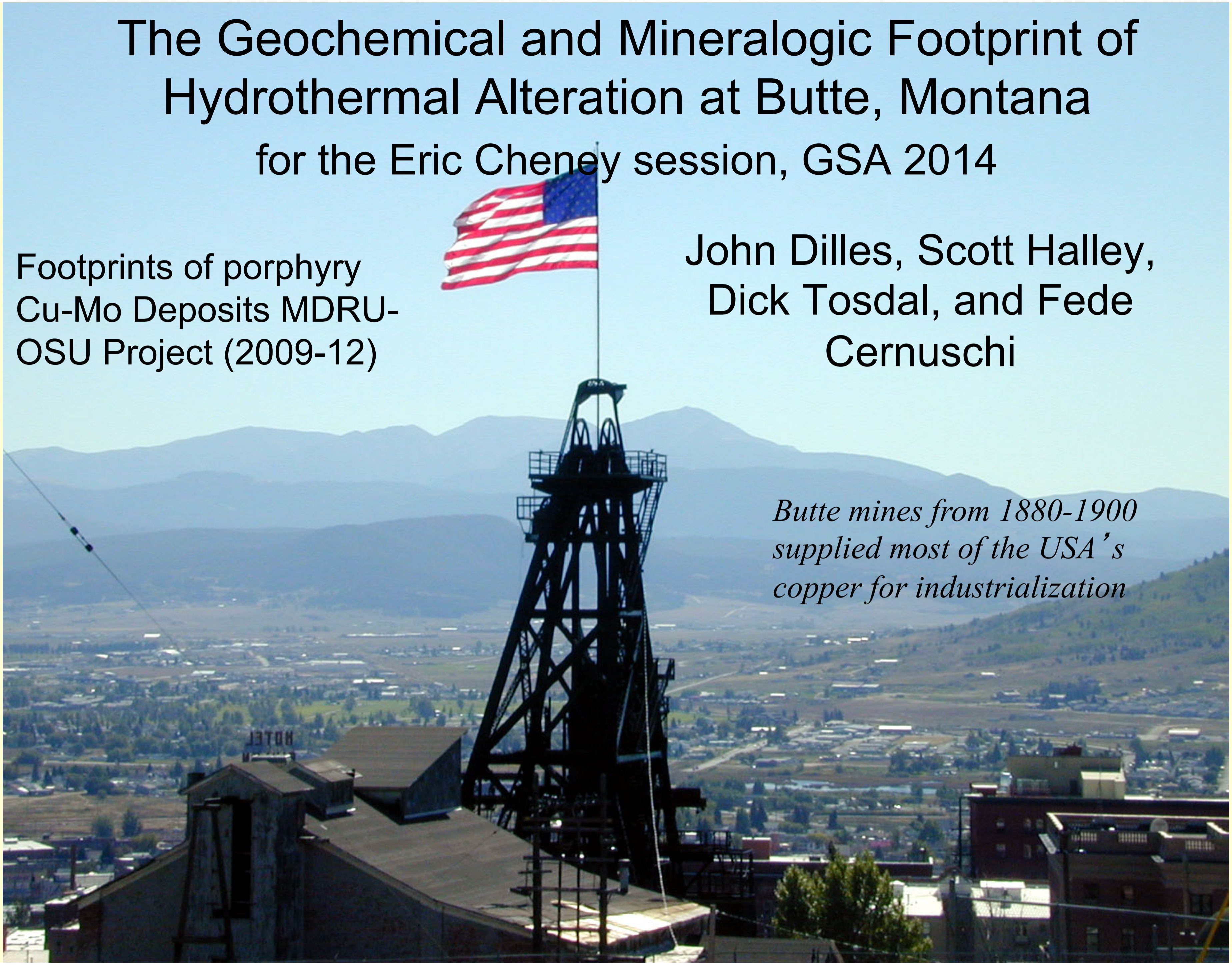
The Geochemical and Mineralogic Footprint of Hydrothermal Alteration at Butte, Montana

for the Eric Cheney session, GSA 2014

Footprints of porphyry Cu-Mo Deposits MDRU-OSU Project (2009-12)

John Dilles, Scott Halley, Dick Tosdal, and Fede Cernuschi



Butte mines from 1880-1900 supplied most of the USA's copper for industrialization

The Legacy of Eric Cheney

- Scientific research
  - Lange & Cheney (1971) Sulfur isotope reconnaissance of Butte, Montana: Econ. Geol., **66**, 63-74.
  - Later interest in regional geology, sedimentary basins, & the Archean—all from a field geology perspective
- Teaching & mentoring (Prof at U Washington)
  - Dedicated to training undergraduates & graduate students
  - Mentored by field work & collaboration with minerals companies
- Geologic Community
  - Participant in GSA Cordilleran Sections (especially field trips)
  - Organizer for NW Geol Soc, & NW Miners (Left-lateral leaps..)
- *Concerned about future: "Mineral resource geology in academia: An impending crisis?" (Hitzman et al., 2009)*

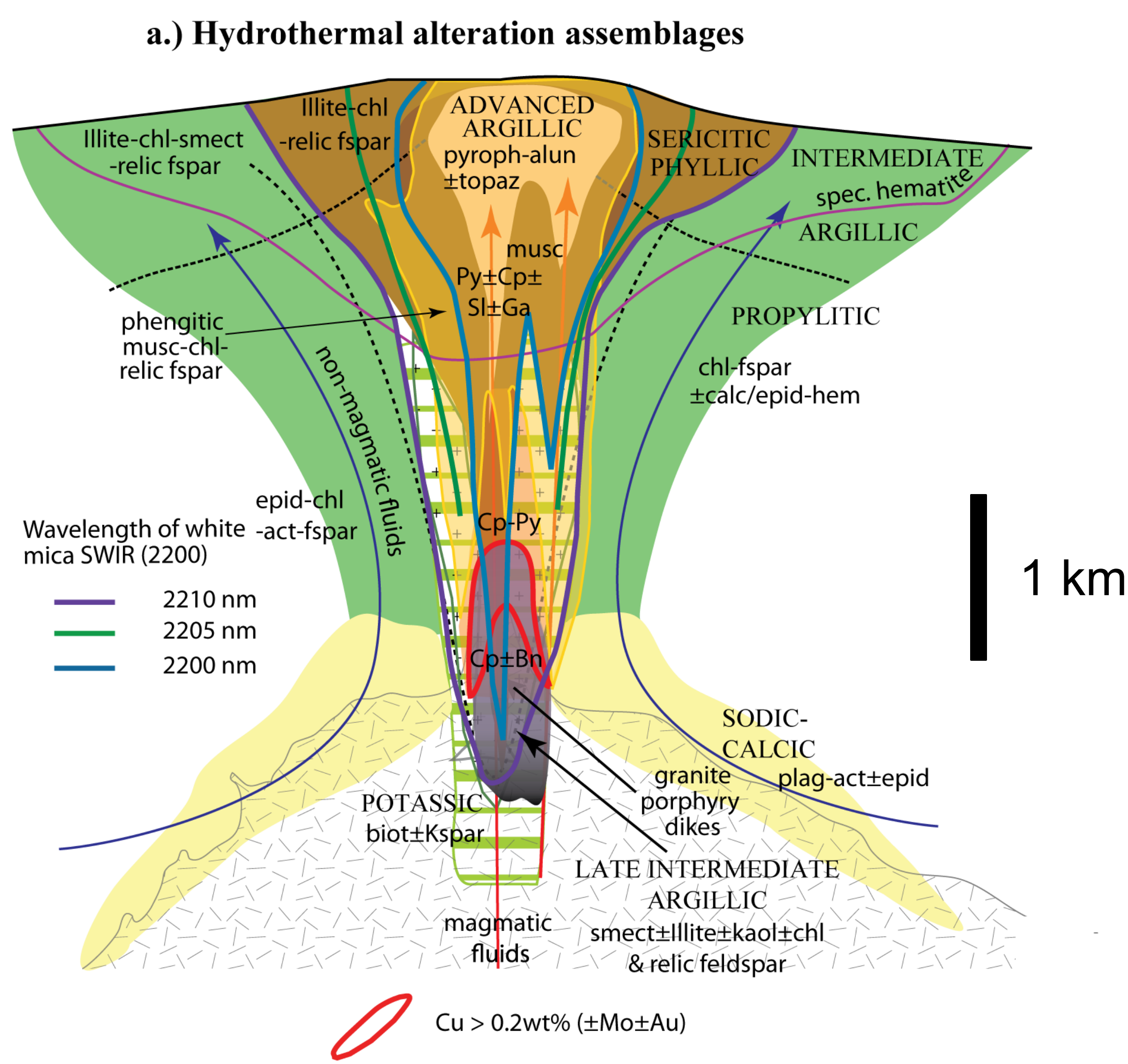
Vertical Zonation of Hydrothermal Alteration & Metals

•***Footprint*** is the trace metal anomaly resulting from vertical & lateral flow of hydrothermal fluids plume.

•Here, data from ***Yerington, Nevada***; fluid flow dominantly vertical (typical case)

•Yerington is ***atypical*** because of large amounts on non-magmatic fluids

Halley, Dilles, Tosdal submitted manuscript



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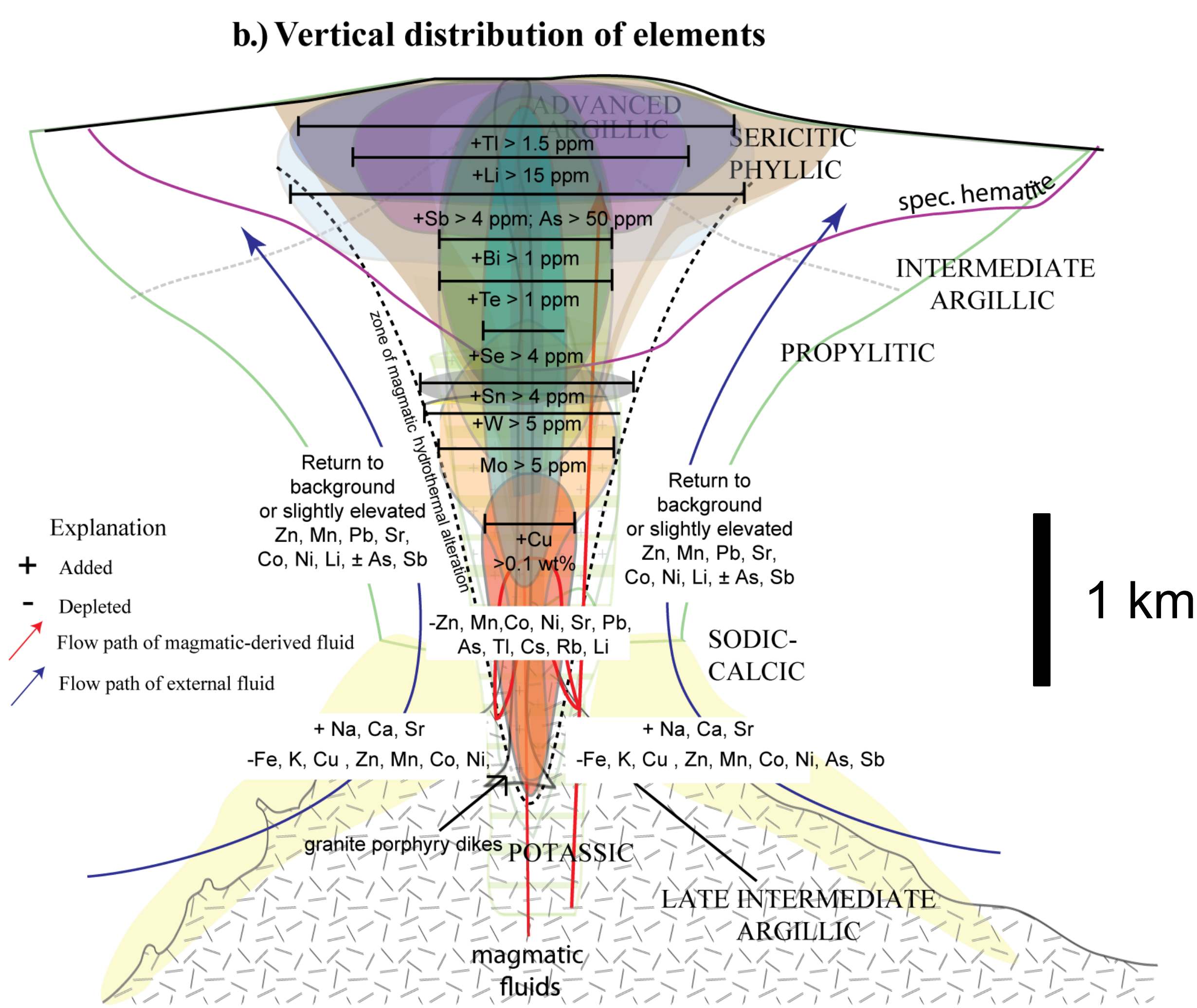
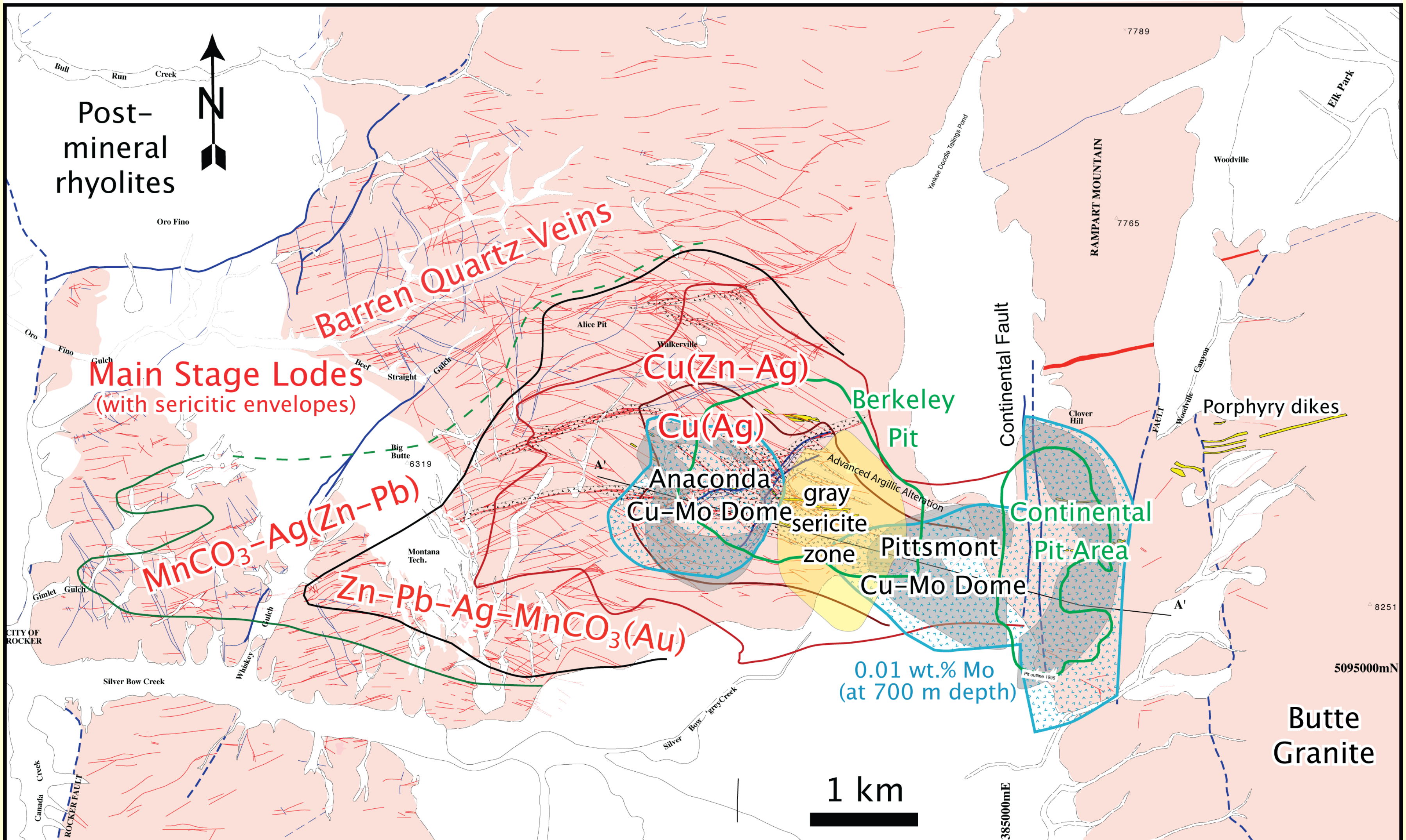


Halley et al. Figure 1

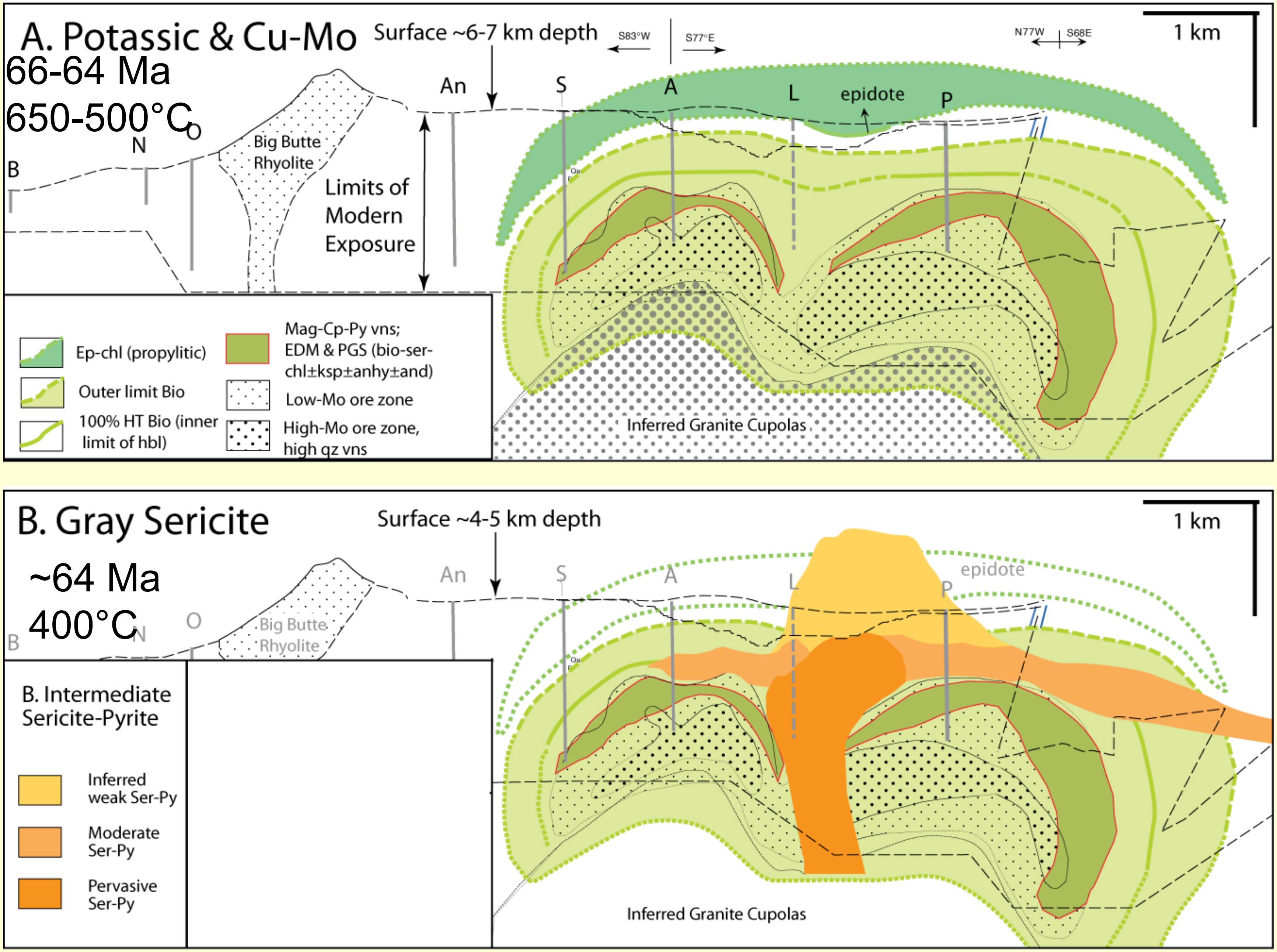
Rock samples analyzed via 46 element commerical ICP & ICP-MS. Detection limit ~crustal abundance for many trace elements

Butte Ore Distribution



Geologic map from Houston & Dilles, 2013

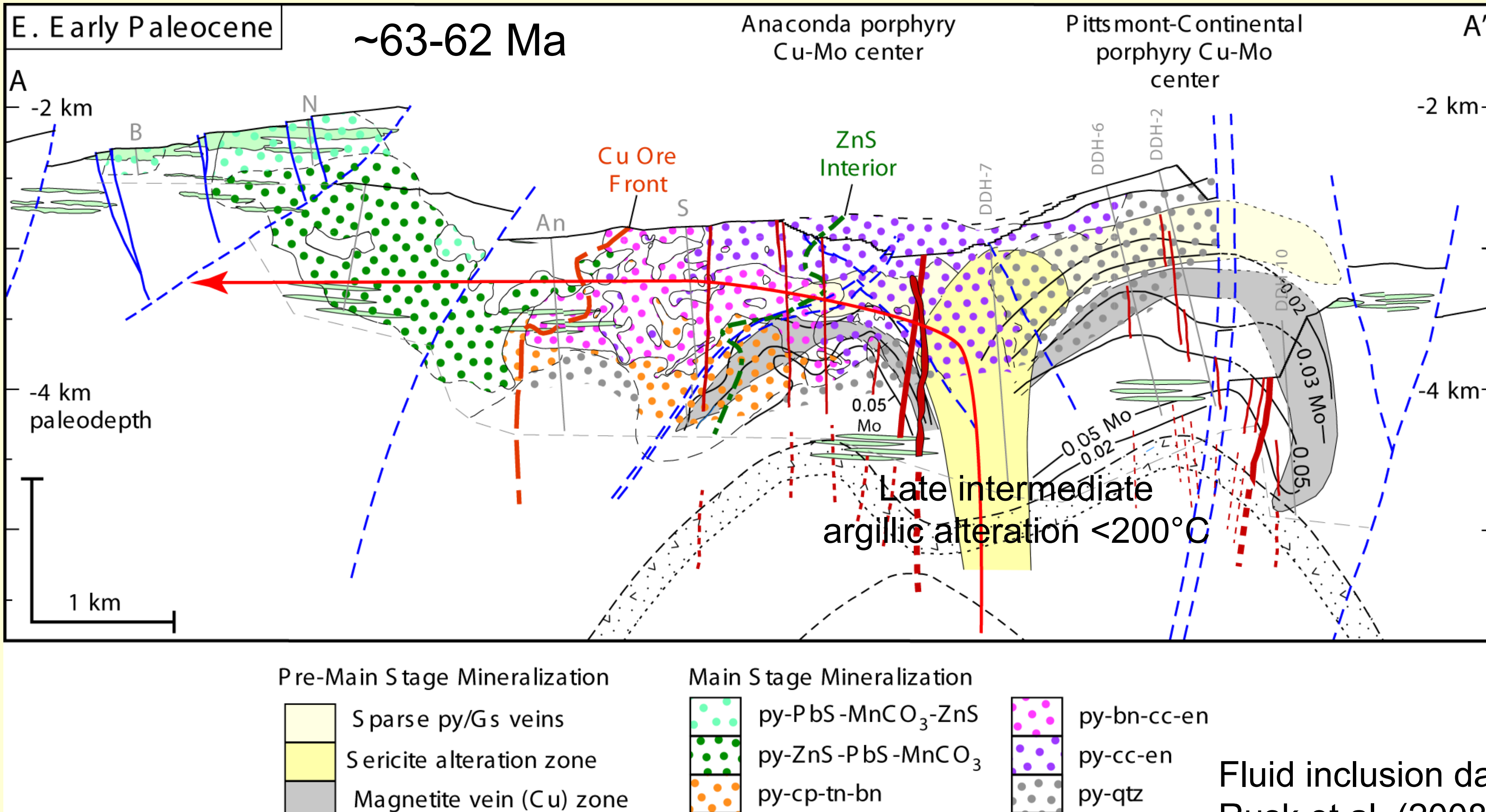
Butte Hydrothermal evolution



East-West XS Ore Metal Zones in Main Stage Veins
(from Proffett, 1979; Restoration by Houston & Dilles, 2013)

Late, low T flincs
210°C, 80 bars, 2-4 wt% NaCl

Early, high T flincs
290-330°C, 5 wt% NaCl



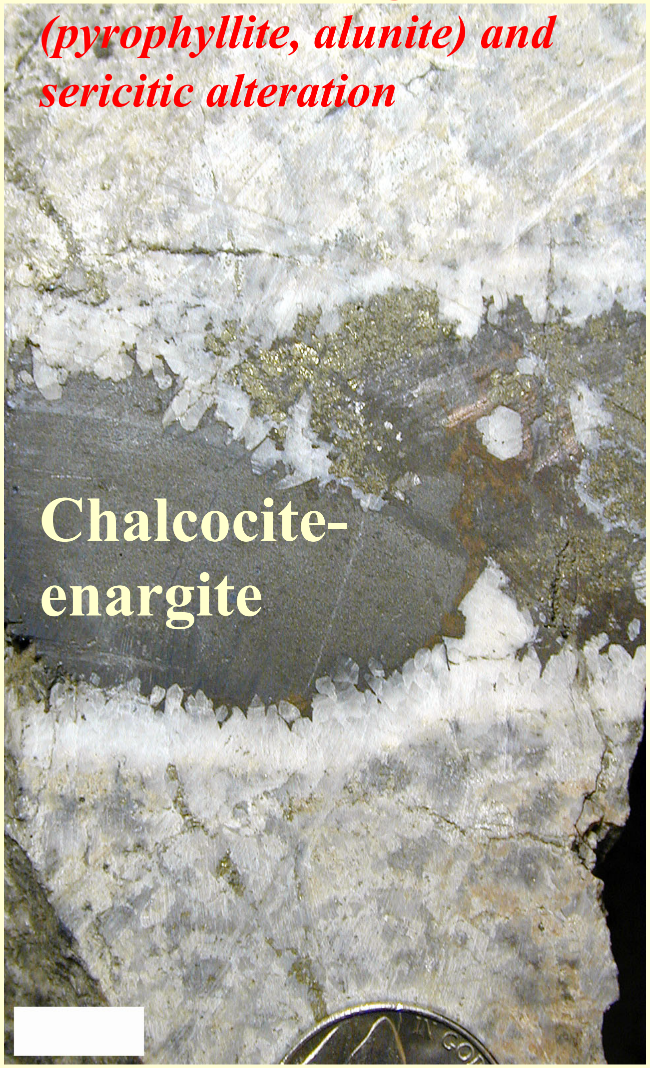
Fluid inclusion data:
Rusk et al. (2008)
Ortelli et al. (2013)

Main Stage Mica

From Central Ore Zone (Cu-Ag)

Py -- cc + enarg ± Cv ± Bornite

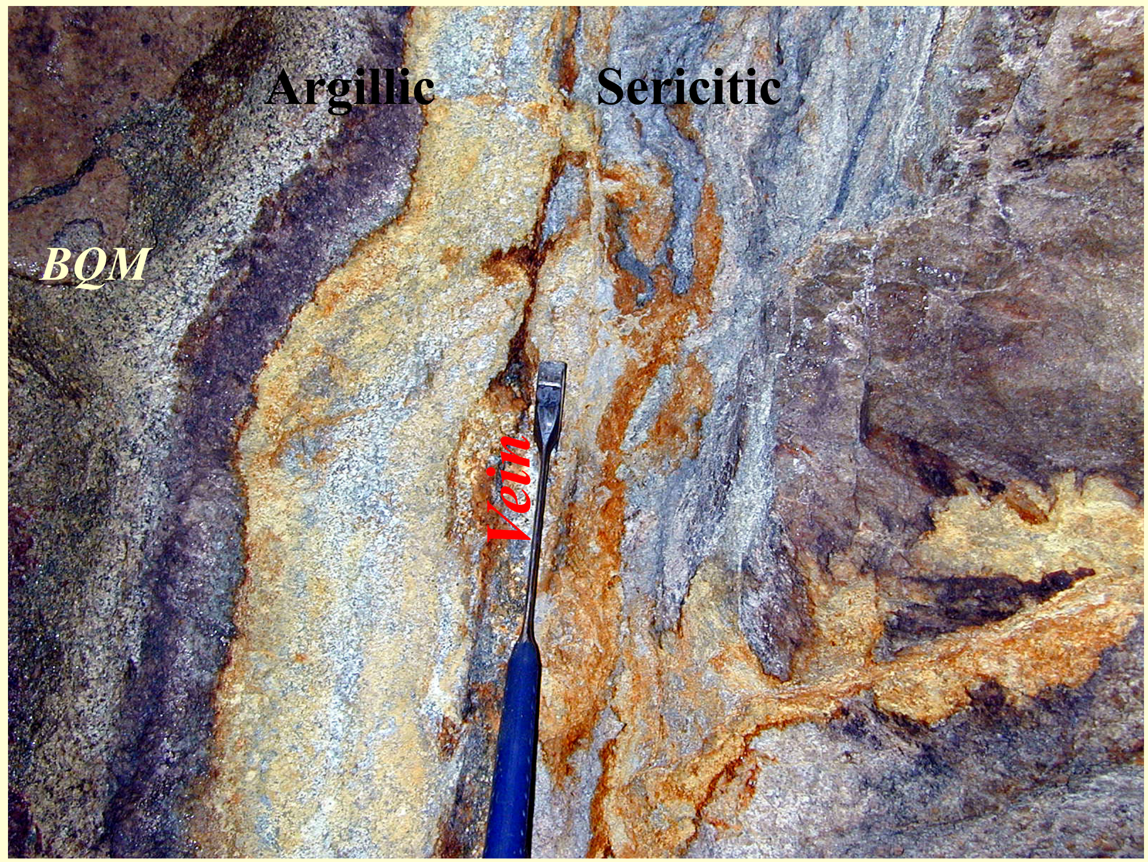
With advanced argillic (pyrophyllite, alunite) and sericitic alteration



From Intermediate Ore Zone (Cu-Zn-Ag)

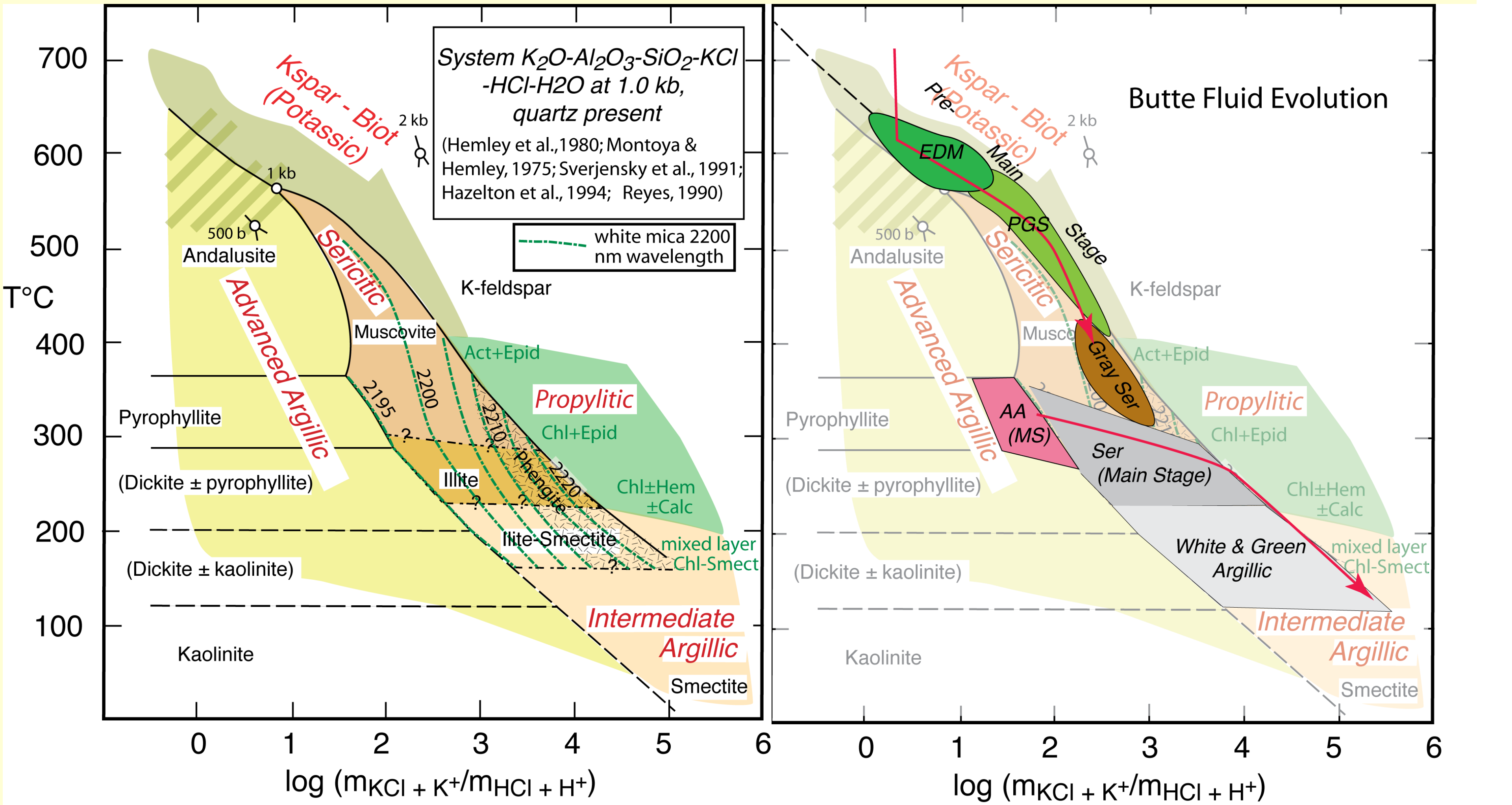
Py + Chalcopy + Sphalerite ± Bornite ± Galena

With sericitic alteration

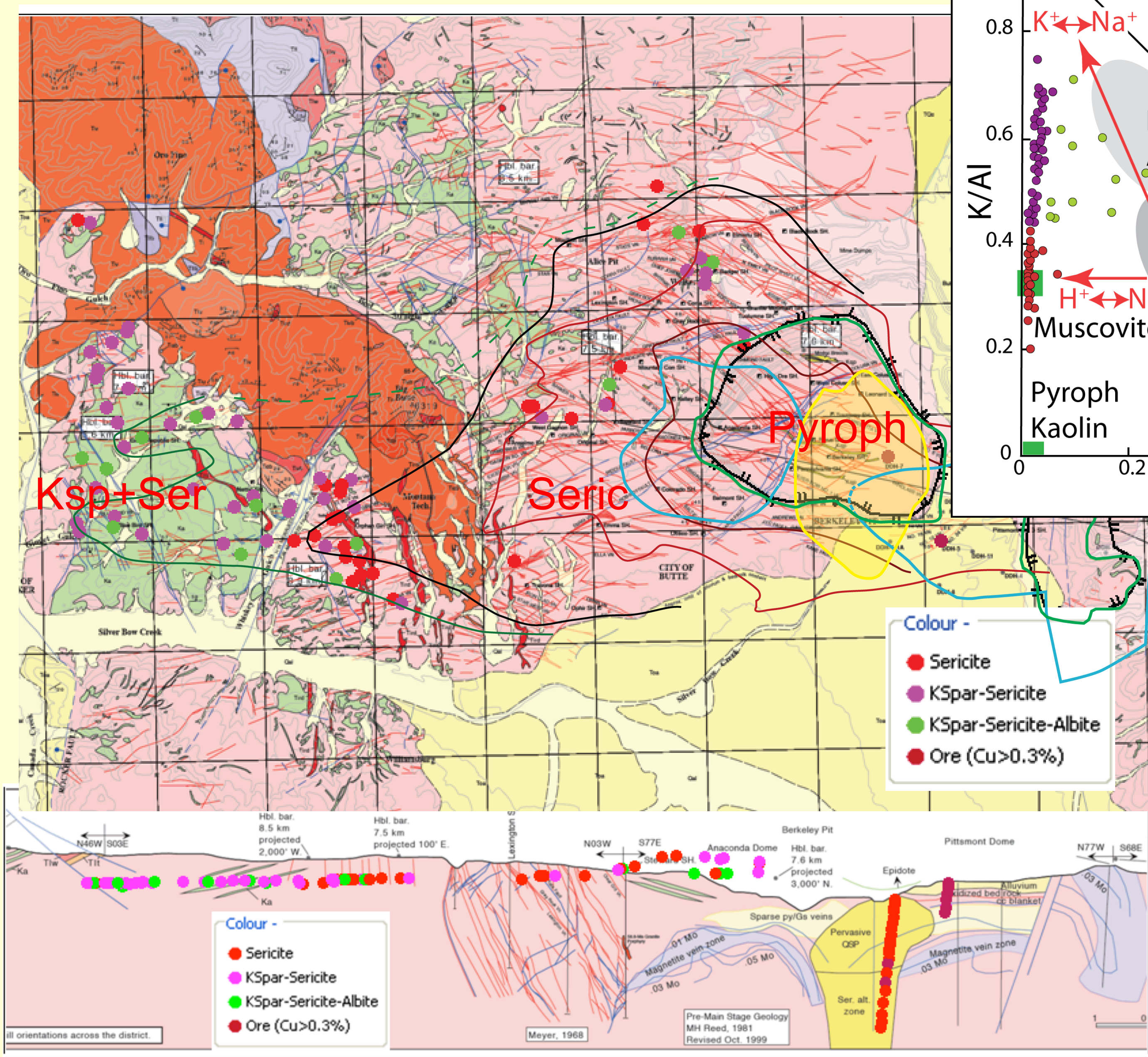


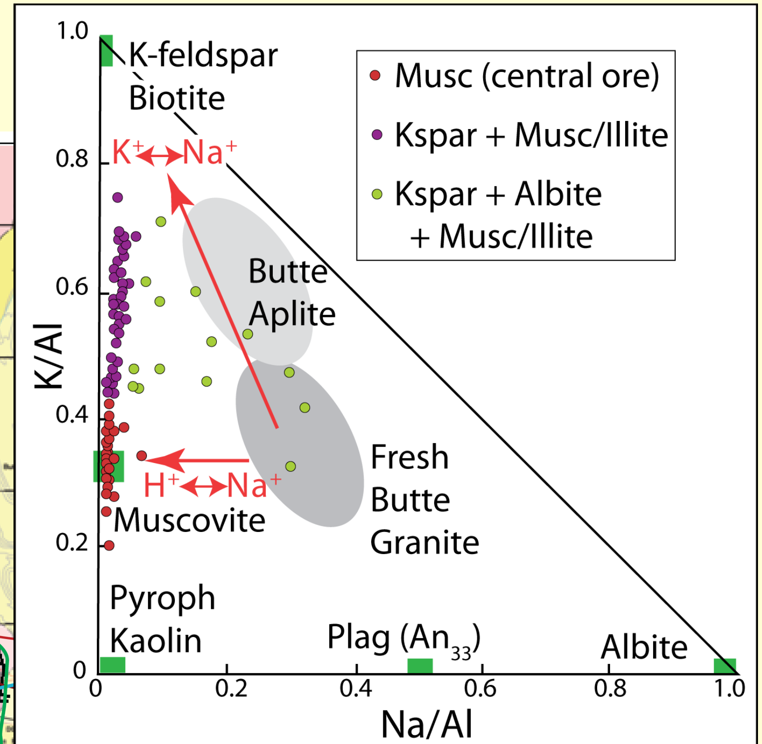
Butte Hydrothermal Fluid K^+/H^+ ratios

Note rock-buffering with feldspar except in Gray Sericite, AA, and strong Main Stage Sericite in center of district



Mineralogy from Whole Rock Chemistry

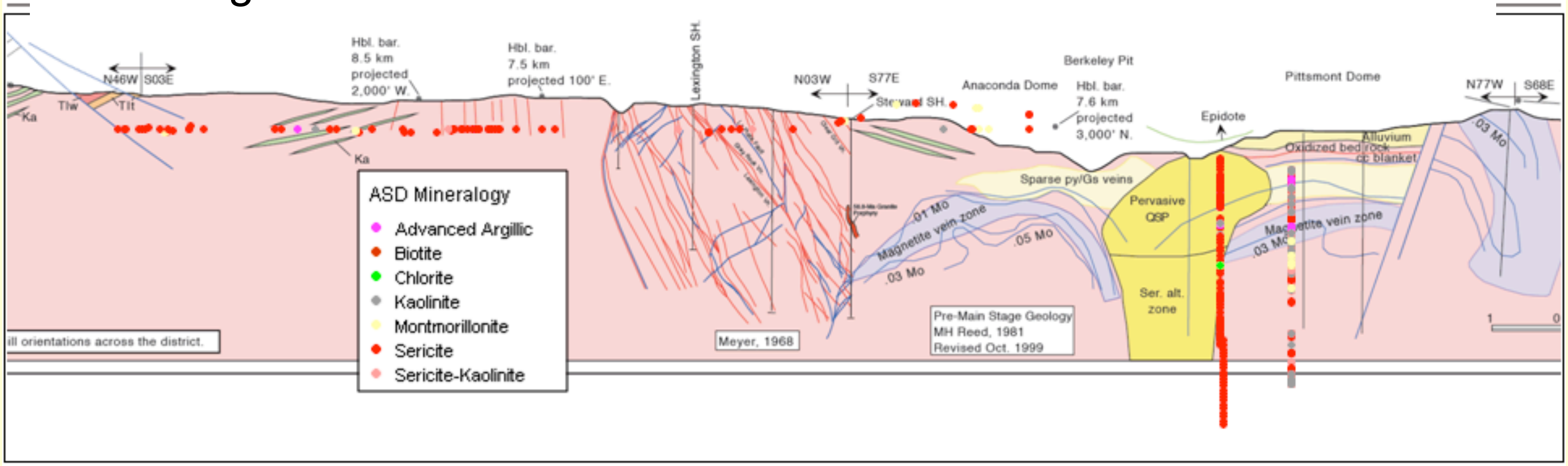




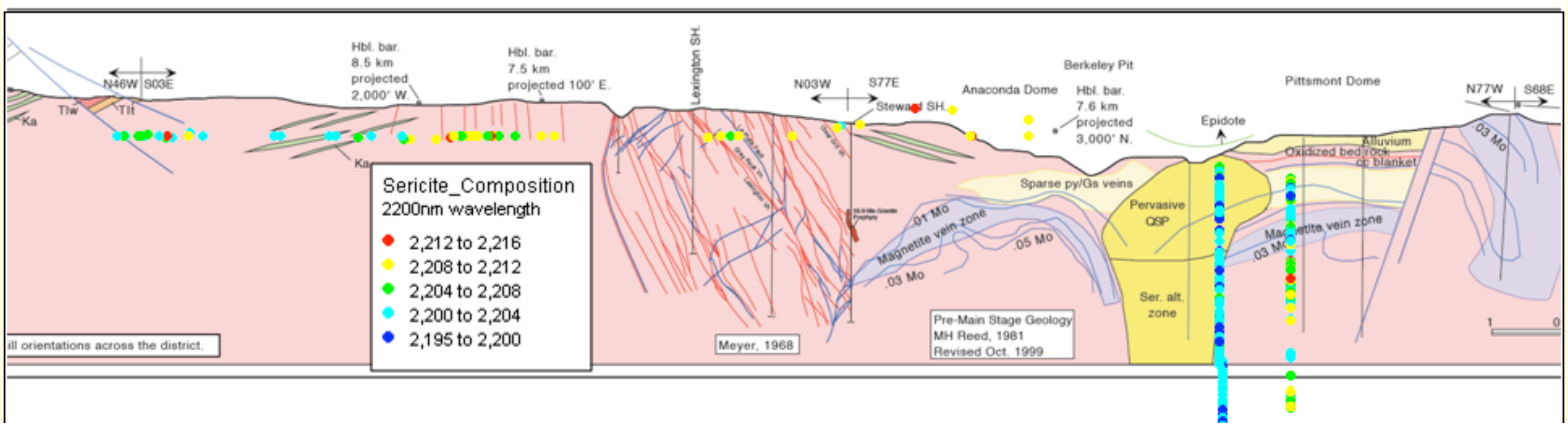
Both acid (H^+)
& K^+ are added
In Main Stage
Sericitic alteration

ASD mineralaogy on East-west section

Musc, Pyroph, late Smect-Illite-Kaol in center, Musc-Illite in peripheral Main Stage zones



Short Wavelenghth (2195-2204 Musc, Pyroph) & late illite-smectite (2205) in center, Long wavelength (2204-2216) phengitic Musc-Illite in periphery



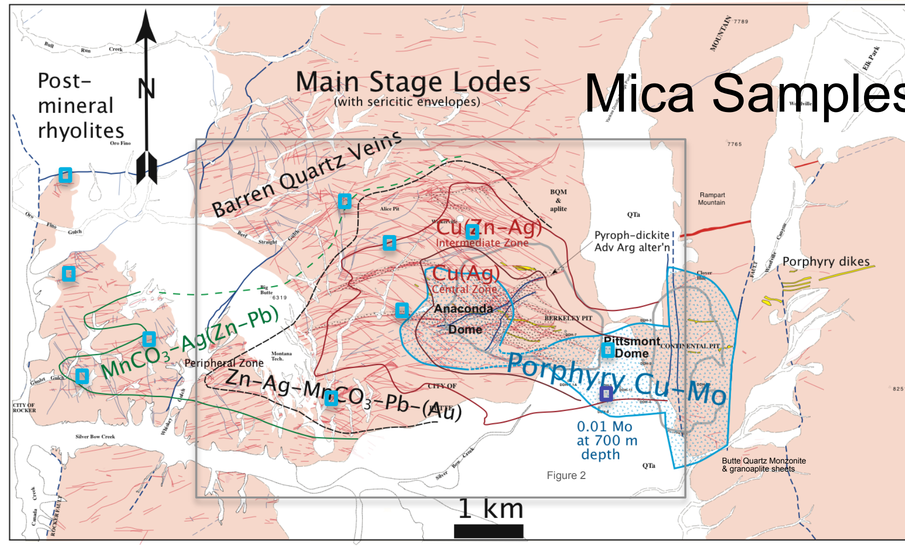
Mica compositions in Main Stage

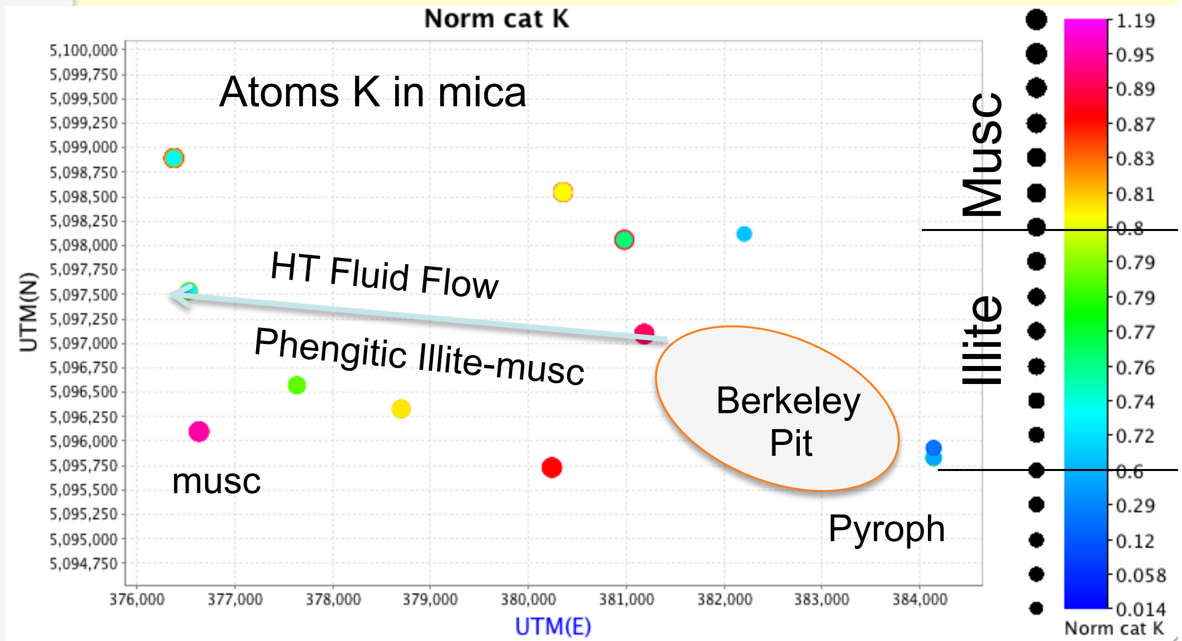
Figure 3. Spatial locations of 11 samples analyzed by EMPA and LAICPMS, showing **Potassium** atoms per formula unit (apfu) of white mica.

Note that Illites and phengitic micas are largely found near the center of the district (east side of maps) and muscovites found on the western periphery.

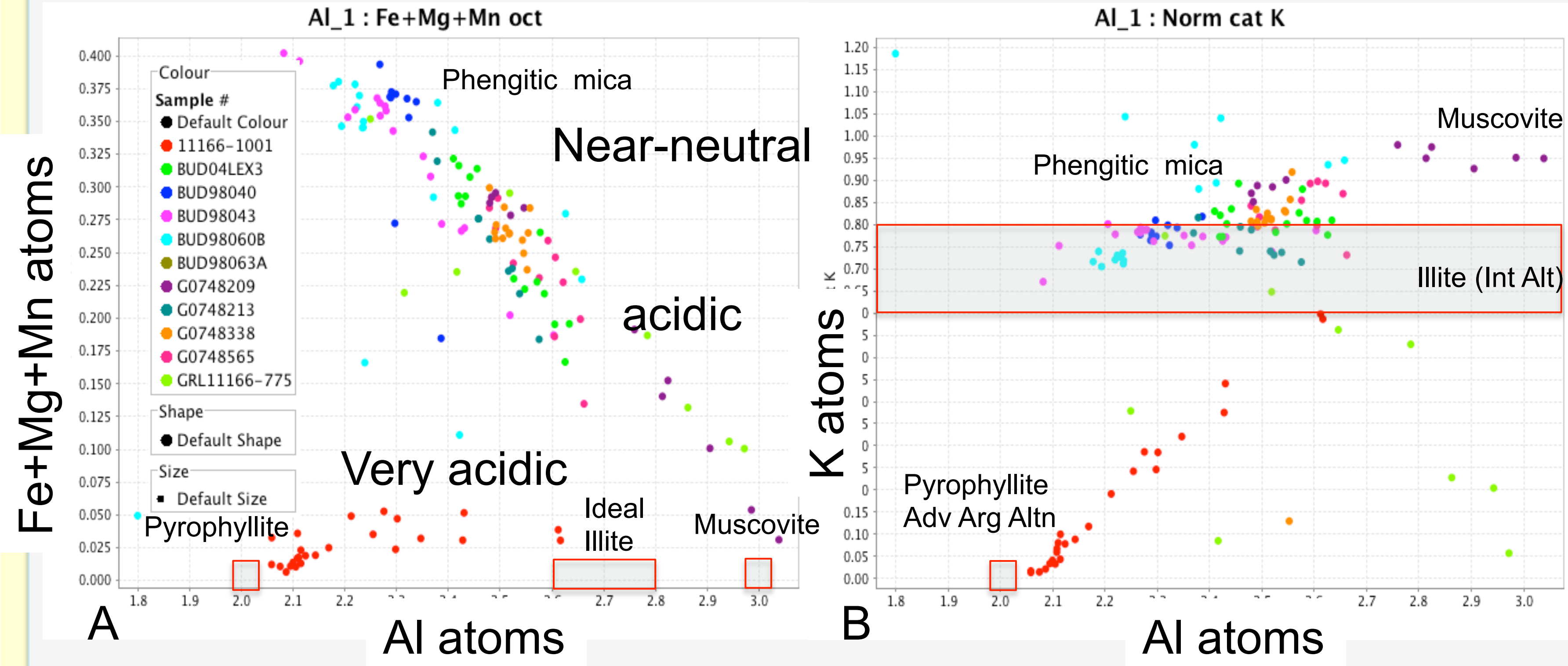
Hydrothermal fluids flowed from the center of the district (east) to the west.

So the distribution of low-temperature illites in the center of the district represents a late Intermediate Argillic overprint on earlier sericitic alteration.





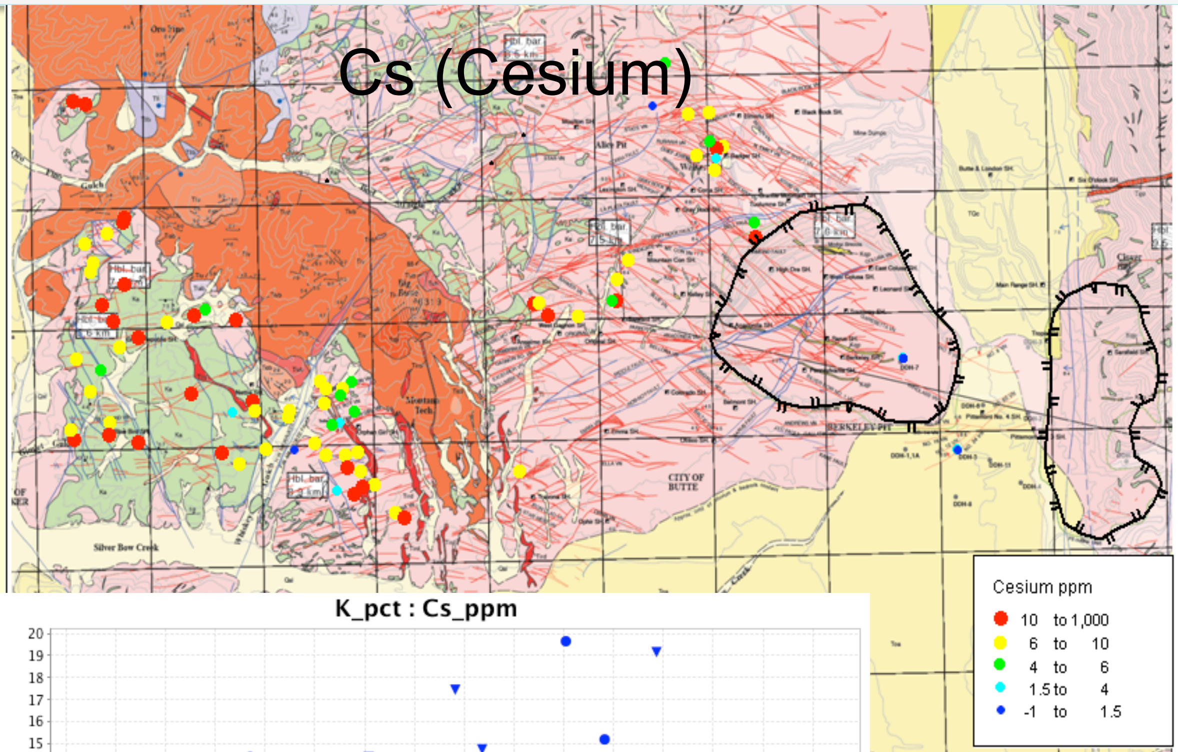
Butte Mica Compositions in Main Stage range from Musc to Illite

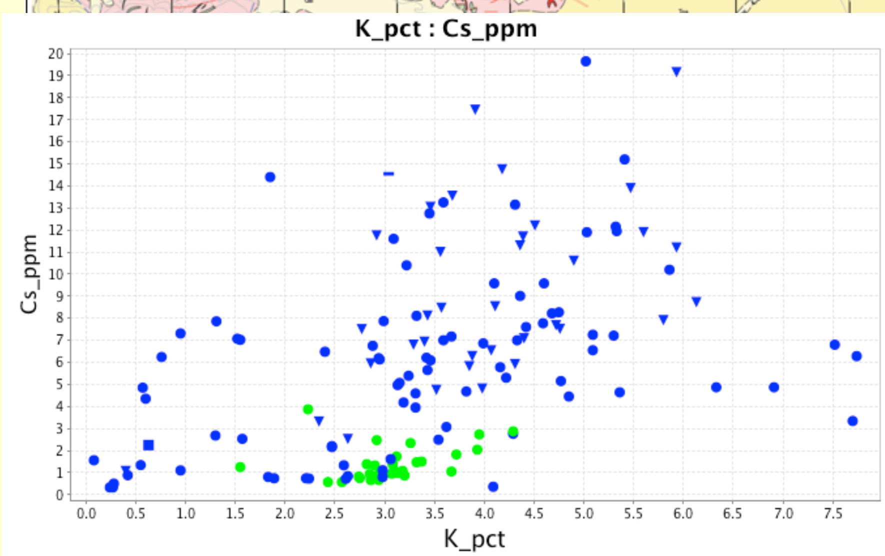


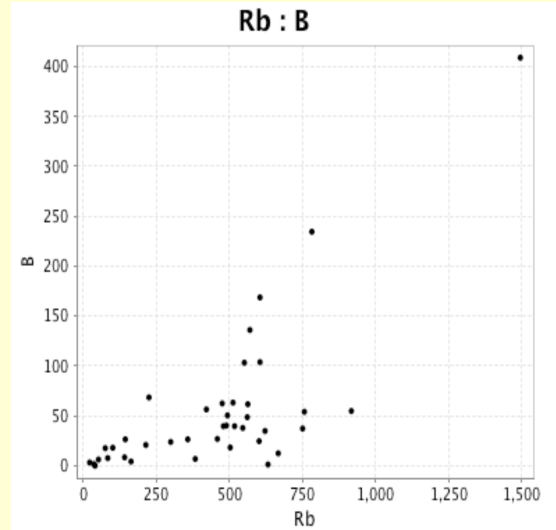
Ideal compositions of sheet silicates. A. Atoms per formula unit (apfu) of Al versus Octahdral Mg+Mg+Mn; B. Al vs K (apfu). Note that white micas formed on Main Stage veins span from pyrophyllite-muscovite (330-300°C) in the center of the district to phengitic muscovite (~300-325°C) at the western periphery of the district. Where late intermediate argillic alteration has been superimposed, principally in the center of the district, illite (<300°C) has formed.

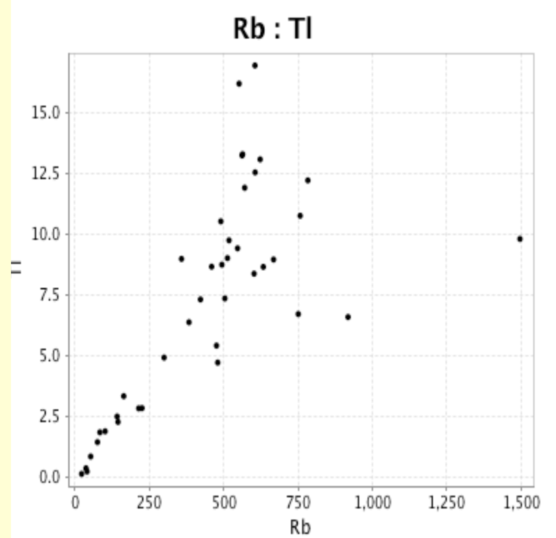
Trace Element Compositions of Micas –via ICP-MS

Micas have high Rb, Cs, Tl, Ba, B, Sc, V, Cr, Mn ,Zn, Cd, & Sn, but have little Cu, As, Co, & W. Most of the rock anomalies of Rb, Cs, Tl, Ba, Sc, V, Cr, and Sn (minor Mn, Zn, Cd) are therefore likely contributed by these metals lying in the white mica structure.







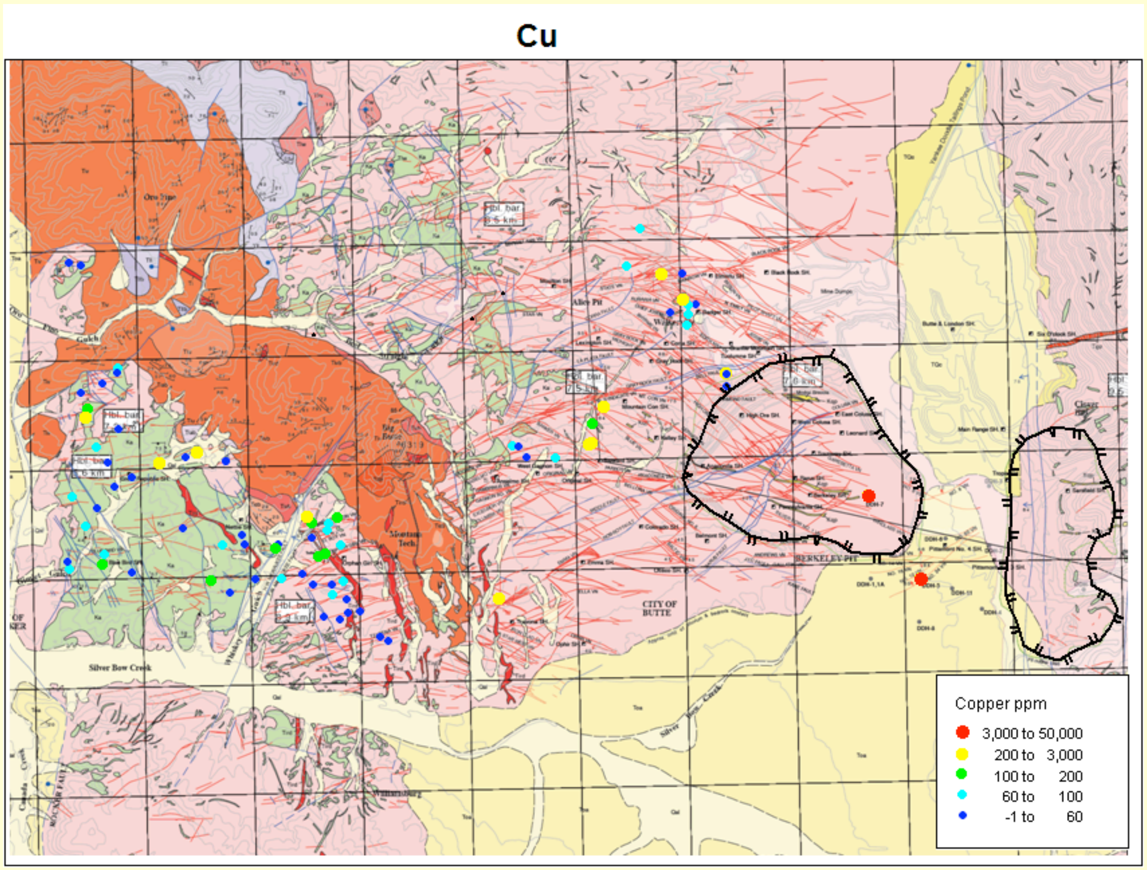


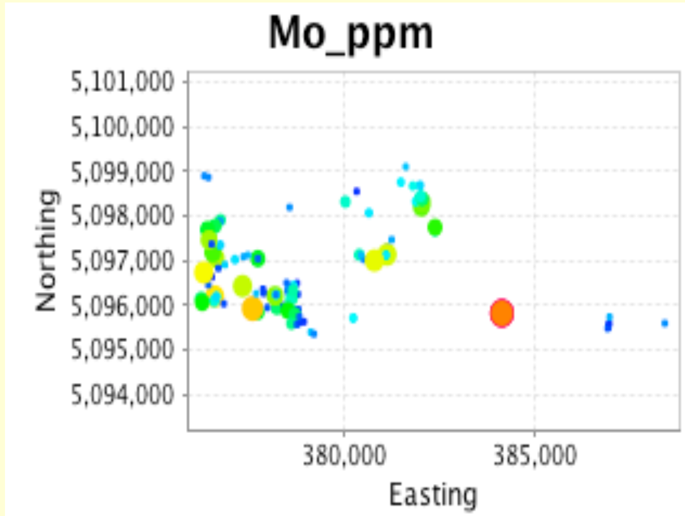
Copper, Molybdenum, & Tin (Sn) Geochem

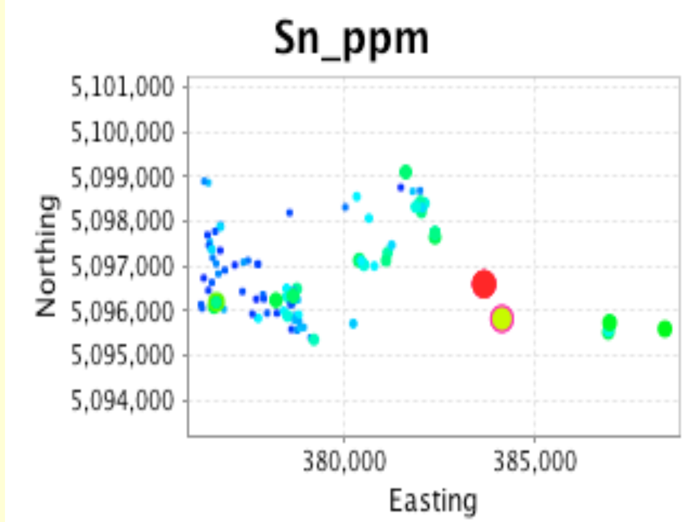
Cu >1000 ppm in ppy Cu-Mo

Cu mostly <200 ppm in peripheral Main Stage vein selvages

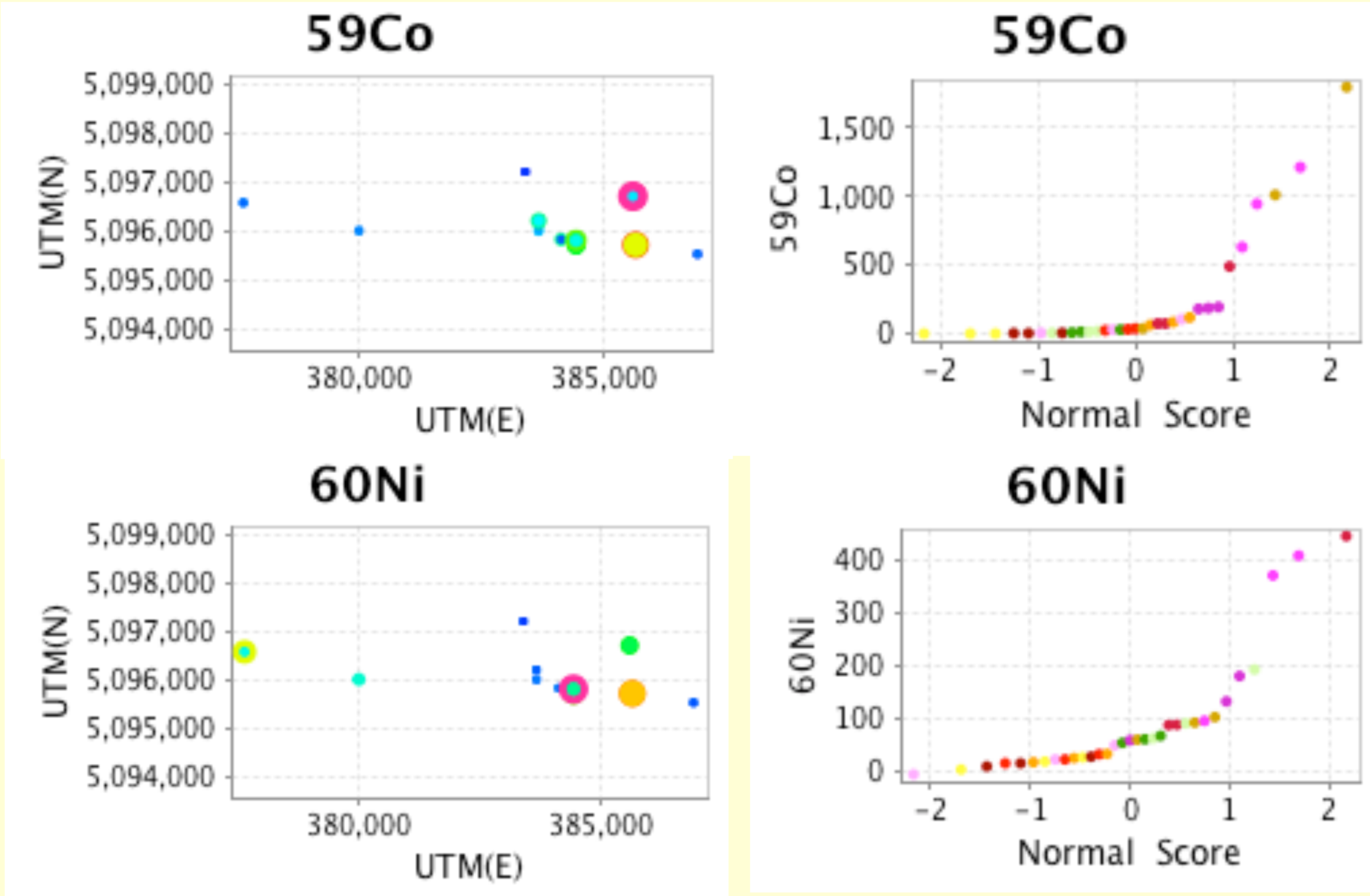
A. Central to lateral tin (Sn) anomaly;
B. widely dispersed Mo anomaly about the central Mo-ore zone







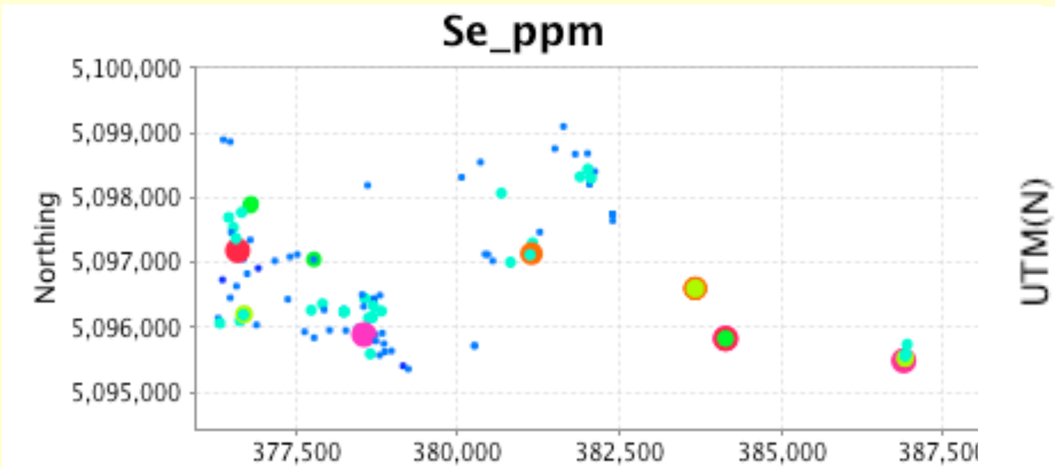
Metals incorporated into pyrite: Co, Ni, As, Te, Se
LAICPMS Data: Co, Ni in Pyrite in central zones

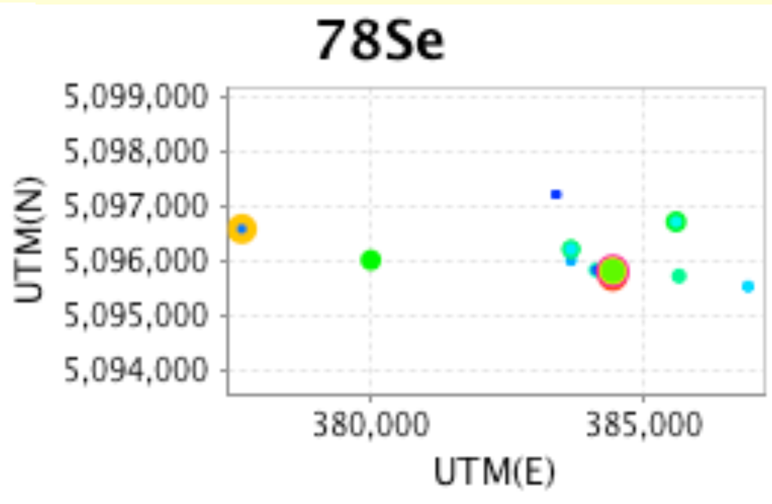


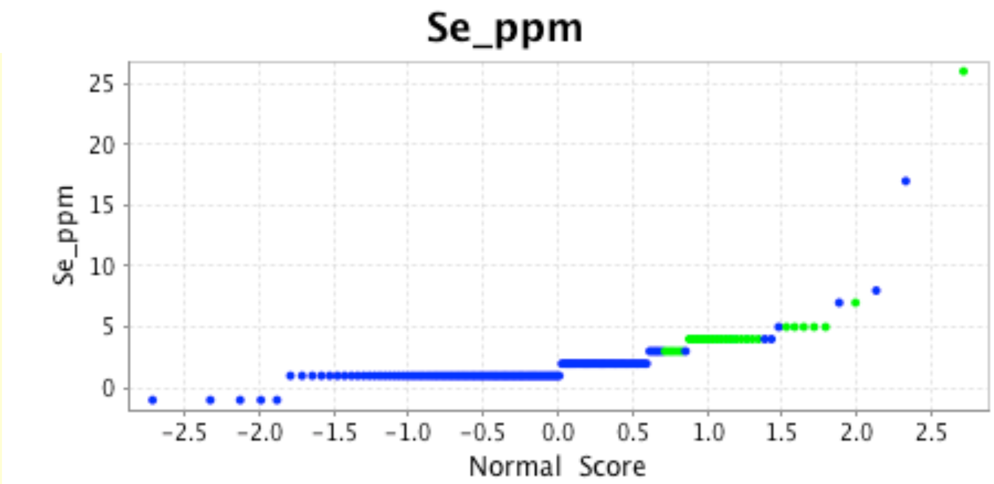
Se in pyrite can explain the Se in rock anomaly

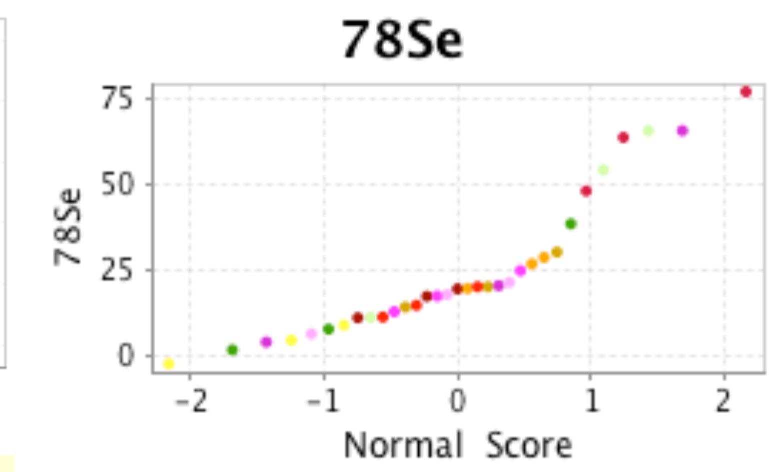
Se in whole rock

Se in pyrite







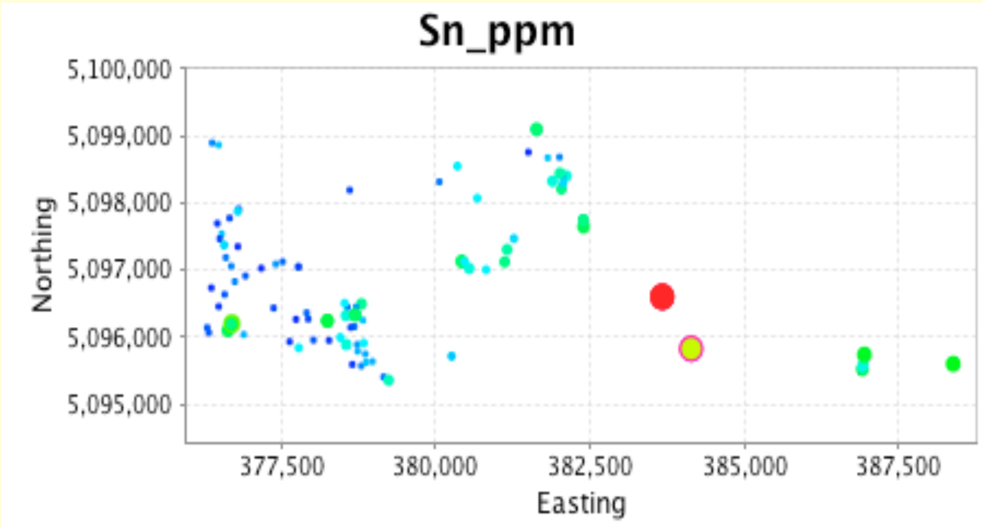


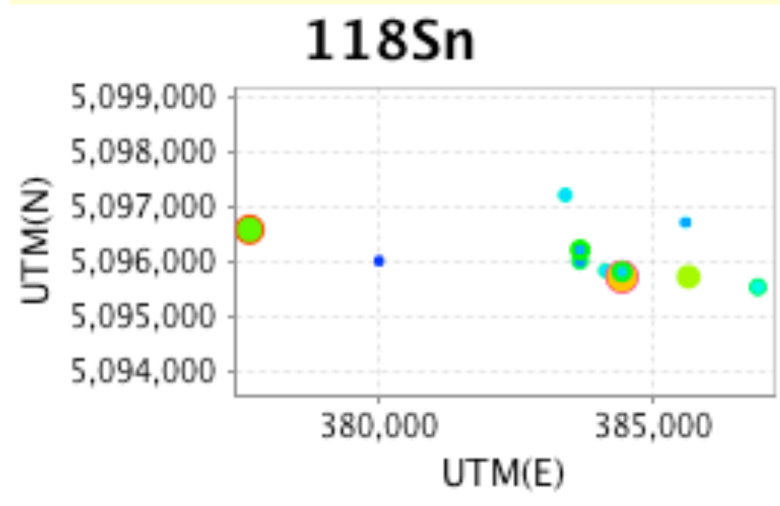
Tin, pyrites cannot account for rock Sn anomaly

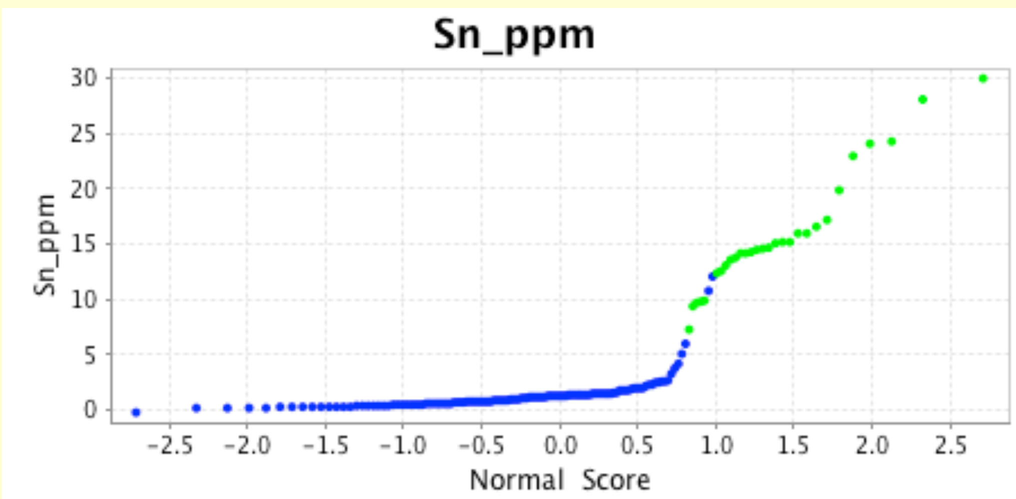
Sn & Mo occur in other phases (Cassiterite?, Molybdenite)

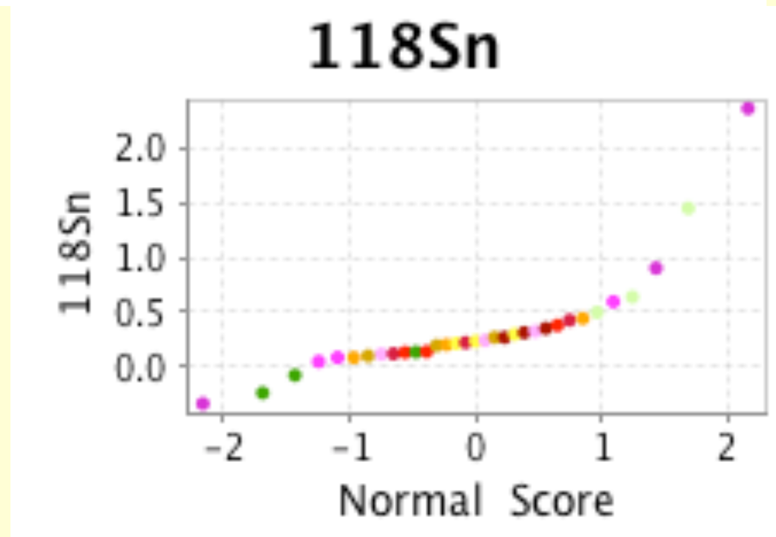
Sn in whole rock

Sn in pyrite





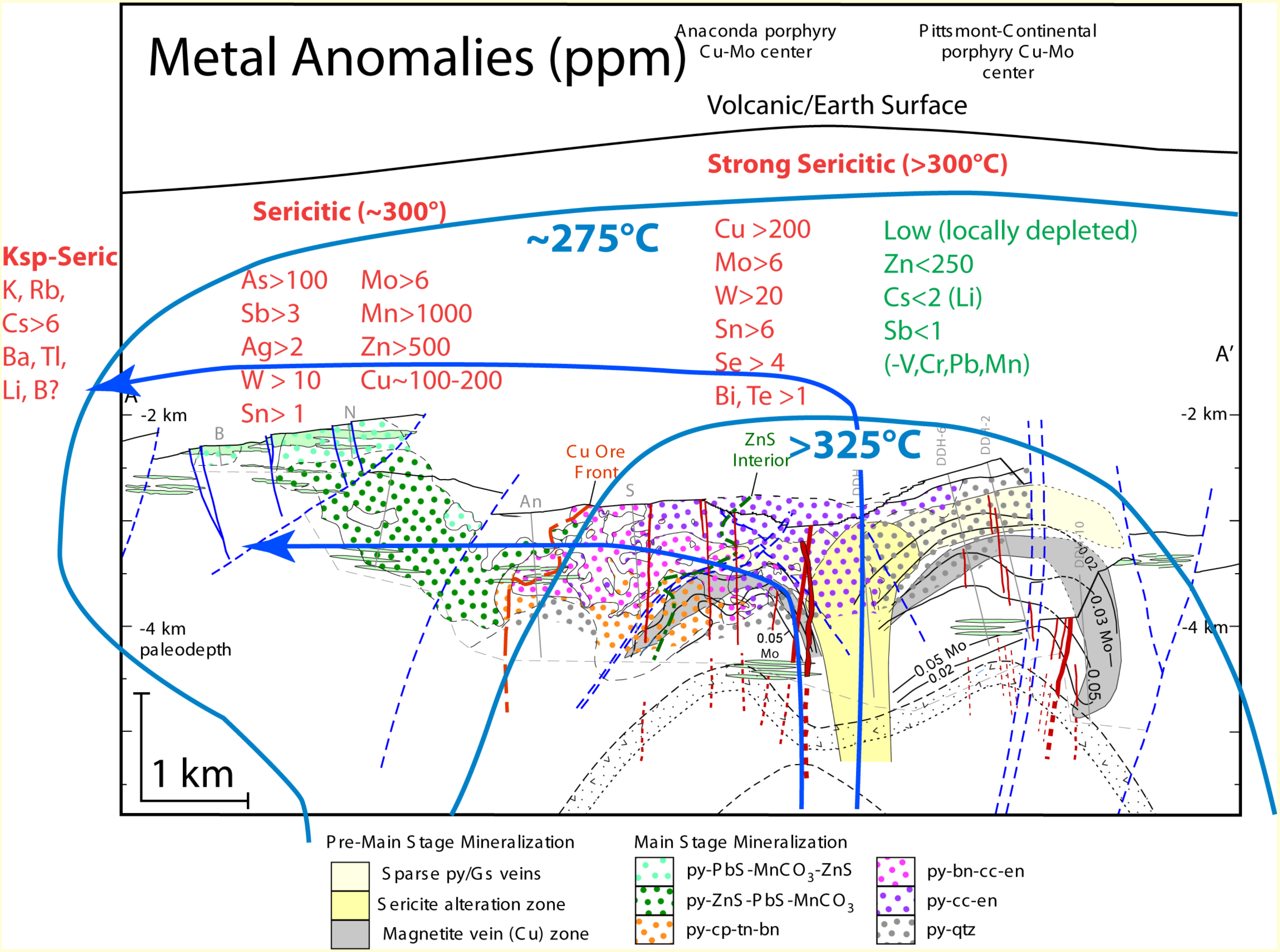




Summary of lateral metal zonation

Element	EDM (ppm)	Gray Ser	MS Intermediate	MS Periphery
Cu	4000	~2000	~1000	<200
Mo	>100	>6	>6	>6
Bi, Te	>1	>1	--	--
Se	>4	>4	--	--
As	>100	>100	>100	>100
Sb	low	low	>3	>3
W	>20	>20	>10	>10
Sn	>6	>6	>2	>1
Ag	>2	>2	>2	>2
Zn	~100	>250	>500	>500
Cs	<2	<2	>6	>6

Butte Lateral metal zoning in sericitic alteration



Summary of Main Stage metal anomalies

- Cs, Rb, Ba, Li, Tl anomalous in MS (>5 km)
  - Hosted in micas & chlorite
- Mo, Sn, W, Mn, (Zn, Pb, Ag) anom in MS (5km),
- Sb, As dispersed 1-5 km
- Bi, Se, Te <1 km
  - Se (&Te?) in pyrite, centrally
  - Sn locally in micas
- Cu, Mo, Co, Ni
  - Anomalous in central porphyry Cu-Mo zones. Co & Ni present in pyrite, Cu & Mo in Cu-sulfides & Molybdenite