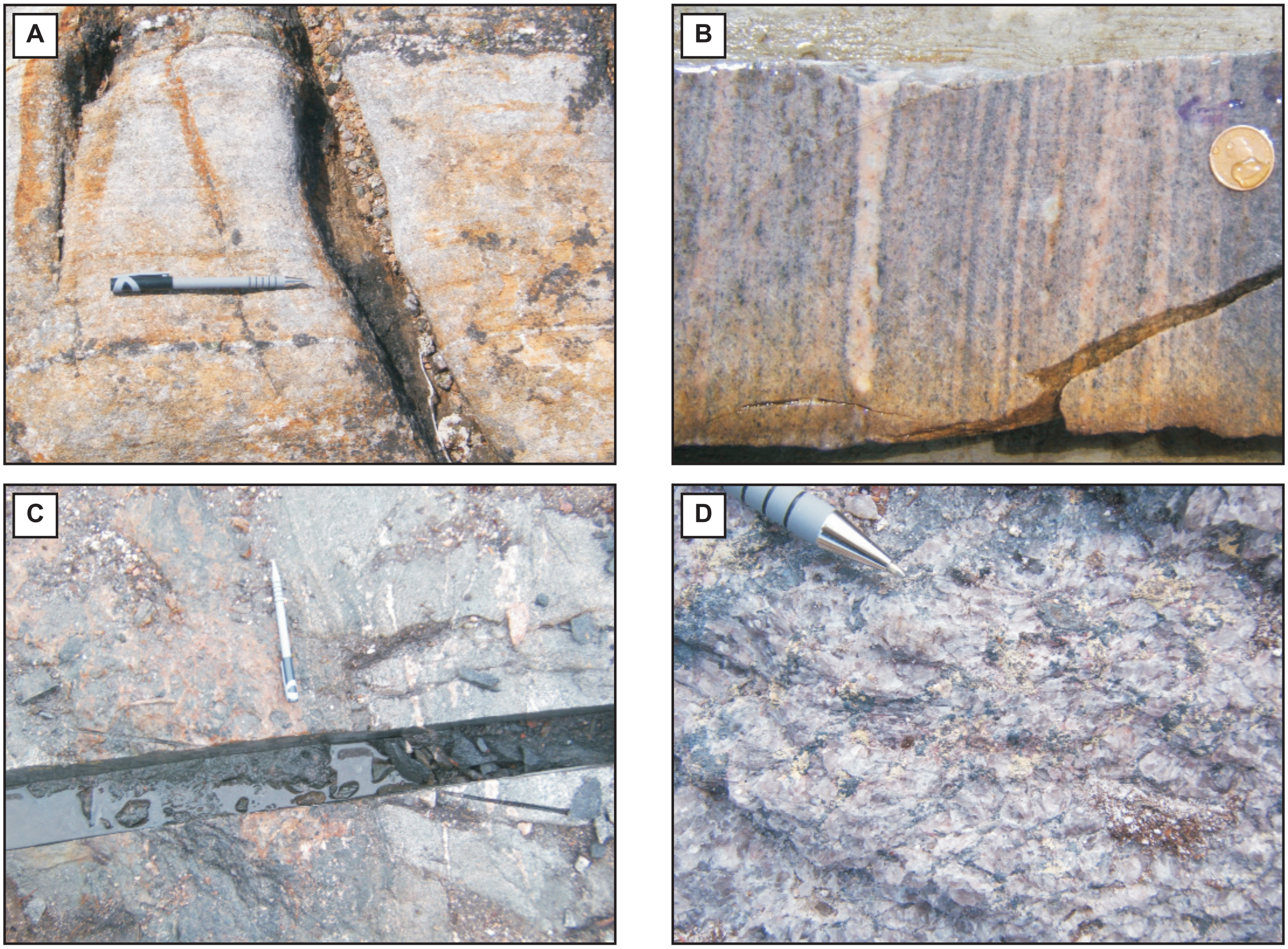

Plate 6. *Rock types and mineralization from the Port Hope Simpson area, southeast Labrador. A) Fine-grained, banded quartzofeldspathic gneiss containing REE mineralization, near the St. Lewis access road. B) Detailed view of channel sample, showing the fine-scale banding. C) Contact zone between mineralized pegmatite (left) and amphibolitic host rock (right) at the Wood (Highree) Island prospect; the pen marks the contact zone. D) Close-up view of mineralized quartz-rich pegmatite zone on Wood Island, showing the yellow-weathering mineral suspected to host the REE in this area.*

rane. The quartzofeldspathic gneisses that host mineralization near St. Lewis are of unknown age and uncertain protolith. If they are derivatives of igneous rocks, a Mesoproterozoic age is probable, as deformed examples of such occur in a deformed state elsewhere within the Lake Melville Terrane (*e.g.*, the North River Syenite; Gower, 1996). It is presently unclear if these gneisses are truly of peralkaline composition, but their major-element geochemistry may have been disturbed through metamorphism. All of these questions present interesting avenues for future research.

LABRADOR–QUEBEC BORDER: STRANGE LAKE TO LAC RAMUSIO AREA

Location and Exploration History

The Labrador–Québec border area in north-central Labrador (Figure 1) is poorly known, and most geological maps for Labrador are derived from reconnaissance work in the early 1970s (Taylor, 1979), although some parts of Québec were mapped more recently (Bélanger, 1984). The area is attracting exploration, in part, due to results from

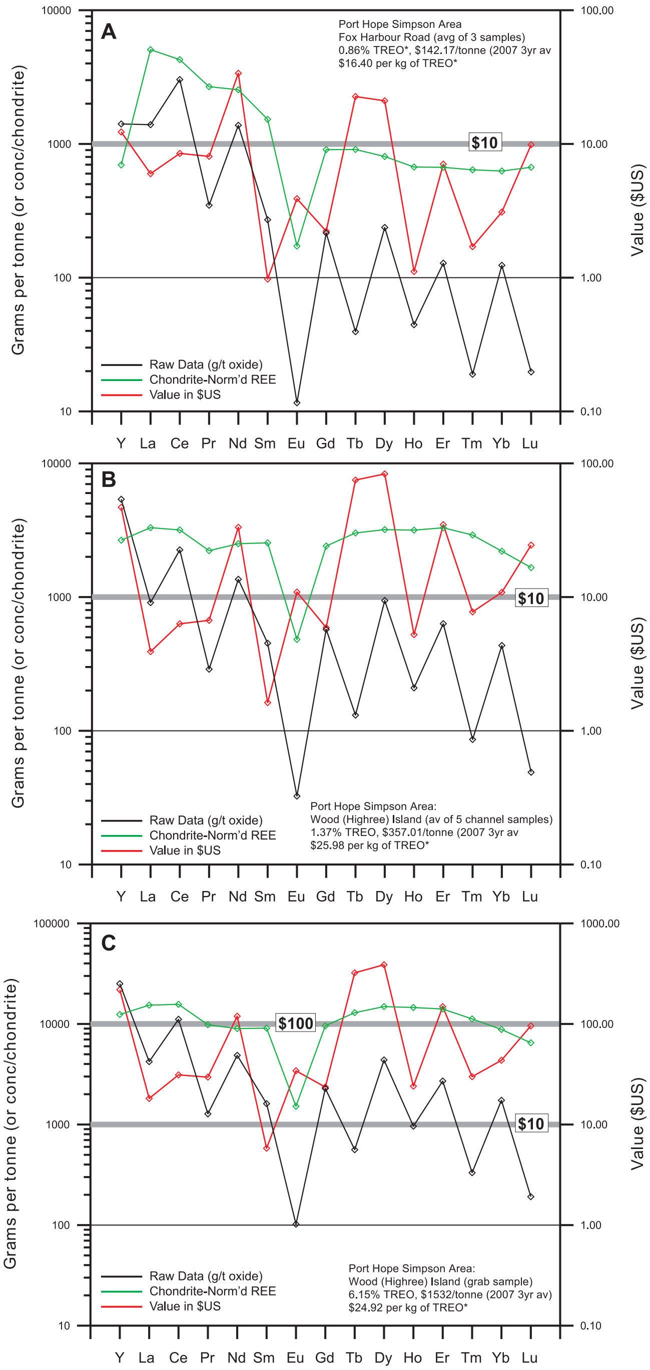

Figure 15. *Average REE contents and valuations of prospects in the Port Hope Simpson area, data from Search Minerals (Press Release, August 26, October 21, 2010). A) Average values for mineralized grab samples from the Fox Harbour - St. Lewis area. B) Average of several channel samples from the Wood (Highree) Island prospect. C) Analyses of an individual pegmatite zones at the Wood (Highree) Island prospect. Chondritic normalization and REE price assumptions are the same as for Figure 2.*

regional geophysical surveys completed by the GSC GEM program, which defined radiometric anomalies in the Lac Ramusio area. New lake-sediment data in adjacent Québec also point to potential targets, and the prominent ring complex identified at Misery Lake is now the site of exploration program aimed at REE (*see* Quest Rare Minerals website information). In 2010, Midland Exploration investigated two claim blocks located partially or entirely in Labrador, designated as Ytterby 2 and 3 (Figure 1). The company reported REE mineralization on both sides of the border (and exactly on the border) at Ytterby 2, and also several new zones at Ytterby 3, which is entirely within Labrador (Midland Exploration, Press Release, September 23, 2010). No advanced exploration work such as channel sampling or drilling has yet been completed.

Geology and Mineralization

This entire area sits within the Mistastin Batholith, a large Mesoproterozoic intrusion that straddles the border (Figure 1). Rapakivi-textured granites are abundant within it, and occur in both areas (Plate 7). However, there are several other previously unmapped rock types, including older quartzofeldspathic to amphibolitic gneisses, and leucocratic granites of varied texture and appearance. The Ytterby 2 area contains a medium- to coarse-grained red, anomalously radioactive syenite to granite that sits mostly in Québec, but extends locally into Labrador. The Ytterby 3 area contains a coarse-grained syenitic intrusion that sits within a circular magnetic low flanked by a region of high magnetic relief associated, in part, with its metamorphic country rocks (R. Banville, personal communication, 2010). The REE mineralization at Ytterby 2 is associated with a pegmatite–aplite dyke that intrudes rapakivi granite in Labrador, but trend toward the evolved granite unit in adjacent Québec (Plate 7A, B). Grab samples from the Pamela showing contain over 13% TREO*, including 8% Ce_2O_3, 3.4% La_2O_3 and 3.4% Nd_2O_3. Two other zones, one located exactly on the border and the other in Québec, are also associated with the granite (Plate 7C) or its contact regions, and contain up to 1.65% TREO* (Midland Exploration, Press Release, September 23, 2010). The Ytterby 3 area revealed several mineralized zones, locally containing up to 8.3% TREO*. These were undiscovered when the author visited the area, and have not been examined directly; they are reported to be associated with iron-oxide-rich zones (Plate 7D) near the margins of the syenitic intrusion, and to extend laterally for up to 100 m (Midland Exploration, Press Release, September 23, 2010, October 19, 2010). The REE profiles for samples from these showings indicate strong LREE enrichment, notably for La, Ce and Nd, but the overall *in-situ* value of such material is high; there is little docu-

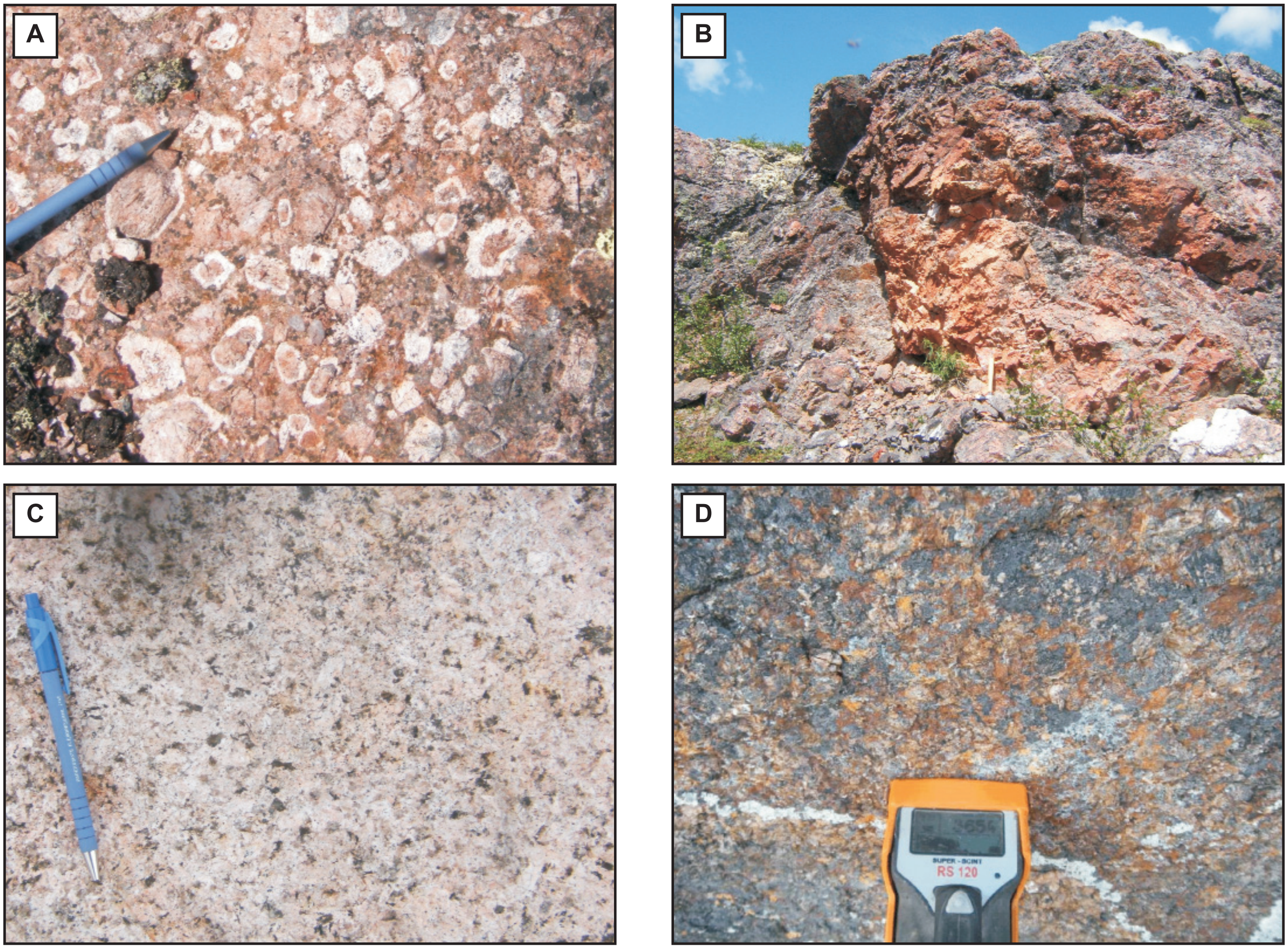

Plate 7. *Rock types and mineralization from the Québec–Labrador border region, south of Strange Lake. A) Typical rapakivi-textured granite that characterizes much of the Mistastin Batholith in this region. B) Mineralized pegmatite–aplite zone (right) cutting rapakivi granite (left) at the Pamela showing on the Ytterby 2 project area. C) Leucocratic, anomalously radioactive, syenite to granite unit located close to the showing, but mostly outcropping within Québec. D). Iron-oxide-rich syenitic rock containing REE mineralization at the Central Zone showing on the Ytterby 3 project area, Labrador; photo courtesy of R. Banville, Midland Exploration.*

mented enrichment in Zr or Nb (Figure 16). The mineralogical context of the REE remains unknown, but the radioactive mineral at the Pamela showing reveals REE-related absorption features in VIRS data (Kerr *et al.*, *this volume*) Portable XRF analyses completed by Midland Exploration confirm that this mineral is strongly enriched in LREE, but do not categorically identify it (R. Banville, personal communication, 2010).

Discussion

The interesting initial results from this short-duration exploration program in a remote area clearly illustrate a deficiency in basic geological knowledge in this hinterland region of Labrador. This entire area is mapped as a single unit, but cursory examination of local geology in the Ytterby 2 and Ytterby 3 areas during 2010 shows that it is much more complex, including older metamorphic rocks and smaller bodies of compositionally evolved syenite and granite. Geological maps for adjacent regions of Québec that have received more recent attention indicate the presence of 'syénogranits alcalins' (Bélanger, 1984) that may also represent this rock type. There is no geochronological information for evolved rocks that seem spatially associated with mineralization, but they intrude the rapakivi granites, and must be late. The mineralization discovered is LREE-enriched, but the grades, notably for Nd, are encouraging. The exploration program here and in adjacent Québec was driven by fundamental tools, notably surficial geochemistry and airborne-radiometric surveys. The results provide a powerful argument for extending regional geophysics and more detailed lake-sediment sampling through this little-known part of Labrador.

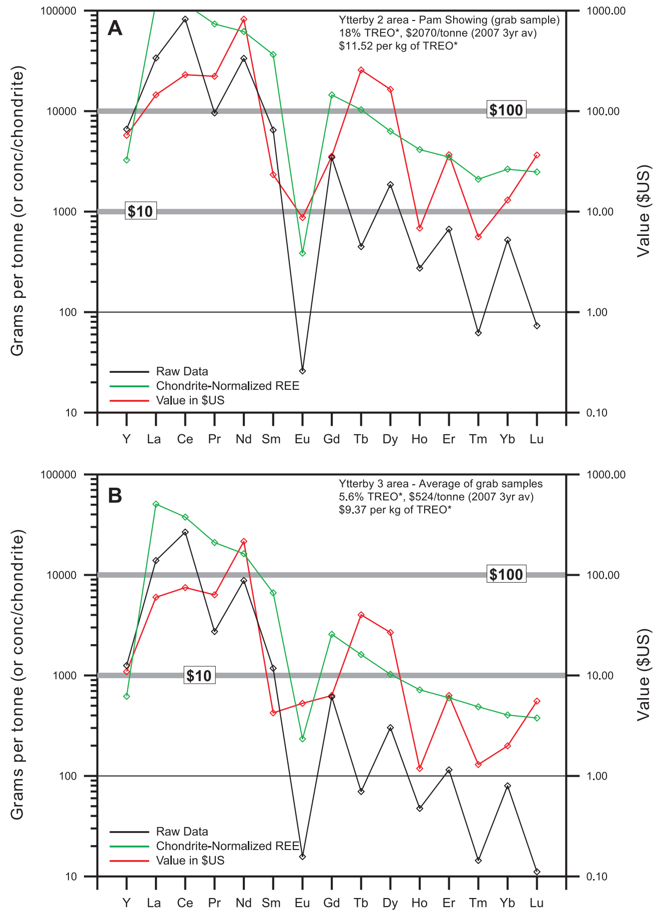

Figure 16. *Average REE contents and valuations of new showings in the Québec–Labrador border region south of Strange Lake, data from Midland Exploration website. A) High-grade mineralization from aplite–pegmatite dyke at the Pamela Showing, Ytterby 2 project area. B) Average of mineralized samples from the Ytterby 3 project area.*

OTHER AREAS OF REE EXPLORATION IN LABRADOR

The preceding sections provide details of the main areas of REE and RM mineralization in Labrador, and results from the most extensive exploration programs of 2009 and 2010. However, the search for REE mineralization is not confined to these areas, and this section briefly summarizes two areas from which interesting preliminary results have recently emerged. These have not been visited by the author, and public-domain information is presently confined to company websites and Press Releases.

Michikamats Area, Central Labrador

This exploration project is located in the Smallwood Reservoir area, close to the Québec–Labrador border (Figure 1). The area is underlain largely by Mesoproterozoic intrusive rocks including the large Michikamau anorthosite intrusion and its associated marginal granite units. One of these, the Michikamats granite, was dated at 1459 ± 2 Ma as part of a regional mapping project (Krogh, 1993). Recent high-resolution aeromagnetic surveys completed through this area as part of the Geo-mapping for Energy and Minerals (GEM) program defined several prominent circular magnetic anomalies thought to represent ring-complexes. The most prominent of these is at Misery Lake in Québec, where Quest Rare Minerals now has an exploration project, but the second most prominent anomaly is located within the Michikamats granite in Labrador. Relatively little is known about this area, but brief visits in 2010 indicate that the magnetic anomaly is associated with relatively homogeneous syenites and monzonites (P. Valley, personal communication, 2010; J. Goutier, personal communication, 2010). The mineral rights are presently held by Fieldex Exploration, but there was no extensive exploration in 2010, and no Press Releases were issued. A map posted on the company website shows sample locations and indicates TREO* results using symbol size and colour. These imply several samples from which values of 0.25% to 0.91% TREO* were obtained. The similarity of the aeromagnetic expression, and the monzonitic to syenitic compositions, may imply a link between the Michimikats and Misery Lake areas, and the rock types are described as visually similar (J. Goutier, personal communication, 2010).

Popes Hill Area, South-central Labrador

This exploration project is located a short distance west of the Happy Valley–Goose Bay (Figure 1), adjacent to the Trans-Labrador Highway and was initially explored for uranium in 2006. Analysis of samples at that time indicated that radioactivity was mostly linked to thorium. Reanalysis of samples in 2010 indicated high REE contents in many, with values up to 7.9% TREO* (Silver Spruce Resources, Press Release, October 28, 2010). The host rocks are sheared and altered orthogneisses of presumed Paleoproterozoic age, within the Grenville Province. The REE enrichment is reported to be associated with enrichment in magnetite and minor sulphides. Subsequent exploration work in late 2010 and early 2011 included additional sampling and prospecting, ground geophysical surveys and reconnaissance diamond drilling. No results have yet been released from drilling, but assay data from grab samples posted on the company website indicate a wide range in TREO* values ($<$ 1% to $>$ 20%) and that the LREE (notably La, Ce and Nd) are present in most abundance. The average values for La (1.26%), Ce (2.54%) and Nd (0.92%) represent most of the potential value of the mineralization, but Dy contents of almost 800 ppm are also significant. The company also recently released preliminary information from a preliminary mineralogical study suggesting the presence of REE-enriched titanite and apatite, and noting also the presence of monazite and allanite (Silver Spruce Resources, Press Release, February 22, 2011). The drilling program is still in progress as of writing.

CONCLUDING REMARKS

Historical exploration for rare-metals (RM) over 50 years and the more recent quest for rare-earth elements (REE) demonstrate that Labrador contains potentially important resources of both, and includes favourable geological environments that are underexplored or unexplored. The REE potential of zones known previously for Zr, Nb and Be is now confirmed, but assessment of their resource potential requires more detailed work. The high level of exploration, since 2008, provides much new data in the form of geophysical surveys and assay results, and also creates new material for research studies, notably in the form of trench exposures and drillcore. There are many possible avenues for research that could aid in the assessment of these deposits, and in exploration for their undiscovered counterparts. There is an absence of information concerning mineralogical controls on the REE in these deposits, and this topic is far from academic, as it has implications for the feasibility of processing should adequate resources be defined. Even at Strange Lake, which has a long history of study, the distribution of REE is only partly understood. On a wider scale, there is great scope for structural and metamorphic studies on deposits within the Grenville Province, and for isotopic and geochemical studies to better define the timing and genesis of host igneous suites in all areas. Deposits in Labrador all seem to be associated with peralkaline igneous suites of known or presumed Mesoproterozoic age, but other types of REE deposits may also represent valid targets. For example, there is a common spatial and genetic association between peralkaline magmatism and carbonatites. Carbonatites are known in most other parts of the Canadian Shield, but have never been reported in Labrador, which is puzzling. These rocks are harder to recognize than one might suppose, particularly in metamorphosed terranes such as the Grenville Province. There are also high-grade vein-style REE deposits in other areas (*e.g.*, Hoidas Lake in Saskatchewan) that may represent additional exploration models.

In the final analysis, exploration is pragmatic, and understanding the tools that can be used in the search is just as important as understanding the nature of the target. This article emphasizes geological aspects of deposits, rather than exploration methods. Several geophysical and surficial geochemical exploration techniques are potentially valuable in regional REE exploration, and these aspects remain to be covered elsewhere. The contribution of regional lake-sediment geochemical data to early stage exploration projects in the Grenville Province, and in the Québec–Labrador border region, is cited here as the most obvious example. Improved knowledge of the geology of REE deposits in Labrador, and improved understanding of effective exploration techniques in the local context, will hopefully coalesce in future years, and allow us to find new and perhaps unexpected places where rare earths can be unearthed.

ACKNOWLEDGMENTS

This article is based on compilation of published and unpublished historical information, combined with limited field work in 2010. The long-term contributions of Randy Miller at the GSNL in the 1980s and 1990s are acknowledged as important sources. Exploration companies active in Labrador during the summer of 2010, notably Midland Exploration, Rare Earth Metals Inc. and Search Minerals, are thanked for their assistance and hospitality, and for comments on the contents of this article. Robert Banville, Randy Miller, Glenn Penney and Wayne Reid are thanked for their input. Pat Collins of Quest Rare Minerals is thanked for discussion of the Strange Lake deposit and recent exploration in adjacent Québec. Heather Rafuse at the GSNL is thanked for invaluable help in tracking sometimes obscure information, and for assistance in the interpretation of data. Finally, Bruce Ryan is thanked for providing many comments and suggestions that improved the text and illustrations for this article.

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