Porphyry Coppers

Lecture 21

Fundamentals of Earth Resources

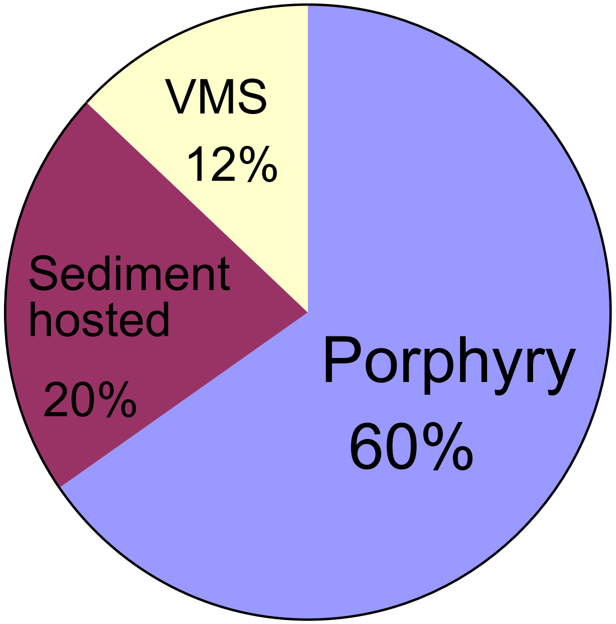
Resources from Earth's Internal Energy

L. Cathles

2007

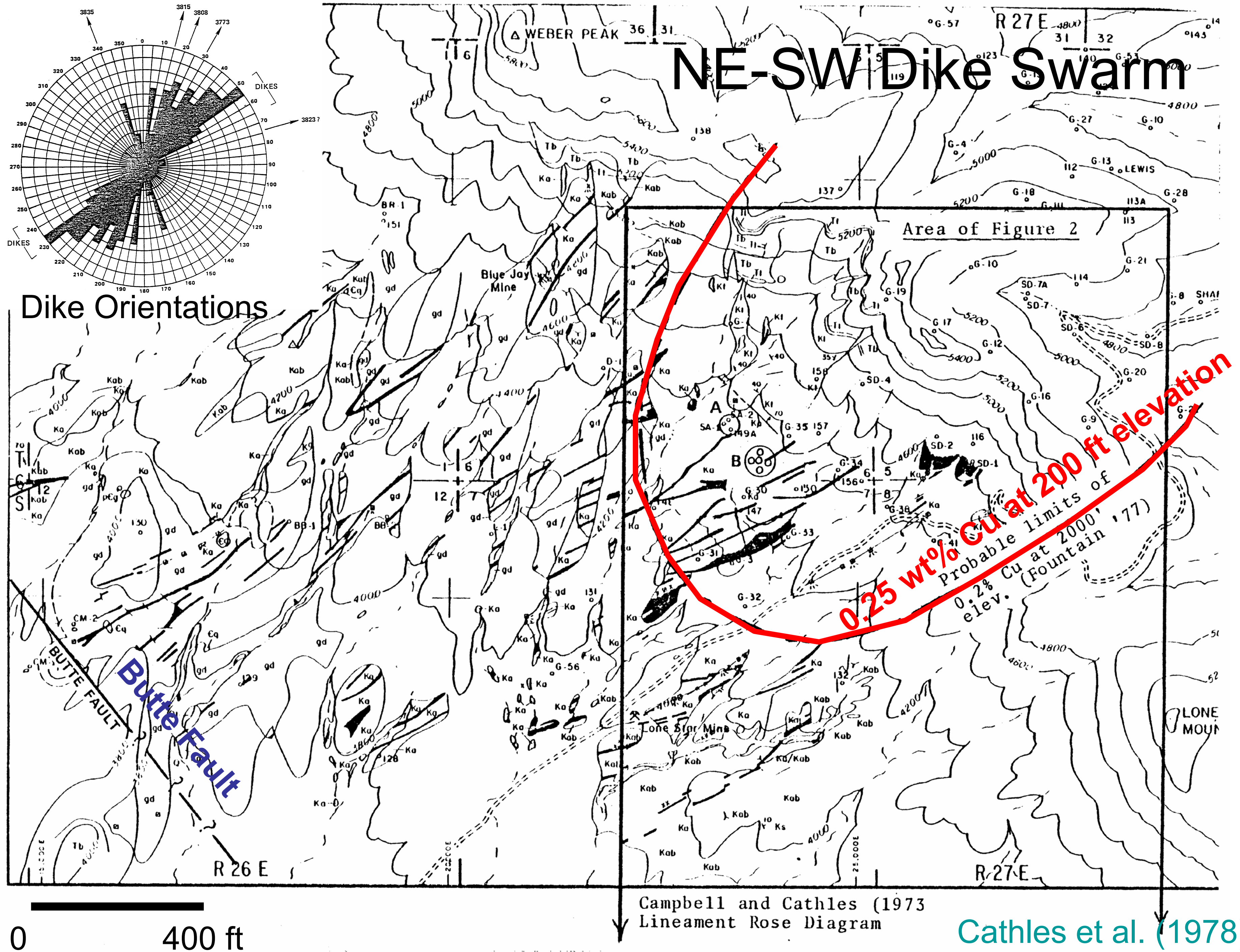
See p. 303-4 Craig et al., 2001

Porphyry deposits



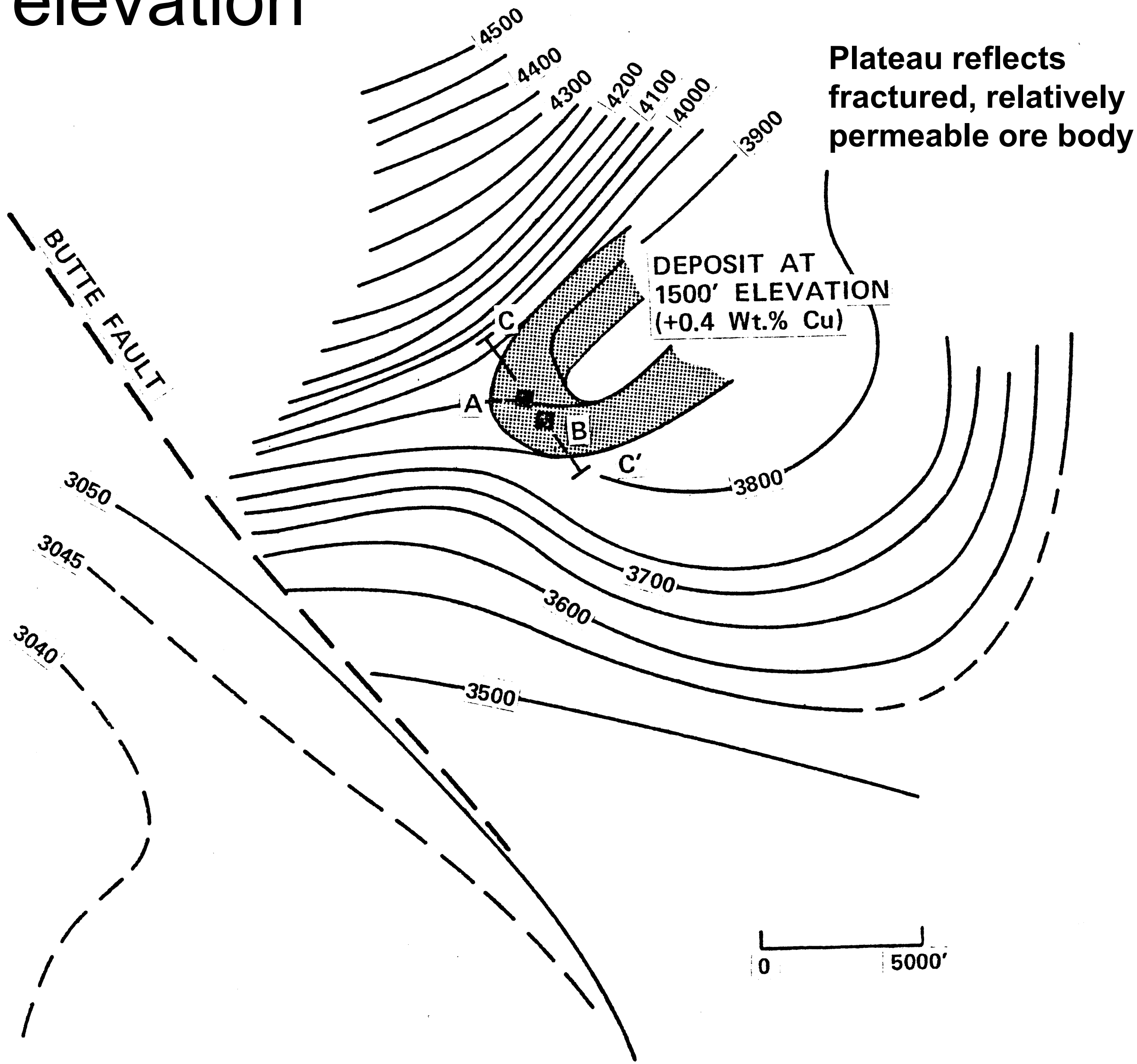
Current Cu Production
(percent of 600 10^6 t yr^{-1})

Safford Az being developed by Phelps Dodge



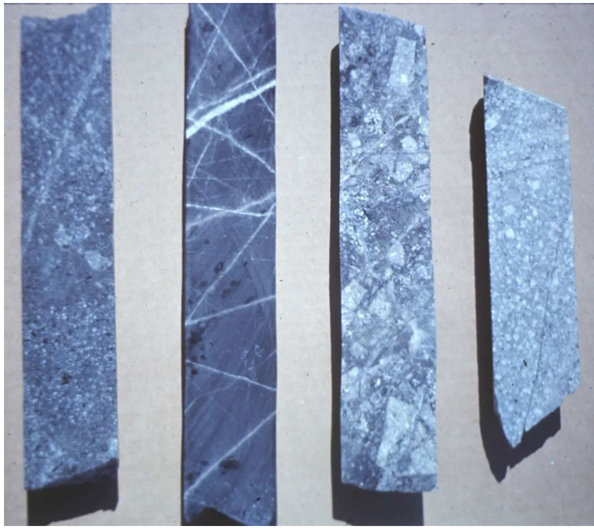
Cathles et al. (1978)

Water table elevation

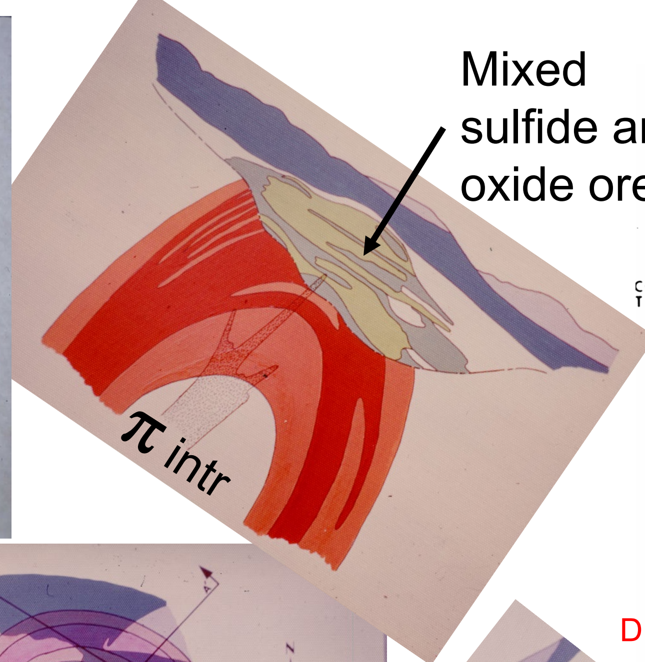


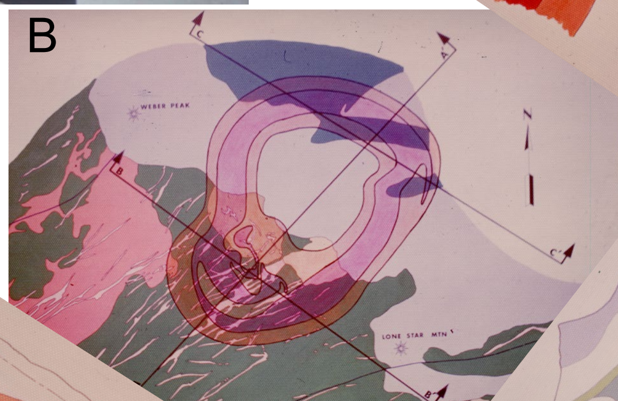
Cathles et al. (1978)

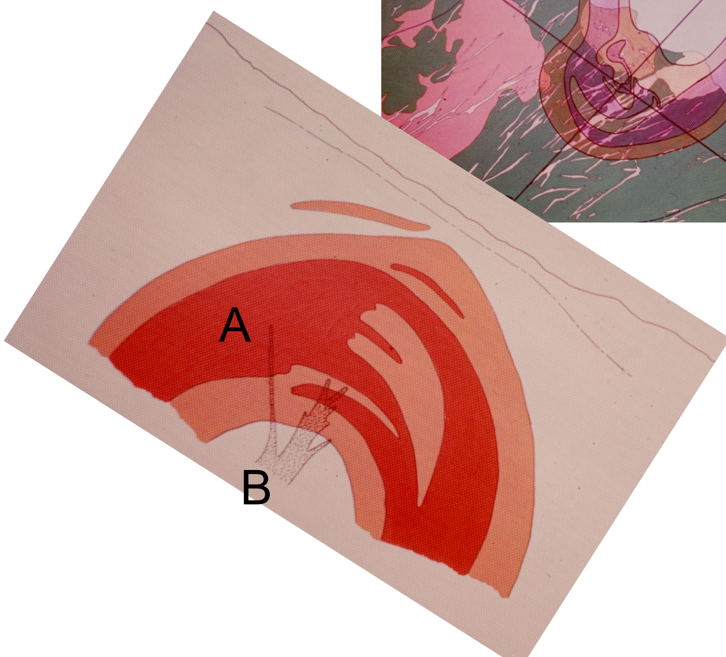
Ore body shaped like inverted canoe

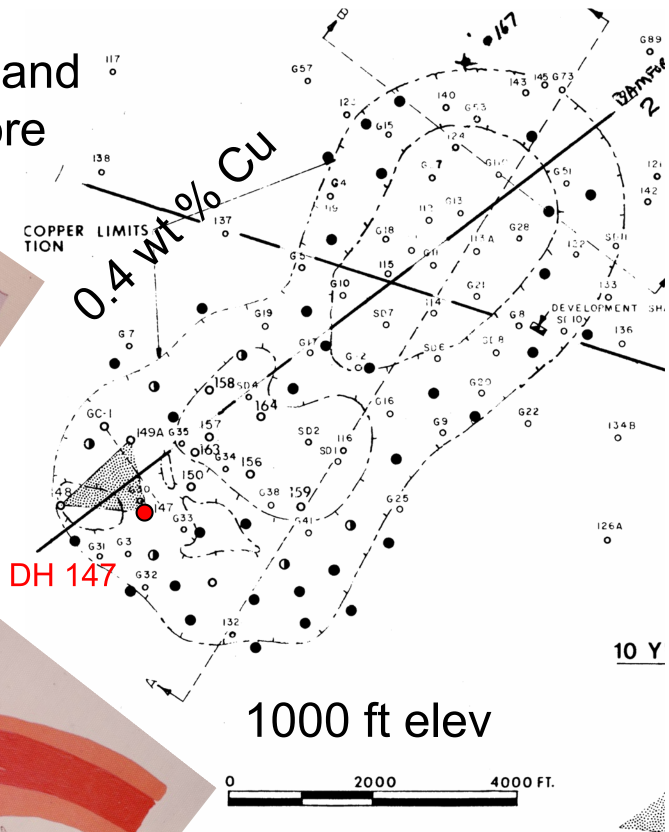


A B

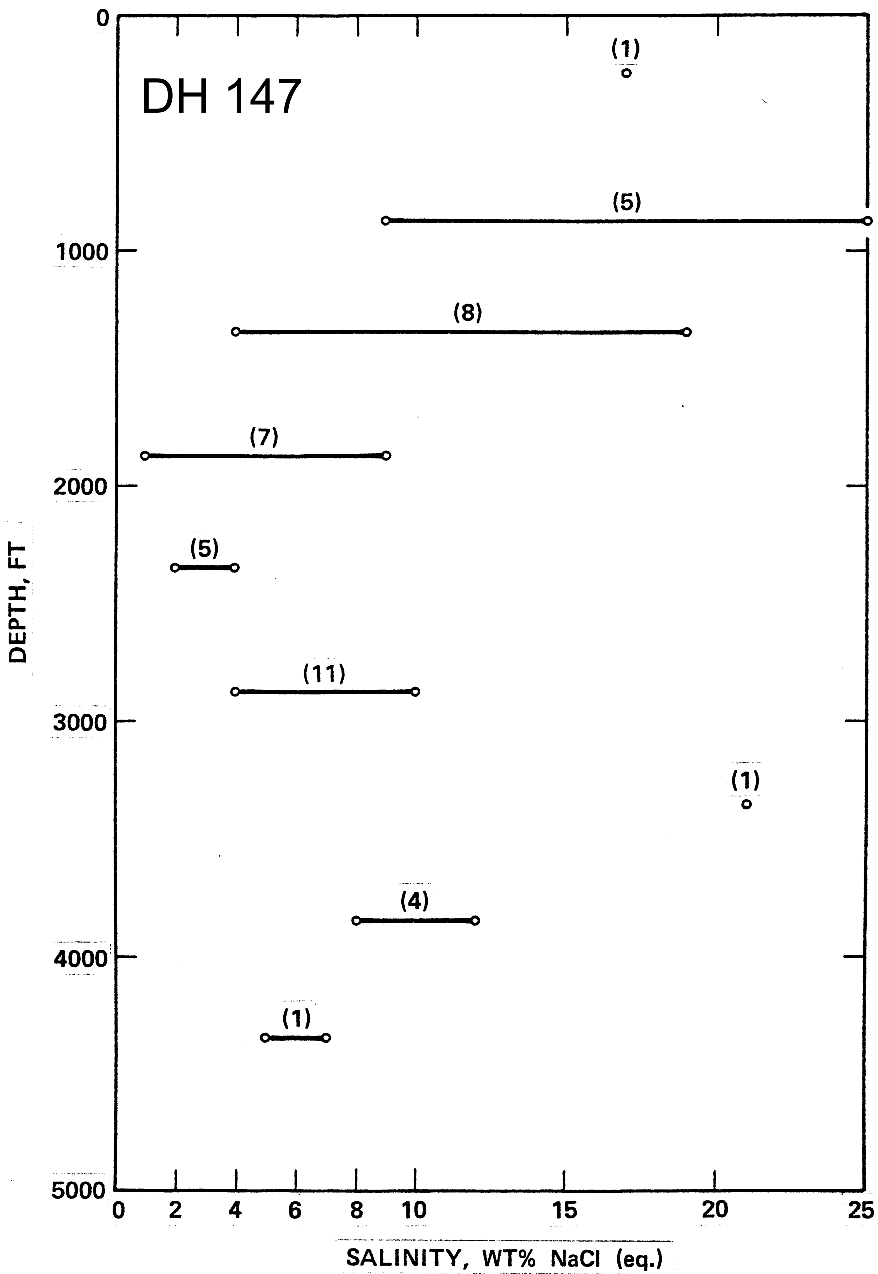




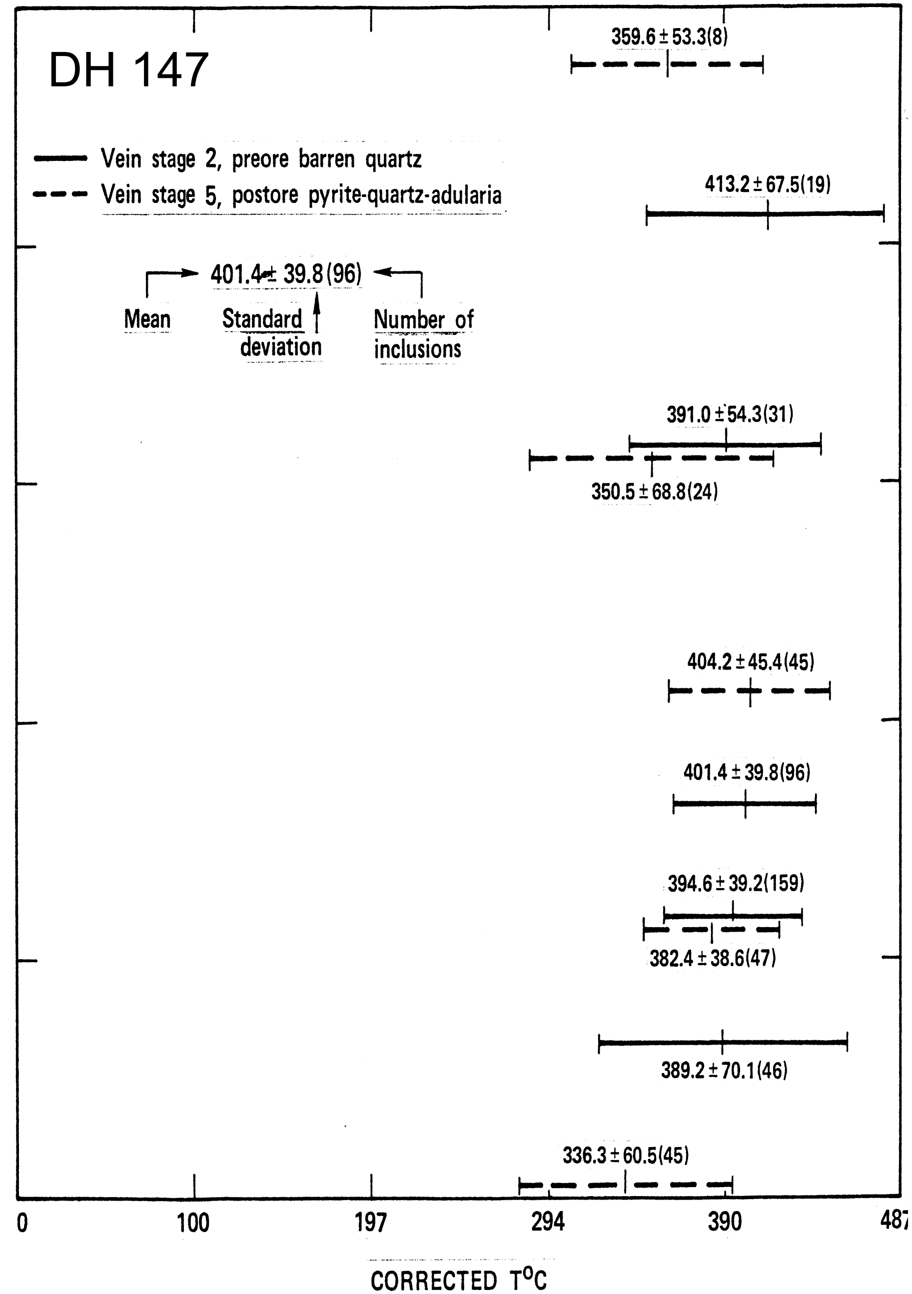




KCC AIME presentation 1978

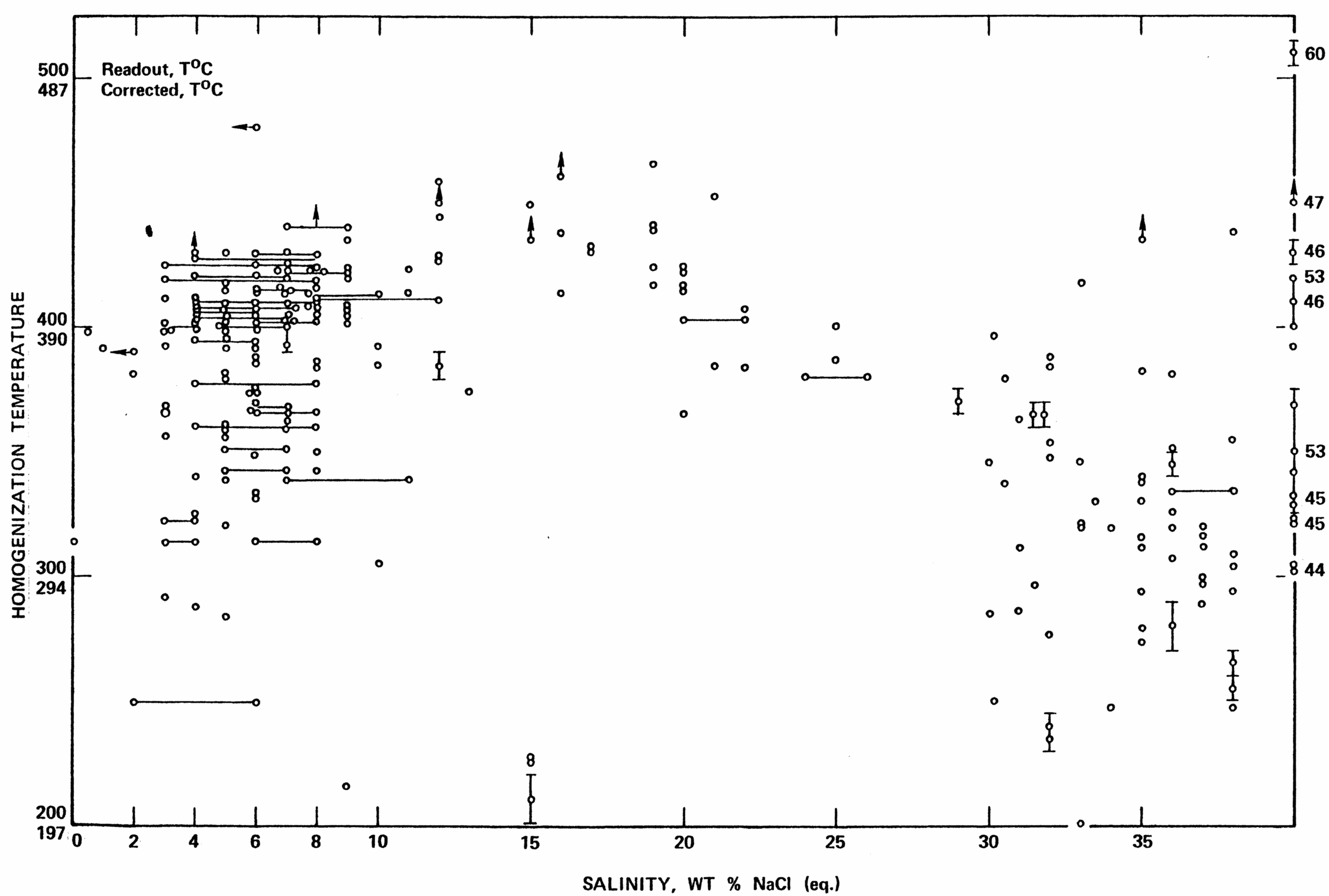


Vapor homong. fluid incl.



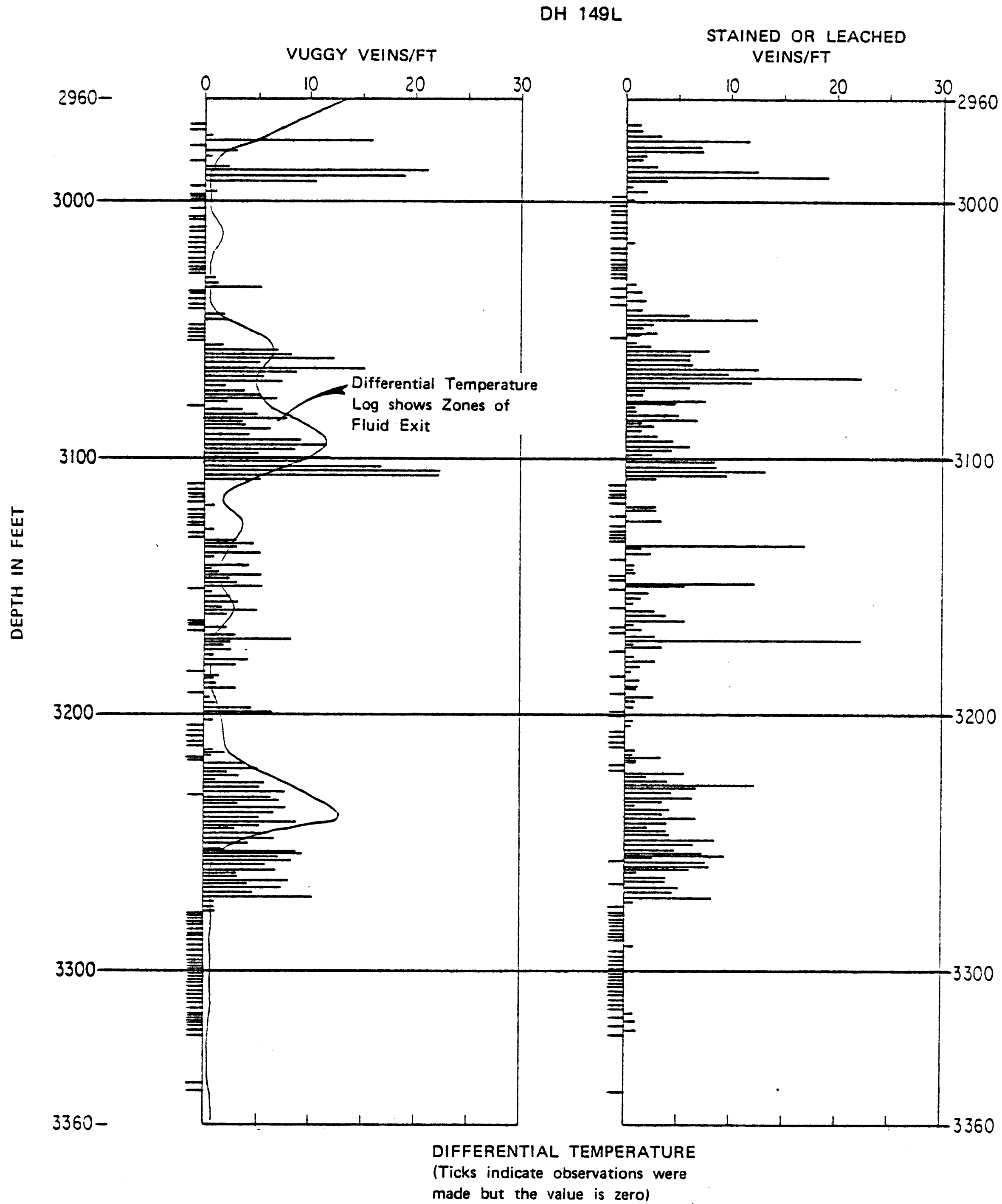
Dudas (1977)

Bimodal distribution of salinity



Dudas (1977)

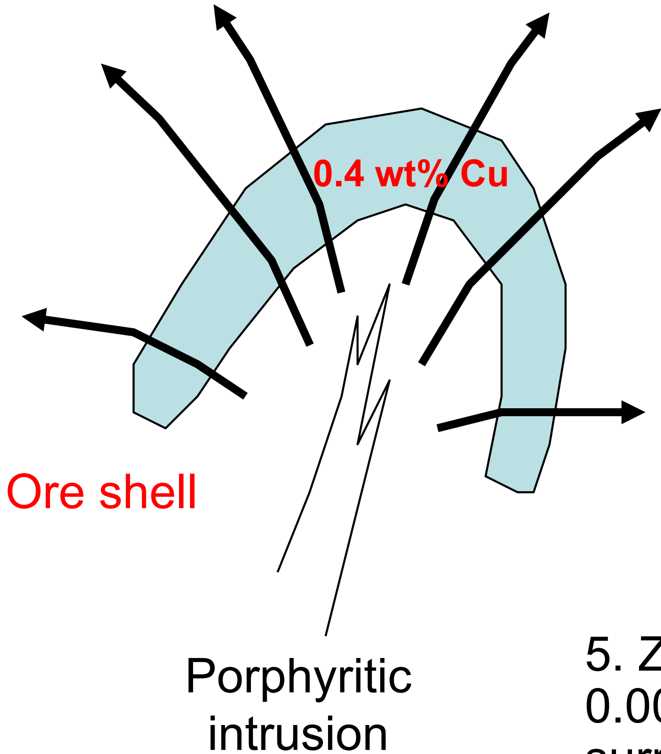
Metals in veins
30% of veins vuggy
Vuggy veins are permeable
10-20 vv/ft



Cathles et al. (1978)

Genesis

Sulfur anomaly (with Me added)



1. Deposits form when lithostatically-pressured magmatic fluids vent, decompress, and undergo phase separation

2. Sufide precipitation homogenizes aperture of flow fractures (anti-wormholing)

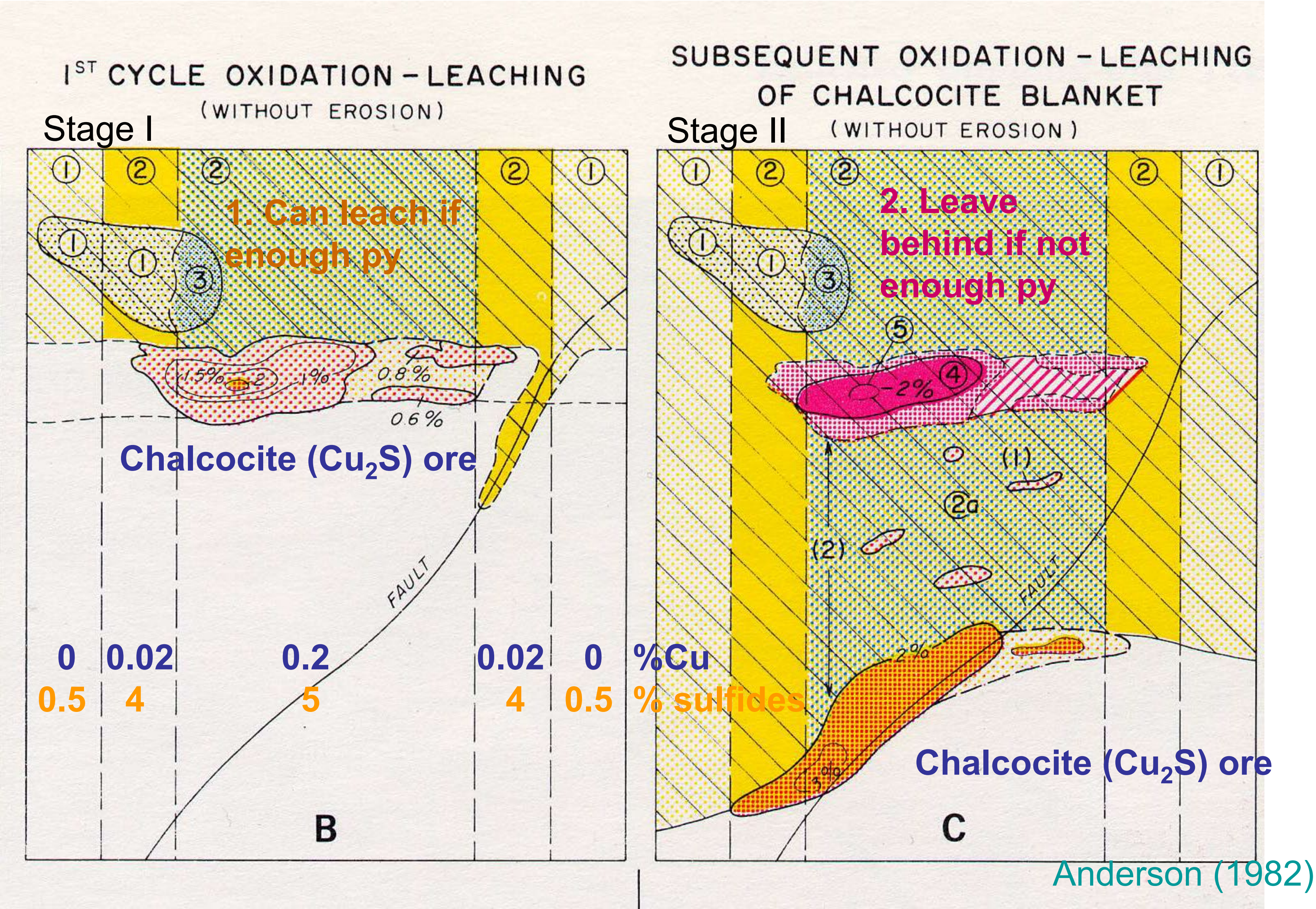
3. Pyrite halo extends beyond ore shell. P_2O_4, TiO_2 and BaO at 0.X wt%.

4. Ni and Co are incorporated in py. Whole rock concentrations of 0.00x wt%. Also W, Mo, V, Sn, …

5. Zn and Pb at fringes (up to 0.02 and 0.006 wt% bulk)- scavenged from surroundings

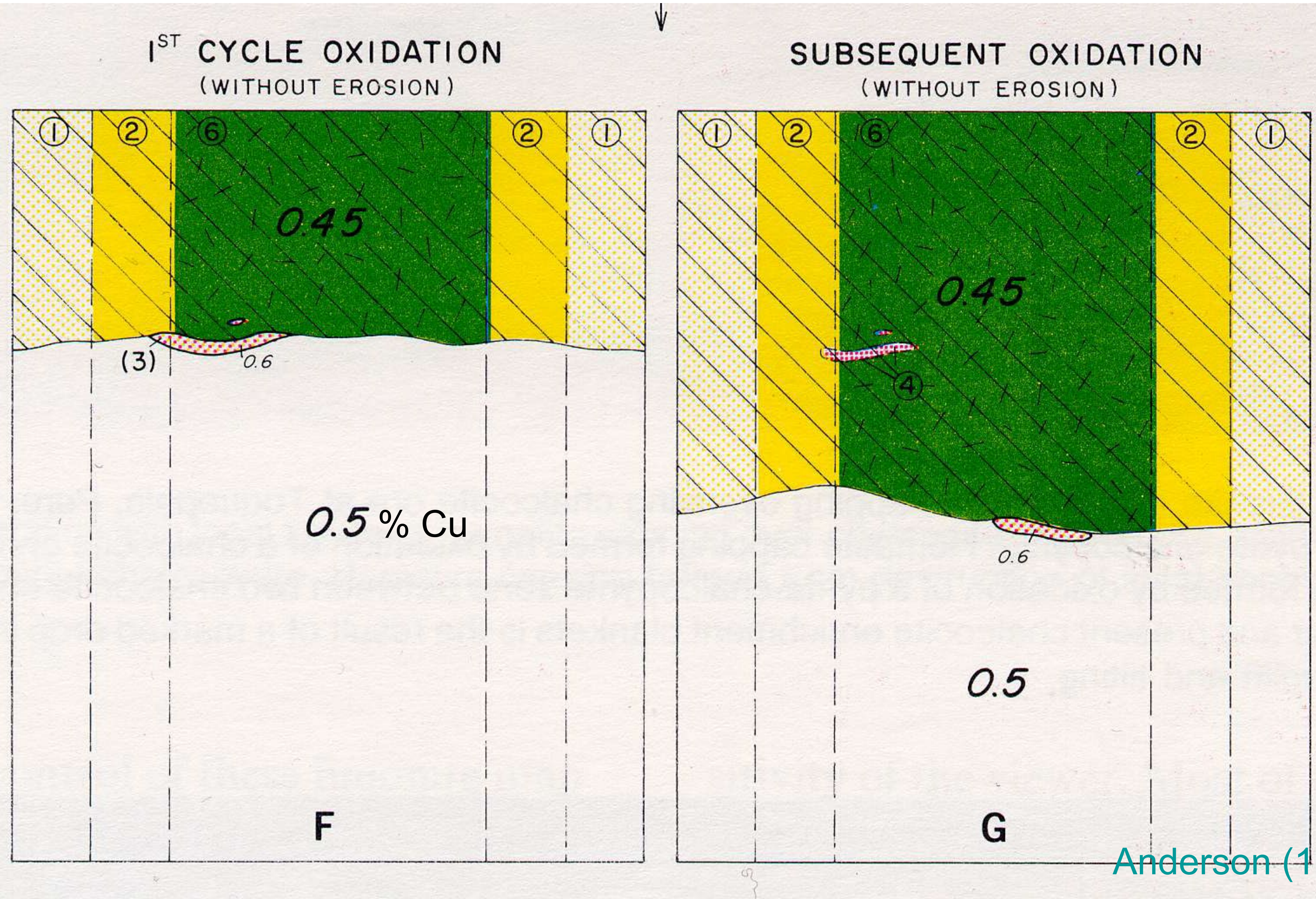
6. Magmatic fluid supplied by much larger intrusion as it crystallizes

Weathering can enrich porphyries



Anderson (1982)

No leaching if 0.5% Cu and 1 vol% total sulfides … not enough acid generated



Anderson (1982)

Jarosite leach cap and chalcocite (enriched) ore at Butte, Montana

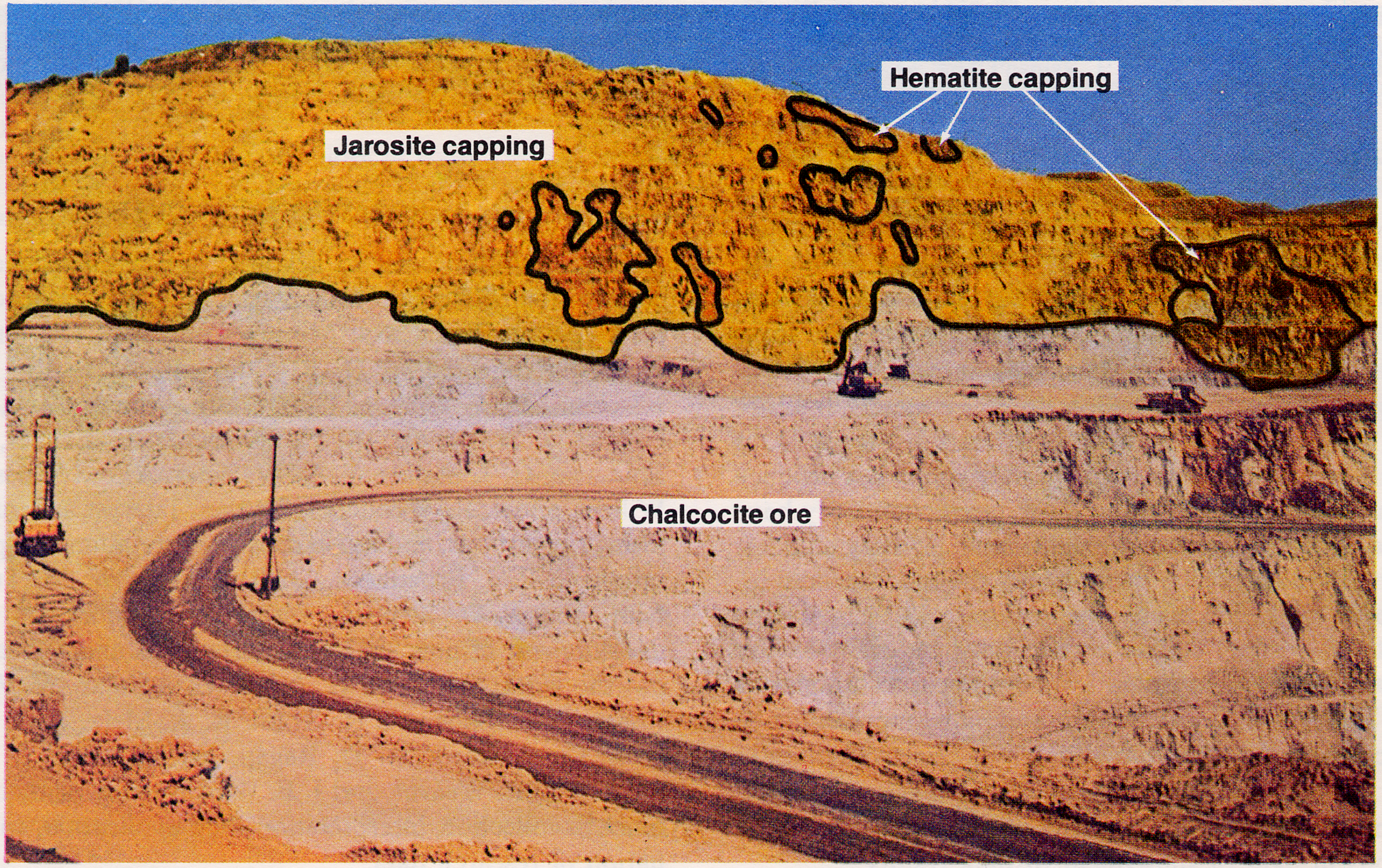
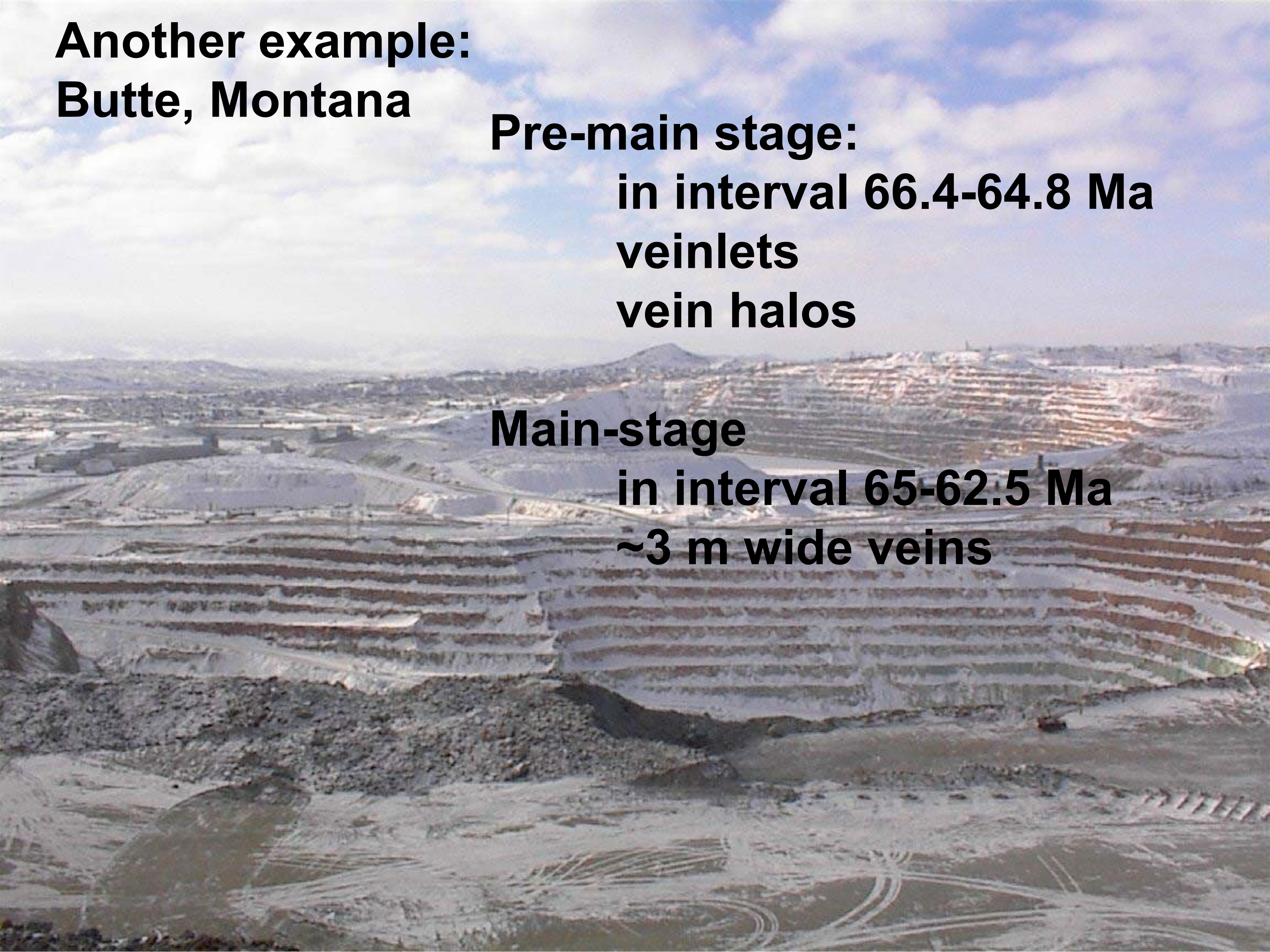


Figure 12.17. Jarosite capping with local zones of hematite capping over chalcocite ore at Butte, Montana. Jarosite capping formed by oxidation of pyrite-chalcopyrite. Hematite capping formed from destruction of local zones of chalcocite enrichment.

Anderson (1982)

Another example: Butte, Montana



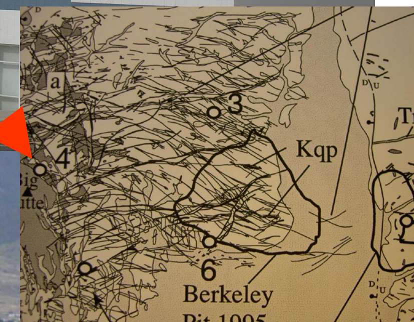
Pre-main stage:

- in interval 66.4-64.8 Ma
- veinlets
- vein halos

Main-stage

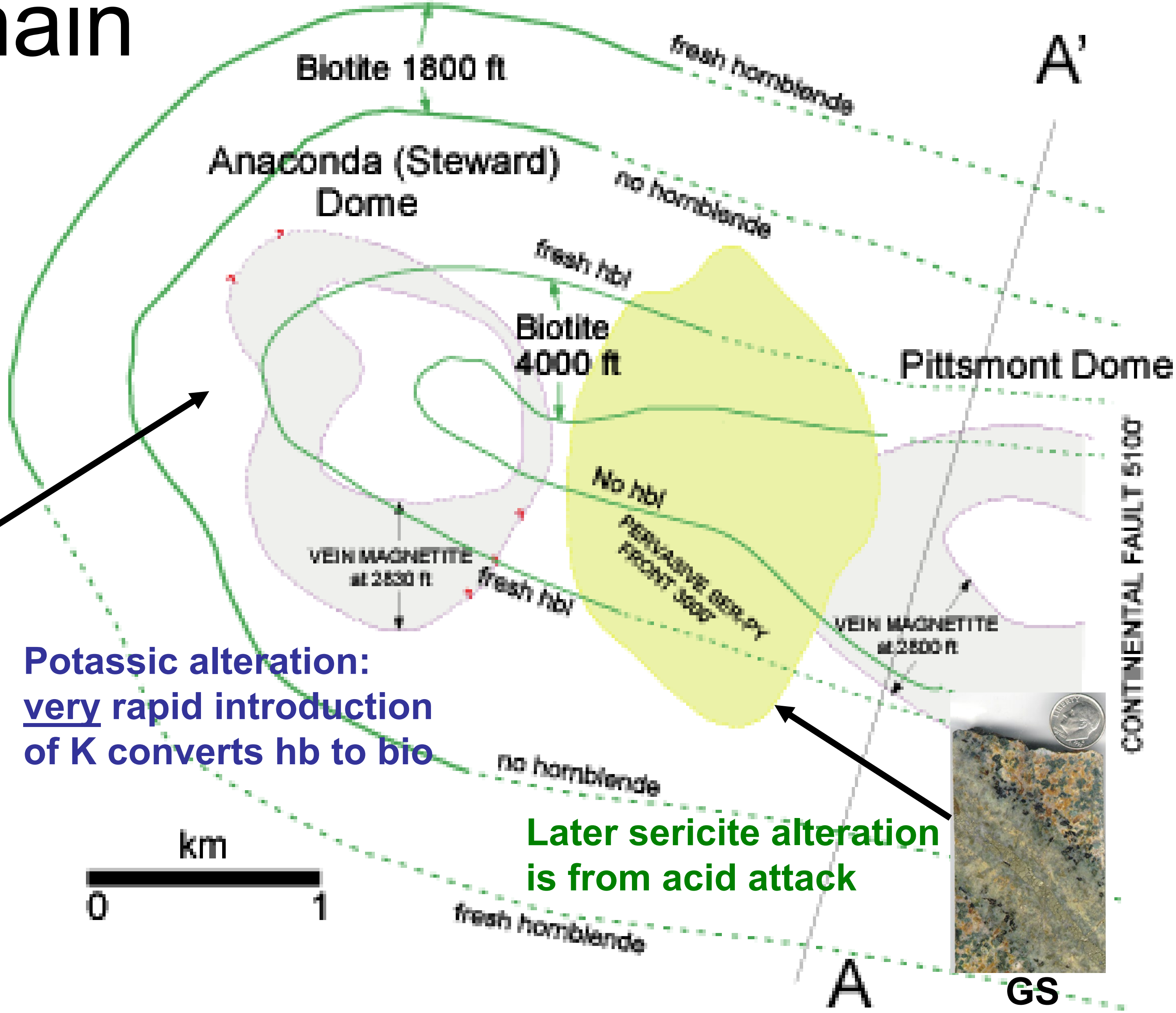
- in interval 65-62.5 Ma
- ~3 m wide veins

Headframes along **Main Stage** Veins



Pre-main stage Butte

EDM
Hb+K→bio

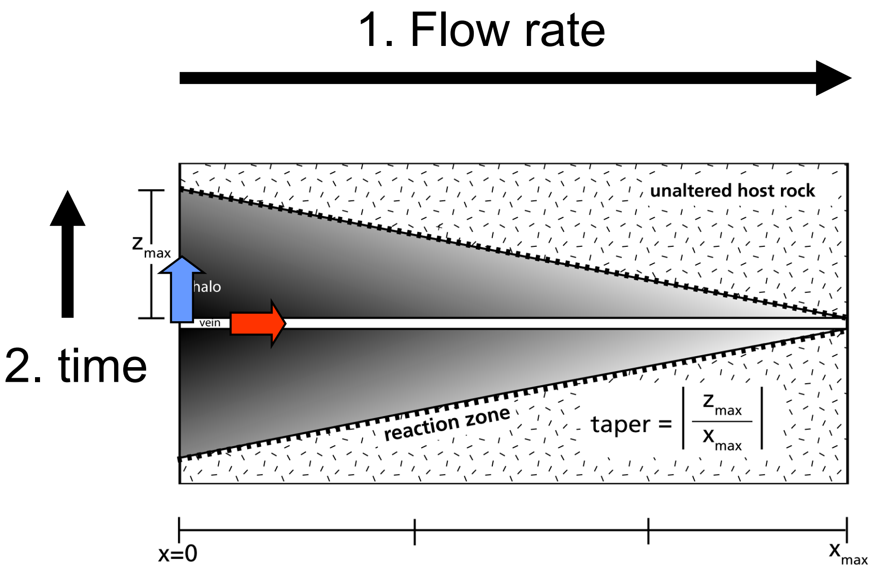


Potassic alteration:
<u>very</u> rapid introduction of K converts hb to bio

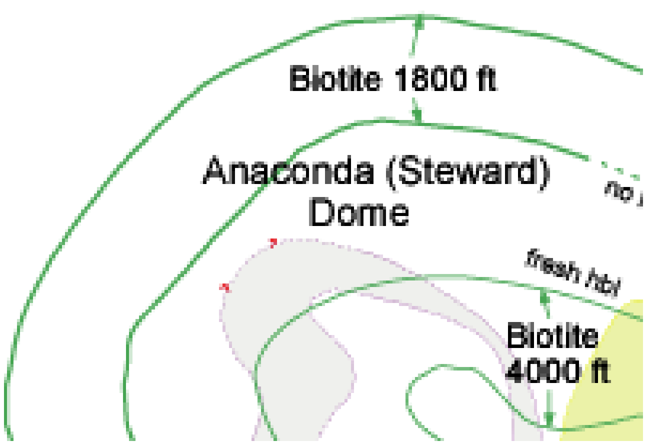
Later sericite alteration is from acid attack

GS
acid attack

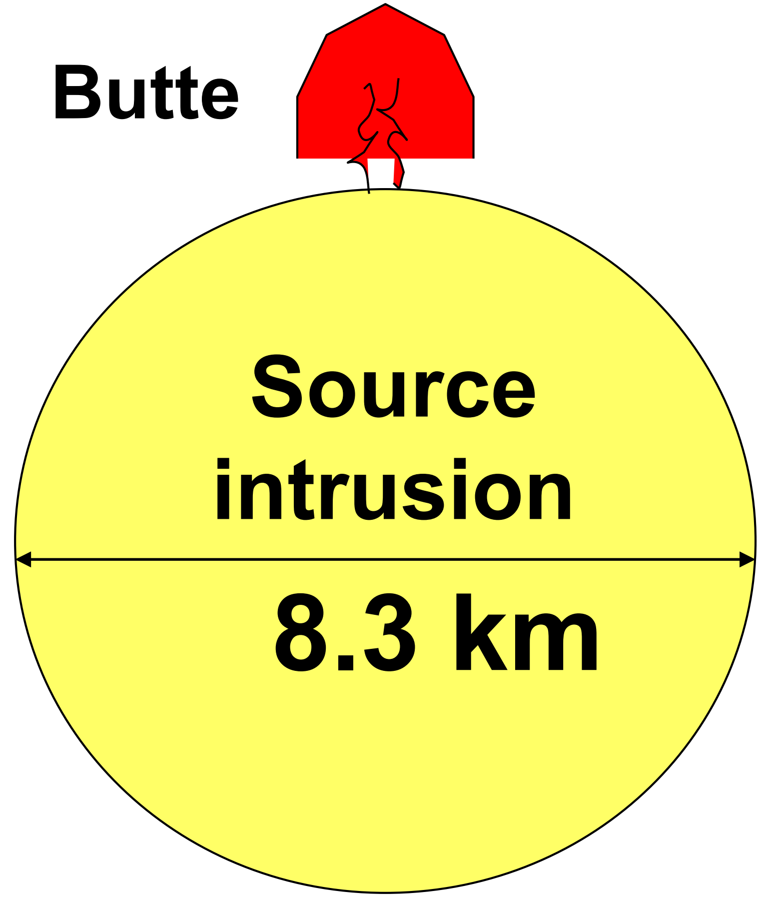
Porphyries are barely-controlled explosions



Potassic transition zone width requires potassic alteration formed in **~800 yrs**



3. Total alteration measures fluid expelled



5 wt% magmatic water vented

Acid vein halos develops only as $\downarrow$T allows SO_2 and H_2S dissociation & acid generation

crkl

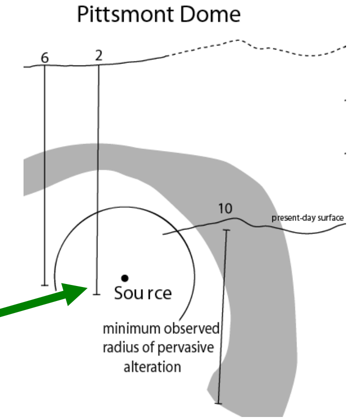
Hot fluid not acid

EDM

Q-mo

BQ

no halos ever formed at center- hot until flow stopped



Cooler fluid very acid

EDM

PGS

GS

Ditance from source and time

Sericite alteration is a donut…

Mn Vein (Distal Main Stage)

Butte Conclusions

1. Initial volatile release very rapid (900 yrs Butte)
2. Intensively fractures host (dilation, uplift)
3. Potassically enriches very large volume
4. Heats to ~600C an even larger volume
5. Mineralization and acid alteration occurs as venting wanes and system cools
6. Main stage opened a few very large cracks
7. Some porphryies explode like Pinotubo (which hosted porphyry mineralization)

The bottoms of porphyries

(and the sulfur problem)

See deep into system at Ely, Nevada

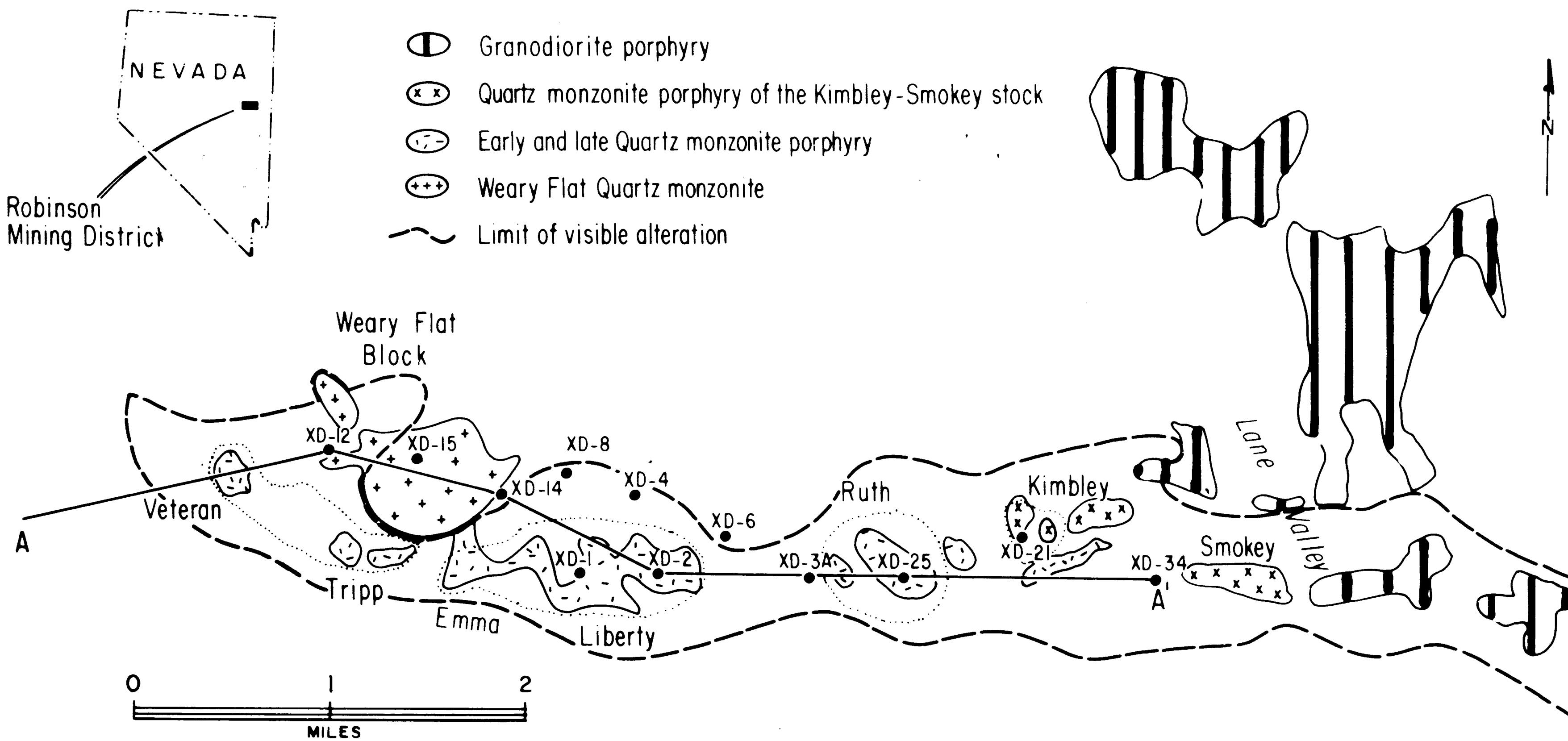
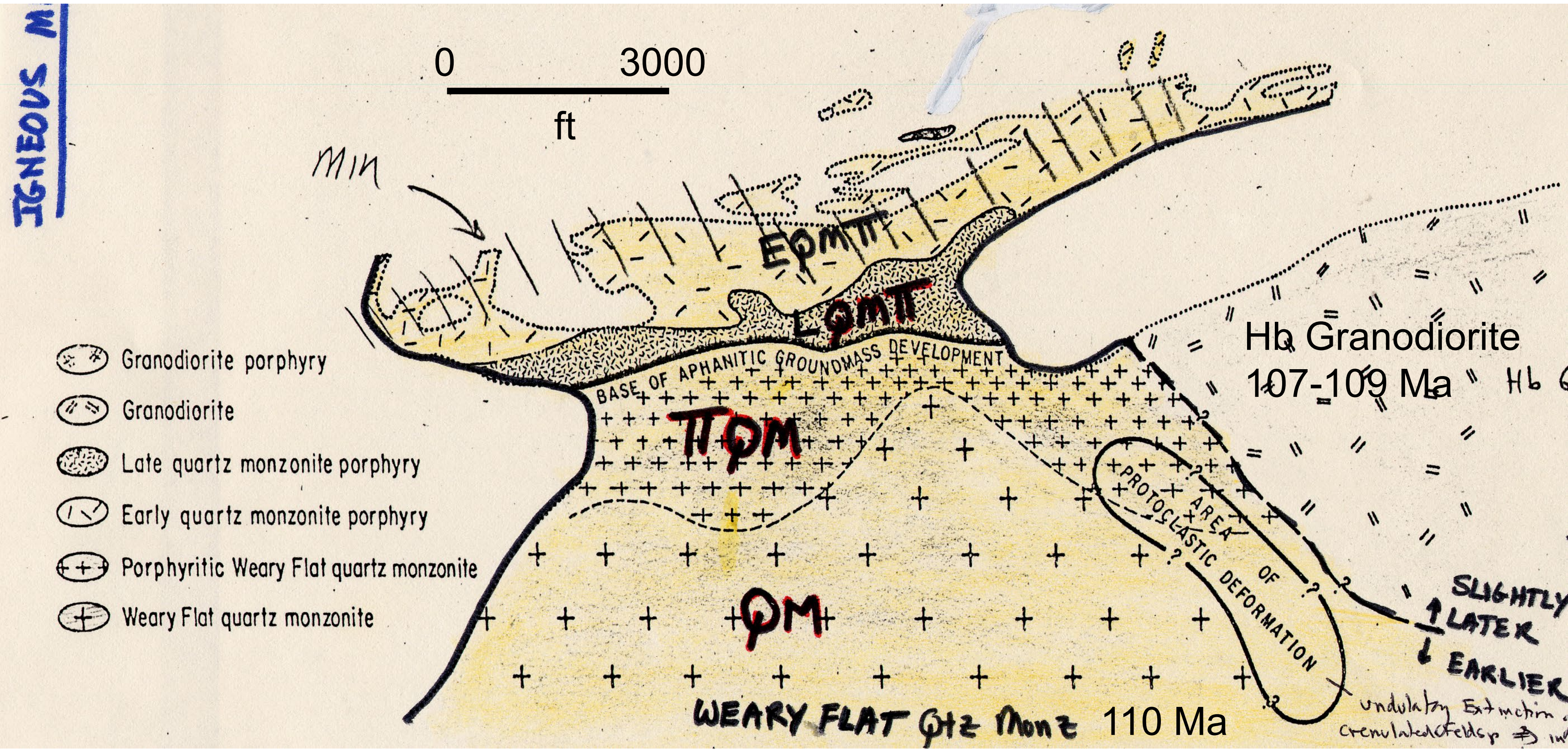


Figure 1. Location map of porphyry-copper deposits in the Robinson Mining District, White Pine County, Nevada, showing cross section position, drill-hole collars, and distribution of lower Cretaceous quartz monzonites and granodiorites.

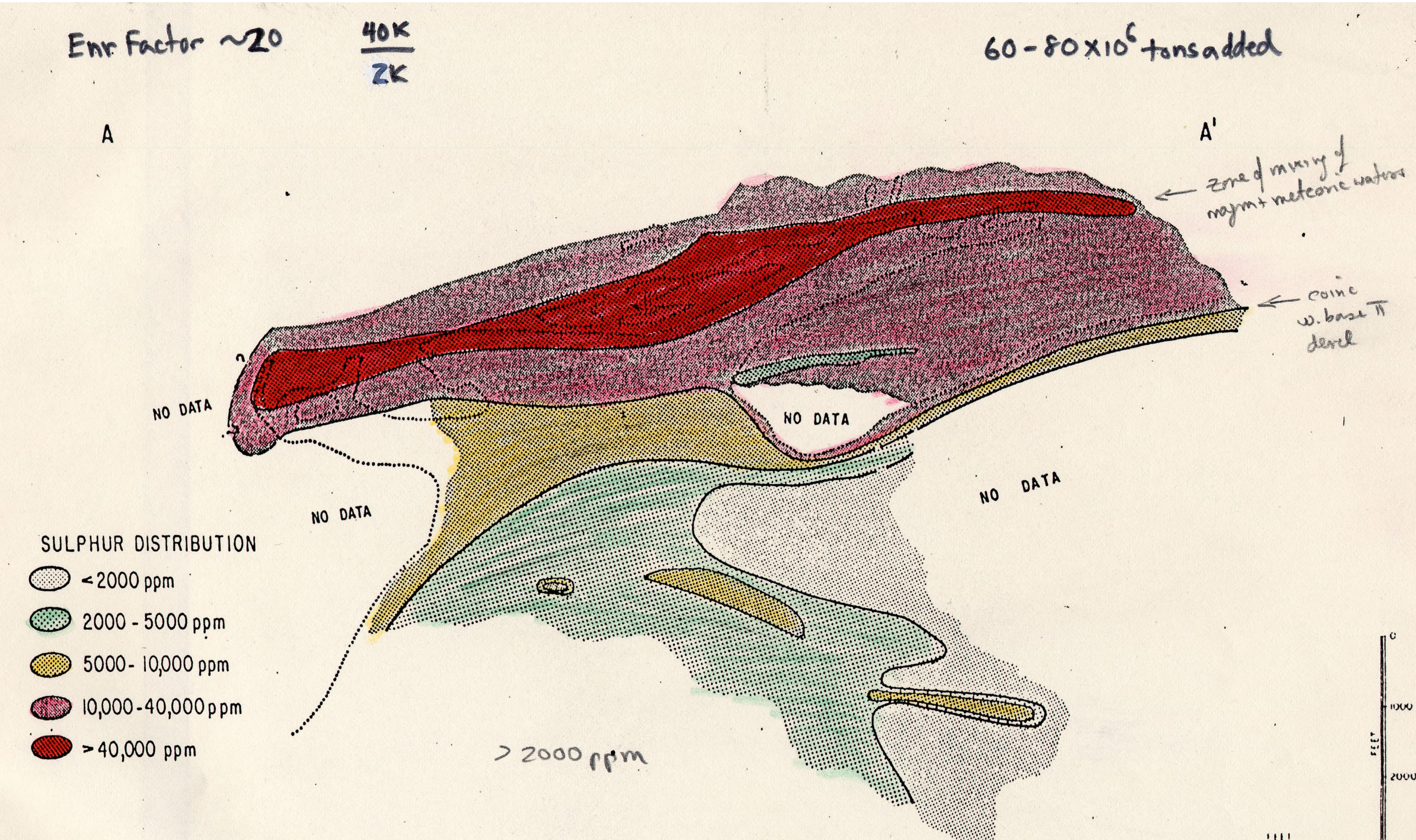
… put the pieces together

Westra (1979)

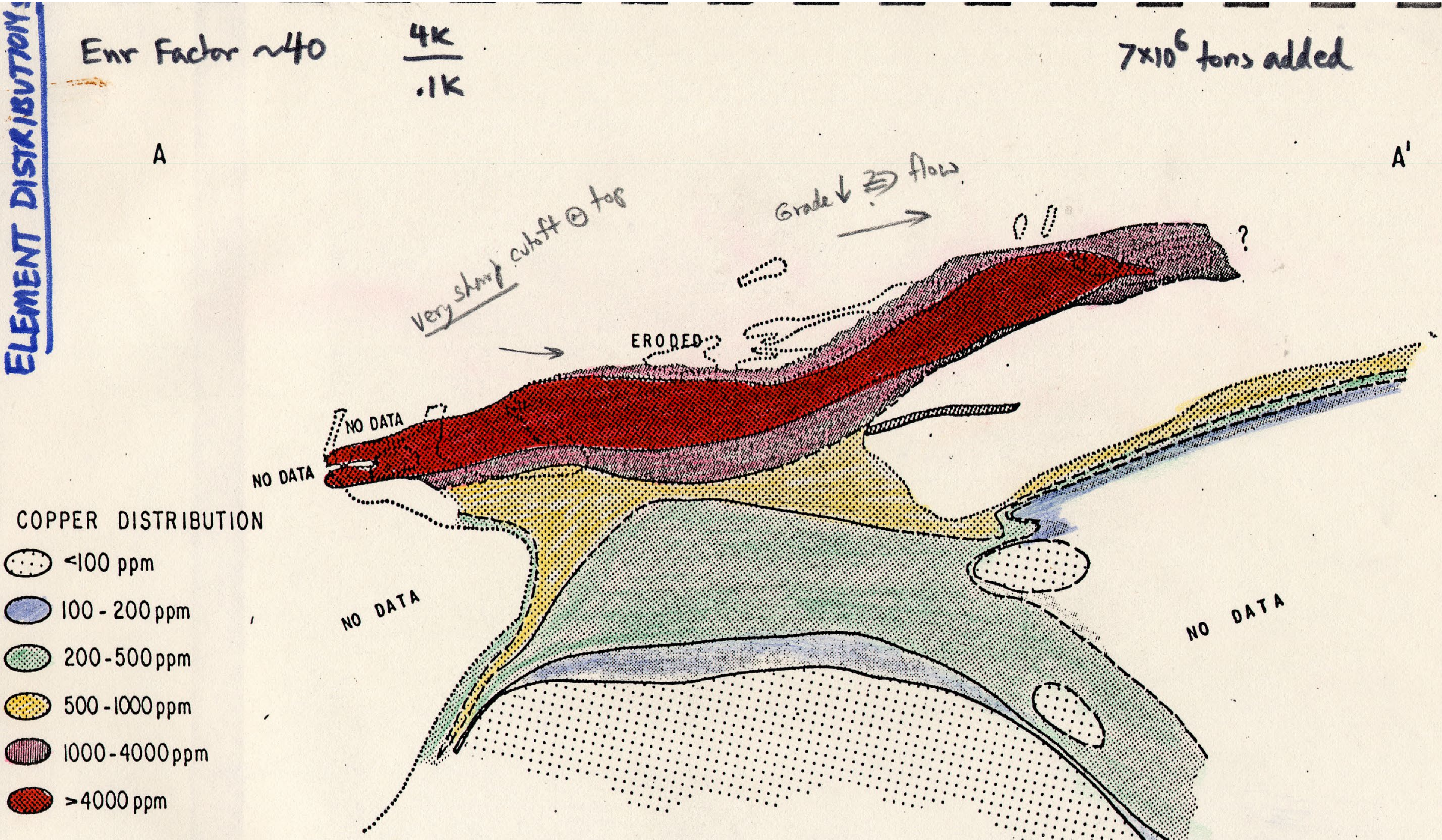
Restored system reveals Weary Flat Qtz Monz as source magma



$60\text{-}80 \times 10^6$ tons S added

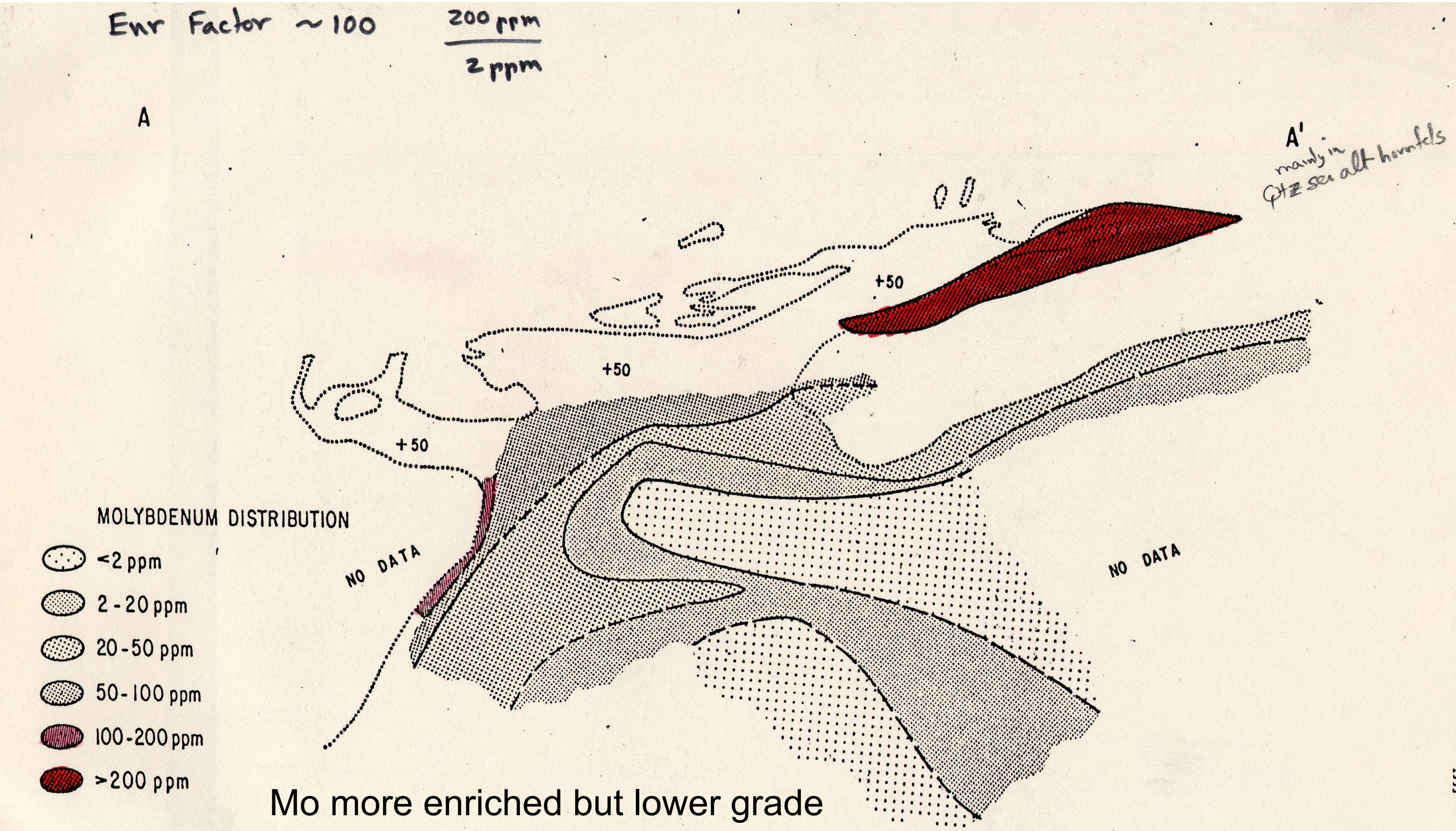


7×10^6 tons Cu added



System is a S anomaly with a little Cu added

Significant Mo enrichment

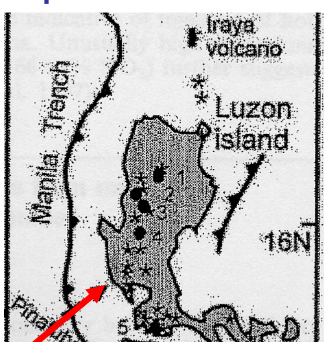


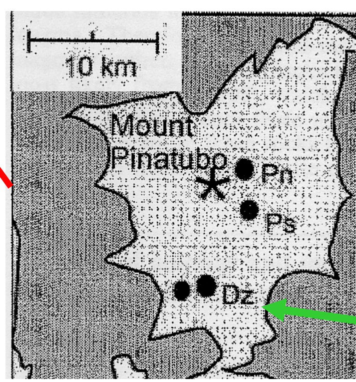
Mo more enriched but lower grade

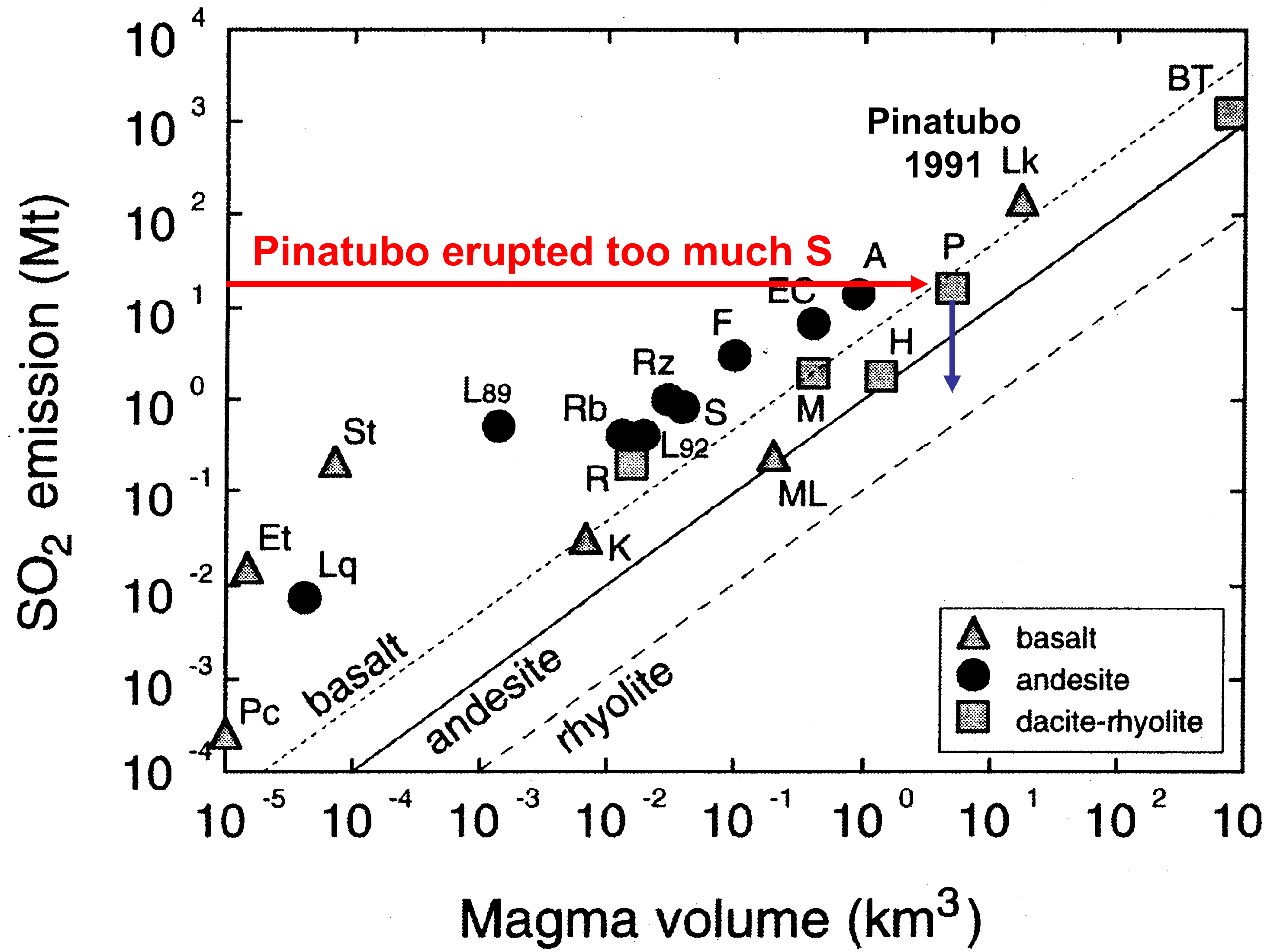
The excess sulfur problem

June 1991 Pinatubo vented **17×10⁶ t S** with 5 km³ dacitic pyroclastics which could hold ~1 ×10⁶ t S

Pinatubo area hosts several porphyry Cu deposits





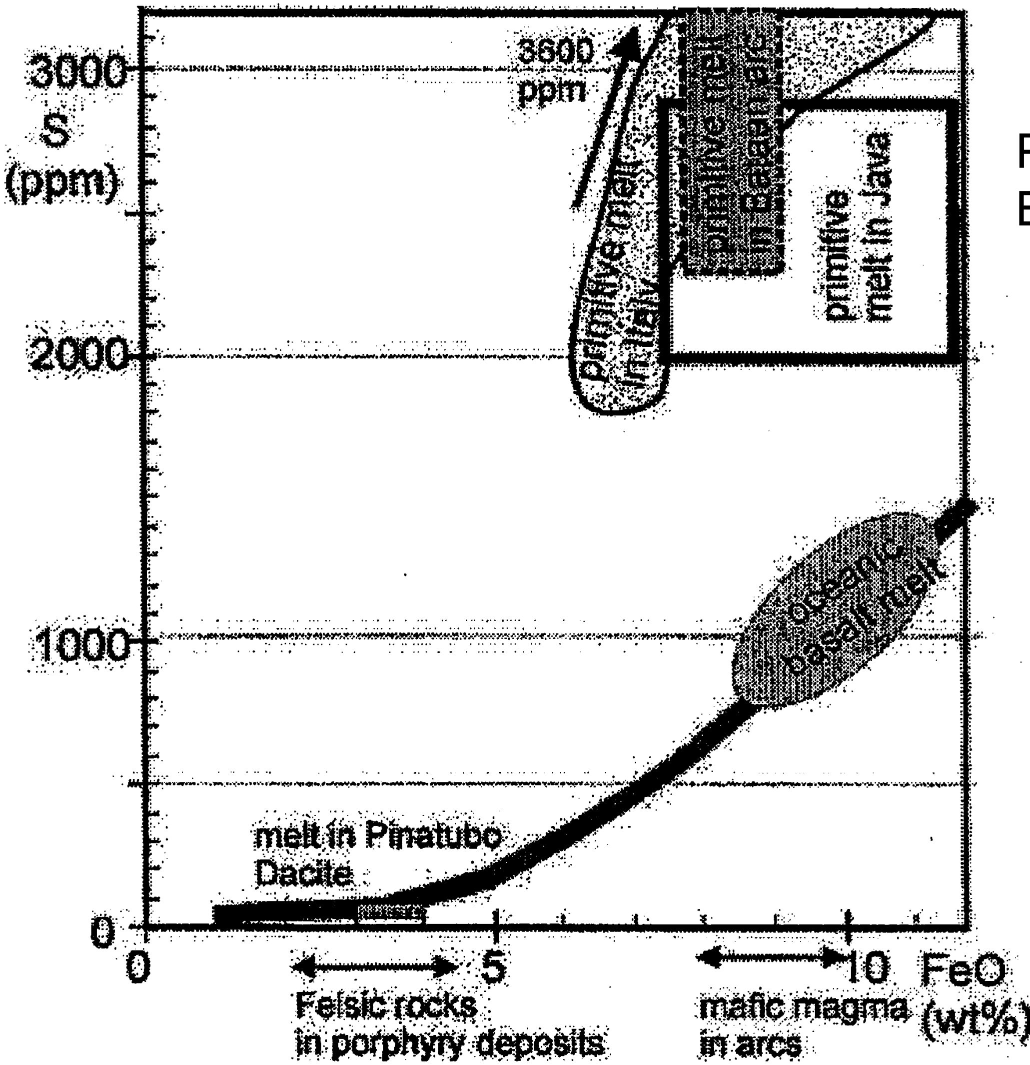


Pisumpan + Pinpin 20 Mt @ 0.4% Cu and ~1g/t Au in Quaternary dacite volcanics

Dizon, 187 Mt @ 0.36% Cu

Wallace (2003)

Mafic magmas can be rich in S



Primitive melts in Java, Italy, and Bataan carry 2000-3000 ppm S

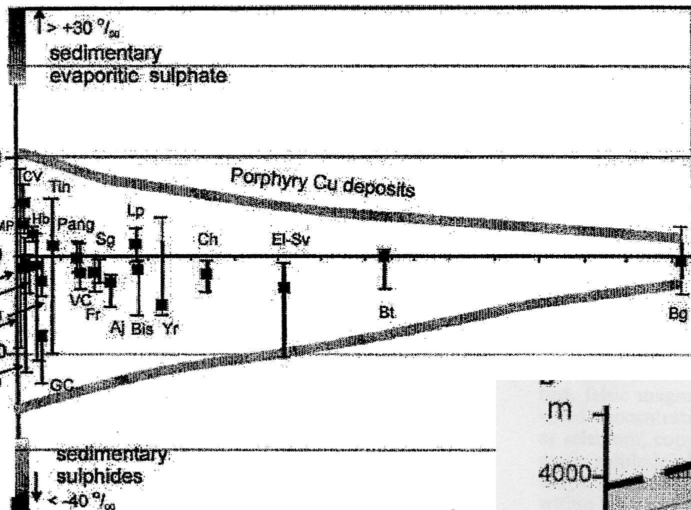
Ocean basalt 1000 ppm S

Felsic rocks carry very little S because they are Fe-poor

Hattori and Kieth (2001)

Hattori suggests basalts contribute S

1. S in porphyry deposits is from 0‰ seawater



20

-20

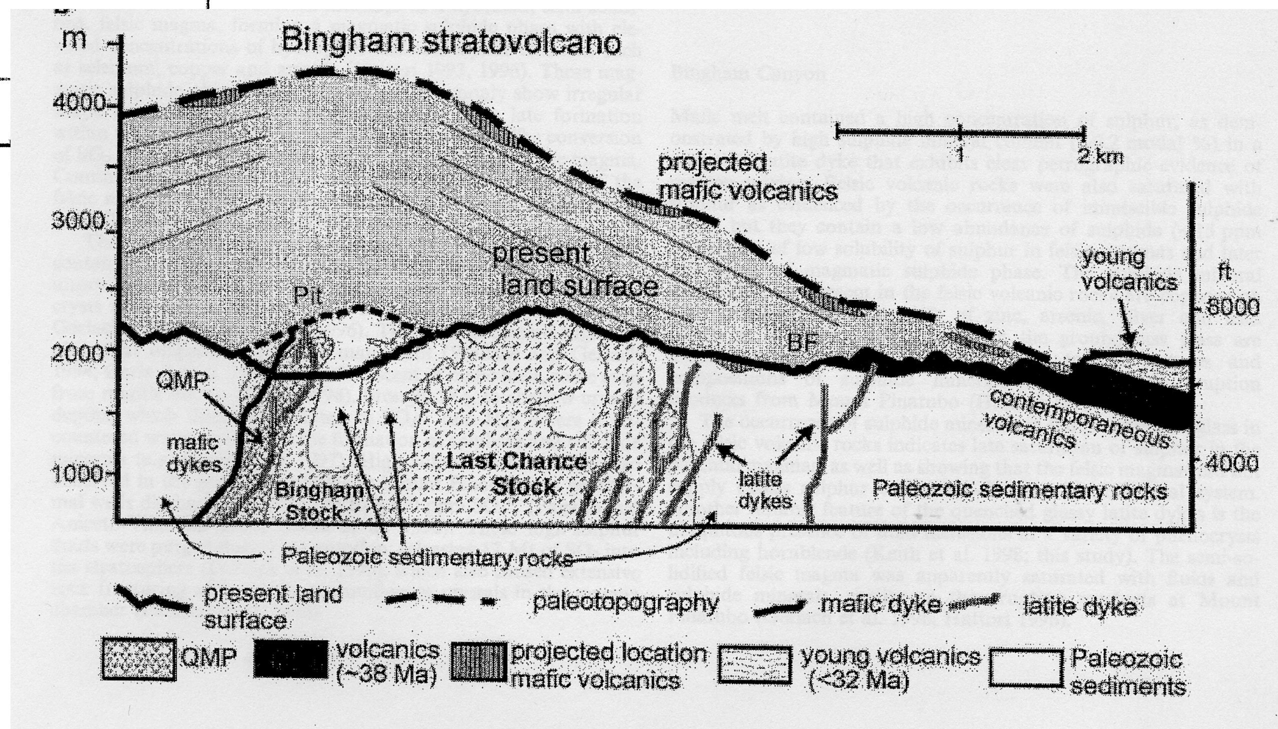
$\delta^{34}S$[‰]

10 20

Cu [Mt]

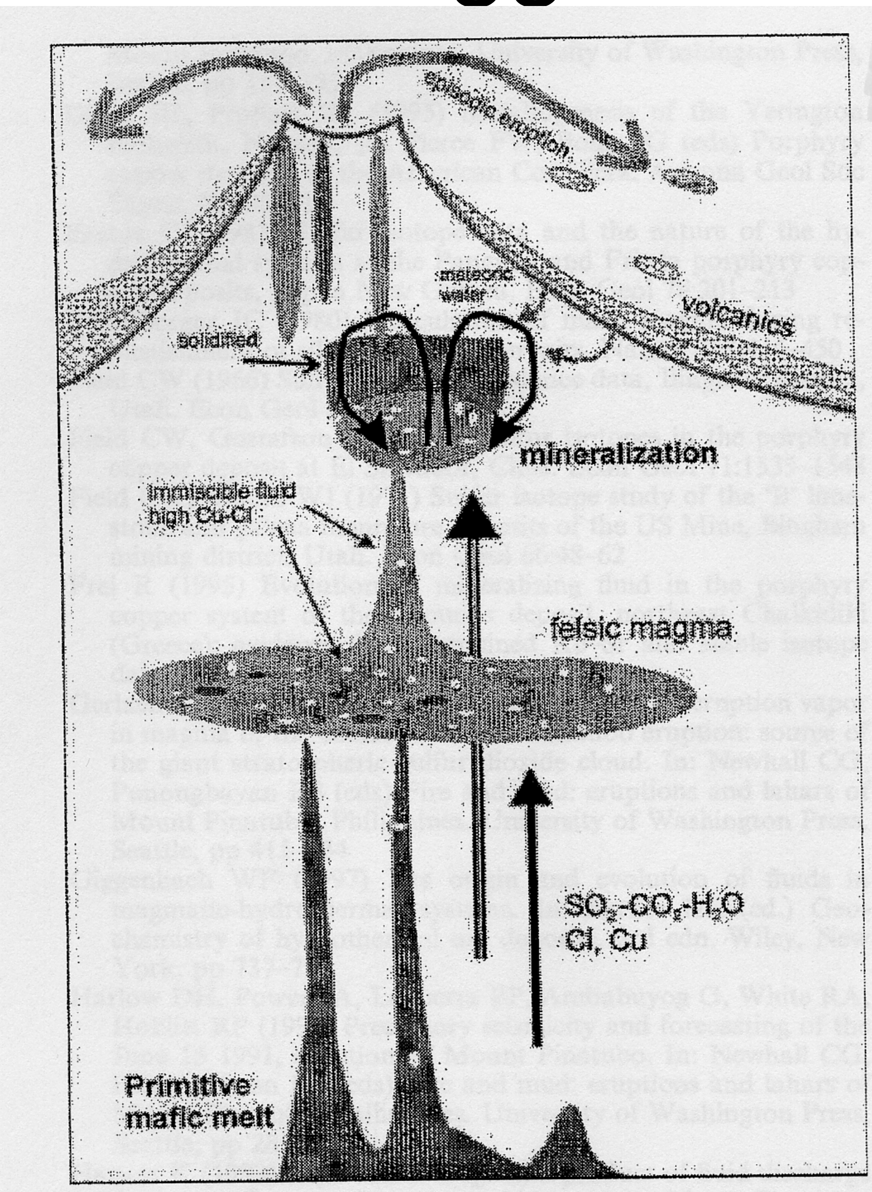
2. Bingham Porphyry Cu-Au >22 Mt CU and > 1,250 t Au has high Mg primitive dikes with identical age to mineralization, textures suggest felsic and mafic magmas mixed

(Bingham Canyon Utah is the biggest copper and the biggest gold mine in North America)



Hattori and Kieth (2001)

Injection of mafic magmas triggered volatile release



3. Porphyry are fractured and deposit formed

2. Volatiles released explosively from felsic magma chamber

1. Mid to deep crustal sill injects mafic magma

Hattori and Kieth (2001)

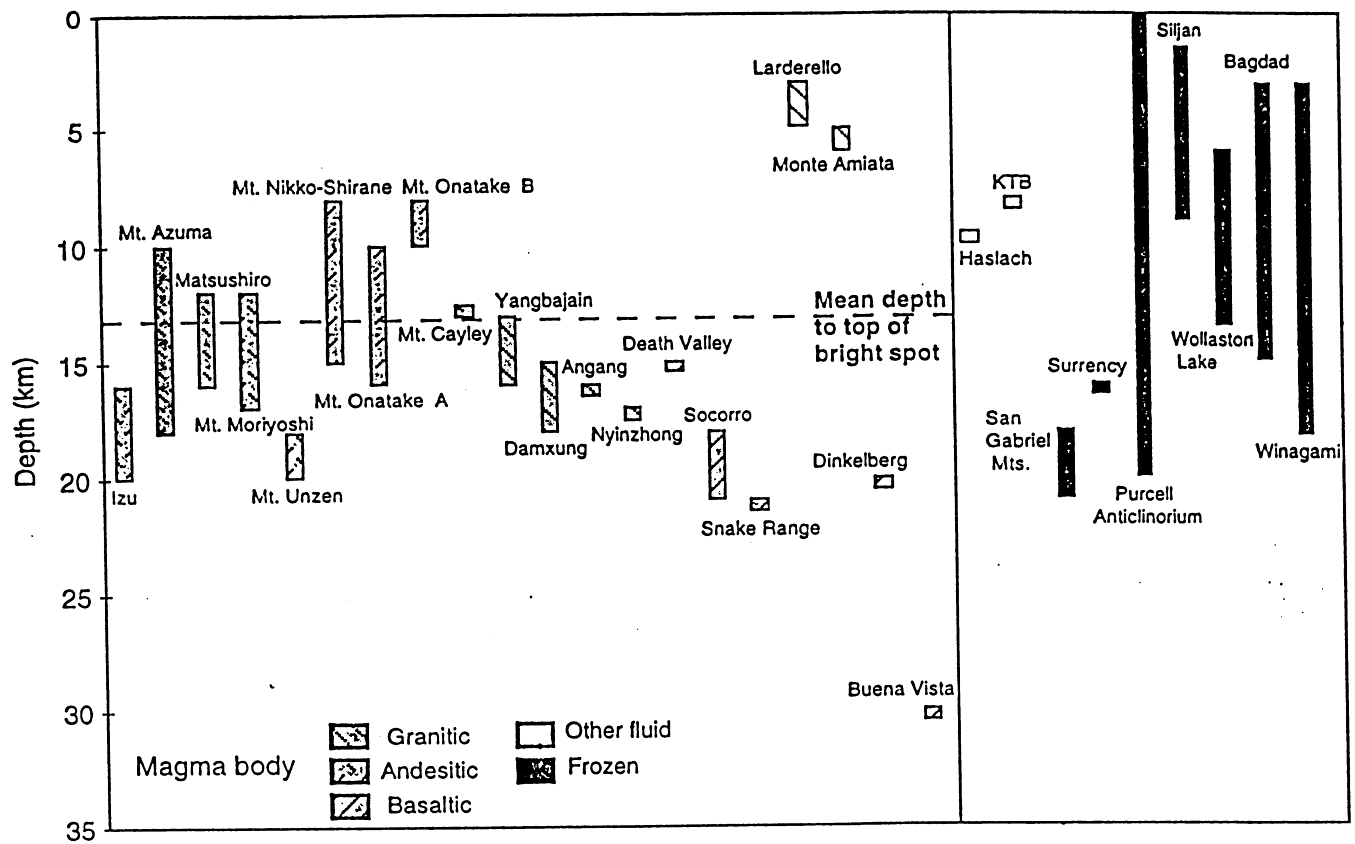
Porphyry S can be supplied by sills

S in 5 porphyries = 1.5 km cubes with 2 wt% S

Can be supplied by 50 km diameter sill 240 m thick that contributes 500 ppm S

Mid crustal mafic sills common

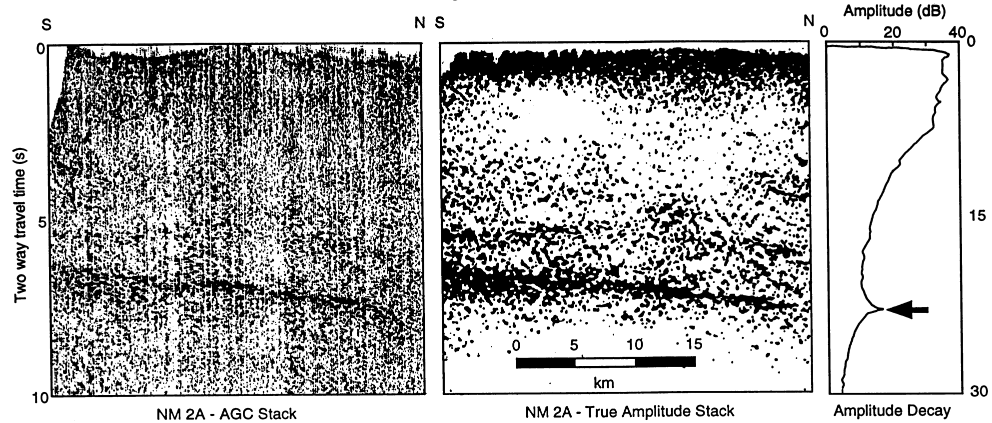
~ depth to brittle-ductile transition



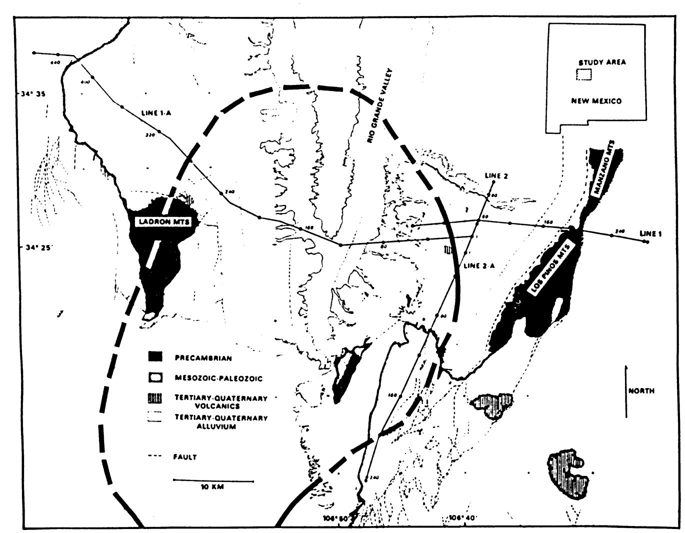
Ross and Brown, Reviews Geophysics, Accepted 1997

A hot sill 75x50 km underlies Socorro New Mexico

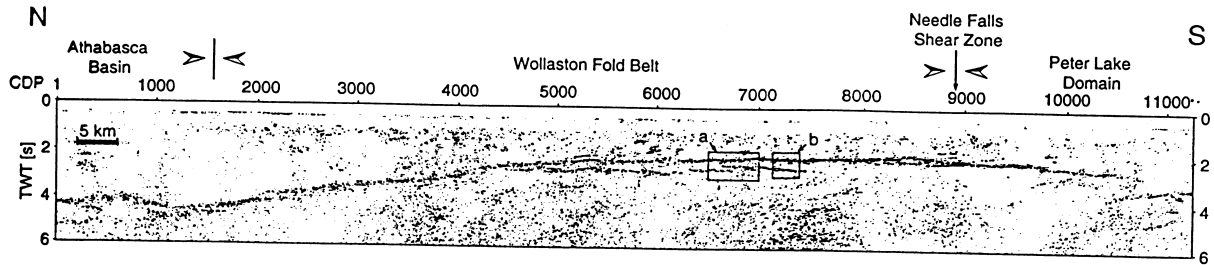
Socorro New Mexico Bright Spot
~50 km Diameter, 18-20 km depth

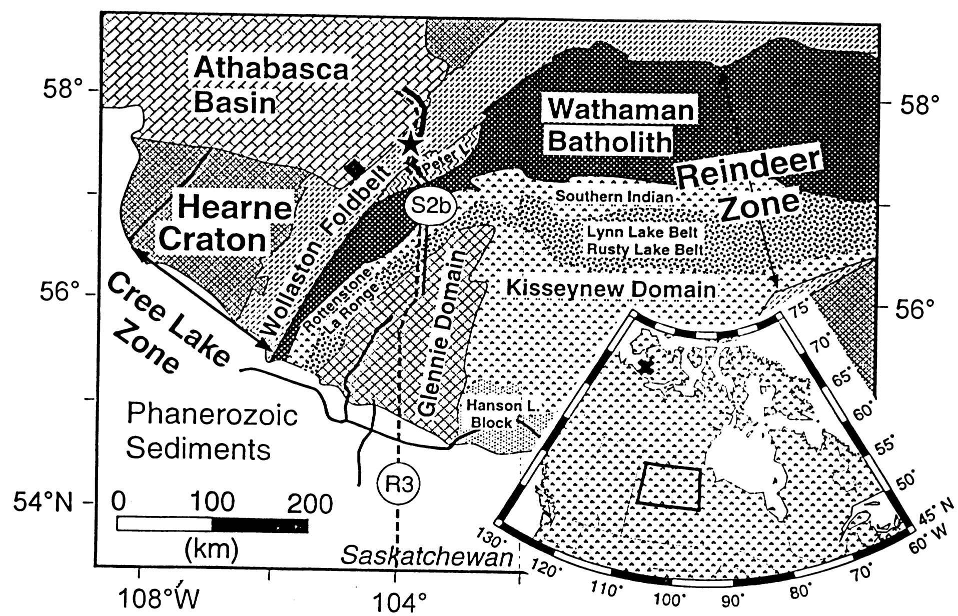


Ross and Brown, Reviews Geophysics, Accepted 1997



Wollaston Lake Reflector Extends 160 km Across Trans Hudson Orogen Hinterland at 6-13 km Depth





Geology; March 1997; v. 25; no. 3; p. 271–274; 5 figures.

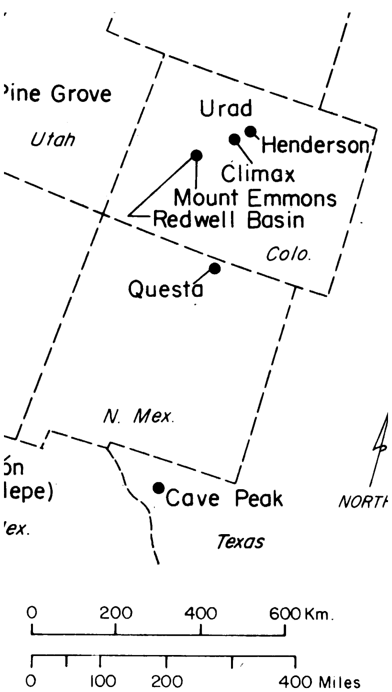
Mandler and Clowes, Geology, 25, p. 271, 1997

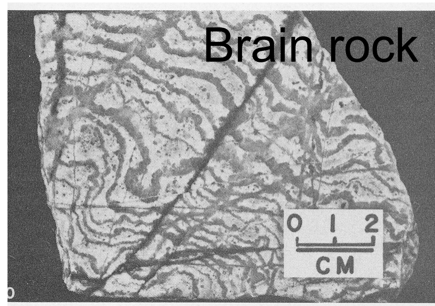
The flavors of porphyries

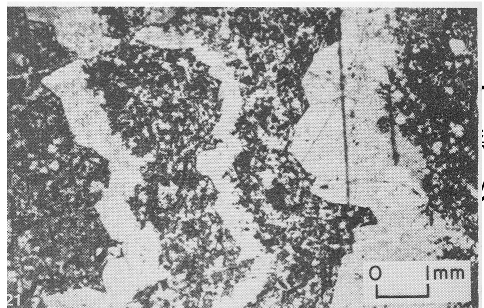
Cu, Mo, Sn-W, Au

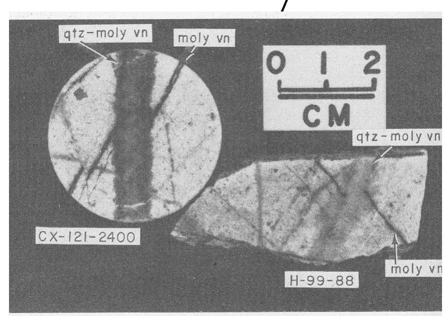
The Climax Porphyry-**Mo**

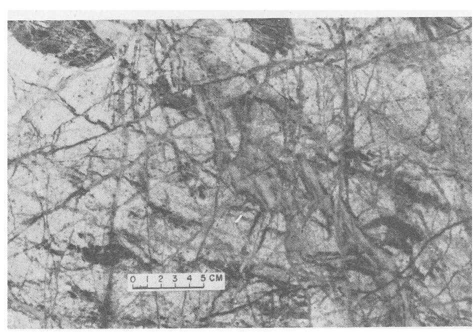
Climax, Co











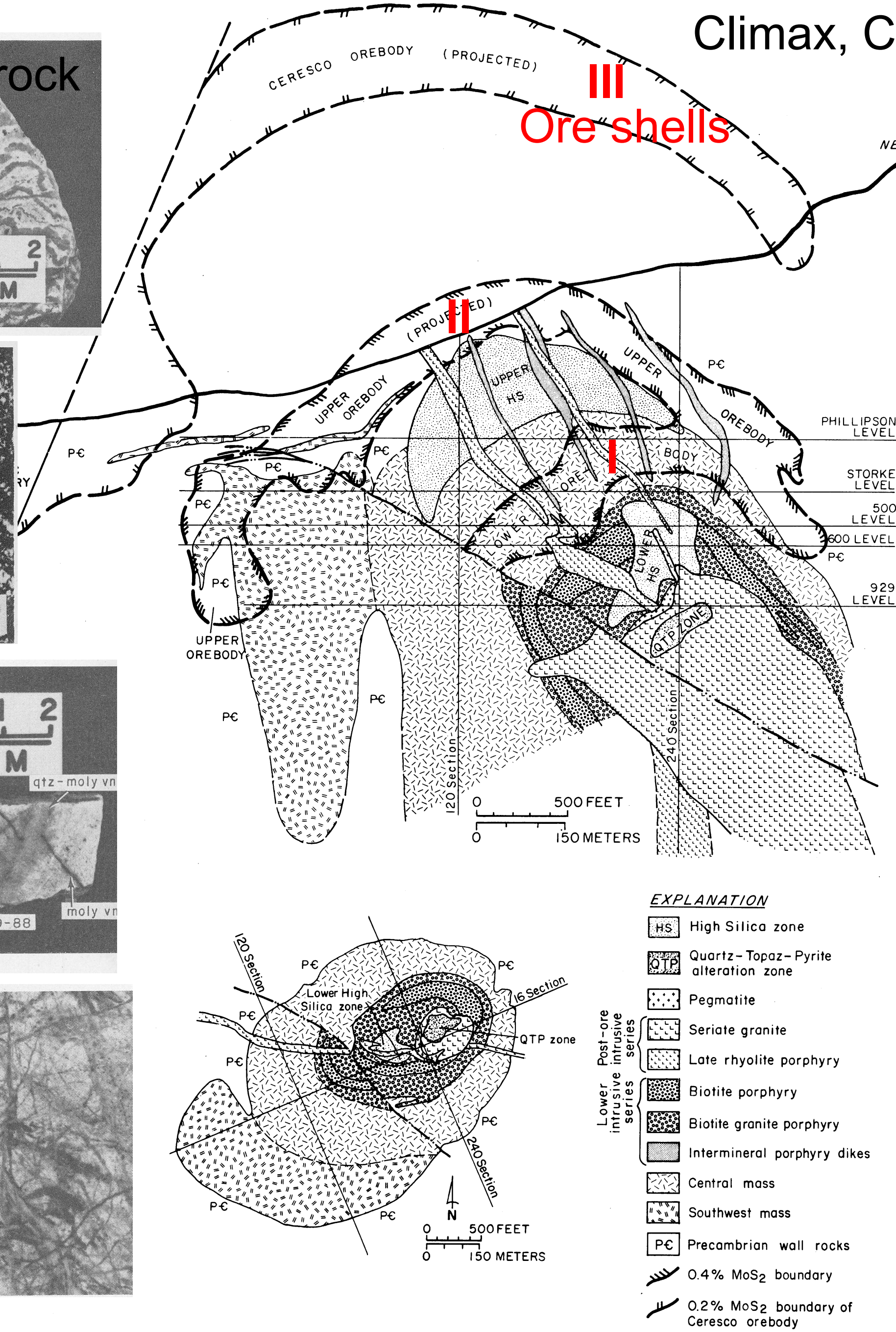


FIG. 2. Climax section 16 showing generalized geology and ore zones. Generalized geologic map of 929 level (inset) shows location and orientation of section 16.

White et al. (1981)

1. Deeper (inhibits Cu)
2. Multiple shells
3. More contained
4. Oxidized relative to W

⇨ Depth and magma f_{O2} control metal mix

Partitioning relations

- Deeper volatile separation favors Mo and W over Cu
- Lower f_{O2} favors volatiles rich in W rather than Mo
- Cu $\rightarrow$ po, Au $\rightarrow$ Cu and Fe Sulfides. Thus oxidized magmas favor Cu, and magmas which loose volatiles without precipitating Cu or Fe sulfides favor gold

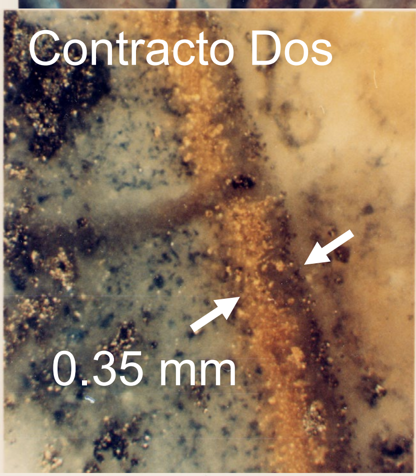
Candela (2005)

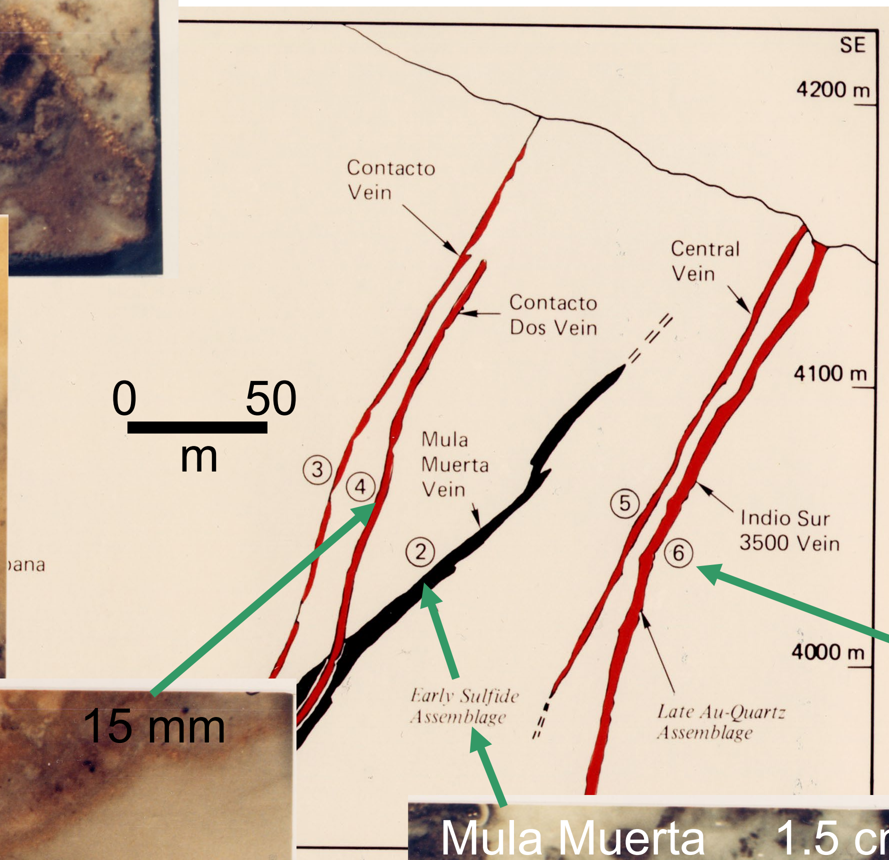
The tops of porphyries

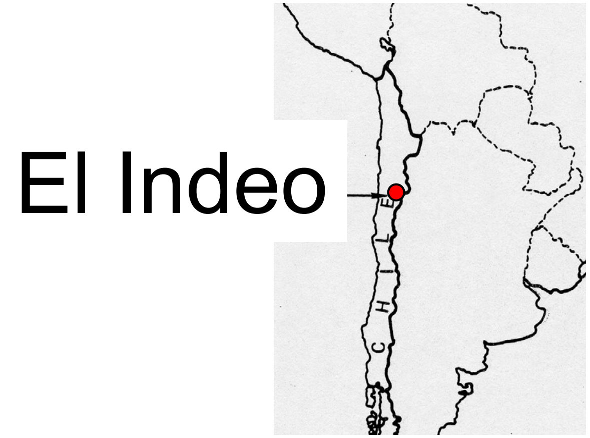
More gold

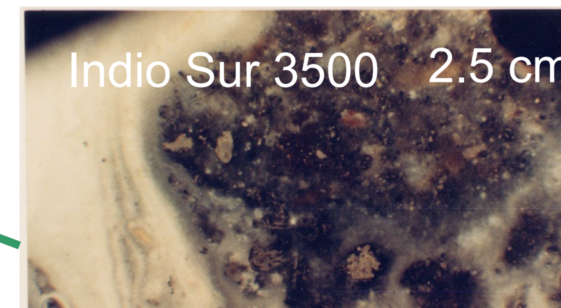
Gold- frosting on top of porphyry

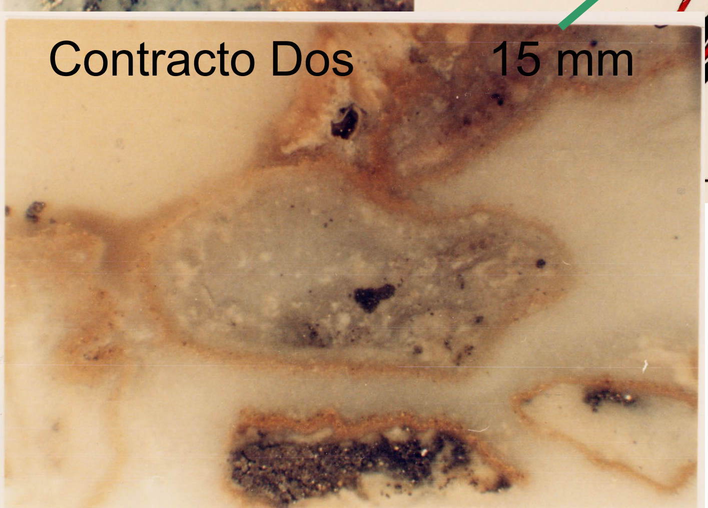
Consequence of near-surface venting magmatic volatiles

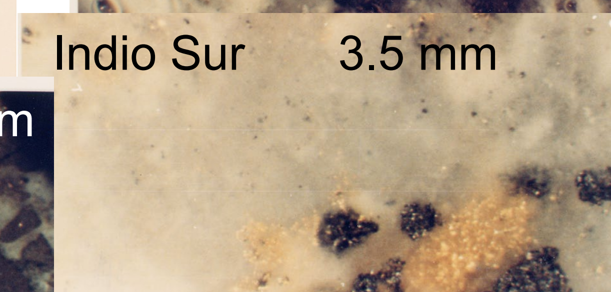












O'Brient (1984)

Fluid salinity controls Au

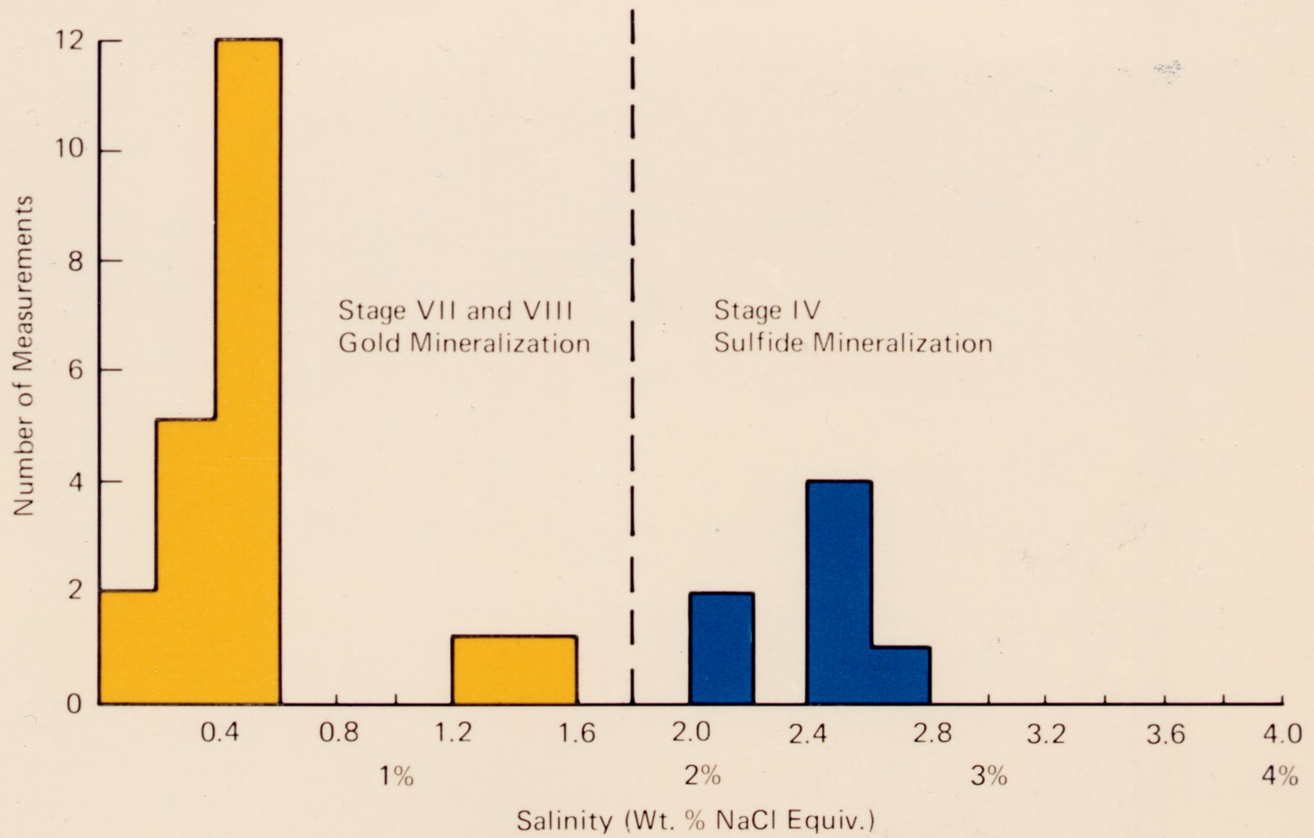


Figure 30

Fluid inclusions have a bimodal salinity distribution that can be correlated with specific mineralization stages. The earlier sulfide-rich stage is moderately saline, but the younger gold-rich stages were precipitated from distinctly fresher waters.

O'Brient (1984)

Inferred system evolution

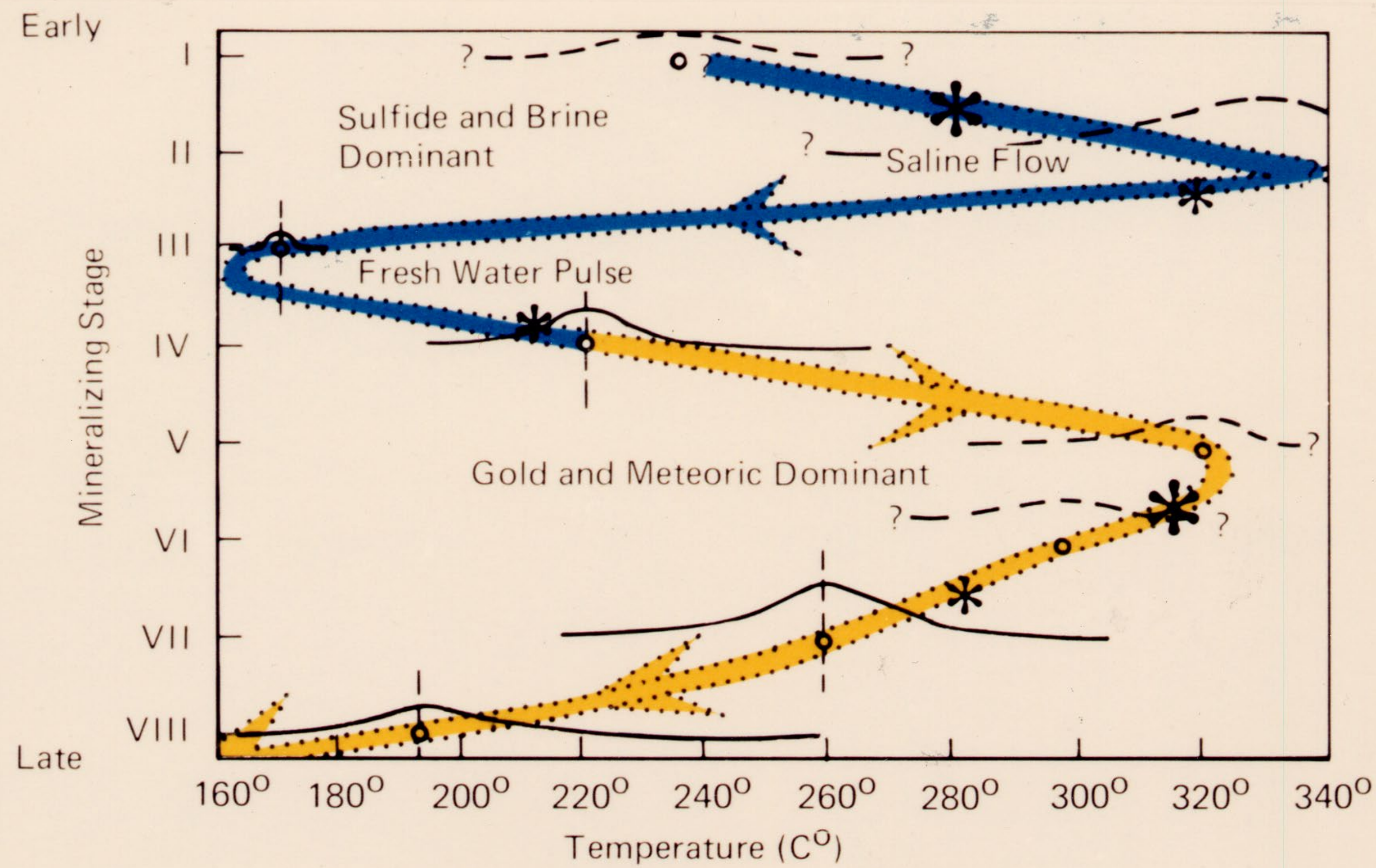
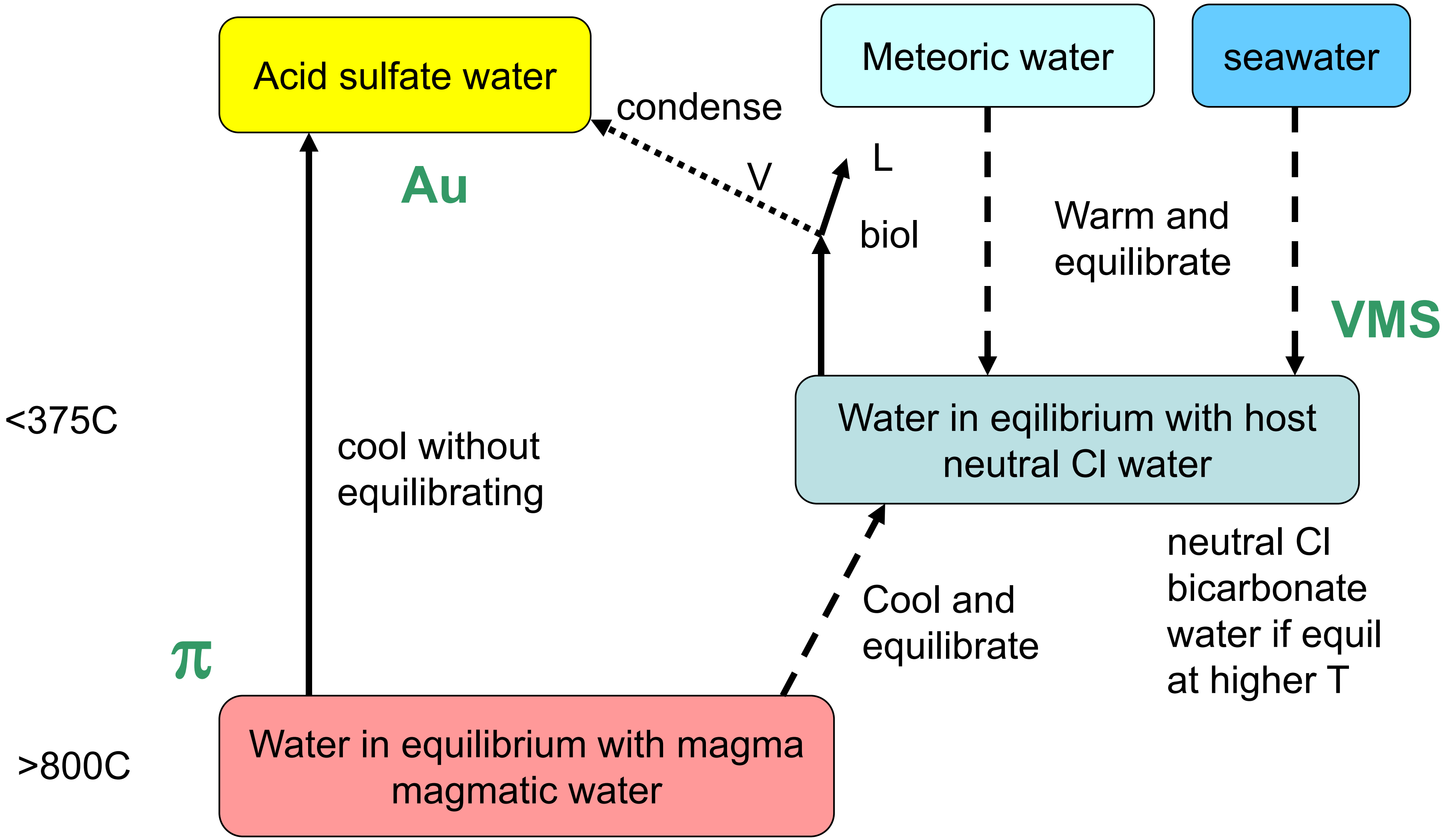


Figure 41

Composite (and highly schematic) plot of fluid evolution at El Indio. Actual fluid inclusion means, shown by vertical dashed lines, used to constrain stages III, IV, VII, and VIII; inferred temperatures from mineral assemblages used for rest. Brecciations are marked with *, with larger symbol for bigger events.

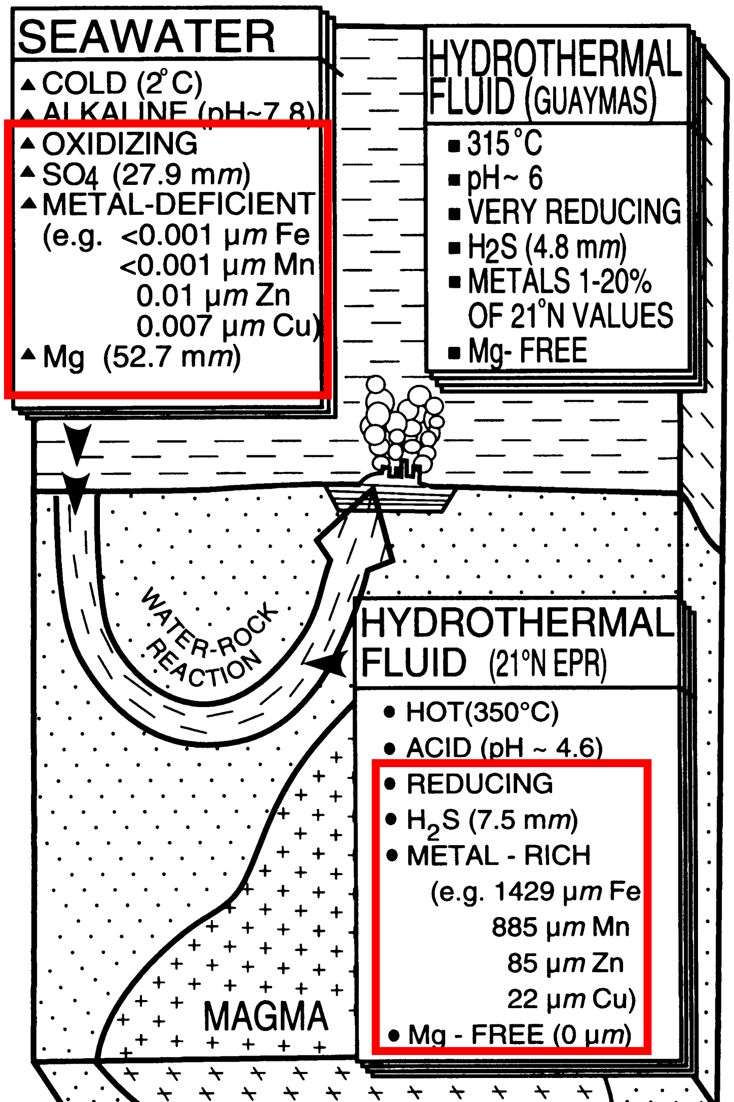
O'Brient (1984)

Summary of fluid types and relations



The metal cycle

SW sulfur enriches ocean crust

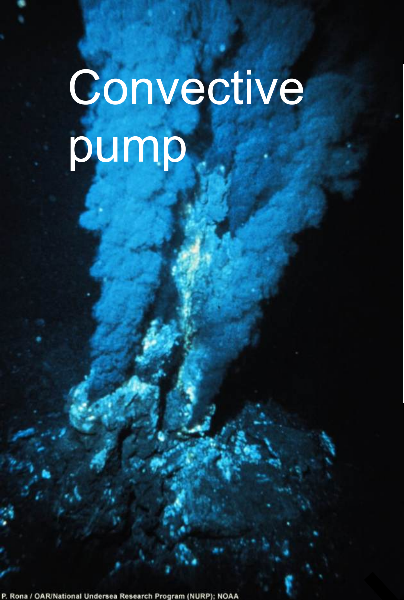


Scott (1997)

Chemical change due to MOR convection

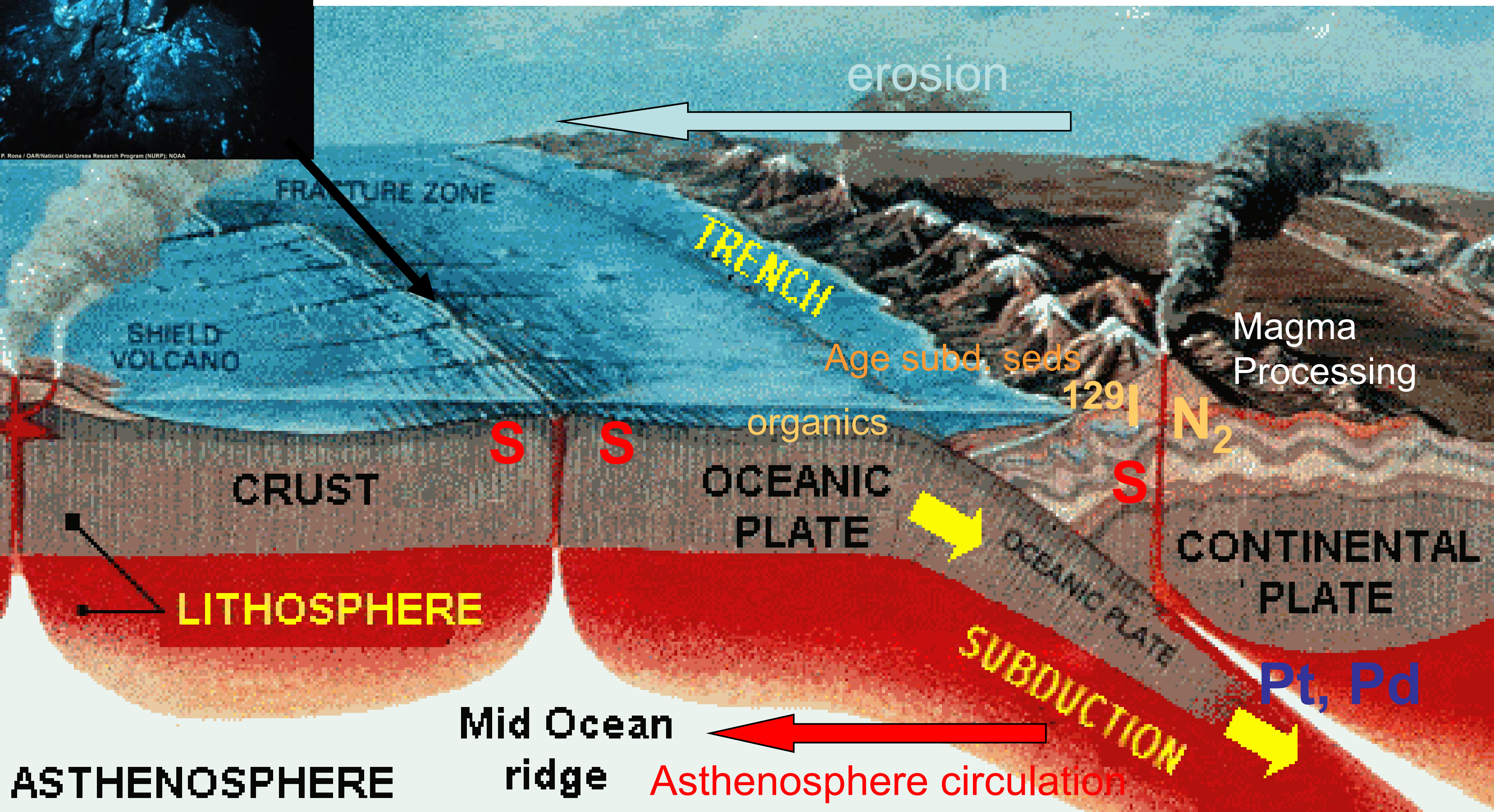
	Δ [mmol]	At Wt	10^{12} mol/yr	10^{6} t/yr
S	-20.4	32	3.7	**120#**
Mg	-52	24.3	9.3	**226#**
Fe	1.492	55.84	0.27	**15**
Mn	0.885	54.93	0.16	**8.8**
Zn	0.085	65.37	0.015	**1**
Cu	0.022	63.54	0.004	**0.25+**

Numbers assume 180 $km^3\ yr^{-1}$ seawater circulation ≥300°C
3x larger @ >150°C.
Cumulative Cu production = 600×10^6 t = 2400 yrs of circultn



1. East Taupo Volcanic Zone N_2 and I from organics
   N_2/Ar ~400; ^{129}I age equals that of subducted organics
2. Porphyry S isotopically from seawater
3. Pt, Pd from mantle source

Hattori and Kieth (2001), Fehn and Snyder (2003), Giggenbach (1997)



Summary

1. Porphyries, one of most important OD types, form where magmatic water vents from qtz monzonite intrusions
2. Magmatic water, in equilibrium at high T, is highly reactive (acid) when cooled
3. Basaltic sill intrusions contribute S and may trigger rapid expulsion of magmatic volatiles
4. Porphyries source of Cu, Au, Mo, Sn, W, and REE (Pt, Pd,Th,…)
5. Gold deposits like El Indeo form near surface where magmatic volatiles vent
6. Top (Au) and bottom (p) of vent system mineralized, middles may be barren
7. Metal cycle (concentr in oceanic crust and sediments with recirculation through asthenosphere and erosion) may account for enriched regions

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