REE mineralization associated with peralkaline complexes in Newfoundland and Labrador

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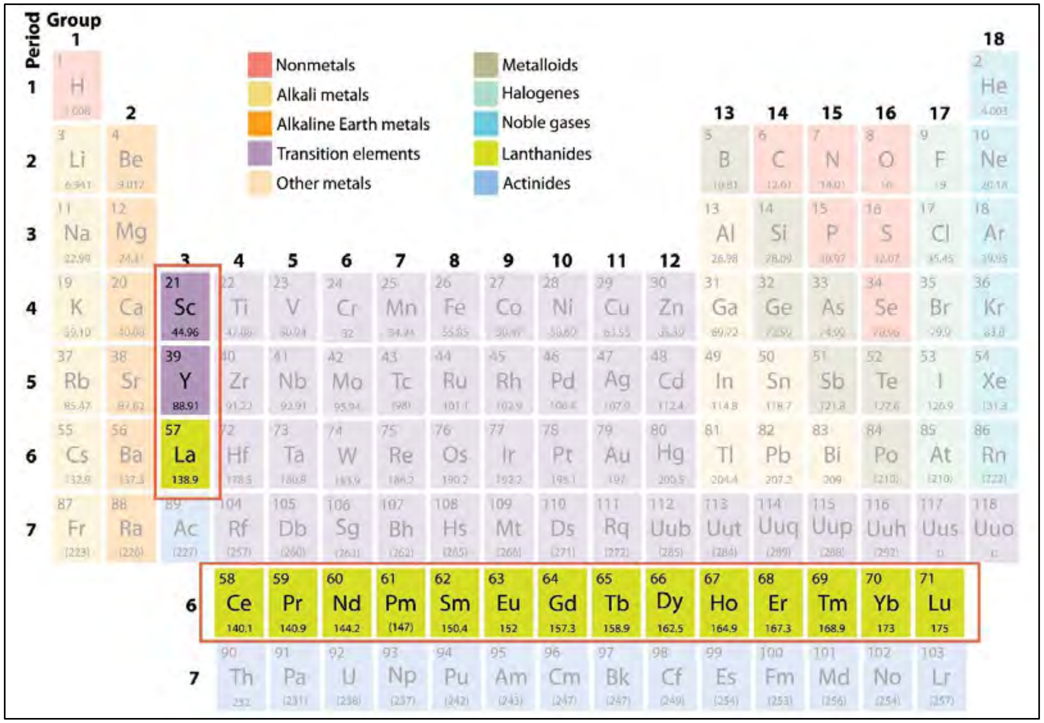
Outline

- Rare earth elements (REE): list, uses
- Deposit types
- Metallurgical challenges
- Peralkaline complexes: rock types, REE mineralization, tectonic setting, temporal distribution
- Labrador peralkaline complexes: Fox Harbour, Strange Lake, Red Wine-Letitia Lake, Flowers River
- REE occurrences in Newfoundland
- Exploration

Rare Earth Elements (REE)



- REE include 15 lanthanides (La to Lu) plus Sc and Y
- Have similar chemical and physical properties: they all form stable 3+ charge ions of similar size, except a few (e.g. Eu)
- Lanthanide contraction: they decrease in radius with increasing atomic number
- They are not rare based on their relative abundance in Earth's crust, but unusual to find them in quantities sufficient for economic extraction

Divided into :

LREE: La to Sm
HREE: Gd to Lu

Or:

LREE (light REE): La to Nd
MREE (middle REE): Sm to Ho (Pm does not occur in nature)
HREE (heavy REE): Er to Lu

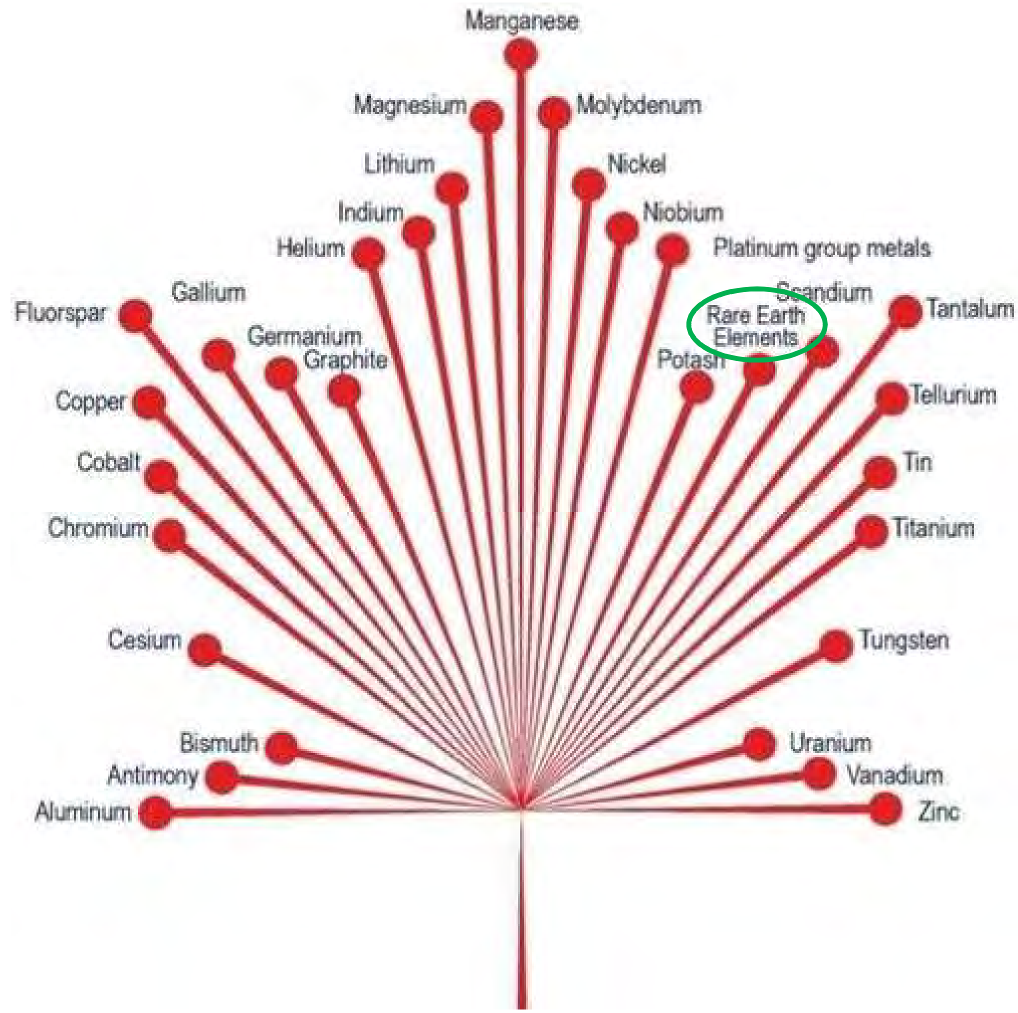
https://www.rareelementresources.com/rare-earth-elements/rare-earth-elements#.Y0V3slLMJPY; Hollings and Wyman, 2013

Critical minerals

Canada’s Critical Minerals List 2021:

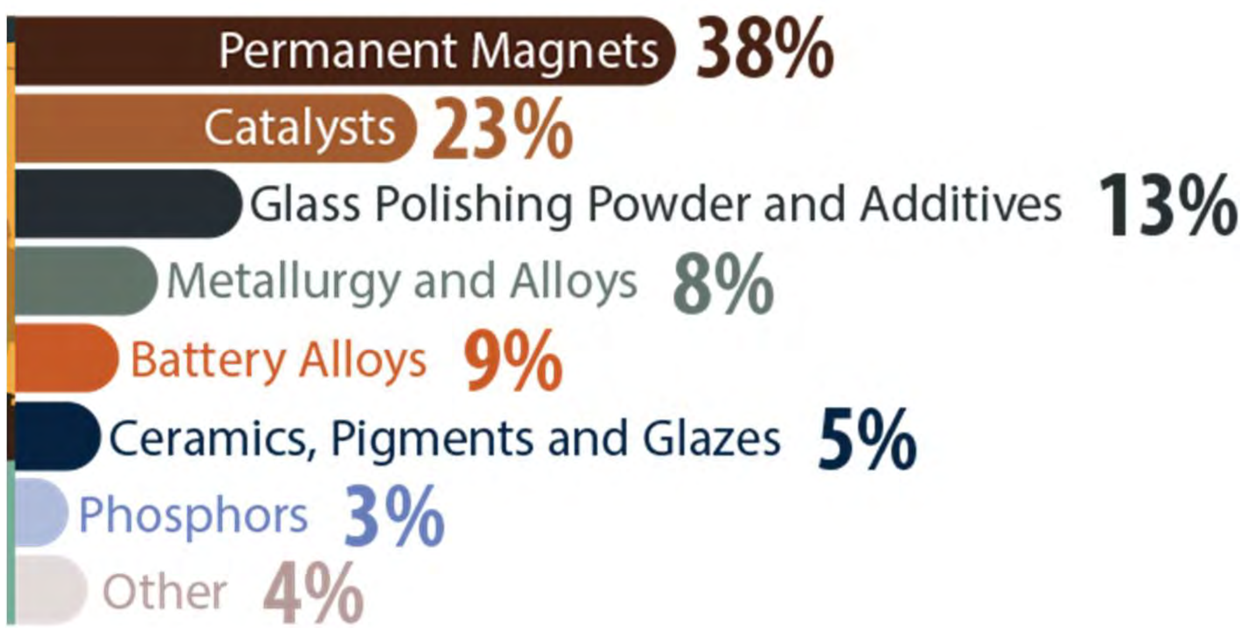
- Essential to Canada’s Economic Security
- Required for Canada’s transition to a low-carbon economy
- Provide a sustainable source of critical minerals for our partners

REE are part of the critical minerals list and also in the early prioritization list released in September 2022



https://www.nrcan.gc.ca/our-natural-resources/minerals-mining/critical-minerals/23414;
https://www.canada.ca/en/campaign/critical-minerals-in-canada/canada-critical-minerals-strategy-discussion-paper.html

REE uses



Critical for transition to low-carbon economy

Electronics, clean energy, aerospace, automotive, defense industry

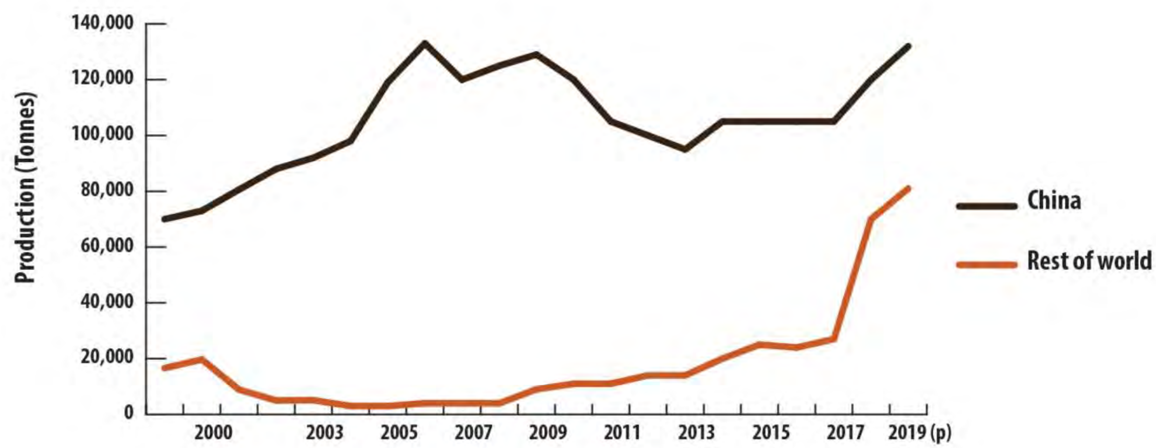
Permanent magnets: cell phone, TV, computers, cars, wind turbines, jet aircrafts

https://www.nrcan.gc.ca/our-natural-resources/minerals-mining/minerals-metals-facts/rare-earth-elements-facts/20522

REE production in the world

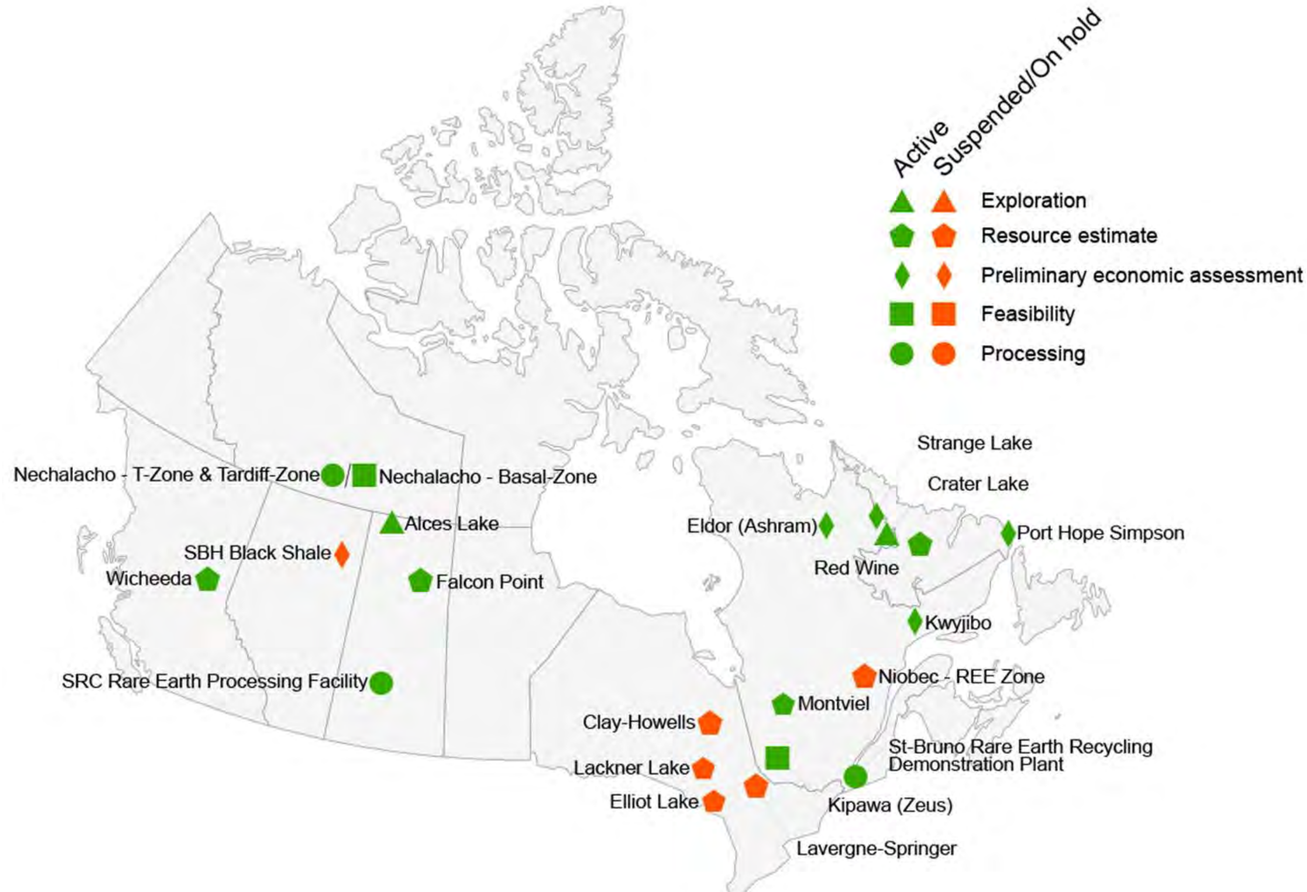
World production of REEs, by country, 2020 (p)

Ranking	**Country**	**Thousand tonnes**	**Percentage of total**
1	China	140	57.5
2	US	38	15.6
3	Burma	30	12.3
4	Australia	17	7
5	Madagascar	8	3.3
	Other	10.3	4.2
	Total	**243.3**	**100**



https://www.nrcan.gc.ca/our-natural-resources/minerals-mining/minerals-metals-facts/rare-earth-elements-facts/20522

REE projects in Canada



Canada is not a current producer, but has some of the largest resources/reserves of REE

In 2021, Nechalacho initiated a small-scale demonstration mining project.

https://www.nrcan.gc.ca/our-natural-resources/minerals-mining/minerals-metals-facts/rare-earth-elements-facts/20522

REE Deposits

Four types of REE deposits:

1. Carbonatites: primary source of LREE (not significant in NL)
2. Peralkaline complexes:
    - Enriched in both HREE and LREE
    - Early studies indicate that processing and mining may be more beneficial than carbonatites and ionic clay
    - Also enriched in HFSE (Nb, Zr, Th, U), F, P, Sc
3. Ion-adsorption clay-type: primary source of HREE
4. Placer-type

All known REE occurrences in NL are likely associated with peralkaline complexes.

Verplanck and Hitzman, 2016; Dostal, 2016; Goode, 2021; Beard et al., 2022

Metallurgical challenges

- The diversity of minerals even within one district is much greater than in base or precious metal deposits
- REE minerals represent 233 (4 %) of the 5,455 known minerals
- Currently only 4 are processed commercially: Bastnaesite-Ce, Monazite-Ce, Loparite-Ce, Xenotime-Y, and Apatite in the past

Mineral	Formula	REE oxides %
Allanite (Ce)	$(Ln,Ca,Y)_2(Al,Fe^{3+})_3(SiO_4)_3(OH)$	38
Allanite (Y)	$(Y,Ln,Ca)_2(Al,Fe^{3+})_3(SiO_4)_3(OH)$	39
Apatite	$(Ca,Ln)_5(PO_4)_3(F,Cl,OH)$	19
Barylate	$BaBe_2Si_2O_7$	
Bastnäsite (Ce)	$(Ln,Y)(CO_3)F$	75
Britholite (Ce)	$(Ln,Th,Ca)_5(SiO_4,PO_4)_3(OH,F)$	32
Elpidite	$Na_2ZrSi_6O_{15}\cdot 3H_2O$	
Eudialyte	$Na_4(Ca,Ln)_2(Fe^{2+},Mn^{2+},Y)ZrSi_8O_{22}(OH,Cl)_2$	9
Fergusonite (Ce)	$(Ln,Y)NbO_4$	53
Fergusonite (Y)	$YNbO_4$	46
Gadolinite (Ce)	$(Ln,Y)_2Fe^{2+}Be_2Si_2O_{10}$	60
Gadolinite (Y)	$Y_2Fe^{2+}Be_2Si_2O_{10}$	48
Gittinsite	$CaZrSi_2O_7$	
Kainosite (Y)	$Ca_2(Y,Ln)_2Si_4O_{12}(CO_3)\cdot H_2O$	38
Loparite (Ce)	$(Ln,Na,Ca)(Ti,Nb)O_3$	30
Monazite	$(Ln,Th)PO_4$	65
Parisite (Ce)	$Ca(Ln)_2(CO_3)_3F_2$	61
Pyrochlore	$(Ca,Na,Ln)_2Nb_2O_6(OH,F)$	
Steenstrupine (Ce)	$Na_{14}Ln_6Mn_2Fe_2(Zr,Th)(Si_6O_{18})_2(PO_4)_7\cdot 3H_2O$	31
Synchysite (Ce)	$Ca(Ln)(CO_3)_2F$	51
Synchysite (Y)	$Ca(Y,Ln)(CO_3)_2F$	42
Titanite	$(Ca,Ln)TiSiO_5$	4
Xenotime (Y)	$(Y,Ln)PO_4$	61
Zircon	$(Zr,Ln)SiO_4$	4

Dostal, 2016; Beard et al., 2022 and references within

Metallurgical challenges

GOOD

- Metallurgical procedures are in the pilot stage for a few other minerals including: Eudialyte, Steenstrupine, Allanite
- Recovery rates and energy usage are also improving
- Peralkaline/alkaline rocks include other critical elements that are commercially extracted: Nb (pyrochlore, columbite), Ta (columbite), P (apatite), Zr and Hf (zircon)

LESSON

- REE mineralogy and texture (grain size, mineral associations) should be considered early in the exploration process: petrography, SEM, other microanalytical techniques

Beard et al., 2022 and references within

Peralkaline/alkaline rocks

Alkaline implies enrichment in Na and K: granites and syenites

Peralkaline: molar (Na+K)/Al > 1 (agpaitic index), therefore contain minerals with excess alkalis such as sodic pyroxene (aegirine) and amphibole (arfvedsonite, hastingsite)

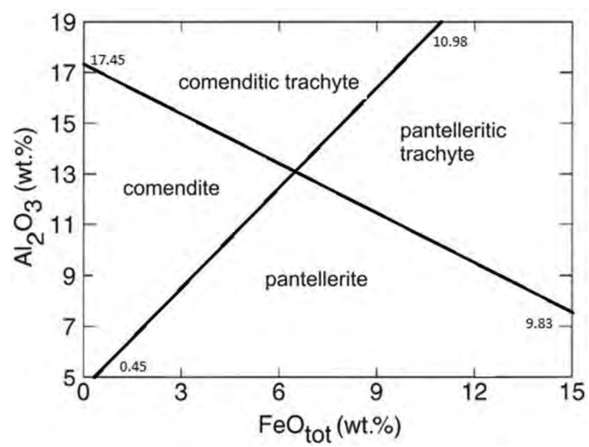
Peralkaline rocks can be both silica-saturated (quartz-bearing) or silica-undersaturated (feldspathoid-bearing: nepheline, no quartz)

Peralkaline volcanic rocks include pantellerite (higher Fe and lower Al content), comendite, pantelleritic and comenditic trachyte, phonolites

Feldspathoid-bearing rocks with (Na+K)/Al < 1 are classified alkaline

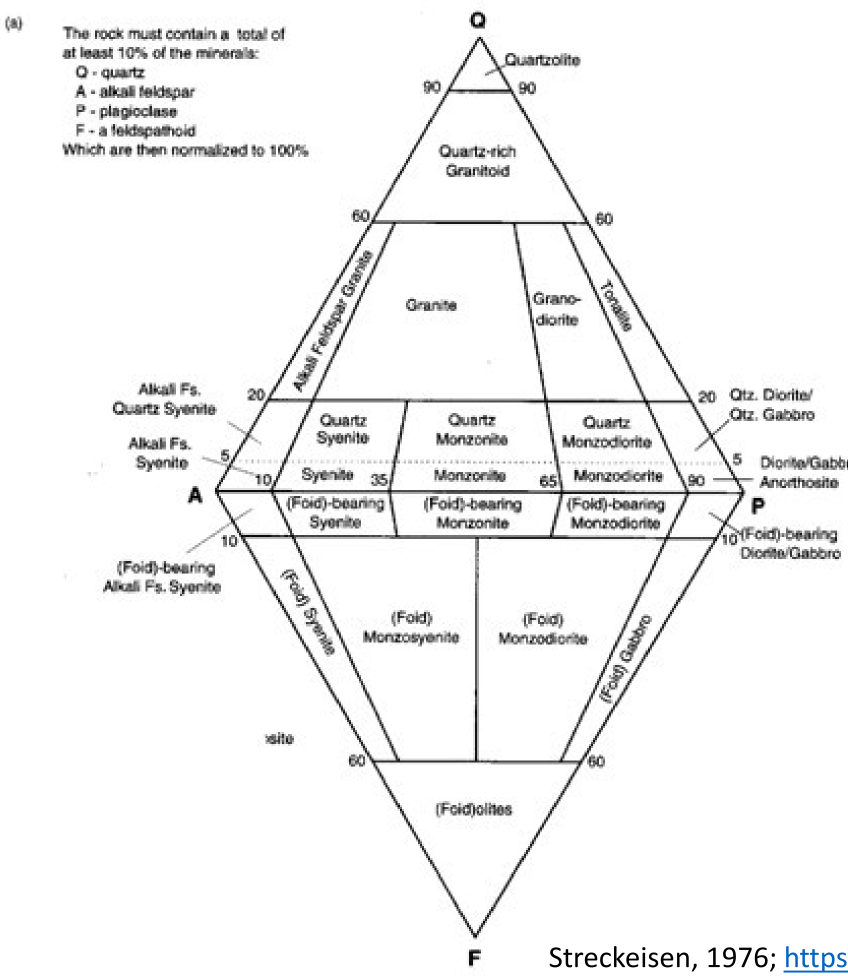
Dostal, 2016; Beard et al., 2022

Peralkaline granite

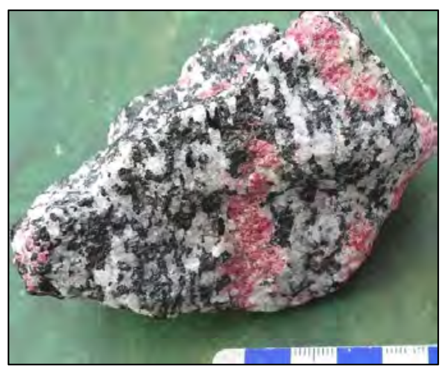


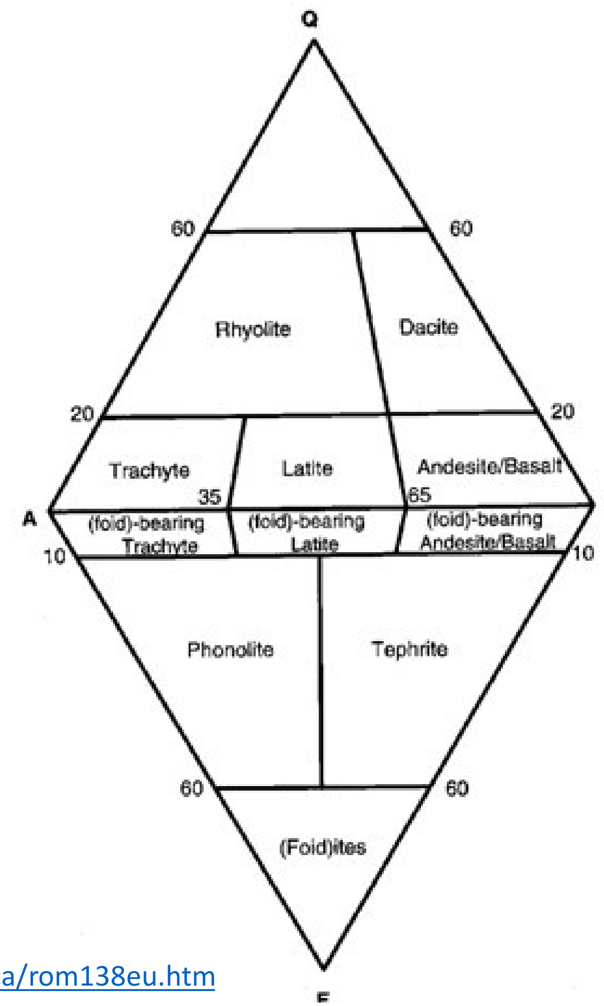
Pantellerite

Rock types



Foid = felspathoid
(nepheline, sodalite)





Streckeisen, 1976; https://minrocscience.com/; https://turnstone.ca/rom138eu.htm

Peralkaline complexes

Typically polyphase intrusions, but not all phases are peralkaline

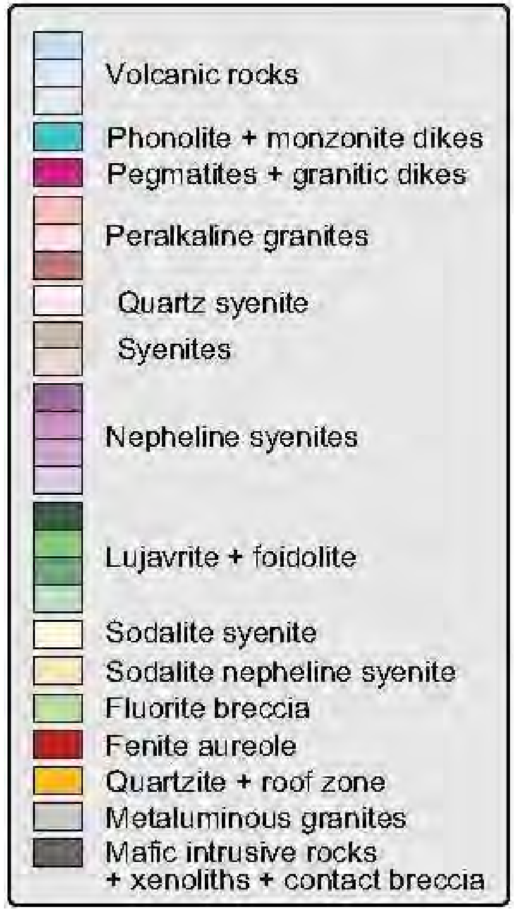
Not all peralkaline complexes contain REE mineralization

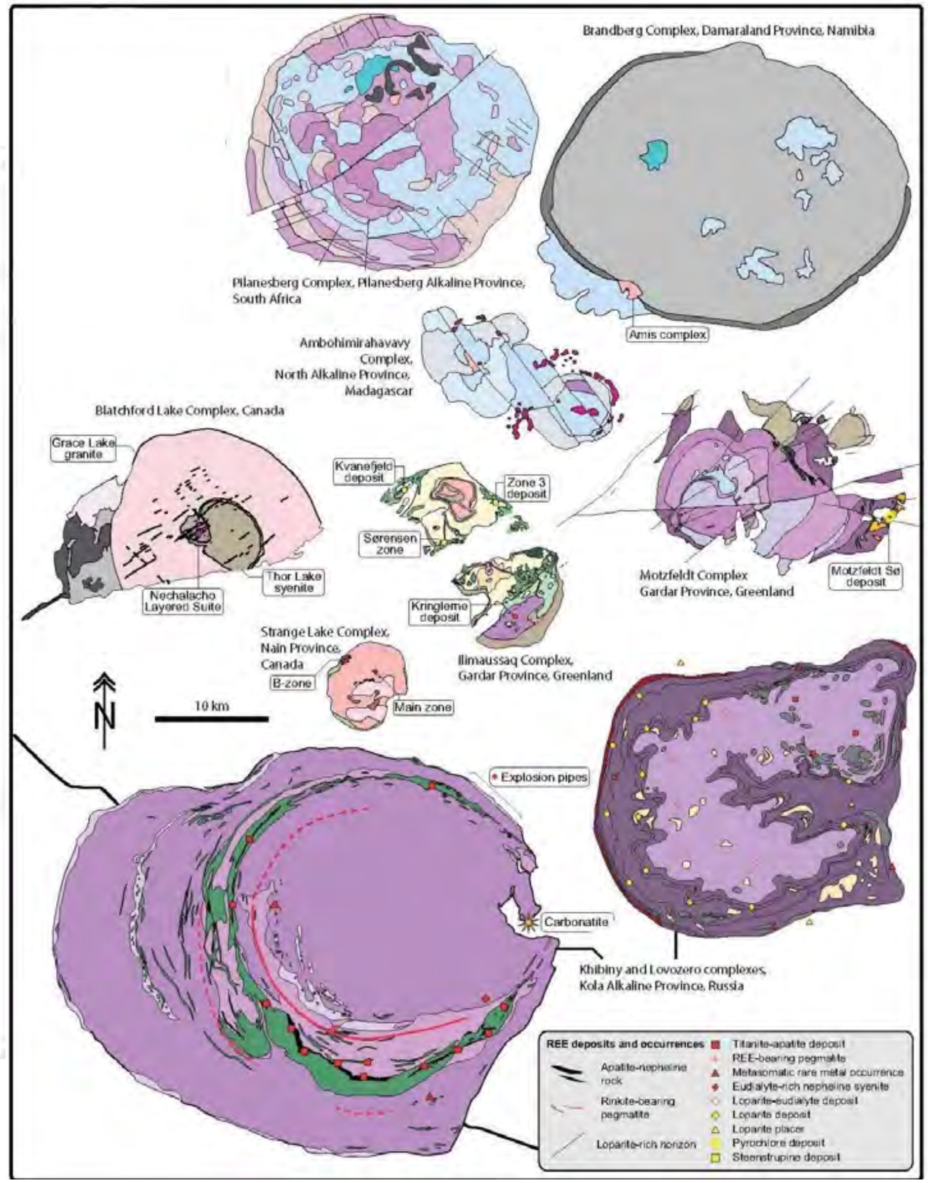
Only a few phases are associated with REE-HFSE mineralization

Some are bimodal (felsic and mafic)

Range in size from 5-40 km

Quartz-undersaturated complexes are larger





Lujavrite = nepheline syenite rich in eudialyte, arf, aeg
Fenite = alteration around complexes

Beard et al., 2022

Genetic model

Magmatic processes:

- REE are incompatible elements
- Low-degree partial melting in the mantle
- Protracted fractional crystallization in a magma chamber (protracted due to high volatile content)

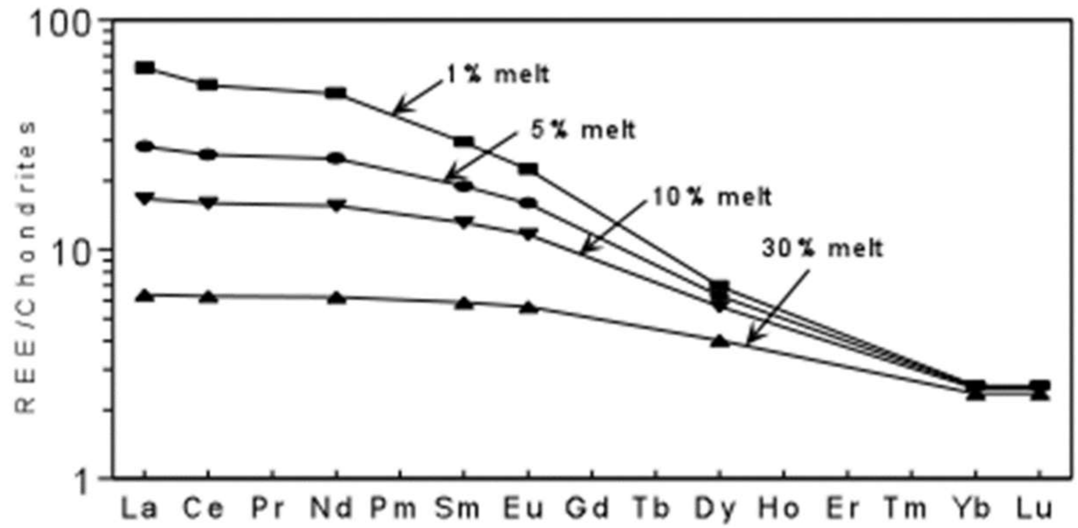
Do not easily fit into the crystal structure of common rock-forming minerals due their unusual characteristics (size, charge), therefore they prefer the liquid

Also include volatiles (F, CO_2, P) and HFSE (Zr, Nb, U, Th)

Incompatible elements are enriched during partial melting and fractional crystallization

Hydrothermal processes:

- Late magmatic hydrothermal
- Origin of hydrothermal fluid is volatiles exsolving from cooling magma and remobilizing REE

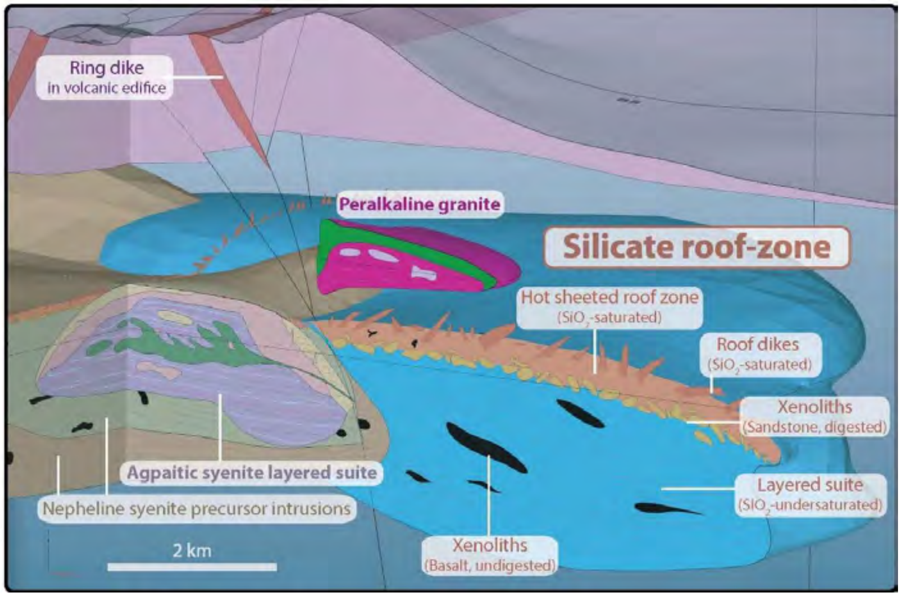


Incompatible element concentration in the melt will decrease with increasing degree of melting

https://www2.tulane.edu/~sanelson/eens212/magmadiff.htm; Dostal et al., 2016; Vasyukova and Williams-Jones, 2018; Beard et al., 2022

REEE mineralization

Orthomagmatic – within igneous layered cumulates, usually in quartz-undersaturated phases

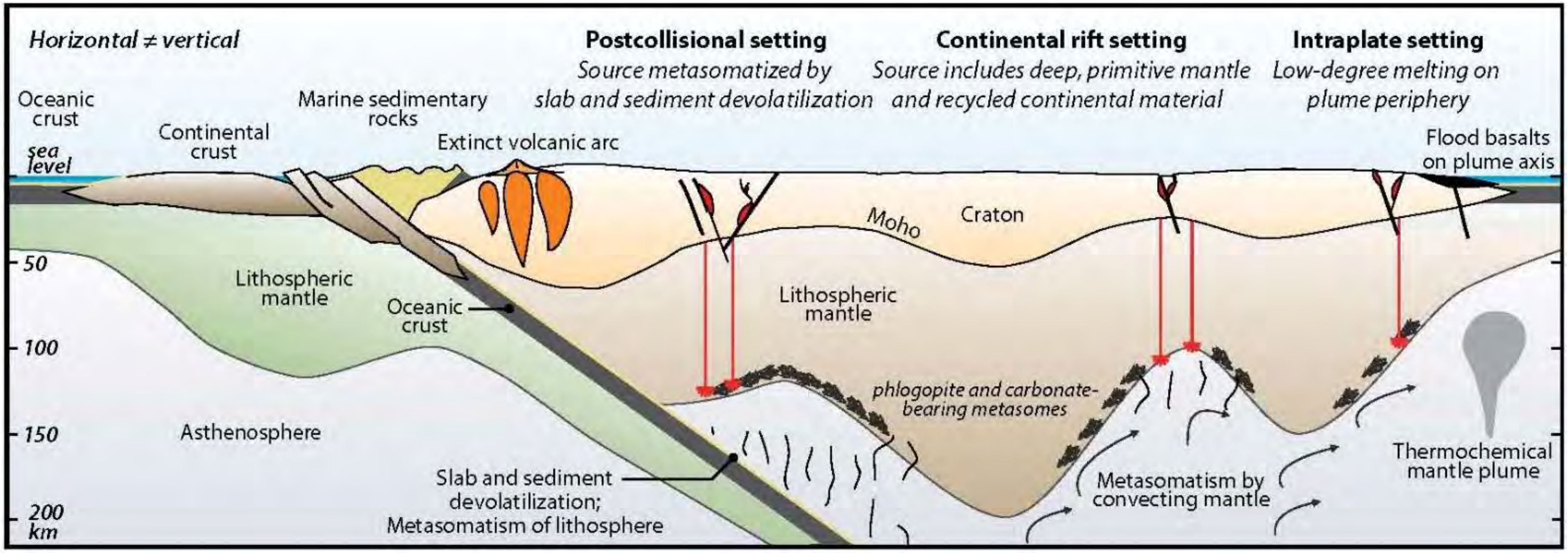


Combination of magmatic and hydrothermal processes (top of intrusions):

- Silicate roof zone: mineralized lenses and pegmatites
- Peralkaline granite – upper margins of intrusions: hydrothermal alteration and pegmatites

https://www.alexstrekeisen.it/english/pluto/ilimaussaq.php; https://www2.bgs.ac.uk/hiTechAlkCarb/naturalLaboratories.html;
Hunt et al., 2017; Beard et al., 2022

Tectonic setting



Low-degree (high pressure) partial melting of mantle beneath thick continental crust

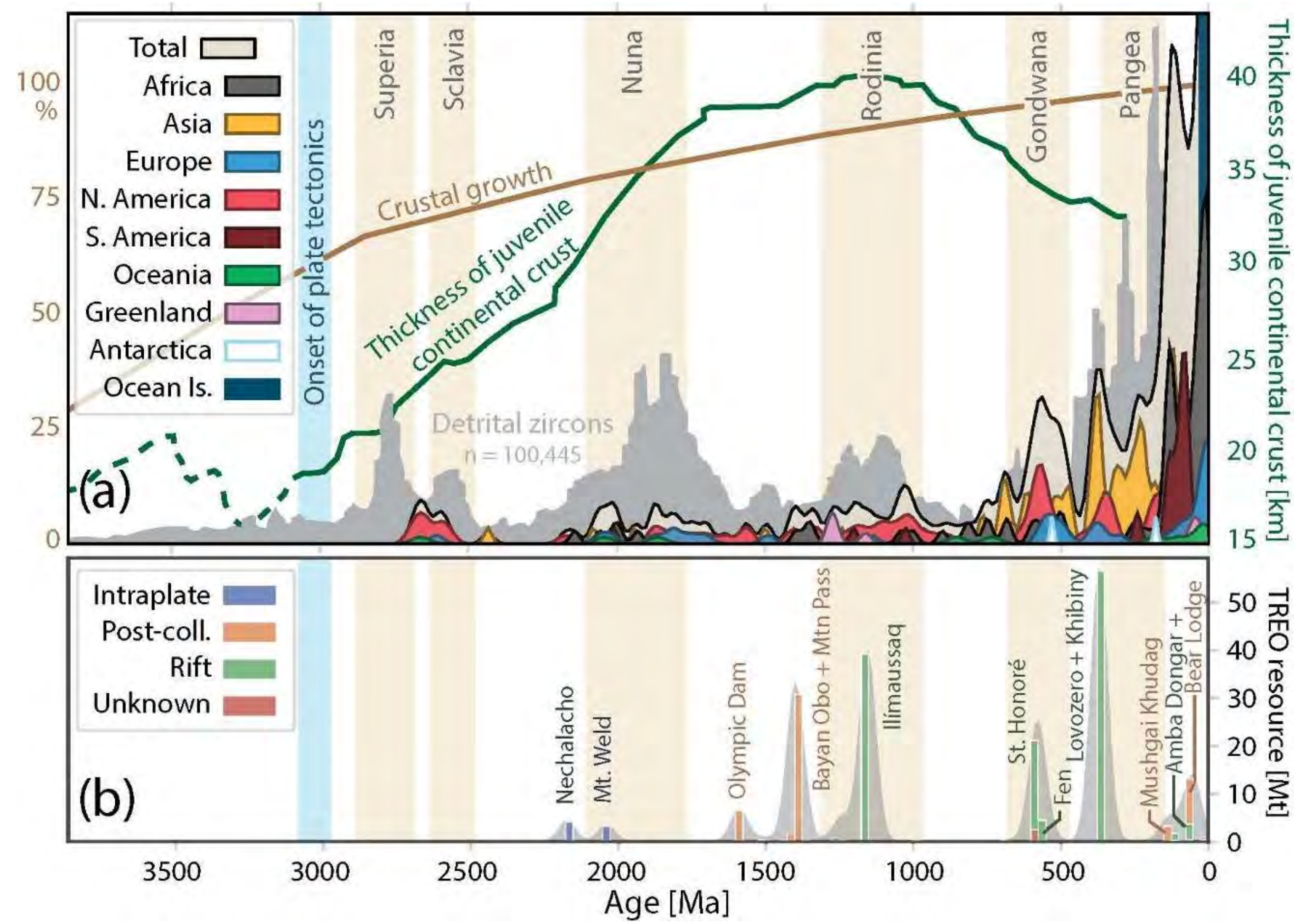
Enriched (metasomatized) mantle source: contains volatiles (F, CO_2) that enable enrichment of metals during fractional crystallization in the crust; contains minerals such as phlogopite, magnetite, amphibole, apatite, carbonate, garnet

May be spatially associated with carbonatites

Goodenough et al., 2016; Beard et al., 2022

Temporal distribution

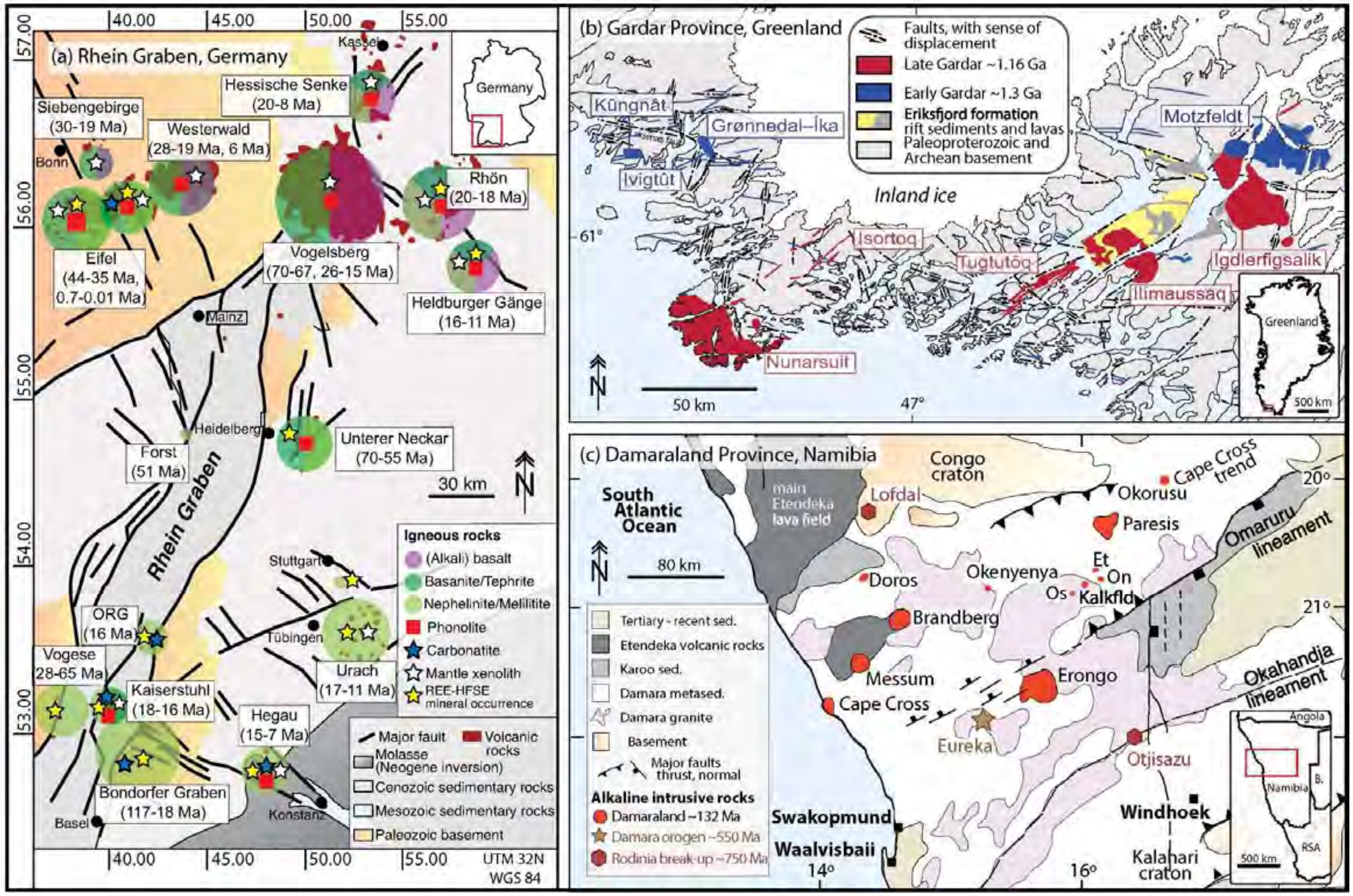
- Function of the thickness of continental crust
- Episodic with peaks associated with continental rifting and existence of supercontinents
- Oldest is Neoarchean
- Big peak in the Mesoproterozoic when continental crust thickness >35 km



Beard et al., 2022

Geological setting of deposits

- Crustal-scale features that can accommodate magma ascent from the mantle
- Intersections of crustal lineaments
- Peralkaline complexes occur in clusters/alignments



Beard et al., 2022

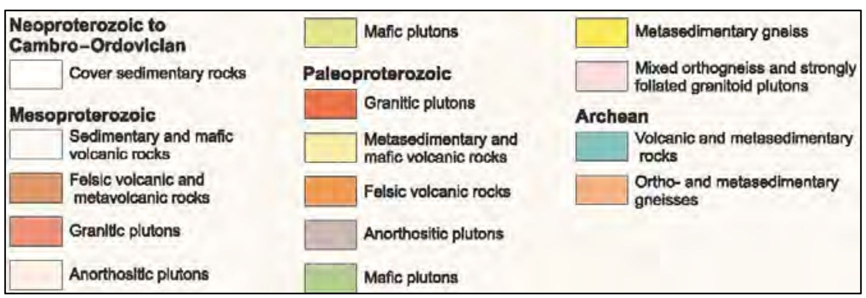
Labrador REE mineralized peralkaline complexes

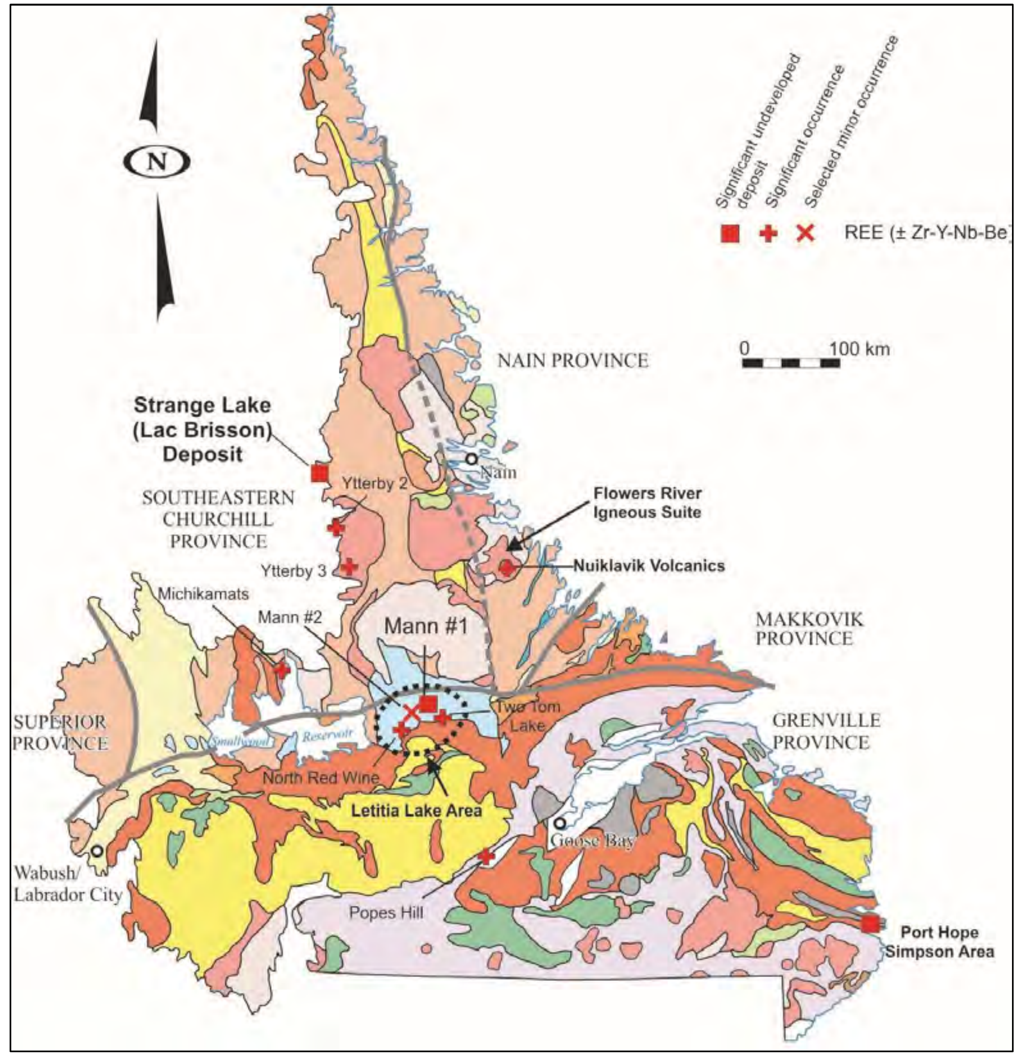
Include:

- Strange Lake
- Flowers River Igneous Suite
- Red Wine – Letitia Lake
- Fox Harbour Volcanic Belt (FHVB)

Mesoproterozoic (~1.3 Ga)

Interpreted to have formed due to crust migrating above spreading centre





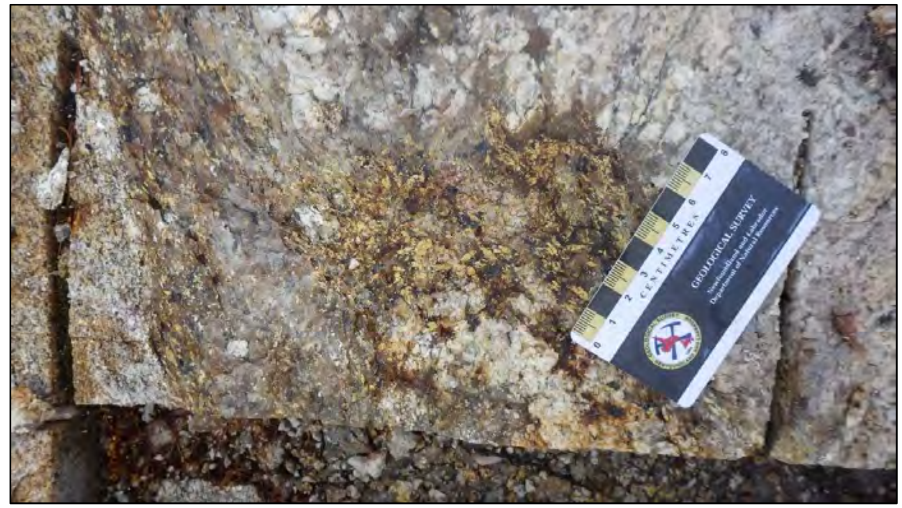
Gower and Krogh, 2002; Kerr et al., 2011

Labrador peralkaline complexes project

- Multi-year project funded by GSNL and GSC (through TGI), in collaboration with Search Minerals Inc. and MUN (structural study with Dr. Eric Thiessen)

- Purpose of project is to advance the understanding of the genesis of REE deposits, focusing on Labrador

- Work started with the FHVB, because although it is in an advanced stage of exploration, it is understudied compared to the other deposits, and easily accessible

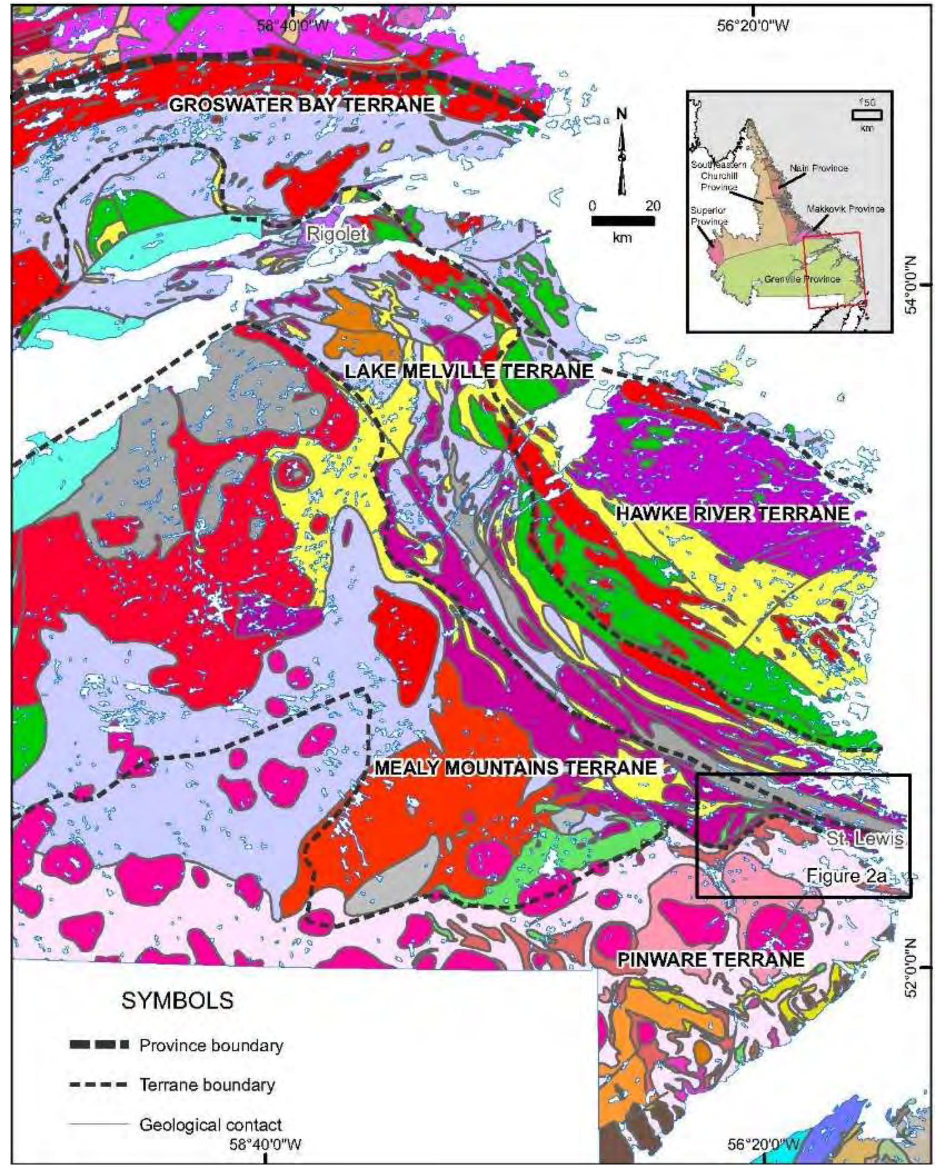


Geological setting

FHVB is located in the Grenville Province mostly in the Mealy Mountains terrane, straddling the boundary with the Lake Melville terrane

REE mineralization (e.g. HighREE) also occurs in the Pinware terrane in rocks most likely related to the FHVB

Wardle et al., 1997



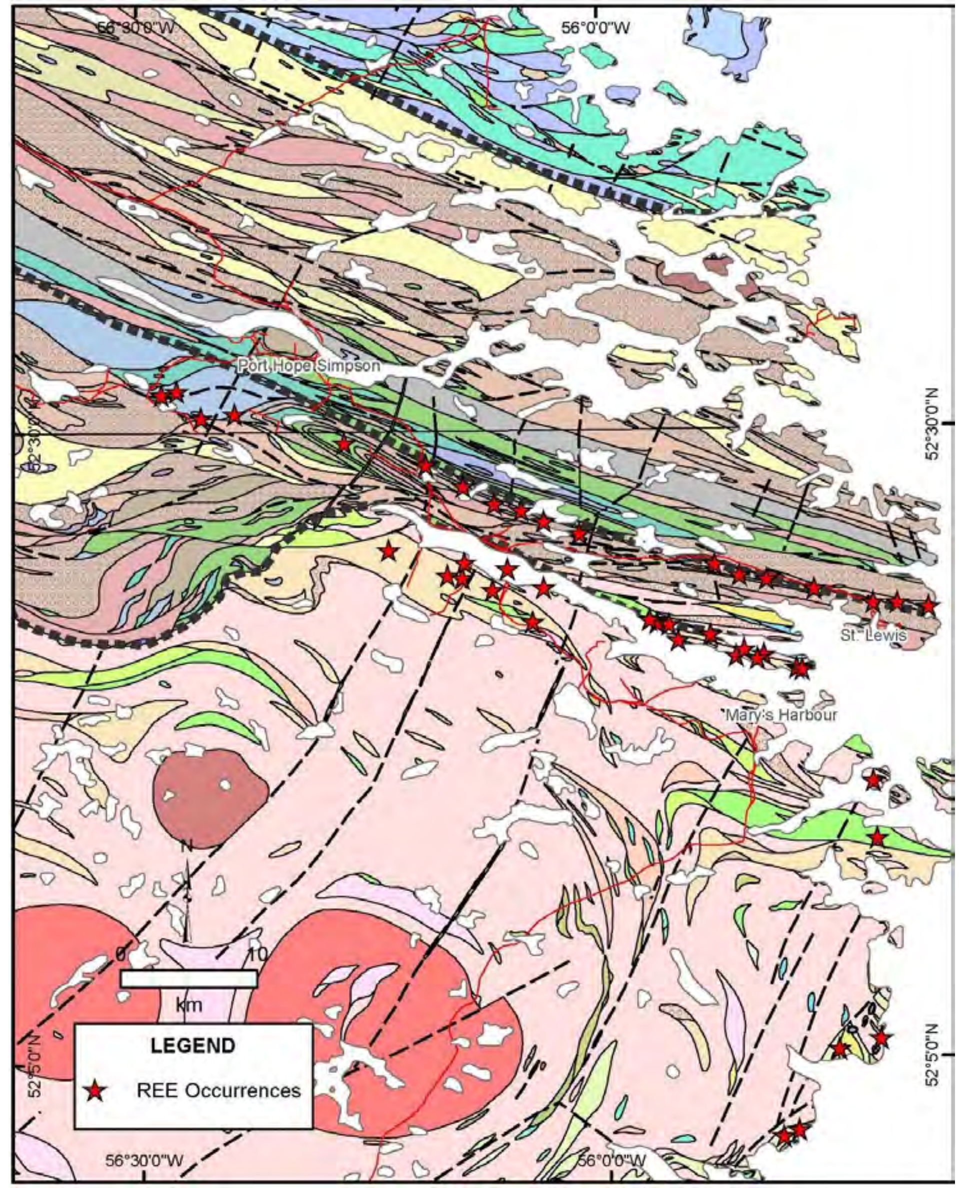
Geological setting

FHVB intrudes early Labradorian (~1.65 Ga) felsic and mafic rocks, although they have not been dated

REE occurrences in the Pinware terrane (e.g. HighREE Island) are hosted in late Paleoproterozoic and early Mesoproterozoic granitoids

The spatial extent of FHVB and associated intrusions is unknown and controversial

Strongly deformed and metamorphosed to amphibolite facies during Grenville orogenesis



Gower, 2010a, b, 2019; Haley, 2014; Miller, 2015

Fox Harbour Volcanic Belt

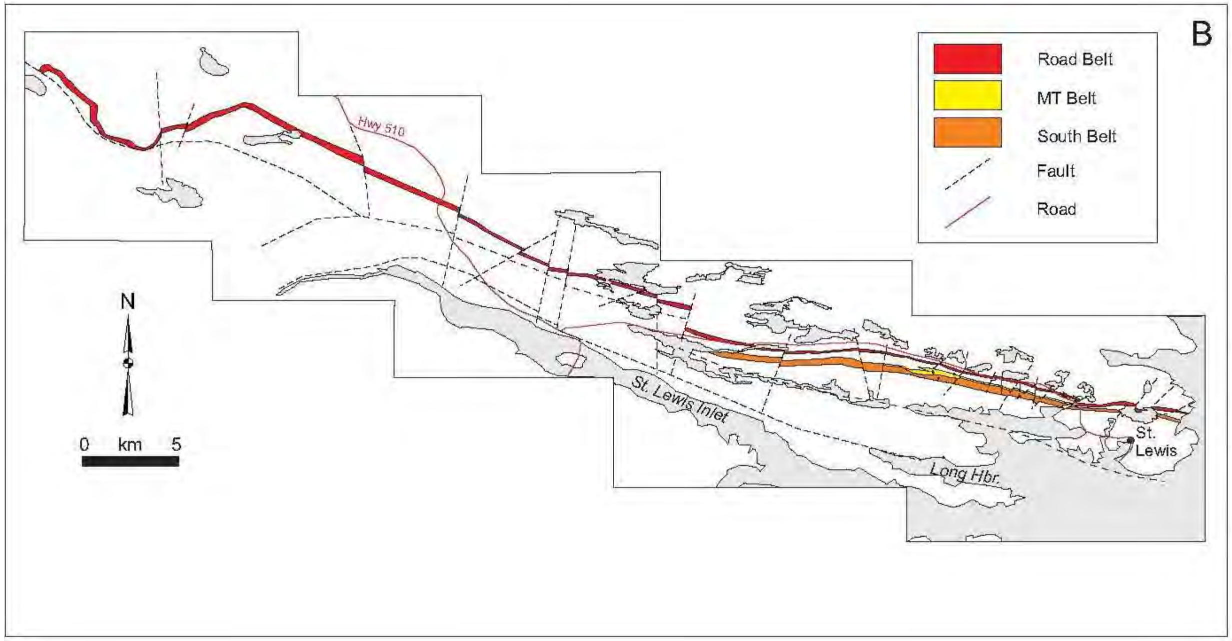
FHVB is ~64 km long, divided into EFHVB and WFHVB, separated by a fault

Composed of 3 belts in the east: Road, Magnetite and South belts, and 1 belt in the W (Road Belt)

Rock types:

- peralkaline volcanic rocks (pantellerite to comendite and pantelleritic to comenditic trachyte)
- non-peralkaline rhyolite
- mafic to ultramafic volcanic rocks
- minor volcanogenic sedimentary rocks
- quartzite

Main deposits: Deep Fox and Foxtrot in the EFHVB, Fox Meadow in the WFHVB



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)
- Zr-rich pantellerite (more than 15 000 ppm Zr)

Gower, 2010a, b, 2019; Haley, 2014; Miller, 2015

REEE mineralization

Most of the occurrences are in the Magnetite and Road belts

REE minerals include: allanite (mostly LREE), fergusonite (HREE with minor LREE), titanite-LREE, chevkinite, bastnaesite, synchysite, monazite and rare columbite

Deep Fox: 5.1 Mt of indicated resource with 394 ppm Pr, 1,469 ppm Nd, 202 ppm Dy, 34 ppm Tb; and 3.3 Mt of inferred resource with 366 ppm Pr, 1,381 ppm Nd, 198 ppm Dy, 33 ppm Tb

Foxtrot: 10.0 Mt of indicated resource with 366 ppm Pr, 1,368 ppm Nd, 176 ppm Dy, 30 ppm Tb; and 3.0 Mt of inferred resource with 371 ppm Pr, 1,384 ppm Nd, 177 ppm Dy, 30 ppm Tb

Resources are NI 43-101 compliant, Ciuculescu et al., 2022

EFHVB

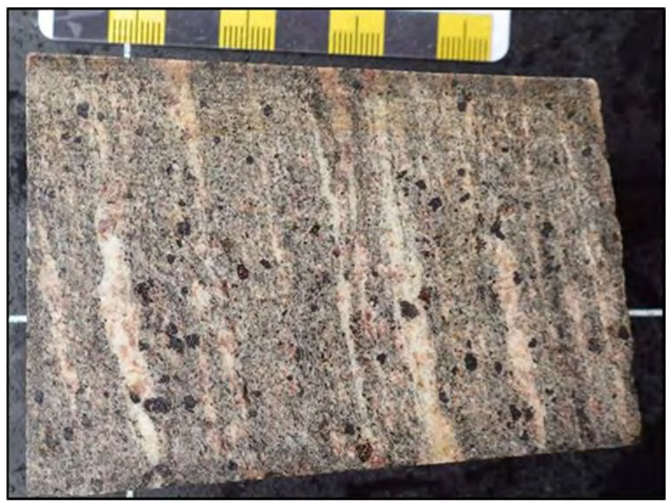
Lots of layering at every scale – primary igneous layering + foliation + tight folding

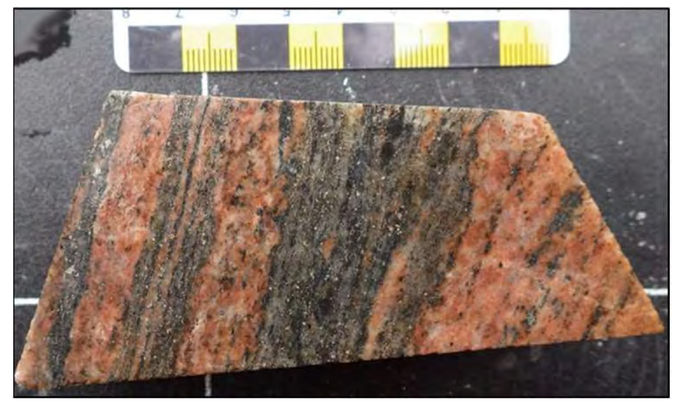
Pegmatites

EFHVB - Pantellerite

Pantellerite:

- Quartz
- Albite
- K-fp
- Magnetite
- Pyroxene
- Biotite
- Amphibole
- Zircon
- Titanite
- Fluorite

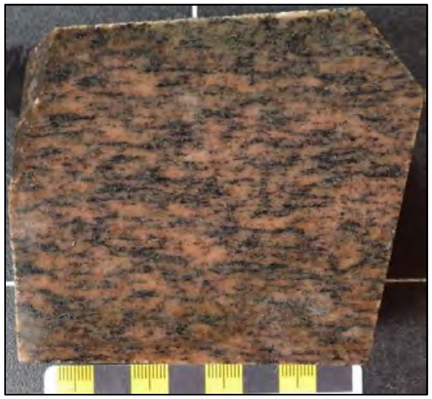




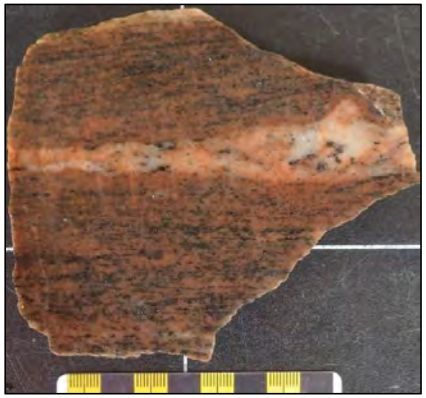
Non-peralkaline rhyolite intruded by pantellerite

Pantellerite is usually strongly magnetic and has a high count with the scintillometer (up to 20 times the background level)

Rock types in the EFHVB



Comendite



Non-peralkaline rhyolite

Mafic volcanic rocks with epidote pod

Epidote pod (Haley, 2014)

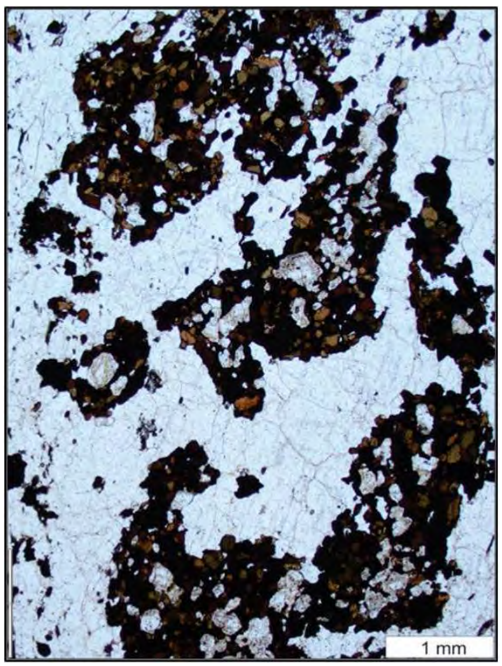
Volcanic origin?

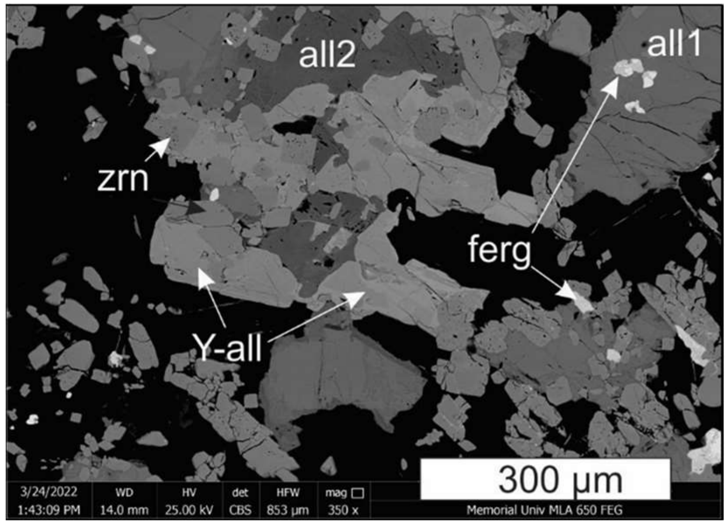
It was proposed by Miller (2015) based on:

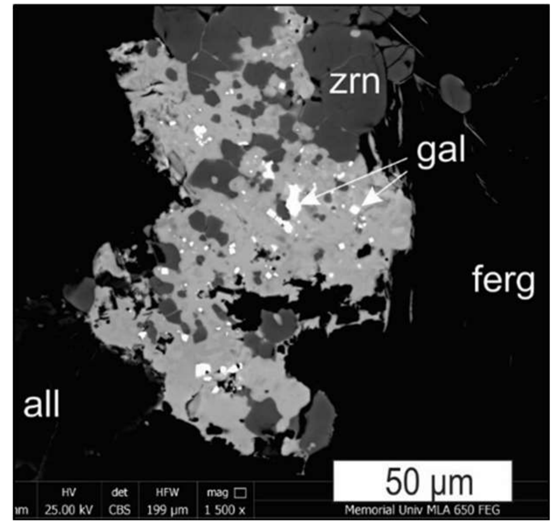
- Mafic units interlayered with the felsic units
- Layering within units most likely volcanic
- Metasedimentary rocks interpreted to be volcaniclastic
- Presence of epidote pods interpreted as altered pillows (Haley, 2014) or alteration pipes (Gower, 2019)

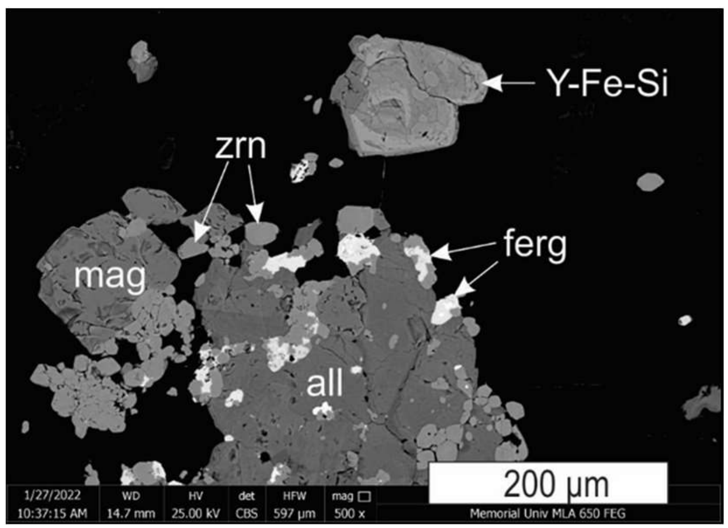
REE minerals in EFHVB

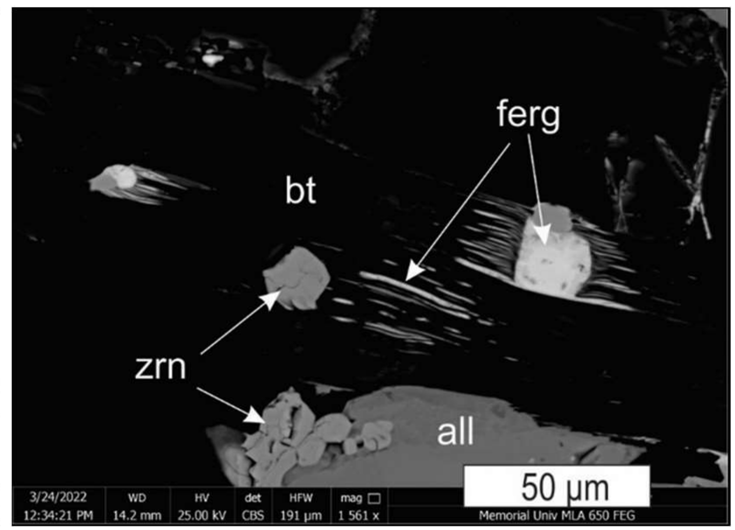
- Allanite: $(Ce, Ca, Y, La)_2(Al, Fe^{+3})_3(SiO_4)_3(OH)$
- Fergusonite: $(Y, HREE) NbO_4$
- Y-Ca-Fe-LREE-Si mineral





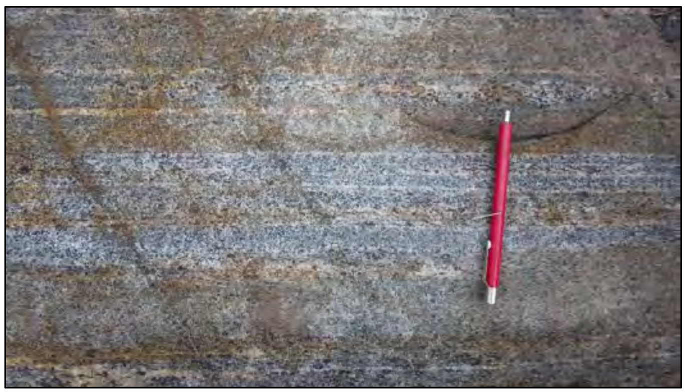






WFHVB

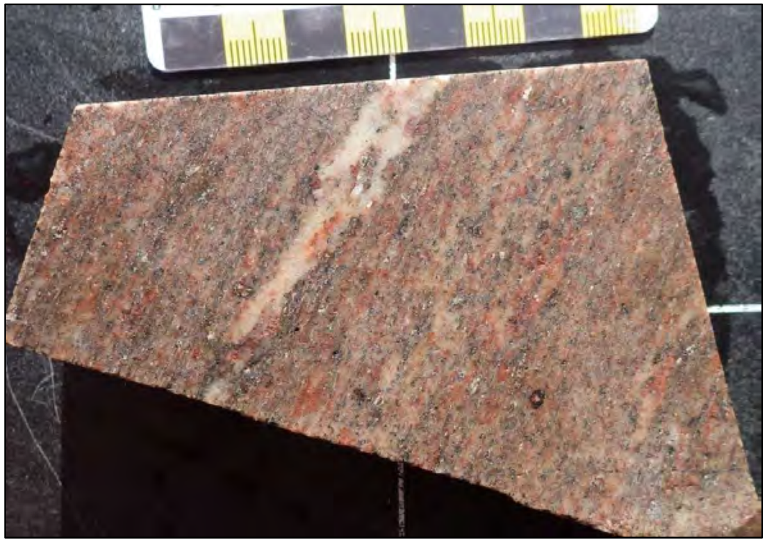


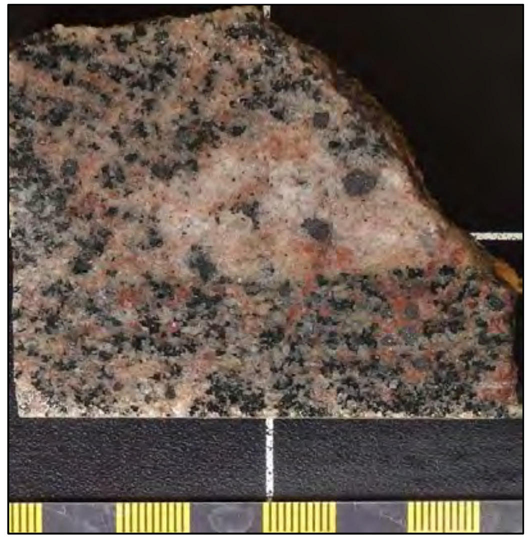



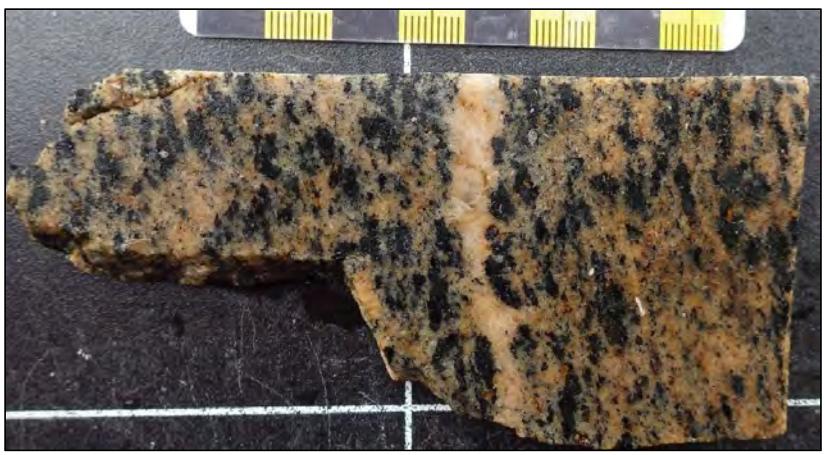
Mafic inclusions?

Layering: primary, foliation, folding
Lots of pegmatite
More mafic minerals
Less magnetic: some rock types contain ilmenite, not magnetite
Lower count with the scintillometer than the EFHVB (X3 the background)

Rock types in the WFHVB







Pantellerite, pantelleritic trachyte, comendite, comenditic trachyte

Can't always distinguish them in the field, but they are mineralized

Mafic rock is metagabbro/basalt

Less magnetic, lower count

Minerals in pantelleritic trachyte:
- Albite
- Pyroxene
- K-feldspar
- Zircon
- Amphibole
- Magnetite/Ilmenite
- Quartz

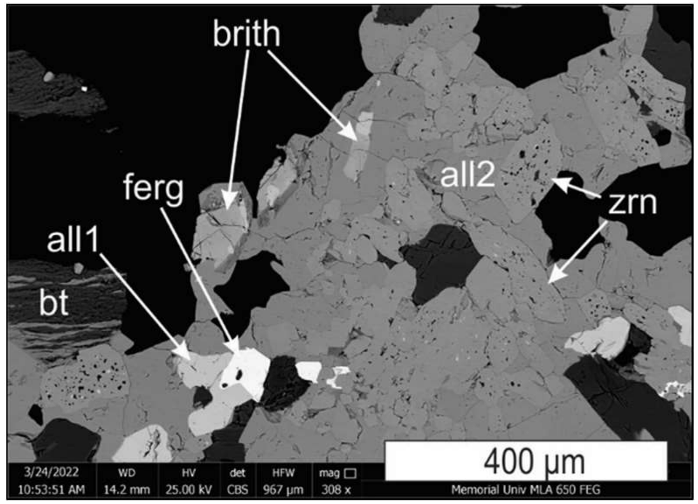
REE minerals in WFHVB

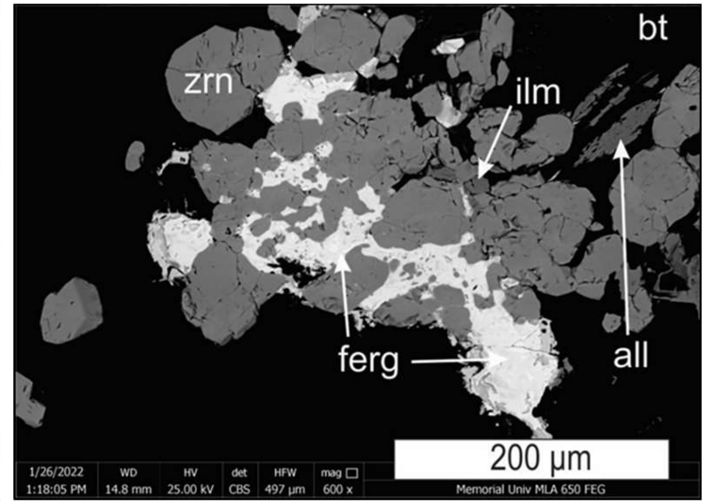
Allanite

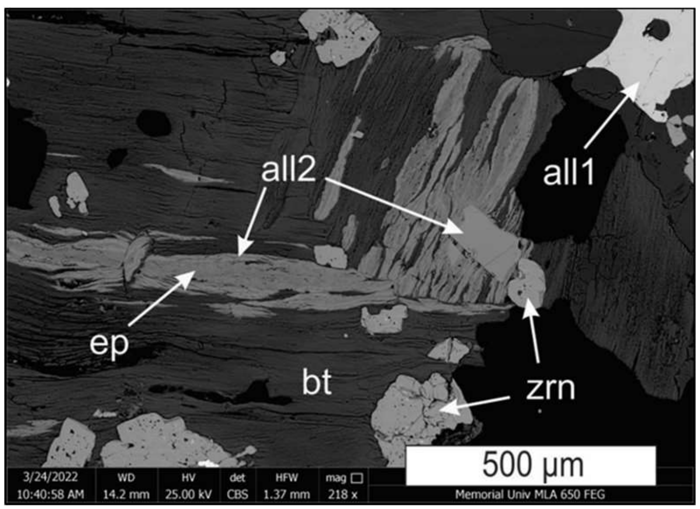
Titanite-LREE

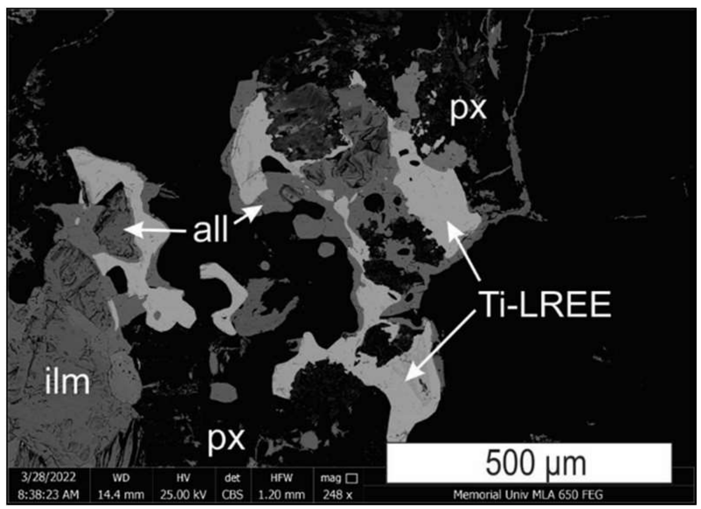
Fergusonite

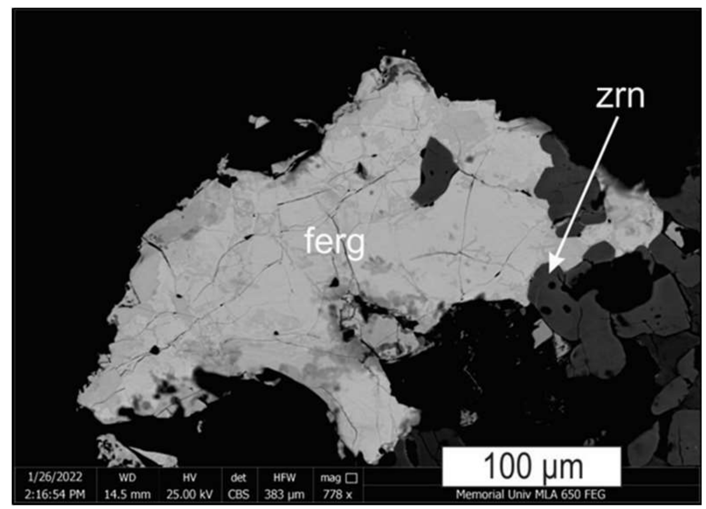
Britholite: $(LREE,Ca,Th)_5(SiO_4,PO_4)_3(OH,F)$







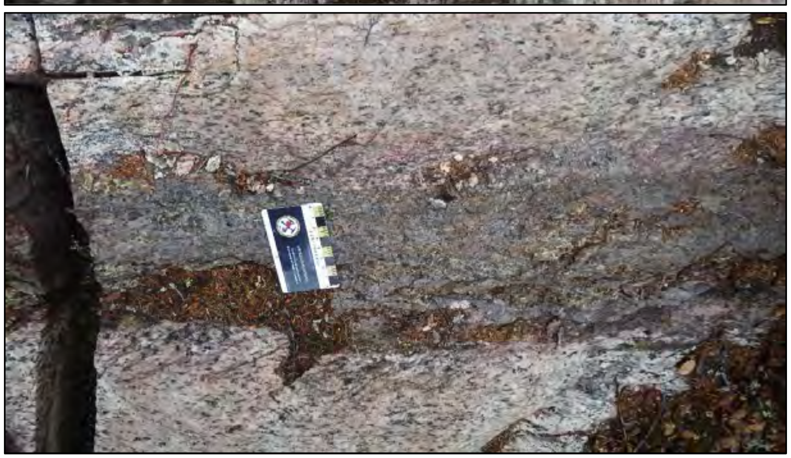




South of FHVB

Mineralization occurs in “pegmatites” hosted in different rock types, some of which may be the intrusive/subvolcanic part of the FHVB (Miller, 2015)?






REE mineralization is medium grained, locally occurs with pegmatite

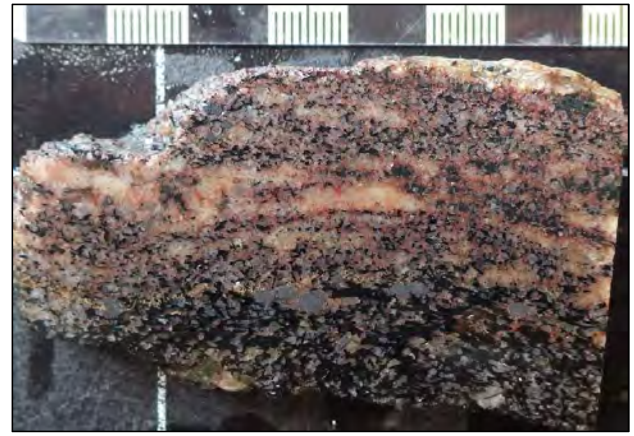
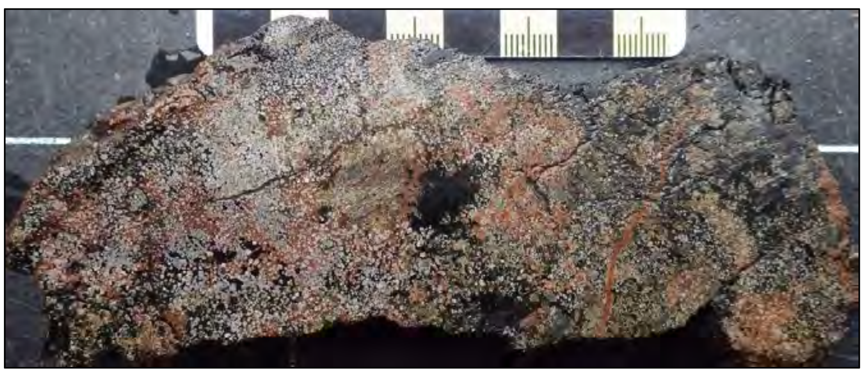
Minerals include:
- Quartz
- Albite
- Amphibole
- Magnetite
- Biotite
- Titanite

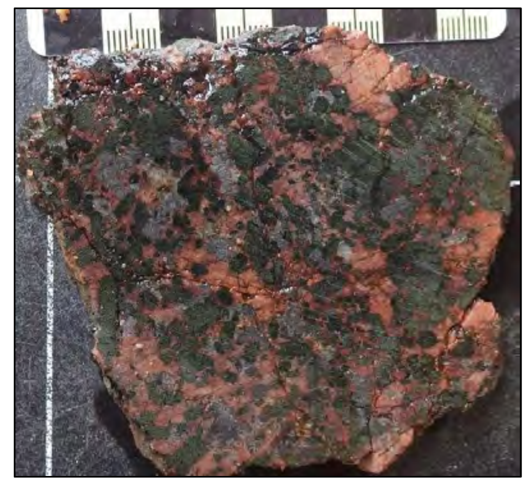
Magnetic or not

Scintillometer count varies from background to up to X170 of the background

SFHVB mineralized rocks

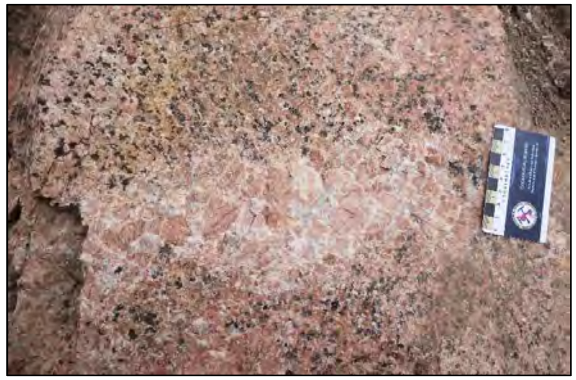


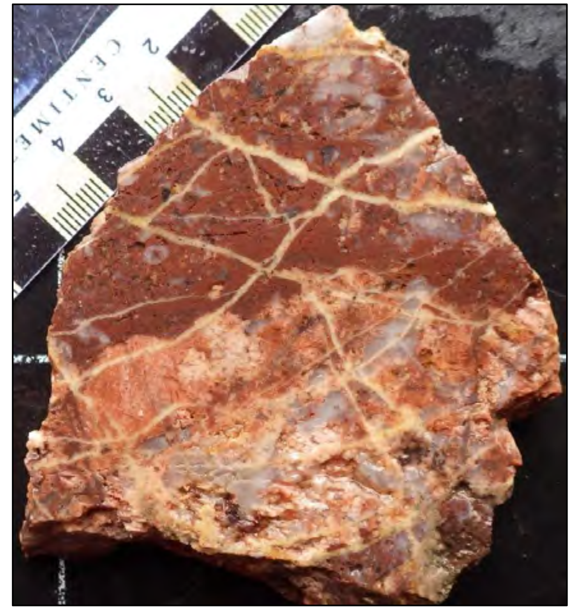



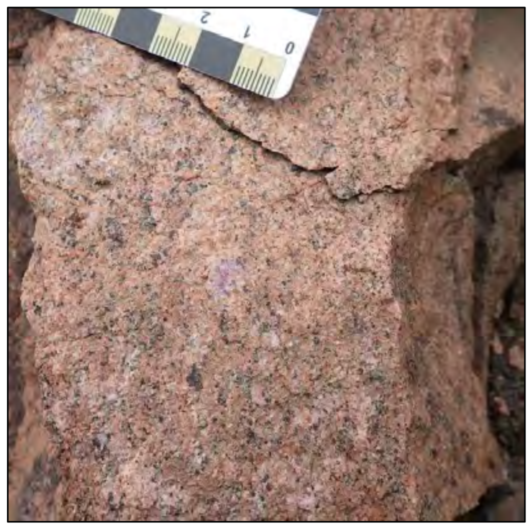


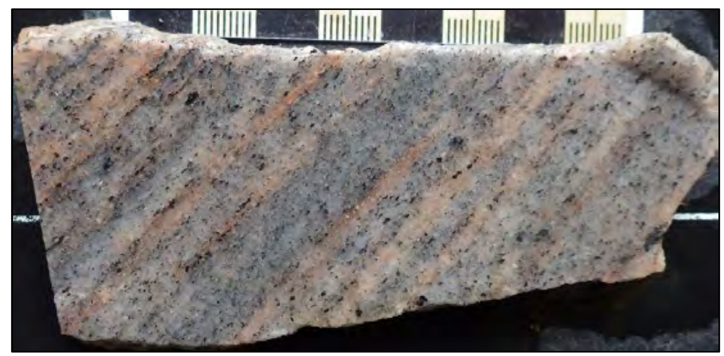
Rocks associated with mineralized pegmatites

Are they the intrusive equivalent of the FHVB?









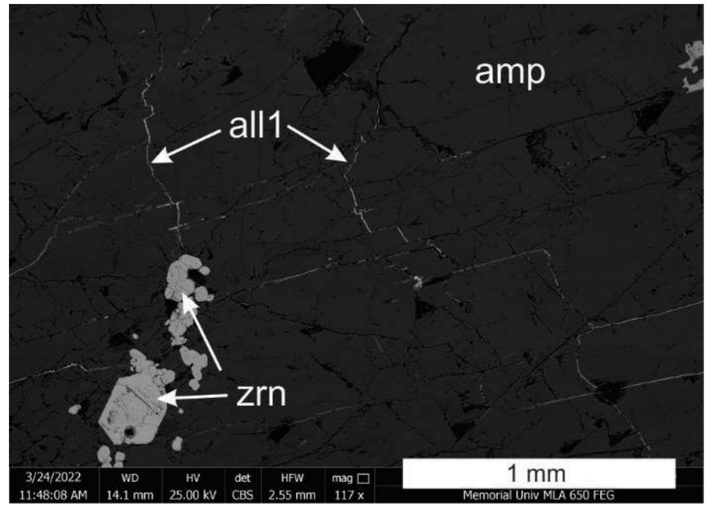
Some of them probably yes:
Contain magnetite, titanite, fluorite
Scintillometer count higher than background

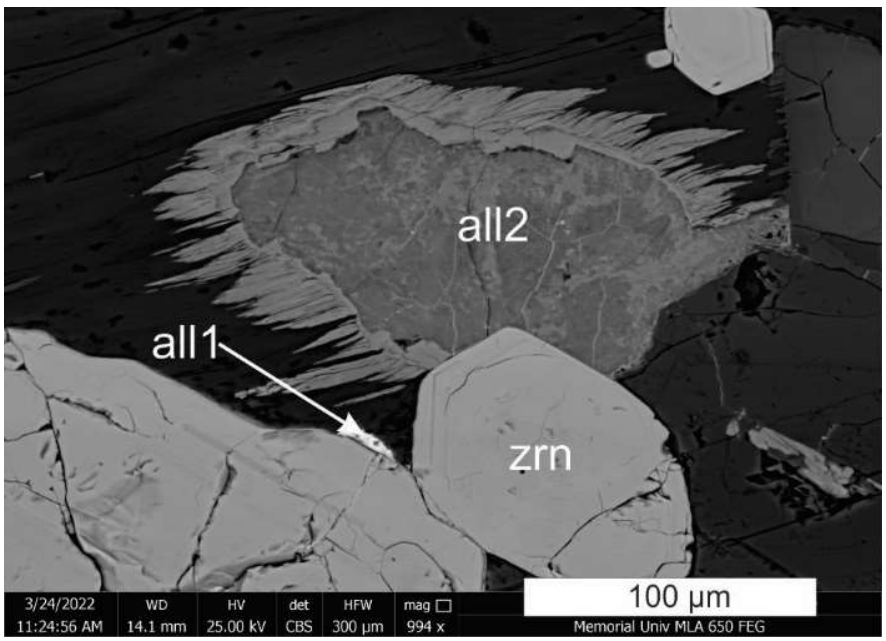
Indication for top of intrusion: breccia (tuffisite?), coarse and fine-grained

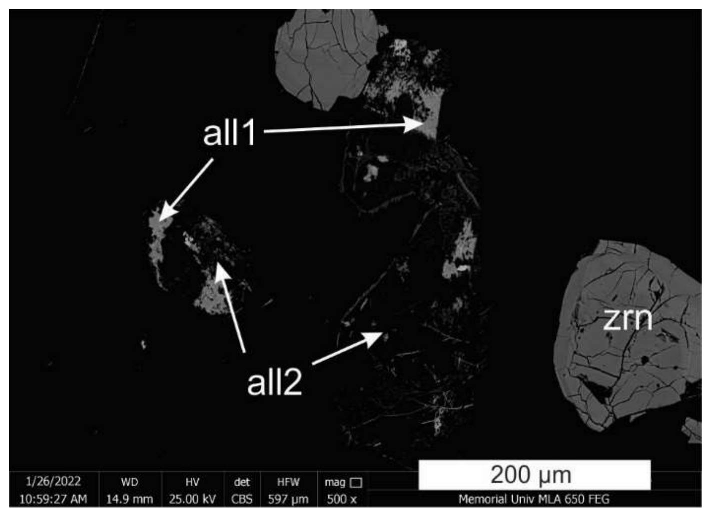
REE minerals at HighREE

Allanite

Synchysite: $Ca(REE)(CO_3)_2F$







What type of REE mineralization is in the FHVB??

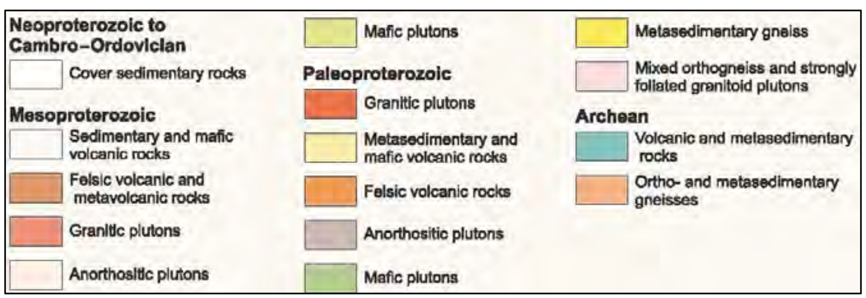
- Orthomagmatic for FHVB?
  - Layered, but probably not cumulate
  - Orthomagmatic usually occurs in quartz-undersaturated rocks
- Silicate roof- zone?
  - Should have quartz-undersaturated beneath?
- Peralkaline granite?
  - Yes, south of FHVB (top of granite, mineralization occurs in pegmatites)
  - Not in the FHVB (no REE pegmatites, REE minerals occur in pantellerite)
- Miller (2015): small volumes of late, strongly fractionated magma intruding near vents as vent/caldera filling

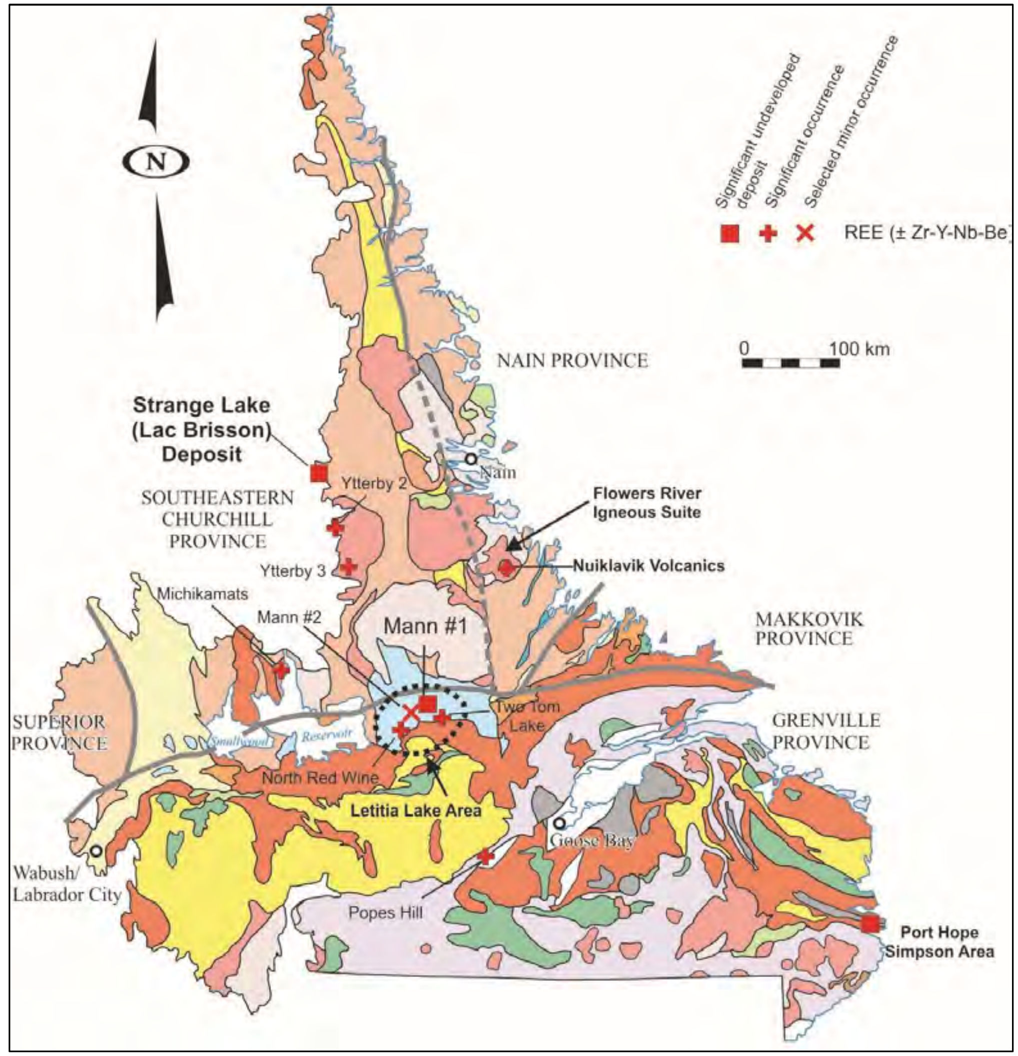
Other REE mineralized peralkaline complexes

Strange Lake

Red Wine – Letitia Lake

Flowers River Igneous Suite





Gower and Krogh, 2002; Kerr et al., 2011

Strange Lake

Rock types: peralkaline granites

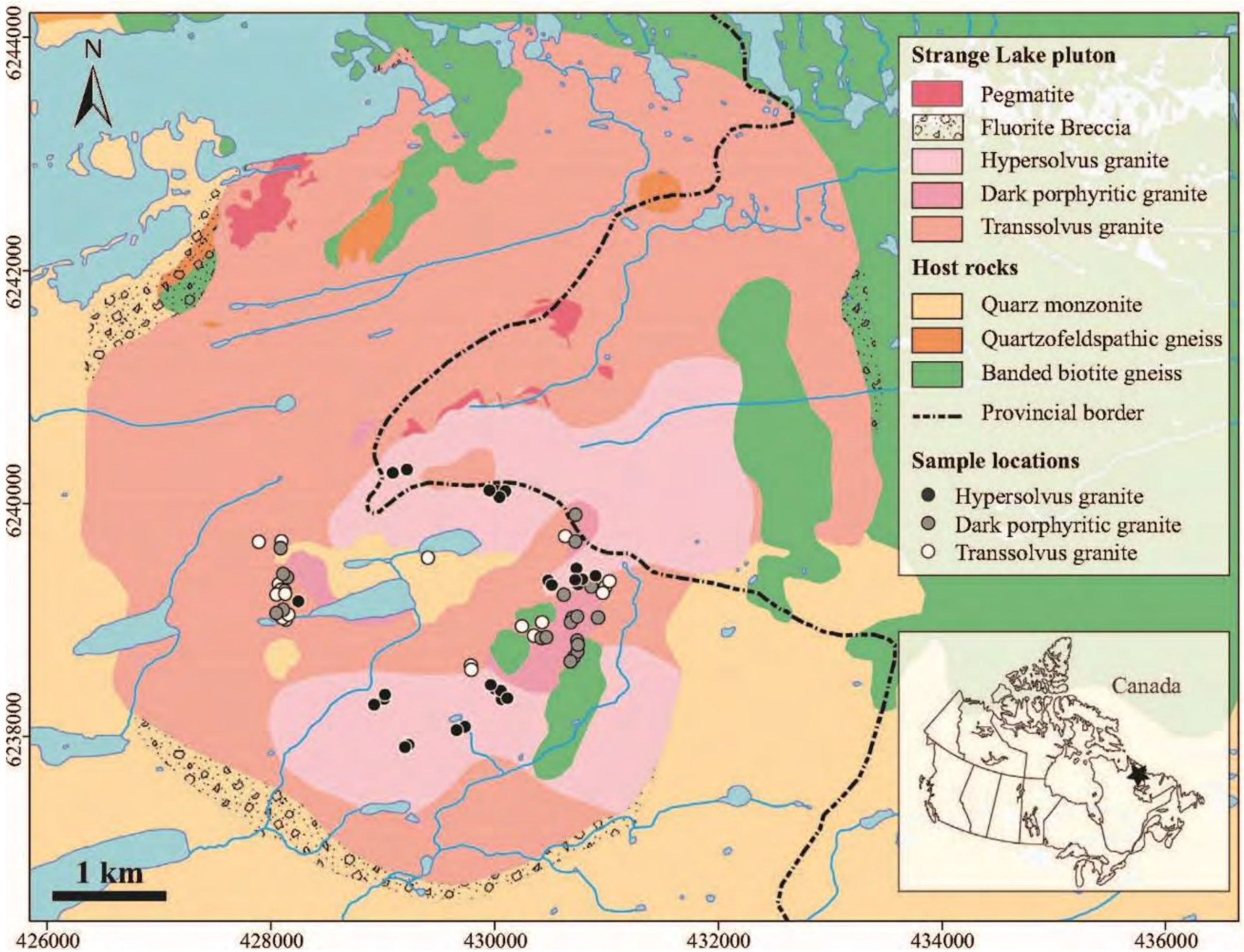
Mineralization occurs in pegmatites (peralkaline granite type)

REE minerals (complex Na-Ca silicates): gittinsite, zircon, kainosite, gerenite, gadolinite, pyrochlore, allanite, elpidite

Age: 1240 ± 2 Ma

Combination of magmatic and late-magmatic hydrothermal processes

Source: mantle + 5-15% crust (Nd-Sm)



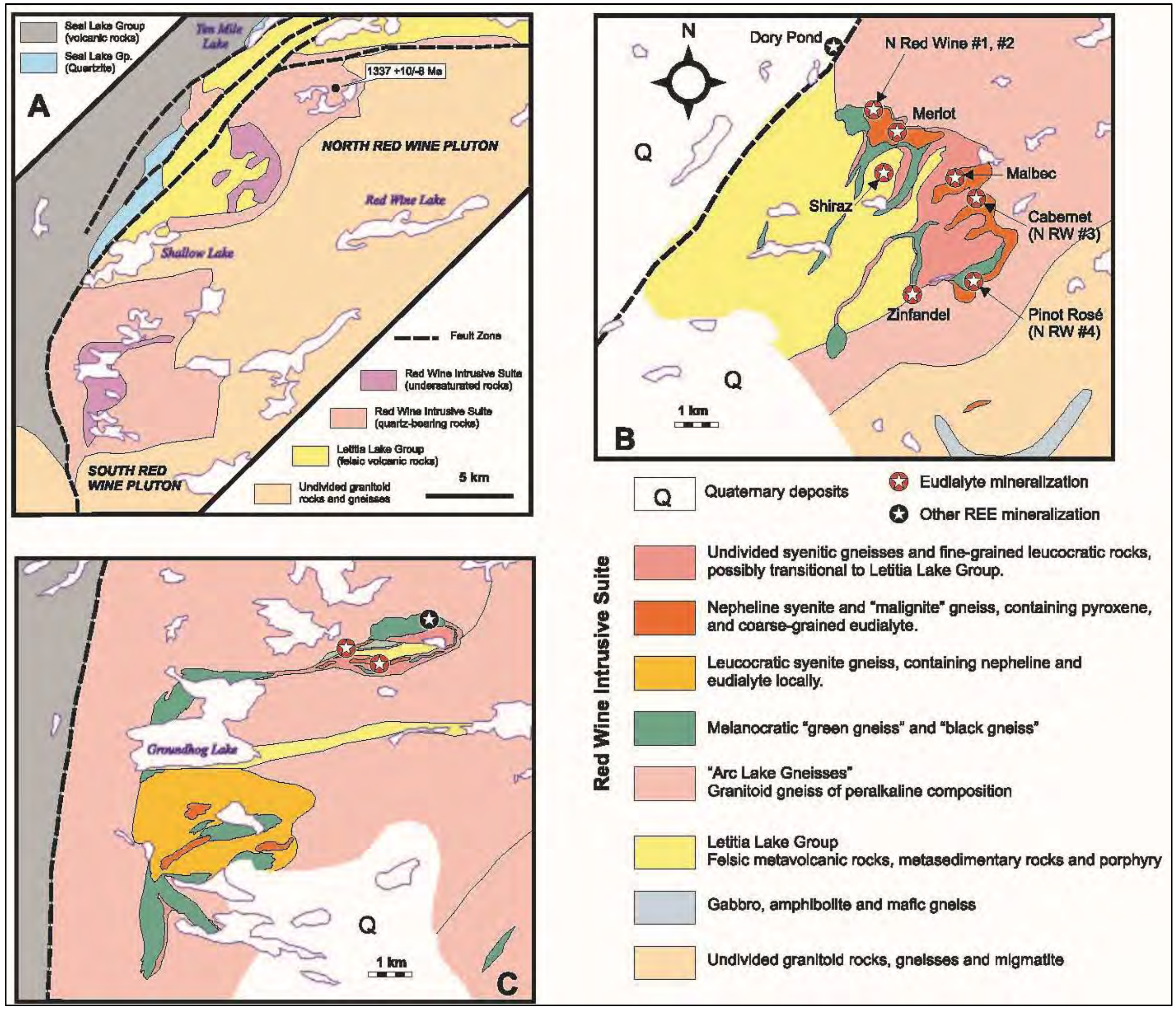
Miller et al., 1997; Kerr, 2011, 2015; Siegel et al., 2017, 2018; Vasyukova and Williams-Jones, 2018 and references within

Red Wine

Rock types: peralkaline q-undersaturated (foid syenites) q-saturated (peralkaline granite) rocks

REE minerals: eudialyte (magmatic) , britholite, monazite, REE-bearing apatite (hydrothermal)

Age: 1330 + 13/-11 Ma, 1337 +10/-8 Ma, 1345 ± 75 Ma



Curtis and Gittins, 1979; Thomas, 1981, 1983; Gandhi, 1988; Curtis and Currie, 1981; Kerr, 2011; Crocker, 2014

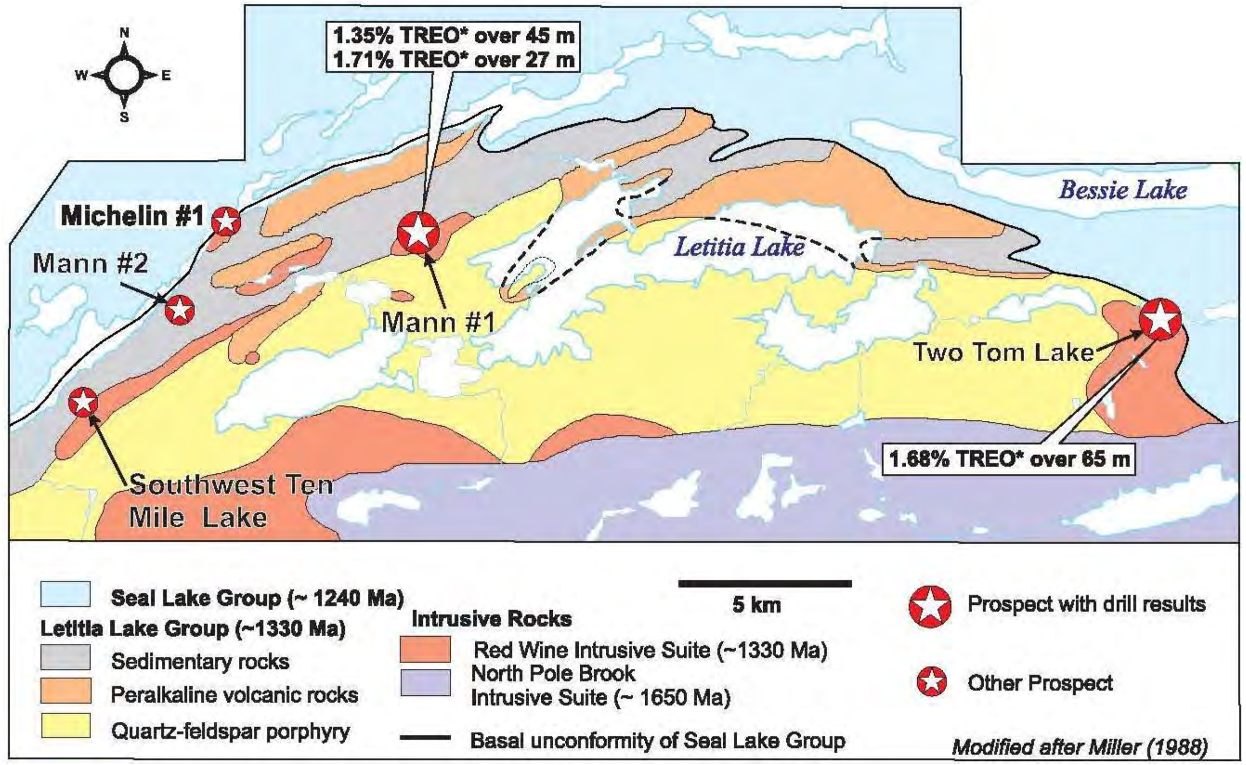
Letitia Lake

Rock types: peralkaline granite and rhyolite (pantellerite to comendite)

Also contains: Nb, Be

Age: 1330 +40/-20 Ma, 1327 ± 4 Ma

Minerals (not enough data): monazite, Ce-Ca-silicate, eudialyte/eucolite, allanite, gadolinite, pyrochlore, catapleiite, rosenbuschite



Westoll, 1971; Marten, 1975; Thomas, 1979, 1981, 1983; Curtis and Currie, 1981; Hill and Thomas, 1983; Miller, 1987; Wilton, 2010; Kerr, 2011; Tetra Tech, 2012; Crocker, 2014

Flowers River

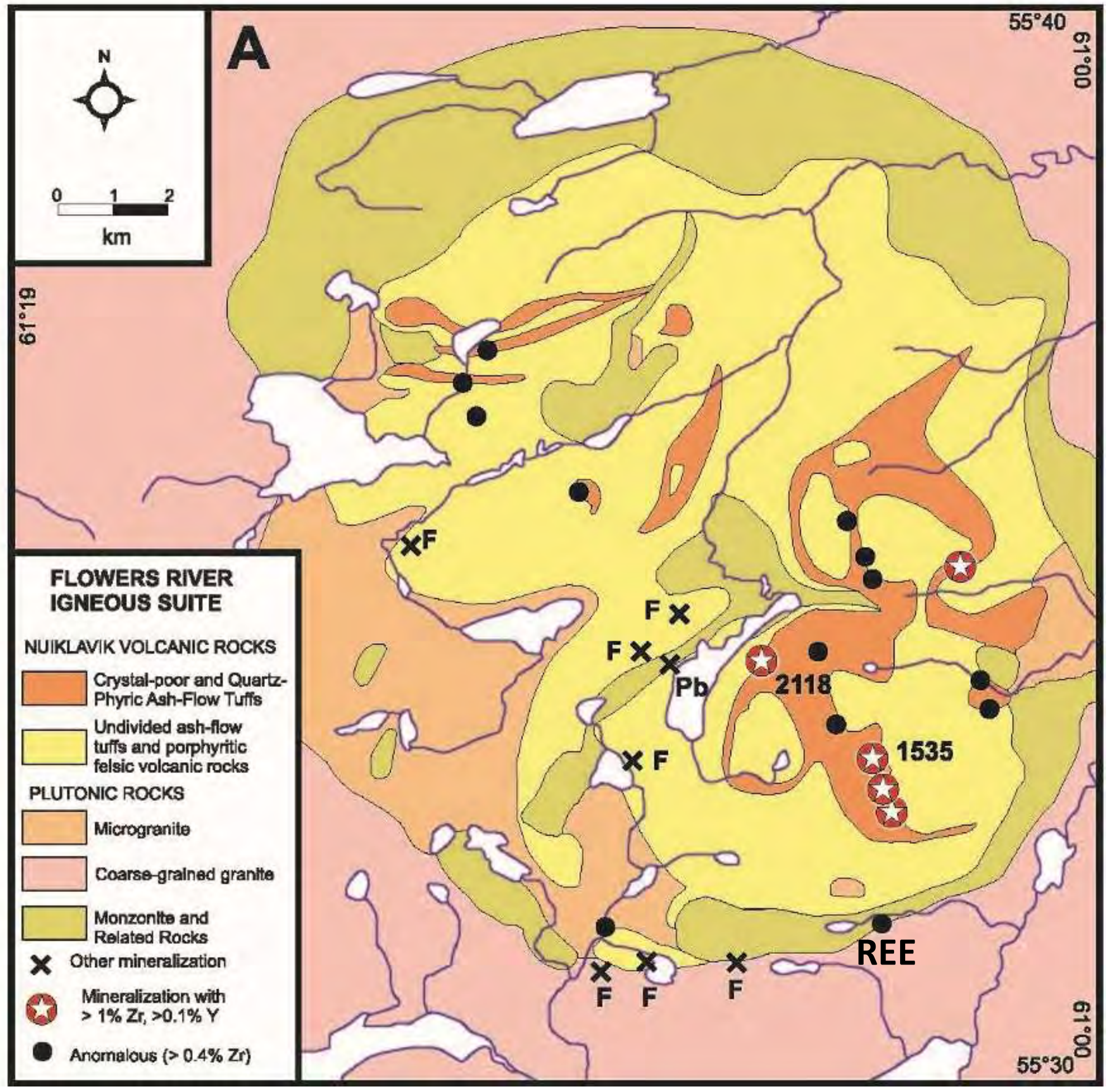
Rock types: peralkaline granites and coeval volcanic rocks

Age: 1290 ± 3 Ma, 1281 ± 3 Ma, 1271 ± 3 Ma

Minerals: bastnaesite, allanite, monazite

Also contains: Y, Zr

REE mineralization occurs in aplitic dykes in felsic volcanic rocks



Hill, 1982; Miller, 1988, 1992, 1993; Seymour et al., 2008; Kerr, 2011; Ducharme et al., 2021

REE in Newfoundland

Cross Hills

Rock types: peralkaline granite (547 +3/-6 Ma), biotite granite, quartz syenite

Mineralization hosted in peralkaline aplite dykes

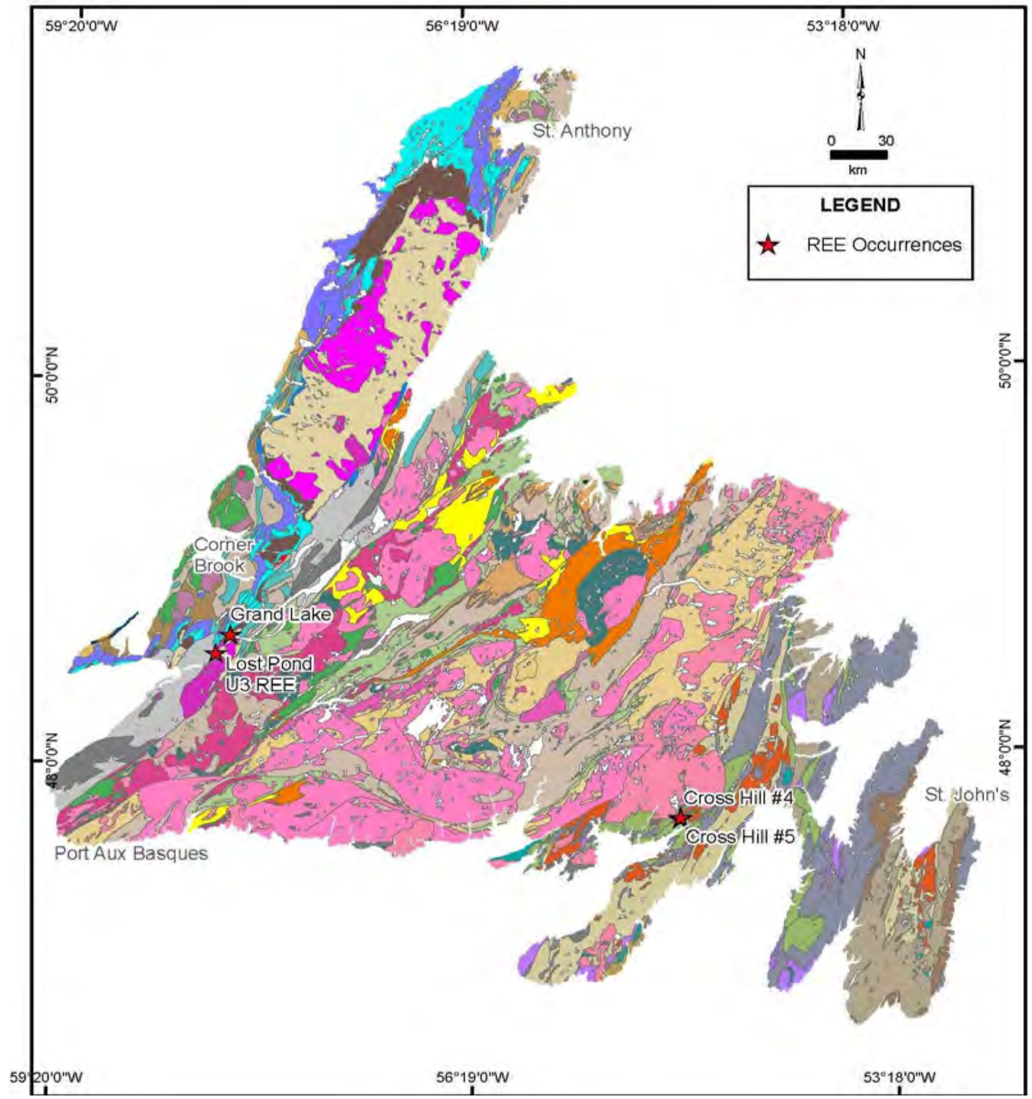
REE minerals: baddelyite, fergusonite, unidentified minerals

Hare Hill area: Lost Pond and Grand Lake occurrences

Rock types: peralkaline granite (Hare Hill granite – 605 Ma?), quartz syenite

Some of the REE mineralization is hosted in pegmatite, granite, mafic intrusive rock

REE minerals: monazite, zircon, allanite, apatite

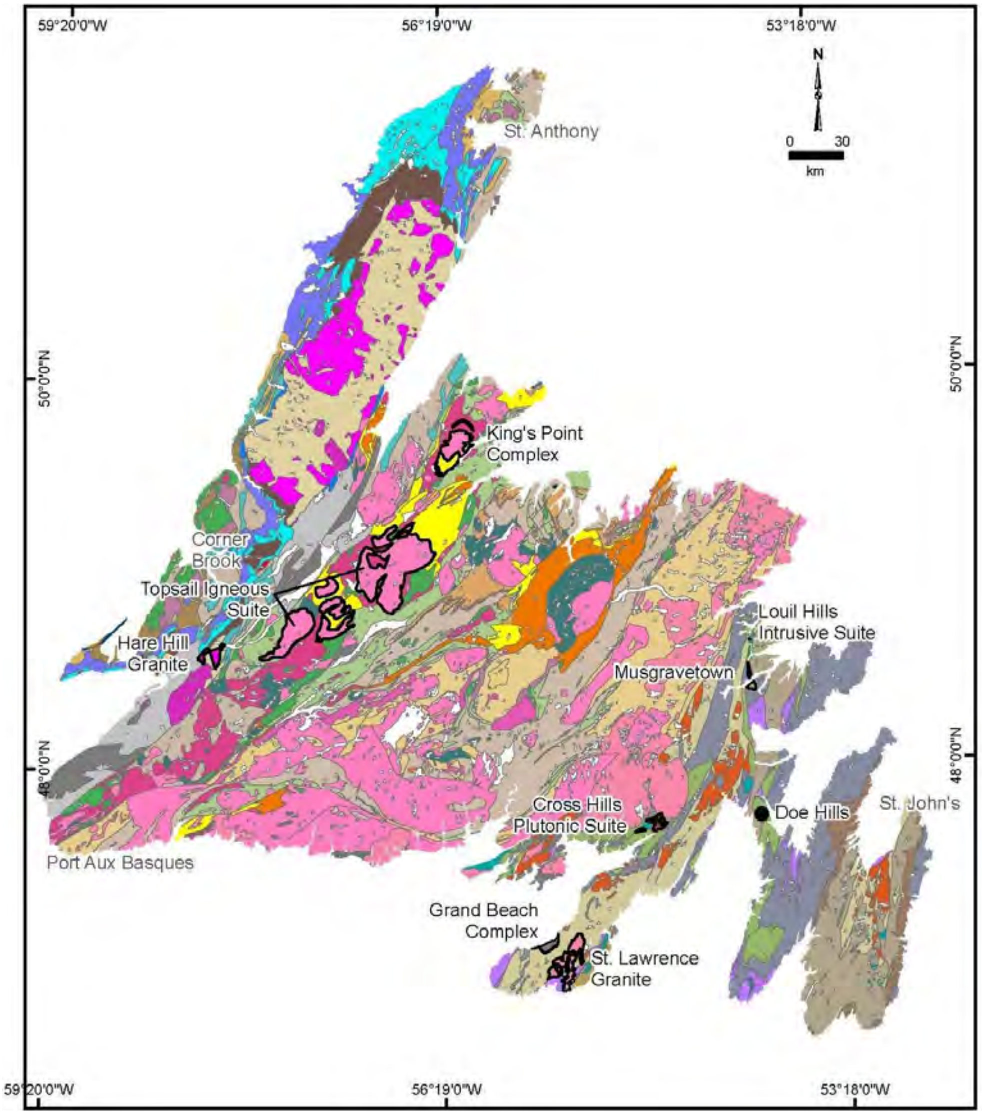


Whalen and Currie, 1984; Tuach, 1991; Miller, 1991; Churchill et al., 2003; Penney and Reid, 2009; Smith and Lentz, 2011

REE potential in Newfoundland

Miller (1991) based on gamma ray scintillometer readings:

- Kings Point Complex (427 Ma): peralkaline and non-peralkaline intrusive and extrusive rocks, pegmatite and aplite dykes
- Louil Hills Intrusive Suite (~572 Ma): peralkaline granite
- St. Lawrence Granite (~372-376 Ma): peralkaline to non-peralkaline granite and rhyolite
- Grand Beach Complex (~396 Ma): porphyritic granite and rhyolite
- Musgravetown and Doe Hills (~605 Ma) segments of the Bull Arm Formation: rhyolite
- Topsail Granite (~427-429 Ma): peralkaline intrusive and extrusive



Whalen et al., 1987; Krogh et al., 1988; Coyle, 1990; Miller, 1991; Tuach, 1991; Miller and Abdel-Rahman, 1995; O'Reilly et al., 2009; Magyarosi et al., 2019; Mills et al., 2020

Exploration

Most peralkaline rocks are magnetic and weakly radioactive due to presence of K, U and Th

Airborne magnetic (greater depth) and radiometric surveys (~30 cm below surface):

Province scale (line spacing <400 m):

- Mapping structural lineaments that may represent crustal permeability
- Search for intrusive systems under the surface
- Radiometric surveys detect the U, Th, K content of rocks, which are elevated and spatially associated with REE mineralization

District-scale:

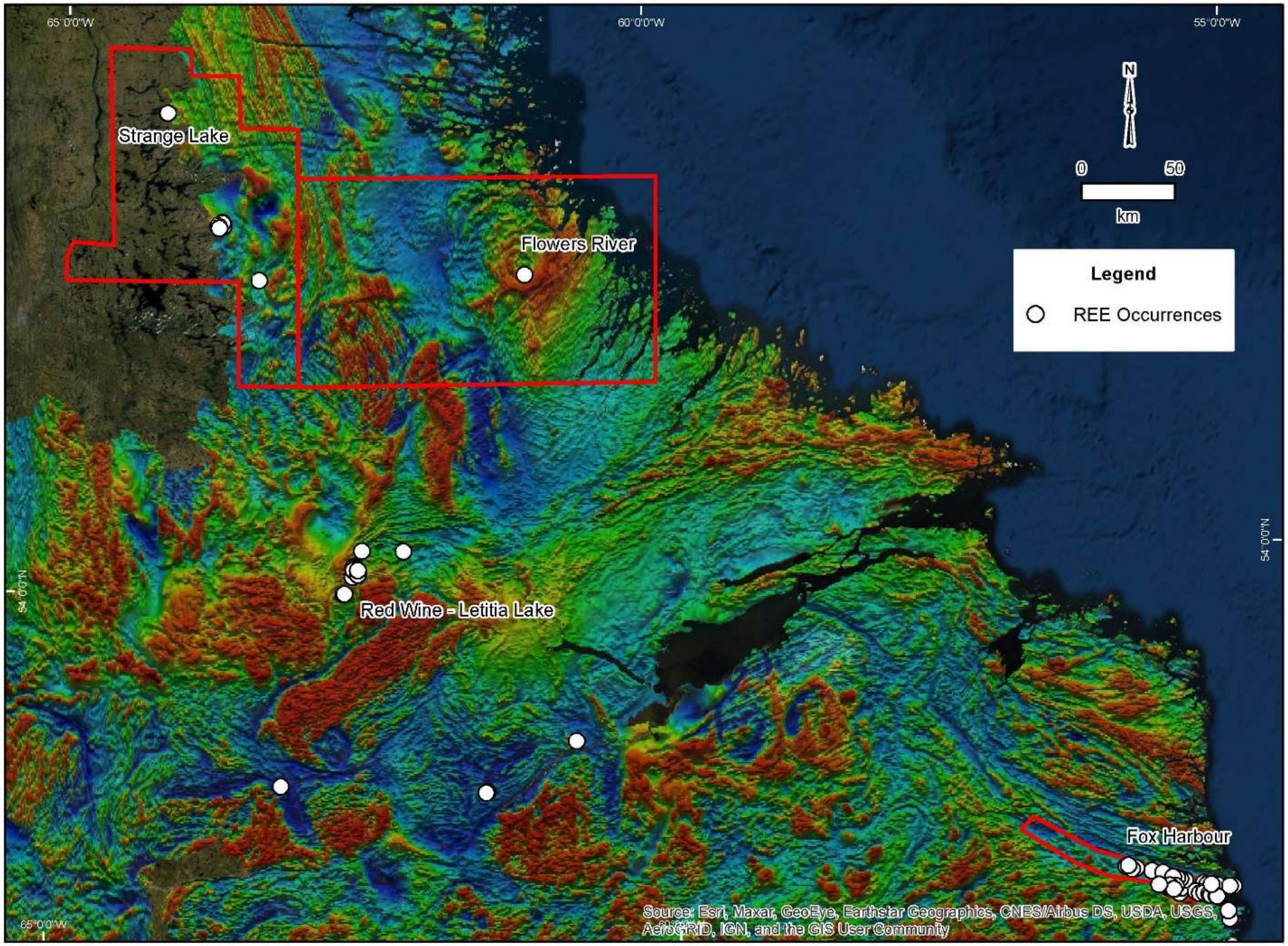
- Higher resolution (70-100 m spacing) to distinguish different phases within complex

Beard et al., 2022

Geophysical maps

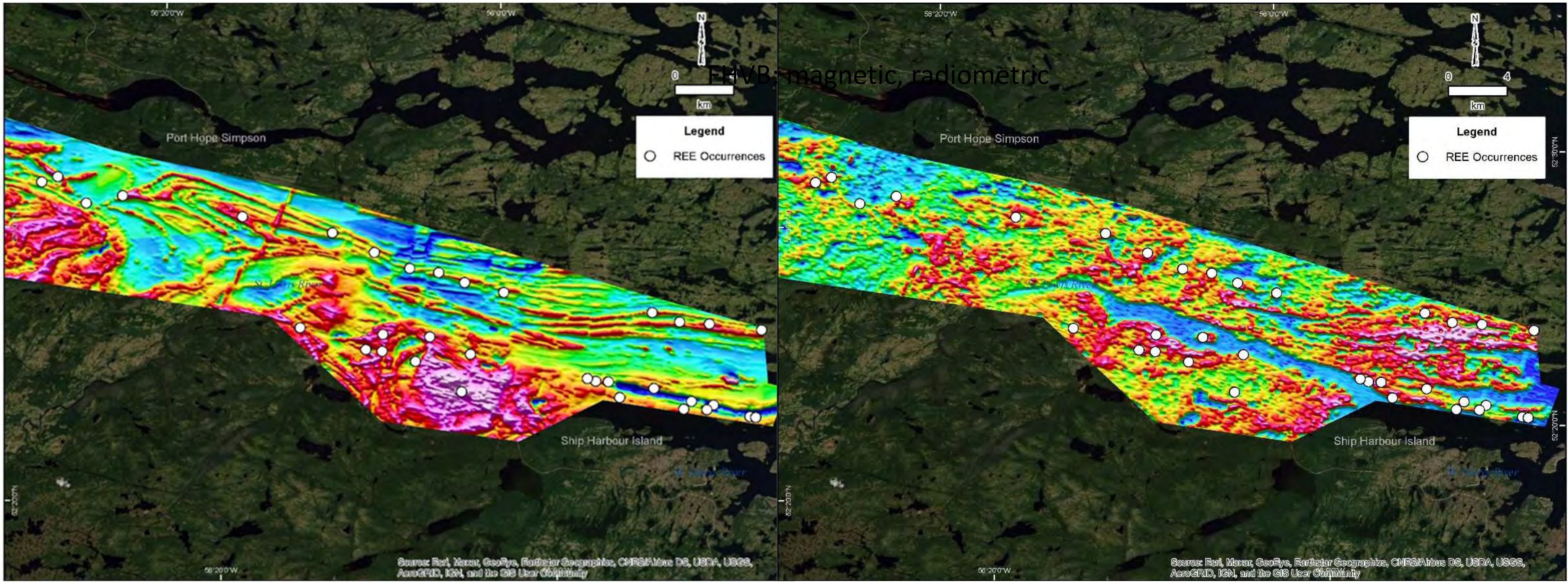
Labrador airborne residual magnetic map

800 m line spacing



https://www.geosurv.gov.nl.ca/airborne/disp_airborne.asp?SURVEY_ID=DN09898, Geofile NFLD/2063, GSC

Geophysical maps



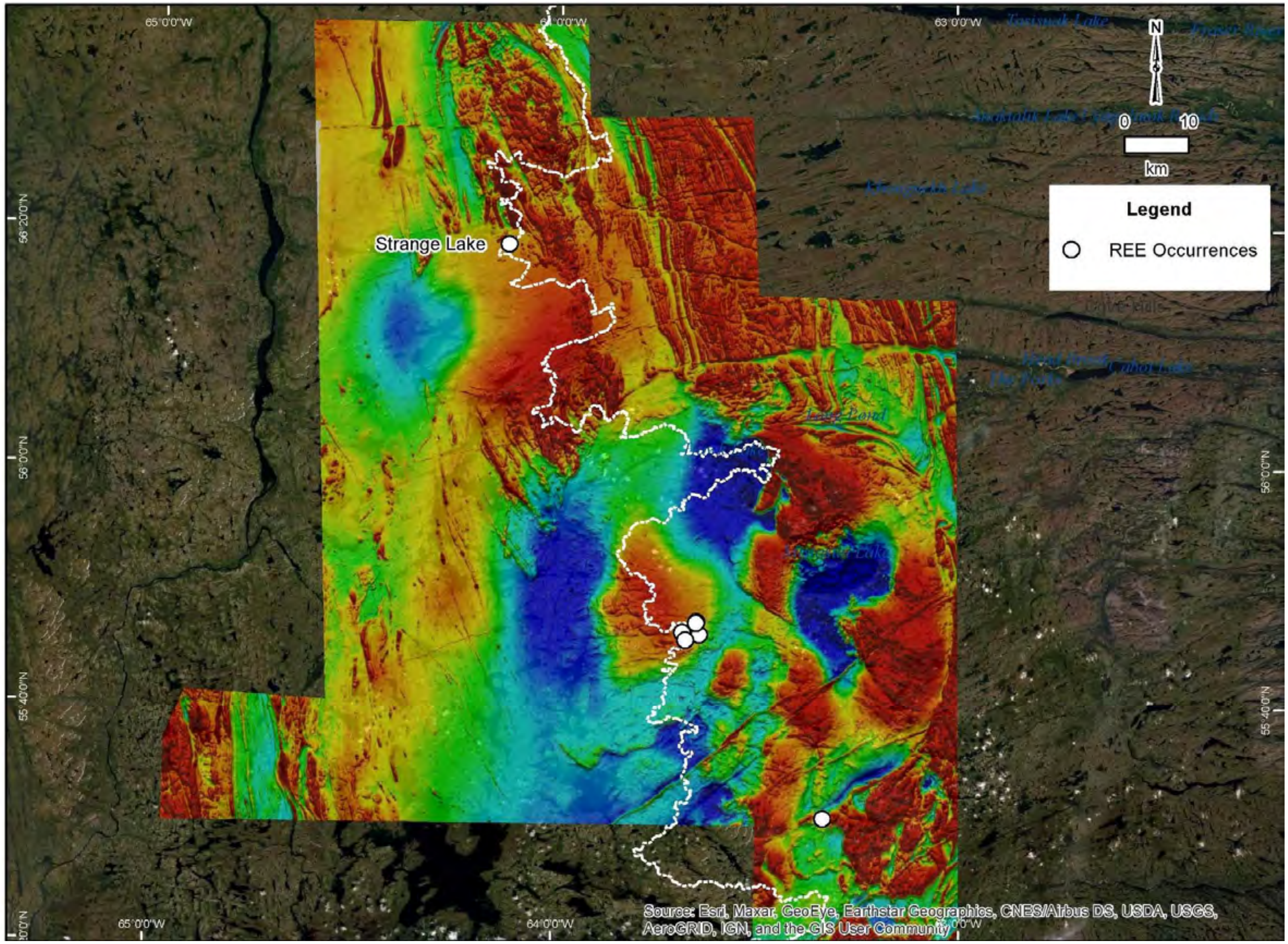
FHVB airborne residual magnetic intensity (RMI) and radiometric total count maps
250 m line spacing

https://www.geosurv.gov.nl.ca/airborne/disp_airborne.asp?temp=n&SURVEY_ID=DL15131, Geofile LAB/1635, Search Minerals

Geophysical maps

Strange Lake area airborne residual total field magnetic map

200 m line spacing

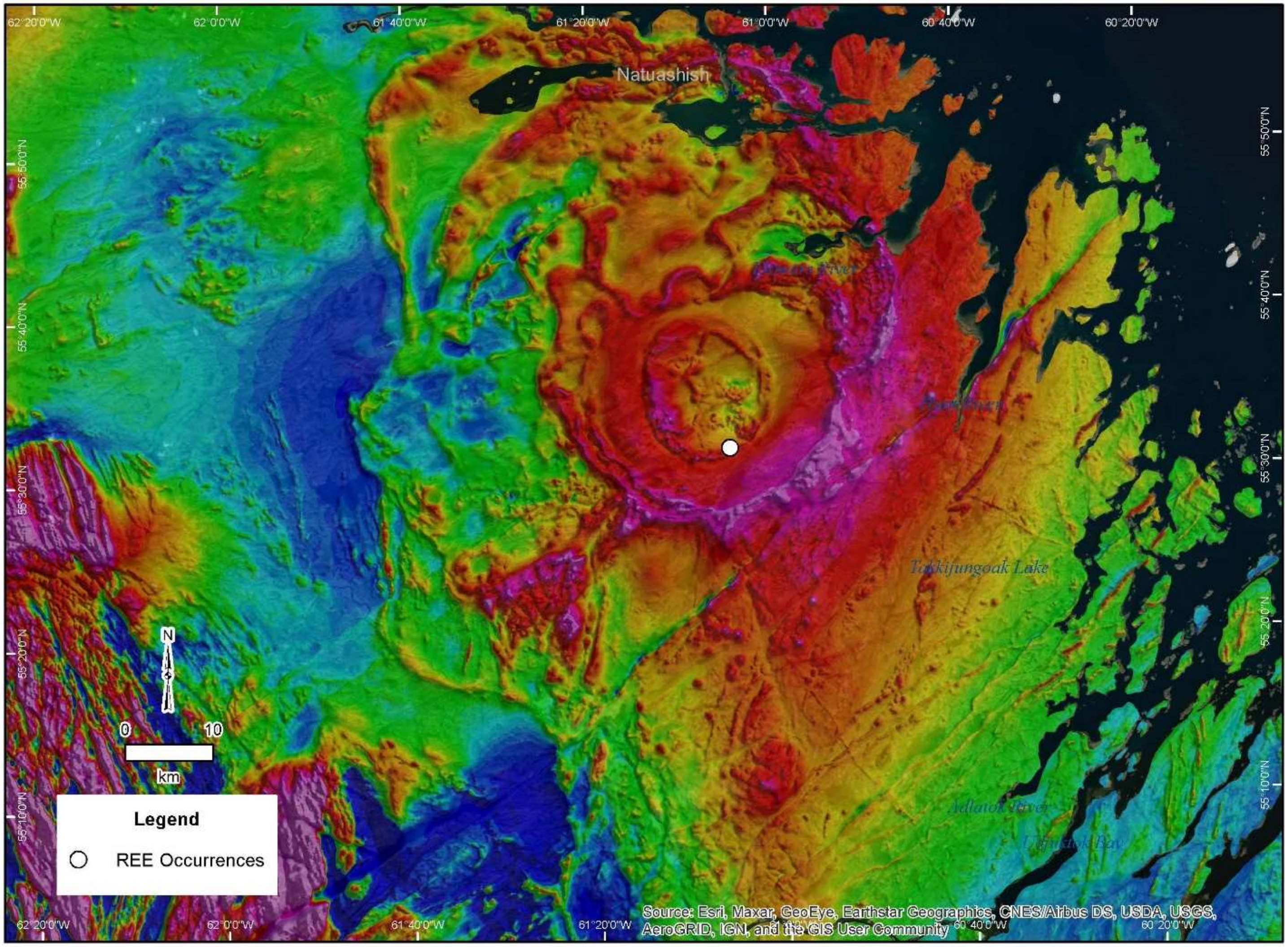


https://www.geosurv.gov.nl.ca/airborne/disp_airborne.asp?SURVEY_ID=DL09907, Geofile 13M/13/0099, GSC, GSNL, DRNFQ (Quebec Survey)

Geophysical maps

Flowers River airborne residual total field magnetic map

200 m line spacing



https://www.geosurv.gov.nl.ca/airborne/disp_airborne.asp?SURVEY_ID=DL09909, GSC and GSNL, Geofile LAB/1737

Exploration

Geochemical surveys: till (Heather Campbell), stream sediment, grab samples

Hyperspectral imaging techniques are under development

Magnetometer/magnet

Handheld gamma ray scintillometer (RS-120 or 125 Super-Scint):

- REE mineralization is commonly associated with U and Th contained in REE minerals, zircon, titanite or U and Th minerals (thorite), but not always!

Rent magnetometer/scintillometer from Mineral Incentives Program (mineralincentive@gov.nl.ca)

Highest count = 26,000 (~170 times background)

Thank you!

- Arianna Sheppard (field assistant)
- Lindsay Oldham (field assistant)
- Randy Miller (Search Minerals)
- Dylan Goudie (SEM)
- Kim Morgan (maps)
- GSNL (everyone)
- GSC (Anne-Aurélie Sappin, Dave Corrigan, Nicole Rayner-geochronology)
- Eric Thiessen, Nicolas Prieto Moreno (structural geology)