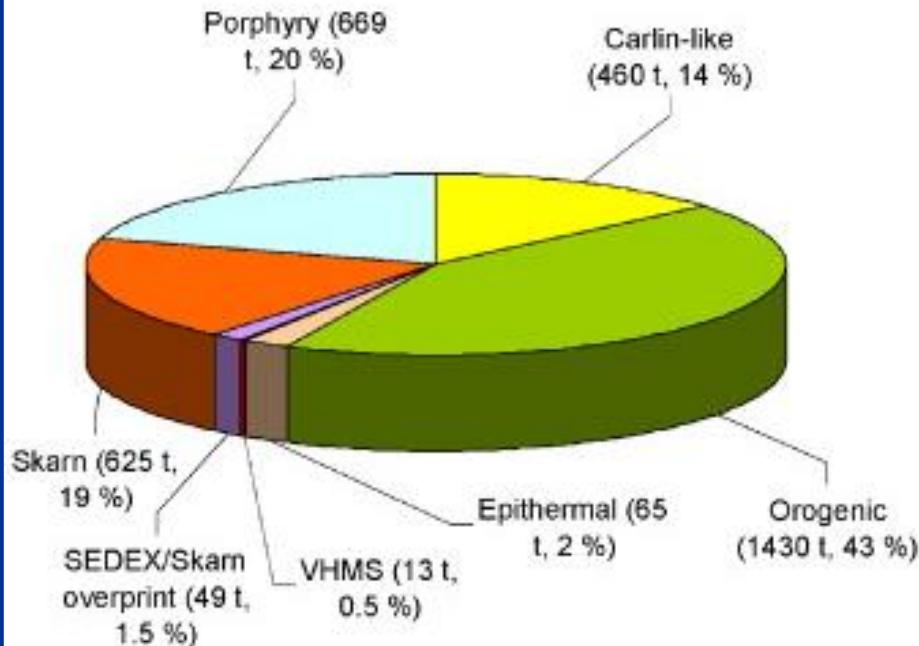


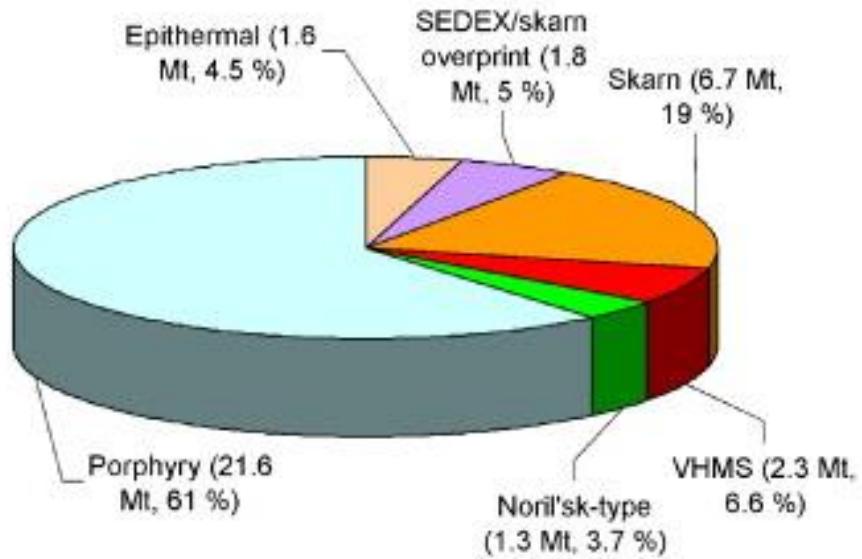
Porphyry Deposits

The Importance of Porphyry Deposits as a Copper and Gold Resource

Gold Resources

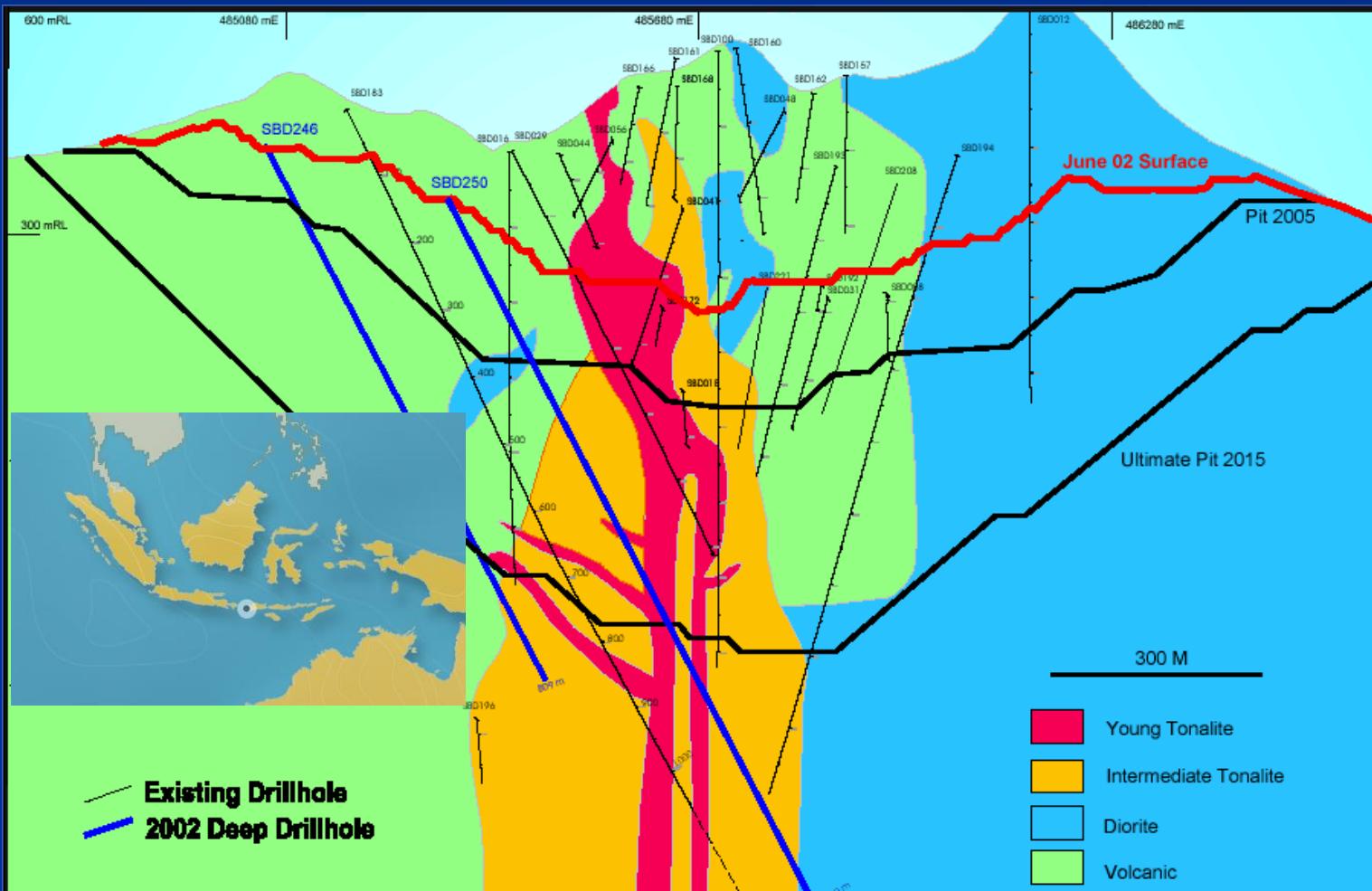


Copper Resources



A Geological Cross Section through the Batu Hijau Porphyry Deposit, Indonesia

(920 million tons of ore grading 0.55 wt.% Cu, 0.42 g/t Au)

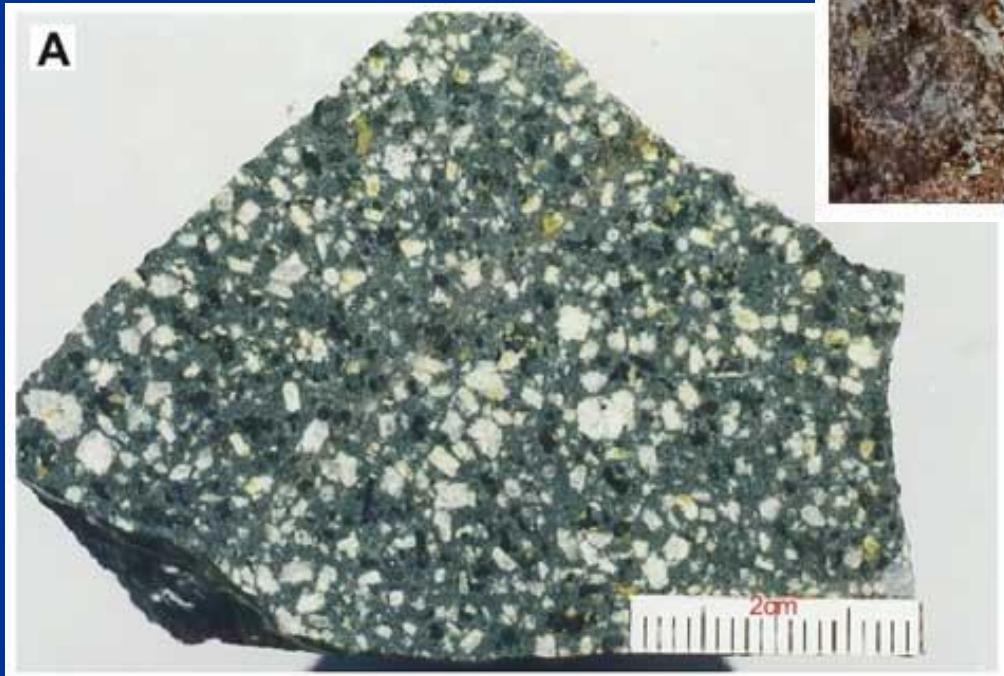


Batu Hijau Porphyry Cu-Au Deposit, Indonesia



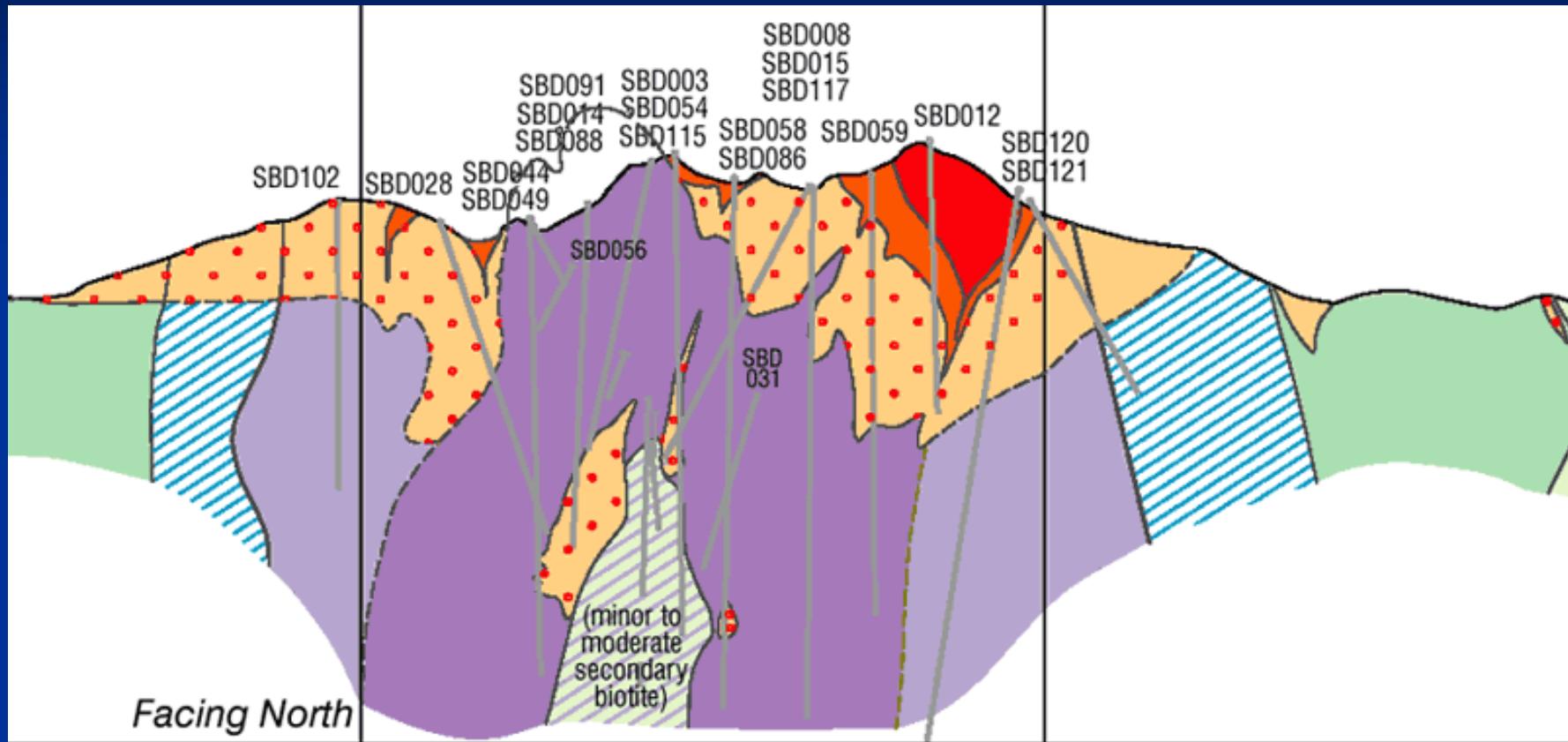
Batu Hijau Porphyry Cu-Au Deposit, Indonesia

Tonalite porphyry



Goethite-coated quartz veins
cutting sericite-altered diorite

Hydrothermal Alteration at Batu Hijau



LATE-STAGE

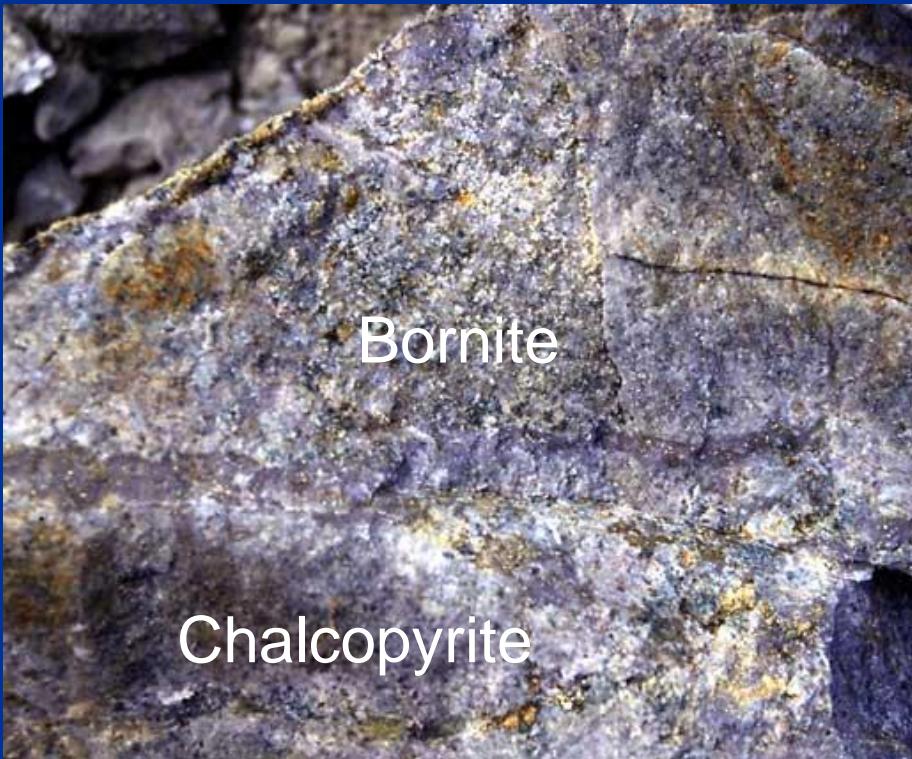
- Advanced argillic (AA)
- Sericitic/Paragonitic
- Intermediate argillic (red stipple indicates sericite)
- Illitic (<20% interlayered smectite)
- Calcite - chlorite - clay (Santong diatreme)

EARLY-STAGE

- Strong biotite (>90% mafic minerals replaced)
- Limit of relict or weak biotite
- Actinolite (approximate)
- Moderate epidote (>20% plagioclase replaced)
- Epidote replacement of plagioclase
- Epidote absent (background chlorite)

Batu Hijau Porphyry Cu-Au Ores

Hypogene

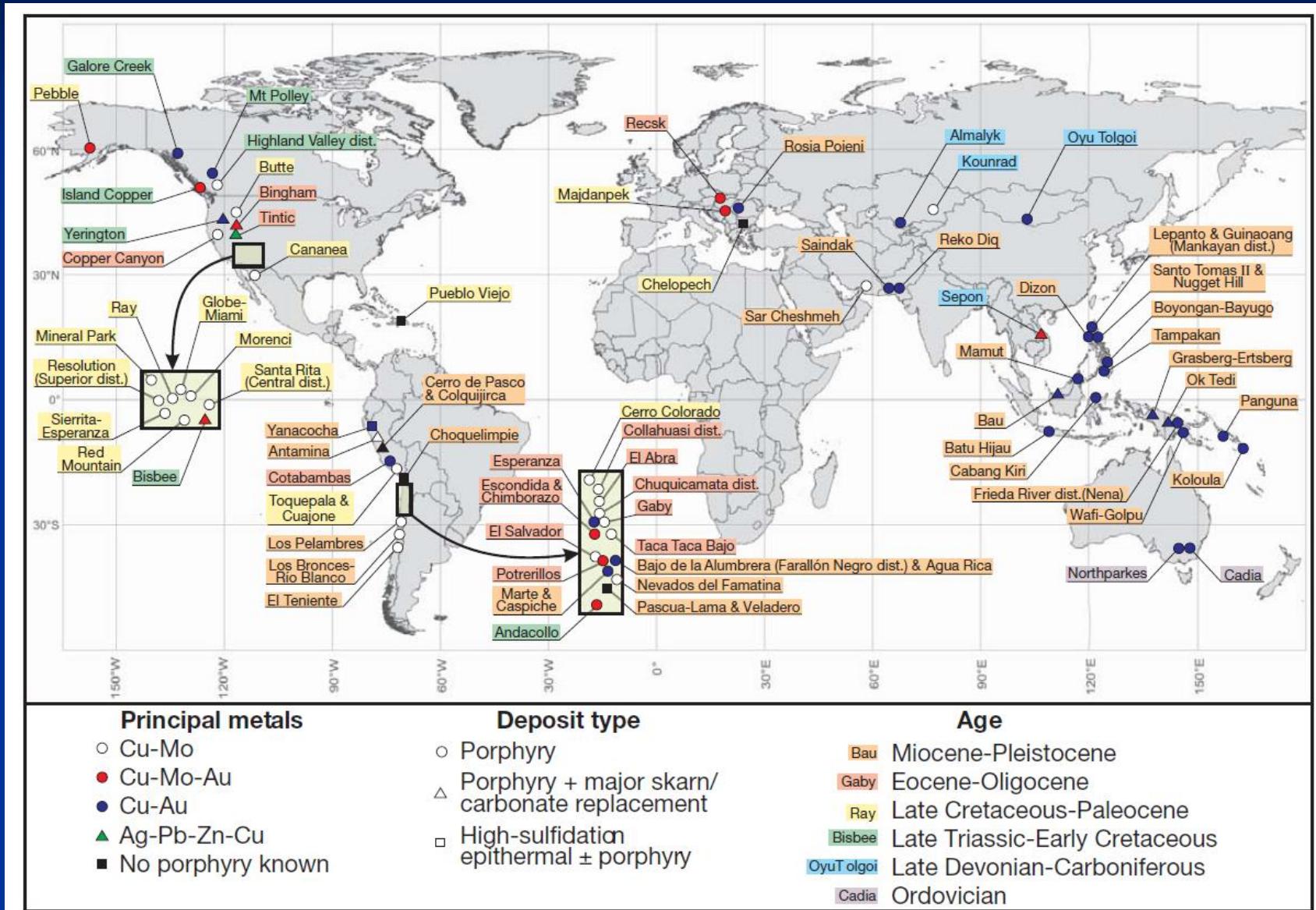


Supergene

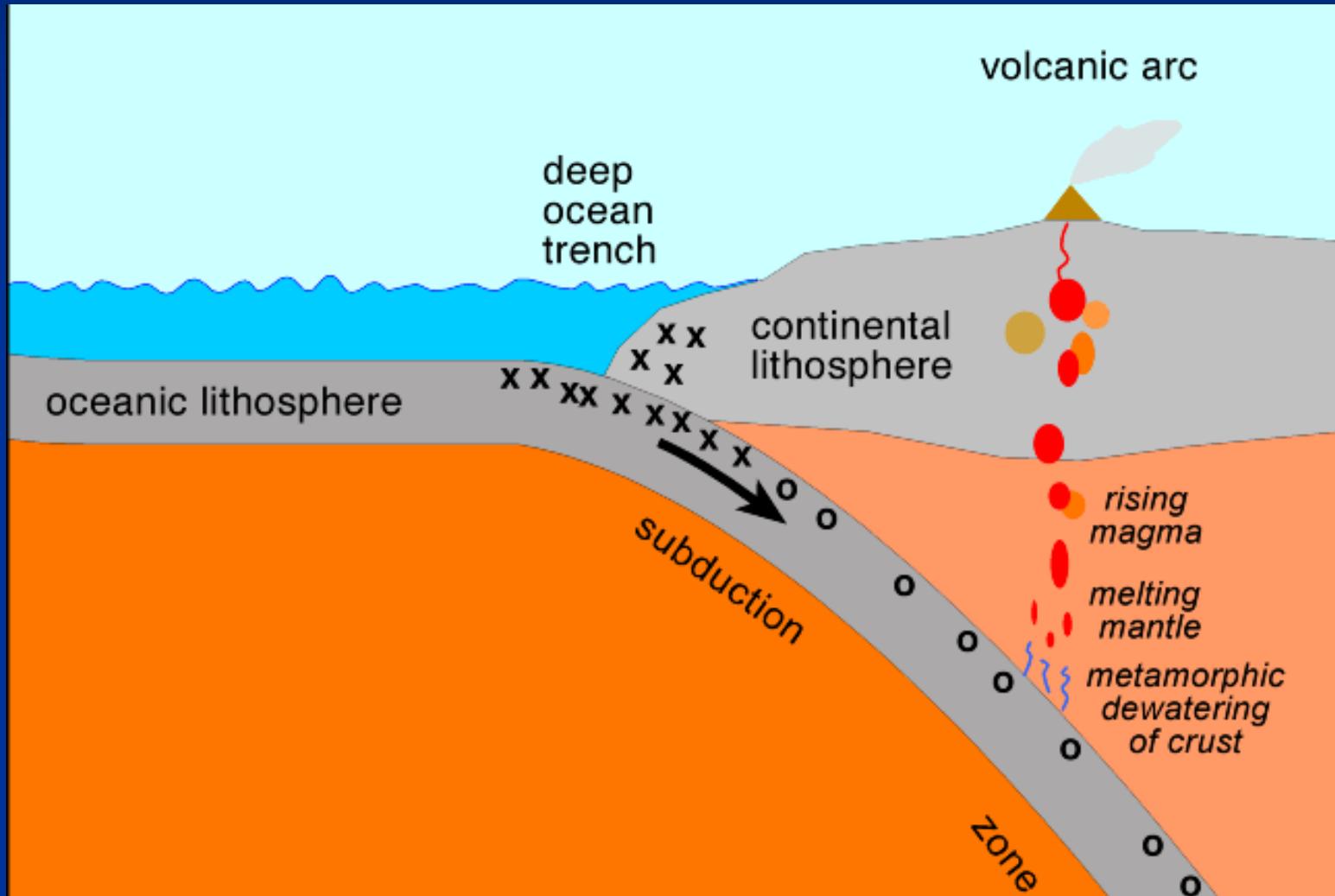


Malachite

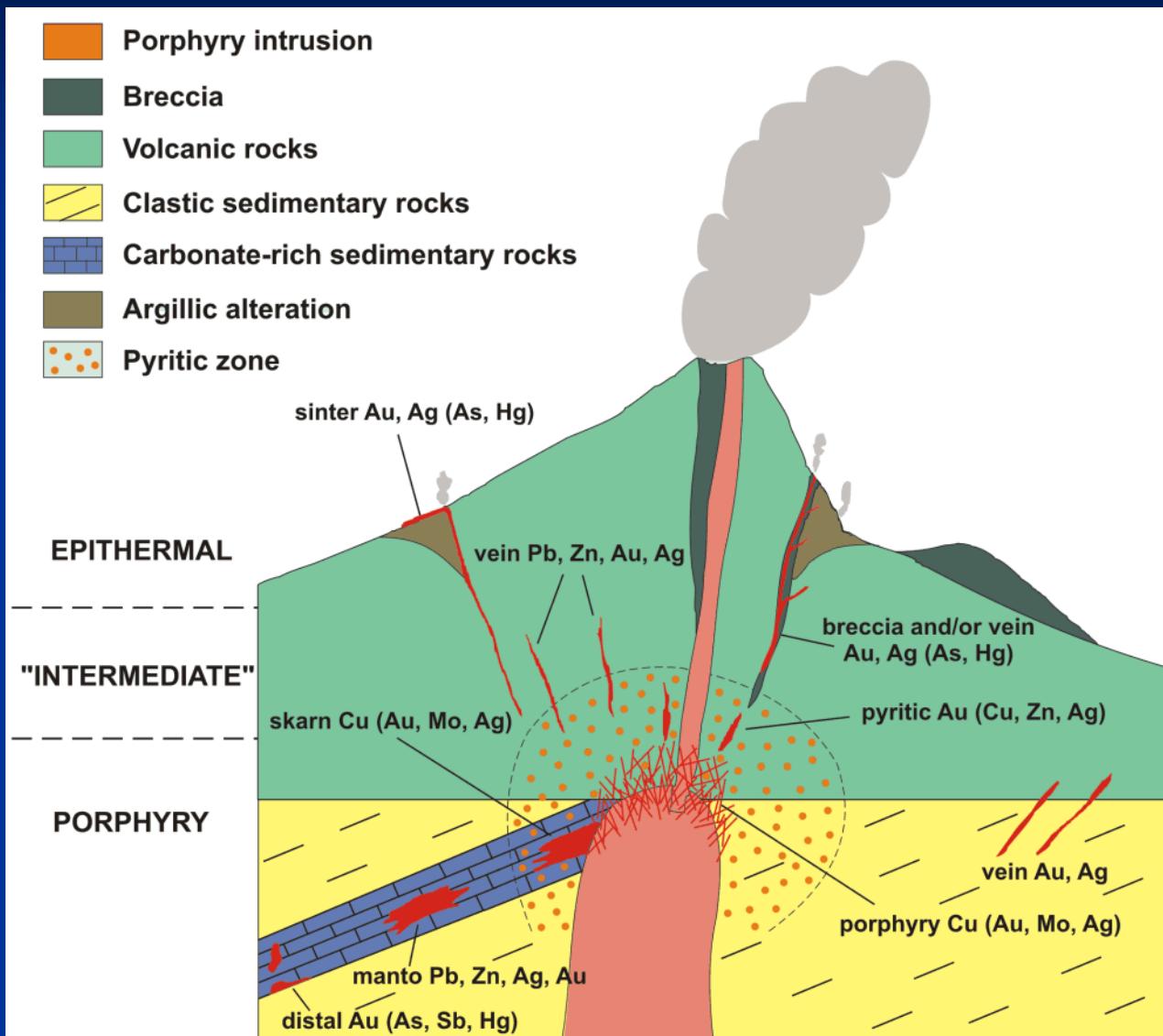
Spatial Distribution of Porphyry Deposits



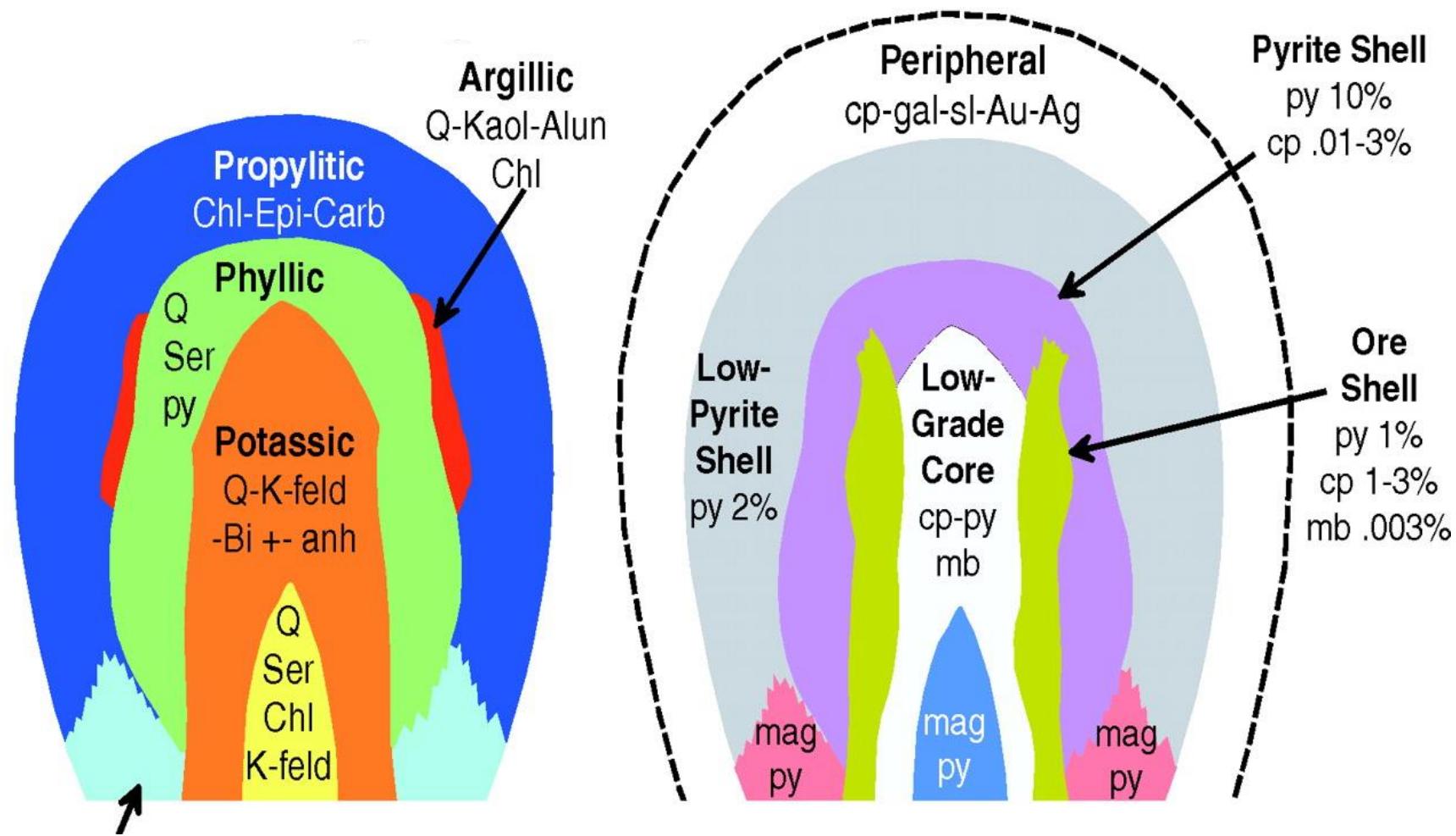
The Origin of Porphyry Cu-Au-Mo Magmas Hydration Melting



Porphyry-epithermal-skarn system - overview

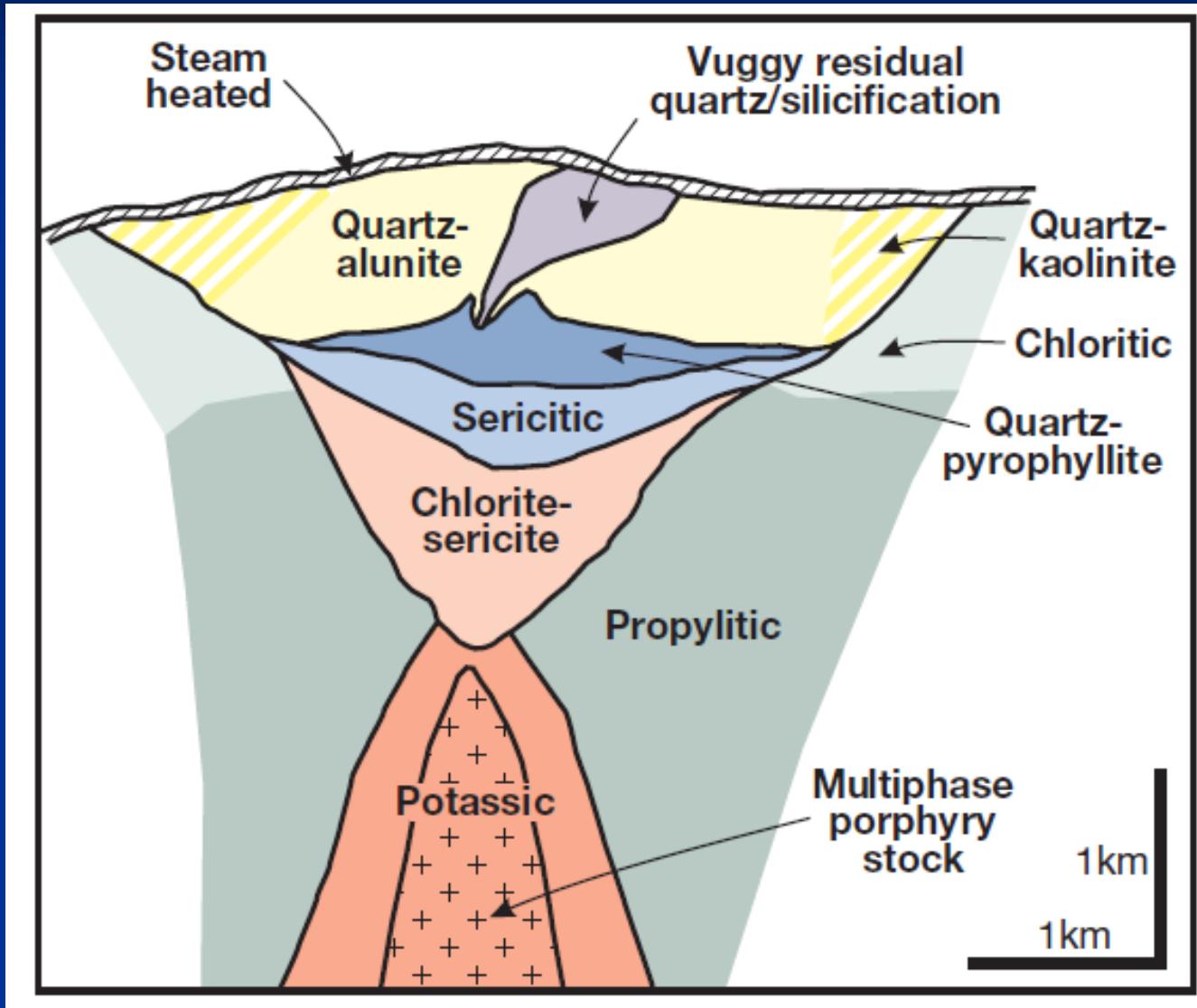


Idealized Porphyry Alteration/Mineralization (Lowell and Gilbert, 1970)

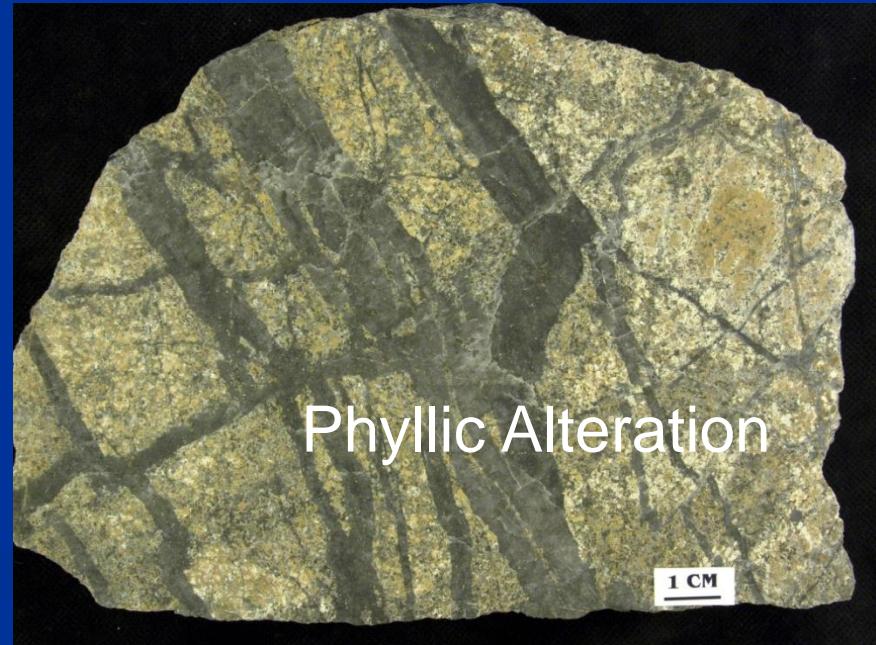
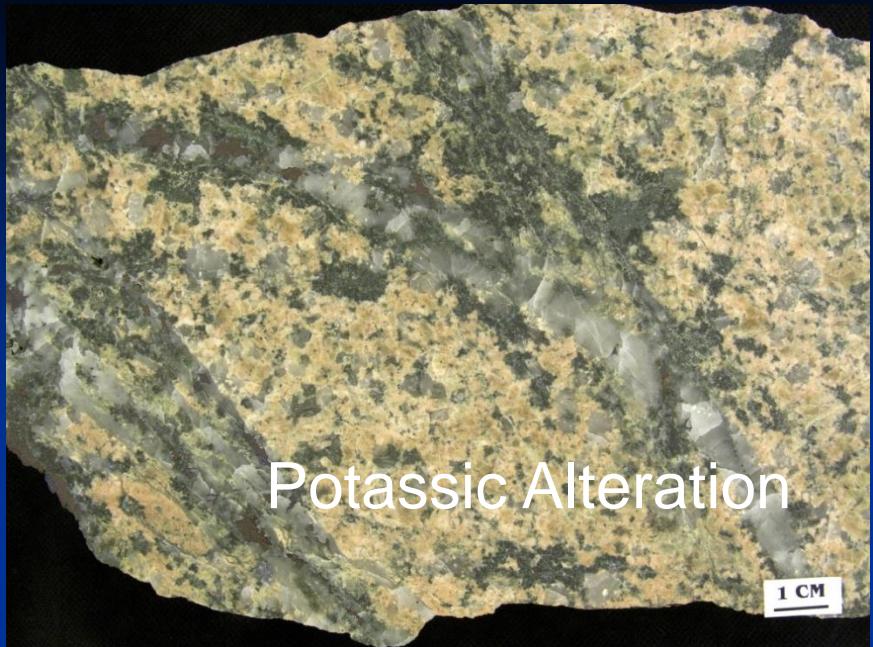
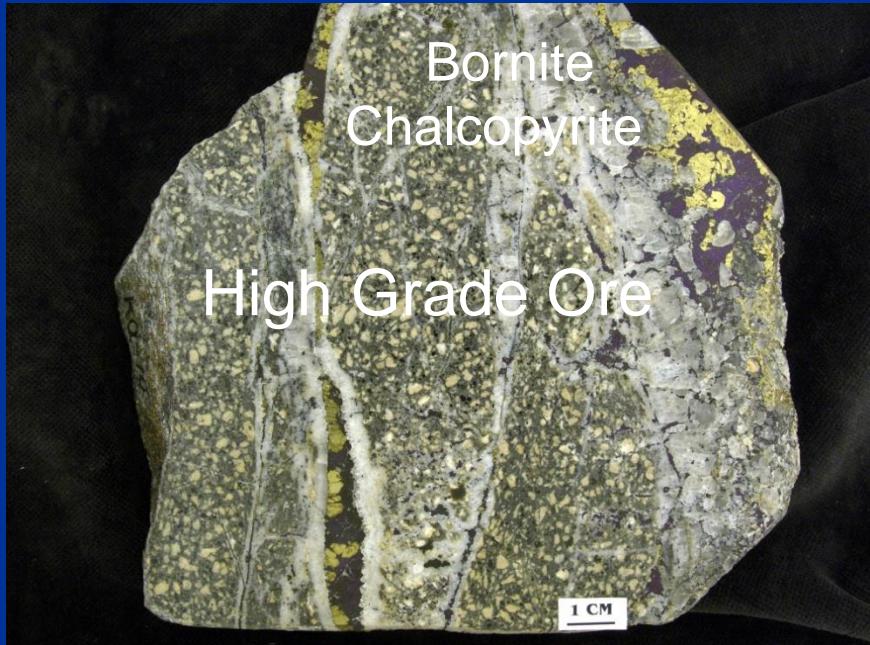


Schematic Porphyry-Epithermal Alteration

Sillitoe (2010)



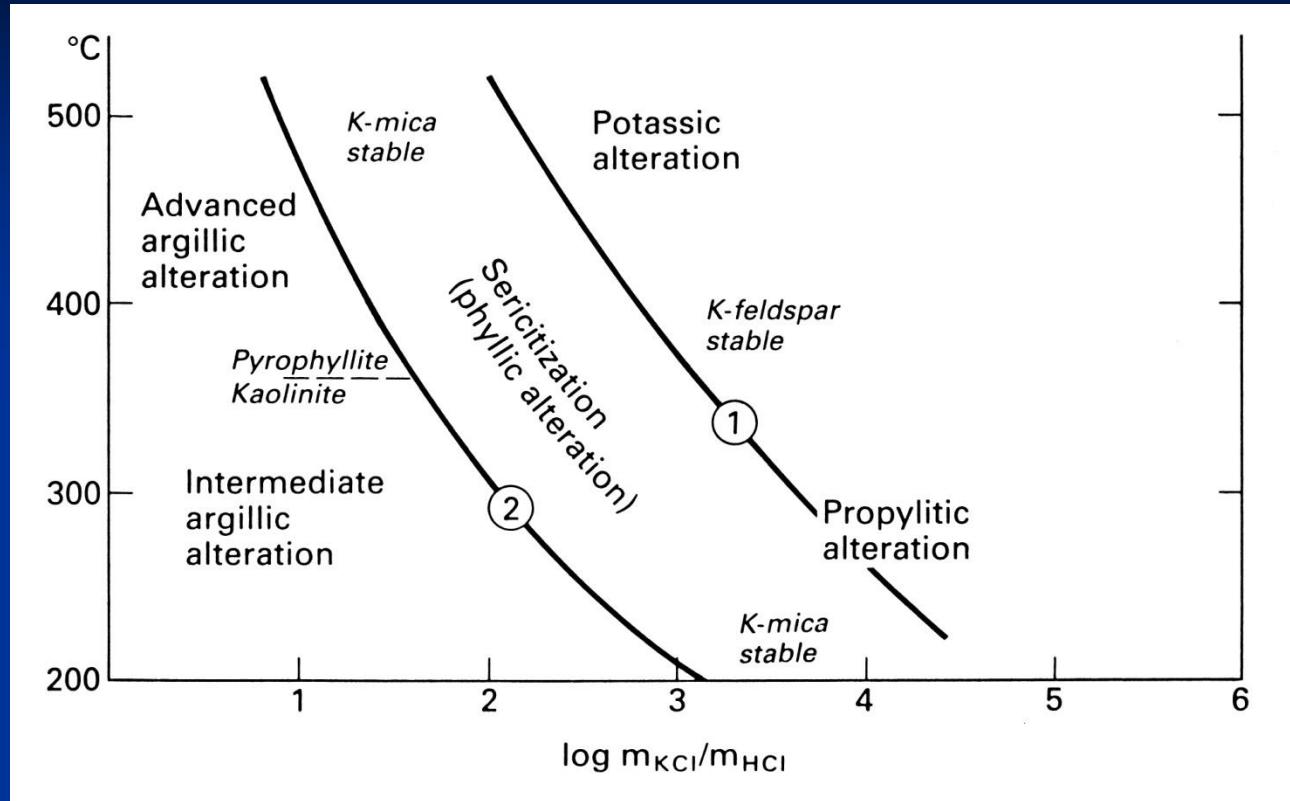
Porphyry Ore and Alteration Textures



Potassic Alteration Revealed by Staining



Hydrothermal Alteration – Chemical Controls



K-feldspar

Muscovite

Quartz

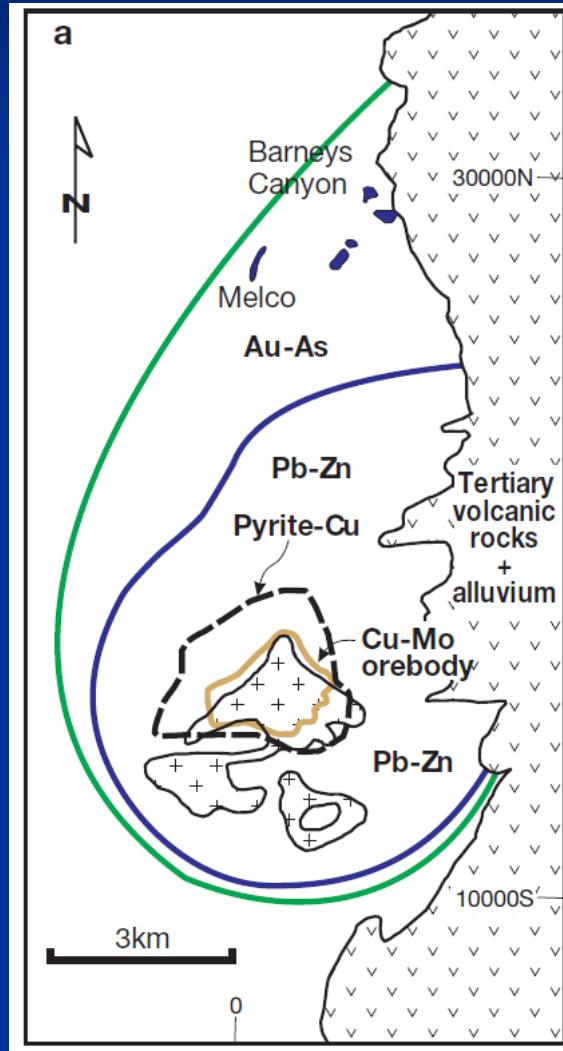


Muscovite

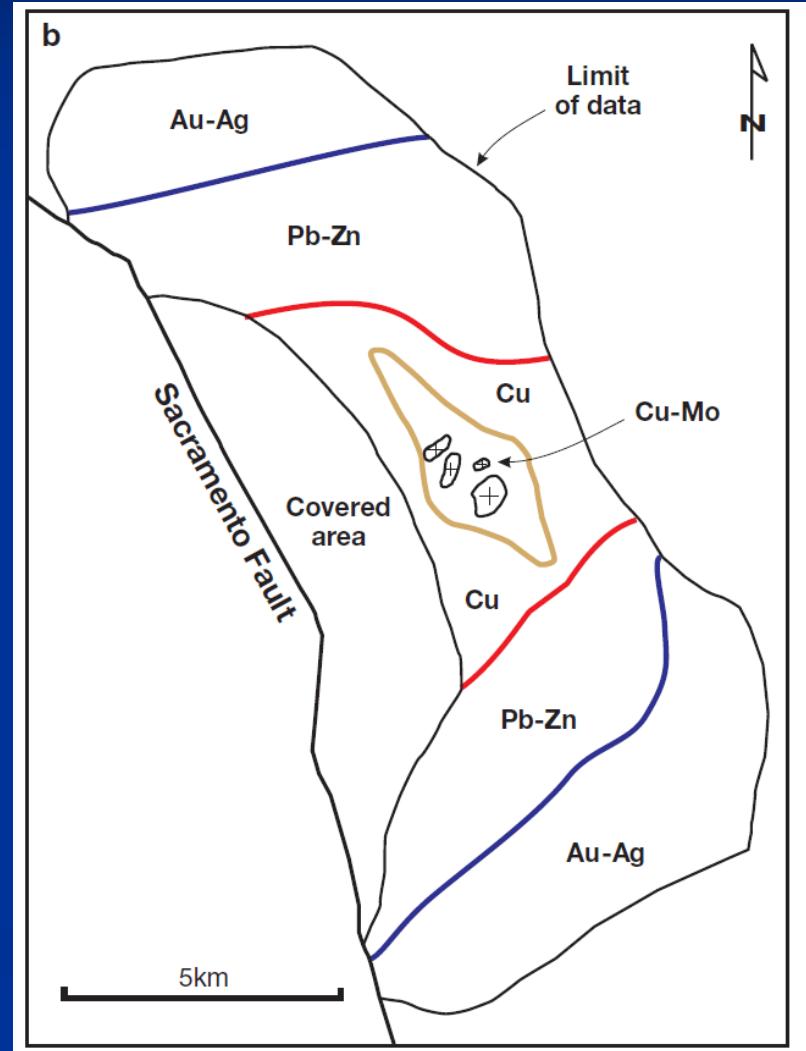
Kaolinite

Metal Zonation in Porphyry Systems

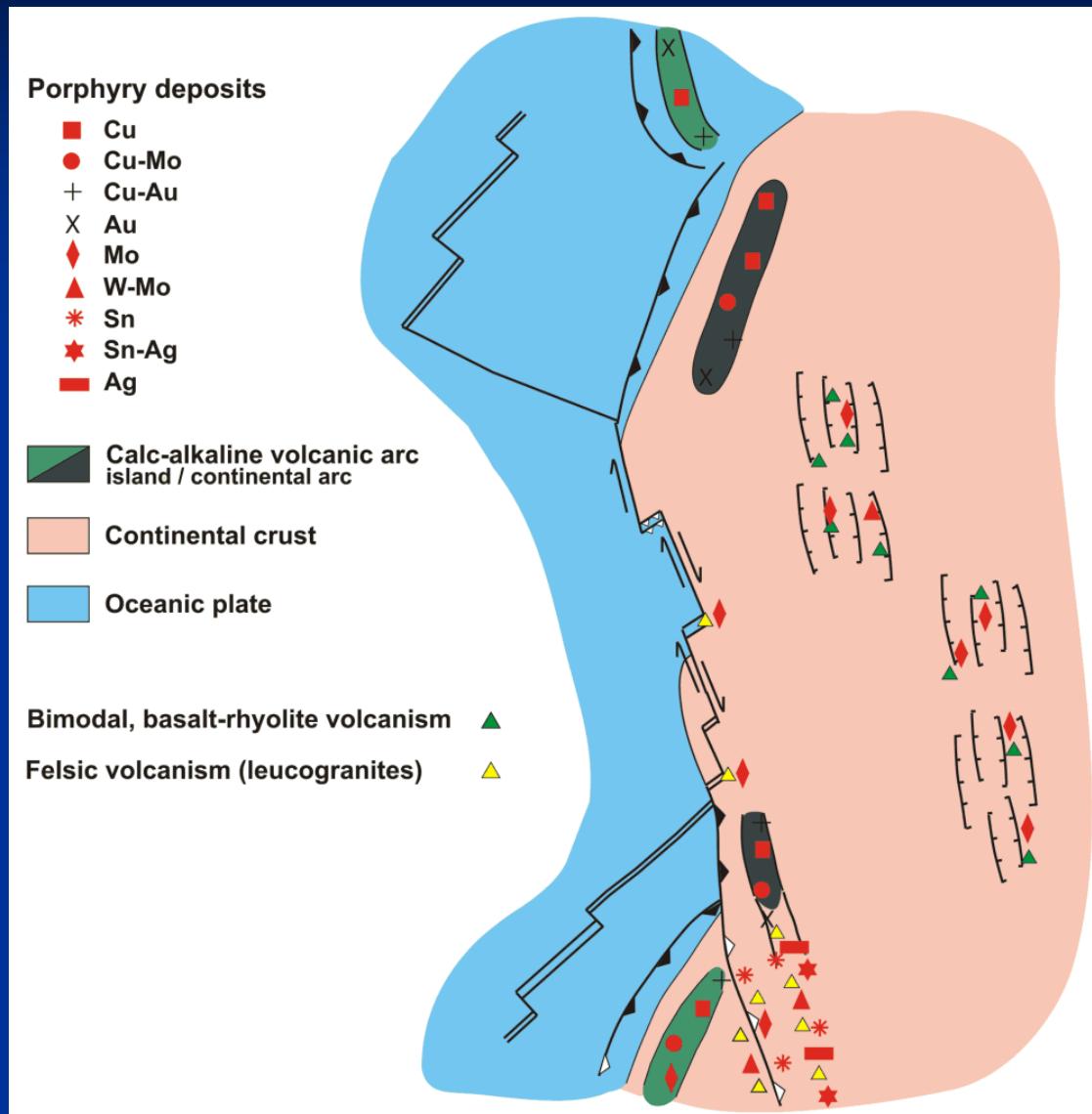
Bingham



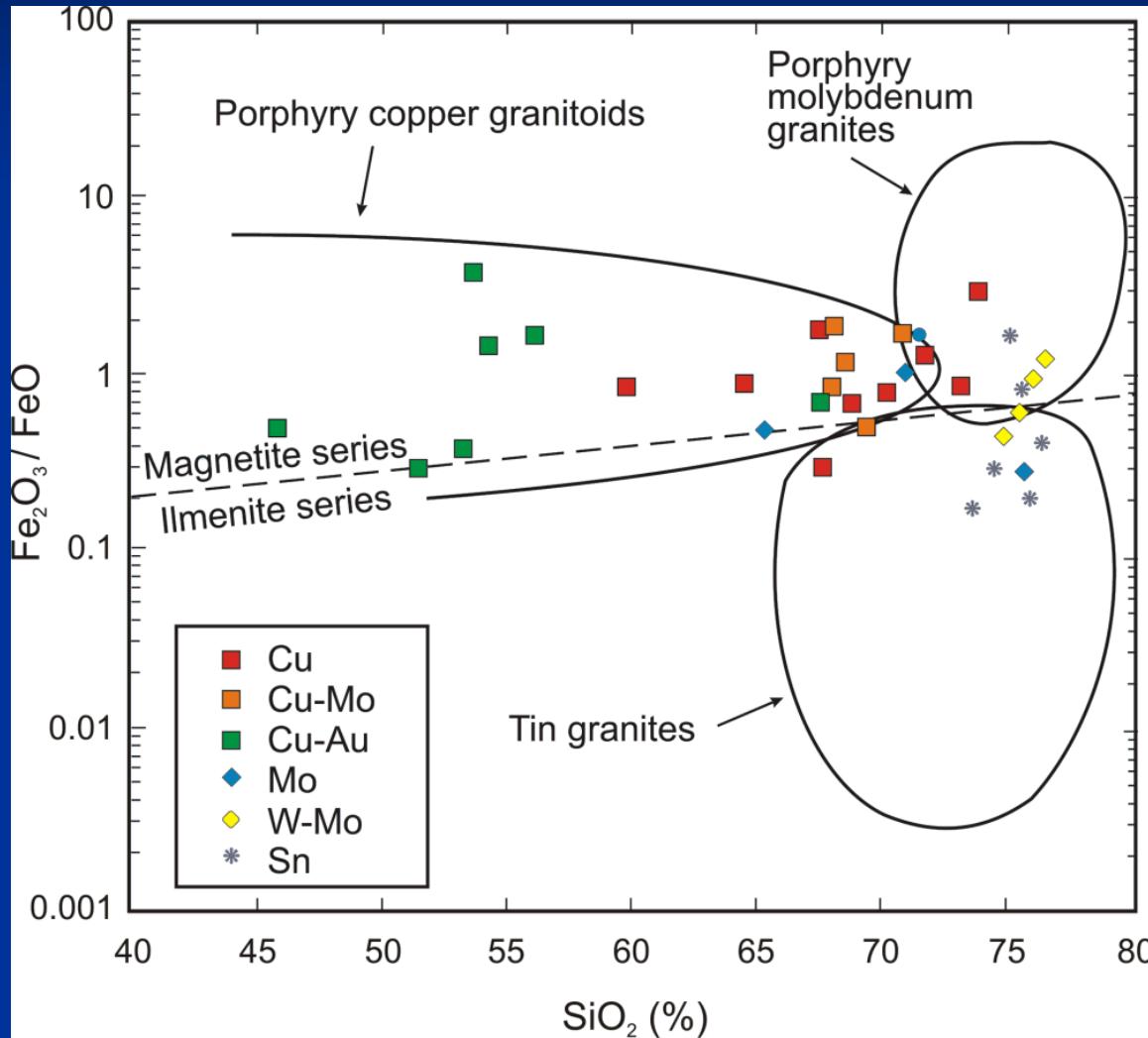
Mineral Park



Tectonic Setting of Porphyry Deposits

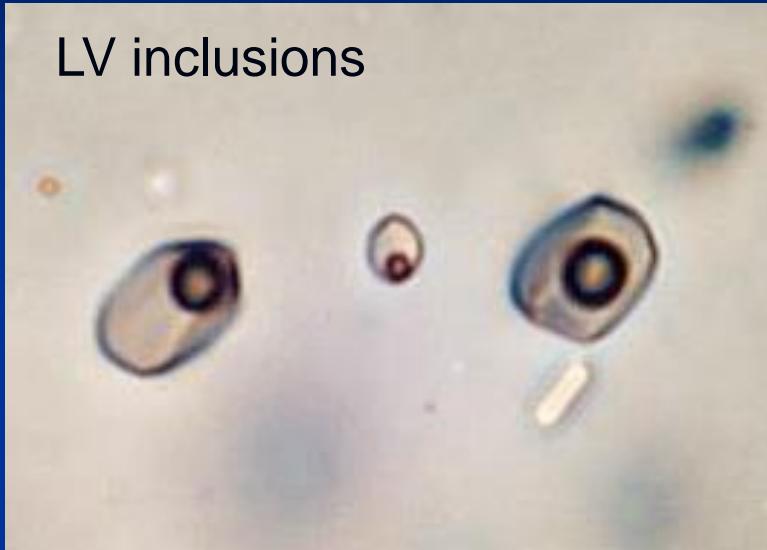


Porphyry metal associations as a function of intrusive composition

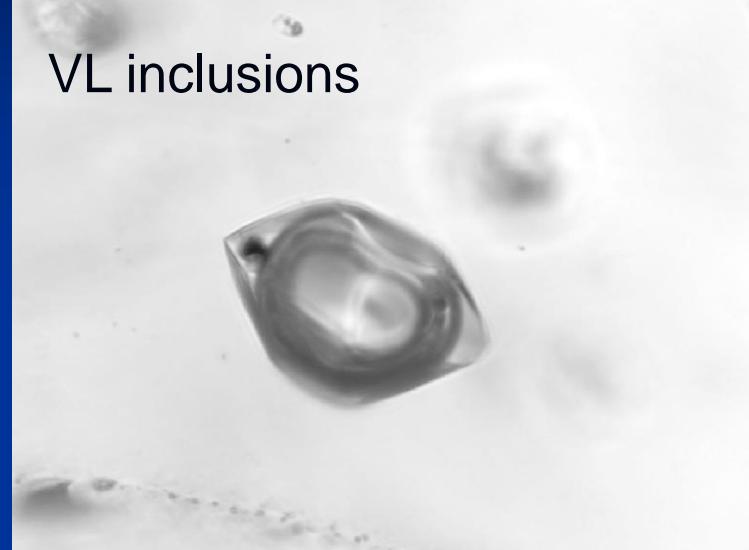


Fluid Inclusions in Porphyry Ore Depositing Systems

LV inclusions



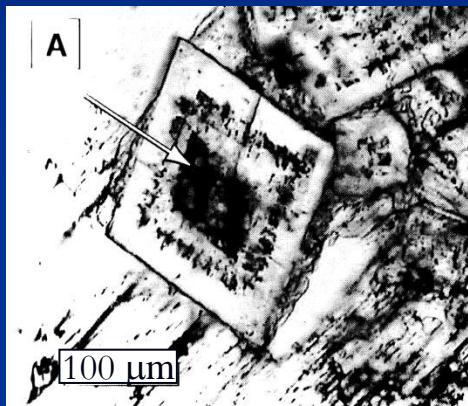
VL inclusions



Aqueous-carbonic
Fluid inclusion



Primary, Pseudosecondary and Secondary Fluid Inclusions



Primary and
pseudosecondary
fluid inclusions in
dolomite

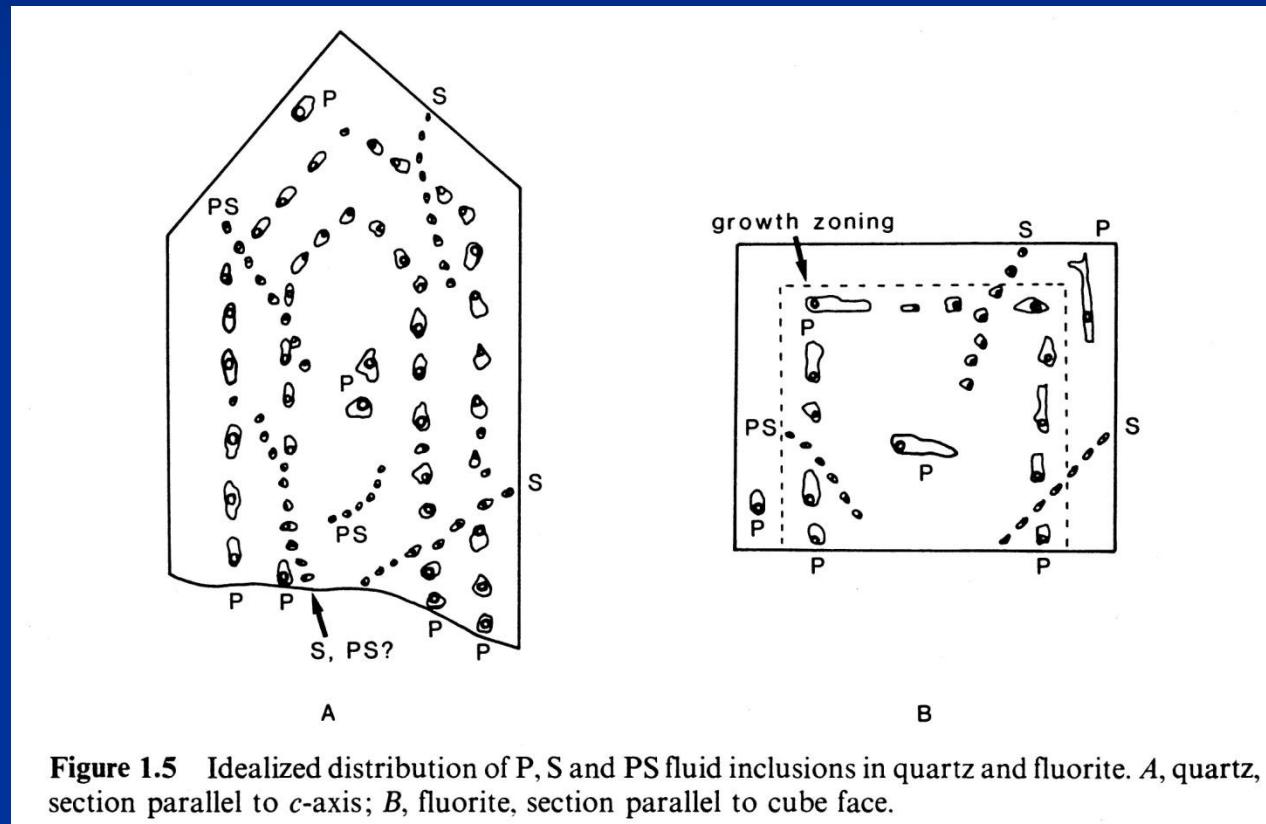
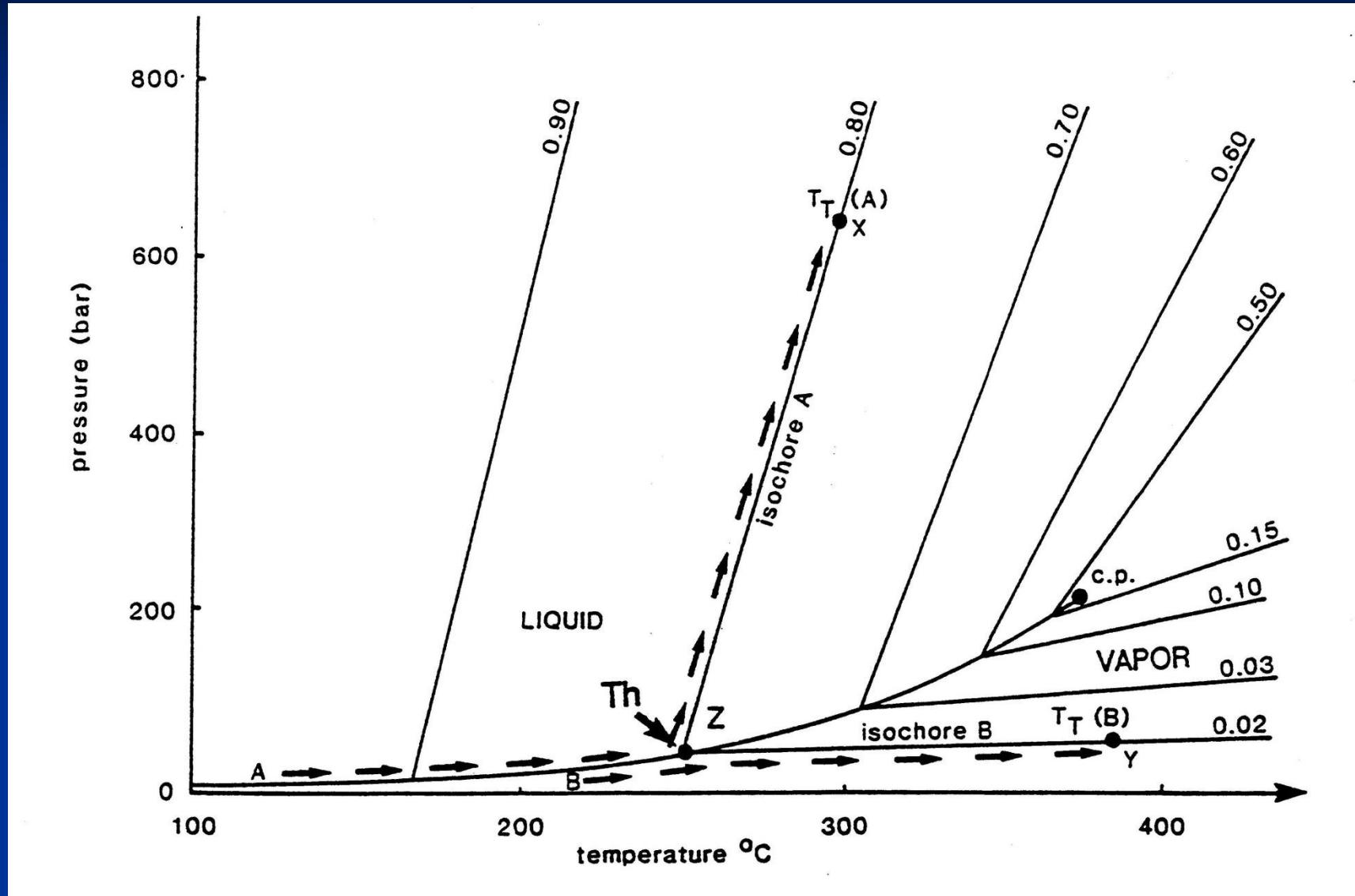


Figure 1.5 Idealized distribution of P, S and PS fluid inclusions in quartz and fluorite. *A*, quartz, section parallel to *c*-axis; *B*, fluorite, section parallel to cube face.

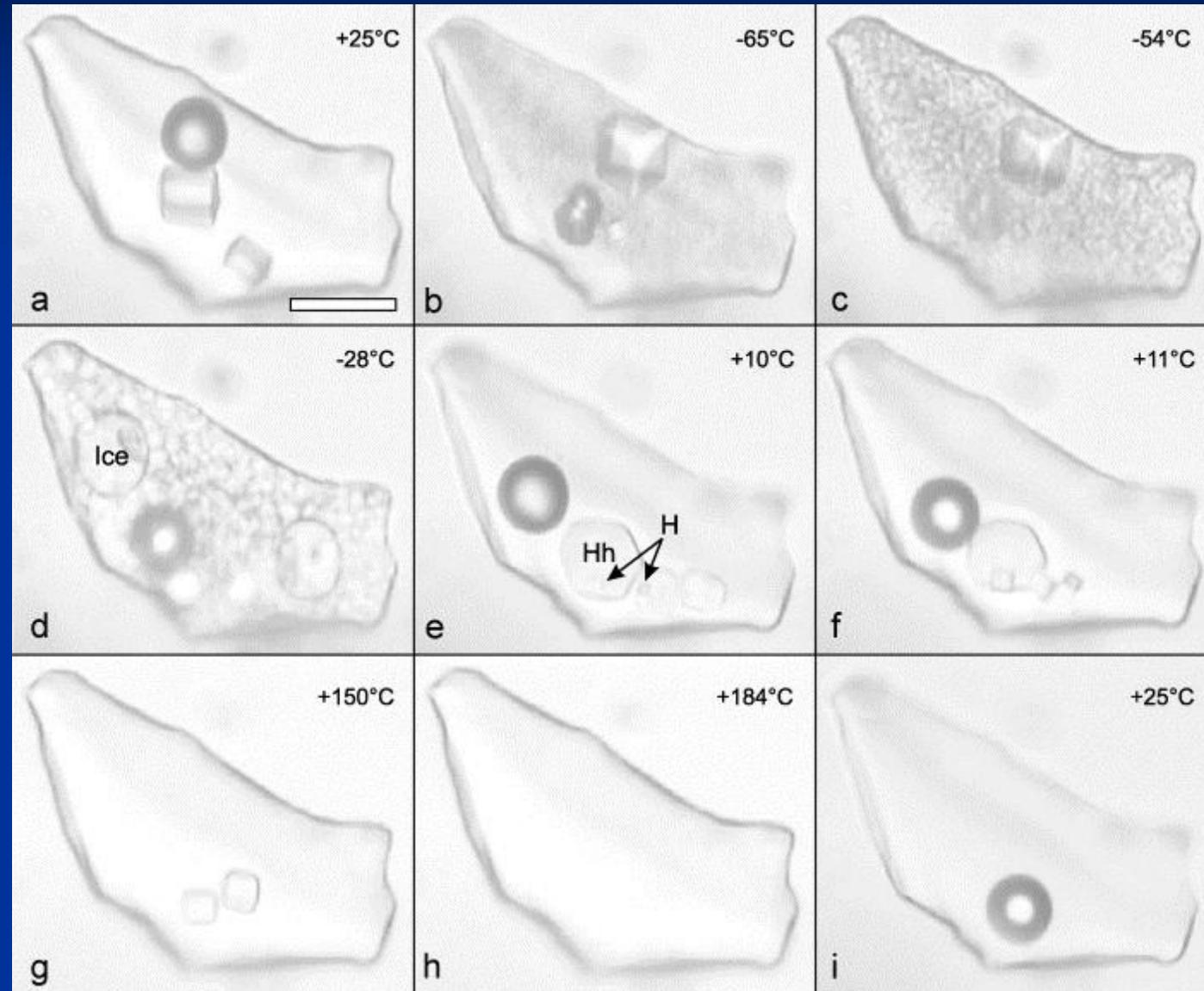
Isochores for Fluid Inclusions in the System H₂O



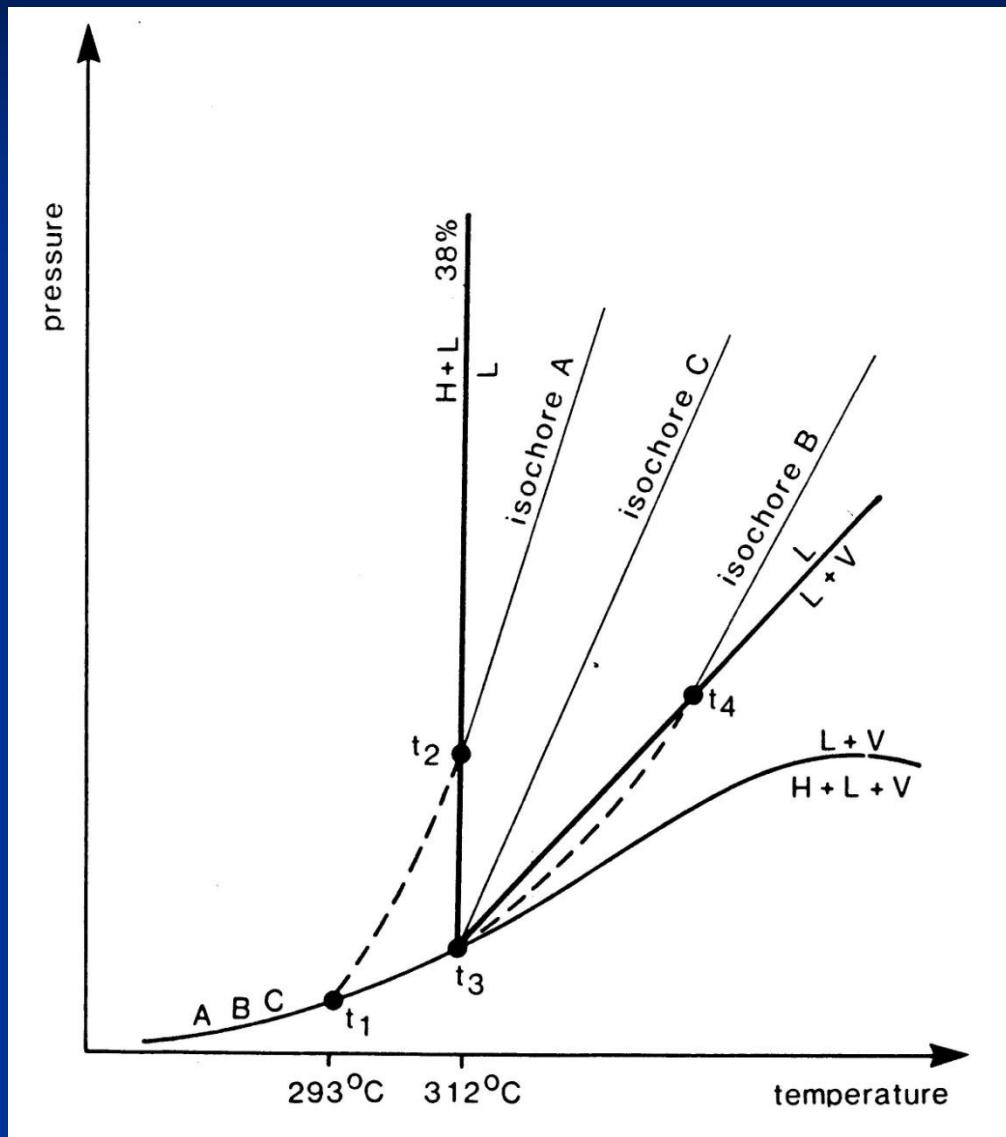
Fluid Inclusion Microthermometry



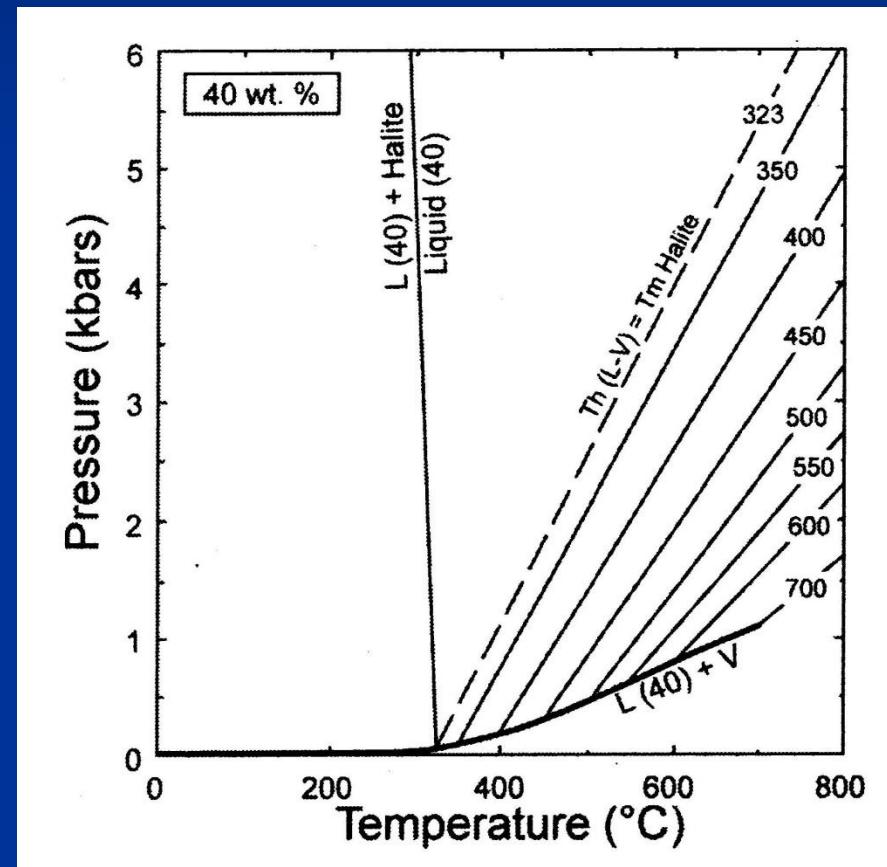
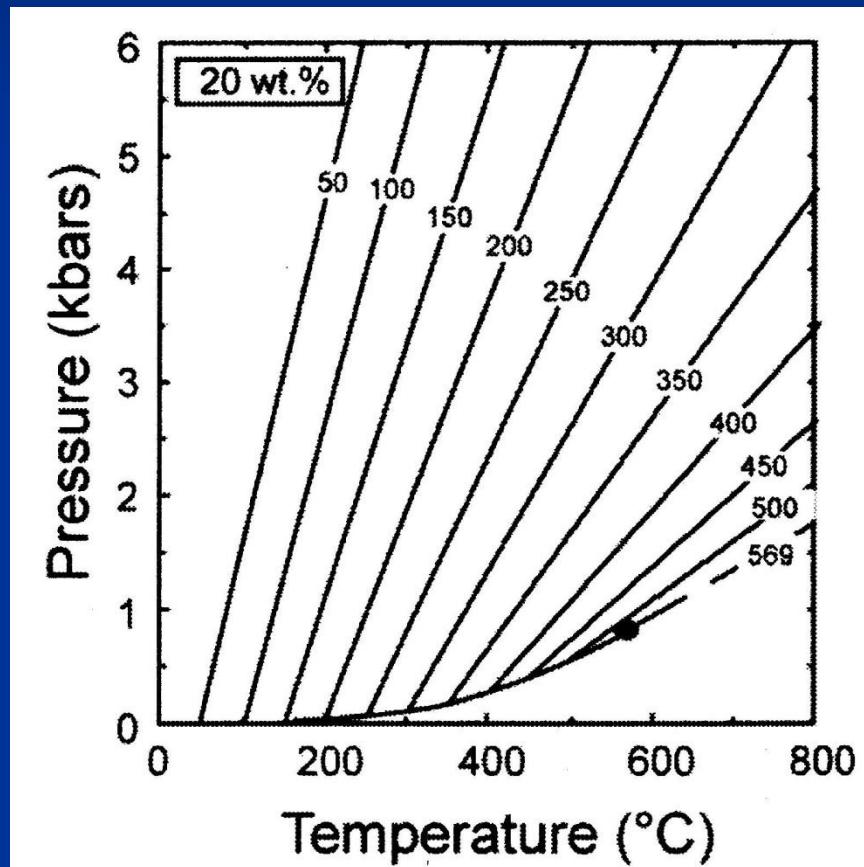
Microthermometry of Aqueous Fluid Inclusions



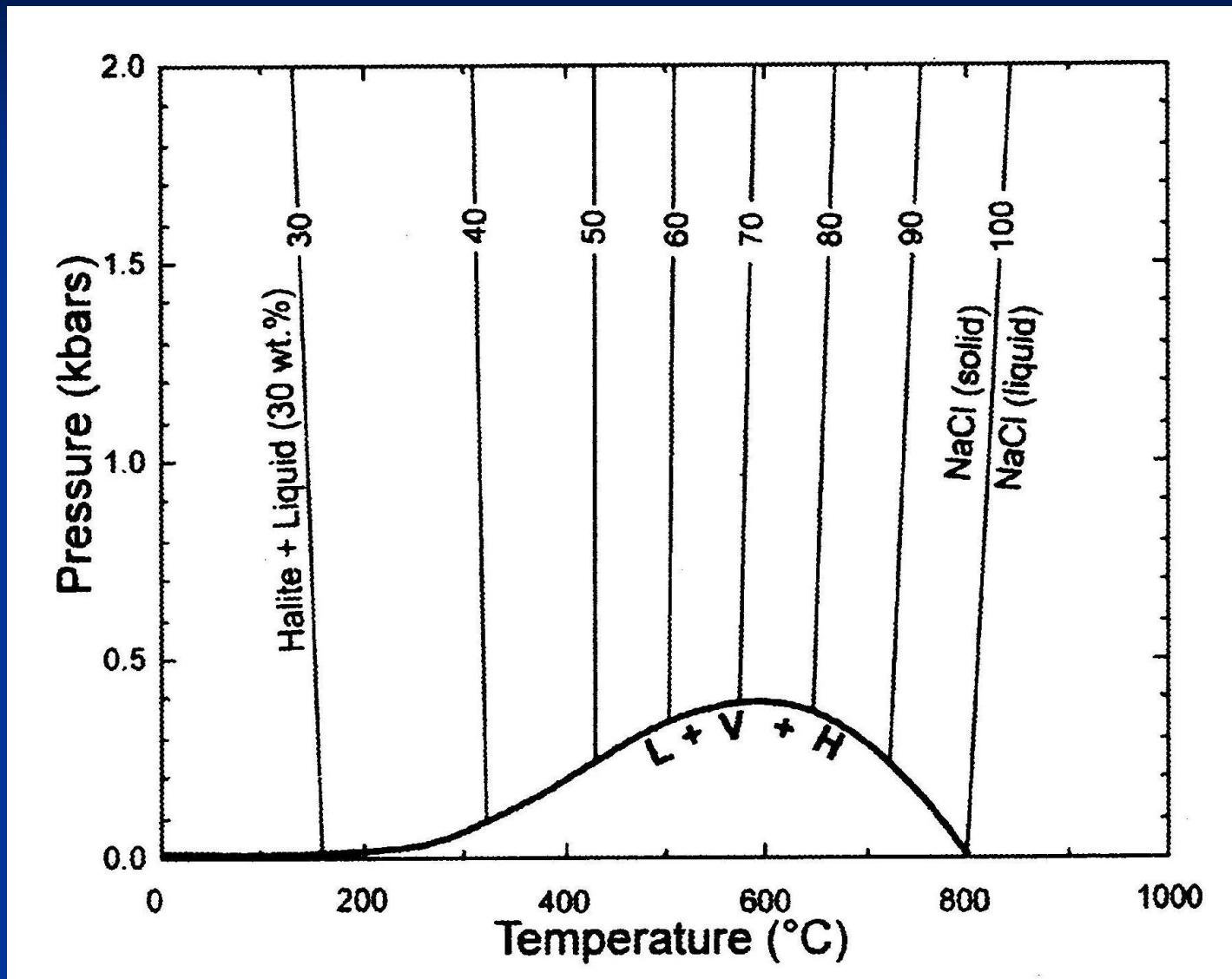
Isochores for Halite-bearing inclusions



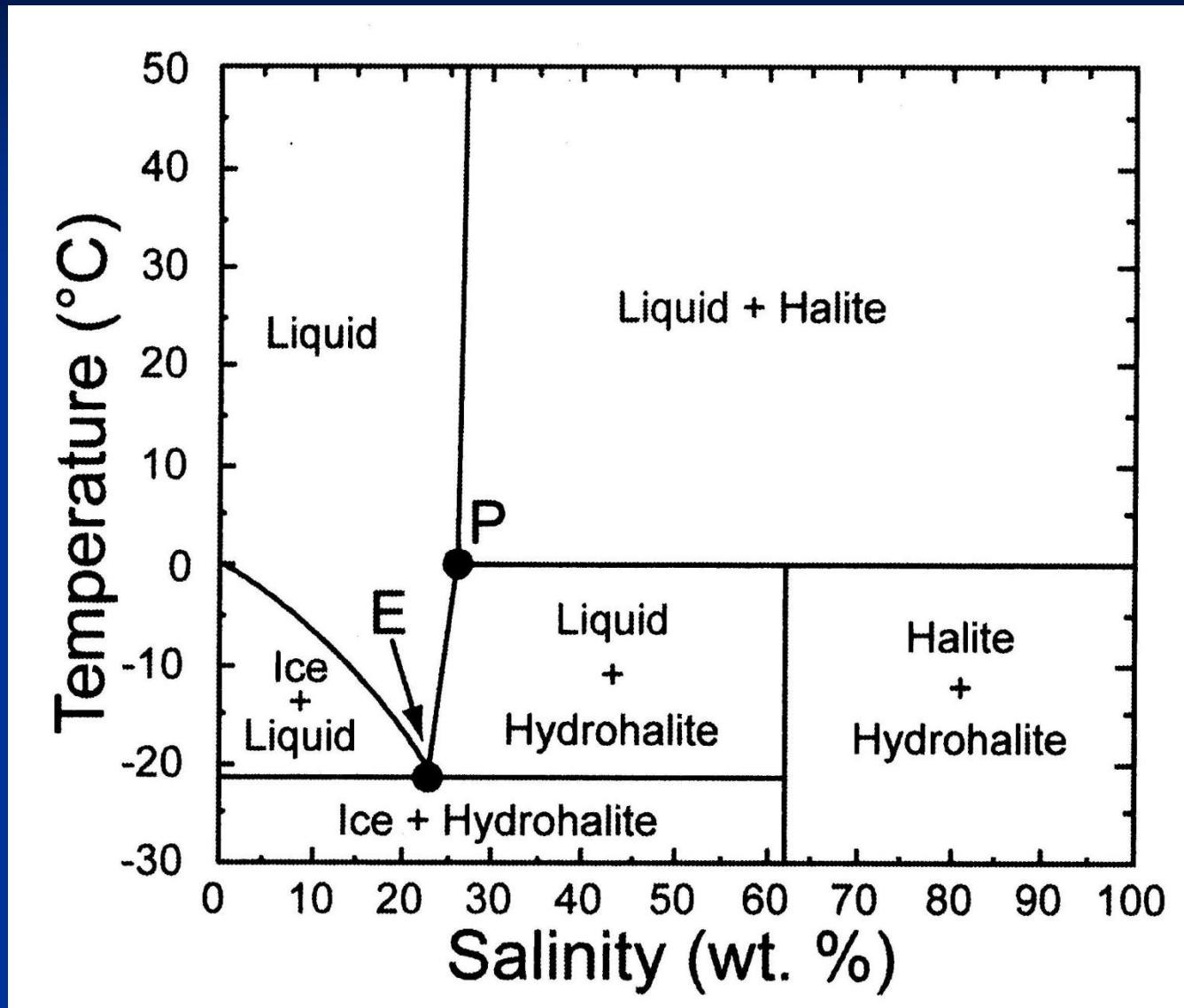
Isochores for the System NaCl-H₂O



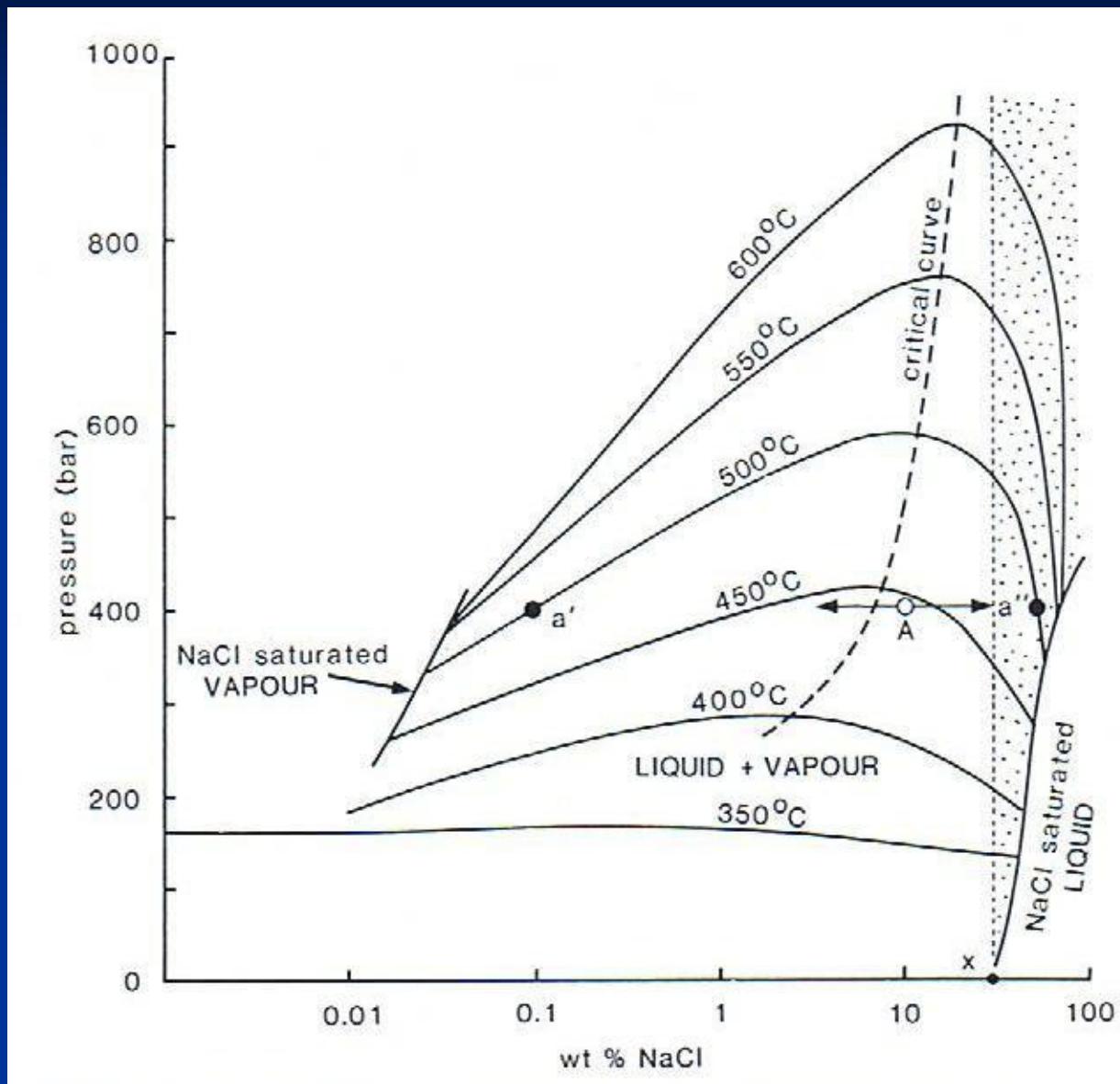
Salinity Determination from Halite Dissolution



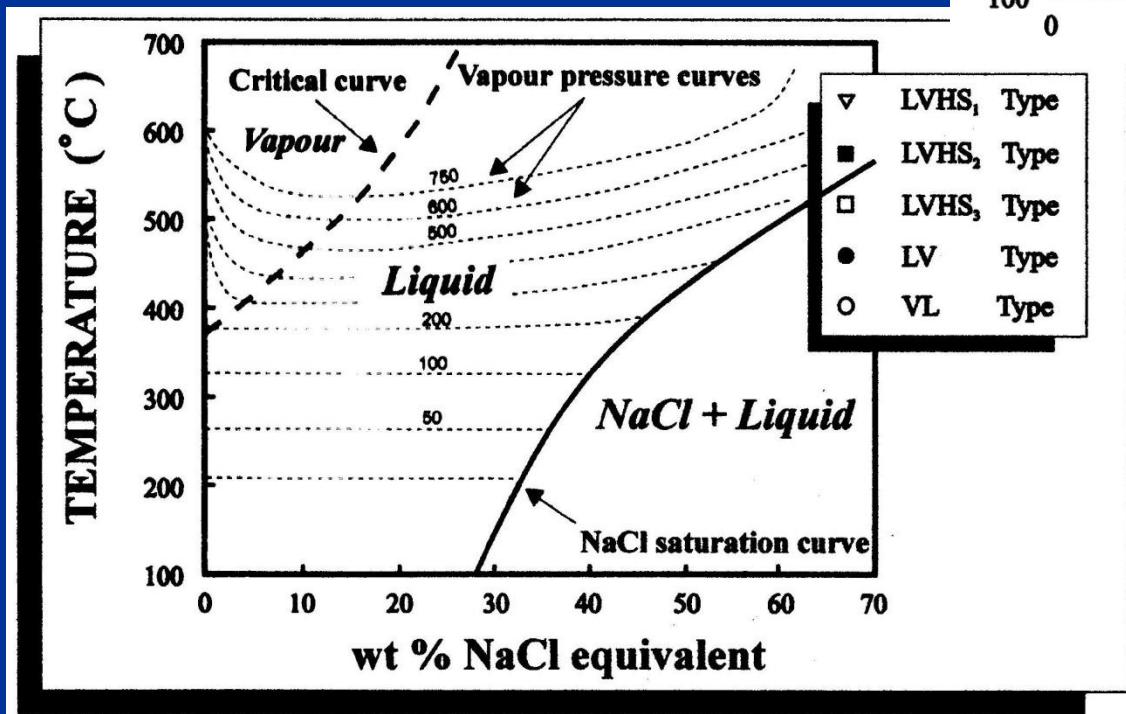
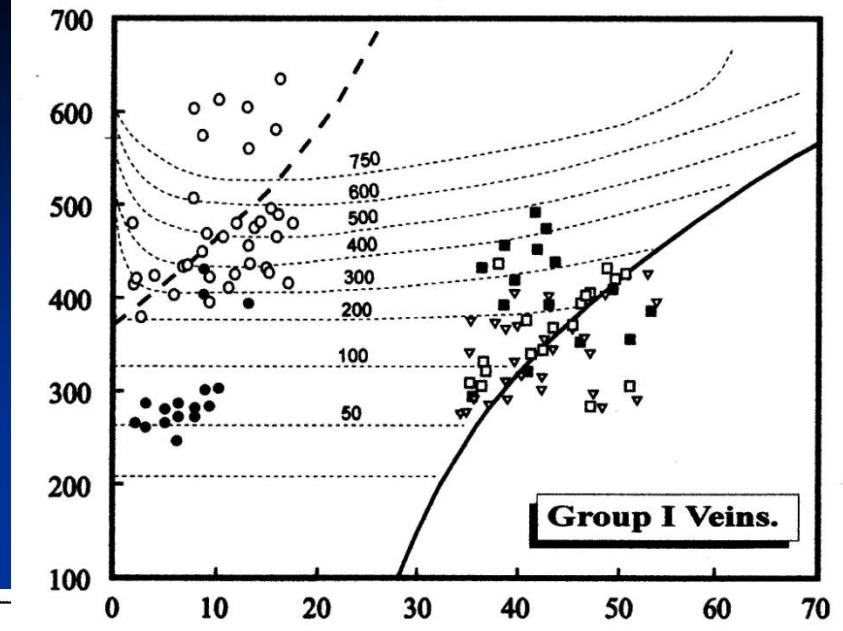
Salinity Determination from Ice Melting



P-T-X Relationships in the System NaCl-H₂O

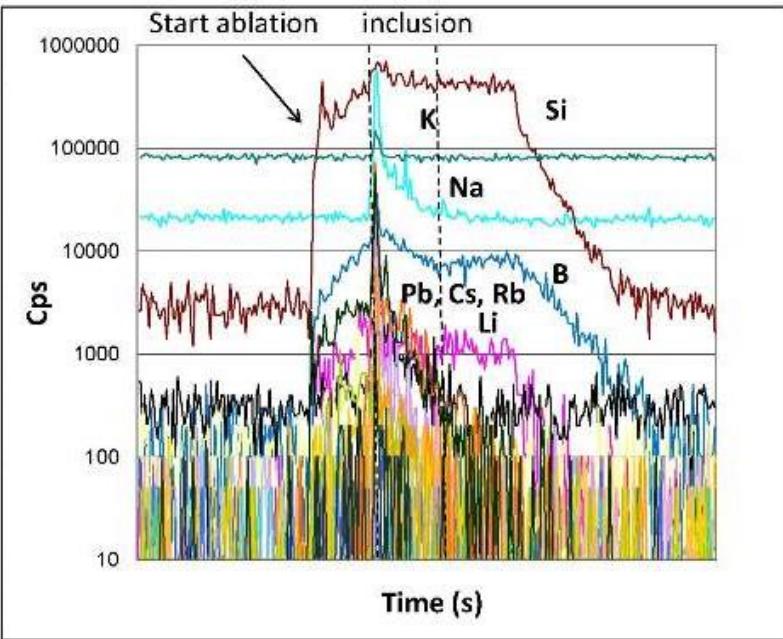
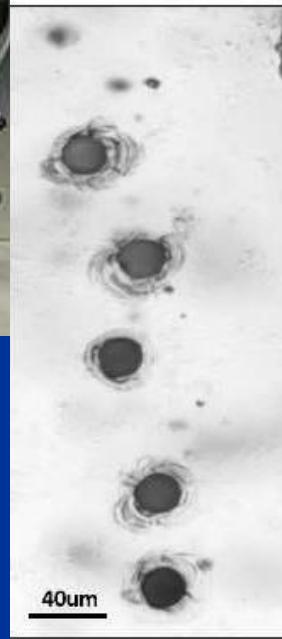
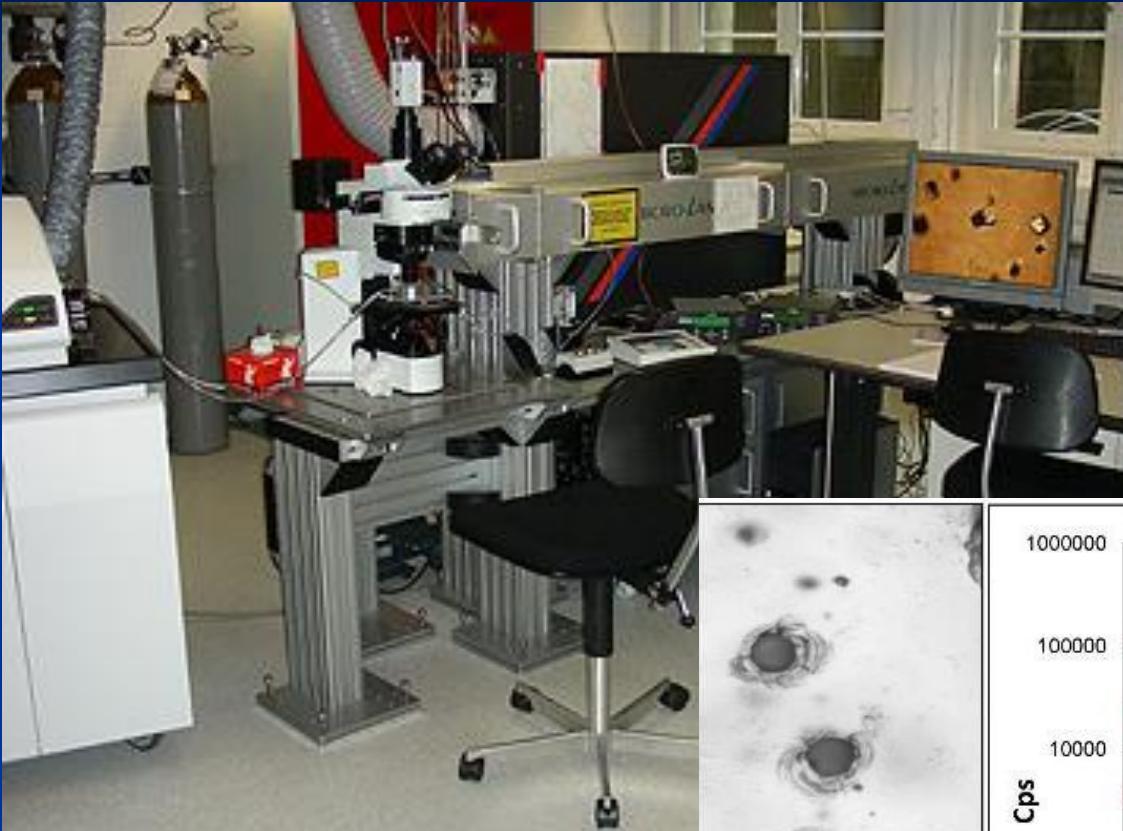


Salinity-Temperature Relationships in Porphyry Systems



Note existence of high temperature VL and LVS inclusions. Evidence of boiling or condensation?
Data from the Sungun Cu-Mo porphyry, Iran
(Hezarkhani and Williams-Jones, 1997)

Laser Ablation ICP-MS and Fluid inclusions



Stable Isotope Data for Porphyry Deposits

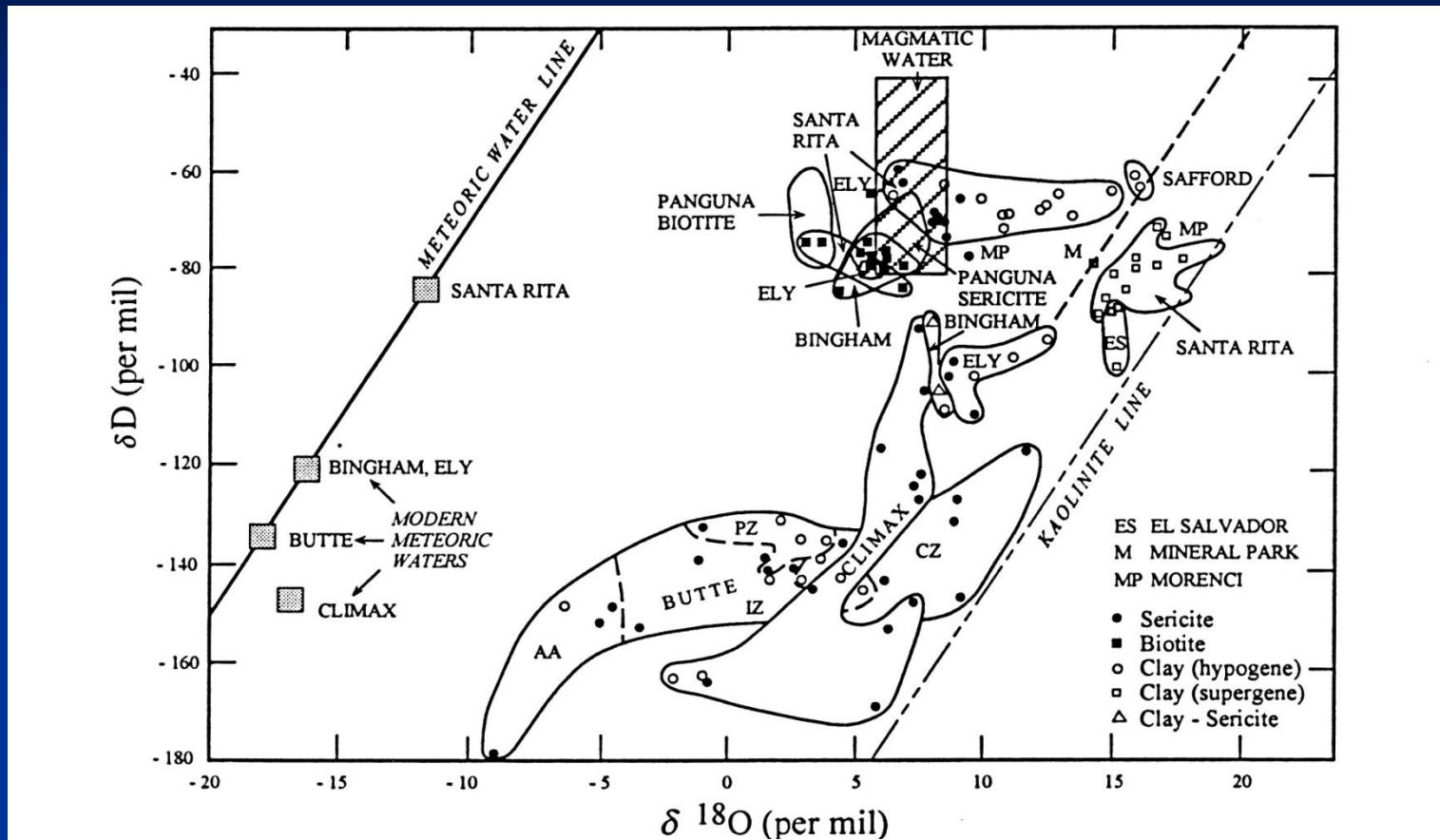
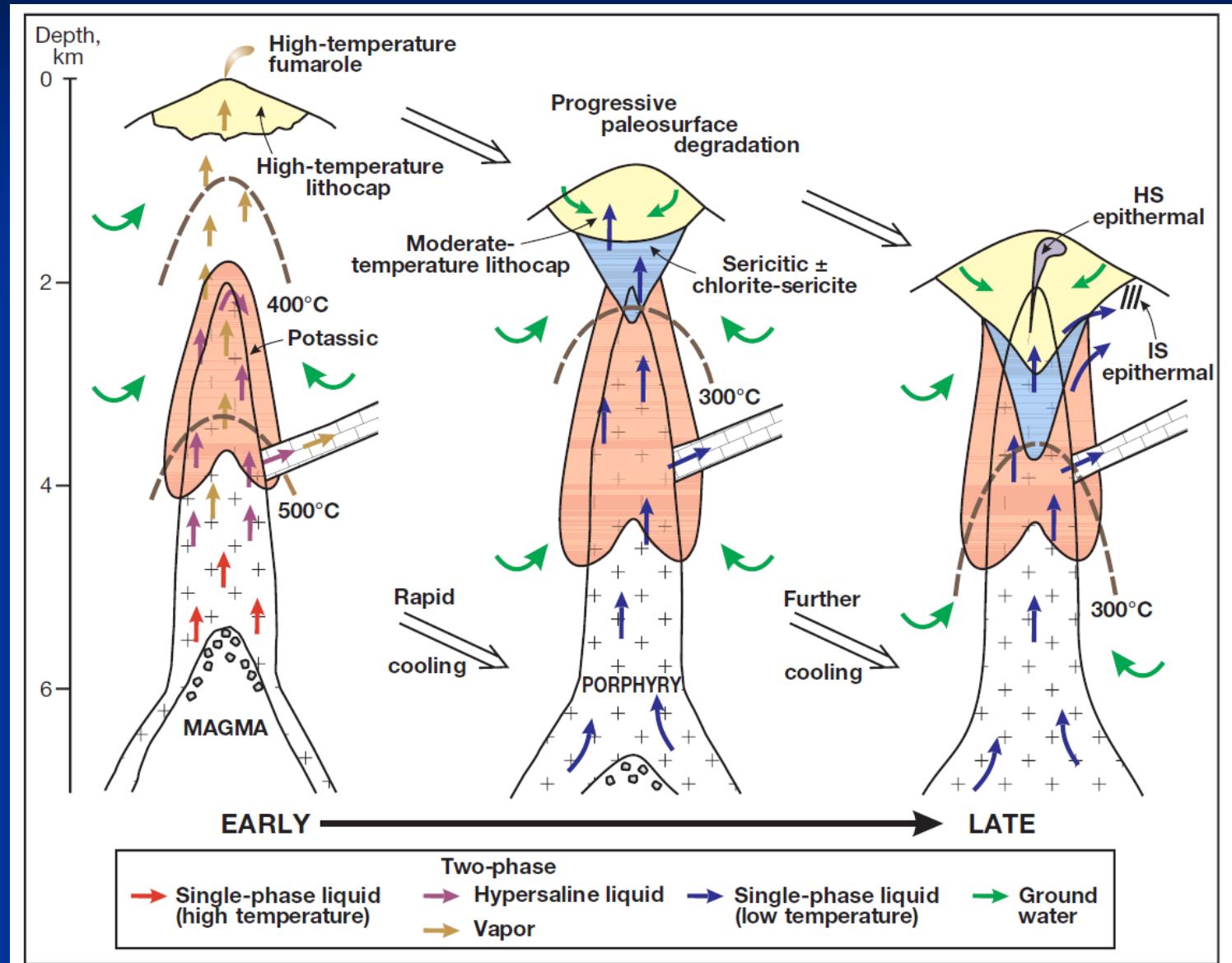


Figure 8.13. Plot of δD vs. $\delta^{18}\text{O}$ for hydrous minerals from porphyry copper and porphyry molybdenum deposits in relation to the “meteoric water line” (Craig 1961), “kaolinite line” (Savin & Epstein 1970) and the field of primary magmatic water (Taylor 1974). The dotted line near the ‘kaolinite line’ is drawn merely to emphasize the separation of supergene and hypogene clays. Biotites from the El Salvador deposit (Sheppard & Gustafson 1976) plot within the cluster for biotites from other porphyry copper deposits. For the Butte deposit: AA = advanced argillic alteration, PZ = peripheral zone, IZ = intermediate zone, CZ = central zone. Approximate values for modern meteoric waters are from White (1974). Sources of data for porphyry deposits: Ford and Green (1977); compilation by Taylor (1979).

Porphyry-Epithermal System Evolution



Chemical Controls on Ore Formation

Deposition of Chalcopyrite (CuFeS_2)

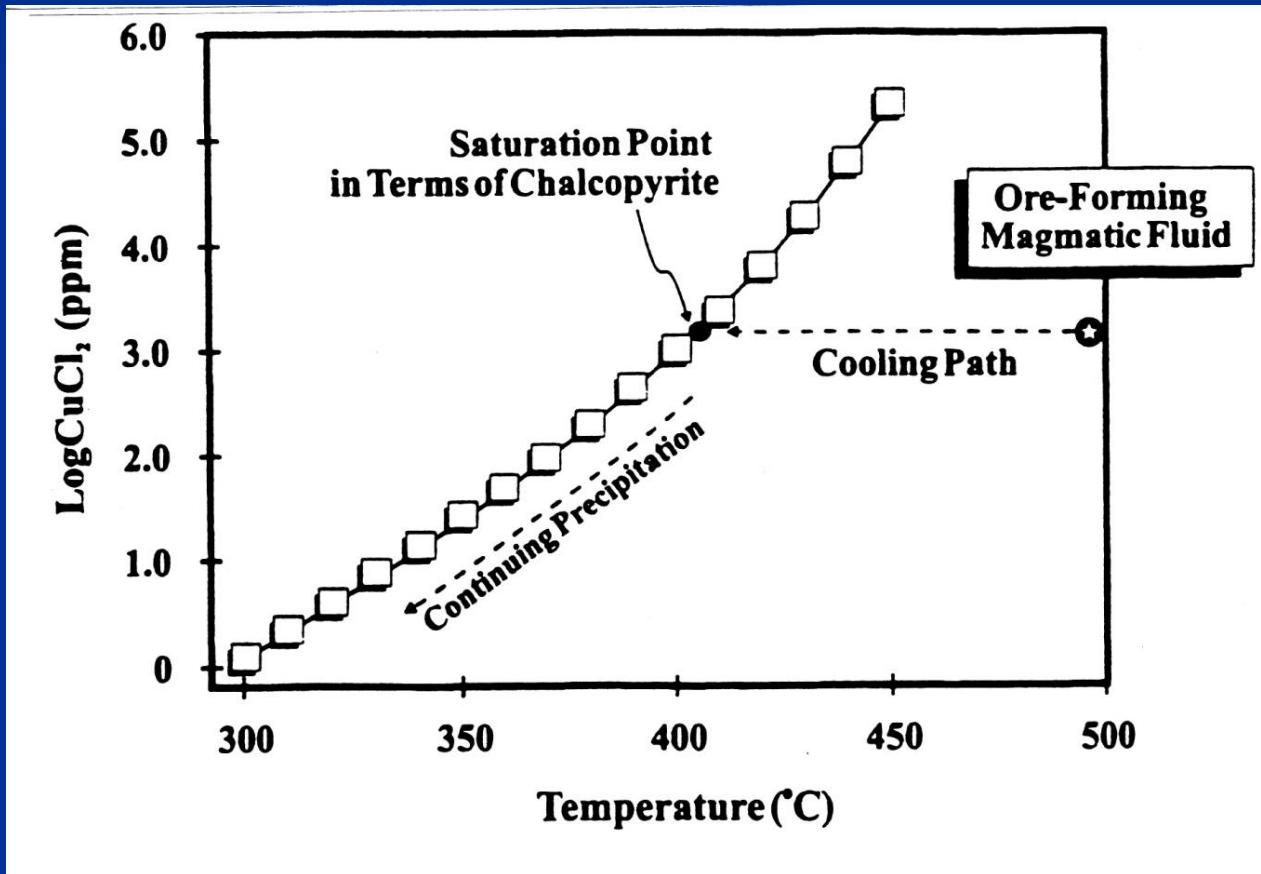


Deposition favoured by an increase in $f\text{O}_2$,
an increase in $f\text{H}_2\text{S}$ and an increase in pH

What about temperature?

Decreasing Temperature – the Main Control on Porphyry Copper Ore Formation?

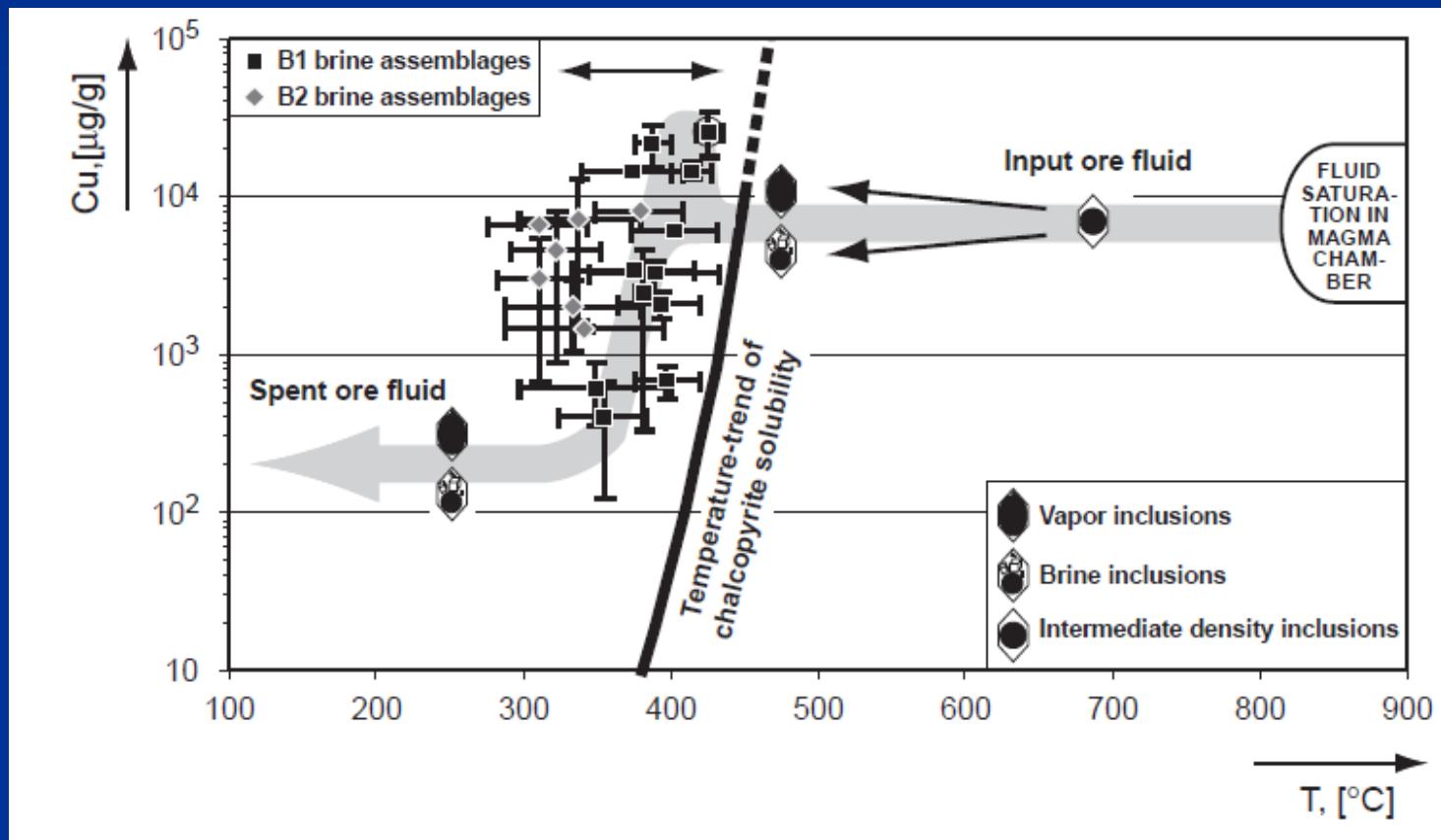
Modelling ore deposition in the Sungun porphyry, Iran.
Solubility of chalcopyrite in a 1 m NaCl solution.



Copper solubility drops to ~ 4,000 ppm at 400 °C, the temperature of ore formation and 1 ppm at 300 °C

Decreasing Temperature – the Main Control on Porphyry Copper Ore Formation

Copper concentrations in fluid inclusions of the Bingham porphyry, USA

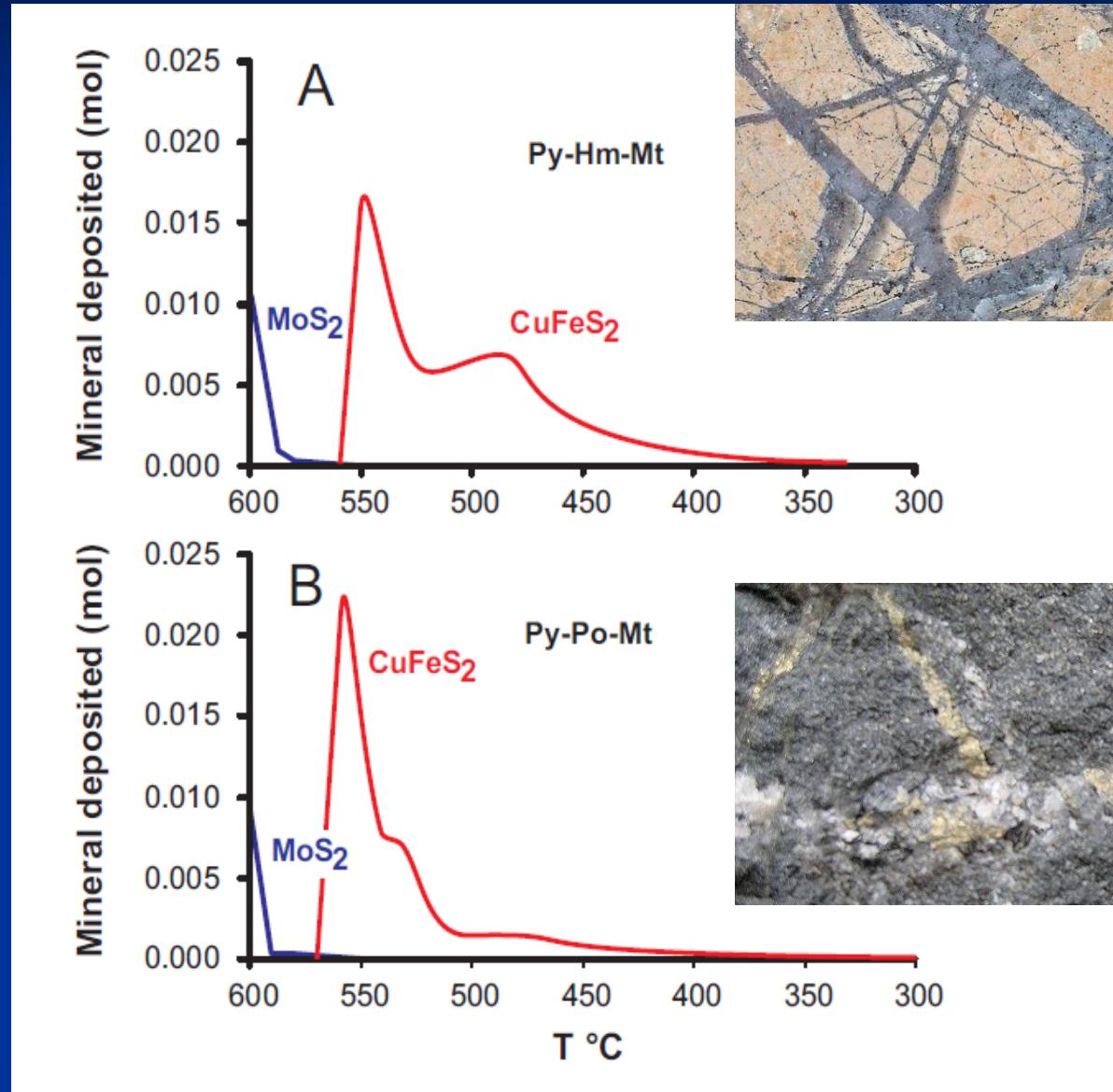


(Landtwing et al., 2005)

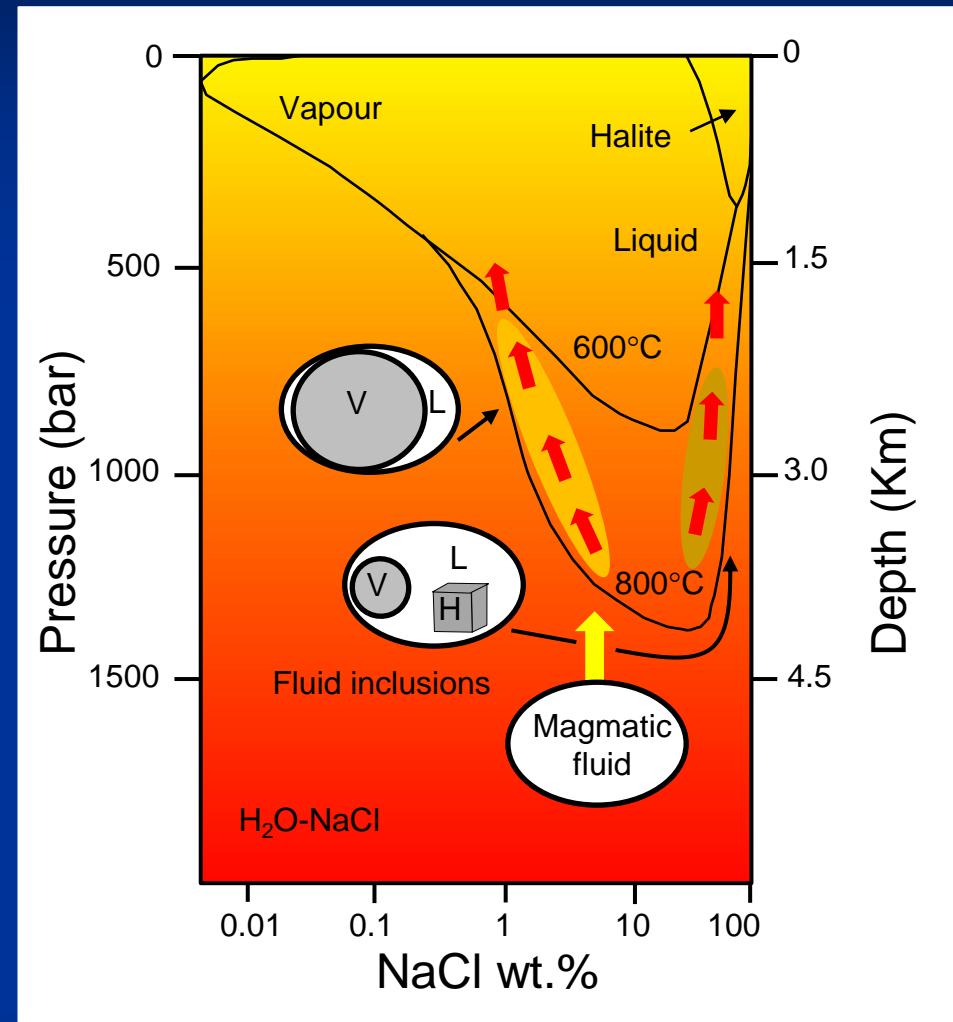
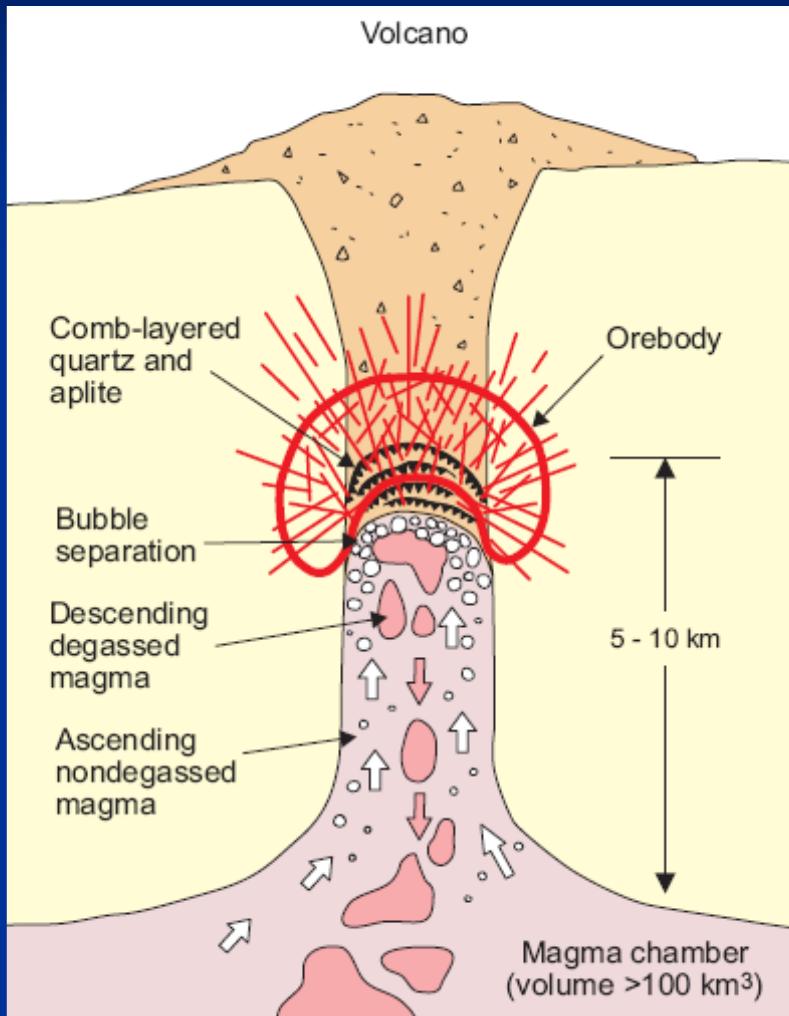
Cu-Mo Zoning in Porphyry Systems

Porphyry Cu-Mo deposits are commonly zoned with a deeper, higher temperature molybdenite-rich zone and a shallower, lower temperature chalcopyrite-rich zone.

Cooling of an aqueous fluid initially containing 2 m NaCl, 0.5 m KCl, 4000 ppm Cu and 1000 ppm Mo in equilibrium with K-feldspar, muscovite and quartz.



Magma Emplacement, and the Nature of the Exsolved Fluid

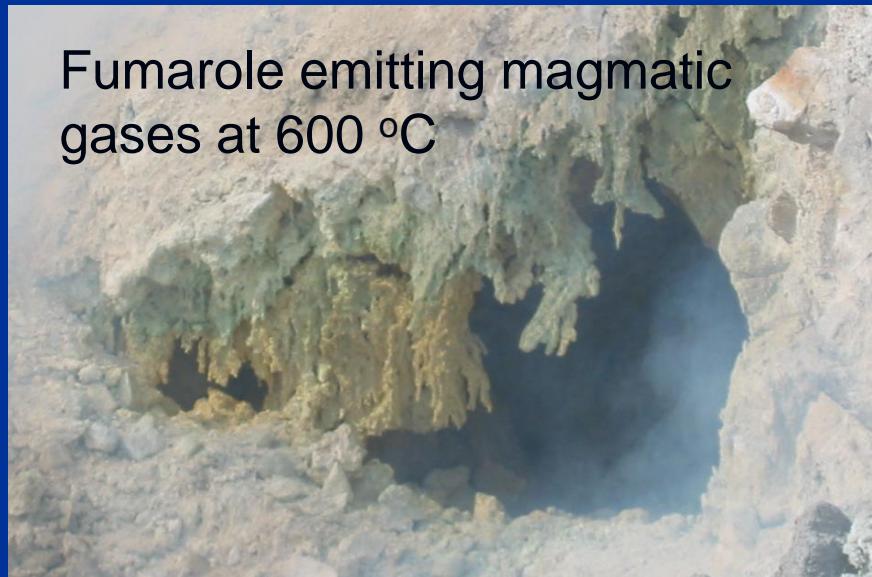


Transport of Metals by Vapour?

Summit of Merapi volcano, Indonesia

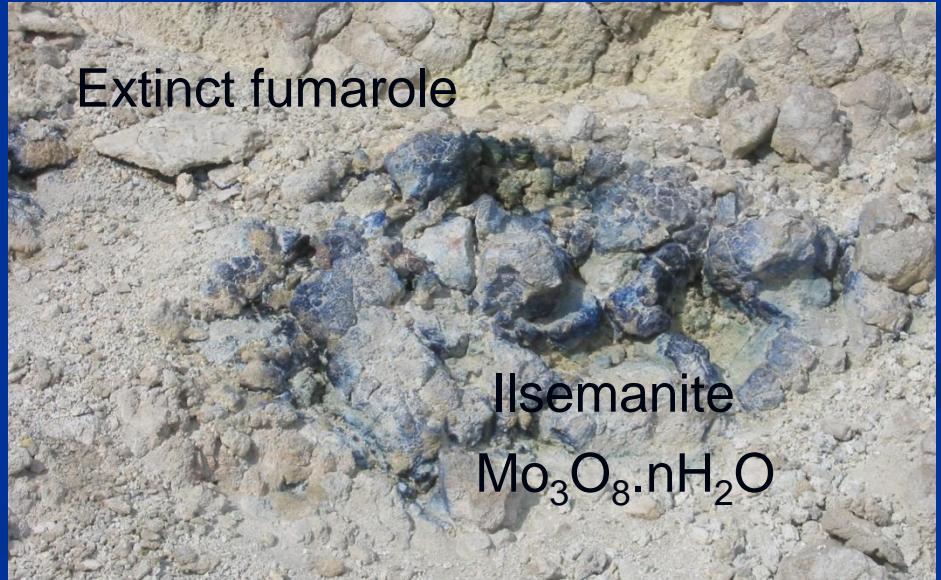


Fumarole emitting magmatic gases at 600 °C

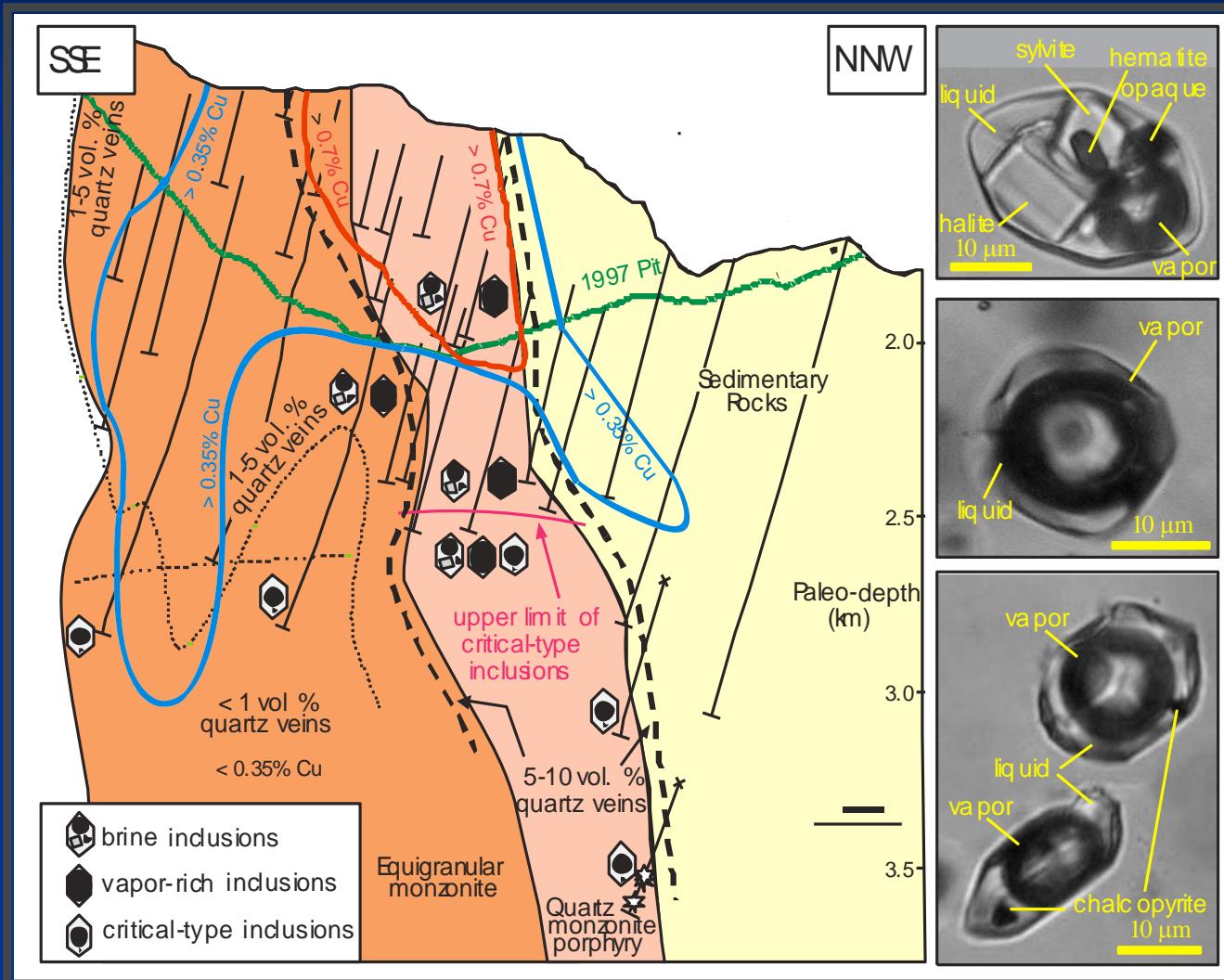


Extinct fumarole

Ilsemanite
 $\text{Mo}_3\text{O}_8 \cdot \text{nH}_2\text{O}$

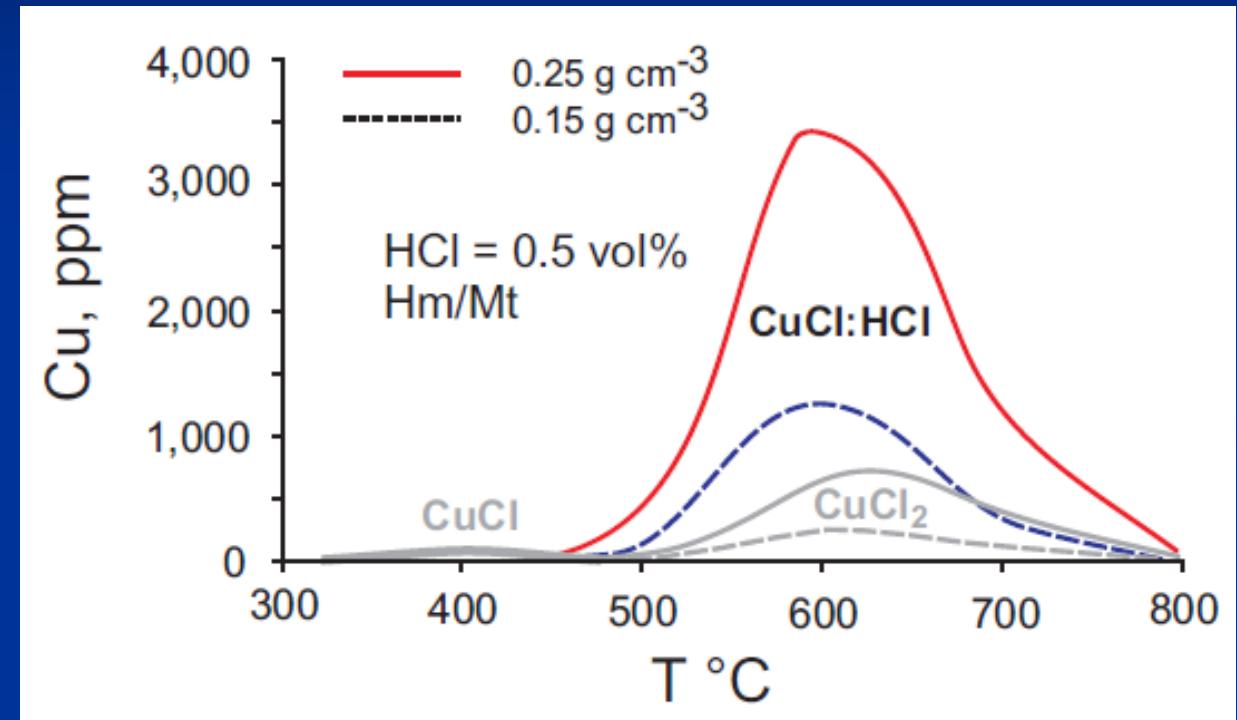
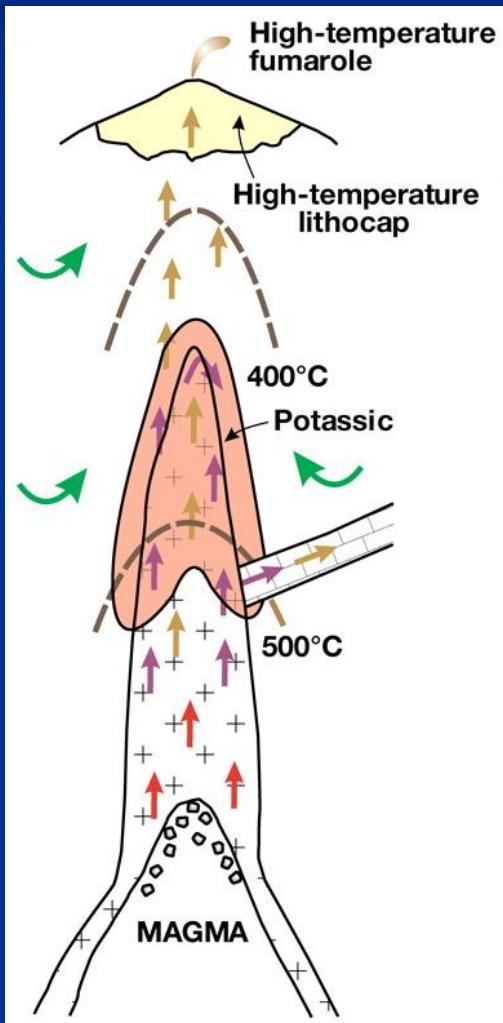


The Bingham Porphyry Deposit - A Case for the Vapour Transport of Copper



(Williams-Jones and Heinrich, 2005)

The Solubility of Chalcopyrite in Water Vapour

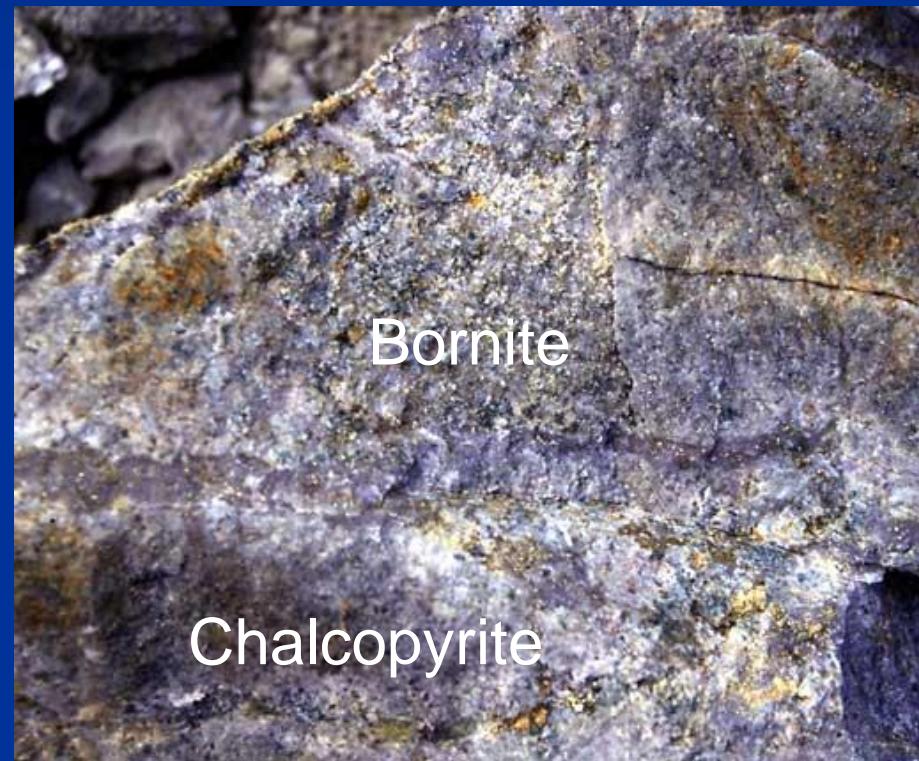


Increasing PH_2O promotes hydration (and solubility) and increasing temperature inhibits hydration.

From Hypogene to Supergene



Hypogene



Bornite

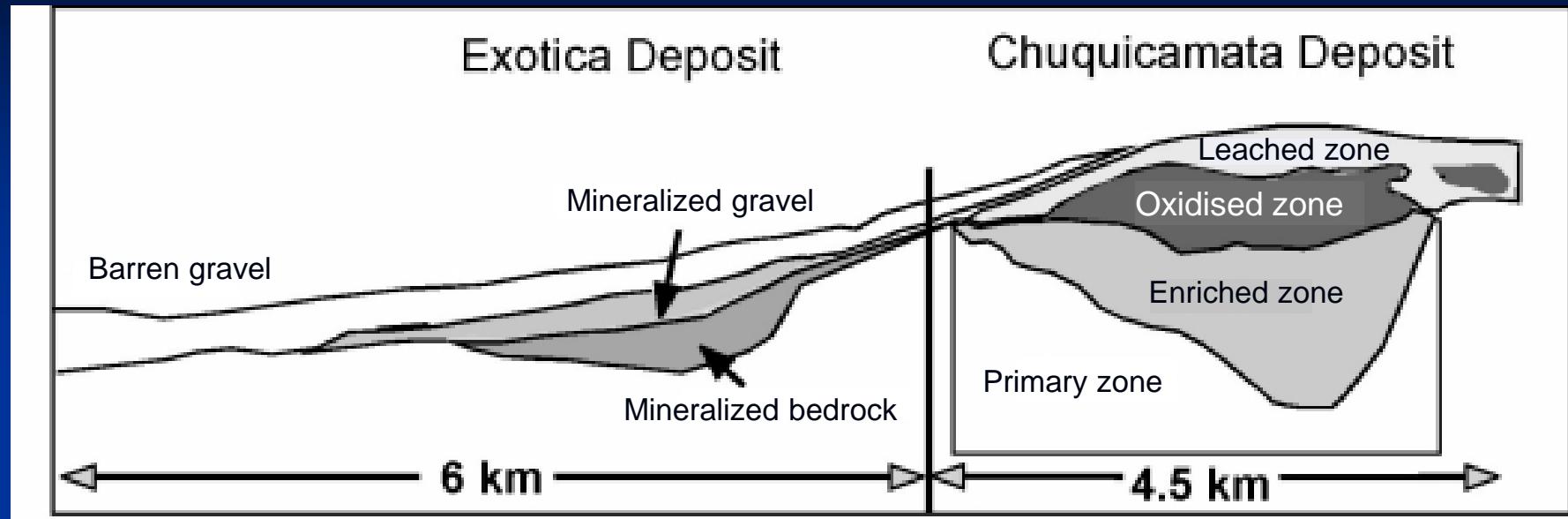
Chalcopyrite

Supergene

Malachite



Supergene enrichment



Leached zone – acidity creation



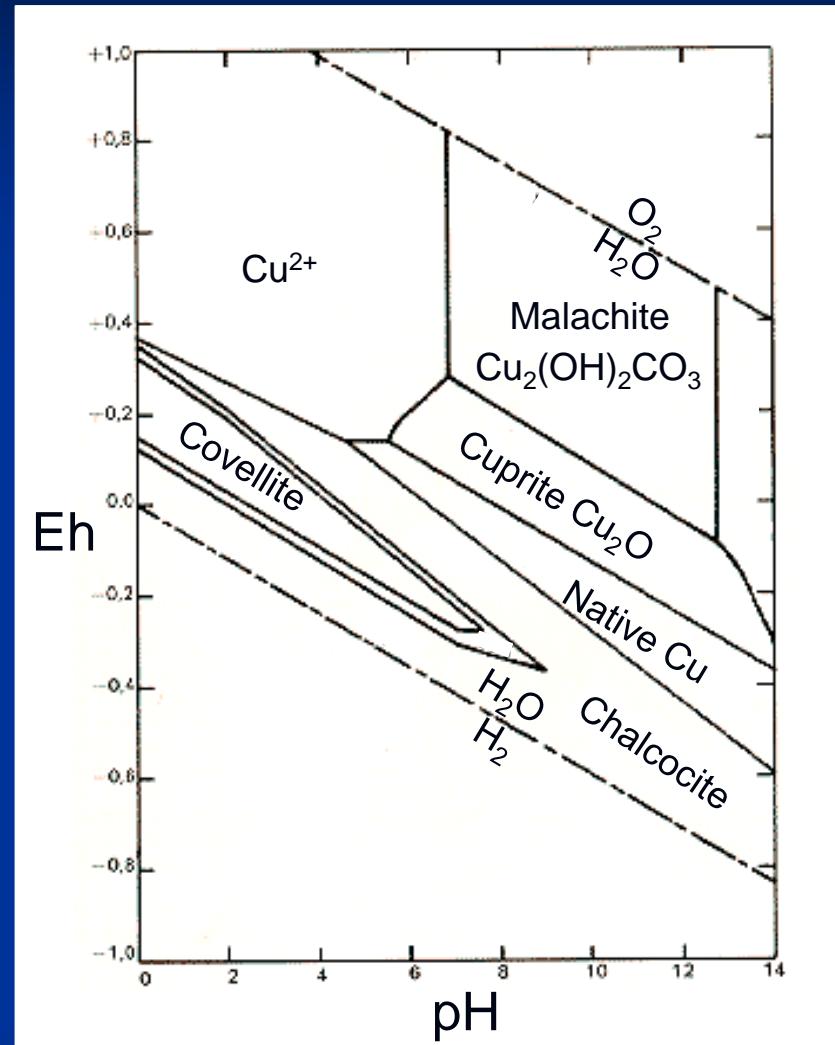
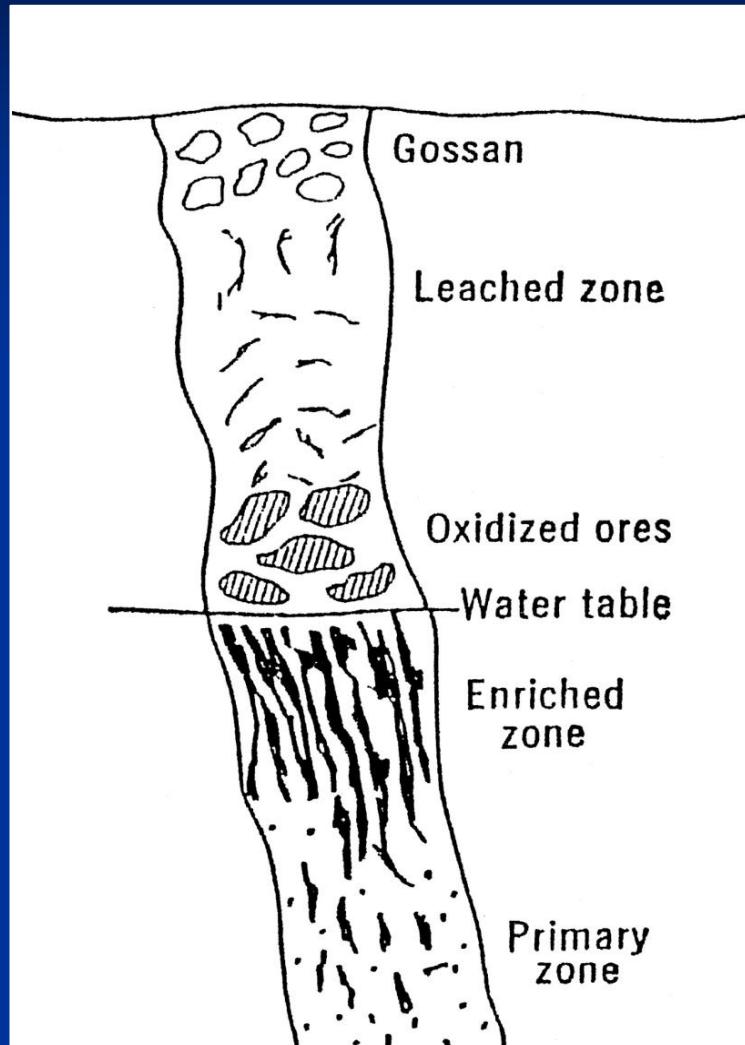
Oxidised zone – Fe and Cu oxides, acidity creation



Enriched zone – reduction and sulphide deposition



Supergene enrichment



References

- Evans, A.M., 1993, Ore geology and industrial minerals, an introduction: Blackwell Science, Chapter 14.
- Pirajno, F. 2009, Hydrothermal processes and mineral systems, Springer, Chapter 5.
- Seedorff, E., Dilles, J.H., Proffett Jr, J.M., Einaudi, M.T., Zurcher, L., Stavast, W.J.A., 2006, Porphyry Deposits: Characteristics and origin of hypogene features in Hedenquist et Al. (eds) Economic Geology One Hundreth Anniversary Volume, p.251-298.
- Sillitoe, R.H., 2010, Porphyry copper systems: Econ. Geol., 195, 3-41.
- Williams-Jones, A.E. and Heinrich, C.H., 2005, Vapor transport of metals and the formation of magmatic-hydrothermal ore deposits: Econ. Geol., 100, p.1287-1312.