Geological Survey of Canada
Commission géologique du Canada

The setting, age, alteration and mineralization at the MAX molybdenum Mine

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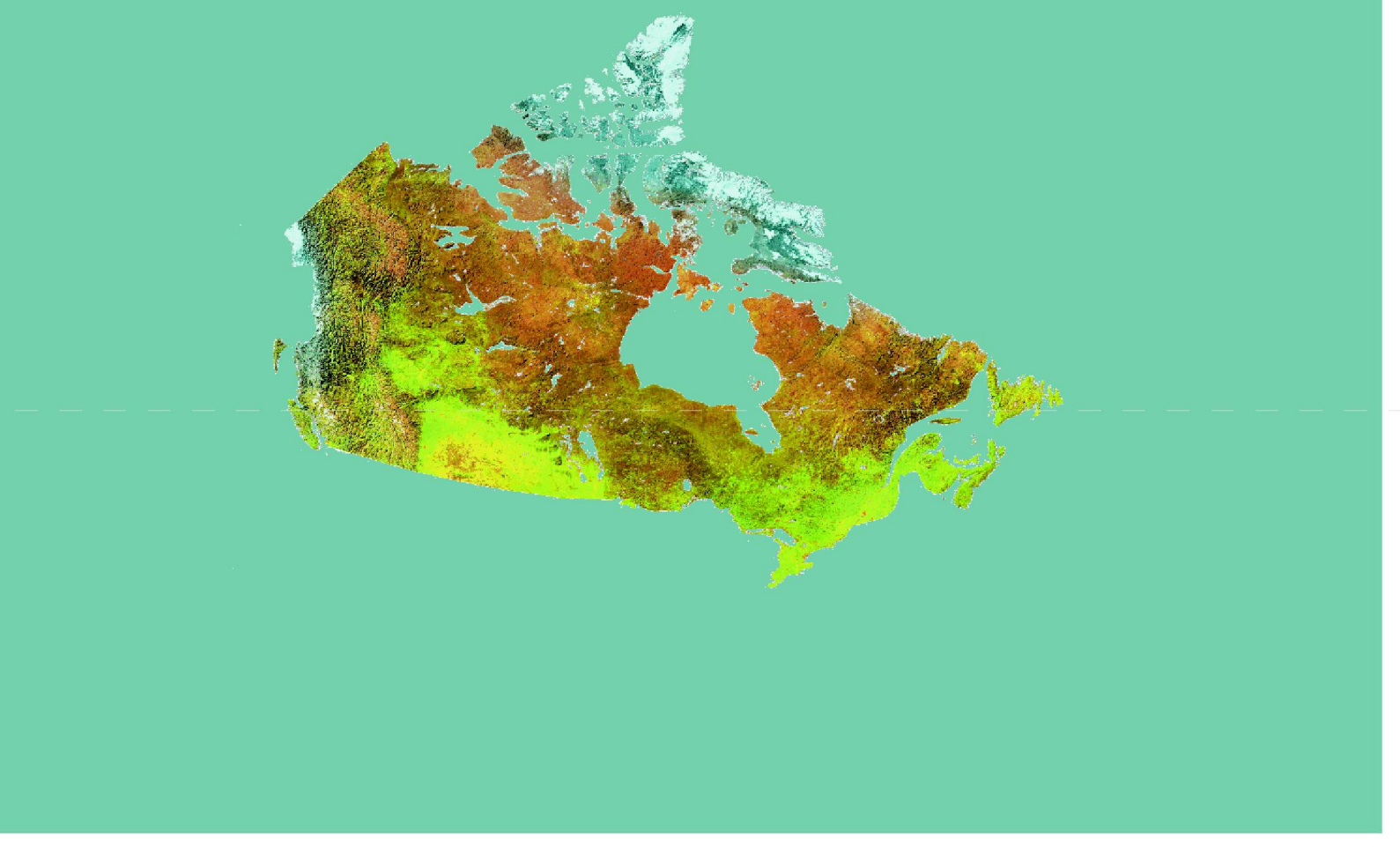


SUMMARY

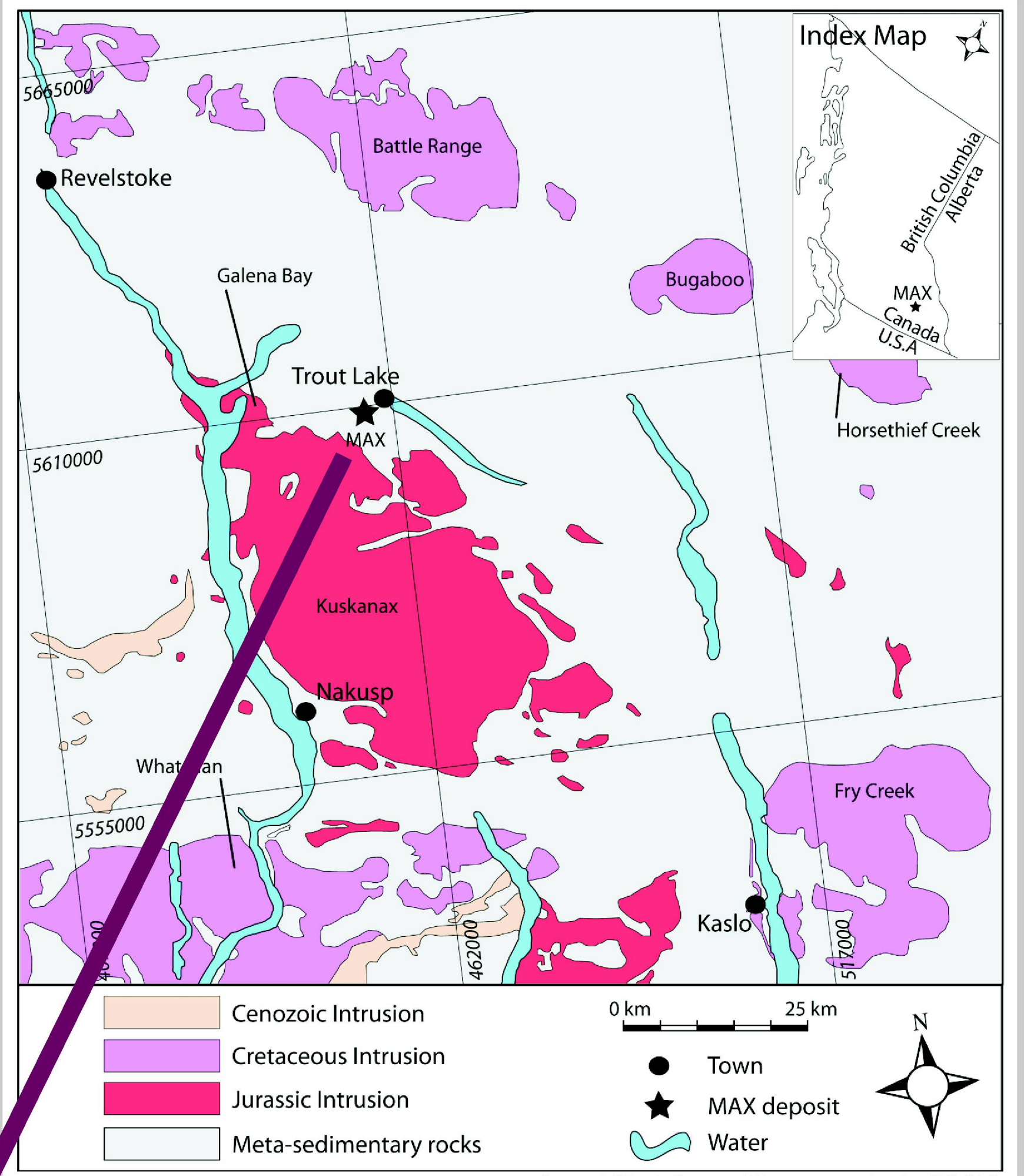
MAX is a porphyry Mo deposit at the northern end of the Kootenay Arc and located near Trout Lake village in southeastern British Columbia (5609565N, 457374E, NAD 83, Zone 11). Molybdenite is hosted by the Late Cretaceous Trout Lake stock (80.2 ± 1.0 Ma; see below) in a well developed quartz vein stockwork. Intrusive phases range in composition from granodiorite to tonalite and quartz diorite. They intruded multiply-deformed phyllite, schist, and marble of the Paleozoic Lardeau Group which are regionally and contact metamorphosed.

Previous studies demonstrated that many giant porphyry deposits possess long-lived histories characterized by repeated pulses of magmatism and hydrothermal activity. MAX is a relatively small, but locally high-grade porphyry Mo deposit, which lacks multiple long-lived overprinting hydrothermal events. Consequently, the detailed relative history of small-scale intrusive (dike emplacement) and hydrothermal events (vein paragenesis) can be clearly established. In this study, we attempted to resolve the absolute timing of these intrusive and hydrothermal events by utilizing multiple geochronometers. Lithogeochemistry and fluid inclusion results were then interpreted within this temporal framework. This poster is a summary of Lawley (2009).

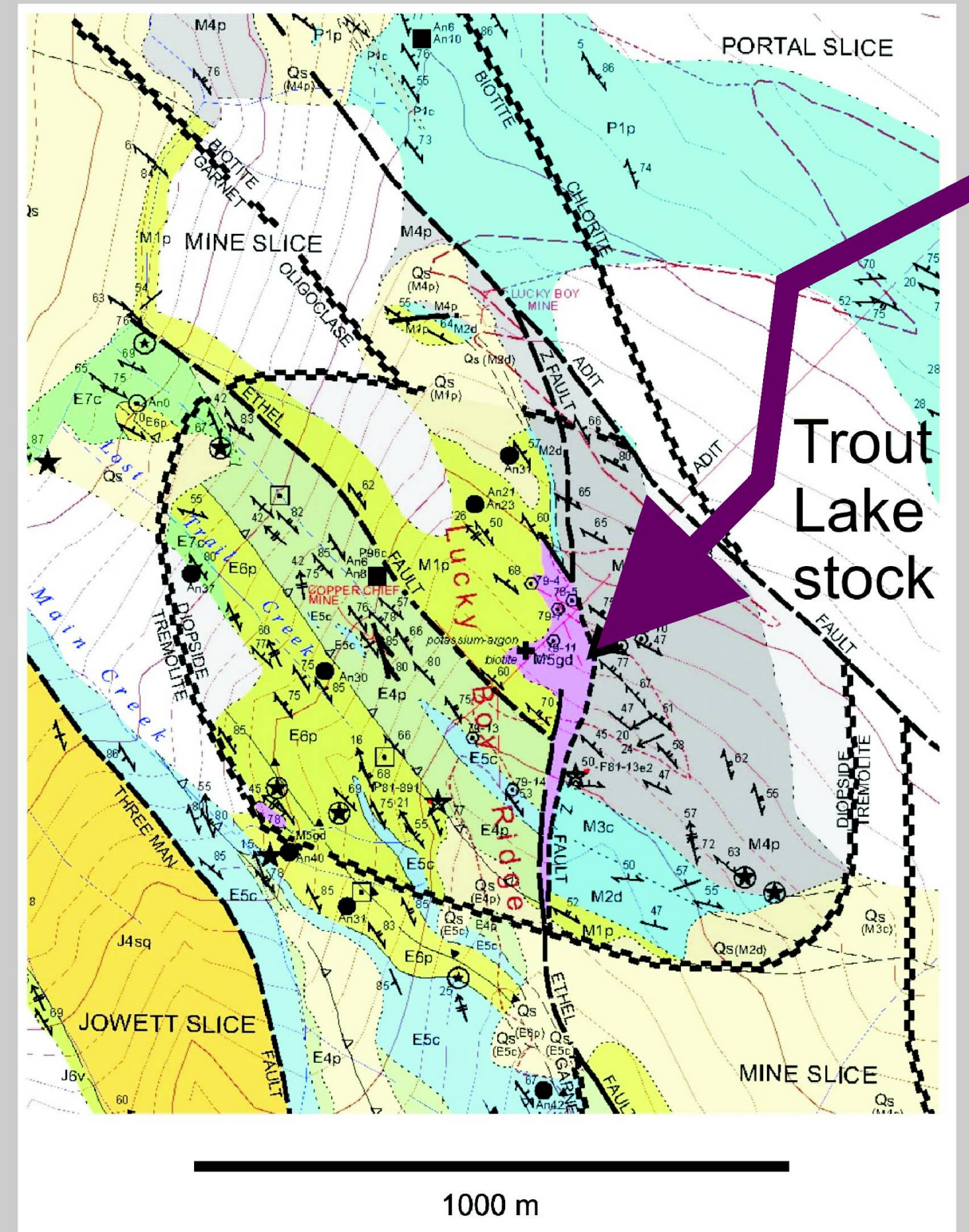
MAX is typical of low grade, arc-related deposits associated with fluorine-poor and calc-alkaline magmas (Carten et al., 1997) typical of most porphyry Mo deposits in British Columbia Low salinity MAX fluids are also typical of porphyry Mo deposits globally.

The results of the U-Pb (80.9 ± 1.6 Ma and 80.2 ± 1.0 Ma) and Re-Os dating (80.5 ± 0.4 Ma, 80.2 ± 0.4 Ma, and 80.1 ± 0.4 Ma; average = 80.3 ± 0.2 Ma) of early and late dikes and molybdenite all overlap within analytical error, showing that magmatism and Mo mineralization occurred on a time scale shorter than the resolution of these methods. 40Ar/39Ar plateau ages for igneous and hydrothermal biotite, and hydrothermal muscovite from Mo veins range from 80–76 Ma, and are consistent with cooling ages or minor 40Ar-loss following a short-lived magmatic–hydrothermal event at ~80 Ma

REFERENCE: Lawley, C.J.M. 2009. Age, geochemistry, and fluid characteristics of the MAX porphyry Mo deposit, southeast British Columbia: Unpublished M.Sc. Thesis. University of Alberta, Edmonton, Alberta, 170 p.



(modified from Massey et al., 2005)

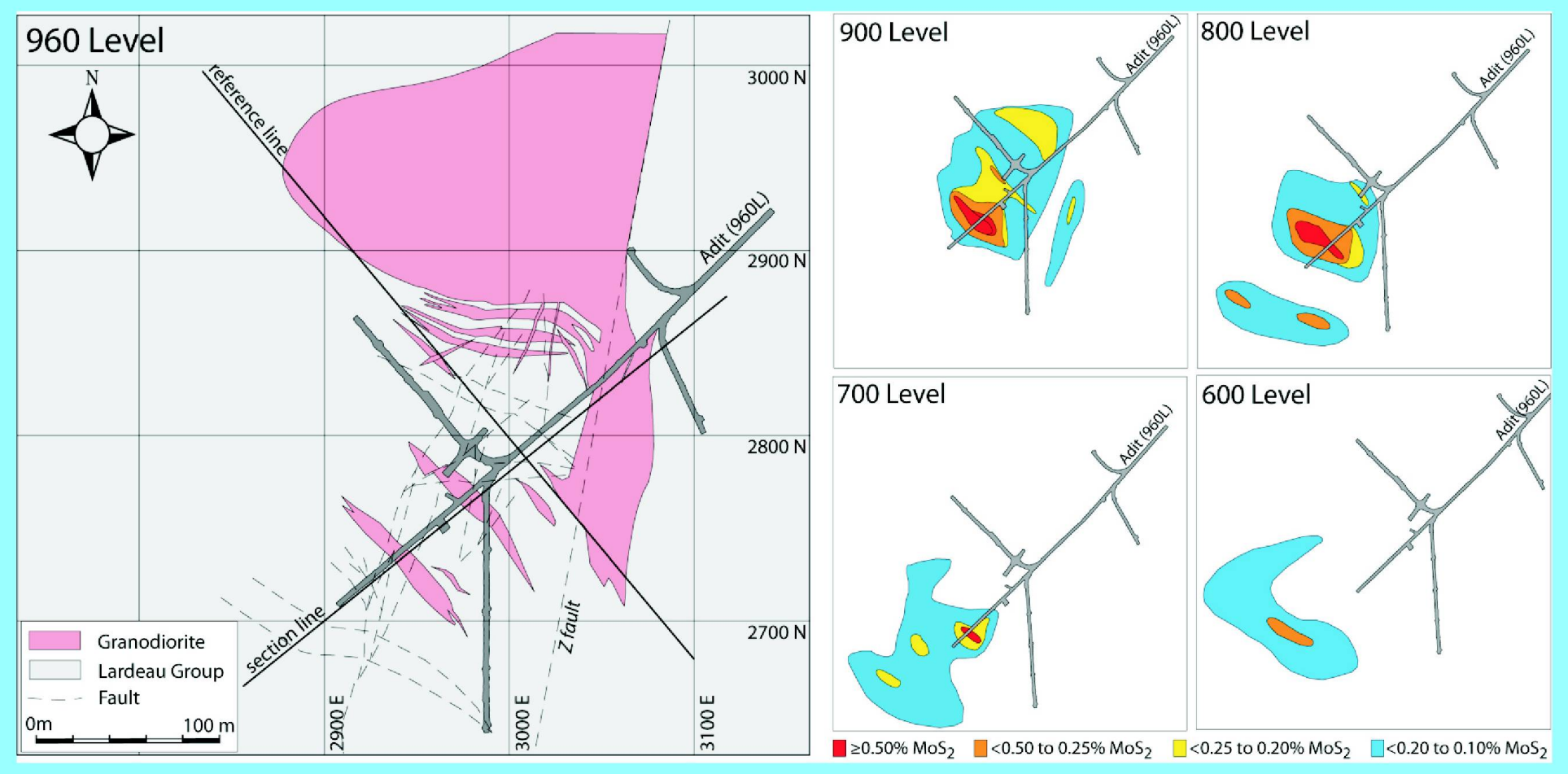


Regional geological setting from Read et al. (2009). Note tremolite-diopside contact metamorphic aureole isograd within which the extent of the presently-known molybdenite mineralization occurs. Unit M5gd is granodiorite of Trout Lake stock; location of earlier-determined 79 +/- 3 Ma K-Ar date is shown. See Read et al. (2009) for more details of the country rock geology.

Mo Mineralization and Vein Styles

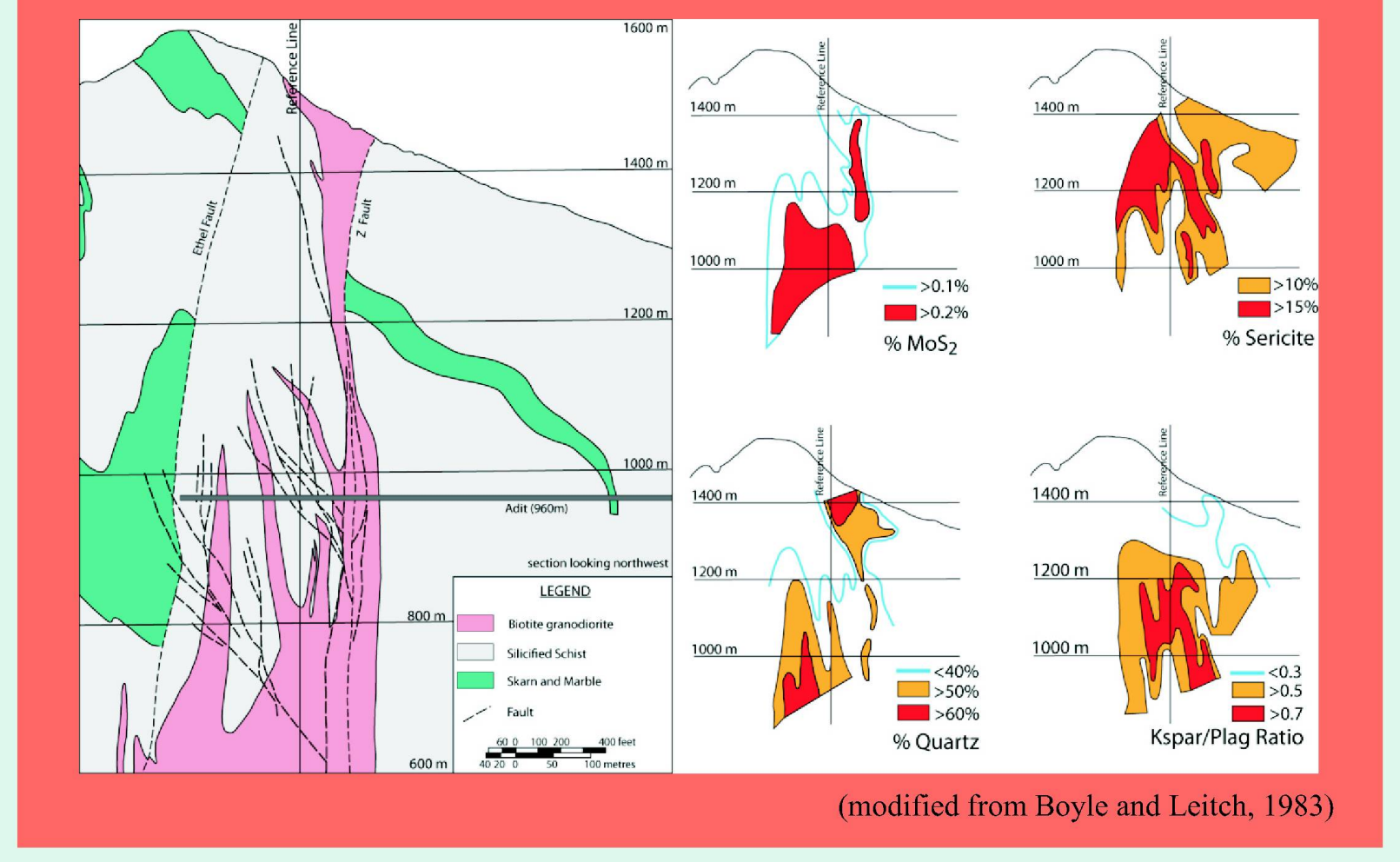
A high-grade Mo zone (i.e., 280,000 tonnes at 1.95% MoS2 with a 1.0% MoS2 cutoff (Macauley, 2004) is intimately associated with one of several lenticular granodiorite dikes extending from the much larger biotite granodiorite body at depth. Molybdenite mineralization in this zone is present as coarse-grained disseminations within granodiorite, molybdenite-pyrrhotite intergrowths, and irregular stringers that are oriented parallel to the strike of the dikes and the regional foliation. High-grade Mo mineralization is restricted to the upper portions of the host dike and becomes progressively lower grade with increasing depth (see contours in sections below). Low-grade Mo mineralization is hosted by a well-developed quartz vein stockwork.

Sheeted quartz ± feldspar veins crosscut irregular molybdenite stringers within granodiorite and are in turn crosscut by a variably oriented quartz ± feldspar ± molybdenite vein stockwork. Quartz ± feldspar veins commonly show evidence of open space filling and repeated opening and regeneration of mineralized fluids. Crenulated quartz, molybdenite, and feldspar veins known as "brain texture" provide further evidence of a rhythmic period of mineralization (Shannon et al., 1982).



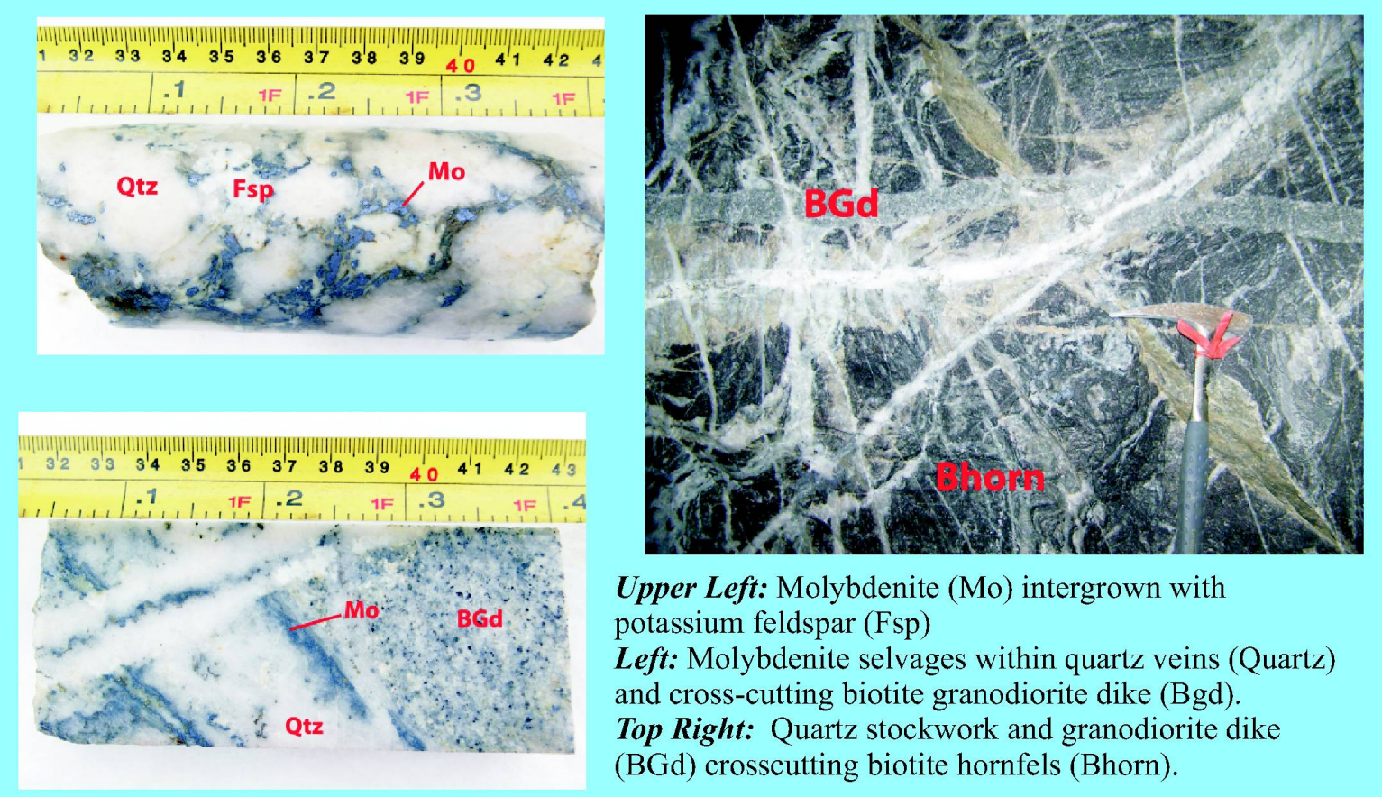
Alteration Assemblages

Potassic alteration is characterized by biotite + K feldspar flooding, and is most strongly developed within the high-grade molybdenite zone. Silicic alteration, characterized by quartz flooding and increased quartz vein density, is also most strongly developed within the high-grade zone. Phyllic alteration, characterized by muscovite ± pyrite ± calcite, is widely distributed and locally pervasive. Late propylitic alteration is widely distributed and is characterized by chlorite ± epidote ± muscovite ± calcite ± titanite ± pyrite. Phyllic alteration overprints early silicic and potassic alteration, whereas propylitic alteration overprints all other alteration assemblages.



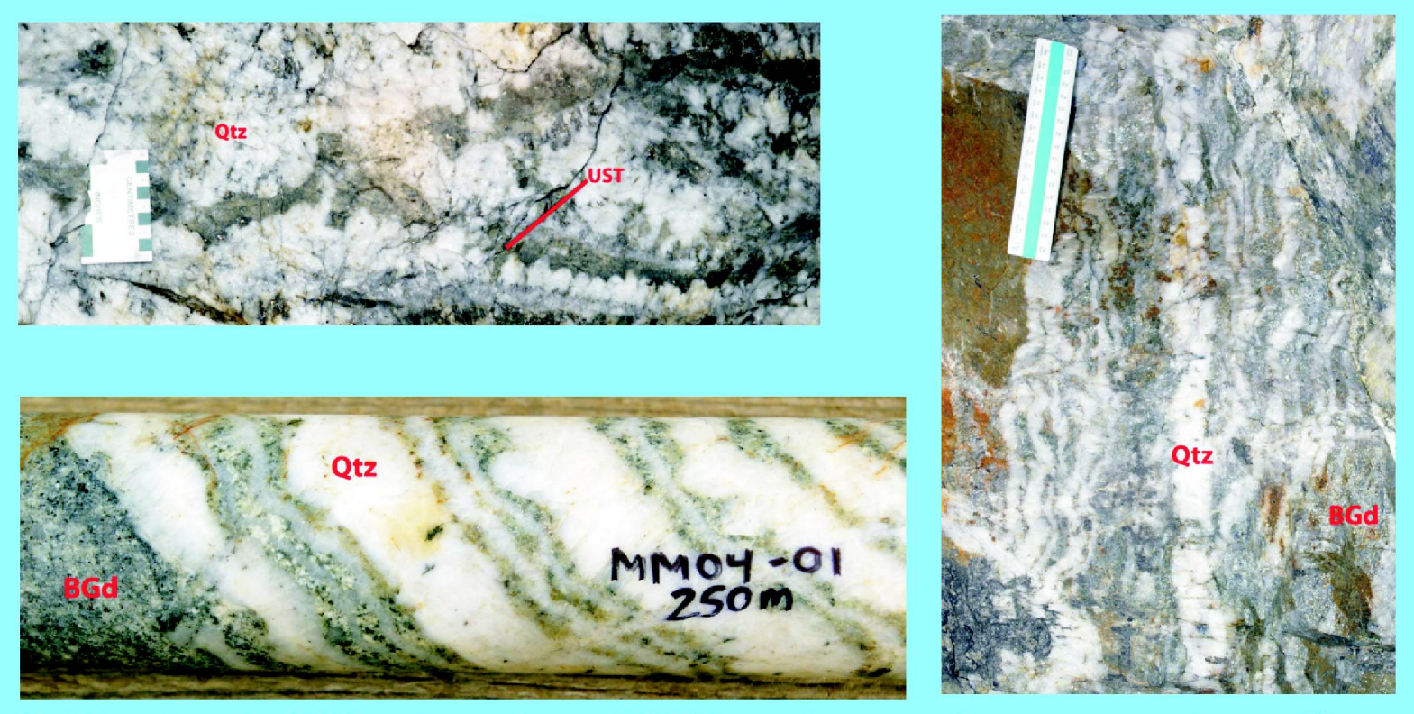
(modified from Boyle and Leitch, 1983)

Mo Mineralization



Upper Left: Molybdenite (Mo) intergrown with potassium feldspar (Fsp)
Left: Molybdenite selvages within quartz veins (Quartz) and cross-cutting biotite granodiorite dike (Bgd).
Top Right: Quartz stockwork and granodiorite dike (BGd) crosscutting biotite hornfels (Bhorn).

Vein Styles

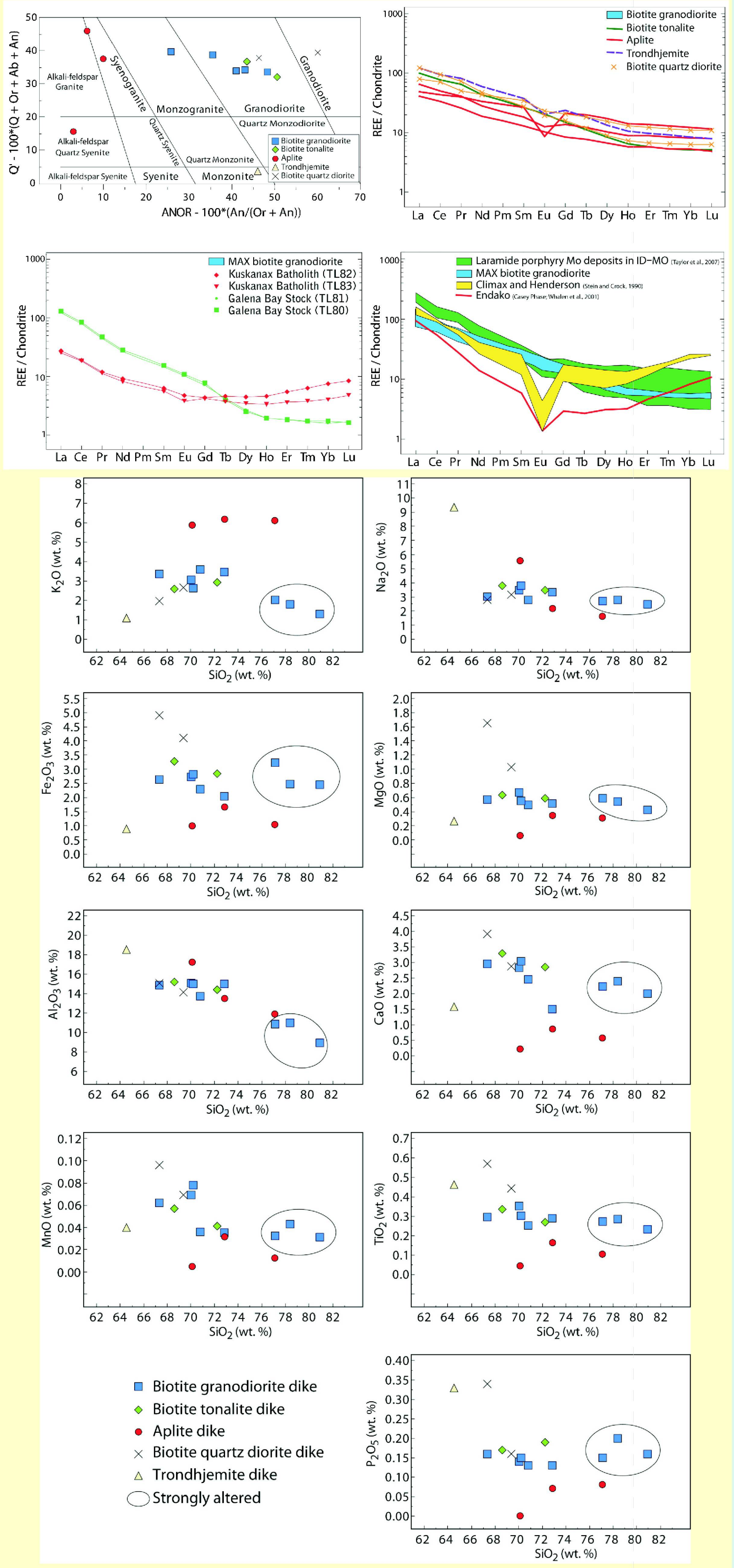


Unidirectional solidification textures (UST) in underground exposures and core. These textures are interpreted to represent periodic release of volatiles at the top of a cooling magma chamber. BGd = biotite granodiorite; Qtz = quartz

Lithogeochemistry Results

All of the intrusive rocks from MAX are classified as felsic (granodiorite, granite, alkali-feldspar granite and quartz syenite) and are enriched in light rare earth elements relative to chondrite values, with shallow, monotonic listric-shaped slopes towards the heavy rare earth elements (Lawley, 2009). Samples from nearby, older Mesozoic Galena Bay and Kuskanax batholiths exhibit distinct trace element patterns compared to MAX phases. This observation suggests that MAX and nearby Jurassic batholiths are not genetically related.

MAX phases are also distinct from the Endako porphyry hosts and the giant porphyry Mo deposits in Colorado in terms of REE compositions.



Geochronology Results

Samples collected to constrain mineralization events included:

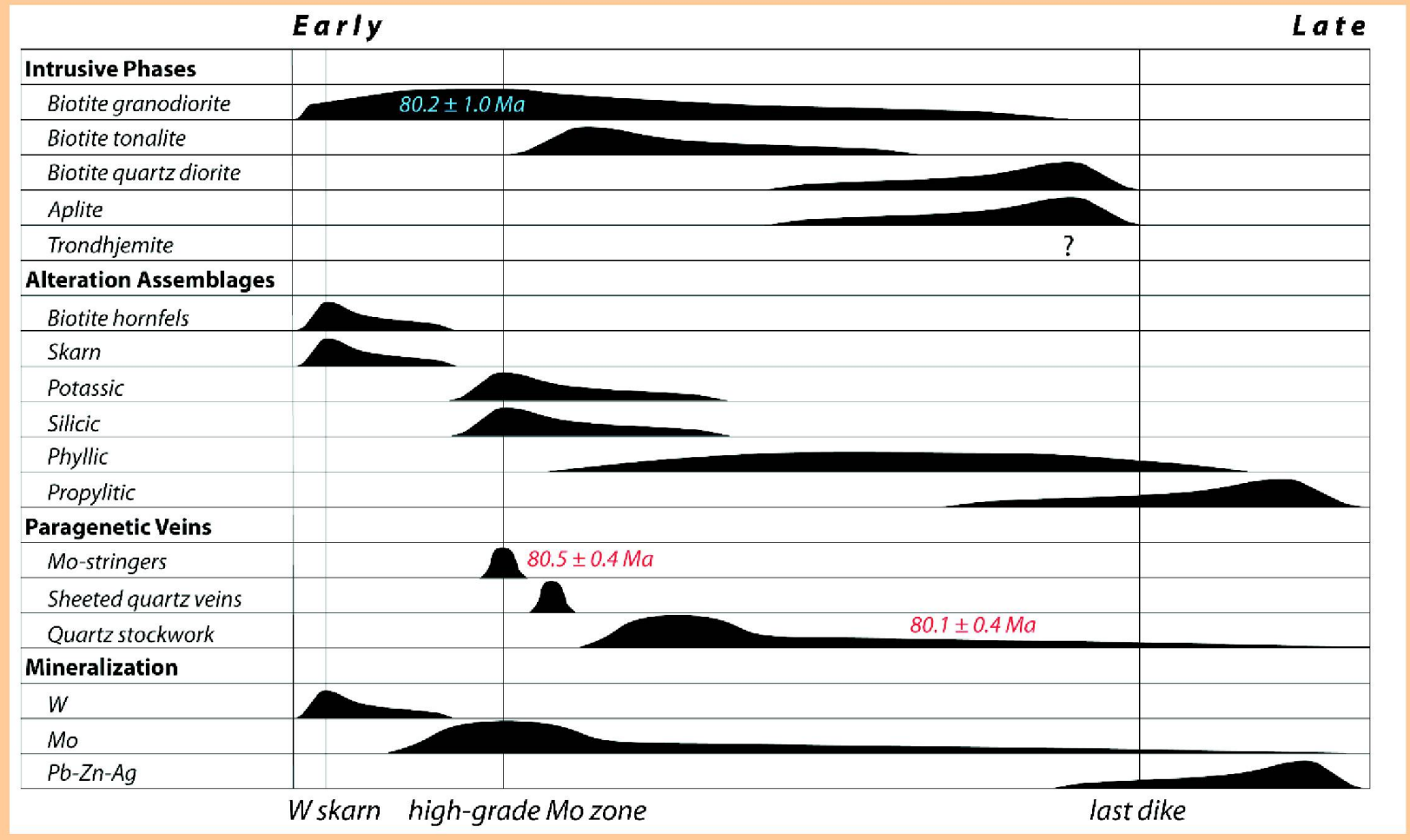
a) granodiorite dikes which host or post-date the high-grade mineralization;
b) three molybdenite samples which span earliest to latest minerlization events, and;
c) mica from four samples which include those from the pre- and post-ore dikes sampled for U-Pb dates, hydrothermal biotite, and hydrothermal muscovite (intergrown with the molybdenite dated by Re-Os method).

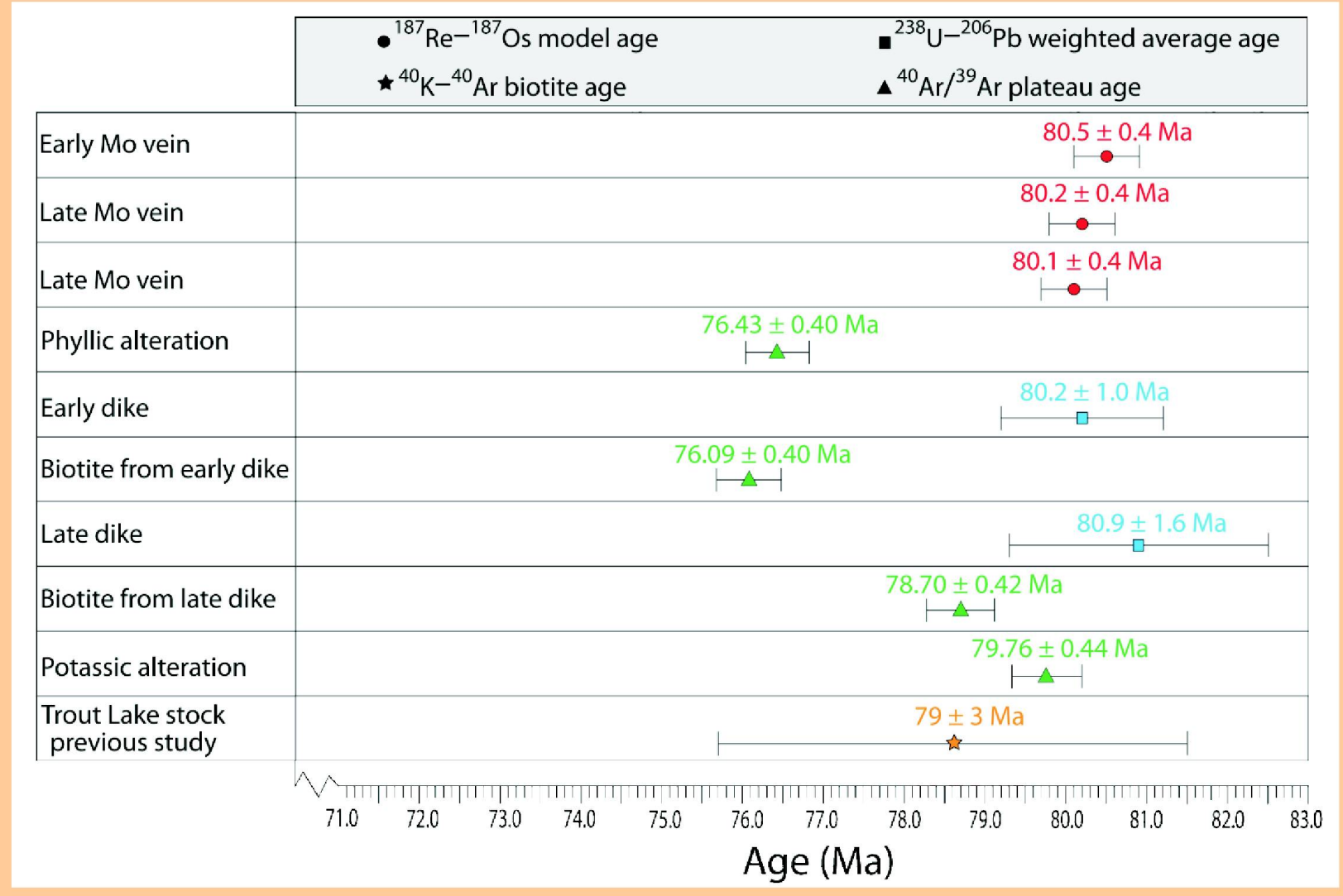
Re-Os data
Rhenium contents in the three molybdenite samples varied from 19.71 to 44.15 ppm, and total Os varied from 2.5 to 3.5 ppb. Calculated model ages are all within error of each other at *80.5 ± 0.4 Ma, 80.2 ± 0.4 Ma, and 80.1 ± 0.4 Ma*, indicating that the timing of earliest and latest Mo mineralization cannot be resolved within analytical error. A weighted average of the three ages calculated using ISOPLOT (Ludwig, 1991) yields *a combined age 80.3 ± 0.2 Ma* at 2 sigma (MSWD = 1.06), suggesting that molybdenite was deposited over a restricted time period of 0.4 m.y.

U-Pb data
Weighted average 206Pb/238U ages for selected zircons from early- and late-granodiorite dikes, analyzed via LA-ICP-MS methods, are within analytical error of each other at *80.9 ± 1.6 Ma* (2 sigma, MSWD = 0.43, n = 66) and *80.2 ± 1.0 Ma* (2 sigma, MSWD = 1.05, n = 70), respectively.

40Ar/39Ar data
All four 40Ar/39Ar samples yielded plateaus that represent more than 50% of the 39Ar. Igneous biotite from a late granodiorite dike yielded a plateau age of *78.28 ± 0.42 Ma* (MSWD = 1.6), which is slightly younger than a U-Pb zircon age for the same dike (80.9 ± 1.6 Ma). Hydrothermal biotite yielded a plateau age for potassic alteration of *79.76 ± 0.44 Ma* (MSWD = 0.48), which is in good agreement with the Re-Os molybdenite ages.

The remaining two samples have slightly younger plateau ages. Igneous biotite from an early granodiorite dike yielded a plateau age of *76.09 ± 0.40 Ma* (MSWD = 0.99), which is significantly younger than a U-Pb zircon age for the same dike (80.2 ± 1.0 Ma). Hydrothermal muscovite (intergrown with molybdenite) yielded a plateau age of *76.43 ± 0.40 Ma* (MSWD = 1.4), which is also significantly younger than a Re-Os molybdenite model age from the same sample (80.1 ± 0.4 Ma). The younger 40Ar/39Ar plateau ages may reflect unusually slow cooling of the magmatic–hydrothermal system, or a late thermal disturbance of the K-Ar system.

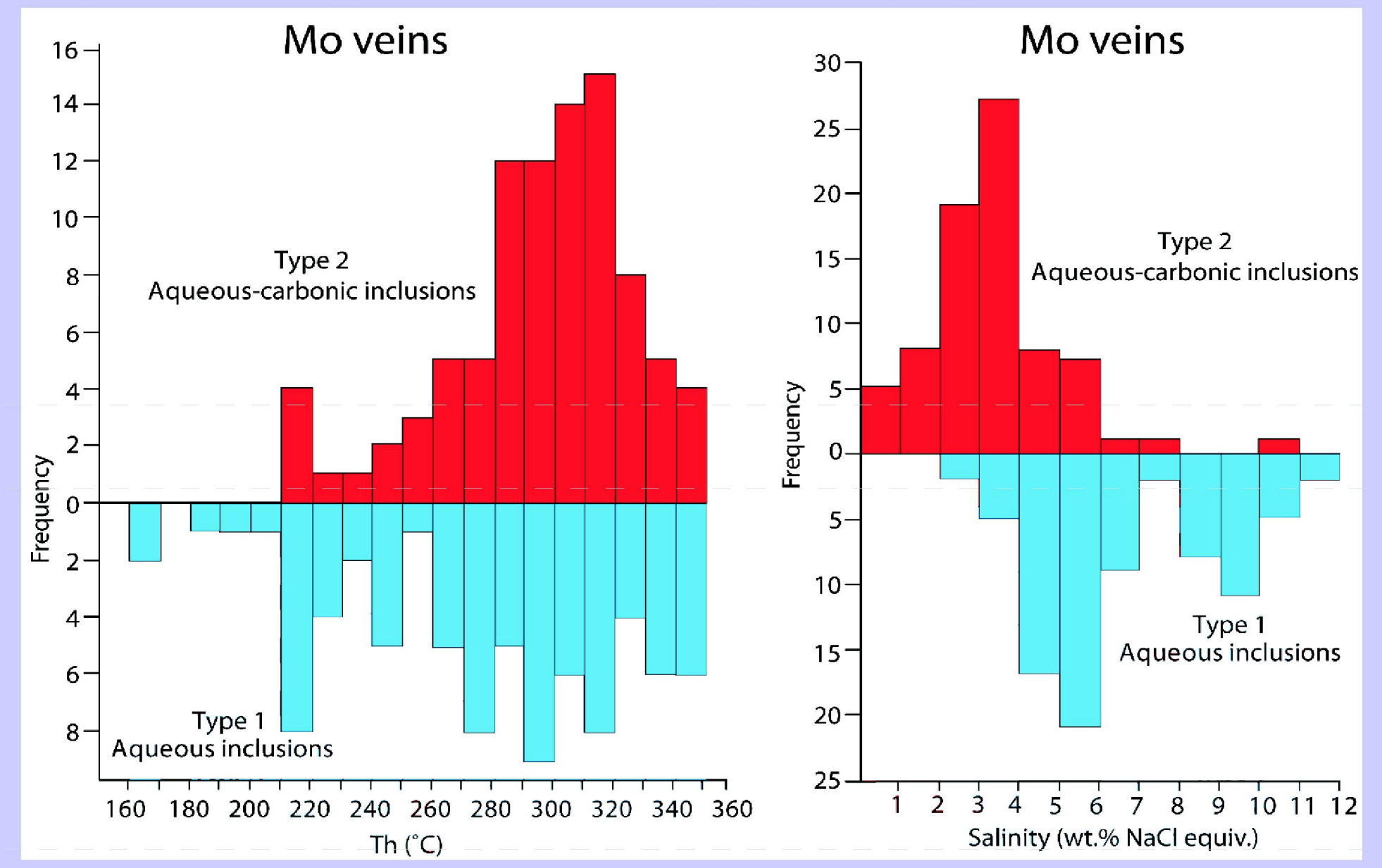




Fluid Inclusion Results

Fluid inclusions in Mo-bearing quartz veins can be divided into two compositional types: type 1, aqueous liquid-rich fluid inclusions; and type 2, aqueous-carbonic liquid-rich fluid inclusions.

Fluid inclusion salinity was calculated from the ice melting point depression using the equation of Bodnar (1993). Hydrothermal fluids in porphyry Mo deposits are typically lower temperature and significantly lower salinity than porphyry Cu deposits. MAX fluids are typical of the low-grade, rift-related porphyry Mo deposit type.



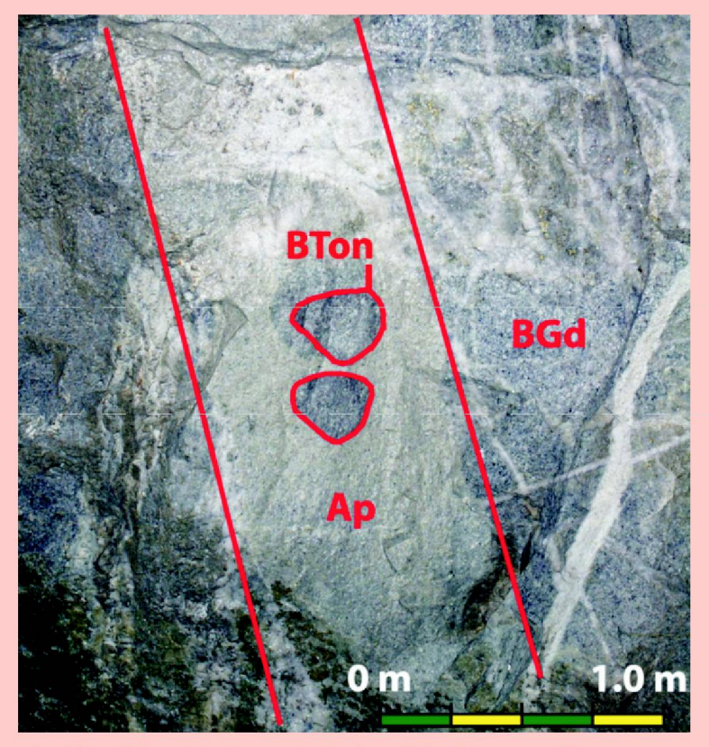
Trout Lake pluton

The pluton comprises compositionally-similar, but texturally distinct biotite-bearing granodiorite, tonalite, and quartz diorite, as well as aplite, and trondhjemite phases which are chemically classified as granite. Intrusive phases have been classified on the basis of modal mineralogy using the International Union of Geological Sciences (IUGS) scheme (Le Maitre, 2002). Examples of pre-ore and post-ore phases within the intrusion are best exposed in the 960 m adit.

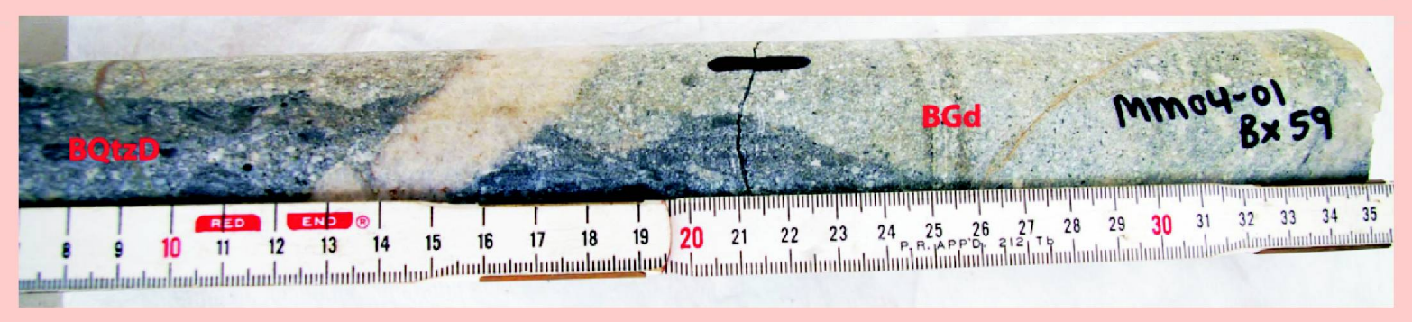
Biotite tonalite (BTon) and trondhjemite contact *(top left image)*

Biotite tonalite (BTon) and aplite (Ap) contact *(image to left)*

Biotite quartz diorite dike (BQtzD) cross-cut a biotite granodiorite dike (Bgd) *(bottom image)*

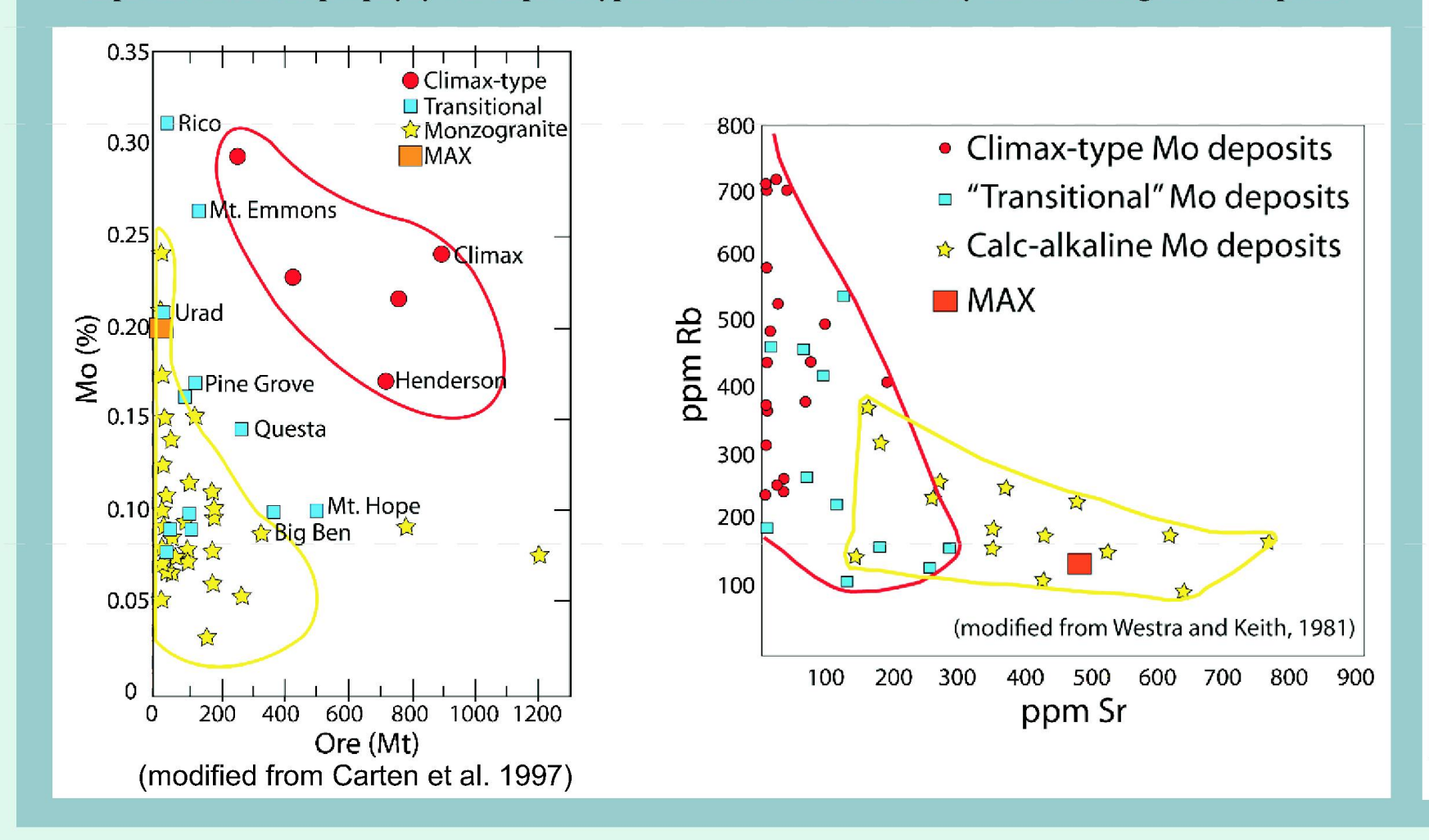


Aplite dike (Ap) containing biotite tonalite (BTon) enclaves crosscut a biotite granodiorite dike (BGd)



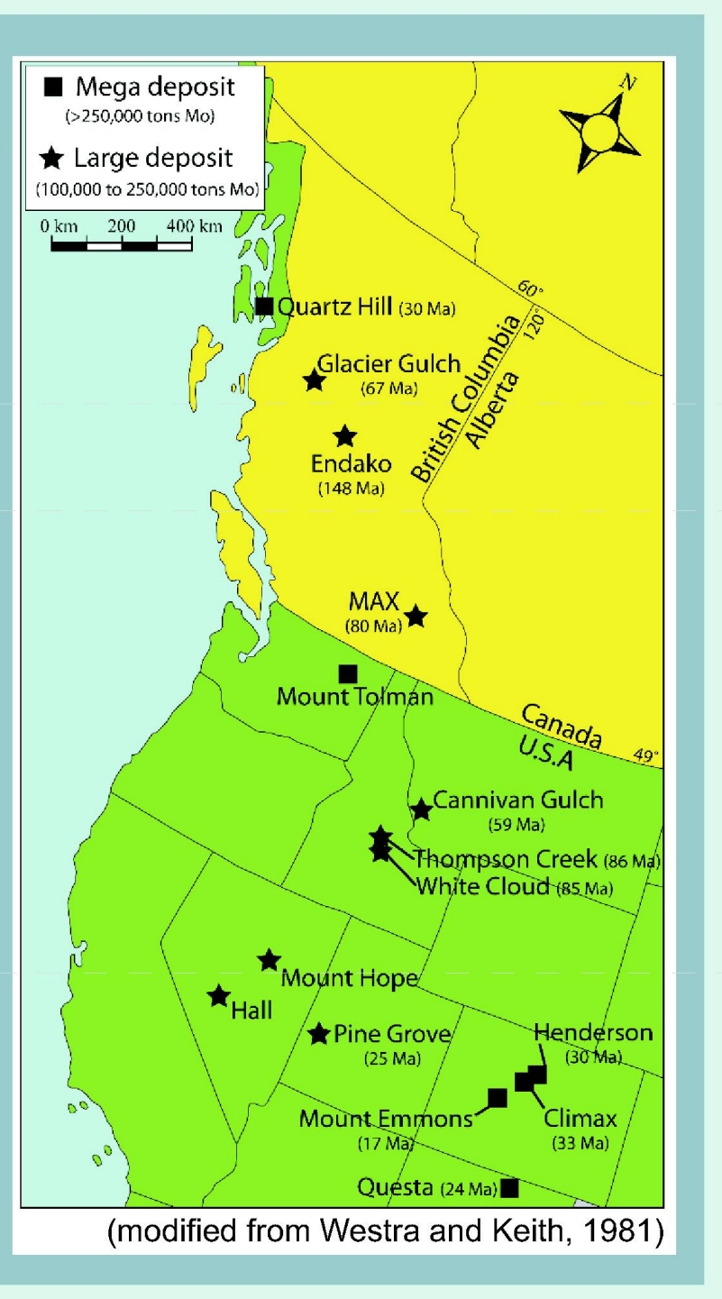
Porphyry Deposit Classification

Carten et al. (1997) argued that all porphyry Mo deposit classification schemes are broadly equivalent, and divided porphyry Mo deposits into two types: (1) high-grade, rift-related, fluorine-rich deposits associated with alkali-calcic intrusions; and (2) low-grade, subduction-related, fluorine-poor deposits associated with calc-alkaline intrusions. Lithogeochemical data from this study indicate that the intrusions associated with the MAX deposit are of intermediate calc-alkaline composition, and that, the small high-grade Mo zone notwithstanding, MAX best fits in the second category of subduction-related, calc-alkaline porphyry Mo deposits. Different porphyry Mo deposit types can also be subdivided by the size and grade of deposit.



(modified from Carten et al. 1997)

(modified from Westra and Keith, 1981)



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