Granite-related critical minerals in Newfoundland

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Prospectors Short Course, Mineral Resources Review 2022

Overview

- What are granite-related critical mineral deposits?
  - Mineral deposit models (How do they get there)
  - Exploration criteria (How do we find them)
- Geology of southern/central Newfoundland and potential for granite-related critical mineral deposits
  - Regional mineral potential
  - Examples of known granite-related critical mineral deposits
- Current research and future GSNL plans

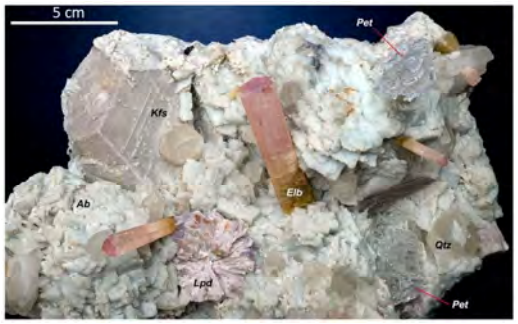
Granite-related critical mineral deposits

- Mineral deposits enriched in critical minerals, associated with intrusion of granitic rocks
- Wide range of mineral deposit types, including pegmatites, greisen, skarns, porphyries, hydrothermal vein-hosted and REE and F enriched peralkaline granites

Rare-metal granitic pegmatite mineralization

Granite-hosted Sn-W mineralization

Rare-metal granitic pegmatite mineralization



LCT pegmatite, Tuscany (Dini et al, 2022)


Tanco Pegmatite Mine (Martins et al, 2013)

- Very coarse grained igneous rocks, most commonly felsic, but do occur in other igneous rocks
- Source of several critical minerals including REE, Li, Cs, Ta, Nb, Sn, Be, but also gem stones (beryl, topaz), high quality feldspar, quartz and mica
- Divided into 2 main types (Černý and Ercit, 2005):
  - ***Li-Cs-Ta enriched pegmatites (LCT pegmatites):1/4 Li production, all Cs production, most Ta production***
  - Nb-Y-F-REE enriched (NYF pegmatites): Include important REE deposits (e.g. Strange Lake B Zone)
- Chemical differences originate from the different chemistry of the parent granite or protolith

LCT pegmatites: How they form

- Most LCT pegmatites, ***but not all***, derived from a “fertile” parent granite
  - Fertile granite is an evolved (highly fractionated) granite
  - Residual melt is enriched in incompatible elements not easily accommodated in common rock-forming minerals (e.g. Li, Cs, Nb, Ta and volatiles)
- Associated with peraluminous (S-type) granites formed as a result of melting of metasedimentary rocks
  - Li and Cs originates from decomposition of muscovite in the metasedimentary source
- Pegmatitic melt leaves granite and forms dike swarms in country rocks up to 10 km from parent granite
- Emplacement depth 4-6 km

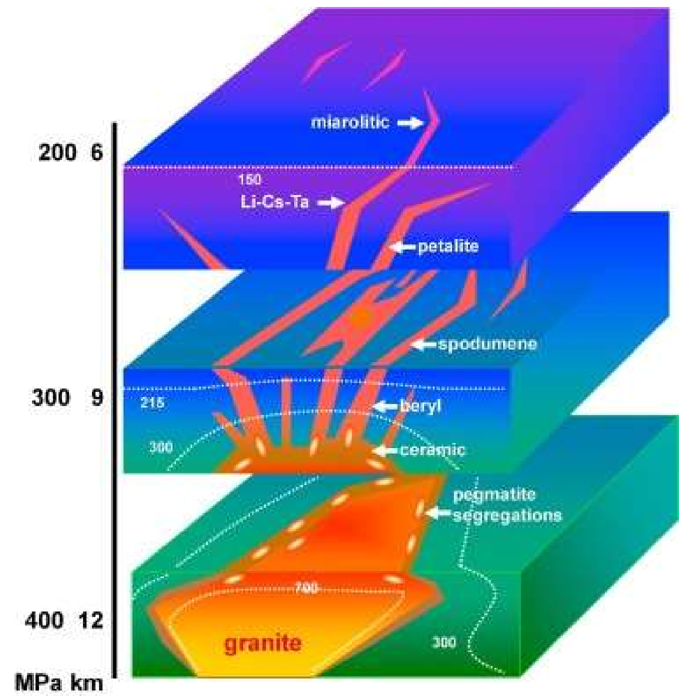


Image from London (2018)

Černý, 1991; Selway et al., 2005; London, 2016 and references within; London, 2018; Steiner, 2019

LCT pegmatites: How they form

- Typical ore minerals include spodumene, petalite, lepidolite, pollucite, columbite-tantalite group minerals
  - Fluorite is rare, F occurs in topaz, lepidolite, apatite
- LCT pegmatites show a distinct geochemical, mineralogical and textural zoning with increasing distance from the granite
  - This is due to increasing degree of fractionation
- It results in greater enrichment in rare elements and greater economic potential with increasing distance (up to ~10 km) from the parent granite

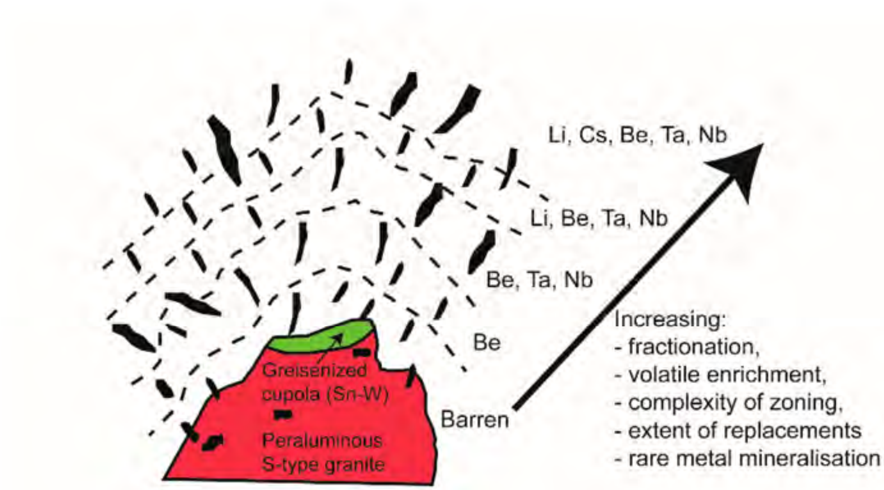


Image from Steiner (2019)

Granite-hosted Sn-W mineralization

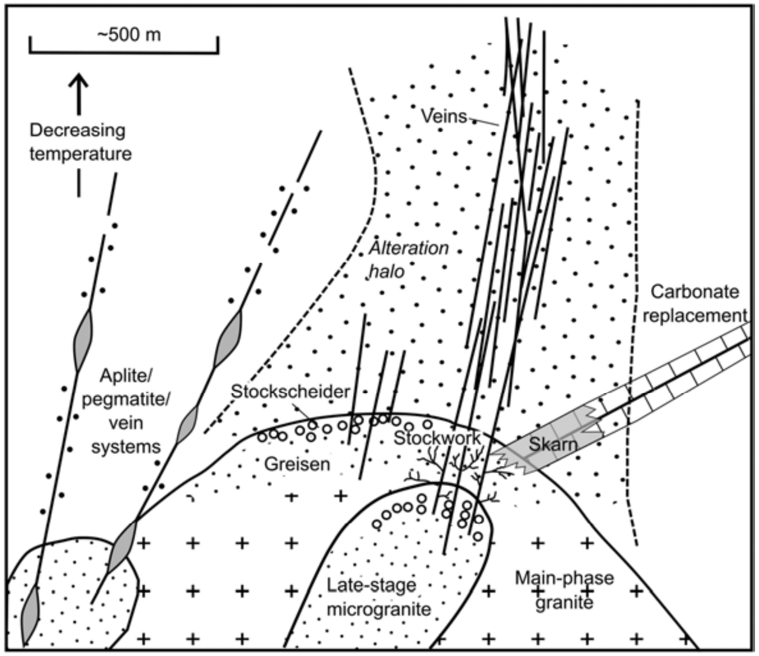

Molybdenite in Sn-topaz greisen, Ackley Granite


Cornish Tin Mine, image from Wikipedia

- Associated with highly fractionated late-stage granites (peraluminous and/or leucocratic)
- Form a variety of deposit types, including greisen, quartz veins, skarn, and less commonly porphyry-type occurrences and pegmatites
  - Greisens are intensely altered granitic rocks (metasomatic) resulting from high temperature alteration by F-rich fluids
- Sometimes spatially associated with porphyry Mo (W-Sn) mineralization,
  - Interpreted to represent intermediate deposit type between porphyry Cu (Au-Mo) deposits and granite-hosted Sn-W mineralization

Granite-hosted Sn-W mineralization: How it forms

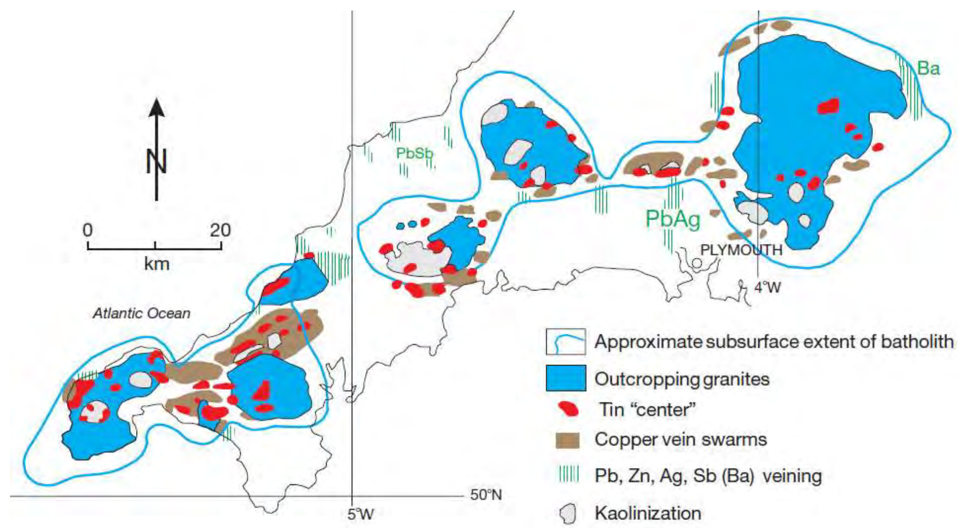
- Peraluminous granites and leucogranites (S-type) formed due to melting of sedimentary protolith
  - Initial metal content of protolith important in forming economic deposits (Romer and Kromer, 2016; Elongo et al., 2022)
- Incompatible elements (Sn, W, Mo) enriched in residual melt/fluids
- Mineralization type depends on location relative to parent granite
  - Greisen preferentially form in roof zones of granite
  - Veins and pegmatites can extend into country rock
  - Skarns form where granites intrude carbonate rocks (not important in Newfoundland)



From Lehmann (2021), modified from Černý et al. (2005)

Granite-hosted Sn-W mineralization: How it forms

- Cassiterite, wolframite, and molybdenite are the main ore minerals with a large range of associated elements (Černý et al, 2005)
- Many deposits have well defined zoning outward from parent granite (Černý et al., 2005; Lehmann, 2021)
  - Inner zone consisting of Sn-W-Cu-As-Bi mineralization
  - Broader halo with vein- or replacement-style Pb-Zn-Ag-Sb-Au-U mineralization of lower temperature



Zoned distribution of mineralization associated with Cornwall deposits, from Černý et al. (2005)

Exploration for LCT and Sn-W deposits

minerals
MDPI

Review

Tools and Workflows for Grassroots Li–Cs–Ta (LCT) Pegmatite Exploration

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GR Focus Review

Phanerozoic tin and tungsten mineralization—Tectonic controls on the distribution of enriched protoliths and heat sources for crustal melting

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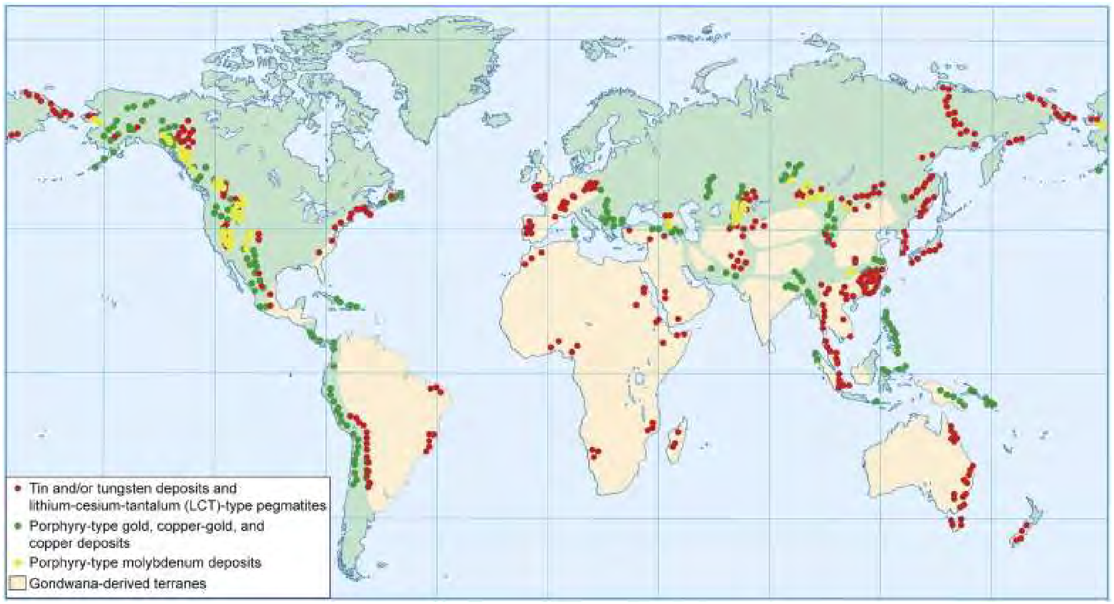
- LCT pegmatites and granite-related Sn-W deposits formed by similar processes and typically found in similar geological settings
- Similar exploration tools can be utilized to determine prospective areas

Global distribution of LCT and Sn-W mineralization



Global distribution of Phanerozoic granite-related mineralization, from Romer and Kromer (2016)

- Phanerozoic Sn-W and LCT deposits typically form discontinuous belts, associated with major orogenies
- Mineralization in these belts is irregular in distribution and related to multiple events
  - Typically a relatively narrow zone prospective for LCT and Sn-W despite widespread occurrence of evolved granite magmatism (Romer and Kromer, 2016; Elongo et al., 2022)

Factors necessary to form economic deposits (Romer and Kromer, 2016)

Giant spodumene crystal, Maine (from Symmons et al., 2019)

Intense chemical weathering of sediments

- Residual enrichment of K, Li, Rb, Cs, Sn, and W on clay minerals
- Most common on interior of large continents (e.g. Gondwana)

Accumulation in tectonic basins

- Chemically weathered sediments transported in large river systems
- Accumulate in basins during fragmentation of original continent
- Tectonically stacked during later orogenesis

Melting of protolith forming S-type granites

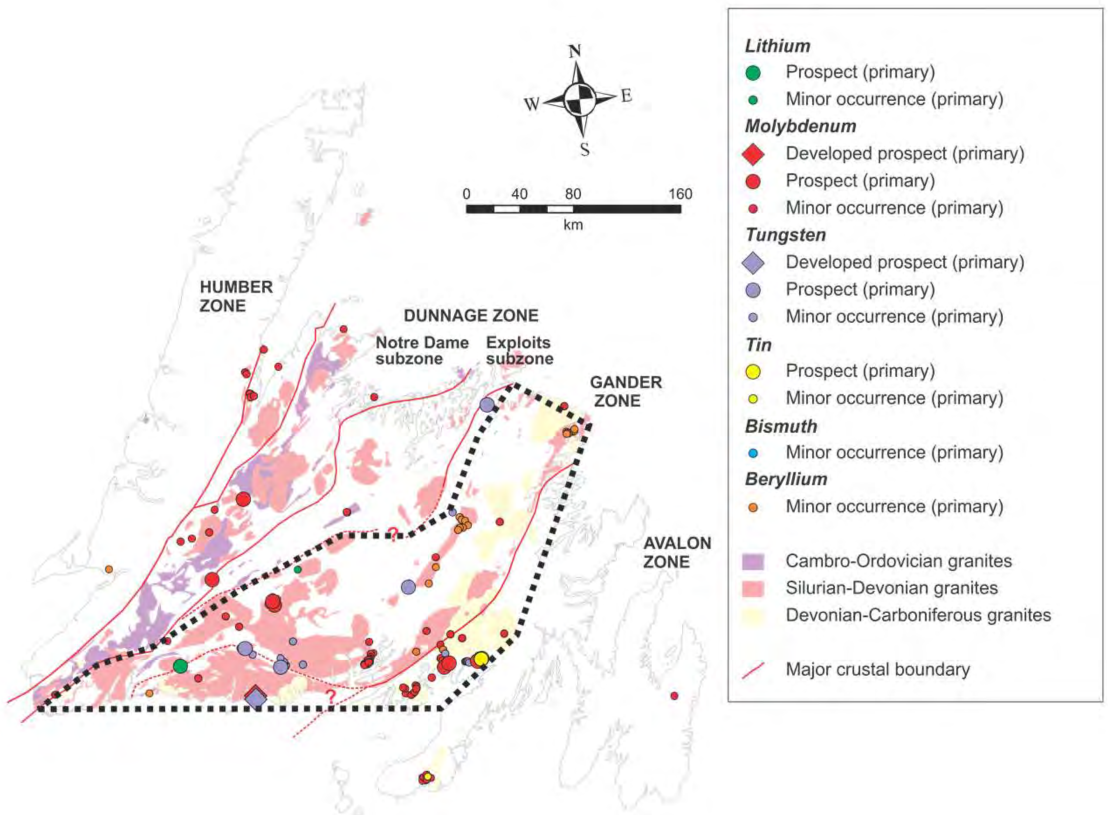
- Partial melting of sediments during crustal thickening or mantle upwelling
- Melting of muscovite (low T) forms LCT deposits
- Higher temperatures need to melt biotite and form Sn-W deposits

Exploration workflow (from Steiner, 2019)

- Identify suitable geological environments (S-type granites in metasedimentary rocks)
- Geological studies and grassroots prospecting
  - Radiometric dating, isotope and mineral geochemistry of pegmatite, granitic and metasedimentary host rocks
  - Identification of granites with two micas (muscovite and biotite), pegmatites with garnet, tourmaline, beryl, Li-bearing minerals
  - Li-bearing minerals (e.g. spodumene) commonly difficult to identify and easy to overlook
  - Geochemical sampling and analysis of soil, till and stream sediments effective method for localizing deposits
  - Partial aqua regia unsuitable to dissolve silicate minerals, need total digestion

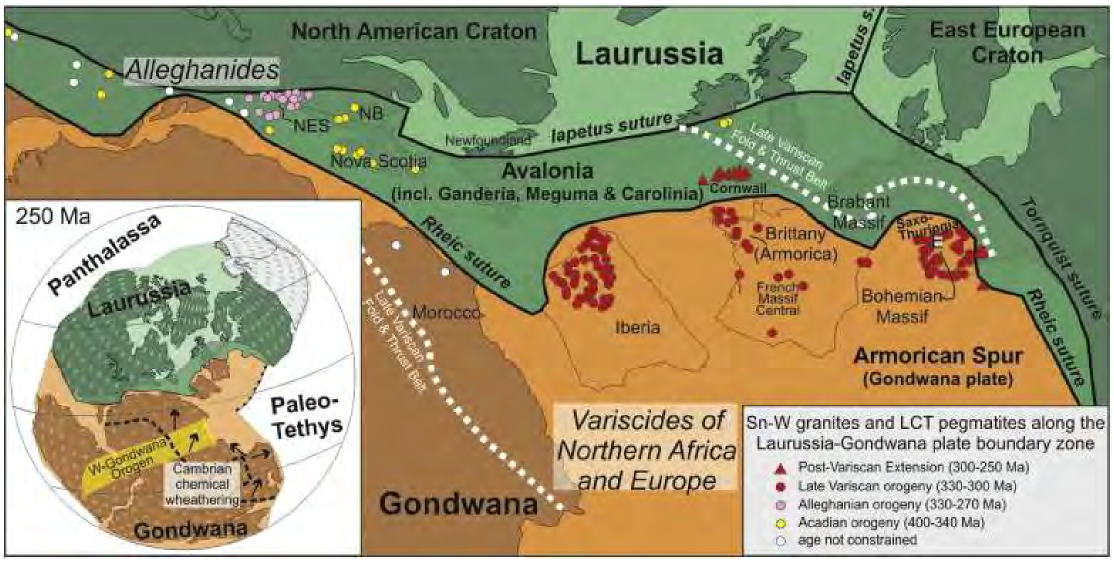
Granite-related critical minerals in Newfoundland

Granite related mineralization in Newfoundland



- Numerous critical mineral occurrences associated with granite plutons in Newfoundland
- Molybdenum occurrences in all lithotectonic zones
- Other commodities typically associated with granites in the Gander and western Avalon zones

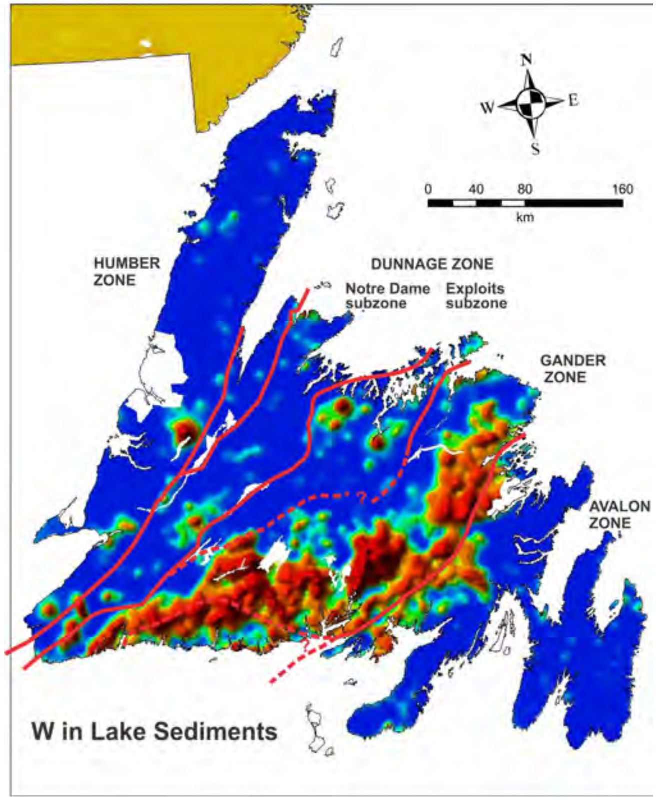
LCT and Sn-W mineralization in Appalachians

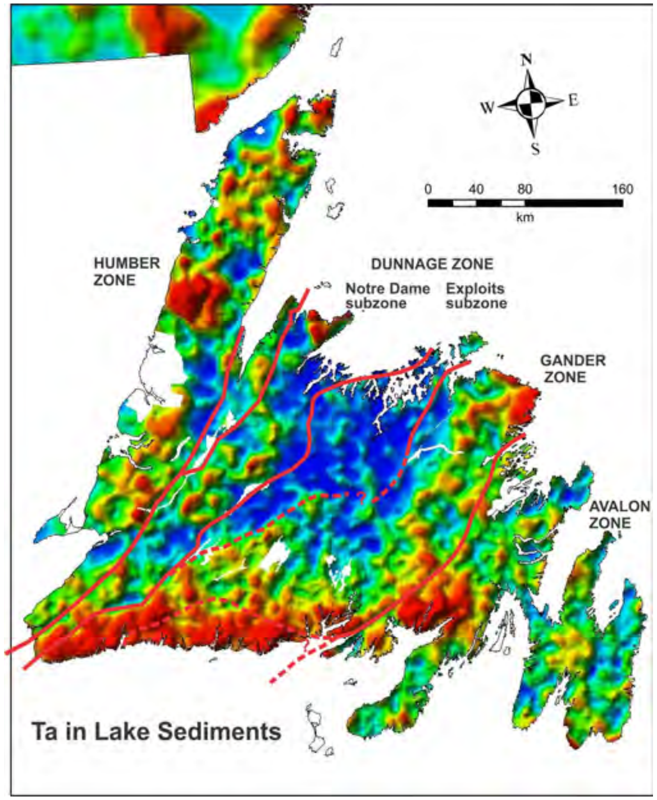


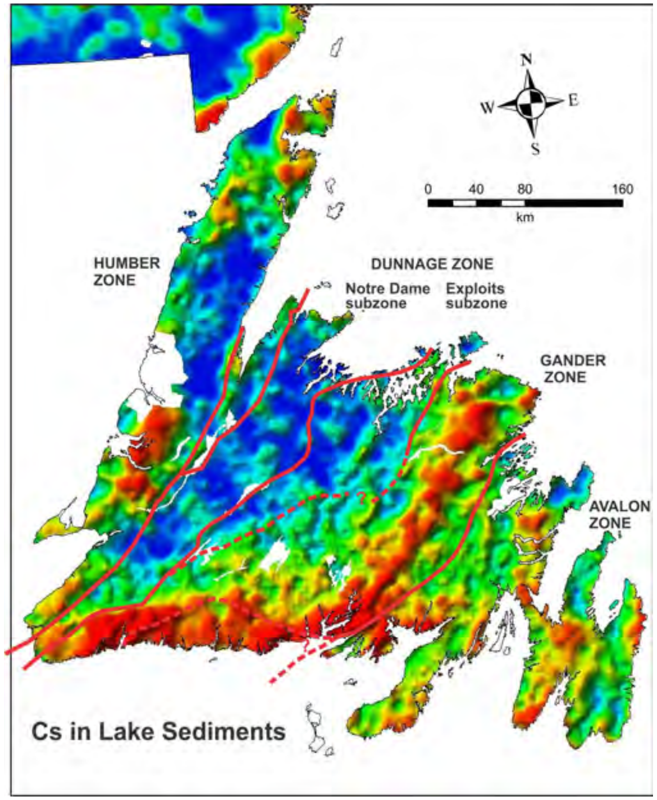
Source: Romer and Kromer, 2016

- Acadian–Variscan–Appalachian host multiple Sn-W and LCT deposits
    - e.g. Cornwall (Sn), Erzgebirge (Sn, W, F), Nova Scotia/New Brunswick (Sn, W, LCT) and New England (LCT)
- Associated with multiple orogenic events between 400 and 250 Ma
- Believed to be related to melting of chemically enriched sediments accumulated during breakup of Gondwana
- Highlight prospectively of Gander and Avalon zones to host significant deposits

Region Lake Sediment Geochemistry

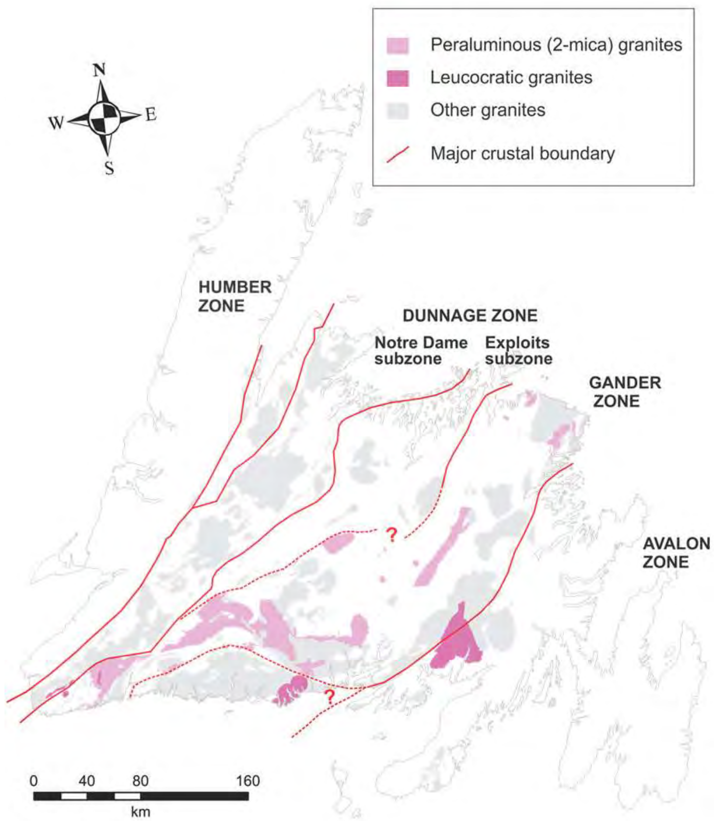






Sources: Geological Survey Resource Atlas, http://gis.geosurv.gov.nl.ca/ accessed 2022

Granite fertility in Newfoundland



- Peraluminous granites and leucogranites (S-type) common in Gander and Avalon zones
  - Possible fertile granites for LCT and Sn-W mineralization
  - Need further assessment to determine potential (lithogeochemistry, mineral chemistry)
- Historical mapping has identified a number of beryl/tourmaline/garnet/lepidolite bearing pegmatites that need reassessment
- Recent work by GSNL has identified LCT pegmatites in central Newfoundland (Magyarosi, 2020)
- Timing of melting and granite emplacement unknown in many cases (Salinic and Acadian orogenies)
  - **BUT** Examples from other belts show timing not critical

Kraken LCT Pegmatites

- Located ~ 30 km northeast of Burgeo
- Multiple folded pegmatite dykes intruding Ordovician metasediments
- Medium to coarse grained pegmatites
    - Elongate spodumene crystals up to 12 cm
    - Common tourmaline in host rocks and at margins of pegmatite dykes
- Located in Bay d'Est Fault Zone, and < 1km from contact with peraluminous Rose Blanche granite
- See presentation this afternoon for more details

Spodumene pegmatite

Spodumene pegmatite

Folded pegmatite dyke in metasediments

Rose Blanche granite

Grey River Tungsten Deposit

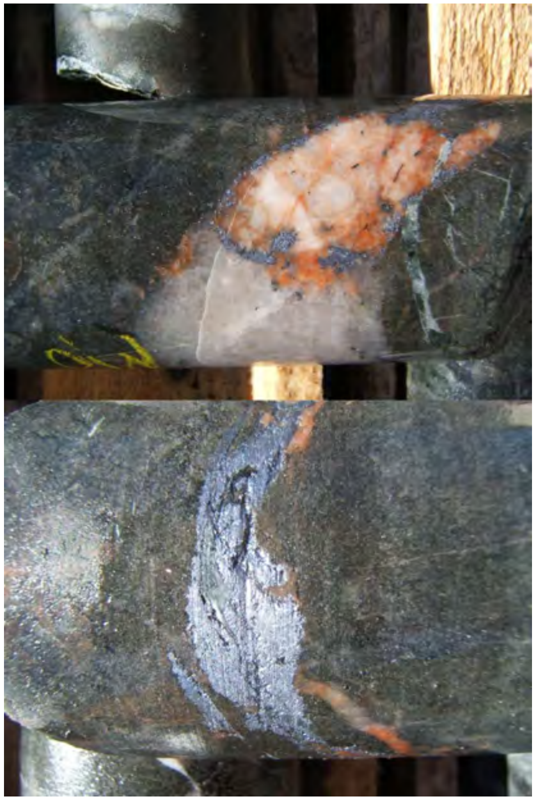
- Located close to the town of Grey River
- Over 600 wolframite and scheelite-bearing quartz veins recorded, with two large veins (#6 and #10)
  - Multiple mineralization stages with enrichment in W, with lesser Mo, Bi, Be, F and Cu
  - Greisen alteration of host metasediments surrounding veins, poorly understood metal zonation in area
  - Associated with intrusion of unknown granitic pluton at depth (Higgins, 1985; Lynch, 2017)
- Inferred mineral resource of 1.17 Mt at 0.73% WO_3 (18.8 Mlbs WO_3)


Town of Grey River

Vein hosted tungsten mineralization, Grey River

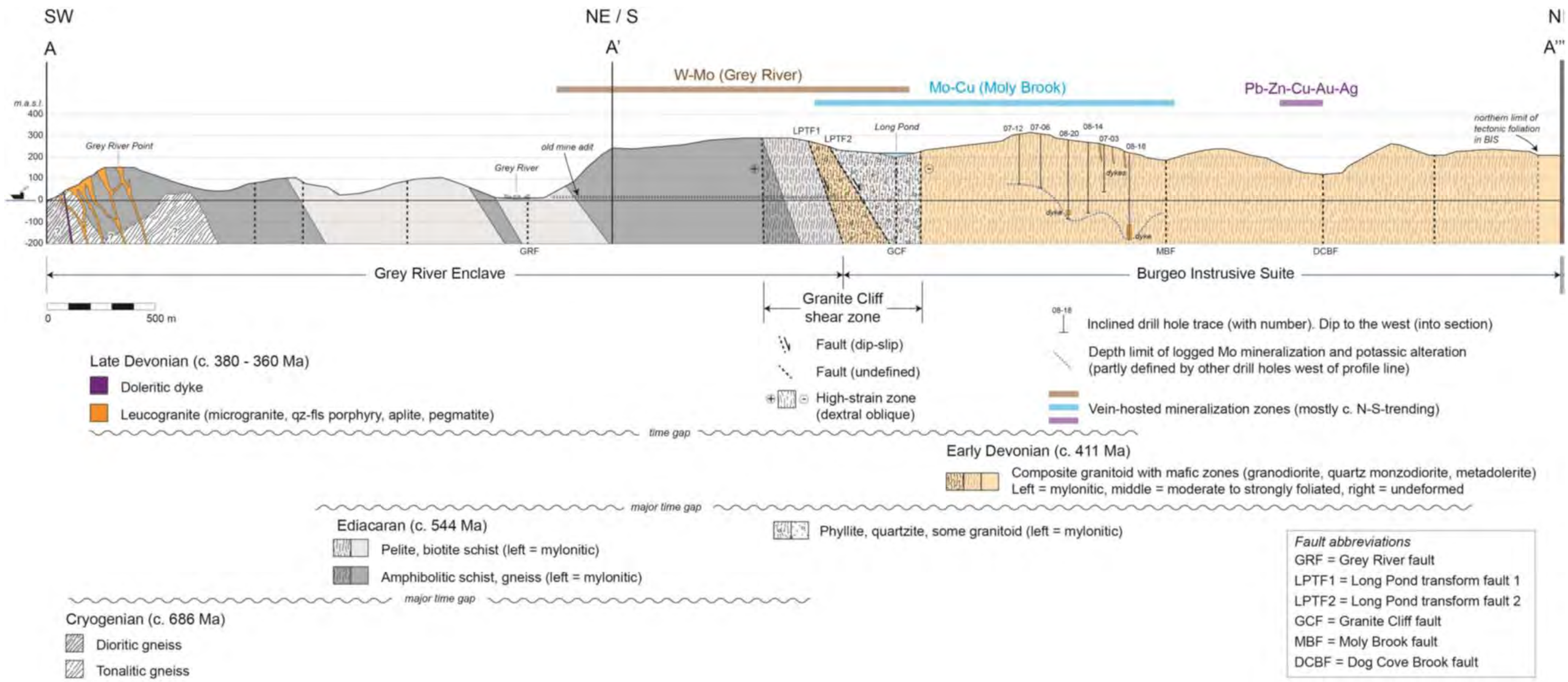
Moly Brook Mo-Cu Deposit

- Located north of Grey River, studied in detail by Lynch (2017)
  - Indicated resource of 86.8 Mt at 0.065% molybdenum (113 Mlbs Mo)
  - Multiple generations of conjugate Mo-bearing veins cutting earlier granite of Burgeo Intrusive Suite, associated with unexposed granite at depth
  - Geological and geochronological evidence indicates Moly Brook and Grey River deposits form part of the same magmatic-hydrothermal system (Lynch, 2017)
- Geological characteristics suggest an affinity with porphyry deposits, but in different geological setting to typical Mo-W porphyries (rift or arc settings)
  - Classified as collisional-type Mo porphyry (Chen et al., 2017; Lynch, 2017)
  - Intermediate deposit between typical Mo porphyries and granite related Sn-W deposits



Vein hosted molybdenum mineralization, Moly Brook

Relationship between deposits at Grey River



Schematic geological cross-section through the Moly Brook-Grey River area (from Lynch, 2017)

Ackley Granite Sn and Mo deposits

- Numerous Sn and Mo prospects located along southern margin of the Ackley Granite
  - Associated with late-stage, highly evolved leucocratic phase of the Ackley Granite (Dickson, 1983; Tuach, 1987)
- Sn greisens and greisen veins common to east, including Esso Showing (up to 0.79% Sn over 0.5m)
  - F-rich fluids near the top of the magma chamber
- Mo-showings common to the west, including Ackley City Prospect (historical resource of 80,000 tonnes at 0.6 percent MoS_2)
  - Late-stage H_2O rich fluids (Tuach, 1987)

Disseminated Mo mineralization in Ackley granite

Greisen vein cutting Ackley Granite

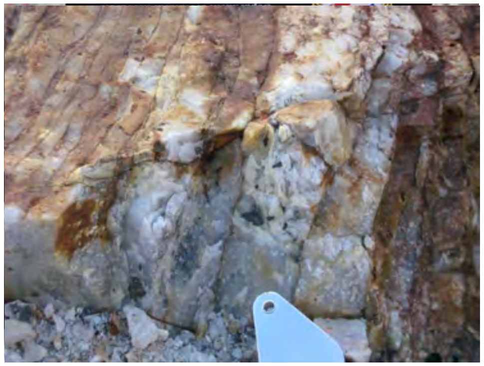
Sn-topaz greisen, Esso Showing

Granite Lake W-Mo-Bi prospect

- Molybdenite and wolframite hosted in sheeted quartz, quartz-greisen and quartz-pegmatite veins in peraluminous granite
- Associated with extensive metasomatism during late-stage magmatic-hydrothermal alteration
- Significant molybdenum mineralization (up to 0.074% Mo over 31.5m) intersected during drilling
  - Similar in style to Moly Brook showing (Kerr, 2013)
- Vein hosted W and Bi mineralization, with grab and chip samples up to 2.43% W (over 2m) and 1.9% Bi (Tuach, 1996)

Granite Lake area

Quartz-molybdenite vein, Granite Lake



W mineralization, Granite Lake

Current and future research

- Collaborative research with government (Geological Survey of Canada), industry and academia
- Ongoing and proposed research projects with Memorial University and StFX University
    - Investigate sediment provenance and chemical weathering
    - Geochronology and geochemistry of potential fertile granites
    - Mineralogy and mineral chemistry of pegmatites
    - Till and stream sediment geochemistry
    - Stream water analysis

Site visit to Kraken Property, September 2021

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