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# PRELIMINARY INVESTIGATION OF RARE-EARTH-ELEMENT MINERALIZATION, FOX HARBOUR VOLCANIC BELT, SOUTHEASTERN LABRADOR

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## ABSTRACT

*Rare-earth-element (REE) mineralization in the Port Hope Simpson area is hosted in the* ca. *1.3 Ga Fox Harbour Volcanic Belt (FHVB), similar in age to other peralkaline complexes associated with REE mineralization in Labrador, including the Strange Lake and Flowers River complexes, and the Red Wine Intrusive Suite. The objective of this multi-year project is to examine the genesis of the REE mineralization within the FHVB, compare the FHVB to the other peralkaline complexes in Labrador, and assist further exploration efforts for this type of deposit. Mineralization within the FHVB was discovered by Search Minerals Incorporated in 2010, and is presently in an advanced stage of exploration; however, details on the genesis of the mineralization remain uncertain. Field work, followed by preliminary petrography and Scanning Electron Microscope (SEM) analysis have revealed some of the REE-mineral associations and textures, highlighted significant differences within the FHVB, and defined research aspects for further work.*

*The FHVB is a 64-km-long belt ranging in width from 50 m in the west to 3 km in the east. It is subdivided into the Road Belt, Magnetite Belt and South Belt, running parallel to each other. The Road Belt extends through the entire length of the FHVB, whereas the Magnetite and South belts only occur in the east. The main lithologies in the eastern part of the FHVB (EFHVB) include pantellerite, comendite, non-peralkaline rhyolite, mafic to ultramafic volcanic rocks, minor volcaniclastic sedimentary rocks and quartzite. The rocks in the western part of the FHVB (WFHVB) are trachitic and more mafic (up to 40% mafic minerals) than the rocks in the EFHVB. All the rocks are metamorphosed to amphibolite facies and are strongly deformed. The style of deformation varies along the FHVB. Foliations in the EFHVB trend west-northwest–east-southeast and dip steeply to the north or south. The plunge of folds changes from east in the southern part of the EFHVB to west in the northern part of the EFHVB. Foliations in the western part of the FHVB trend northwest–southeast and dip steeply to the northeast, and there is more than one generation of pegmatites and more than one deformational event with differing orientations.*

*Most of the known medium- to high-grade REE mineralization occurs in the Road and Magnetite belts. The main ore minerals are allanite, which hosts most of the light REE (LREE), and fergusonite, hosting the heavy REE (HREE) and minor amounts of LREE. The REE minerals are spatially associated with zircon, mafic minerals (amphibole and biotite), and locally magnetite, titanite and apatite. In the EFHVB, higher grade mineralization is hosted in pantellerite and lower grade mineralization is hosted in comendite.*

*The rocks hosting REE mineralization at the HighREE Island occurrence, located ~5 km south of the FHVB, may represent the intrusive and subvolcanic equivalent of the FHVB. The host rocks are peralkaline, but relatively coarser grained, and are also metamorphosed and strongly deformed. Foliations in the HighREE Island occurrence are highly variable and there are several generations of pegmatites and deformational events that have differing orientations. Mineralization occurs in dykes and veins or locally hosted in pegmatites and intermediate rocks.*


## INTRODUCTION

This paper summarizes field and subsequent analytical work completed during the first year of a multi-year project directed to REE mineralization in the Port Hope Simpson–St. Lewis area, southeastern Labrador. The project is funded by the Geological Survey of Newfoundland and Labrador (GSNL) and the Geological Survey of Canada (GSC) through a Targeted Geoscience Initiative (TGI) project, and is being undertaken in collaboration with Search Minerals Incorporated.

Rare-earth-element (REE) mineralization is hosted in *ca.* 1.3 Ga peralkaline volcanic rocks of the Fox Harbour Volcanic Belt (FHVB) that are similar in age to other REE-mineralized Mesoproterozoic peralkaline complexes in Labrador including the Strange Lake and Flowers River complexes and the Red Wine Intrusive Suite (Miller *et al.*, 1997; Crocker, 2014; Ducharme *et al.*, 2021). This project anticipates advancing the understanding of the genesis of REE deposits hosted in peralkaline rocks, which have the potential to become a significant source of REE. These deposits are enriched in both heavy REE (HREE) and light REE (LREE) and may be more beneficial for REE mining and processing compared to the REE deposits hosted in carbonatites and ionic clay that are currently mined (Dostal, 2016; Goode, 2021).

In the Port Hope Simpson–St. Lewis area, REE mineralization was discovered by Search Minerals Incorporated in 2010, and is currently in an advanced stage of exploration. However, the genesis of the mineralization is uncertain, and along with excellent access to the mineralized zones, as well as easy access to full suites of mineralized units, make the occurrences ideal candidates for detailed study. The project will examine the age, chemistry, mineralogy, REE mineralization, crustal source, and the tectonic setting of the rocks hosting mineralization in order to better understand the processes that led to the mineralization, with the aim to assist further exploration for this type of deposit.

## REGIONAL GEOLOGY

The FHVB is located in the Grenville Province in eastern Labrador, which is composed of late Paleoproterozoic to Mesoproterozoic rocks formed *via* multiple orogenic and related events including the Eagle River orogenesis (1810–1775 Ma), Labradorian orogenesis (1710–1600 Ma), Pinwarian orogenesis (1520–1460 Ma), post-Pinwarian–pre-Grenvillian events (1460–1090), Grenvillian orogenesis (1090–920 Ma), and Neoproterozoic and Phanerozoic events (Gower, 2019). The Grenville Province in eastern Labrador is subdivided into five terranes, namely, from north to south: the Groswater Bay, Lake Melville, Hawke River, Mealy Mountains and Pinware terranes (Figure 1; Gower, 2019). The REE occurrences are located in the Mealy Mountains, Lake Melville and Pinware terranes, which are described in detail below. The terranes are distinguished from one another based on the type and degree of deformation and metamorphism they underwent during each orogenic event. The Mealy Mountains terrane is distinguished from the Pinware terrane by the presence of significant pre-Pinwarian history. The Lake Melville terrane went through severe Grenvillian deformation, whereas the Mealy Mountains and Pinware terranes were moderately affected by Grenville orogenesis (Gower, 2019).

A comprehensive publication on the geology of eastern Labrador (Gower, 2019) is based on systematic 1:100 000-scale mapping by C.F. Gower and several other scientists (*e.g.*, van Nostrand (1988, 1992), van Nostrand *et al.* (1992), van Nostrand and Gower (2010), Doherty (1980), Nunn and van Nostrand (1996a, b), Erdmer (1983, 1984), Emslie (1976, 1978a, b) and Hanmer and Scott (1990)). The following sections on the regional and local geology, except the sections on the FHVB and associated mineralization, are derived entirely from Gower (2019).

### MEALY MOUNTAINS TERRANE

The Mealy Mountains terrane is underlain by late Paleoproterozoic rocks and minor amounts of Mesoproterozoic rocks (Figure 1). The oldest units are pre-Labradorian crustal rocks (1810–1770 Ma) consisting of metasedimentary, mostly pelitic gneisses (P3sgn), and minor granitoid rocks of the Eagle River Complex (undivided P3gdn). Early Labradorian rocks (1710–1660 Ma) include mostly granitoids (P3gm and P3gdn), which comprise the most widespread units in the Mealy Mountains terrane, and minor anorthositic, mafic and ultramafic rocks of the Upper Eagle River mafic intrusion (undivided P3gdn). Late Labradorian rocks (1660–1600 Ma) consist of mafic, anorthositic and felsic rocks of the Mealy Mountains Intrusive Suite (MMIS), which is a typical anorthosite–monzonite/mangerite–charnockite–granite (AMCG) complex (P3a and P3g), and granitoids of the Middle Eagle River pluton (P3gr).

Early Mesoproterozoic rocks (1600–1350 Ma) include the Pinware–Mealy Mountains terrane boundary mafic and anorthositic rocks (M1a and M1lga) and anorthositic to felsic rocks of the Upper Paradise River Intrusive Suite (M1g). Middle Mesoproterozoic rocks (1350–1200 Ma) include the bimodal FHVB, which is described below, and the Mealy diabase dykes.

### LAKE MELVILLE TERRANE

The Lake Melville terrane is underlain by late Paleoproterozoic, minor Mesoproterozoic and Neoproterozoic rocks (Figure 1). The oldest rocks include the same pre-Labradorian supracrustal rocks (1810–1770 Ma, P3sgn) that occur in the Mealy Mountains terrane to the south. Early Labradorian (1710–1660 Ma) mafic rocks are represented by the Alexis River Anorthositic Intrusion (P3a) forming an up to 10-km-wide belt extending for approximately 225 km and having a northwest–southeast trend. As in the Mealy Mountains terrane, early Labradorian granitoids (P3gm, P3gdn) represent the most widespread unit. Late Labradorian rocks (1660–1600 Ma) include mostly mafic and anorthositic rocks of the Double Mer White Hills complex (P3ga) and

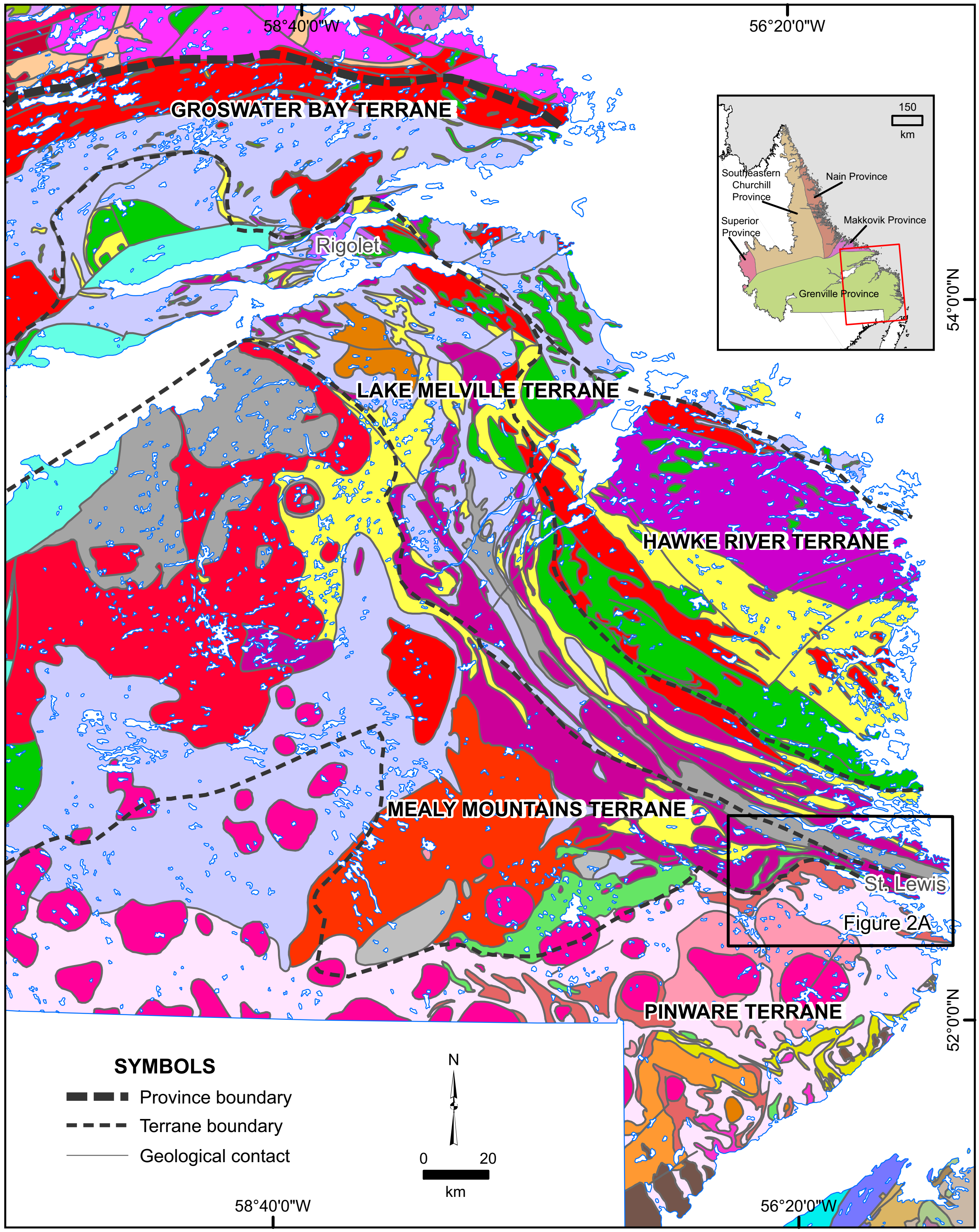



**Figure 1.** *Simplified geology map of the Grenville Province in eastern Labrador (Wardle* et al.*, 1997).*

**LEGEND**

**Phanerozoic**

Ncs Sandstone and nodular limestone

**Neoproterozoic**

Ns Arkose and conglomerate

**Late Mesoproterozoic**

M3gr Syenite to granite

M3gs Granite and syenite plutons

M3mg Monzonite to granite

**Middle Mesoproterozoic**

M2gr Granite plutons

**Early Mesoproterozoic**

M1a Anorthosite and other mafic rocks

M1g Granitoid rocks

M1ga Olivine gabbro and metamorphic equivalents

M1lga Layered gabbro–anorthosite–ultramafic intrusions

M1qd Quartz diorite

**Paleo and Mesoproterozoic**

P-Mg K-feldspar–megacrystic granitoid plutons

P-Mgs Granite, syenite, monzonite, diorite and derived gneiss

P-Msv Metasedimentary and felsic volcanic rocks

P-Msy Syenite, monzonite and diorite

**Late Paleoproterozoic**

P3a Anorthosite and other mafic rocks

P3eg High-level, locally fluorite-bearing, granites

P3g Granitoid rocks

P3ga Mafic intrusive suites

P3gdn Granodioritic orthogneiss

P3gm K-feldspar megacrystic granite and other granitoid plutonic rocks

P3gr Granite, quartz monzonite, granodiorite, syenite and minor quartz diorite

P3sgn Pelitic, migmatitic metasedimentary gneiss and minor psammitic gneiss

P3t Quartz diorite and granodiorite plutons

**Middle Paleoproterozoic**

P2fv Rhyolite, volcaniclastic siltstone and sandstone, minor basalt

P2g Granite and granodiorite

P2tgn Tonalite, granodiorite and monzogranite gneiss

**Mesoarchean**

Amrgn Tonalitic and other gneisses

**Figure 1.** *Legend.*

granitoid intrusions along the boundary between the Lake Melville and Hawke River terranes (P3gr).

Middle Mesoproterozoic rocks (1350–1200 Ma) are represented by granitoids of the Upper North River intrusion (M2gr). Late Mesoproterozoic rocks (1200–900 Ma) include minor granitoids and pegmatites. Neoproterozoic rocks occur along the Lake Melville graben in the north and are composed of clastic sedimentary rocks ranging from conglomerate to shale (Ns).

### PINWARE TERRANE

The oldest units in the Pinware terrane are late Paleoproterozoic (1810–1600 Ma). In the western Pinware terrane, these are composed of supracrustal rocks, foliated and gneissic granitoids and mafic rocks (undivided P3gdn and P-Mgs), whereas in the Henley Harbour district in the east, they are composed of amphibolite, quartzofeldspathic rocks, quartzite, tonalitic gneiss, pelitic rocks and calc-silicate rocks (P-Msv and P-Msy). Foliated gneissic granitoids and minor mafic rocks (P-Mgs and P-Mg) underlie most of the Pinware terrane (Figure 1).

Late Mesoproterozoic to Neoproterozoic rocks in the Pinware terrane are subdivided into late- to syn-Grenvillian granitoid intrusions (1045–985 Ma, undivided P-Mgs and M3gr), early- to post-Grenvillian granitoid and minor mafic intrusions (985–975 Ma, M1lga, M3mg, M3gr and undivided P-Mgs) and late- to post-Grenvillian granitoid intrusions (975–955 Ma, M3gs). Phanerozoic rocks in the Pinware terrane occur in the southeast, along the shoreline, and consist of clastic sedimentary rocks and minor limestone (NCs).

## LOCAL GEOLOGY

### ROCK TYPES

The FHVB is located mostly in the eastern structural wedge of the Mealy Mountains terrane straddling the boundary with the Lake Melville terrane to the north (Gower, 2019; Figure 2A, B). The area is underlain by early Labradorian rocks representing calc-alkaline magmatism that formed during Labradorian orogenesis. Early Labradorian granitoids (1678–1671 Ma) include K-feldspar megacrystic, dioritic and monzonitic gneisses. The most common rock types in EFHVB are foliated to gneissic megacrystic, porphyritic granitoid rocks or augen gneiss, followed by a gneissic granodiorite. Minor amphibolite lenses and layers occurring within the gneisses are interpreted as remnants of dykes. Early Labradorian mafic rocks (1700–1660 Ma) are more common toward the west. At the Fox Meadow occurrence in the WFHVB, the dominant rock types include gneissic anorthosite, gabbro and norite. The FHVB is described below.

Rare-earth-element occurrences on Wood Island (HighREE Island occurrence) and south of the St. Lewis Inlet in the Pinware terrane are hosted in late Paleoproterozoic and early Mesoproterozoic granitoids consisting of foliated granite, alkali-feldspar granite, quartz monzonite, diorite, quartz diorite and leucoamphibolite.

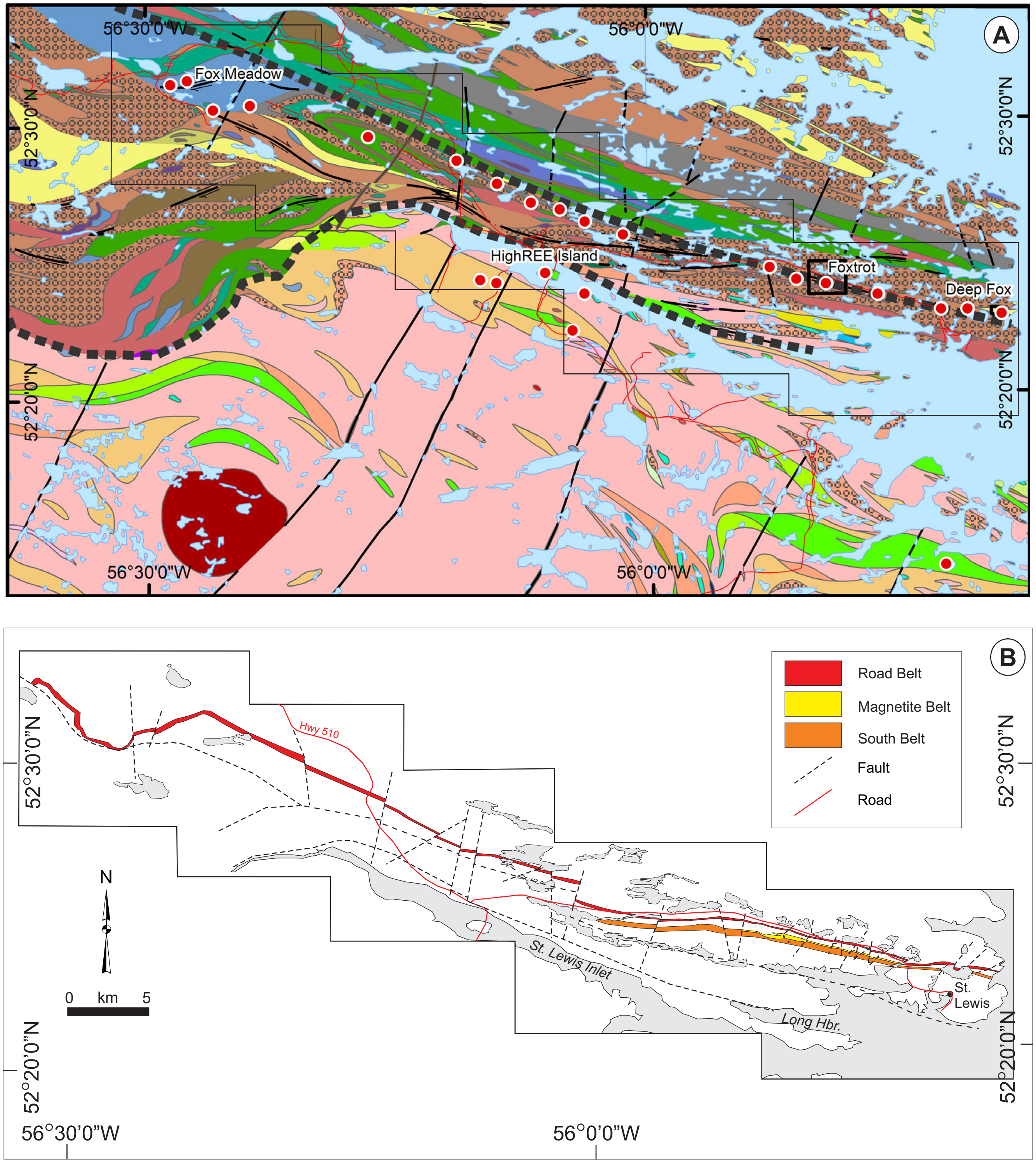



**Figure 2.** *A) Geology of the Port Hope Simpson area (after Gower, 2010a, b, 2019); black squares indicate location of Figure 3 (Deep Fox) and Figure 4 (Foxtrot); 4); B) The Fox Harbour Volcanic Belt (after Gower, 2019).*

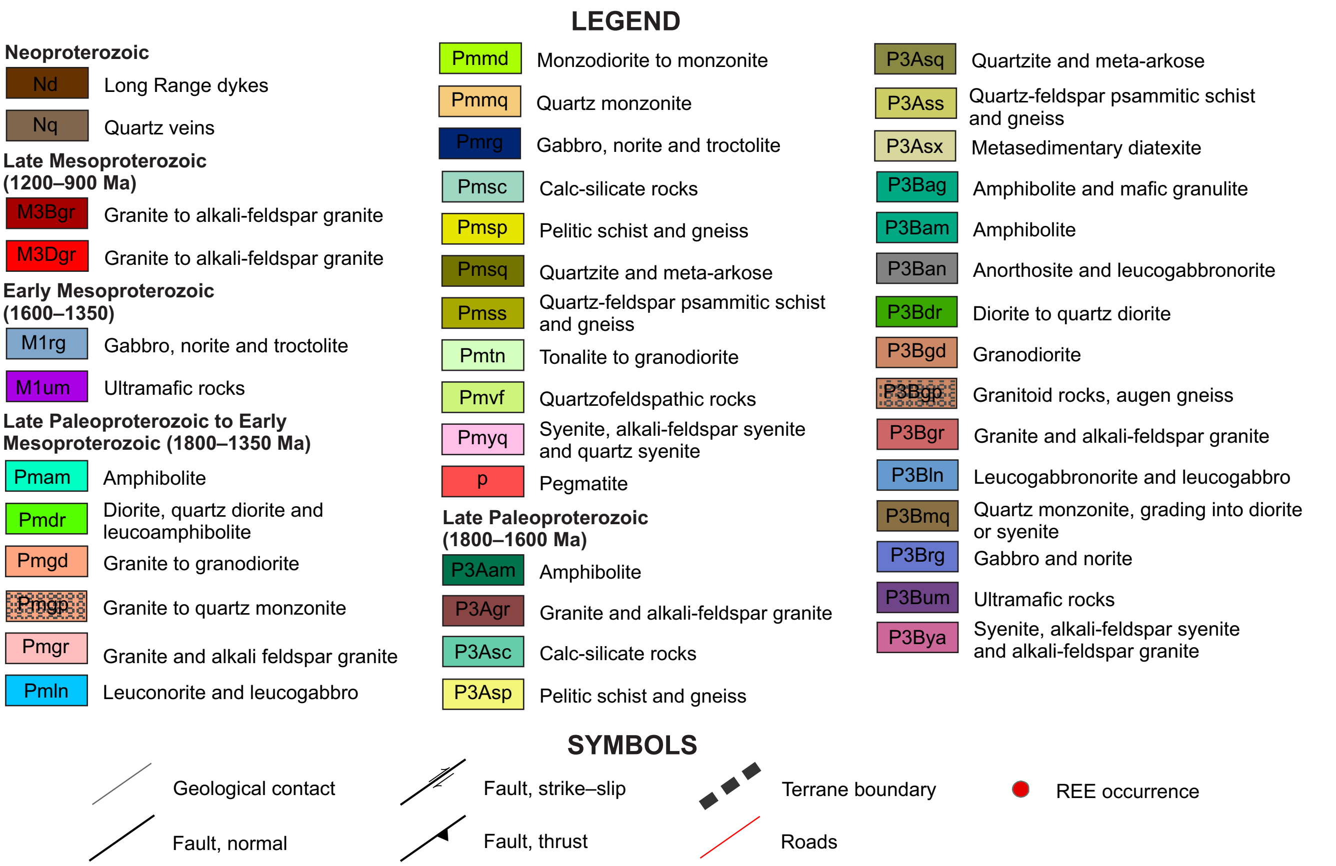



**Figure 2.** *Legend.*

## STRUCTURE AND METAMORPHISM

The eastern Mealy Mountains terrane, which hosts the FHVB, is structurally attenuated, reduced from approximately 80 km in maximum width, to approximately 5 km wide within the eastern structural wedge (Gower, 2019; Figures 1 and 2). The structural attenuation is the result of northwest–southeast compression during the Grenville orogeny and is accommodated by northeast-striking, southeast-verging thrusts/reverse faults and strike–slip faults in the St. Lewis River area west of the FHVB.

Structures in the eastern wedge of the Mealy Mountains terrane suggest dextral-oblique-slip, northeast-side-up motion along the Fox Harbour Fault, which separates the Mealy Mountains and Lake Melville terranes (Figure 2A). The Fox Harbour Fault marks an abrupt change in the orientation of lineations, from steeply northwest-plunging in the south side to shallowly east-southeast-plunging on the north side, without any change in the rock types. The southern boundary of the Mealy Mountains terrane with the Pinware terrane is marked by the Long Harbour Fault that passes through the St. Lewis Inlet. Within the narrow eastern part of the Mealy Mountains terrane, the lineation changes from plunging moderately to the north-northeast in the south, to plunging moderately to the northwest in the north.

The Pinware terrane is subdivided into the eastern, western and southern structural domains. Rocks of the eastern Domain, hosting the HighREE Island occurrence, are strongly foliated or gneissic, and strike north–south to northwest–southeast with lineations plunging to the north or northwest.

No detailed studies on the grade of metamorphism have been completed for the FHVB. The closest pressure–temperature estimate is located approximately 8 km southwest of the Fox Meadow occurrence (Figure 2A) and yielded a temperature of 800°C and a pressure of 8 kbars (Gower, 2019). Haley (2014) indicated that the rocks of the FHVB underwent amphibolite-facies metamorphism during Grenville orogenesis, based on the observed mineral assemblages and zircon growth at ~1.05 Ga.

## FOX HARBOUR VOLCANIC BELT

The FHVB forms a 64-km-long belt striking west-northwest from St. Lewis and ranges in width from less than

50 m in the west to 3 km in the east (Figure 2B). It is subdivided into three belts running parallel to each other, namely, from north to south: the Road Belt, the Magnetite Belt and the South Belt (Haley, 2014; Miller, 2015). The Road Belt extends throughout the entire length the FHVB, whereas the Magnetite and South belts only occur in the eastern half. The REE occurrences, located in the Pinware terrane to the south of the three belts (Figure 2A), are hosted in rocks described as peralkaline volcanic and subvolcanic (Miller, 2015). These rocks have not been dated, but due to similarities to the FHVB, they are interpreted to be genetically related to them.

The FHVB is a bimodal volcanic belt composed of quartz-oversaturated peralkaline volcanic rocks (pantellerite to comendite and pantelleritic to comenditic trachyte), non-peralkaline rhyolite, mafic to ultramafic volcanic rocks, minor volcaniclastic sedimentary rocks and quartzite (Haley, 2014; Miller, 2015). Due to the mylonitized and metamorphosed aspects of the rocks, determining the protolith of these rocks is difficult. Nevertheless, based on the presence of mafic units with the felsic rocks, metasedimentary rocks interpreted as volcaniclastic, and large epidote pods in the mafic volcanic rocks interpreted as altered pillows or alteration pipes, previous workers concluded the protoliths to be volcanic (Haley, 2014; Gower, 2019). Pantellerite in the FHVB typically contains significant amounts of magnetite, locally occurring as phenocrysts, and zircon. Based on the amount of Zr, pantellerite is subdivided into Zr-poor pantellerite (5000 to 10 000 ppm Zr), pantellerite (10 000 to 15 000 ppm Zr) and Zr-rich pantellerite (more than 15 000 ppm Zr).

The age of the FHVB is *ca.* 1.3 Ga as determined with U–Pb in zircon from rhyolitic units in all three belts at the Foxtrot deposit, and the age of metamorphism is Grenvillian at *ca.* 1.05 Ga (Haley, 2014). Based on mineral assemblages, the grade of metamorphism is interpreted as being amphibolite facies. Hafnium isotopes in the FHVB suggest partial melting of the 1.9 to 1.5 Ga crustal rocks as the source of the FHVB (Haley, 2014).

The FHVB was emplaced during post-Pinwarian–pre-Grenvillian (Elsonian) events that affected most of Labrador starting with AMCG magmatism (*e.g.*, Nain Plutonic Suite, Harp Lake Plutonic Suite), followed by peralkaline magmatism, which included the Strange Lake and Flowers River complexes, as well as the Red Wine Intrusive Suite (Gower, 2019). These events are interpreted to be the result of the crust migrating above a spreading centre, providing mantle-derived melts and inciting lower crustal melting, suggested by the decreasing age of AMCG magmatism toward the north and the K-rich nature of granitoids (Gower and Krogh, 2002).

## MINERALIZATION

The most significant REE occurrences in the FHVB are associated with the Road Belt (*e.g.*, Deep Fox, Fox Meadow deposits) and the Magnetite Belt (*e.g.*, Foxtrot deposit). Mineralization is hosted in pantellerite (occurring mostly in the Road and Magnetite belts) and comendite (occurring in all three belts). Zirconium-rich pantellerite and pantellerite host all of the medium- to high-grade mineralization, being characterized by Dy concentrations between 100 and 300 ppm. Comendite hosts low-grade mineralization with Dy concentrations between 20 and 100 ppm. At the Foxtrot deposit, most of the REE are hosted in allanite and fergusonite, where the former contains mostly light REE (LREE), and fergusonite contains heavy REE (HREE) and minor LREE. Additional REE minerals include chevkinite, bastnaesite, synchysite, monazite and rare columbite (Haley, 2014; Masun *et al.*, 2016).

The Deep Fox and Foxtrot deposits are in the most advanced stage of exploration. The resource at Foxtrot includes 7.392 Mt at 0.91% total REE (TREE) of indicated resource and 1.958 Mt at 0.97% TREE of inferred resource (NI 43-101 compliant; Masun *et al.*, 2016). Total REE include all REE from La to Lu, not including the unstable Pm, and Y. The resource at Deep Fox includes 2.329 Mt of indicated resource with 403 ppm Pr, 1486 ppm Nd and 206 ppm Dy (487 ppm $Pr_8O_{11}$, 1739 ppm $Nd_2O_3$ and 237 ppm $Dy_2O_3$) and 3.902 Mt of inferred resource with 357 ppm Pr, 1323 ppm Nd and 181 ppm Dy (432 ppm $Pr_8O_{11}$, 1548 ppm $Nd_2O_3$ and 208 ppm $Dy_2O_3$) (NI 43-101 compliant; Masun, 2019).

In contrast to the peralkaline intrusive complexes, such as Strange Lake, where REE mineralization is associated with late pegmatites and veins concentrating the incompatible elements in the roof zones of the plutons (Miller, 1996, 2015), REE mineralization in volcanic peralkaline complexes, such as at the FHVB, is associated with small volumes of strongly fractionated melts extruding late as vent and/or caldera filling or near-vent magma flows (Miller, 1993, 2015).

### METHODS

In the summer of 2021, field work concentrated on four of the REE occurrences, namely the Deep Fox, Foxtrot (including Road Belt and Foxtrot South), Fox Meadow and HighREE Island occurrences. Field work consisted of data collection (structural measurements, rock descriptions, gamma ray responses) and sample collection, followed by preliminary petrographic examination of representative samples from each area. The most recent analytical work included SEM examination of six samples, and SEM

Minerals Liberation Analysis (SEM-MLA) of three samples. The interpretation of the SEM work has not been completed at the present time, but preliminary results are included in this paper.

Most of the samples were collected from channels cut by Search Minerals Incorporated for exploration purposes. Samples collected include all rock types of the FHVB and representative samples of the country rocks. As REE-bearing minerals typically only occur in trace amounts, identification of mineralized units in the field was aided with a hand magnet and a RS-120 Super-Scint handheld gamma ray scintillometer. In most areas, but not all, REE-bearing minerals are spatially associated with magnetite resulting in mineralized units being magnetic. Gamma ray spectrometers measure naturally occurring radioactive isotopes of K, U and Th, and have been used worldwide in exploration for REE. Spectrometer readings assist with exploration, because the primary host rocks of the REE mineralization are typically enriched in large-ion lithophile elements, which include K and high field strength elements (HFSE) including U and Th (Shives, 2015). The REE minerals typically occur together with zircon and titanite in the mineralized rocks of the FHVB, and commonly contain detectible concentrations of U and Th in their crystal structures or as inclusions of U- and Th-bearing minerals, such as thorite and uraninite. Hence, in most cases, the spectrometer readings correlate well with the amount of mineralization.

Six samples from the Deep Fox, Fox Meadow and HighREE occurrences were selected for analysis using a FEI MLA 650FEG Scanning Electron Microscope (SEM) at Memorial University of Newfoundland (MUN) Micro Analysis Facility (MUN MAFIIC). Qualitative analyses were completed with high throughput Energy-dispersive X-ray Spectroscopy (EDX) detectors from Bruker (https://www.mun.ca/creait/). The purpose of the SEM work was to identify any unknown minerals and select three of the samples for SEM-MLA analysis to determine the abundances of minerals in the samples. The SEM-MLA uses backscattered electron imaging (BEI) to measure the average atomic number of the minerals to establish grain boundaries, then classifies the grains as minerals using a mineral reference list and allows quantitative evaluation of the abundances of minerals, among other characteristics.

# RESULTS

## ROCK TYPES AND REE MINERALIZATION

All rock types in the FHVB are fine to medium grained, strongly foliated and folded, and contain layers and/or lenses of pegmatites and medium-grained felsic rocks. Rare-earth-element-bearing minerals are small and comprise a small volume percentage of the host rock, thereby making them difficult to identify even with the use of a polarized microscope. The two main ore minerals at Foxtrot are allanite and fergusonite (Haley, 2014; Masun *et al.*, 2016). The SEM work confirmed that the main REE minerals at Deep Fox and Fox Meadow are also allanite and fergusonite, and the main REE mineral at HighREE Island is allanite. These minerals look similar under the microscope, especially when they are metamict. Hence, for the purposes of this study, minerals that appear similar to allanite and fergusonite are listed as “REE minerals” in the rock descriptions. Due to similarities in rock types and mineralization, the Deep Fox and Foxtrot deposits, both located in the EFHVB, will be described together.

### Eastern Fox Harbour Volcanic Belt (Deep Fox and Foxtrot)

The main rock types in the EFHVB include pantellerite, containing variable amounts of Zr, comendite, non-peralkaline rhyolite and mafic–ultramafic units (Figures 3 and 4). *Pantellerite* occurs as a fine-grained, pinkish-grey unit with magnetite locally forming phenocrysts up to 0.5 cm in length (Plate 1A). It is strongly magnetic and returns scintillometer readings up to 20 times the background level. It contains up to 10 cm thick layers/pods of pegmatites, composed of quartz, K-feldspar and minor amphibole. The K-feldspar locally occurs as amazonite, especially in areas having high scintillometer readings. Quartz–fluorite veins up to 1 cm thick are common. The minerals in the pantellerite, as determined by SEM-MLA, include quartz (61%), albite (10%), allanite (6%), microcline (6%), magnetite (6%), biotite (4%), zircon (2%), amphibole (2%), titanite (1%), apatite (1%) and trace amounts of fluorite, fergusonite, unnamed REE minerals, garnet and chlorite. The amounts are in area percent. Pyroxene and calcite also occur in other pantellerites. Chlorite occurs as alteration after biotite. The REE minerals are spatially associated with zircon, titanite, magnetite, apatite and mafic minerals (Plate 2A). Magnetite at Deep Fox is typically surrounded by titanite and minor zircon (Plate 2B).

*Comendite* occurs as fine- to medium-grained, pink to grey, non-magnetic to strongly magnetic rocks having scintillometer readings up to 14 times the background level. It is commonly composed of alternating magnetic and non-magnetic layers, with the non-magnetic layers being medium grained and pink and the magnetic layers being fine grained and grey (Plate 1B). It also contains pegmatitic layers/pods up to 20-cm thick composed of quartz, K-feldspar (locally amazonite), and minor amphibole. The minerals comprising the comendite include quartz, K-feldspar (microcline), plagioclase, amphibole and/or biotite, magnetite, zircon, titanite, and REE minerals. Pyroxene, calcite and fluorite are

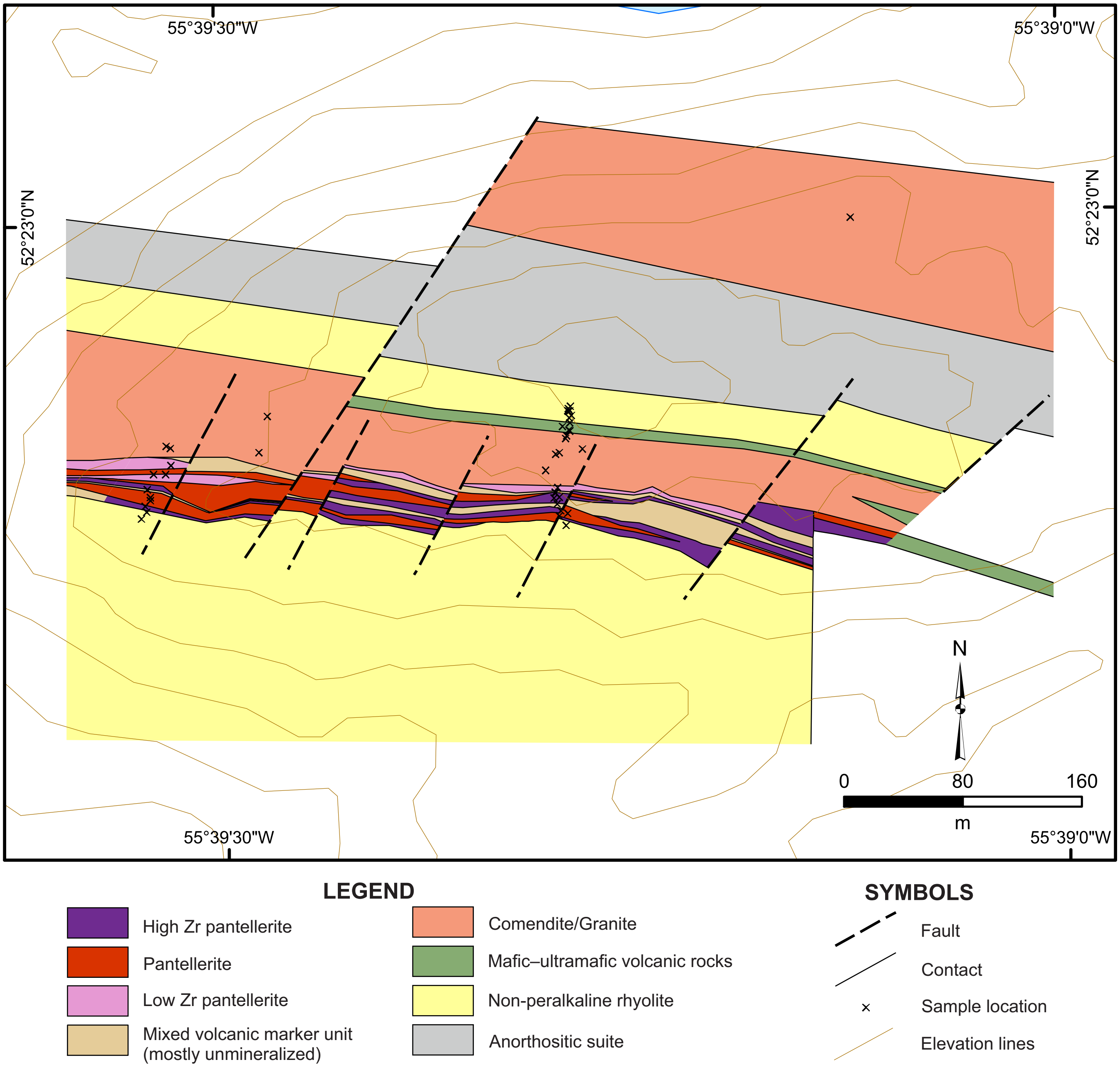



**Figure 3.** *Detailed geological map of the Deep Fox deposit (Masun, 2019).*

also locally present. Chlorite and hematite occur as alteration minerals after biotite and magnetite, respectively. Although these are the same minerals as in pantellerite they occur in different proportions, with generally less magnetite and mafic minerals. The magnetite-rich layers contain more titanite, zircon, mafic minerals, and REE minerals (Plate 2C). Magnetite, when present, is commonly surrounded by titanite at Deep Fox (Plate 2D). Similar to pantellerite, REE minerals occur with zircon, titanite, magnetite and mafic minerals.

The *non-peralkaline rhyolite* is pink, fine to medium grained, non-magnetic to weakly magnetic with scintillometer readings up to 3 times the background level (Plate 1C). The minerals include quartz, K-feldspar (microcline), plagioclase, biotite, pyroxene and/or amphibole, zircon, and trace amounts of titanite and REE minerals. Muscovite occurs in some samples and magnetite is present in the magnetic samples. Chlorite and hematite occur as alteration after biotite and magnetite, respectively. It locally contains pegmatitic lenses and pods up to 15 cm thick composed of quartz, K-feldspar and minor amphibole.

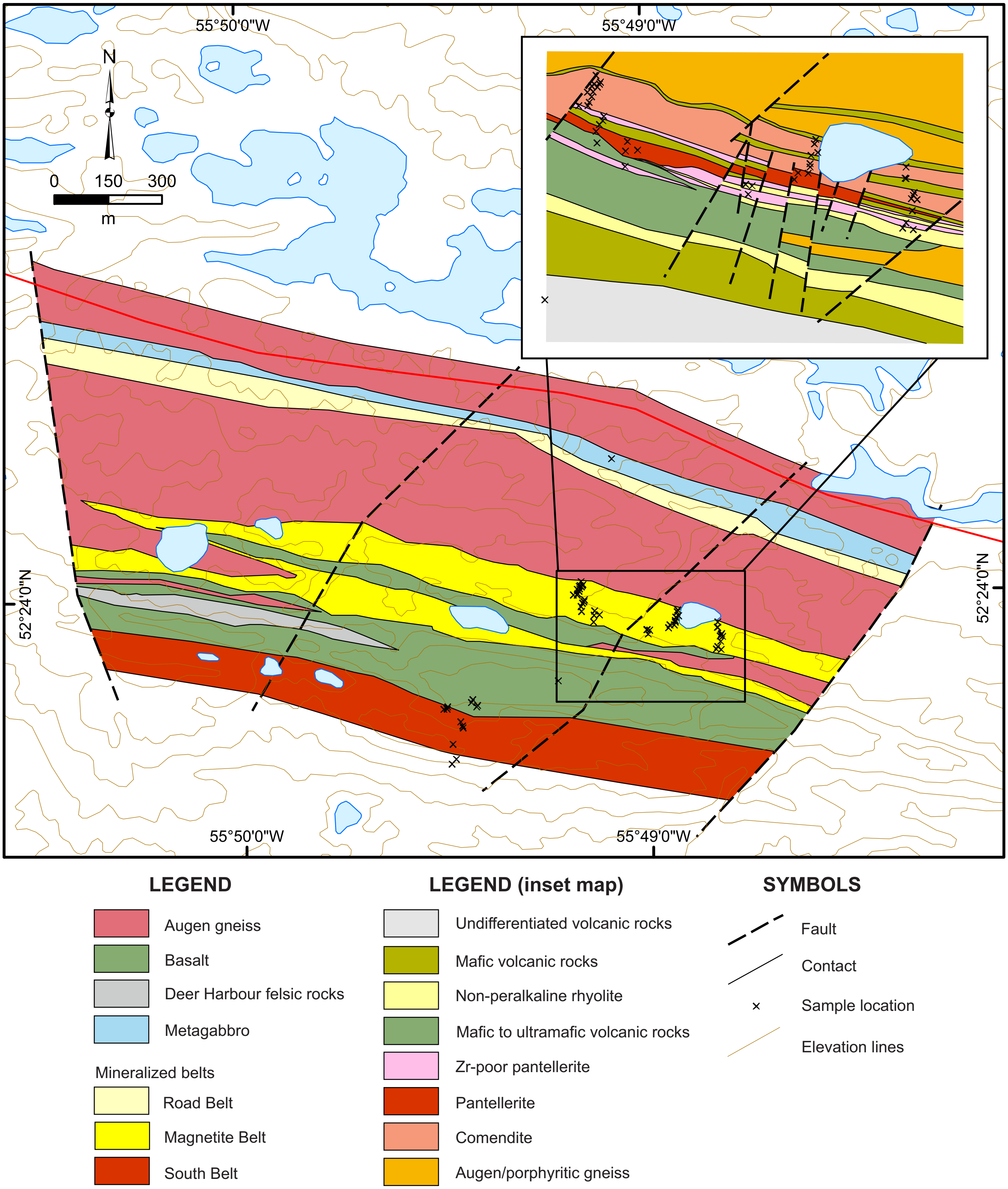
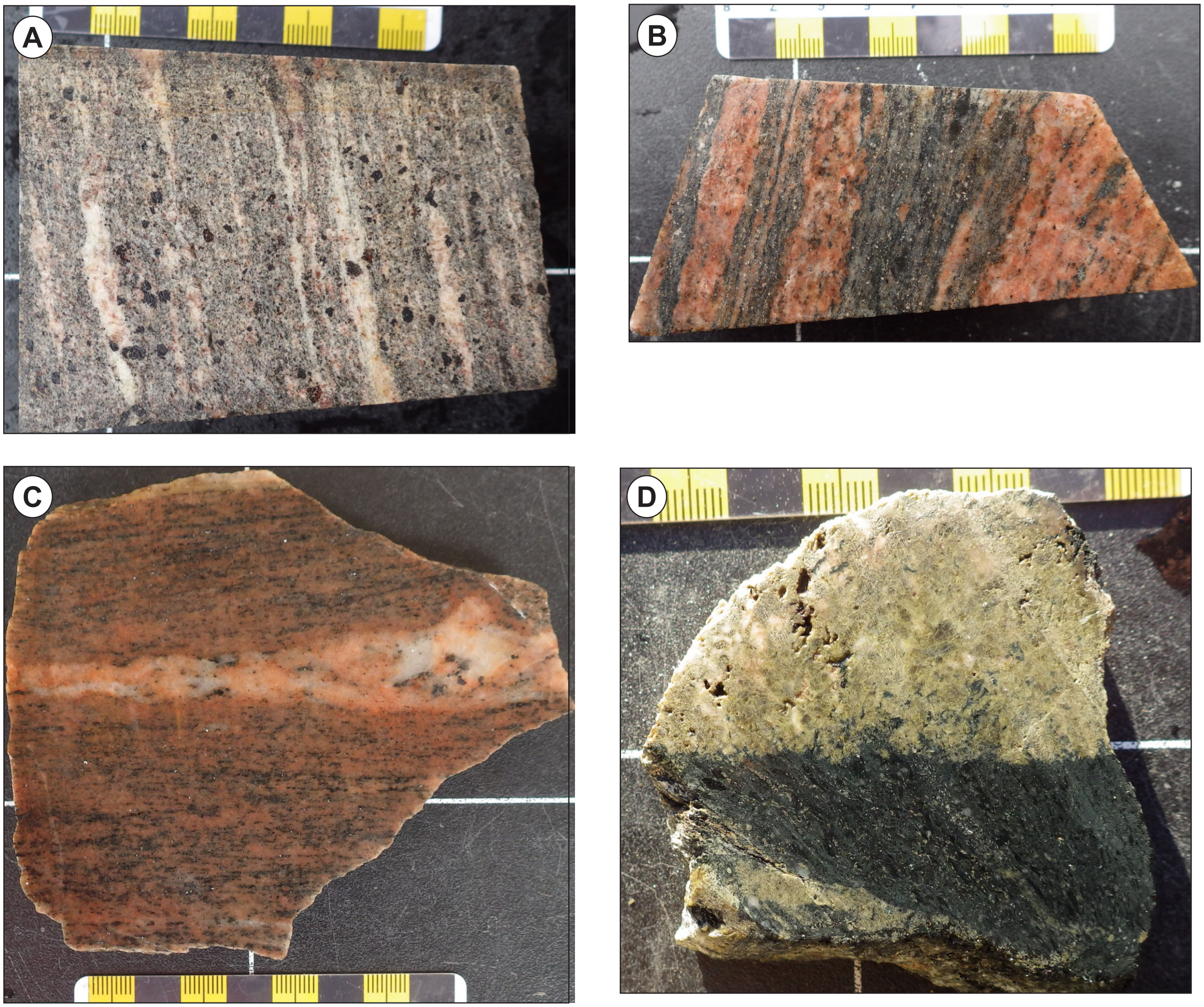



**Figure 4.** *Detailed geological map of the Foxtrot deposit (Miller, 2015; Masun* et al.*, 2016).*



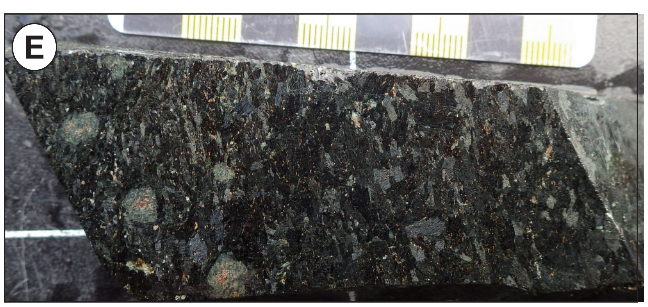




**Plate 1.** *Representative rock slabs from the EFHVB. A) Pantellerite with magnetite phenocrysts; B) Comendite with alternating pink and dark-grey, magnetite-rich layers; C) Non-peralkaline rhyolite; D) Amphibolite with epidote pod (green); E) Amphibolite with partially altered garnet porphyroblasts.*

The *mafic rocks* are dark-green to grey, fine to medium grained and non-magnetic to weakly magnetic. They contain pegmatite layers and pods up to 5 cm thick and locally epidote pods and lenses up to 10 cm or more thick (Plate 1D). Based on preliminary petrography they are amphibolites consisting of amphibole, plagioclase, minor pyroxene, magnetite, titanite, and locally garnet (Plates 1E and 2E). Similar to the felsic rocks, magnetite, if present, is commonly surrounded by titanite at Deep Fox (Plate 2E).

### Fox Meadow

Rock types at Fox Meadow have been preliminarily divided into felsic, intermediate and mafic rocks based on

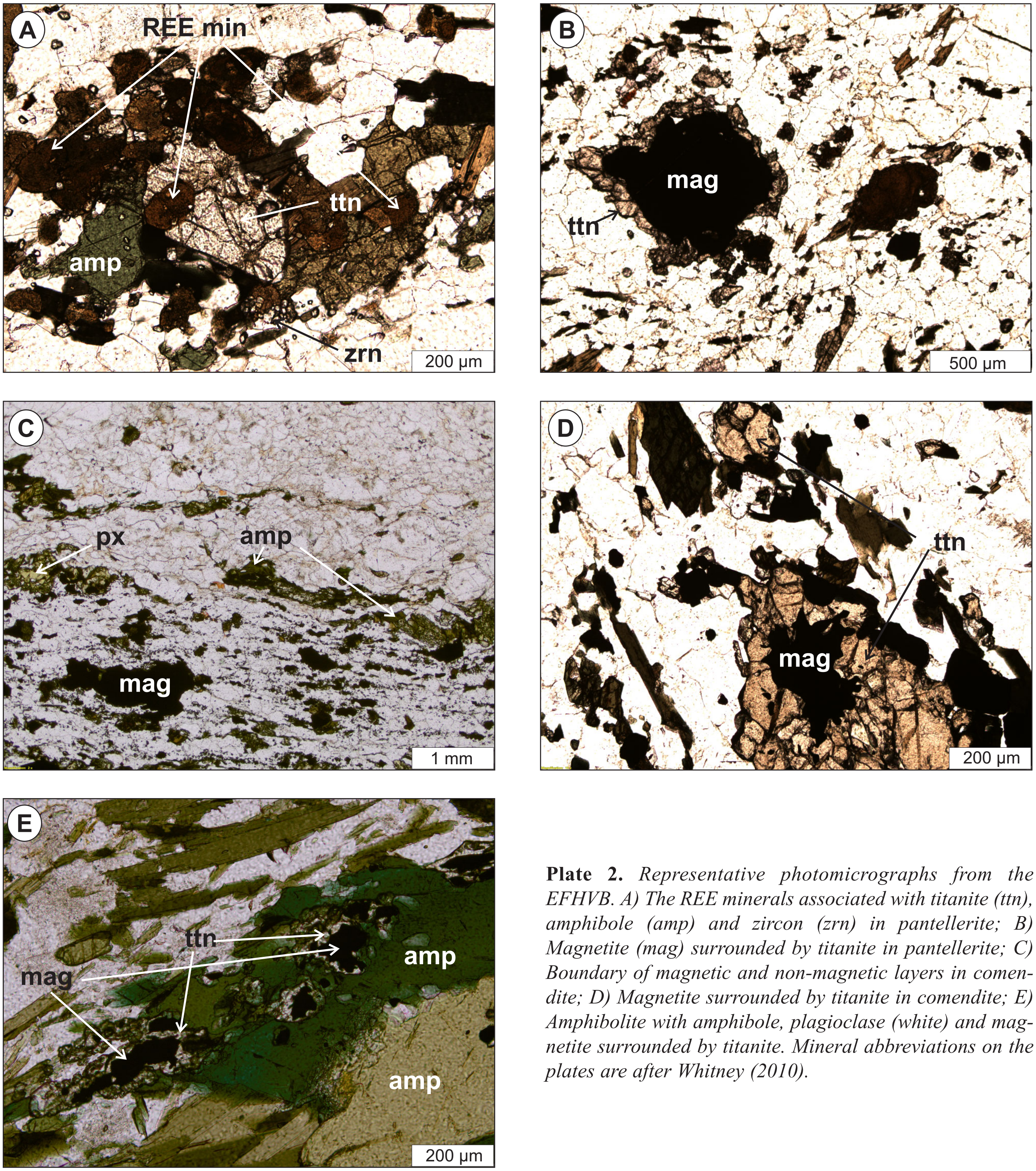



**Plate 2.** *Representative photomicrographs from the EFHVB. A) The REE minerals associated with titanite (ttn), amphibole (amp) and zircon (zrn) in pantellerite; B) Magnetite (mag) surrounded by titanite in pantellerite; C) Boundary of magnetic and non-magnetic layers in comendite; D) Magnetite surrounded by titanite in comendite; E) Amphibolite with amphibole, plagioclase (white) and magnetite surrounded by titanite. Mineral abbreviations on the plates are after Whitney (2010).*

the relative amounts of mafic minerals. Compared to the rocks farther east, these host rocks are generally less magnetic and less radioactive, with scintillometer readings up to 3 times of the background level.

The felsic rock occurs as a pink, fine- to medium-grained, weakly to strongly magnetic gneiss where mafic minerals account for up to 25% (Plate 3A, B). In the strongly magnetic felsic rocks, magnetite locally forms grains up to 0.5 cm in length. Modal mineralogy completed with

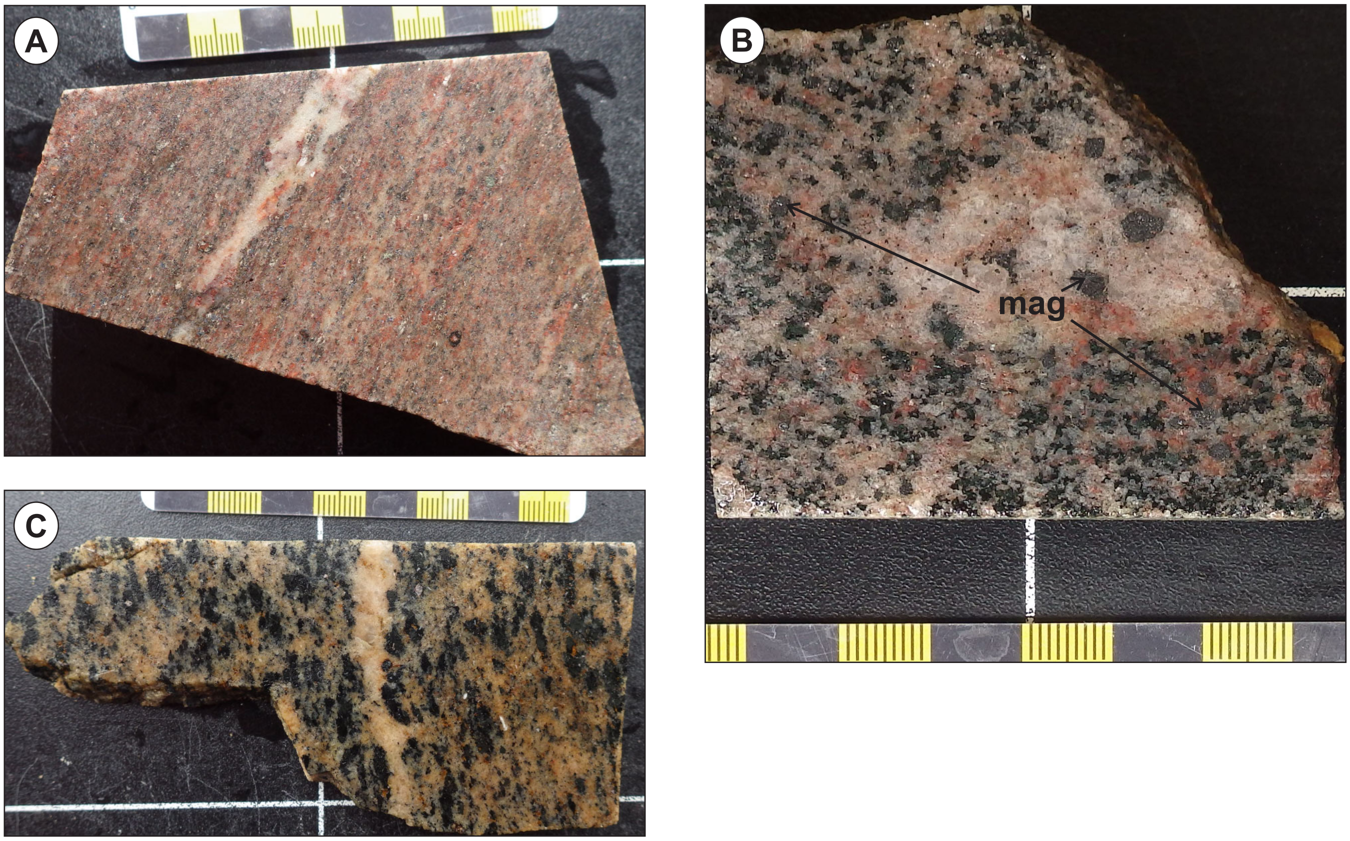


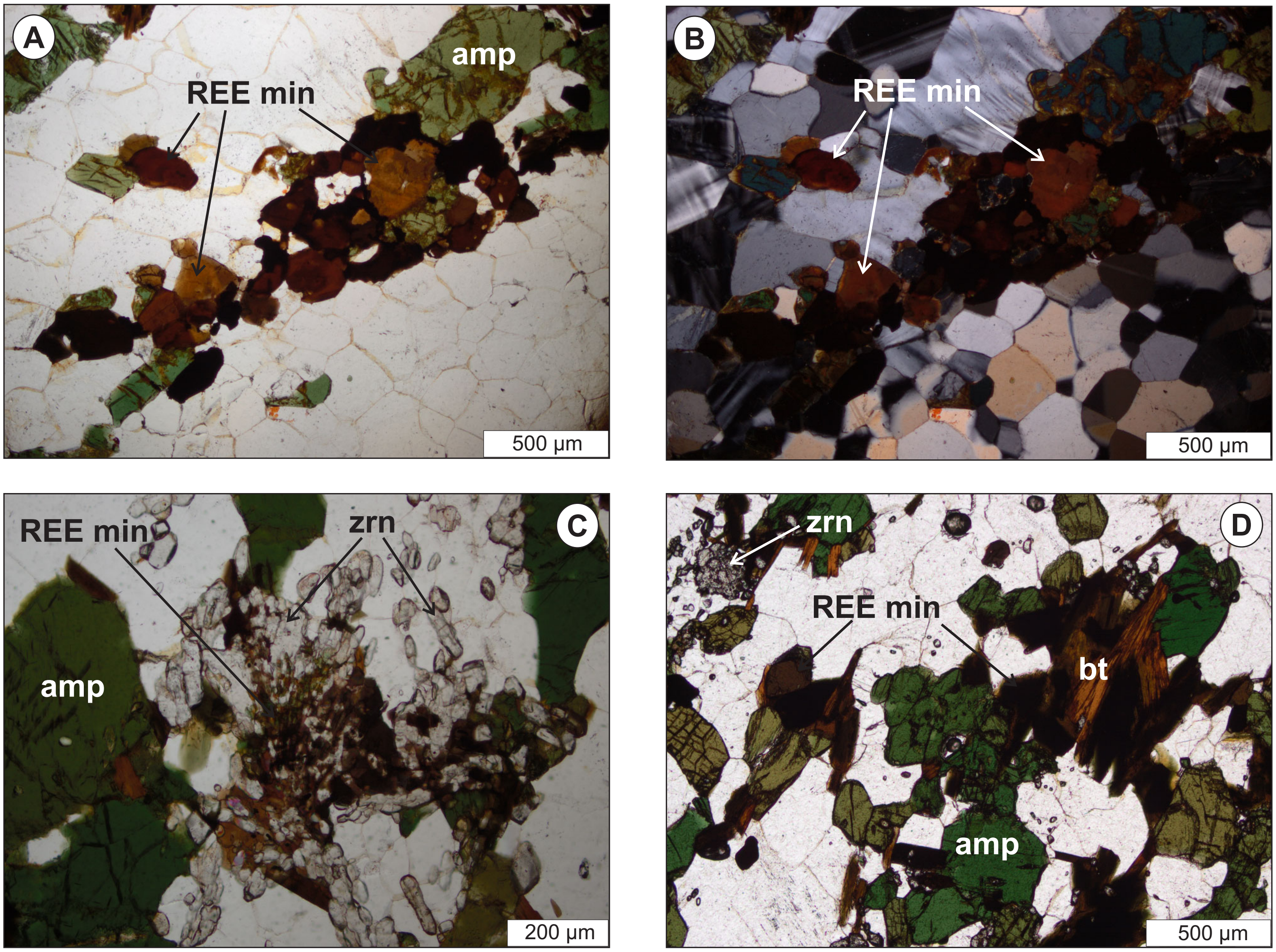

**Plate 3.** *Representative rock slabs from the Fox Meadow occurrence. A) Weakly magnetic felsic rock; B) Strongly magnetic felsic rock with magnetite (mag) phenocrysts; C) Intermediate rock with amphibole phenocrysts.*

SEM-MLA on a weakly magnetic felsic rock revealed that it is trachyte. The main minerals include albite (59%), pyroxene (24%), biotite (8%), zircon (3%), microcline (3%), allanite (2%), amphibole (2%), titanite (1%), and trace amounts of quartz, chlorite, ilmenite, fergusonite, magnetite and two unnamed REE minerals. The amounts are in area percent. Fluorite was observed in other felsic rocks. Titanite is not always present. The REE minerals are spatially associated with zircon, mafic minerals and ilmenite where present (Plate 4A–D). They commonly occur as large grains (<300 µm) in biotite, with the REE minerals surrounded by pleochroic haloes that cause the biotite to locally appear very dark and opaque (Plate 4D).

Intermediate compositions contain up to 40% mafic minerals and are pinkish white, medium grained, and non-magnetic to weakly magnetic (Plate 3C). The minerals include albite, K-feldspar (microcline), quartz, amphibole, pyroxene, biotite, magnetite (in magnetic samples), zircon and REE minerals. The relative amounts of albite and quartz are difficult to determine because albite is commonly untwinned and looks very similar to quartz. Staining techniques will have to be applied to determine the relative proportions of albite and quartz. Some samples also contain titanite. Similar to the felsic rocks, REE minerals occur with zircon, magnetite (if present), and mafic minerals, especially biotite, making it appear opaque. In one sample, amphibole occurs as needles in pyroxene and around the edges of pyroxene (Plate 4E). The mafic rocks are fine-grained amphibolite composed of mainly plagioclase and amphiboles.

## HighREE Island

The rock types at the HighREE Island occurrence include two types of felsic rocks, an intermediate rock, several generations of pegmatites, and REE-mineralized units (Plates 5 and 6). The dominant rock type is a non- to weakly magnetic, pink to pinkish white, medium-grained, granitic gneiss (Plate 5A). The minerals include quartz, K-feldspar (microcline), plagioclase, amphibole and/or biotite, titanite, apatite, zircon, REE minerals, and trace amounts of magnetite (Plate 7A). The amount of mafic minerals is less than 15%. The other felsic rock is a magnetic, fine-grained, greyish pink, granitic gneiss containing cm-scale grey, magnetite-rich layers (Plate 5B). This rock looks similar to the comendite in the EFHVB. It contains the same minerals as the weakly magnetic gneiss, but more magnetite (Plate 7B).



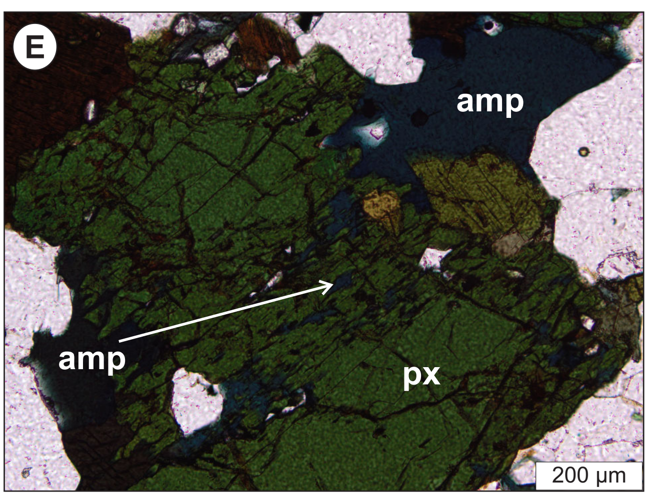




**Plate 4.** *Representative photomicrographs from the Fox Meadow occurrence. A) The REE minerals occurring with amphibole (amp); B) Same as A under crossed polars; C) REE minerals with abundant zircon (zrn) and amphibole; D) The REE minerals with amphibole, biotite (bt) and zircon. Some REE minerals occur within biotite making it appear black and opaque; E) Amphibole occurring as needles within, and around the edges, of pyroxene (px).*

Some of the magnetite is surrounded by titanite, similar to the pantellerite and comendite at Deep Fox.

The intermediate felsic rock is fine grained, non-magnetic and consists of amphibole, plagioclase, biotite, quartz, titanite and apatite (Plate 5C). Pegmatite dykes, of variable generations, up to 4-m wide are abundant at HighREE Island. The older pegmatites are folded, whereas younger pegmatites cut folding, foliation and the older pegmatites. Graphic texture and fine-grained aplitic zones are common

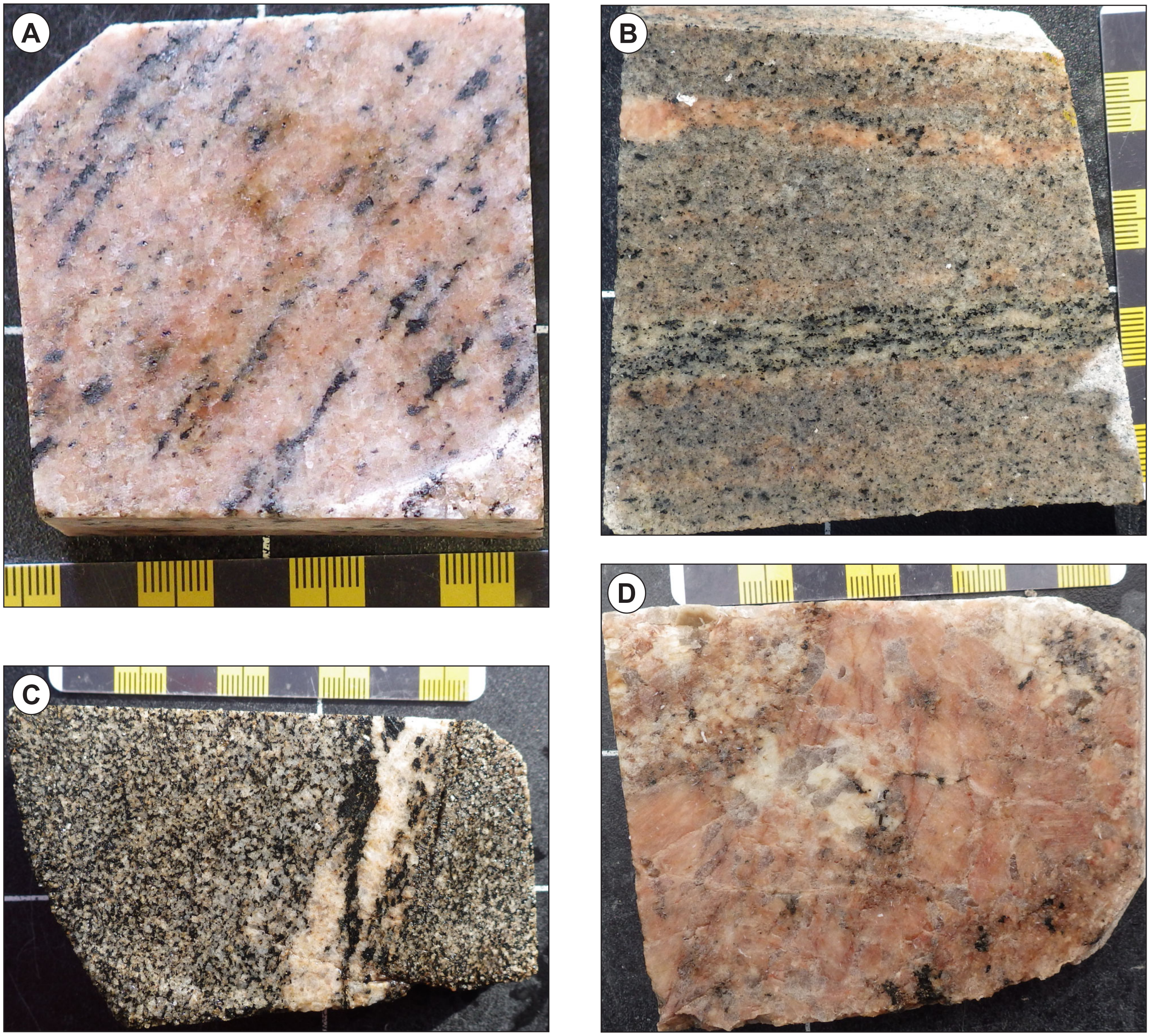



**Plate 5.** *Representative rock slabs from the host rocks of the HighREE Island occurrence: A) Weakly magnetic granitic gneiss; B) Fine-grained gneiss with magnetite-rich layer; C) Intermediate rock; D) Pegmatite with aplitic zone (upper left corner).*

(Plate 5D), being composed of quartz, K-feldspar and locally minor amounts of magnetite and/or amphibole.

Although REE minerals occur in the felsic rocks, most of the REE mineralization at HighREE Island is hosted in separate rock units that have scintillometer readings ranging from background to 24 times the background level. Most commonly, mineralization is associated with a grey to brownish black, medium- to coarse-grained unit that ranges from strongly magnetic to non-magnetic (Plate 6A). According to the SEM-MLA results of one of the mineralized units, the minerals include quartz (63%), amphibole (12%), titanite (10%), magnetite (8%), allanite (2%), albite (1%), biotite (1%), apatite (1%), zircon (1%), chlorite (1%), and trace amounts of ilmenite, muscovite, orthoclase and unidentified REE minerals (Plate 7C–E). The amounts are in area percent. However, some of these units contain biotite as a main mafic mineral, rather than amphibole, and no magnetite. It is locally poikilitic with amphibole forming oikocrysts up to 1.5 cm long (Plate 6B). Some of the mineralization is also hosted in very fine-grained, light brown-pink veinlets that occur in a fine- to medium-grained granitic rock (Plate 6C). The composition of this type of mineralization has not been investigated in detail yet. Some

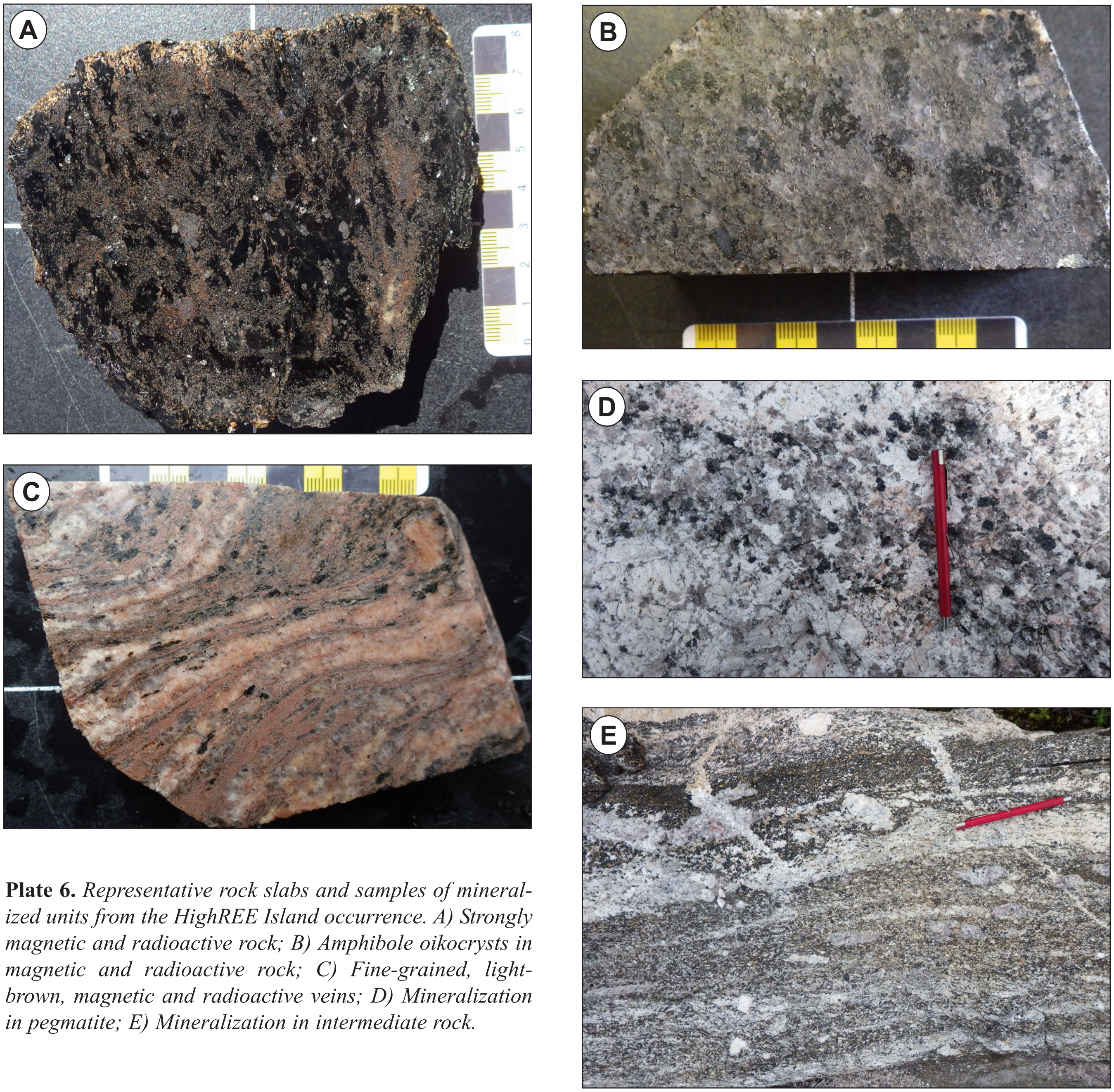



**Plate 6.** *Representative rock slabs and samples of mineralized units from the HighREE Island occurrence. A) Strongly magnetic and radioactive rock; B) Amphibole oikocrysts in magnetic and radioactive rock; C) Fine-grained, light-brown, magnetic and radioactive veins; D) Mineralization in pegmatite; E) Mineralization in intermediate rock.*

of the pegmatites and, locally, the intermediate rocks are mineralized, containing magnetite and REE minerals, suggested by their high scintillometer readings and magnetic nature (Plate 6D, E).

## STRUCTURES

All rocks in the FHVB, except some of the pegmatites, are strongly foliated, mostly mylonitized and likely folded by several deformational events. This is a preliminary description of the structures observed, but more detailed studies are needed to determine the number and characteristics of the deformational events and the effects of these events on REE mineralization.

### Eastern Fox Harbour Volcanic Belt (Deep Fox and Foxtrot Deposits)

Foliations in the EFHVB trend west-northwest–east-southeast with dips ranging from 60 to 90°, both to the north and south (Figure 5). Pegmatite lenses and boudins occur parallel to the foliation. Rotation of pegmatite boudins

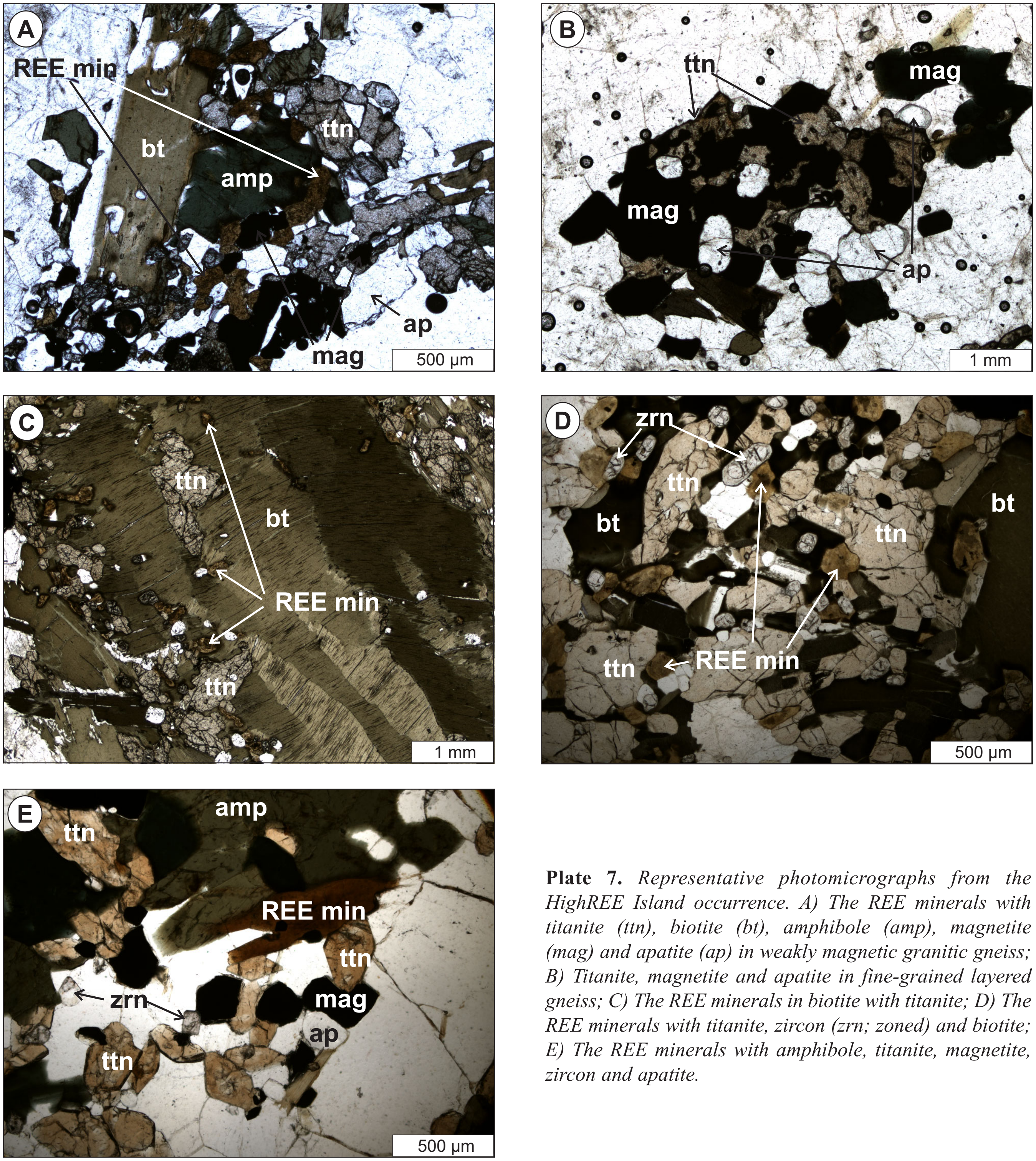



**Plate 7.** *Representative photomicrographs from the HighREE Island occurrence. A) The REE minerals with titanite (ttn), biotite (bt), amphibole (amp), magnetite (mag) and apatite (ap) in weakly magnetic granitic gneiss; B) Titanite, magnetite and apatite in fine-grained layered gneiss; C) The REE minerals in biotite with titanite; D) The REE minerals with titanite, zircon (zrn; zoned) and biotite; E) The REE minerals with amphibole, titanite, magnetite, zircon and apatite.*

(Plate 8A, B), and the presence of Z folds in folded boudins (Plate 8C–F), indicate dextral movement, although locally sinistral movement was also observed.

On outcrop-scale, folds are steeply reclined to vertical, and plunge steeply to the east at Foxtrot in the southern part of the EFHVB and to the west at the Road Belt in the northern part of the EFHVB (Figure 5). The geometry of the folds is generally cylindrical, symmetrical, isoclinal to closed, equant to tall with subrounded to angular hinges (Plate 8C–F). Using the classification of Ramsay (1967), the folds can be classified as 1B to 2 class folds, with ptygmatic folds

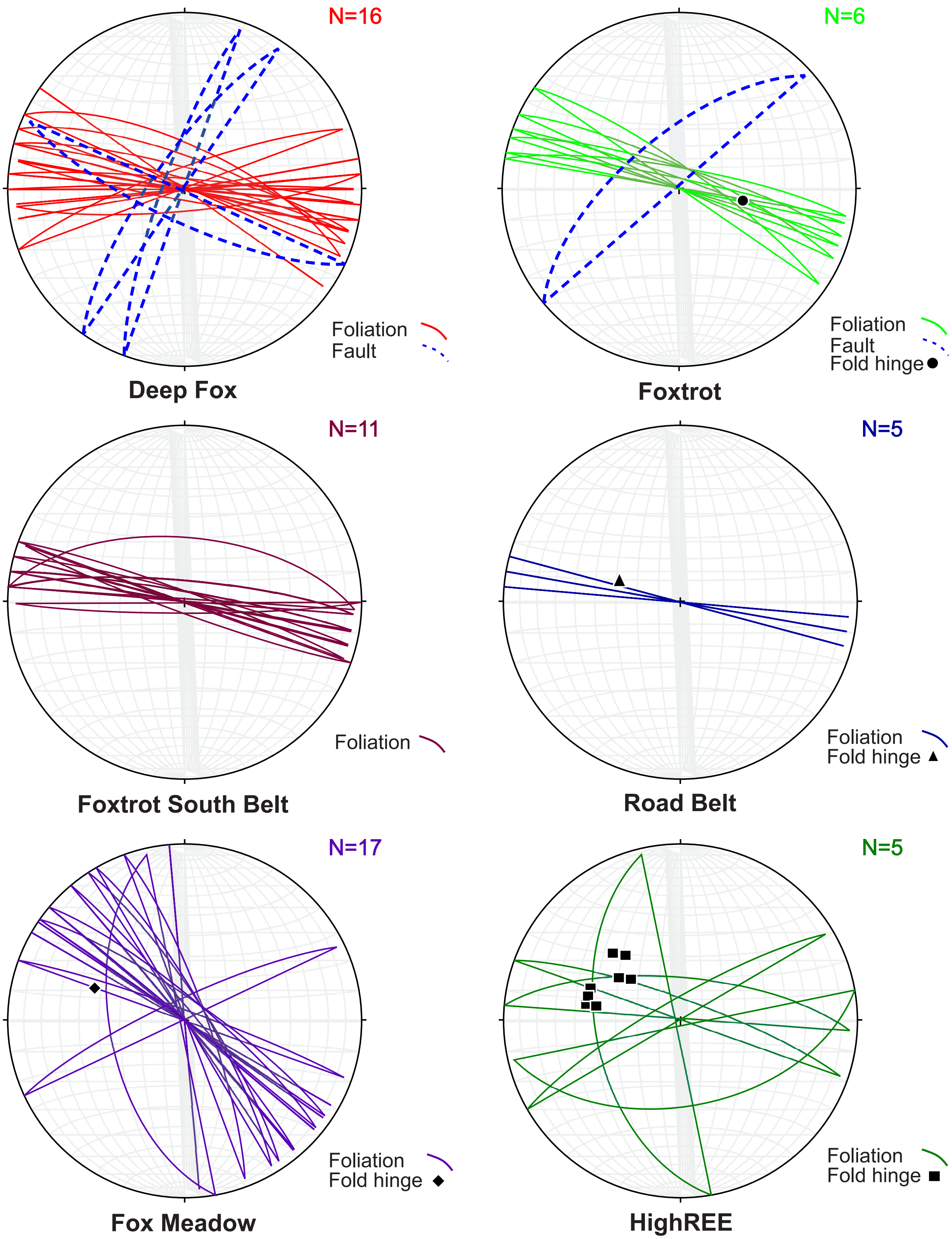



**Figure 5.** *Stereonet plots of structural measurements in the EFHVB (Deep Fox, Foxtrot, Foxtrot South Belt and Road Belt), WFHVB (Fox Meadow) and HighREE Island occurrences.*

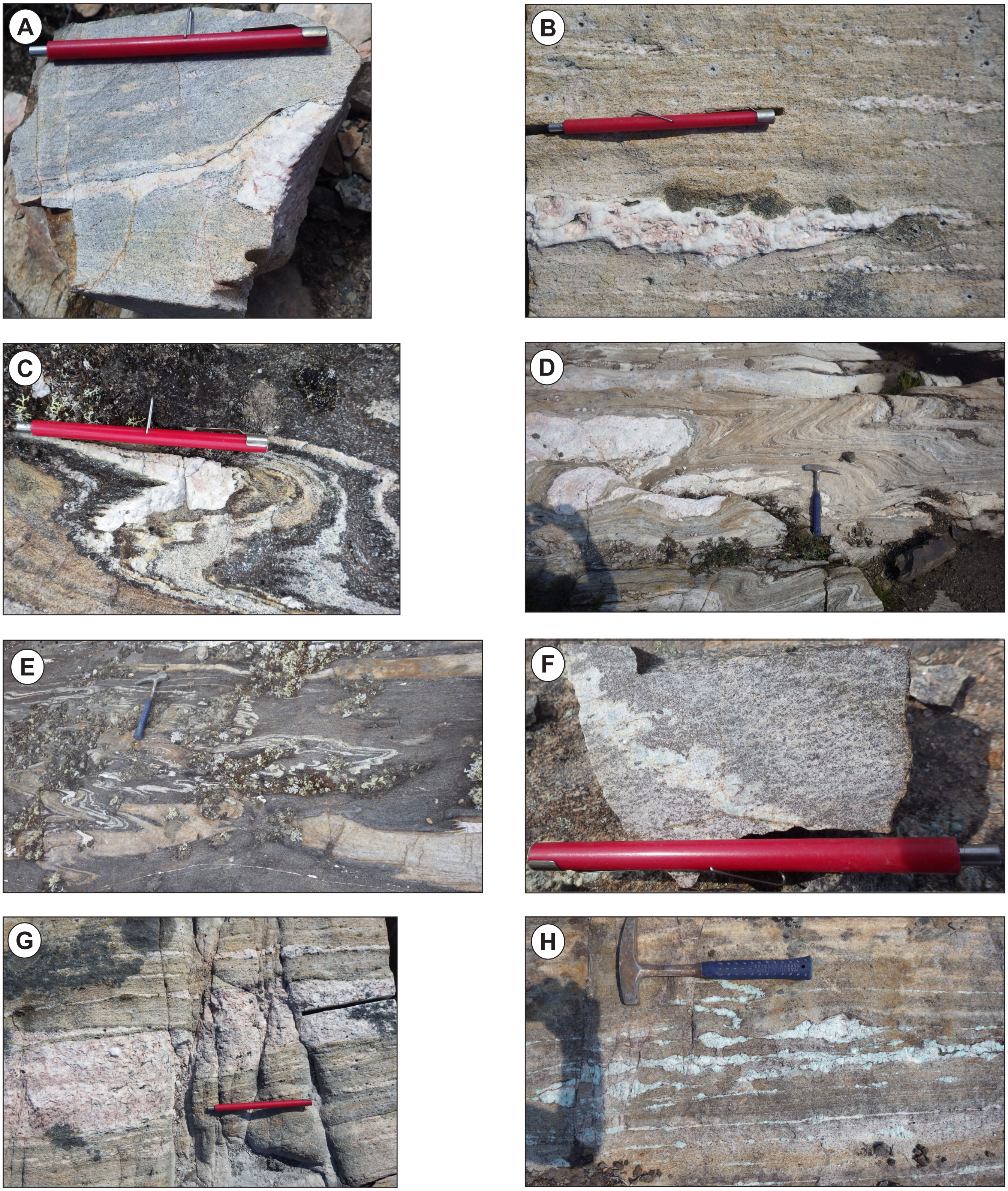



**Plate 8.** *Structural features in the EFHVB. A) Rotated pegmatite boudin indicating dextral movement; B) Clockwise-rotating boudins indicating dextral movement; C and D) Z-folded pegmatites; E) Complex folding of rocks with differing competency; F) Ptygmatic folds of pegmatite layer; G and H) Late brittle faults showing sinistral movement approximately perpendicular to earlier foliation.*

of the more competent pegmatites and felsic layers typically occurring as 1B class folds, and the less competent mafic units forming 1C to 2 class folds.

Late brittle faults were observed on outcrops throughout the EFHVB, predominantly striking southwest with dips ranging from 60 to 80º, but a few southeasterly striking brittle faults were also observed (Plate 8G, H). Detailed mapping from channel sampling and drilling indicate that movement along the late brittle faults is up to 25 m, being either sinistral or dextral (Figure 3). Thicknesses of some units also vary dramatically across some of the late brittle faults indicating that the faults are oblique-slip faults.

### Fox Meadow

Foliations at Fox Meadow trend northwest–southeast (mean value ~315º) with dips ranging from 55 to 90°, predominantly to the northeast (Figure 5). Pegmatite boudins, quartz veins and felsic layers vary from being parallel to the foliation and folded, to being oblique to, or at a high angle to, the foliation, suggesting that there is more than one generation of pegmatites and/or more than one deformational events of differing directions (Plate 9A–D). No late strike-slip faults were observed at the outcrop scale.

Folds are vertical to steeply reclined and plunge moderately to the W (290º/45º). They vary from being cylindrical, symmetrical to asymmetrical, isoclinal to closed, equant to tall and have sharp to subrounded hinges. According to the classification of Ramsay (1967), they are 1C to 2 class folds (Plate 9B–D). Ptygmatic folding of pegmatites and felsic rocks also commonly form 1C to 2 class folds.

### HighREE Island

Foliation at HighREE Island varies from east to west (80 to 290º) with moderate to steep dips (50 to 80º; Figure 5). There are several generations of pegmatites with varying structural habits and relationships. Some pegmatites are tightly or concentrically folded, whereas others crosscut all folds and older pegmatites (Plate 10A, B). Boudins of pegmatites were not observed, possibly due to pegmatites in this area being more massive, locally up to 4 m wide.

There are two distinct generations of folding at HighREE Island (Plate 10C, D). The F1 folds are predominantly represented by 1B to 3 class folds (Ramsay, 1967), forming cylindrical, isoclinal to tight, symmetrical, equant to tall with sharp to subangular folds (Plate 10C–E). Some of the hinges of these folds are collapsed. The F2 folds form

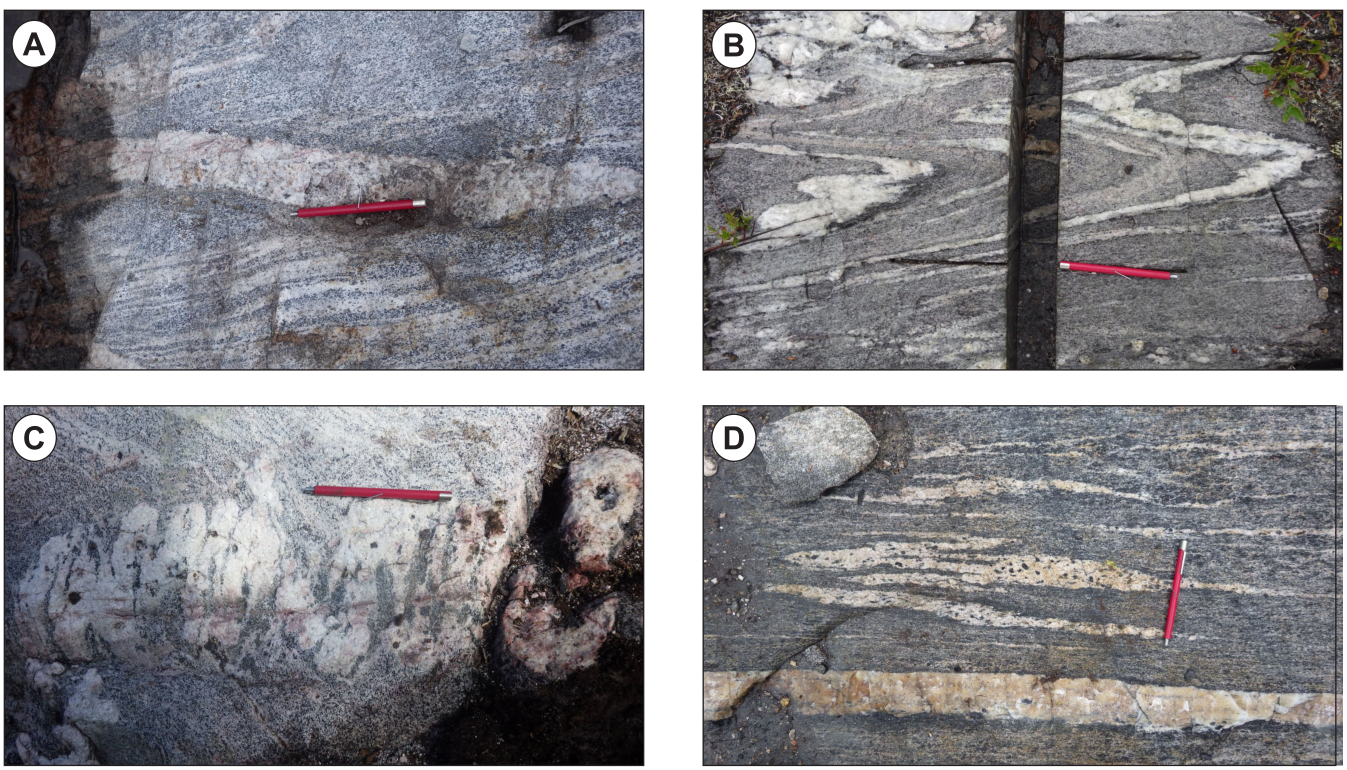
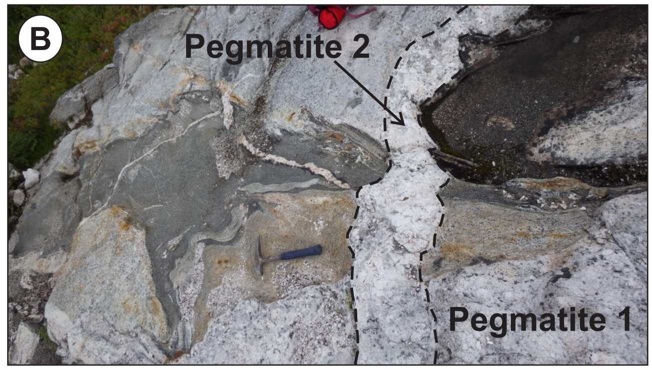
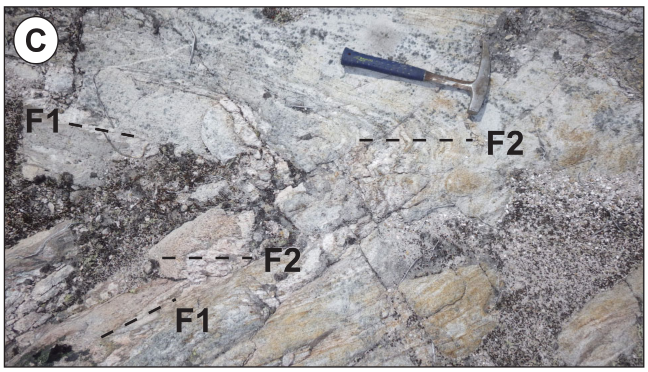
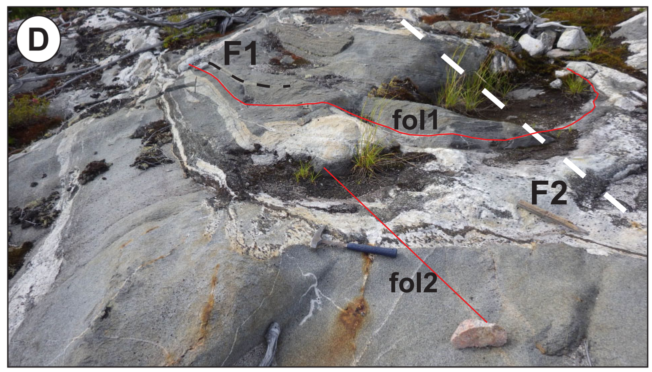


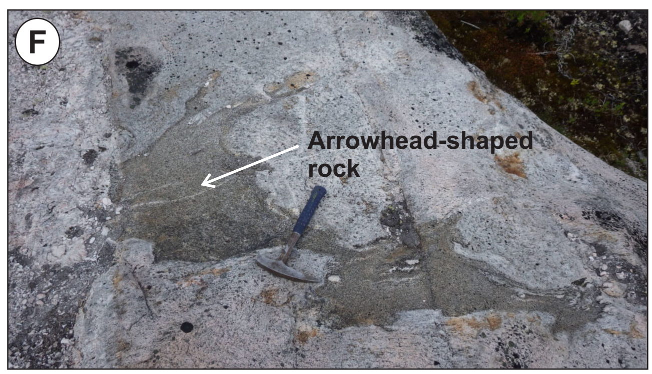

**Plate 9.** *Structural features from the Fox Meadow occurrence. A) Pegmatite dyke crosscutting foliation; B) Tightly folded rock units; C) Ptygmatic folds of pegmatite oblique to the foliation; D) Isoclinal ptygmatic folds of felsic layer.*





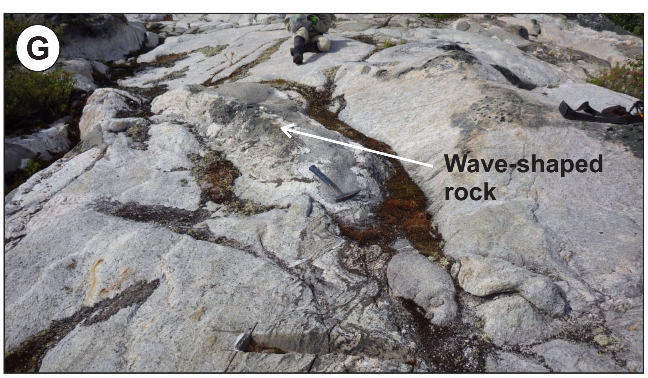




**Plate 10** *Structural features from the HighREE Island occurrence. A) Pegmatite dyke crosscutting foliation; B) Younger pegmatite dyke cutting an older pegmatite dyke; C) Two generations of folds: older F1 folds are refolded by younger F2 folds; D) Moderately plunging, broad, open F2 fold refolding tight F1 fold and foliation (fol1); E) Weakly developed C-S fabric; F) Arrowhead-shaped darker rock indicating fold interference pattern; G) Wave-shaped darker rock indicating fold interference pattern.*

1B class folds that are also cylindrical and symmetrical, but typically occur as broad, closed to open folds with subrounded to rounded hinges (Plate 10D). Refolding of older folds is suggested by fold axes of the tighter folds being refolded (Plate 10C, D). Discontinuous rock units, resembling arrowhead and wave shapes, may also indicate fold interference patterns (Plate 10F, G). Fold hinges predominantly plunge moderately (280 to 320º/45 to 60º) to the west and northwest including both generations of folds, as it is not always possible to distinguish between the two different generations. The REE mineralized units, composed of quartz–magnetite ± biotite ± amphibole, are tightly folded and commonly occur in the hinges of the F1 folds, suggesting that they are either pre- or syn-deformation relative to F1 folding. They extend from the collapsed hinges of tight folds or locally resemble "saddle reef" structures, although the mechanism of formation is uncertain (Plate 11A, B).

## DISCUSSION

### VARIATIONS IN LITHOLOGY, REE MINERALIZATION AND STRUCTURES

Although there are many similarities among the EFHVB, the WFHVB and the HighREE Island, preliminary results have also identified significant differences in lithology, styles of REE mineralization and structural features. Some of the perceived differences between the EFHVB and the WFHVB, such as the relative lack of felsic rocks and the lack of late brittle faults in the latter, may be the result of poor exposure, and hence under-representation of rock units and relationships, in the WFHVB.

#### Rock Types and REE Mineralization

In all areas, REE mineralization is hosted or spatially associated with peralkaline felsic rocks within the FHVB. The REE minerals occur with zircon, mafic minerals, and locally magnetite, titanite, and apatite. In peralkaline rocks, mafic minerals, zircon and REE minerals commonly crystallize late and are spatially associated (Collins *et al.*, 1982; Whalen *et al.*, 1987; Magyarosi *et al.*, 2019), but the association of magnetite, titanite and apatite with these minerals is not well understood. Magnetite is commonly surrounded or spatially associated with titanite, which may be metasomatic (Broska and Petrík, 2015; Mikhailova *et al.*, 2021) or metamorphic in origin (Burziński *et al.*, 2017).

In the EFHVB, most of the REE minerals are hosted in pantellerite and lesser amounts in comendite. Pegmatites, and even the surrounding rocks, around some high-grade mineralization contain amazonite. The amount of REE minerals has a positive correlation with the amount of zircon, magnetite and the scintillometer readings of the rocks. Differences in lithology and REE mineralization between the EFHVB, the WFHVB and the HighREE Island occurrence include:

- The main rock type in the WFHVB is trachitic in composition containing albite as the main mineral instead of quartz, which occurs only in trace amounts. It contains more pyroxene, no apatite, less magnetite and more ilmenite than the pantellerite in the EFHVB.

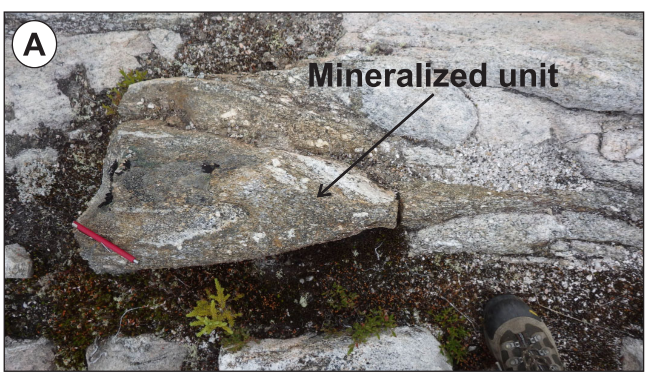
- The REE minerals are the same in the east and west, but there is more allanite in the EFHVB and slightly more fergusonite in the WFHVB.

- The dominant rock type at HighREE Island is a coarser grained variety of the non-peralkaline rhyolite in the EFHVB, with other felsic rocks being similar to comendite in the EFHVB.

- Preliminary examination suggests that HighREE lacks mafic rocks, but contains rocks of intermediate composition. More work needs to be done to determine all rock types found on the island.

- There is a greater abundance of pegmatites at HighREE Island.

- Mineralization at HighREE Island is hosted in distinct units, the most common of which have similar mineralogy to the darker, magnetite-rich layers in comendite in the EFHVB, albeit coarser grained. Some of the mineralization at HighREE Island also occurs in peg-



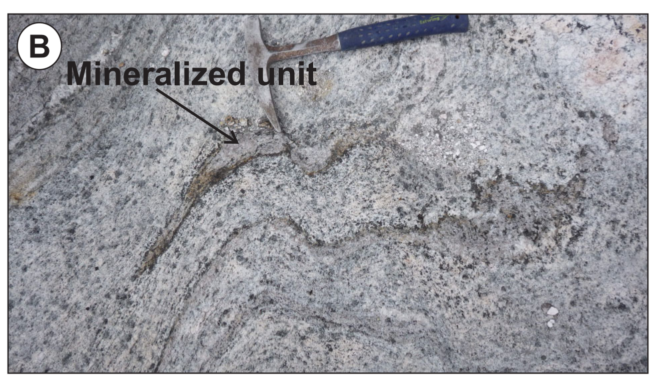




**Plate 11** *Structural features from the HighREE Island occurrence. A) Mineralized unit in the collapsed hinge of a tight fold; B) Mineralized unit resembling "saddle reef" structure.*

matites, the origin of which are unknown, and in the intermediate rocks, or as very fine-grained, strongly magnetic and radioactive brown–pink veinlets.

- At the HighREE Island occurrence, the main REE mineral is allanite and no fergusonite was identified in the samples examined with SEM.

- Apatite is common in the EFHVB and the HighREE Island occurrence, where it is typically spatially associated with REE minerals, but it has not been observed in the WFHVB.

As suggested by Miller (2015), the rocks at HighREE Island may have been intrusive and subvolcanic, rather than volcanic as interpreted for the FHVB. This is indicated by the generally coarser grain size of the rocks at HighREE Island, in addition to the mineralization occurring as separate units, which is similar to Strange Lake, where REE mineralization is hosted in pegmatites intruding peralkaline granite; and the lack of interlayered mafic rocks and associated epidote pods. The intermediate rocks may represent dykes intruding the felsic rocks.

### Structures

The strong foliation displayed by all rock units in the FHVB is interpreted to be mostly due to metamorphism and deformation during Grenville orogenesis. This is suggested by the type of deformation being similar in style and orientation to the surrounding rocks and the Grenvillian age of metamorphism indicated by the growth of zircon in the FHVB (Haley, 2014). However, the presence of primary igneous layering cannot be ruled out and needs to be further investigated.

Pegmatites and felsic layers/lenses occur in all rock types in the FHVB, but in the EFHVB, the pegmatites are concordant with the foliation, and at the Fox Meadow and HighREE Island occurrences there are more than a single generation of pegmatites, crosscutting each other (Plate 10A), some folded and some cutting both foliation and folding. The origin of the felsic layers and pegmatites has not been investigated, but pegmatites intruding metasedimentary rocks on Battle Island, located ~12 km southeast of the EFHVB, some of which are also amazonite-bearing, yielded Grenvillian ages (Kamo *et al.*, 2011; Peressini, 2000). Pegmatites occurring in the Mealy Mountains terrane to the west of the FHVB likewise returned Grenvillian ages (Gower, 2019). Therefore, most of the pegmatites at FHVB probably formed as a result of metamorphism and deformation during Grenville orogenesis. The origin of medium-grained quartzofeldspathic layers has not been investigated, but they are most likely Grenvillian as well, possibly representing leucosomes that originated from the surrounding rocks or migrated upward from greater depths.

The dextral movement and shortening in the EFHVB, observed in this study, is consistent with Gower (2019) suggesting dextral-oblique-slip, northeast-side-up motion in the eastern structural wedge of the Mealy Mountains terrane occurring during Grenville orogenesis. The late brittle faults are more or less parallel to the Long Range dykes and large quartz veins occurring along major faults to the west and southwest and are related to the opening of the Iapetus Ocean (Gower, 2019).

Differences in structures throughout the FHVB include:

- The trend of foliations varies from east to west along the FHVB. In the EFHVB, the foliation has a west-northwest–east-southeasterly strike, whereas in the WFHVB, the foliation changes to a northwest–south-easterly strike (Figure 5).

- In the EFHVB, there is a change in the plunge of folds from south to north, with moderately east-plunging folds in the south and moderately west-plunging folds in the north.

- Pegmatites in the EFHVB are parallel to the foliation, suggesting that they are pre- or syn-kinematic. However, in the WFHVB and HighREE Island, some pegmatites are parallel to the foliation, whereas others crosscut the foliation and are unfolded or gently folded, suggesting more than one generation of pegmatites and/or more than one deformational event of different orientations.

- Tighter folds at WFHVB possibly reflect changes in rock types, pressure and/or temperature.

- Presence of at least two generations of folding of different directions at HighREE Island.

## CONTROVERSIES ON THE GENESIS OF THE FOX HARBOUR VOLCANIC BELT

The REE mineralization in peralkaline rocks typically occurs in two stages (Dostal, 2016). The first stage happens during the fractional crystallization of the magma, which is overprinted by late-magmatic to hydrothermal fluids in the second stage that remobilize and enrich the original ore. However, according to Miller (1993, 2015), REE mineralization in peralkaline volcanic rocks, such as the FHVB, occurs as vent or caldera filling or near-vent magma flows and/or ash-flow tuffs that represent late magmatic, small volumes of strongly fractionated magma. At the FHVB, significantly more work is needed to determine whether REE mineralization is the result of magmatic or hydrothermal processes or a combination of the two processes. These are further complicated by metamorphism and deformation that may have modified REE mineralization. Haley (2014) suggested that metamorphism occurred in a closed system for Lu–Hf and there was no flux of REE into or out of the rocks during metamorphism. However, remobilization of REE within the FHVB may have occurred.

The origin of the FHVB is controversial. In Labrador, peralkaline magmatism and associated AMCG magmatism are interpreted to be the result of the crust migrating above a spreading centre, providing mantle-derived melts and inciting lower crustal melting (Gower and Krogh, 2002; Gower, 2019). Previous research also suggests a mantle input for the A-type peralkaline rocks (Clemens *et al.*, 1986; Eby, 1990; Martin, 2006), including Strange Lake (Kerr, 2015), yet Hf isotopes at FHVB indicate partial melting of felsic crustal material with no apparent input from the mantle (Haley, 2014).

The extent of the FHVB is also problematic. Following regional mapping, Gower (2019) concluded that the FHVB consists of the three mineralized belts, which intrude older rocks separating the three belts. This conclusion was based on the similarities of the rocks separating the three belts to the rocks occurring in the Mealy Mountains and Lake Melville terranes to the west and north of the FHVB. However, Miller (2015) interpreted the rocks between the three mineralized belts to be part of the FHVB and renamed the three belts and the rocks occurring between them as Fox Harbour domain. Miller (2015) also separated the area to the south of the FHVB containing REE occurrences, including the HighREE Island occurrence, from the Pinware terrane as HighREE Hills domain. Clearly, detailed examination and dating of the rocks surrounding the mineralized units is essential to determine the spatial extent of the FHVB.

## SUMMARY

- REE mineralization in the Port Hope Simpson area is hosted in peralkaline rocks of the FHVB.

- The FHVB is ~64 km long, with variable widths between 50 m in the west to 3 km in the east. It is divided into three parallel belts in the eastern half and one belt in the west, and is associated with peralkaline rocks to the south (*e.g.*, HighREE Island).

- The age of FHVB is *ca.* 1.3 Ga (Haley, 2014), similar to other peralkaline intrusions hosting REE mineralization farther to the north (*e.g.*, Strange Lake and Flowers River complexes, Red Wine Intrusive Suite).

- The peralkaline complexes formed during post-Pinwarian–pre-Grenvillian (Elsonian) (1460–1090 Ma) events that were also responsible for AMCG magmatism, some of which is spatially associated with the peralkaline complexes. Peralkaline complexes and associated AMCG magmatism are interpreted to have intruded as a result of the crust migrating above a spreading centre, which provided mantle-derived melts and induced melting of the lower crust (Gower and Krogh, 2002).

- The FHVB and the rocks at HighREE Island were exposed to amphibolite-facies metamorphism and extensive deformation during Grenville orogenesis *ca.* 1.05 Ga.

- Hafnium isotope data from the FHVB suggests partial melting of 1.9 to 1.5 Ga crustal rocks as the source of the FHVB (Haley, 2014).

- The main lithologies in the FHVB are pantellerite, comendite, non-peralkaline rhyolite, pantelleritic trachyte to comenditic trachyte, mafic to ultramafic rocks, minor volcaniclastic sedimentary rocks and quartzite. In the WFHVB, the rocks contain less quartz and more mafic minerals than in the EFHVB.

- In the EFHVB, high-grade mineralization (Dy concentrations between 100 and 300 ppm) is hosted in pantellerite and lower grade mineralization (Dy concentrations between 20 and 100 ppm) is hosted in comendite.

- Pantellerite and comendite are strongly magnetic, due to significant amounts of magnetite, and radioactive, providing easy exploration targets using geophysical tools.

- Mineralized rocks contain significant amounts of zircon. The concentration of Zr in pantellerite containing high-grade REE mineralization is typically more than 10 000 ppm and shows a positive correlation with the ore grade.

- In the FHVB, the main REE minerals are allanite, containing mostly LREE, and fergusonite, containing HREE and minor amounts of LREE (Haley, 2014; Masun *et al.*, 2016). The main REE mineral at the HighREE Island occurrence is allanite.

- The REE minerals are spatially associated with zircon, mafic minerals and locally magnetite, titanite, and apatite.

- All rocks, except some of the pegmatites, are strongly foliated and folded, and metamorphosed to amphibolite facies. However, there are variations in the orientation of the structures and possibly the number of deformational events along the FHVB and at the HighREE Island occurrence to the south.

- REE mineralization at HighREE Island is associated with peralkaline rocks, but occurs in dykes and veins. The host rocks may represent the intrusive and subvolcanic equivalent of the FHVB.

## FURTHER WORK

Further work will include geochronology of the rocks throughout the FHVB, the surrounding rocks (*e.g.*, anorthosite north of the Road Belt, rocks separating the three mineralized belts), and the host rocks of REE mineralization south of the FHVB at HighREE Island. Geochemical analyses will help identify rock types, REE concentrations, and in the interpretation of the tectonics and origin of the host rocks, as well as the relationship between the different units of the FHVB. Further SEM and additional Electron Probe Microanalyzer (EPMA) analyses will be undertaken to identify all minerals (silicate, REE, opaque), textural features, mineral associations, and zoning. This will be helpful in distinguishing various processes leading to REE mineralization, including magmatic, metamorphic and hydrothermal processes, and will help confirm the grade of metamorphism. Neodymium and Sm isotopes, in addition to other isotopes (O, C), will shed light on the origin of the rocks (*e.g.*, mantle *vs.* crustal origin). A detailed structural study will examine the effects of deformation on the host and surrounding rocks, and REE mineralization.

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