# Energy Critical Element and Precious Metal Deportment in Cu-(Fe) Sulphides from the Bingham Canyon Porphyry Cu-Mo-Au deposit

iCRAG IRISH CENTRE FOR RESEARCH IN APPLIED GEOSCIENCES

*Maurice Brodbeck*,Sean McClenaghan,*

*Patrick Redmond and Balz Kamber*

Presentation by Maurice Brodbeck, PhD

Trinity College Dublin
The University of Dublin

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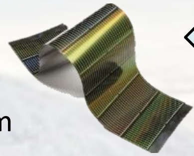
# Research Outline

- Porphyry Cu systems contain ‘Energy Critical Elements’ (ECEs) required for energy related technologies

Thin film PV cells

| In | Ga | Se |
|---|---|---|



| Cd | Te |
|---|---|

Copper indium gallium diselenide (CIGS)

Cadmium Telluride

PV panels

| Ge | Ag | In | Ga | Se | Cd | Te |
|---|---|---|---|---|---|---|

Wind turbines & high strength magnets

Co

Rechargeable (car) batteries

- For example, 90% of the Tellurium is produced in the copper refining process from anode slimes

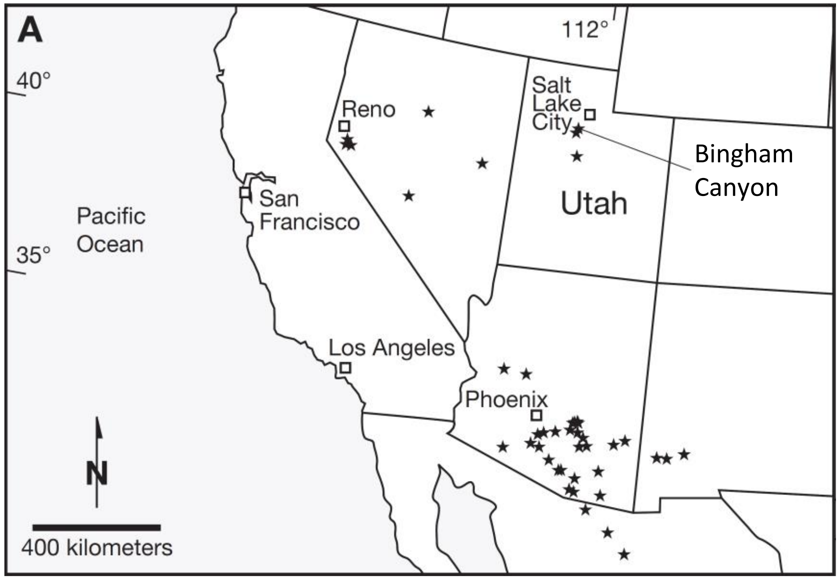
- Limited understanding of the mineralogy of ECEs and penalty elements in copper ores
  -> Effective extraction, processing and refining of ECEs is highly constrained

- Research target: Deportment of ECEs and precious metals in Cu-(Fe) sulphides from Bingham Canyon

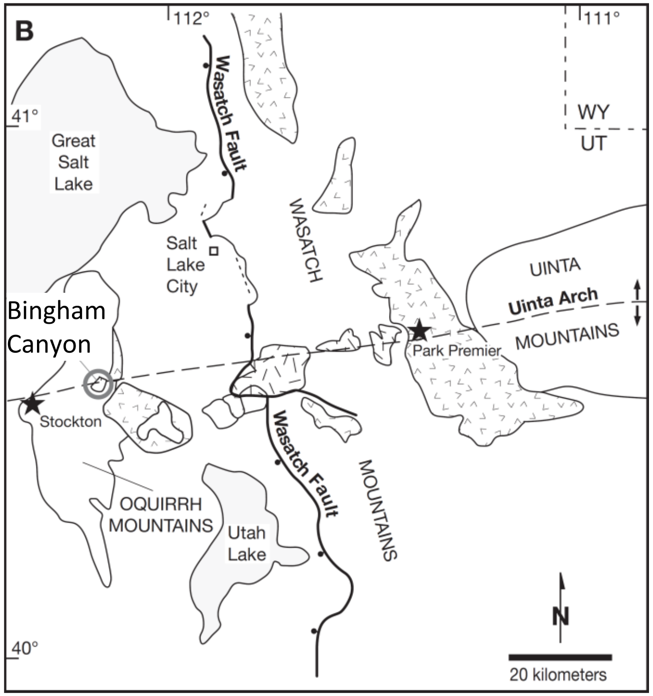
| | |
|---|---|
| ECEs and precious metals: | Co, Ag, Au, Te, Se, Ge, Ga, In |
| Potential Penalties: | As, Cd, Sb, Bi, (Se) |

- Methods: LA-ICP-MS and SEM-EDS

# Bingham Canyon Porphyry Cu-Mo-Au Deposit

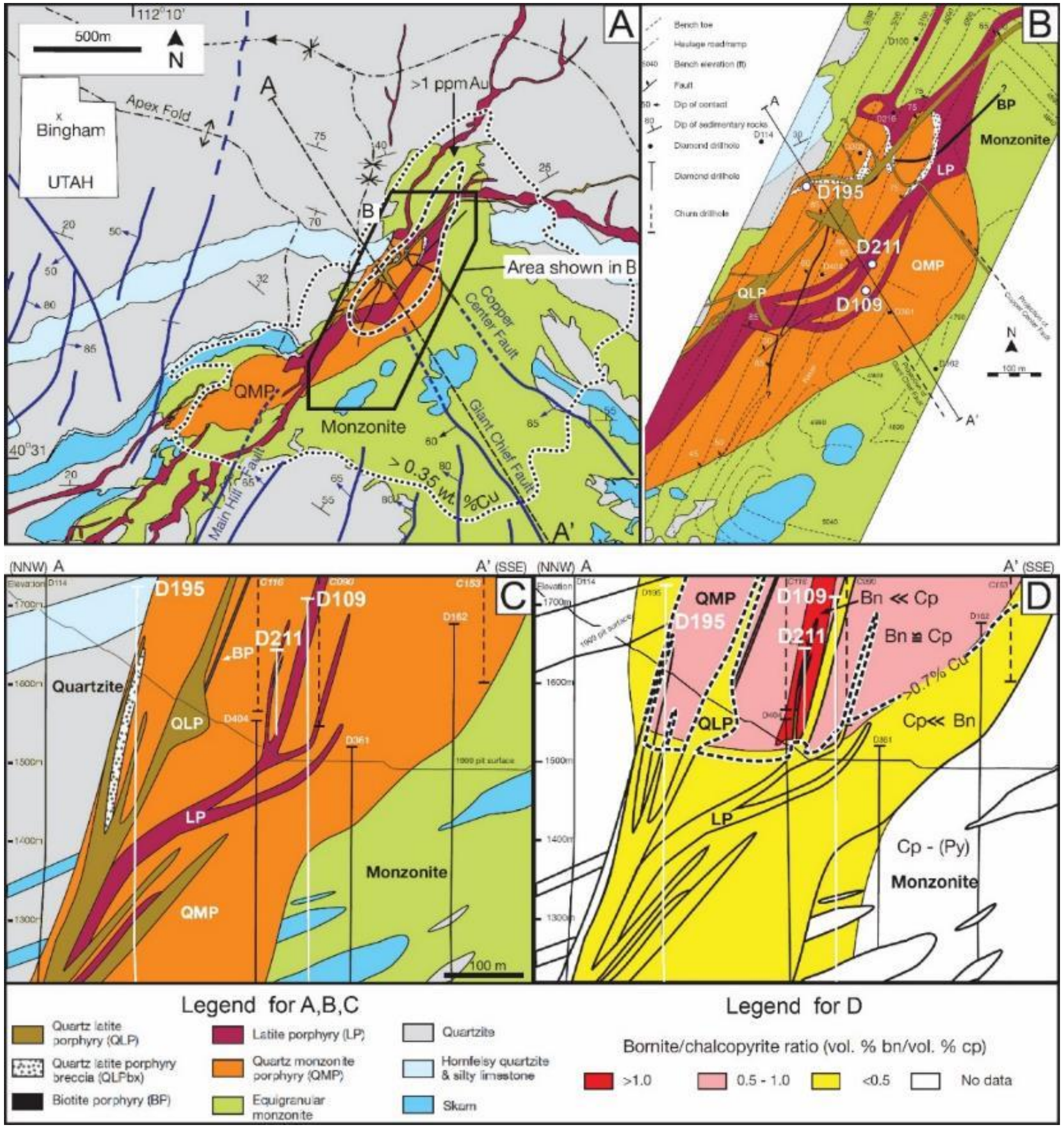



*Location maps modified from Babcock et al. 1995 & Gruen et al. 2010*




- Bingham Canyon is one of the largest and high-grade orebodies in the world
- The deposit is located in the Oquirrh Mountains in northern Utah on the Uinta Arch
- It belongs to a belt of Eocene to Oligocene intrusions and coeval volcanics
- Deposit formation occurred after a change from regional compression to extension in the mid-Eocene
- Centred on the Bingham Stock, a 2 by 2 km multiphase intrusion, emplaced into Palaeozoic siliciclastics and carbonates

# Bingham Canyon Porphyry Cu-Mo-Au Deposit




*Geology and Cu-Fe sulphide ratios at Bingham Canyon, modified after Redmond & Einaudi 2010*

- Study focused on the high grade zone (>1% Cu and >1 ppm Au) on NW side of the deposit
- The oldest intrusion is an equigranular monzonite
- Followed by five distinct crosscutting porphyry phases:
- Quartz Monzonite Porphyry (QMP) is the earliest and volumetrically largest porphyry, contains the highest Cu and Au grades
- Latite Porphyry (LP), set of subparallel NE trending dikes
- Biotite Porphyry (BP) and Latite Porphyry Breccia (QLPbx), narrow dikes only have minor occurrences
- Quartz Latite Porphyry (QLP) is the latest porphyry, truncating all earlier intrusions

# Alteration and Mineralisation

- Alteration: Inner potassic alteration zone ± coincides with the copper orebody, outer propylitic zone, late argillic overprint, sericitic alteration is limited

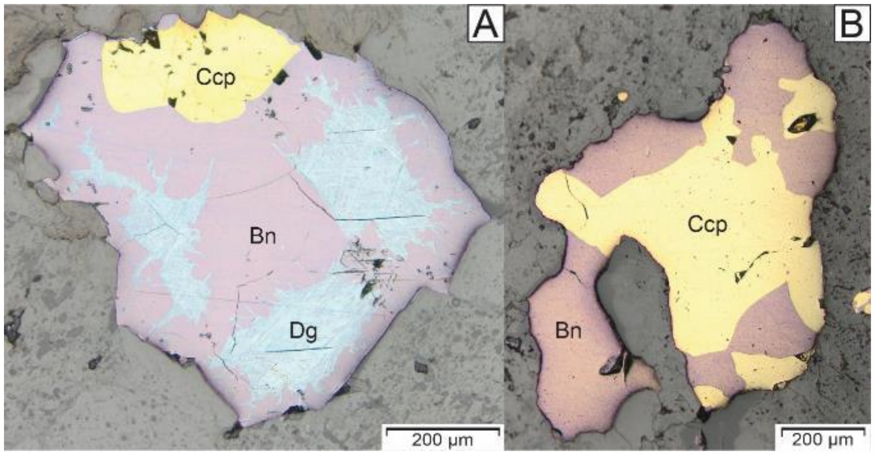
- Each porphyry phase has an associated sequence of quartz veins, sulphide mineralisation and potassic alteration

- The majority of Cu-(Fe) sulphides occur in microfractures and vugs, created by retrograde dissolution of earlier quartz

- Previous microthermometric studies on fluid inclusions (Redmond & Einaudi 2010) indicated that sulphide deposition from high salinity brines occurred at 400 to 350°C at near hydrostatic P ~200 bars

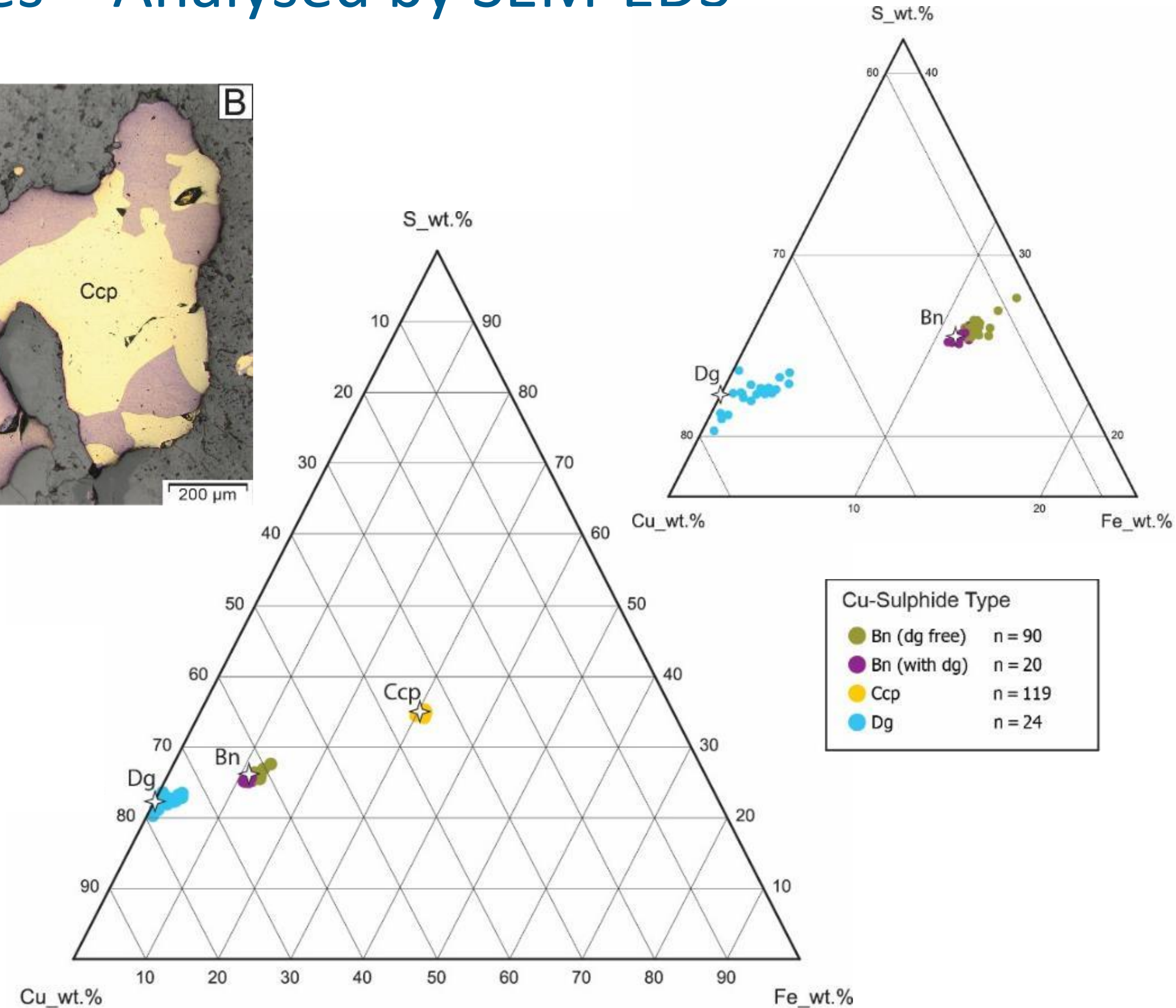
- Alteration intensity, vein abundance, mass of introduced copper and gold decreased through time
  -> interpreted as an effect of metal depletion in the underlying magma chamber

# Cu-(Fe) Sulphides – Analysed by SEM-EDS



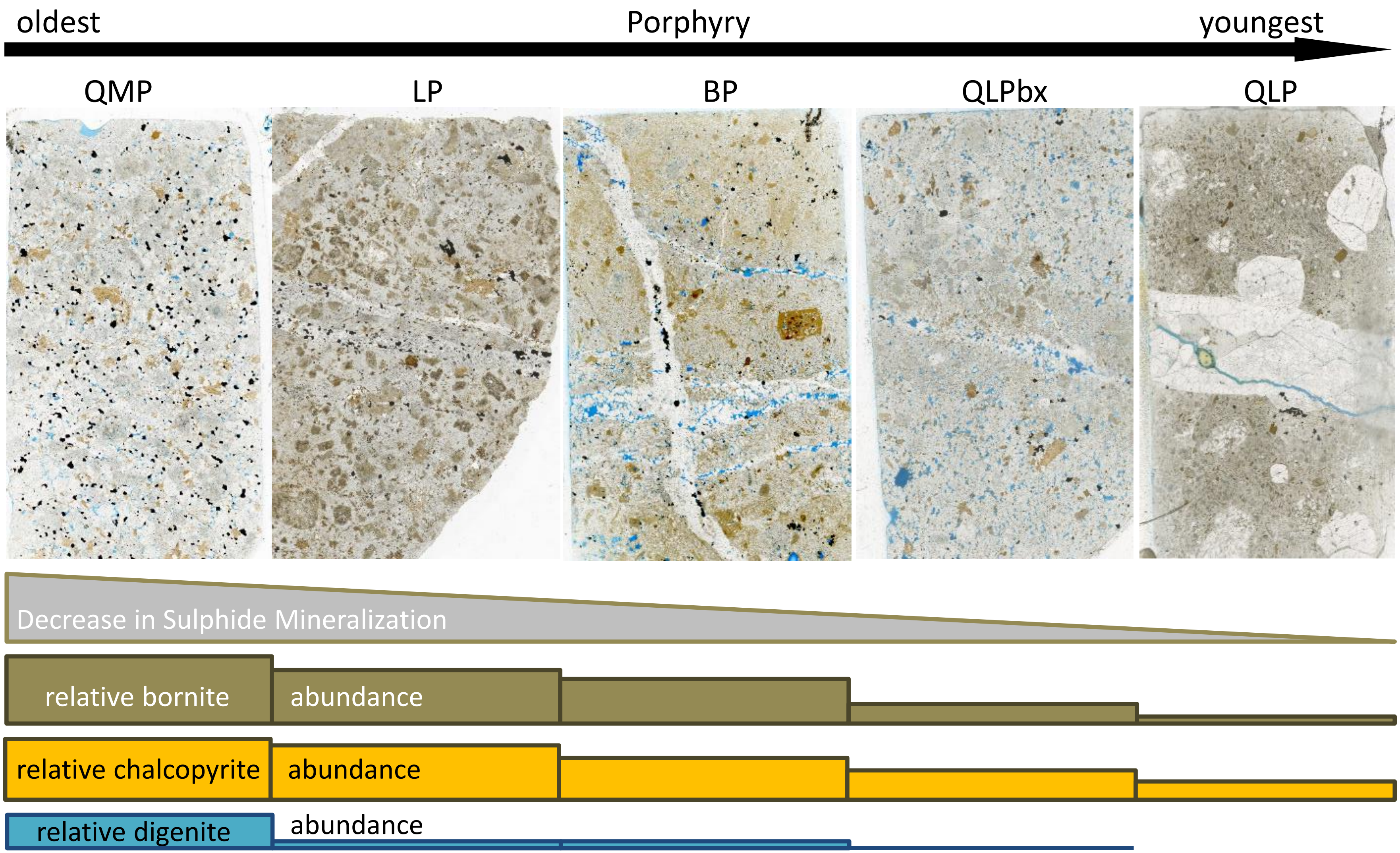

Cu-(Fe) sulphide ore minerals:

- Chalcopyrite (Ccp) – $CuFeS_2$
- Bornite (Bn) – $Cu_5FeS_4$
- Digenite (Dg) – $Cu_9S_5$ as exsolution within bornite




*S-Cu-Fe triplots of compositional data, acquired by SEM-EDS analysis of Cu-(Fe) sulphides from Bingham Canyon*

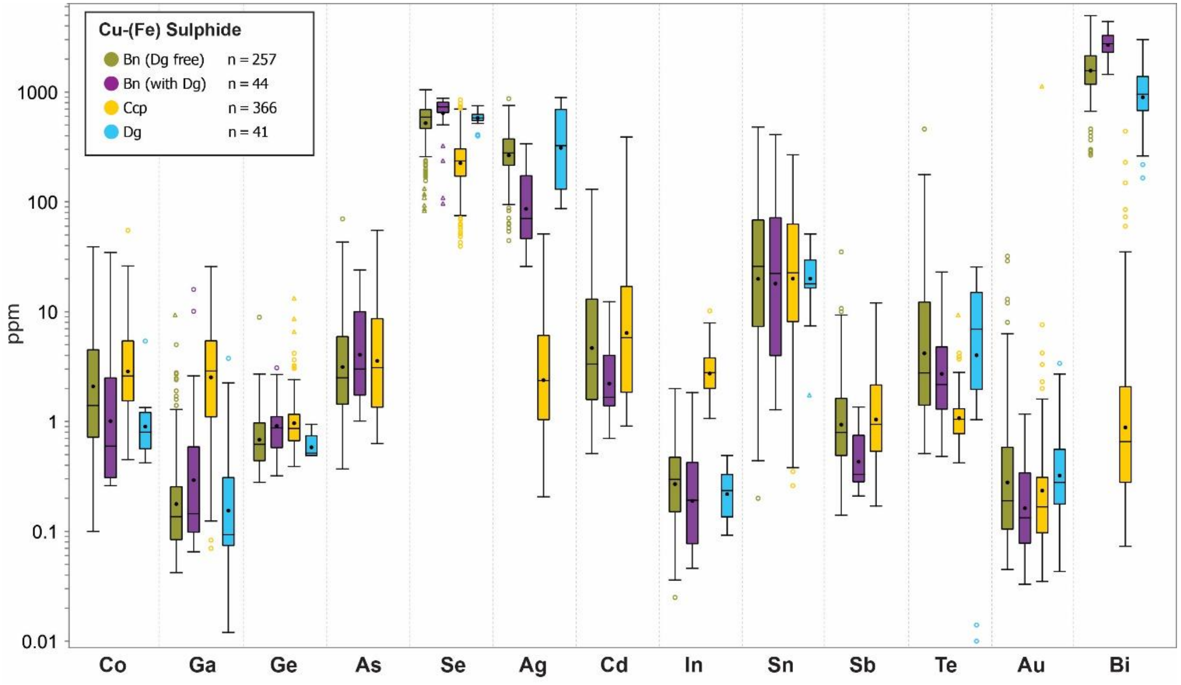
# Cu-(Fe) Sulphide Abundance




*Simplified copper ore mineral abundance across the sequence of porphyry intrusions at Bingham Canyon.*

Maurice Brodbeck, PhD

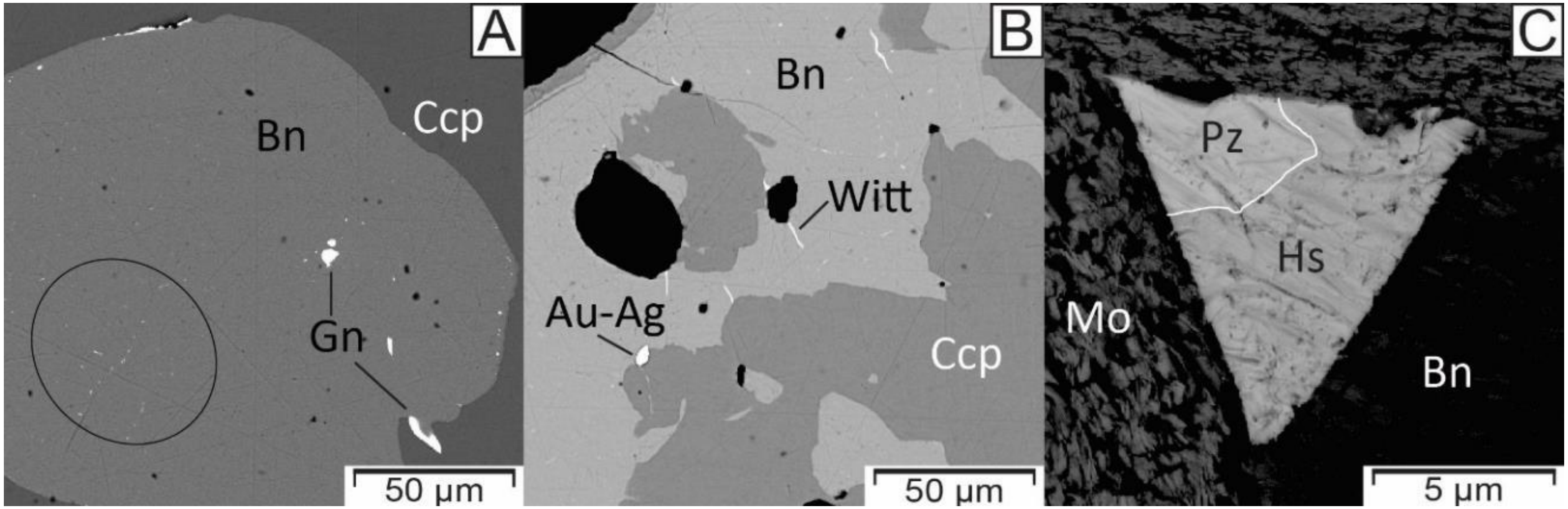
# Trace Element Deportment - Analysed by LA-ICP-MS




*Box and whisker plots of trace metal(loids) in Cu-(Fe) sulphides from the NW zone of the Bingham Canyon porphyry deposit*

- Bornite is the major host for Se, and Bi and is an important silver carrier
- Chalcopyrite is the primary host for Co, Ga, Ge and In
- Digenite yields highest conc. of Ag, Te and gold and significant Se and Bi contents
- Deleterious elements: As, Cd and Antimony generally below 10 ppm, 100s of ppm Se and a few 1000 ppm Bi especially in bornite ± digenite rich ore

# Trace Metal(loid) Residence – Accessory Minerals




*BSE (backscattered electron) images of micron - to nano - scale mineral phases with wt. % levels of precious or critical metal(loids).*

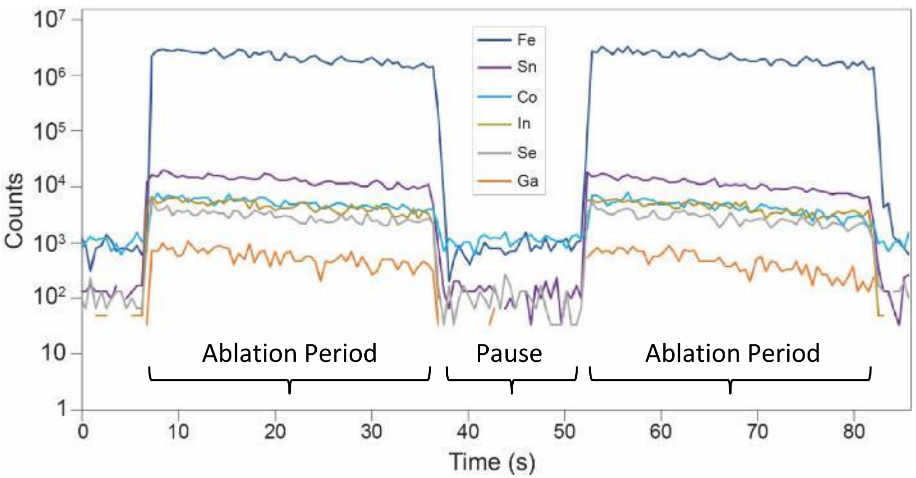
*Compositions of accessory minerals with wt. % levels of precious or critical metal(loids).*

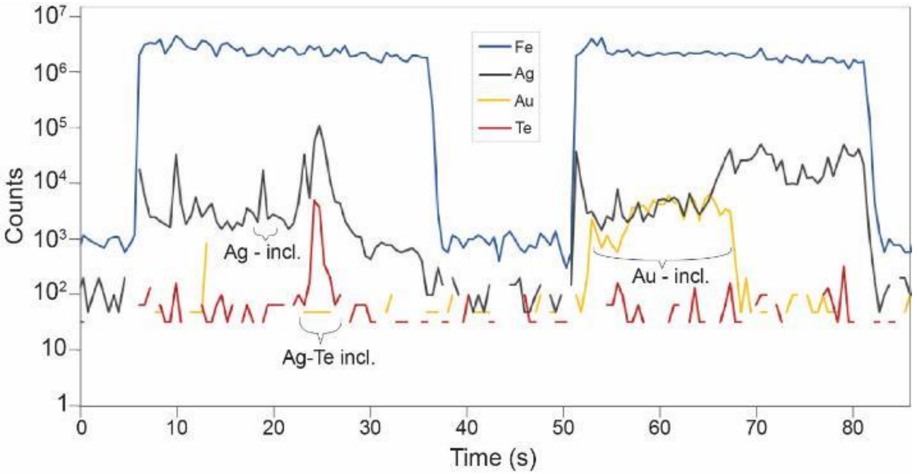
| **Mineral** | **Wittichenite (Witt)** | **Petzite (Pz)** | **Hessite (Hs)** |
|---|---|---|---|
| **Chemical Formula** | $Cu_3BiS_3$ | $Ag_3AuTe_2$ | $Ag_2Te$ |

- Aside from Cu-(Fe) sulphides, accessory minerals contain wt. % levels of precious or critical metal(loids). These are: Se-rich galena, Ag-and Au tellurides (hessite, petzite), electrum and wittichenite
- Electrum grains are the primary hosts of the gold budget at Bingham (Redmond, 2002)
- Tellurides were observed at similar abundance and thus likely control the Te budget at Bingham
- Selenium and Bi occur at levels of 100s to 1000s of ppm in Cu-(Fe) sulphides

-> Galena and wittichenite with minor contribution to Se and Bi budgets, respectively

# Trace Metal(loid) Residence in Cu-(Fe) Sulphides

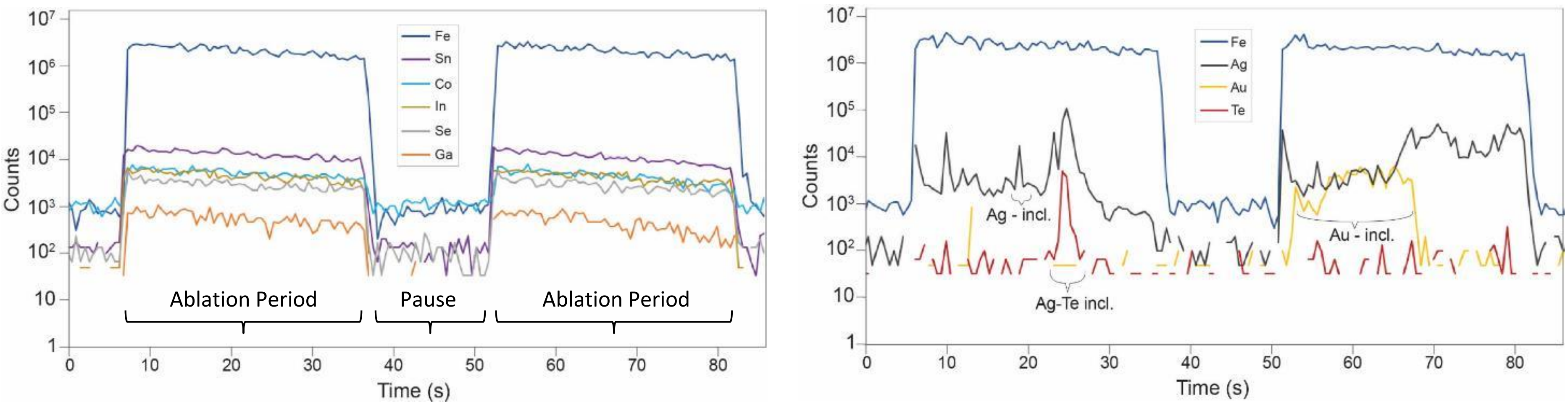



*Time-resolved LA-ICP-MS profiles of 30s spot ablations on chalcopyrite, separated by 15s signal washout periods.*

- The mode of trace metal residence was determined from time-resolved spot laser ablation profiles.
- Trace element ablation profiles that mirror the downhole ablation profiles of major elements (Cu, Fe, S) in Cu-(Fe) sulphides indicate a homogenous distribution within the crystal-> lattice residence
- Distinct peaks in the signal indicate heterogeneous distribution -> distinct inclusions of other minerals

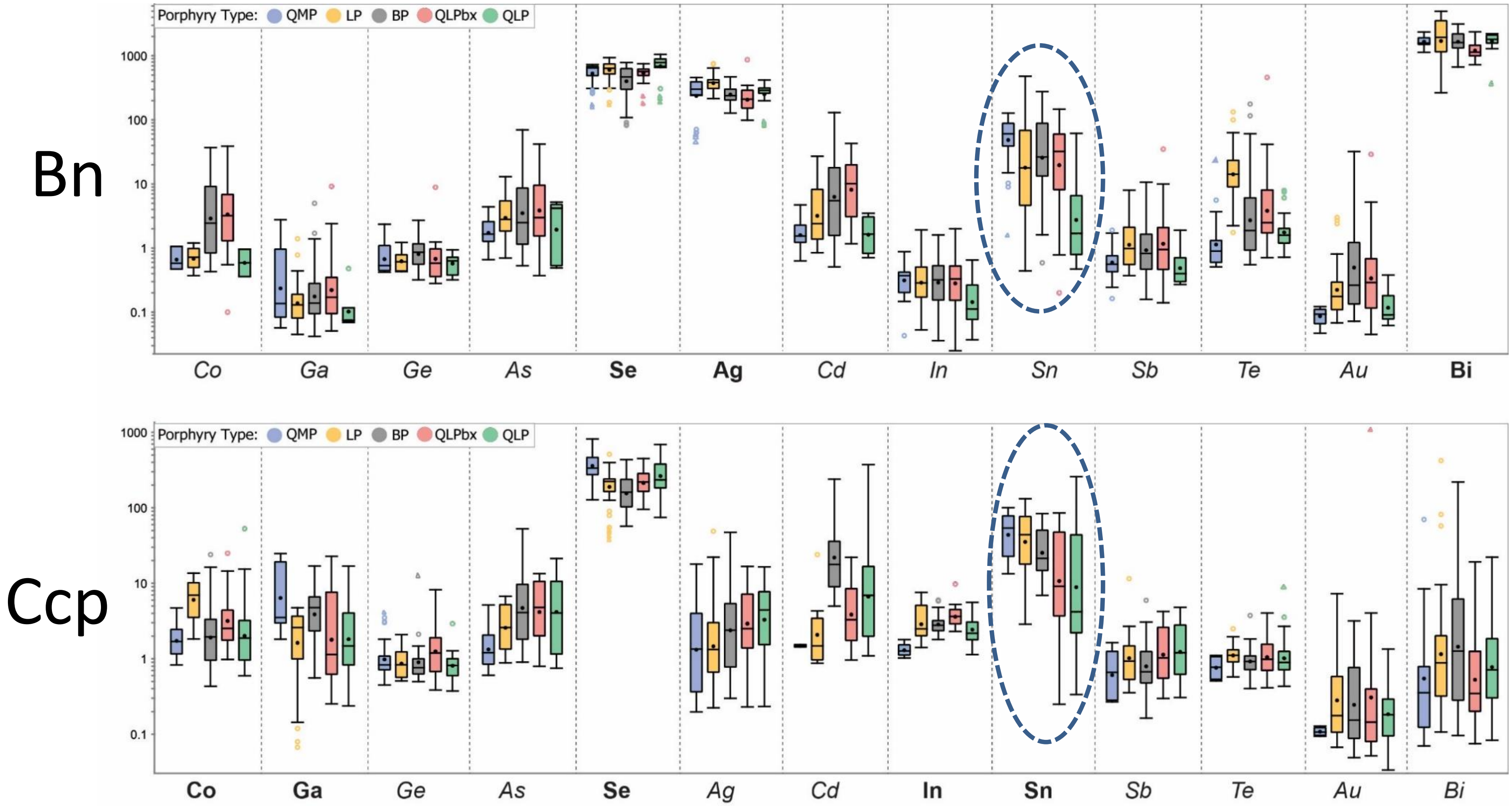
# Trace Metal(loid) Residence in Cu-(Fe) Sulphides




*Time-resolved LA-ICP-MS profiles of 30s spot ablations on chalcopyrite, separated by 15s signal washout periods.*

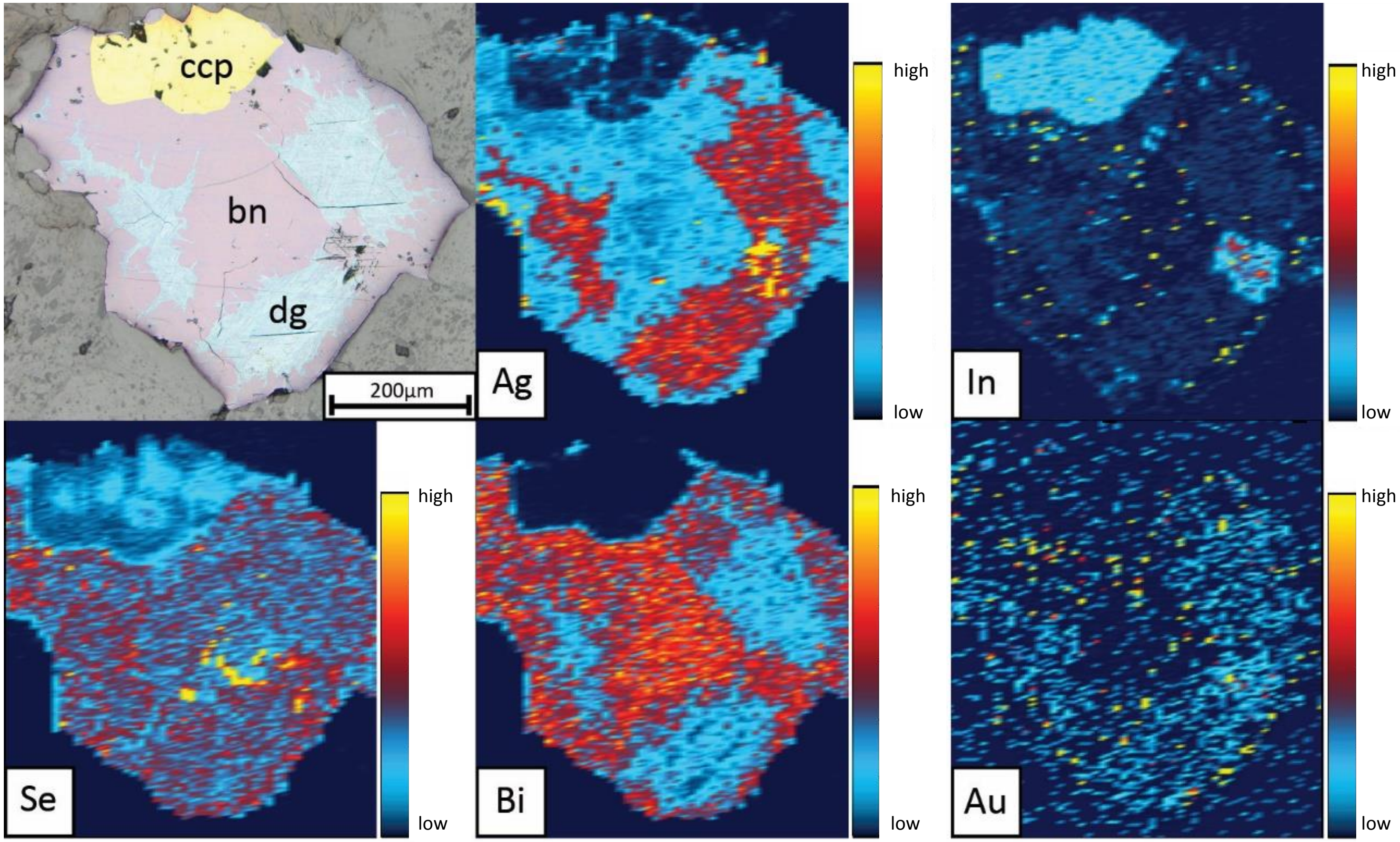
- Ge, As, Cd, Sb and Au are exclusively represented by inclusions in Cu-(Fe) in sulphides
- Se is homogeneously distributed in chalcopyrite, bornite and digenite
- In chalcopyrite, lattice residence is indicated for Co, Ga, Se, In and Sn
- In bornite, lattice residence is indicated for Se, Ag and Bi
- In digenite, lattice residence is indicated for Se, Ag, Sn and Bi

# Trace Element Deportment – by Porphyry Generation




*Box and whisker plots of trace metal(loid)s in digenite-free bornite (top image) and chalcopyrite (bottom image) by porphyry type in sequence from oldest to youngest intrusion. Lattice-bound elements are highlighted in bold font, while elements in italic font are most commonly inclusion-dominated in their host phases. Except for Sn, clear trends over the sequence of porphyry intrusions are not apparent in both digenite-free bornite and chalcopyrite.*

# LA-ICP-MS Mapping of Cu-(Fe) Sulphides




*LA-ICP-MS element distribution maps of a bornite (bn) – digenite (dg) – chalcopyrite (ccp) composite crystal. A reflected light image of the mapped area is shown in the top left. The illustrated maps are semi-quantitative and highlight relative concentration contrasts.*

# Summary

**ECE and precious metal deportment:**

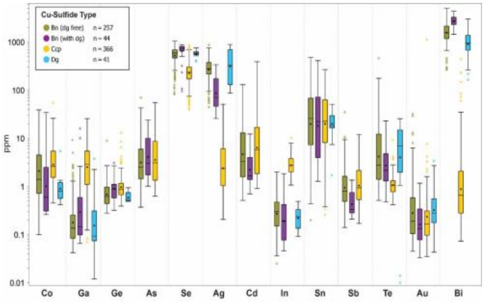
- Metal(loids) residing in the lattice of their host sulphides yield generally highest contents
- Cu-(Fe) sulphide ratios determine the element budgets for the majority of ECEs:
- Abundance of digenite and bornite primarily controls the Ag and the Bi and significantly the Se and Te budget
- Chalcopyrite abundance predominantly controls the Co, Ga and In budget
- Presence of electrum and Ag-(Au) tellurides governs the Au, and tellurides most likely also control the Te budget

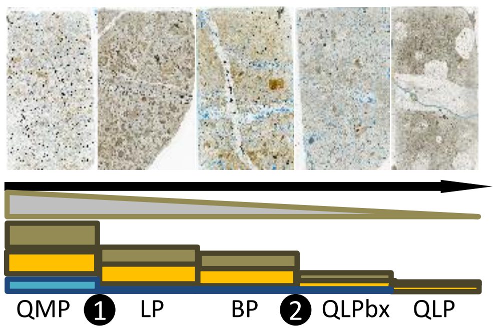
**Systematics from oldest to youngest porphyry:**

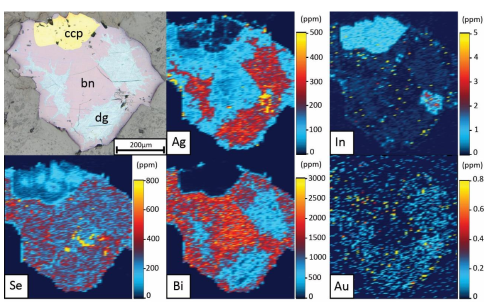
- Oldest porphyry (QMP )with highest trace metal(loid) inventory: highest sulphide + electrum abundance
- Two major drops in sulphide abundance: ❶ QMP to LP ❷ BP to QLPbx
- Constant chemistry of mineralising fluids: Except for Sn, no clear change of trace element contents with porphyry age was recorded

**Metal partitioning between digenite and bornite (during exsolution process):**

- Se equally distributed –> substitutes for S in the lattice
- Ag, Au and Te preferentially partition into digenite
- Bi is largely retained in bornite



**References:**

Babcock, R.C., Ballantyne, G.H., Phillips, C.H., 1995. Summary of the geology of the Bingham district, Utah. Arizona Geol. Soc. Dig. 20, 316–335.

Gruen, G., Heinrich, C.A., Schroeder, K., 2010. The Bingham Canyon porphyry Cu-Mo-Au deposit. II. Vein geometry and ore shell formation by pressure-driven rock extension. Econ. Geol. 105, 69–90.

Redmond, P.B., 2002. Magmatic-hydrothermal fluids and copper-gold ore formation at Bingham Canyon, Utah. Ph.D. Thesis, Stanford Univ. 228 pp

Redmond, P.B., Einaudi, M.T., 2010. The Bingham Canyon porphyry Cu-Mo-Au deposit. I. Sequence of intrusions, vein formation, and sulfide deposition. Econ. Geol. 105, 43–65.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