

Variable characteristics of epithermal Au-Ag deposits: Exploration in Mongolia

- Tectonic settings: porphyry-epithermal relationship
- Epithermal deposits formed in extensional settings
- Epithermal deposits formed in intrusive-centered settings
- Lithocap mineralization: transition to tops of porphyry deposits



*Jeffrey W. Hedenquist
Ottawa, Canada*

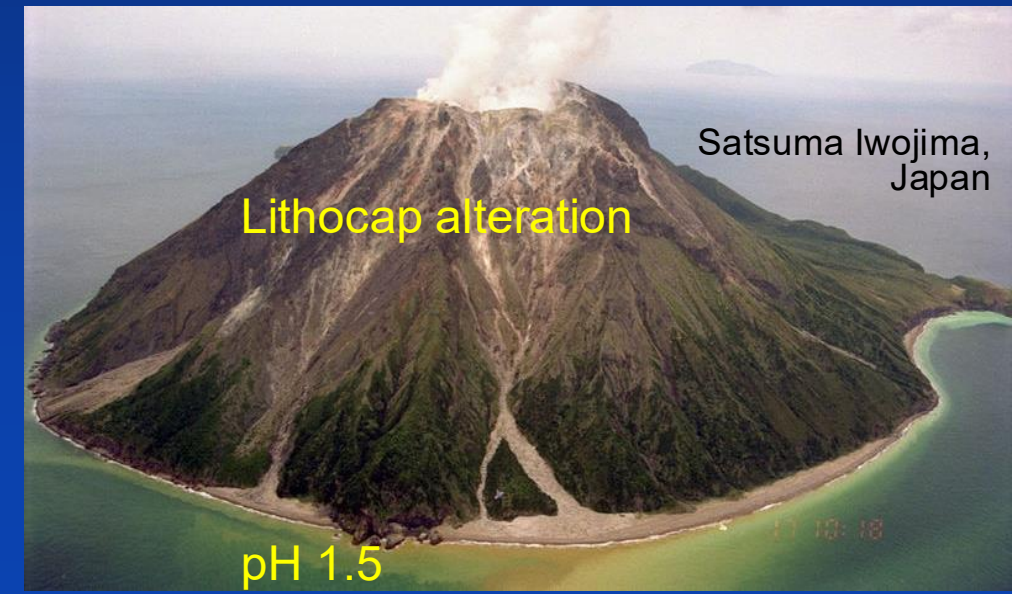


Waiotapu,
New Zealand

pH 5.5

Silica sinter

Evidence
from
active
analogues

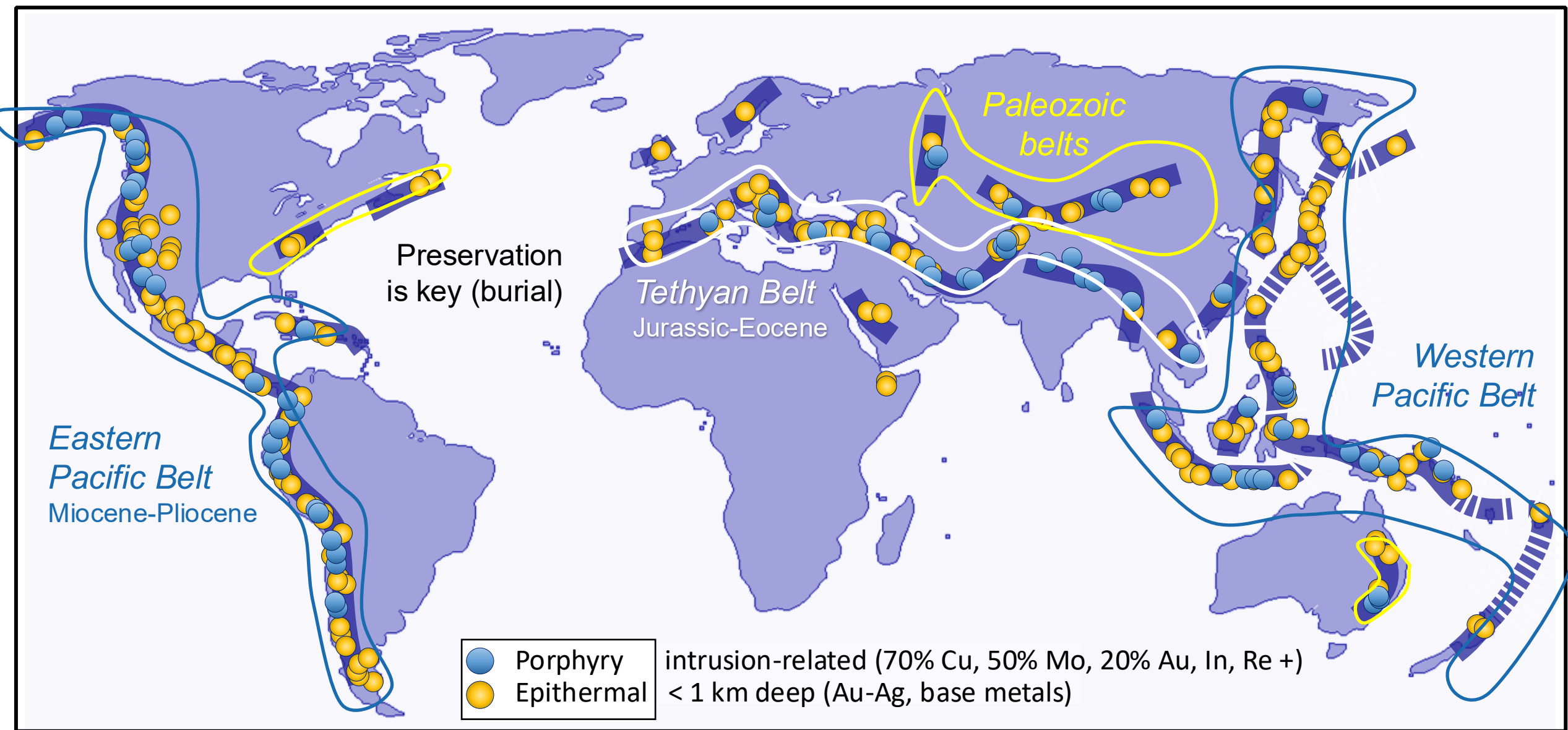


Satsuma Iwojima,
Japan

Lithocap alteration

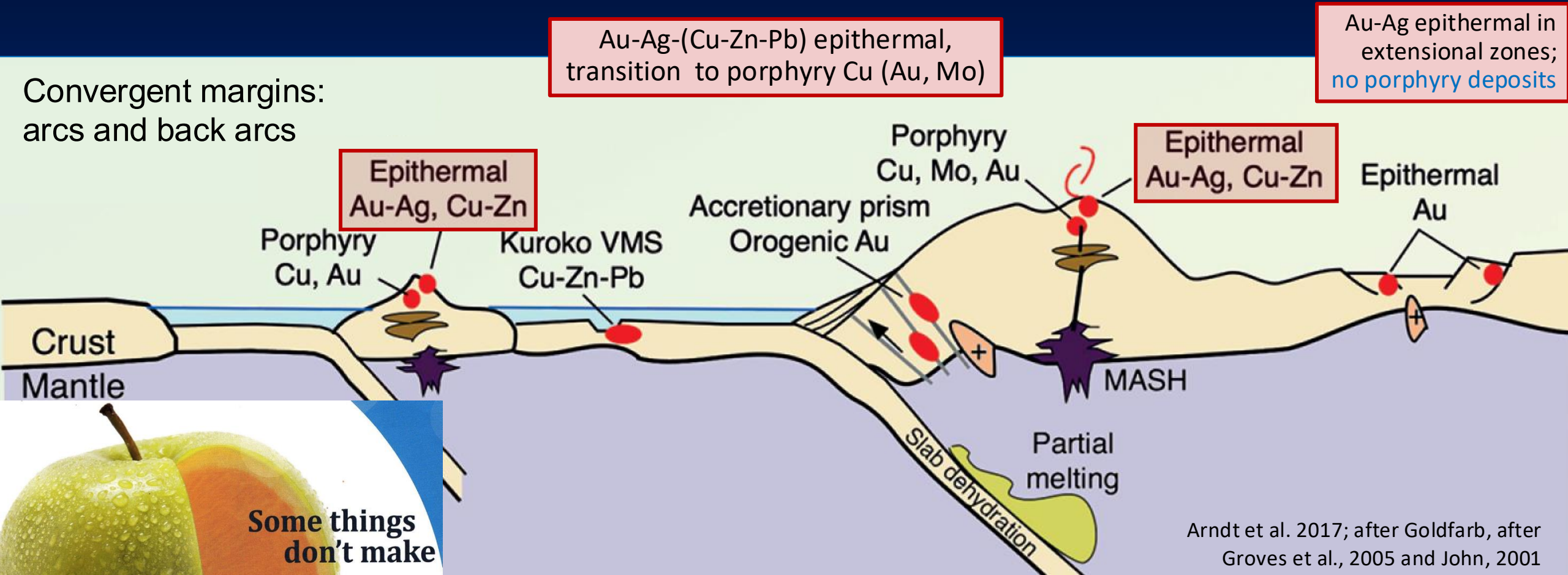
pH 1.5

Location of metallogenic belts at convergent margins: typical epithermal and porphyry deposits

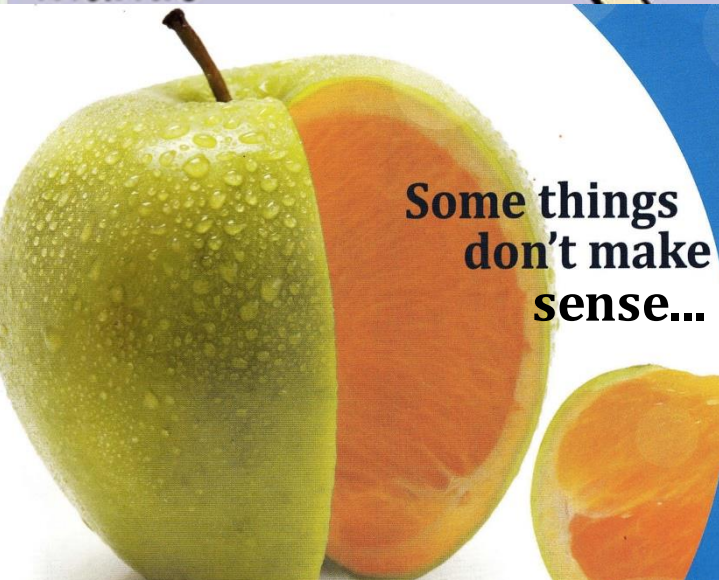


Porphyry systems (porphyry deposits, ~1-3+ km, to epithermal levels, <1 km depth) in volcanic arcs, and epithermal deposits in extensional settings

Convergent margins:
arcs and back arcs



Arndt et al. 2017; after Goldfarb, after
Groves et al., 2005 and John, 2001

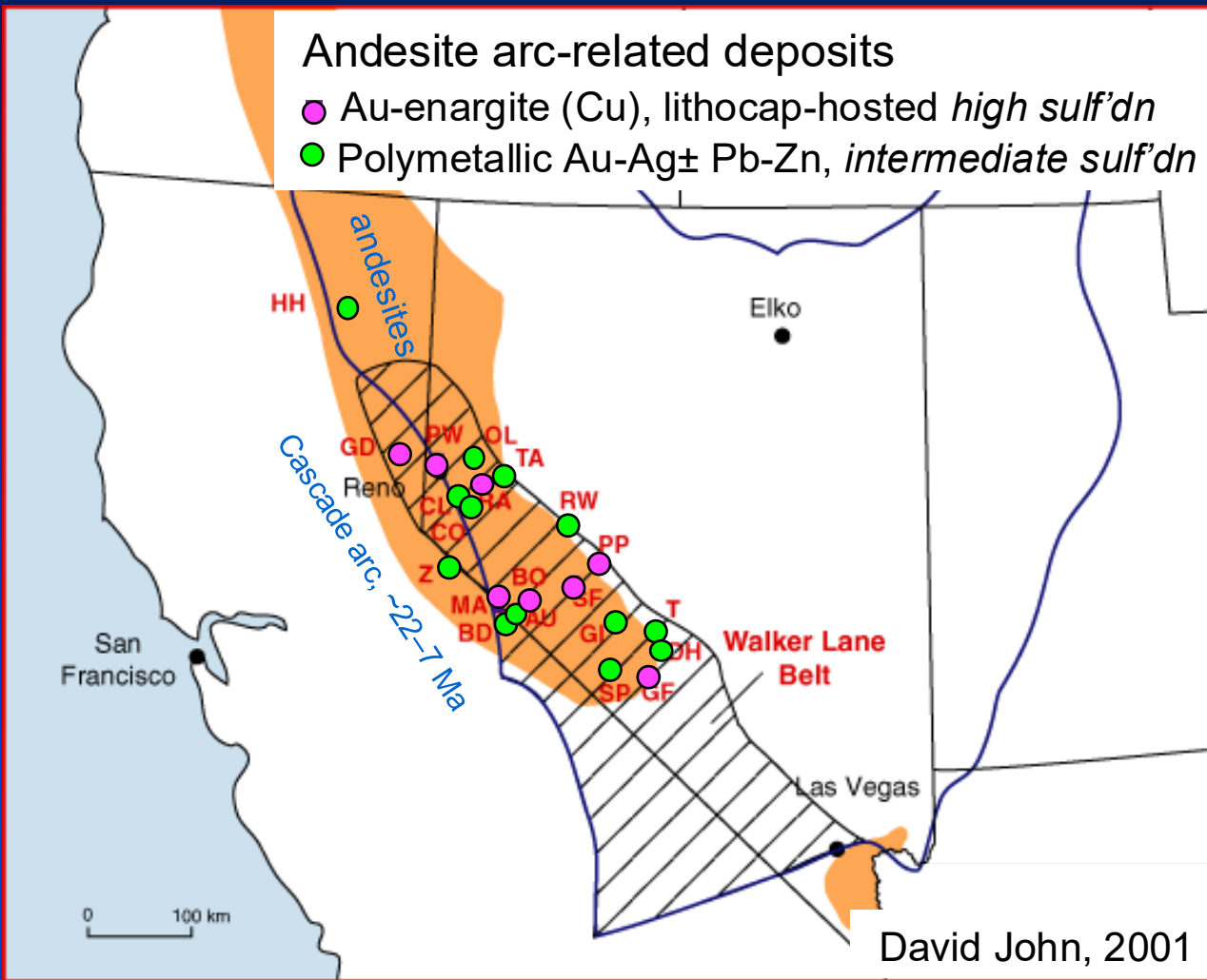
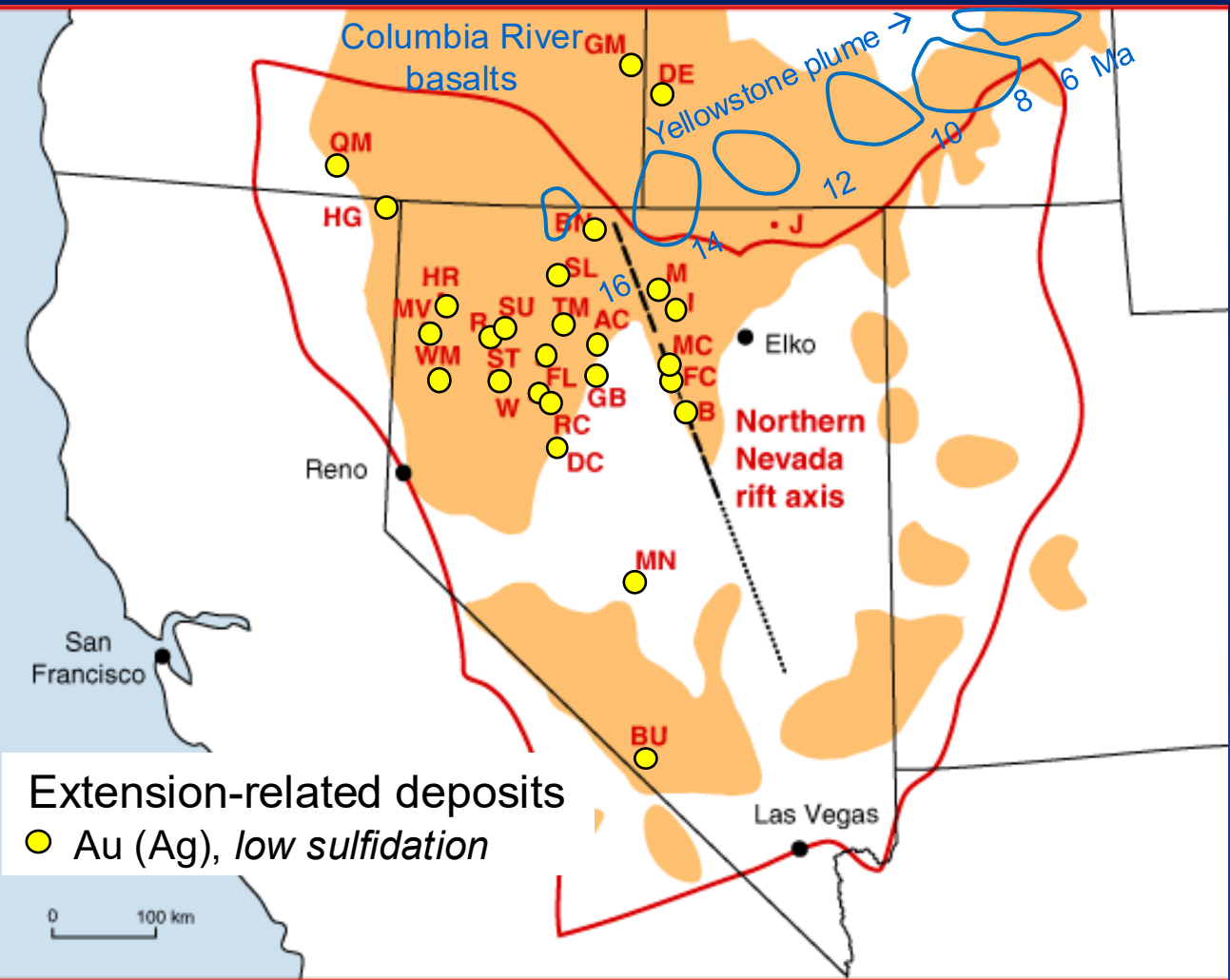


Overprinting, or hybrids?
Avoid squeezing all deposits into endmember models (boxes);
observe and describe!

Cenozoic epithermal Au-Ag deposits, Great Basin, Nevada

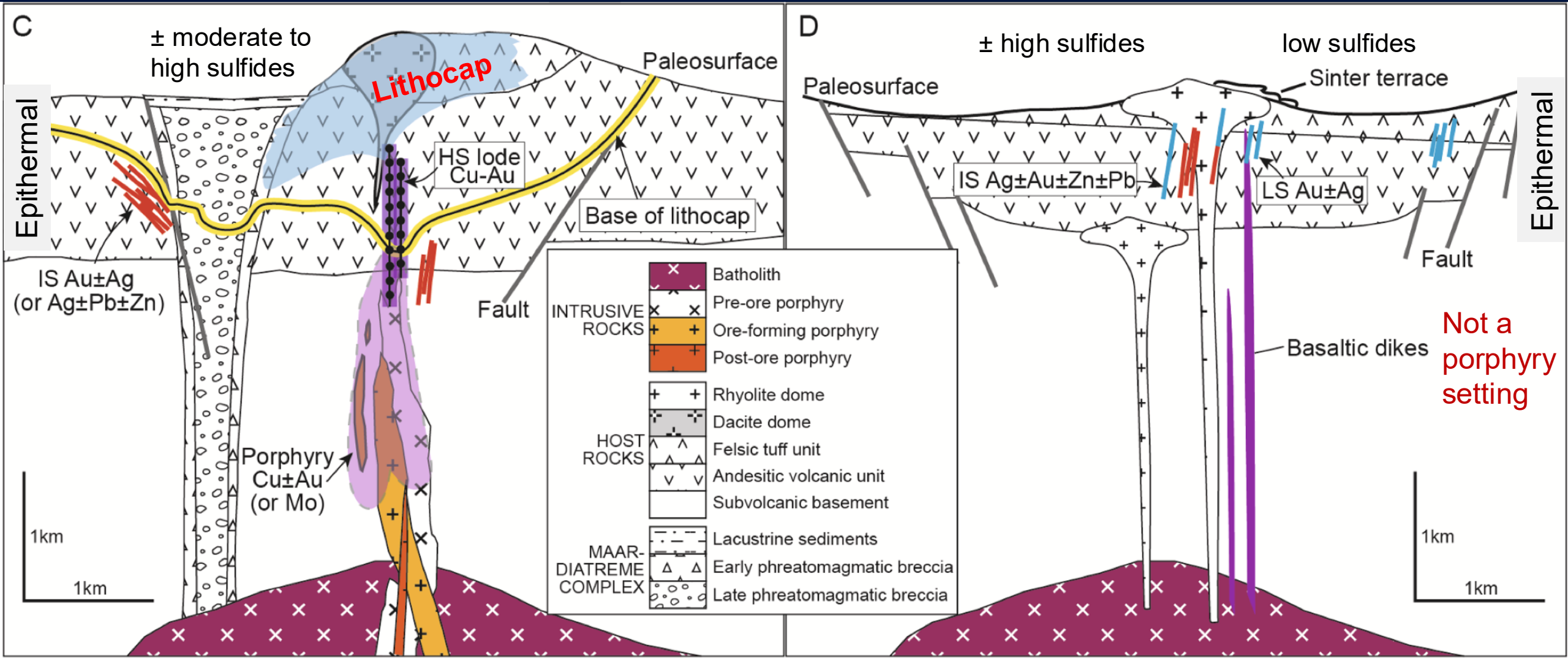
Extension → rifting (back-arc, plume),
bimodal basalt-rhyolite assemblage (~reduced)

Subduction-related continental margin arc,
andesitic assemblage (oxidized)



Tectonic setting: Neutral to compressive (subduction, arcs)

Extensional (back arc, post-subduction)



Paleodepth: Surface to ~1 (1.5) km

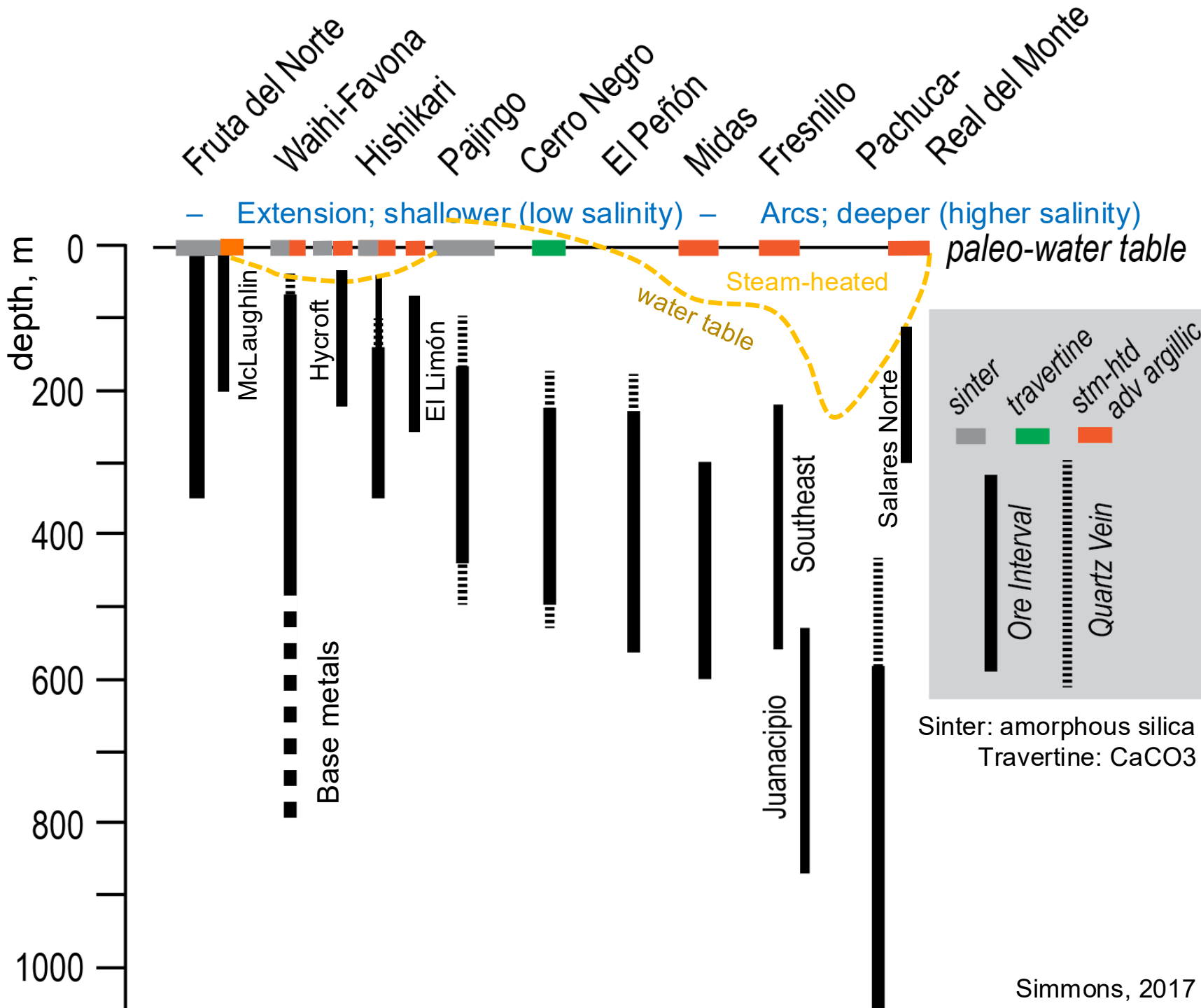
Waldemar Lindgren,
1922, 1933: <1 km
“epi”thermal: “over,
above”



Milestone sinter (tilted),
2 km from DeLamar, ID,
veins (1898 observation)



DeLamar



Waihi, New Zealand, 240+ t Au:

Martha, underground vein mine (1880s-1950s), open pit (1990s~2000), blind vein discoveries (~2000-now, UG)



No. 1 level
(old workings)

No. 3 level

Sea level

No. 7 level



Southern Coromandel peninsula, New Zealand

Lessons: near-mine satellites plus ore deposit discoveries from 2000, *after* 120 years of mining in district

*Analytic signal (nT)
and epithermal veins*

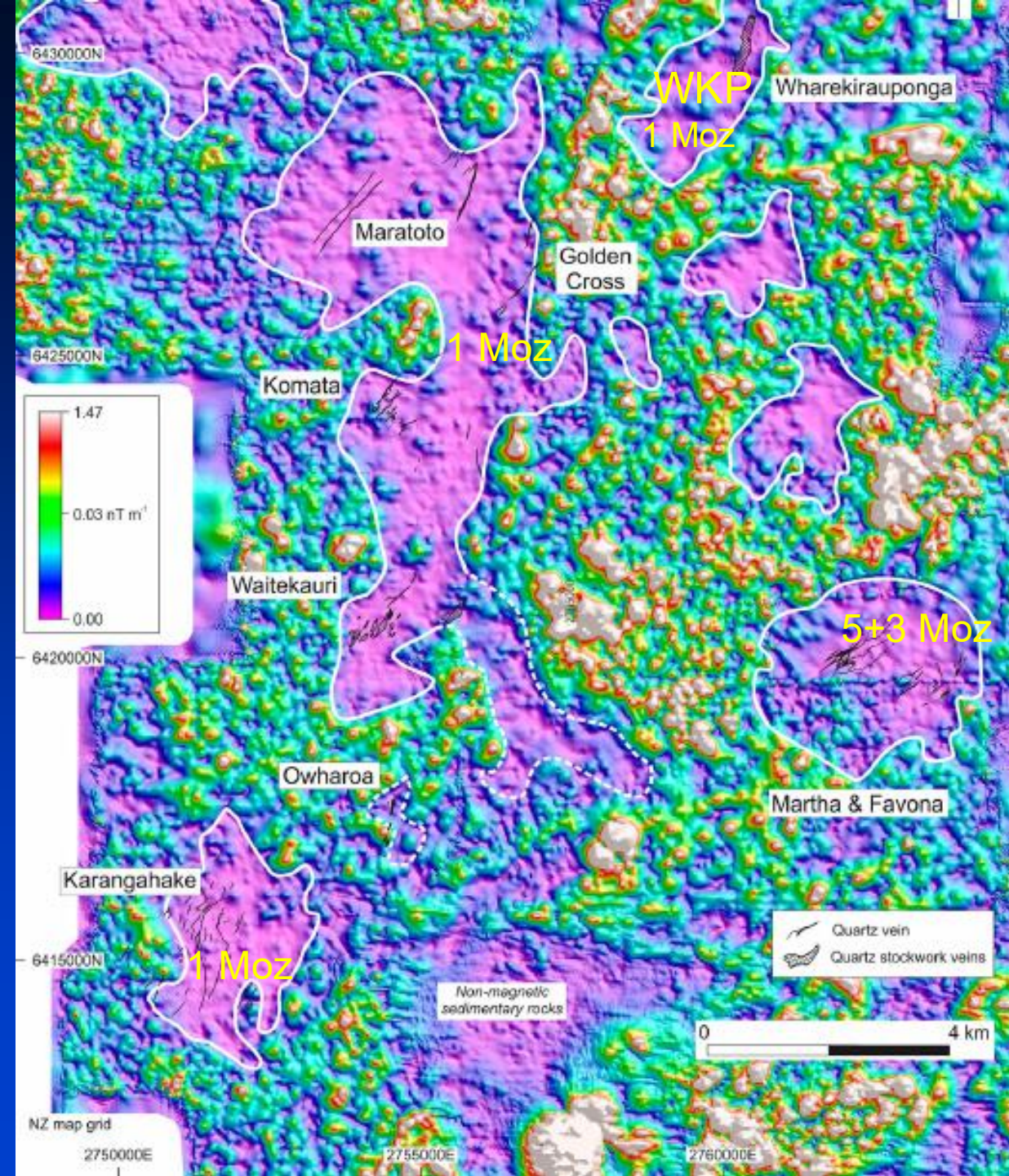
Production from Coromandel peninsula, 1880s to present,
~12.3 Moz Au, ~54.0 Moz Ag
80% from the southern Coromandel. 90% of gold produced from **andesitic host**, with balance from **rhyolite**

Quartz veins range from 200 to 1600+ m length, 0.3 to 5 m wide,
with **vertical mined interval of 170 to 330 m**

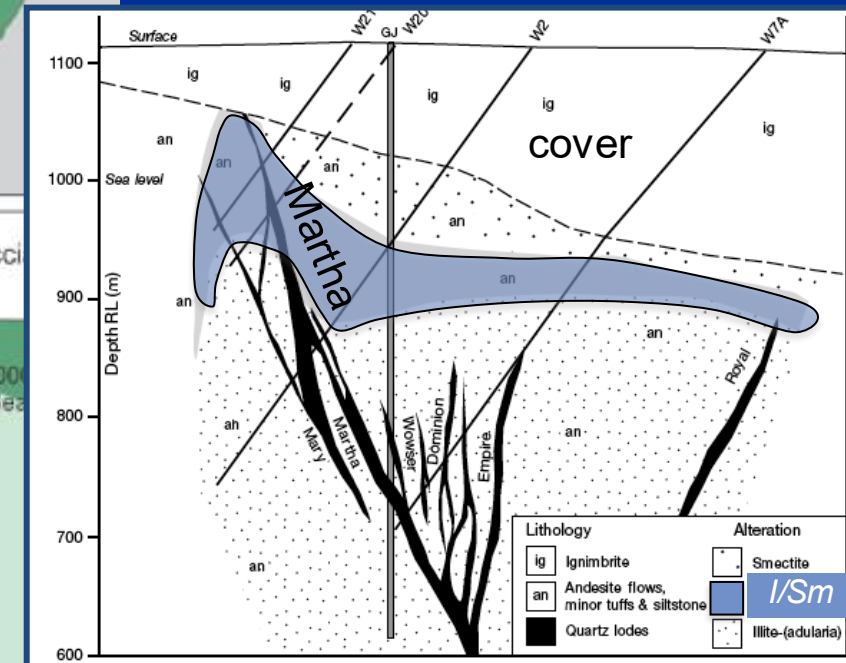
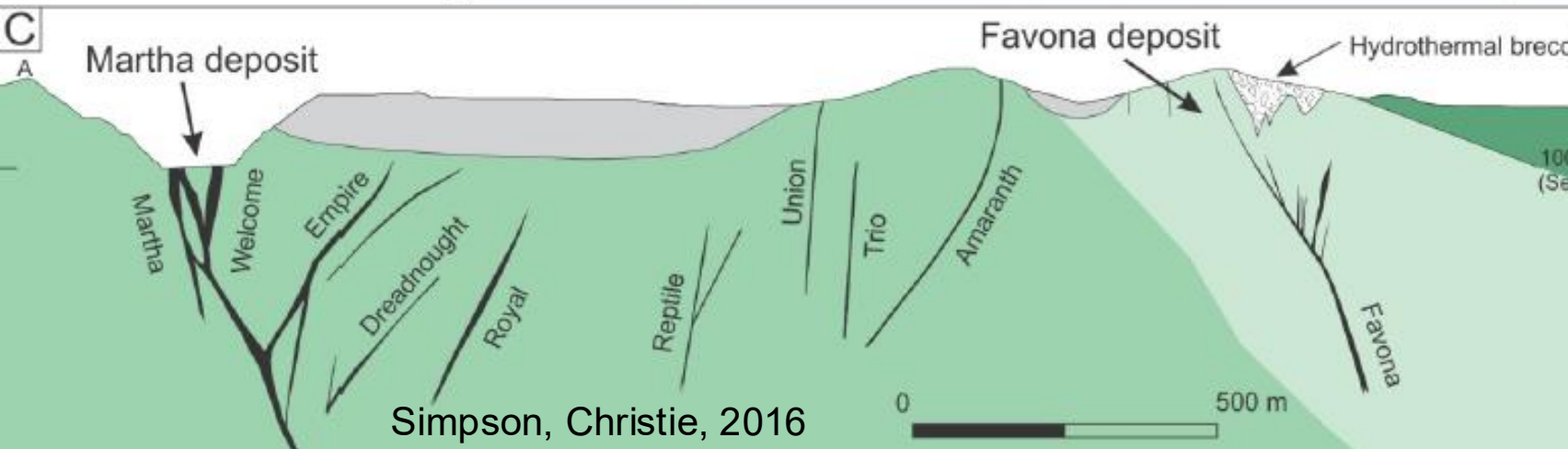
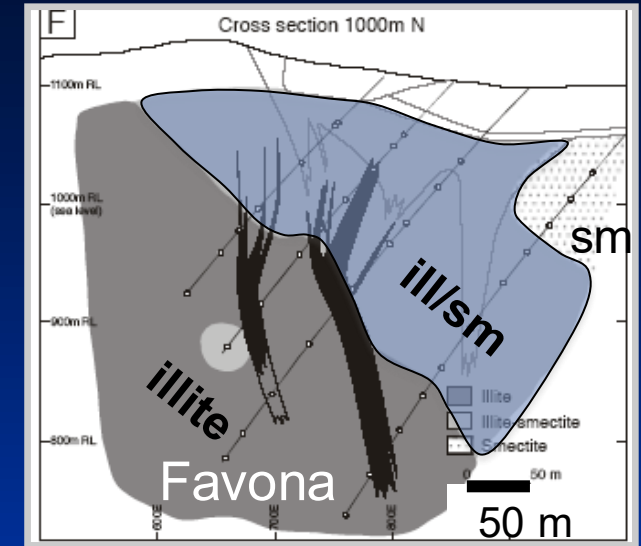
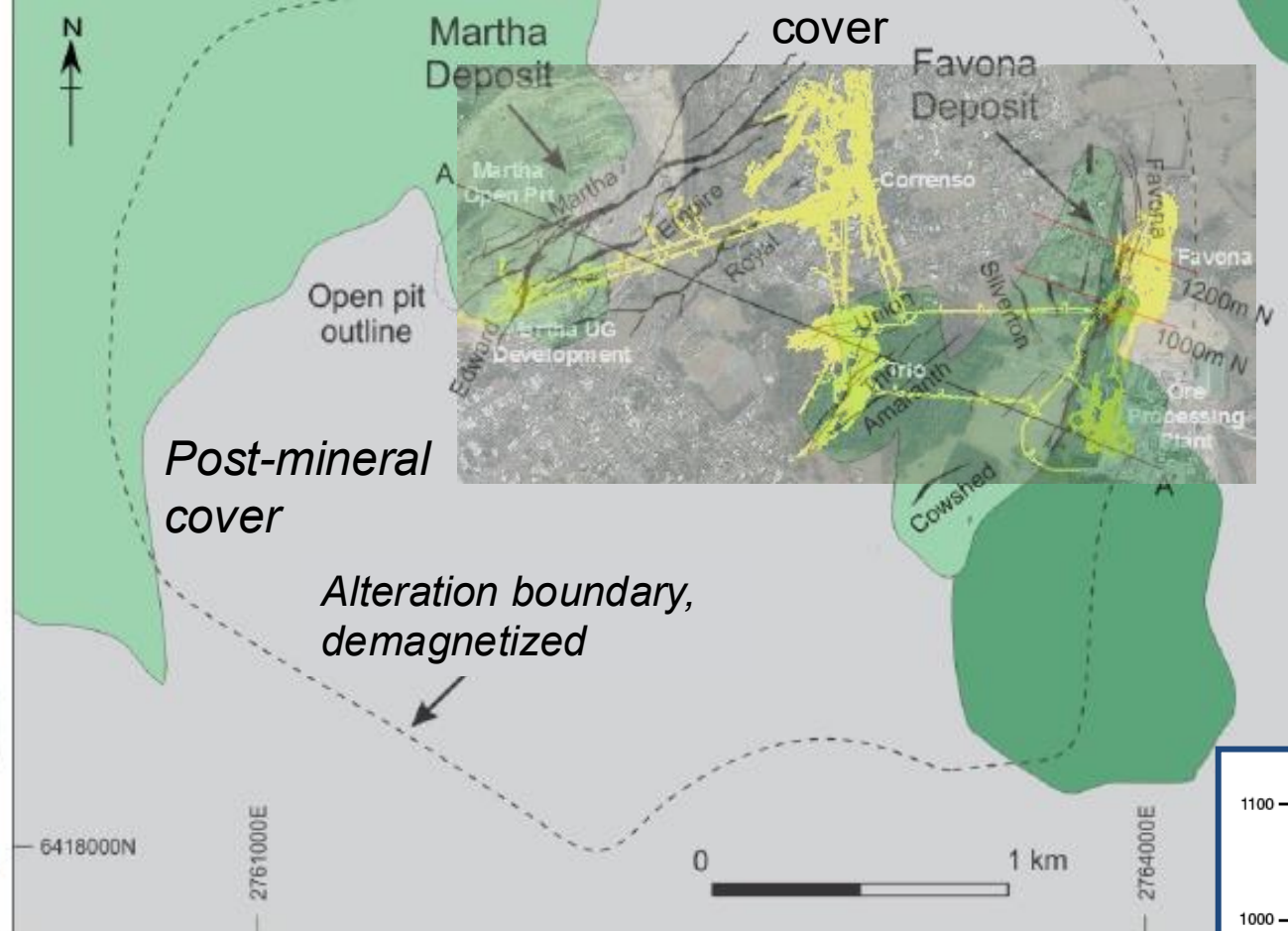
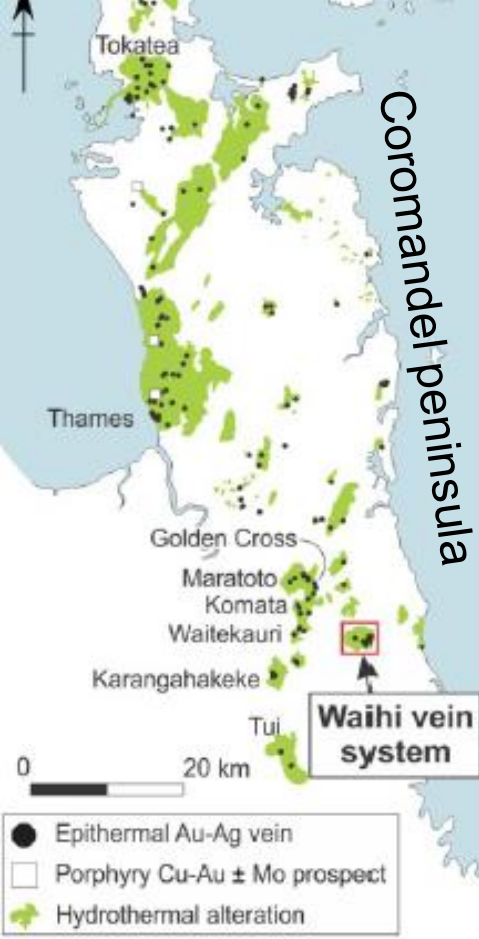
Size of hydrothermal system indicated by magnetite destruction
in volcanic rocks; size of mag low does not correlate with metal
content. Some systems coalesced

WKP, discovered 2017 (1.1 Moz I+I @ >12 g/t)

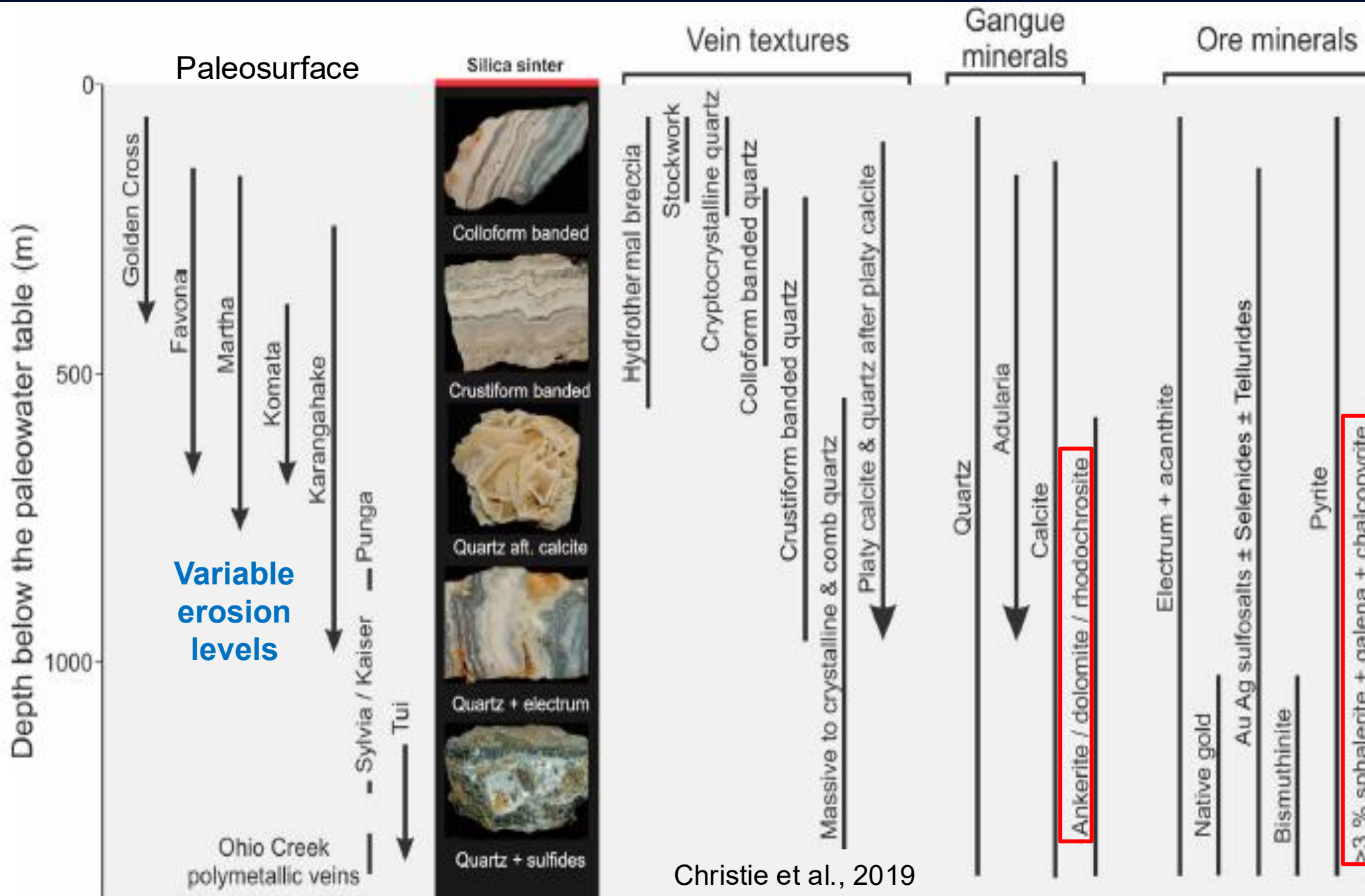
From Simpson and Christie, 2019, based on Morell et al., 2011



Post-2000 blind vein discoveries



Coromandel peninsula, NZ, epithermal deposits: vertical variations in features



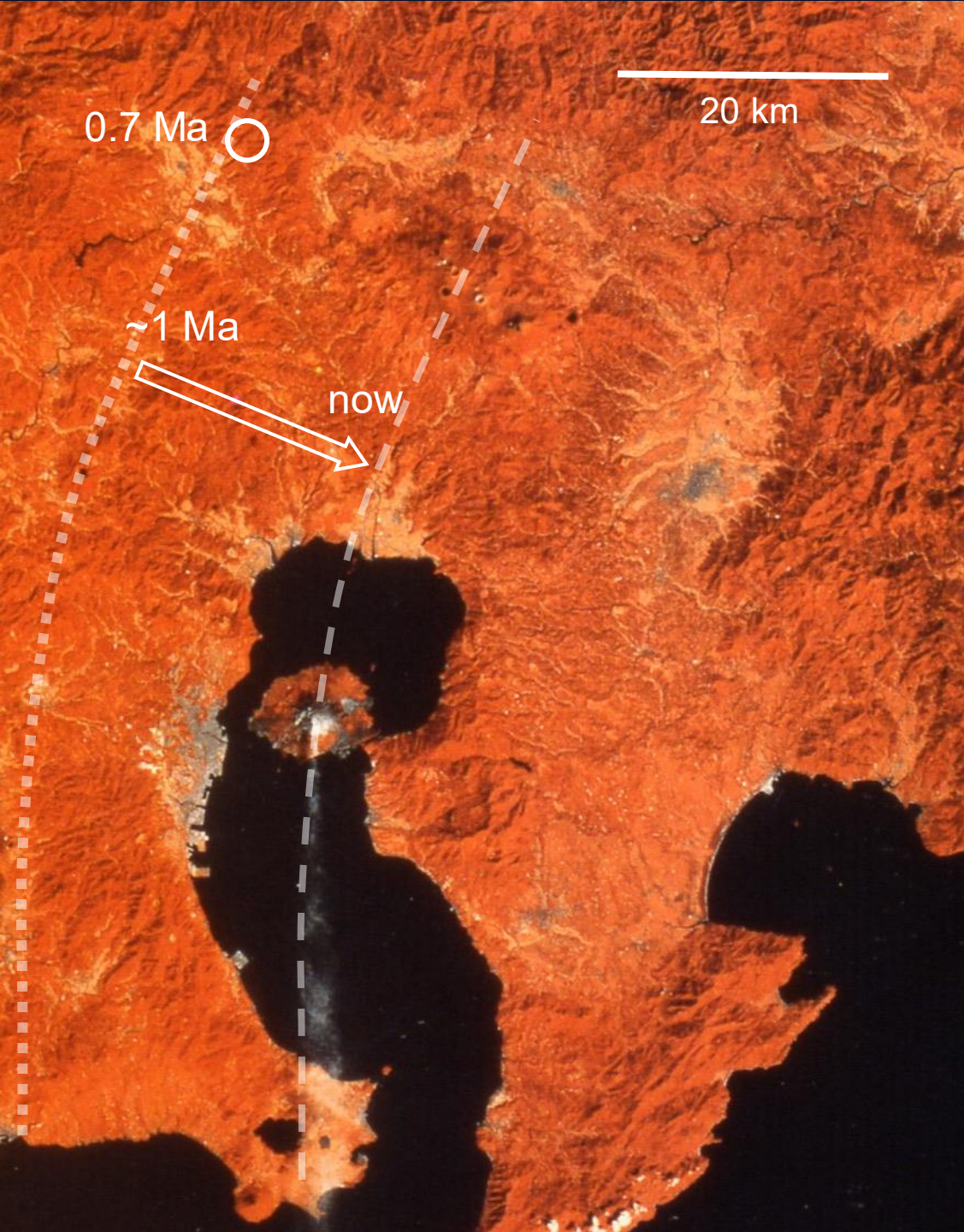
Textures, mineralogy

Martha, Empire vein

Karangahake

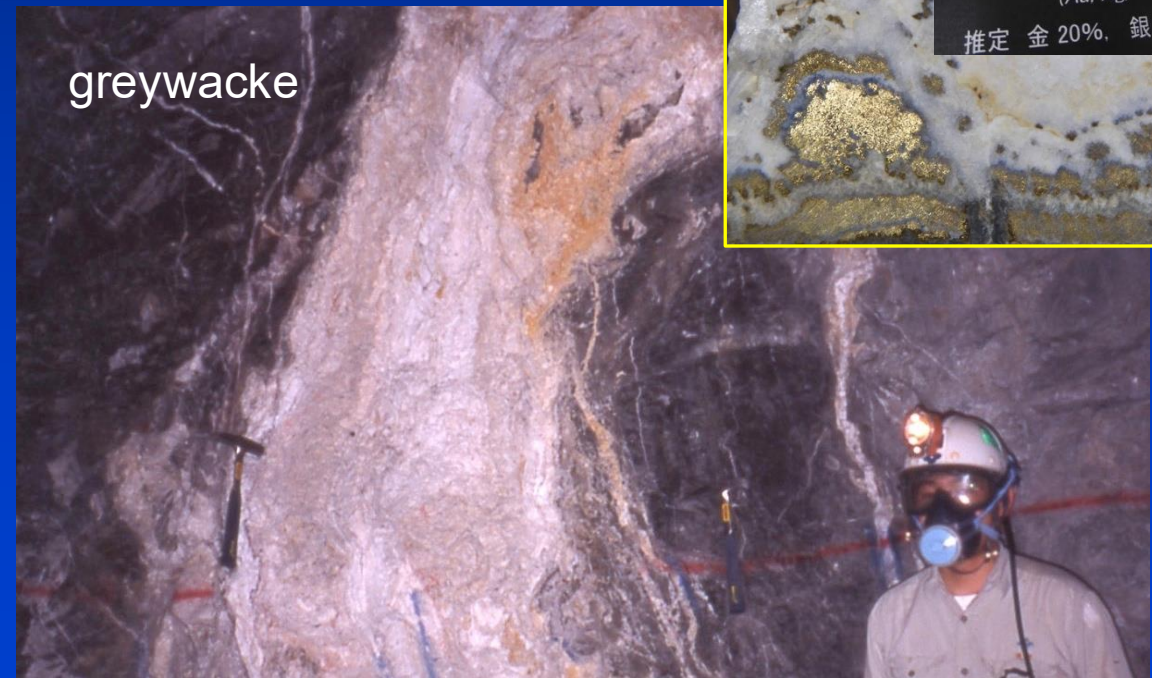
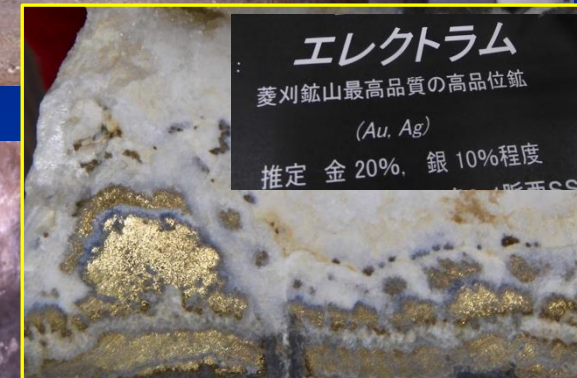
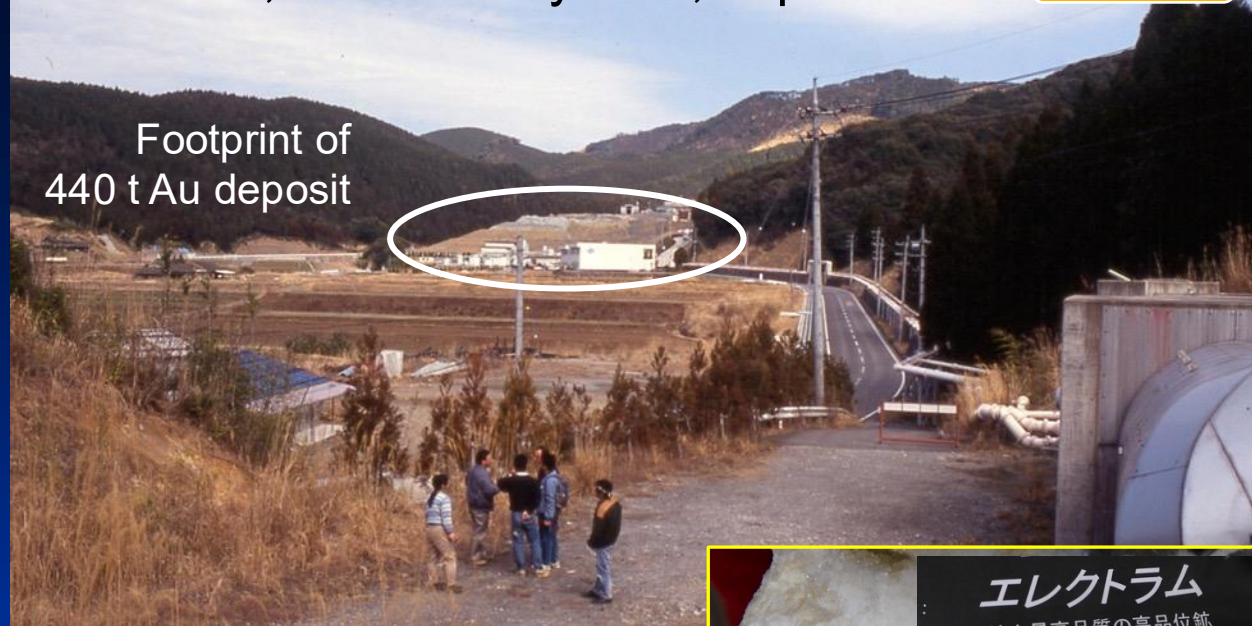
Doug Kirwin photos

Christie et al., 2019



Hishikari, southern Kyushu, Japan

Bonanza



Alteration zoning

Temp. °C

100

200

300

Smectite
Illite/smectite
Chlorite/smectite
Illite
Chlorite

Musc
(ser)

tridymite gone

smectite,
kaolinite

smectite-
chl

highest
paleotemp

Honko deposit

Sanjin deposit

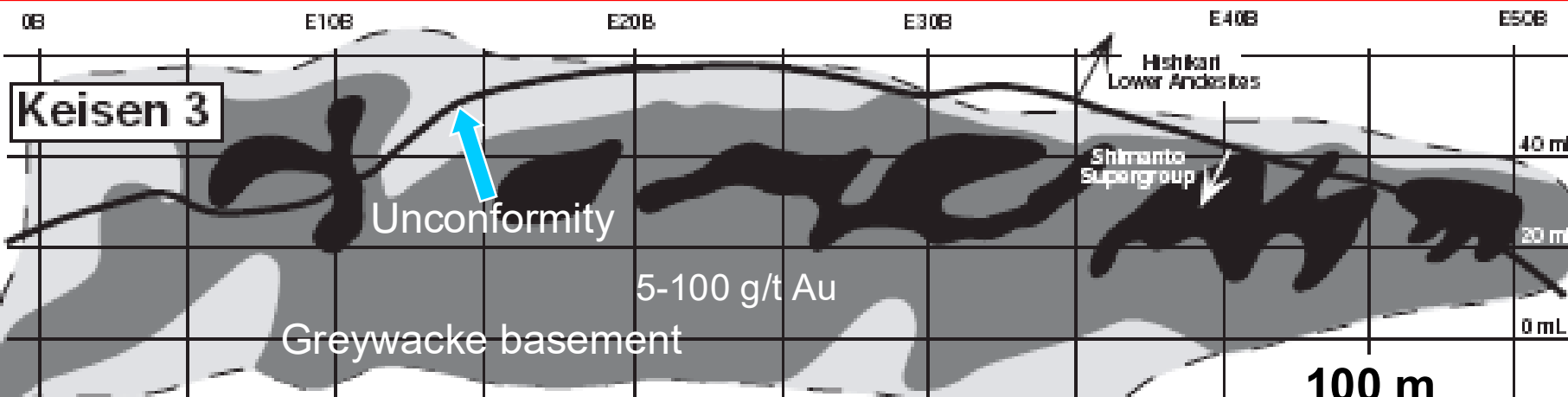
vein projections
to surface

500 m

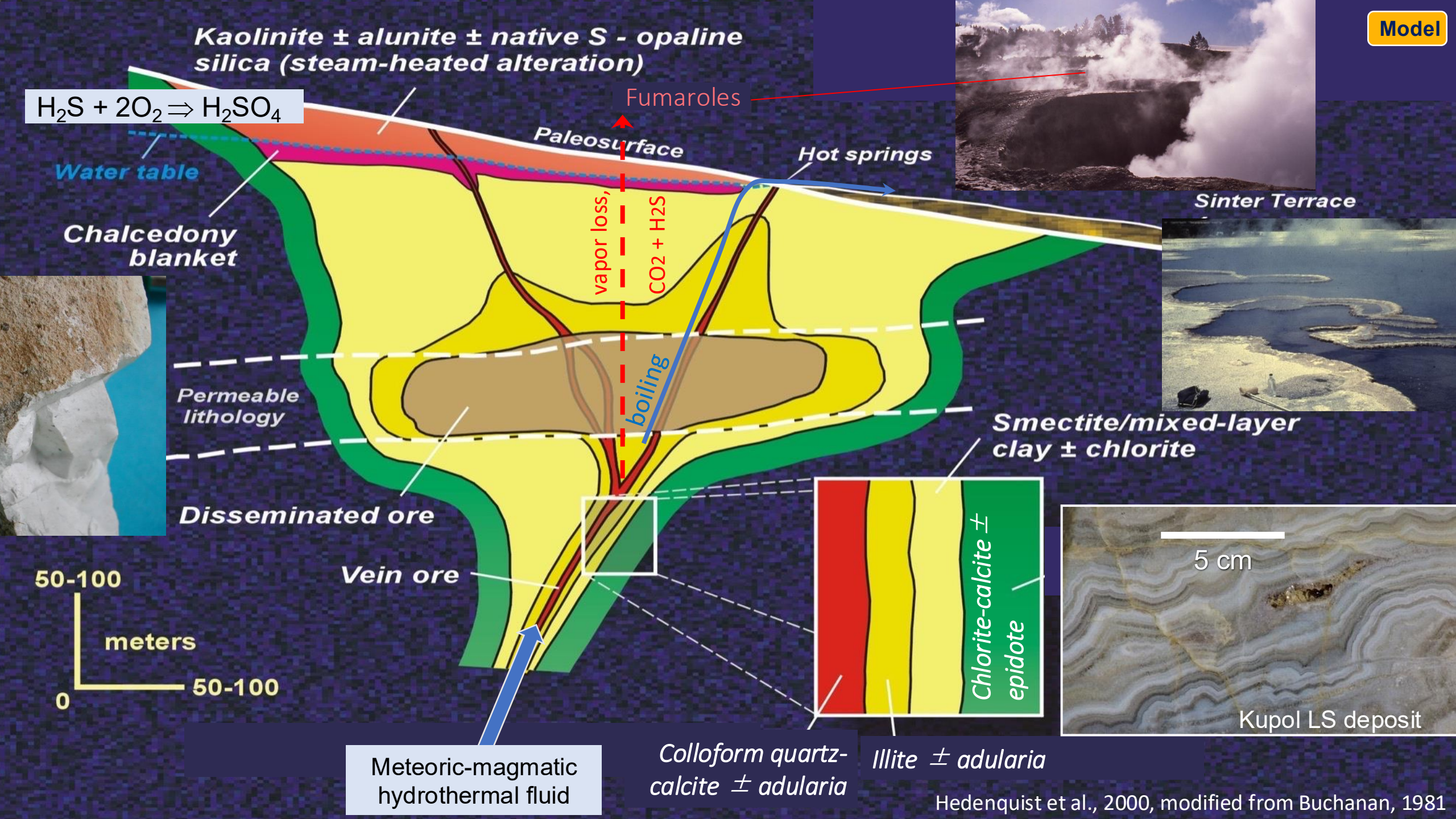
Hishikari, Kyushu:
Alteration from 220
samples, XRD study;
veins projected to
surface, no outcrop

Izawa et al., 1990;
Faure et al., 2002

Yamada deposit



Long section

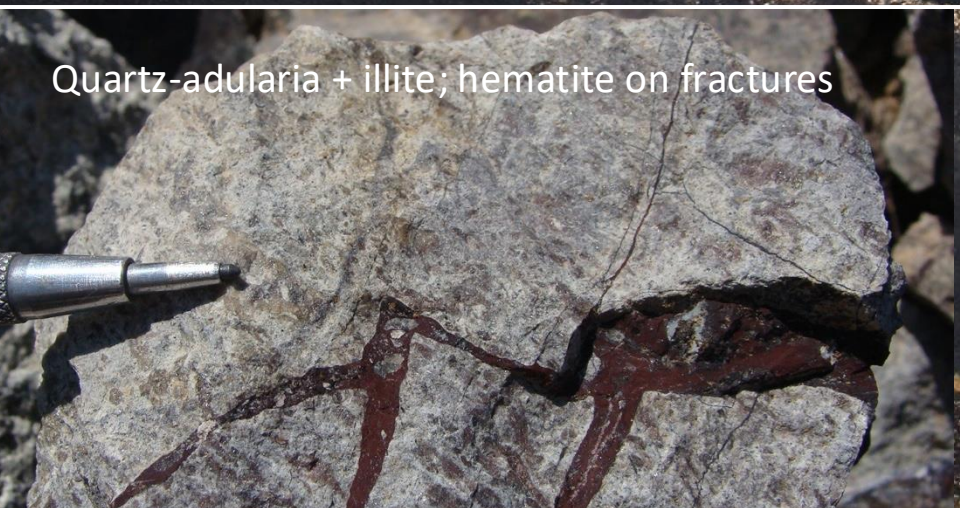
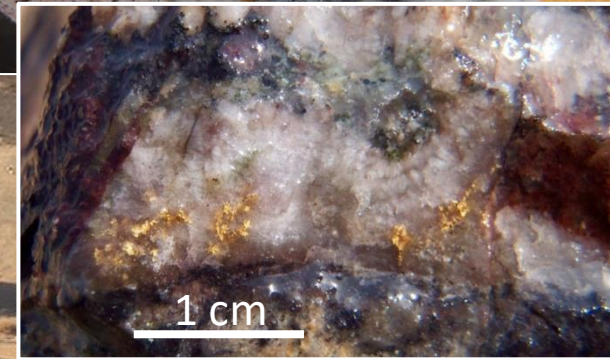
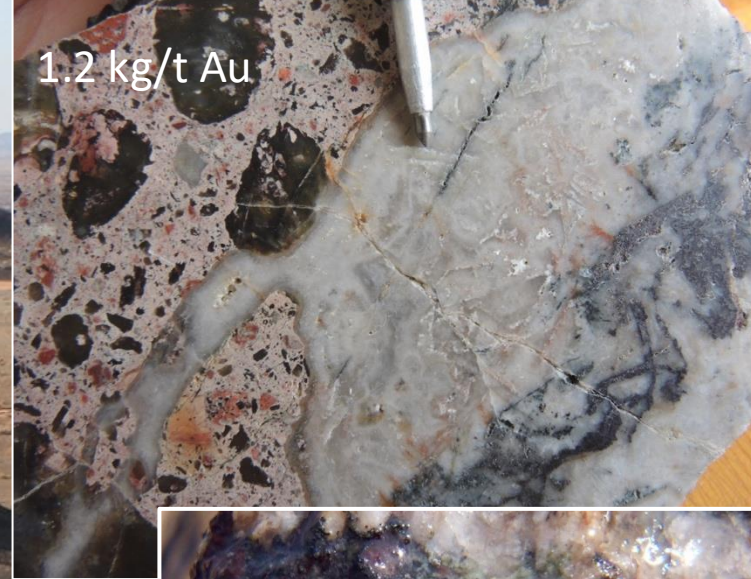
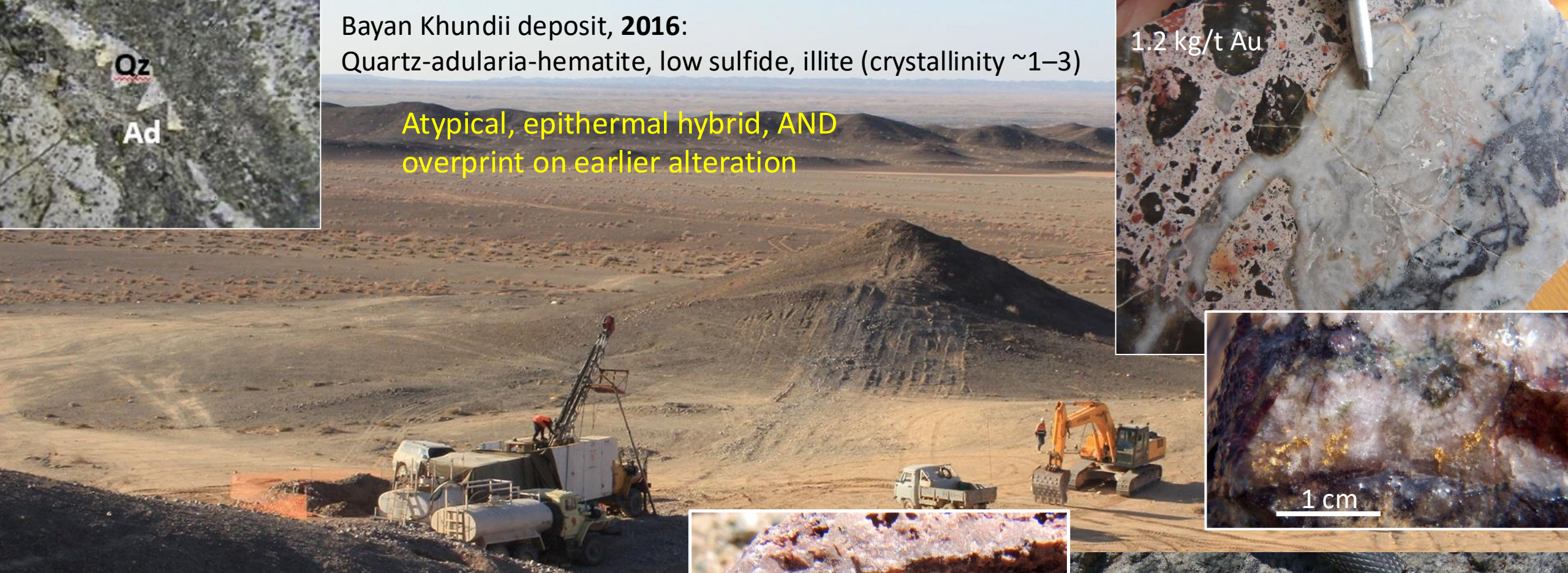


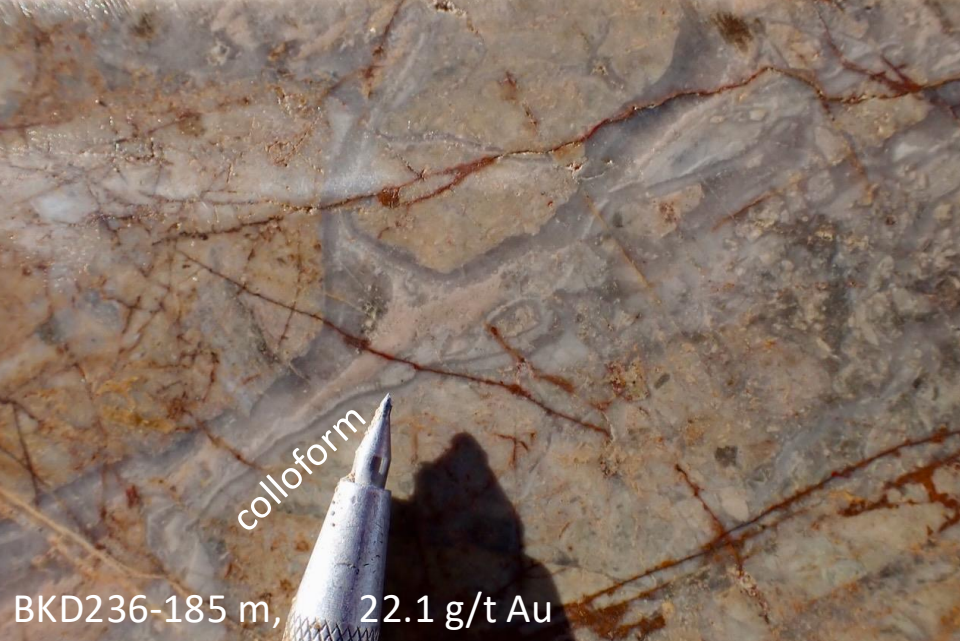


Bayan Khundii deposit, **2016**:

Quartz-adularia-hematite, low sulfide, illite (crystallinity ~1–3)

Atypical, epithermal hybrid, AND
overprint on earlier alteration





BKD236-185 m, 22.1 g/t Au

Bayan Khundii,
2026:

South margin:
Kspar, qtz, mt (Au?)

Deep (**hot**) feeder
zone(s)? to tuff unit,
paucity of colloform
quartz, relatively deep

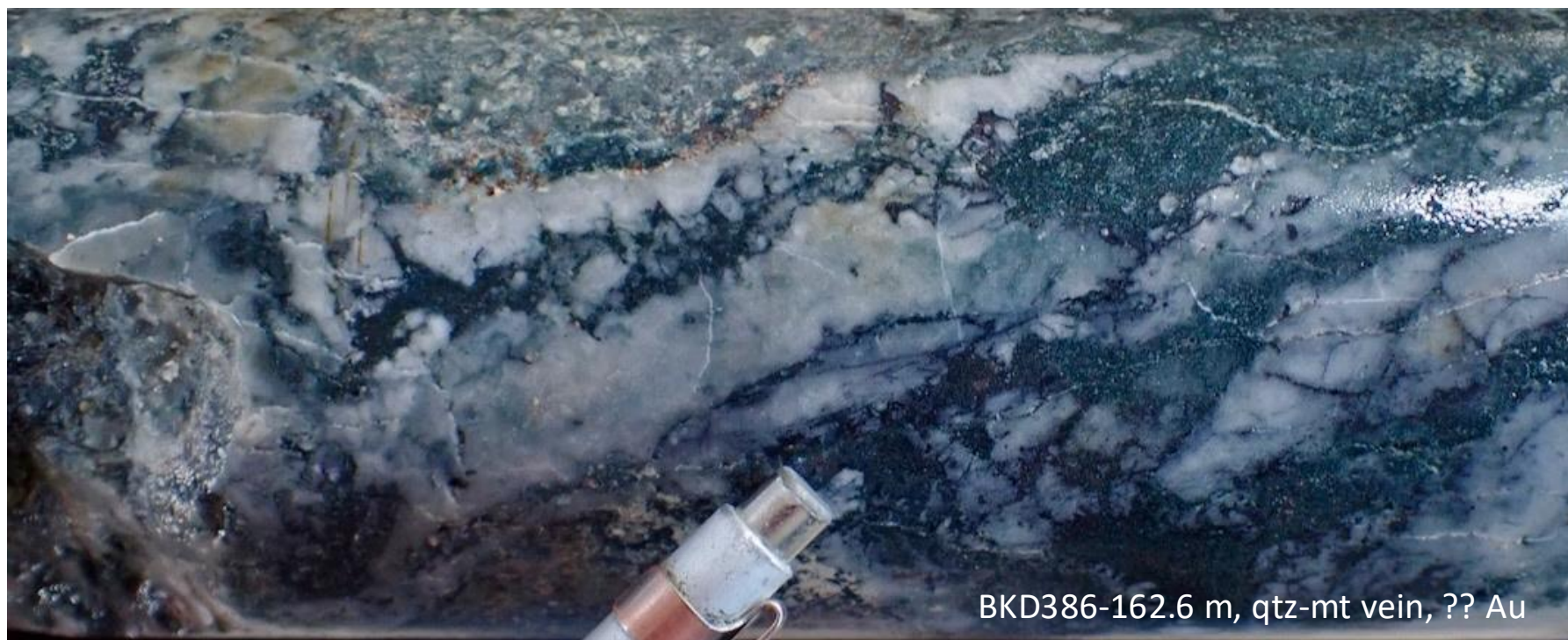


BKD386-162.4 m, qtz-mt-Kspar, ?? Au

K-feldspar



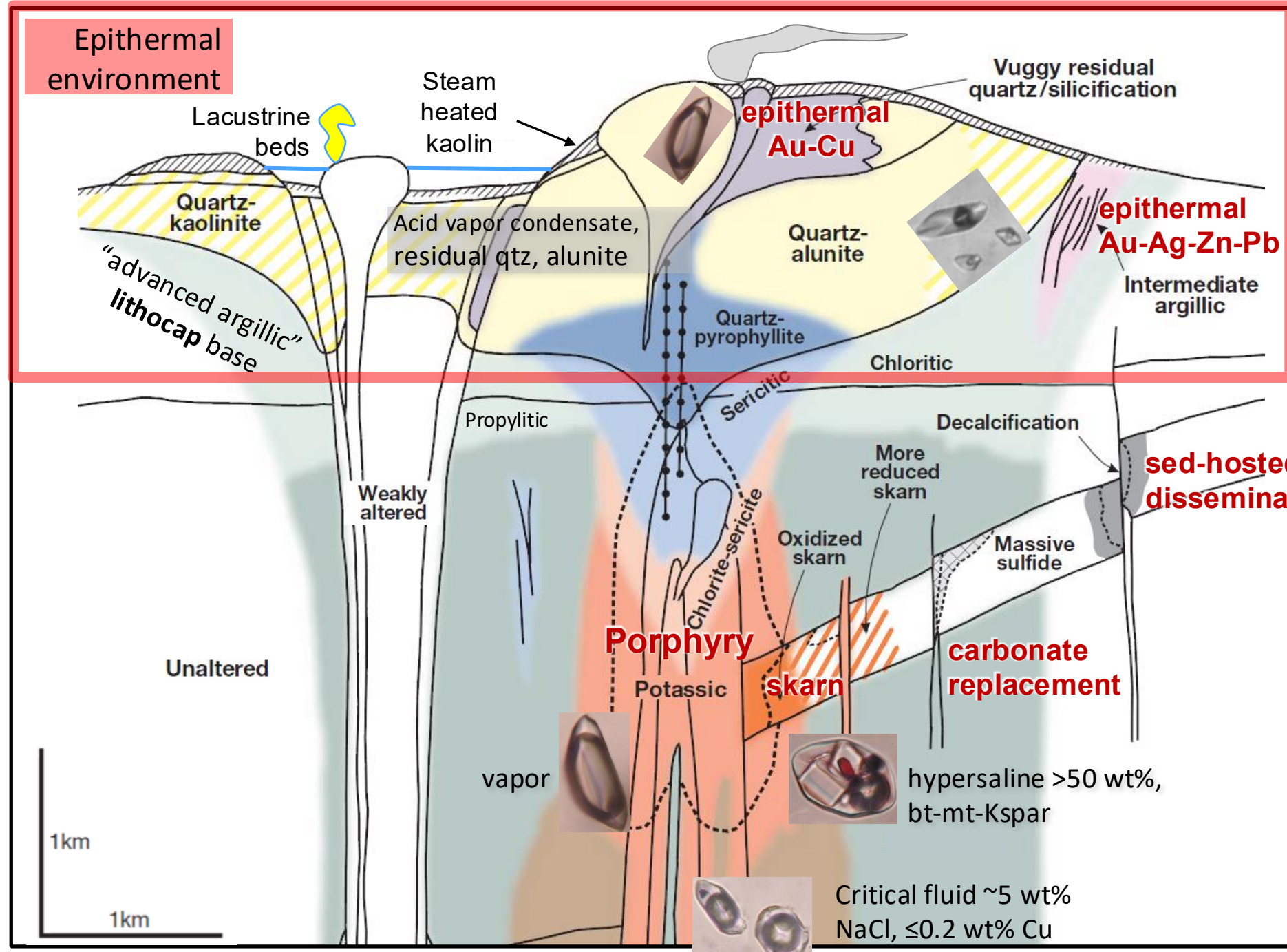
UDH10-123.5 m, 59 g/t Au



BKD386-162.6 m, qtz-mt vein, ?? Au

Arc-hosted porphyry copper systems

Lithocap: lithologic host to residual qtz + halo of advanced argillic minerals, over causative intrusion
Sillitoe, 1995



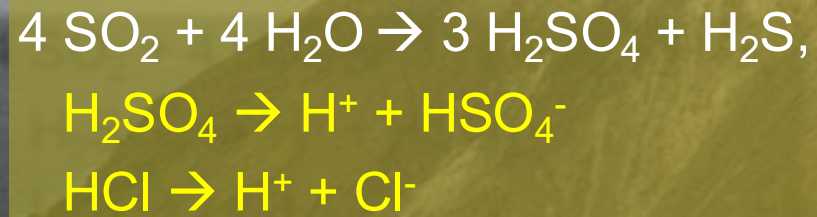
Hypersaline brine and vapor are **linked**; thus potassic and lithocap alteration are **linked**. Henley and McNabb, 1978

Sillitoe, 2010,
Porphyry copper systems,
Economic Geology

Hypogene magmatic vapor condensation:
hyperacidic solutions form advanced argillic
alteration; metal-poor vapor, **barren stage**

~800°C vapors,
HCl, SO₂
(1-2 ppt Au, 10-60
ppb Cu)

cristobalite ($\leq 97\%$ SiO₂),
alunite, < 2 (29) ppb Au



Acid dissociation due to **cooling**,
increased reactivity ($< 250^\circ\text{C}$)

Satsuma Iwojima, Japan:
rhyolite dome, pH ~1.5 springs
Hedenquist et al., 1994

photo: Y. Kawanabe



Summitville Au deposit, CO
residual (vuggy) quartz

quartz-alunite

Lithocap-hosted Iwato Au-enargite-pyrite deposit; **supergene oxidized**

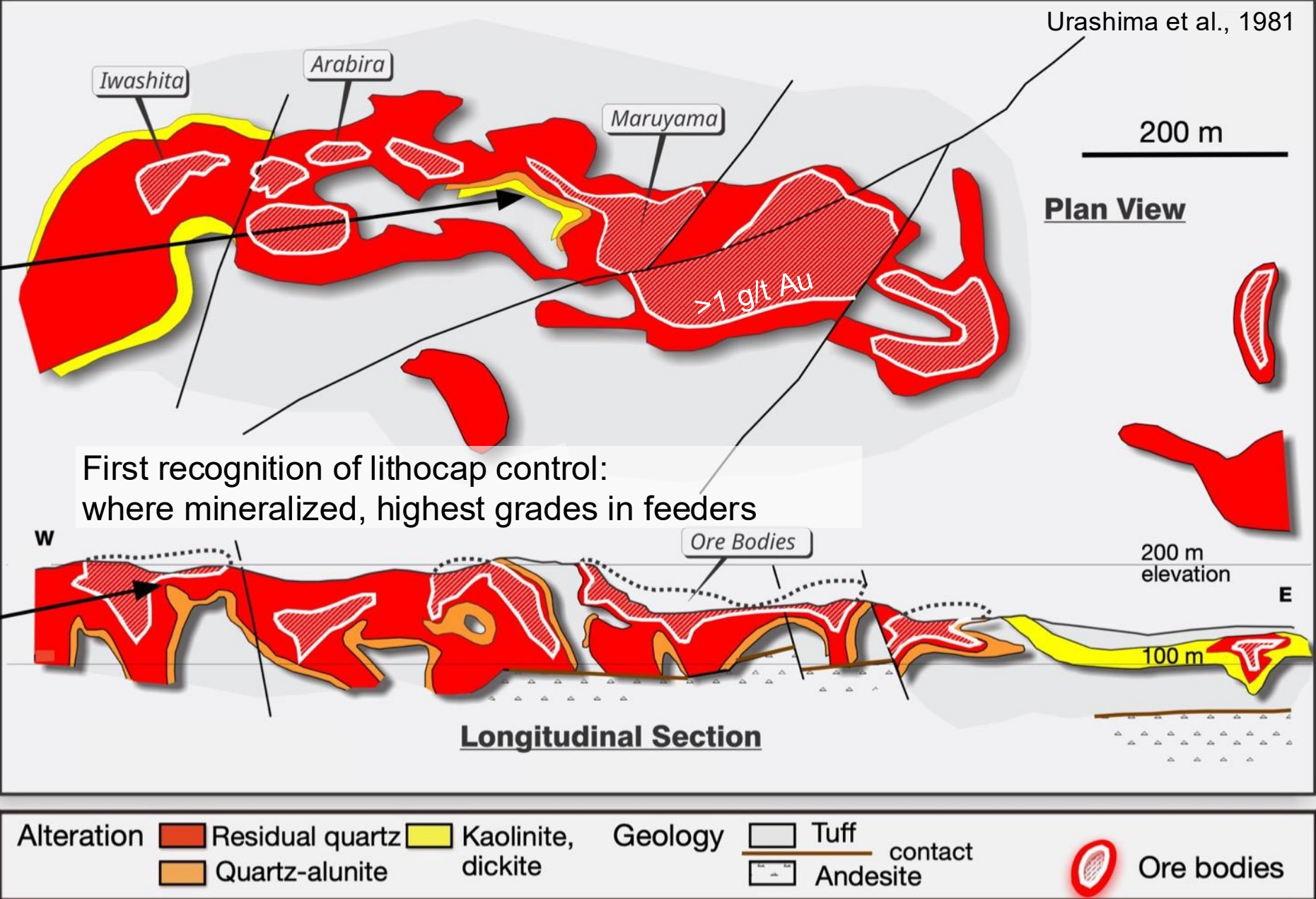
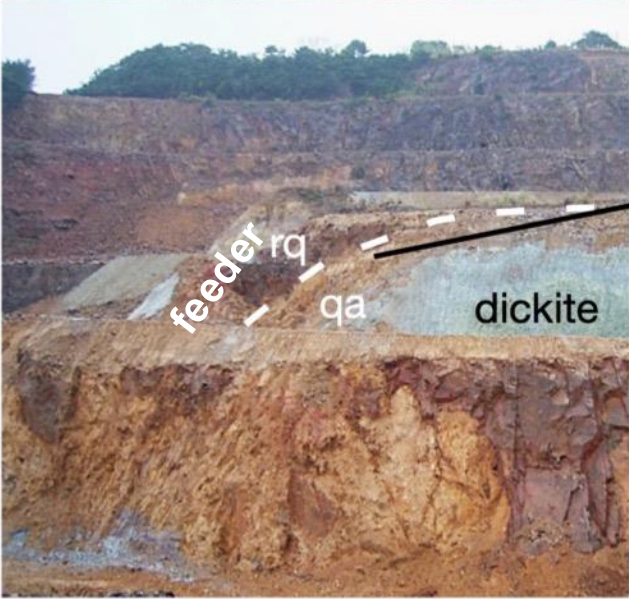
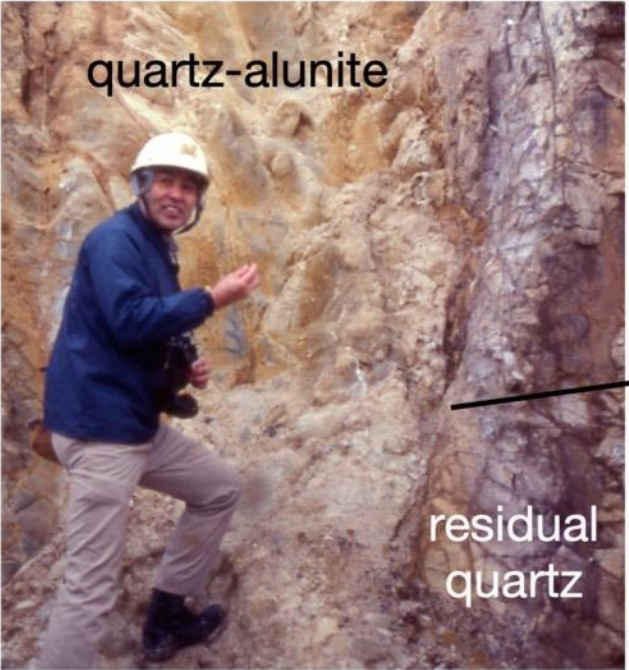
Kyushu, Japan



(pyrite), enargite, covellite, S^0

Residual qtz, vugs after pumice - **lithocap**

Akeshi, W. Pratt



Mankayan district, Luzon, Philippines:

Far Southeast porphyry Cu-Au & lithocap-hosted Lepanto enargite-Au deposits,
+ Victoria Au-Ag-(Cu) quartz-rhodochrosite-anhydrite veins, margin of intrusive center

Mohong Hill
quartz-alunite
lithocap

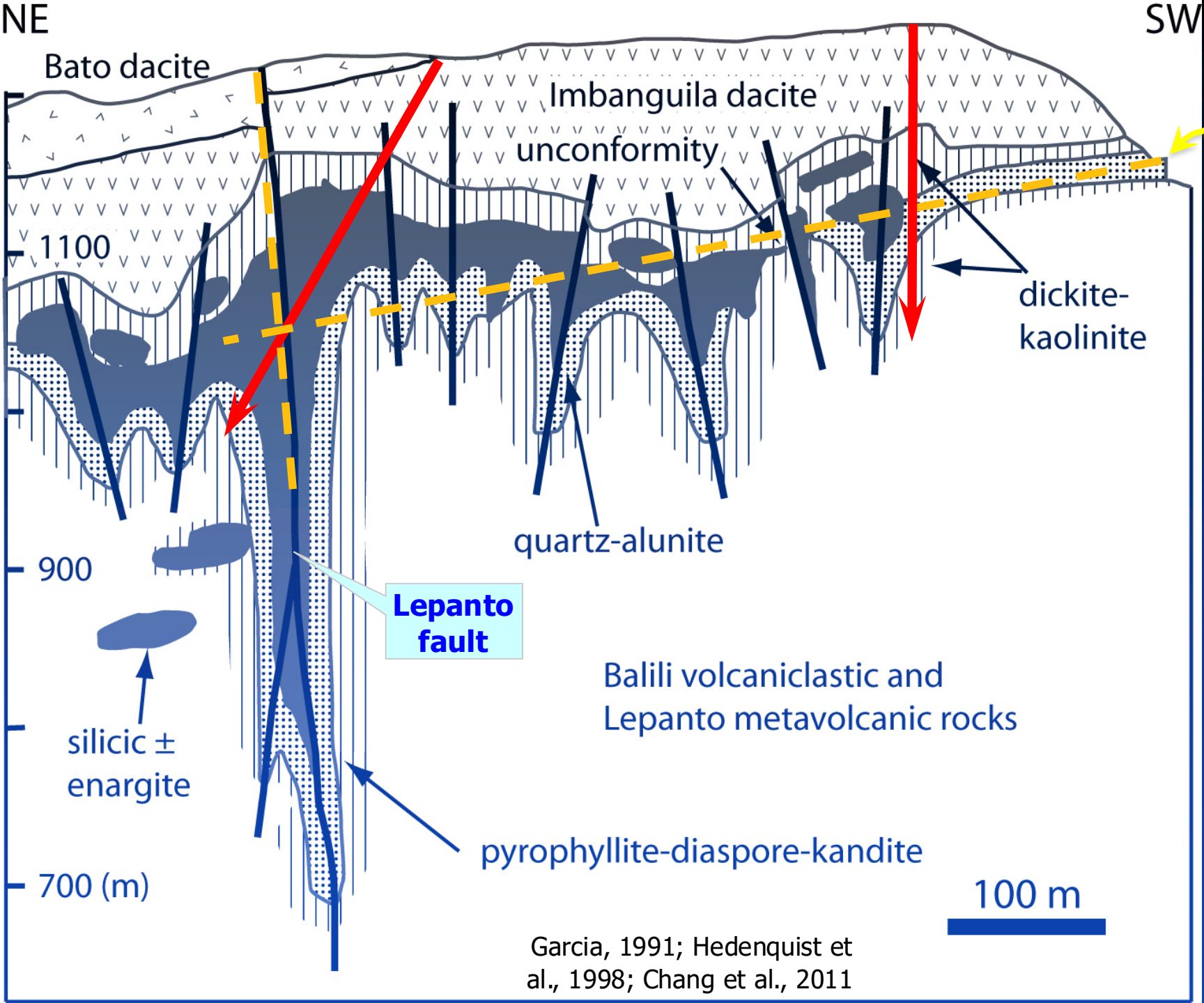
Lepanto lithocap,
Au, Cu

Victoria veins,
Au, Ag

FSE porphyry Cu-Au

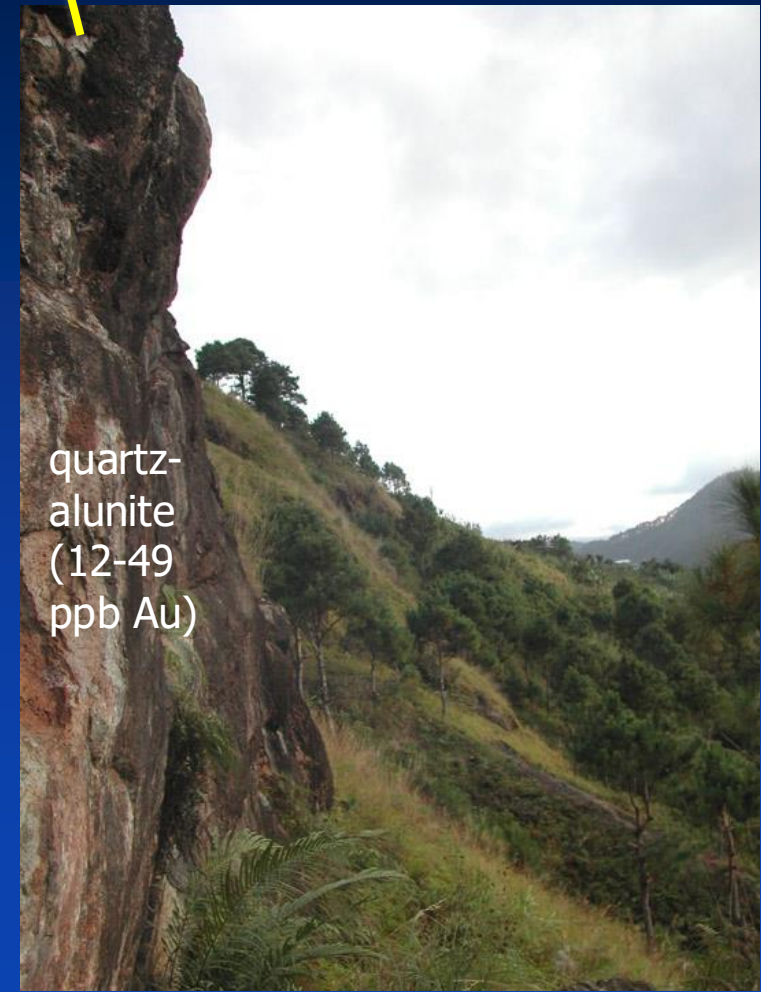
dacite pyroclastics

volcaniclastic
basement



Lepanto ore deposit
(105 t Au, 1 Mt Cu as enargite)

Upward flaring alteration: acid
dissociation due to cooling –
70% ore in feeder zone of
residual quartz lithocap

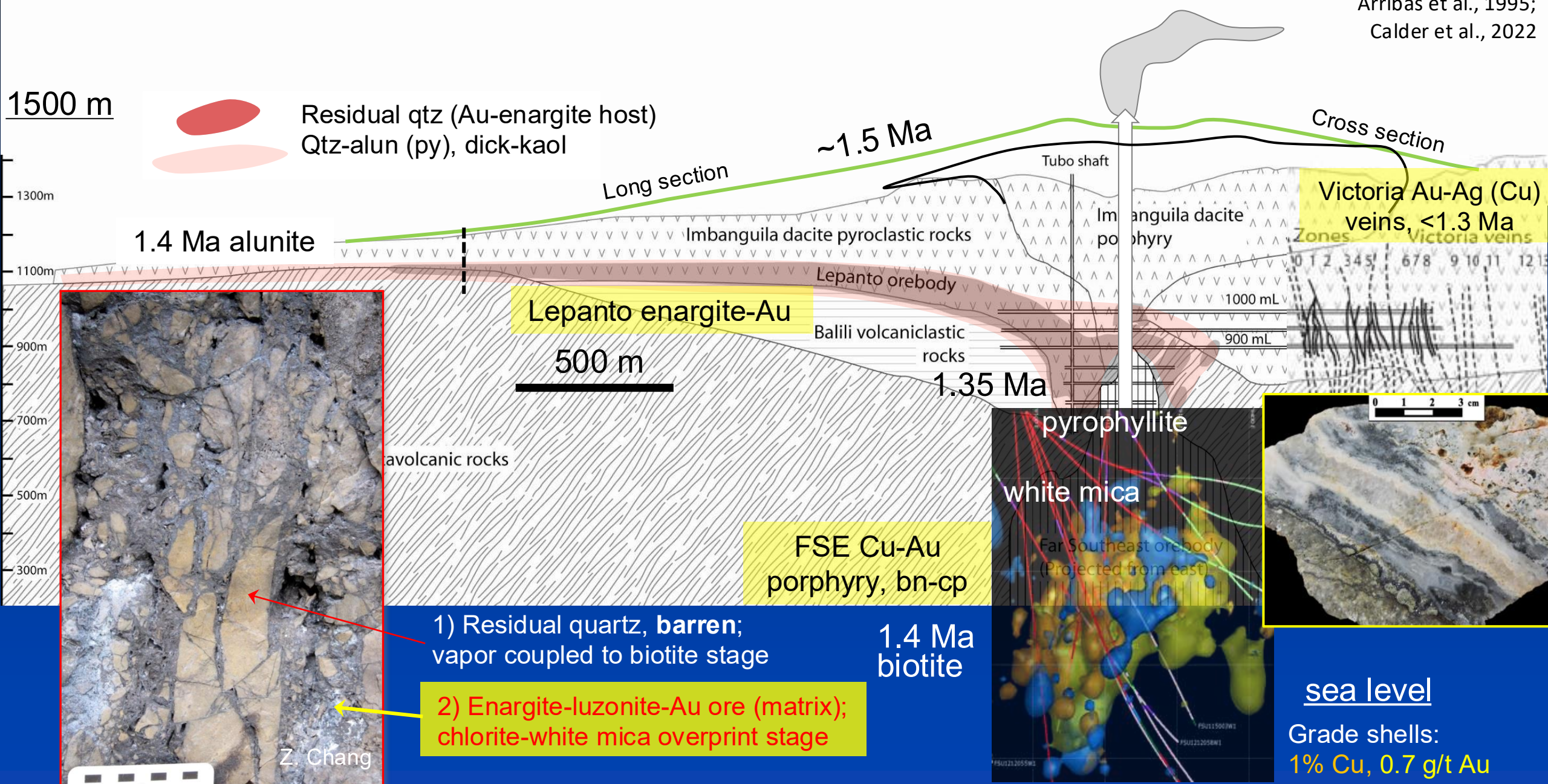


Far Southeast porphyry & Lepanto lithocap-hosted and Victoria epithermal vein deposits

600 t Au + 5 Mt Cu 105 t Au + 1 Mt Cu, 70 t Au

Porphyry system

Arribas et al., 1995;
Calder et al., 2022



Victoria zone 4,
Vein 225



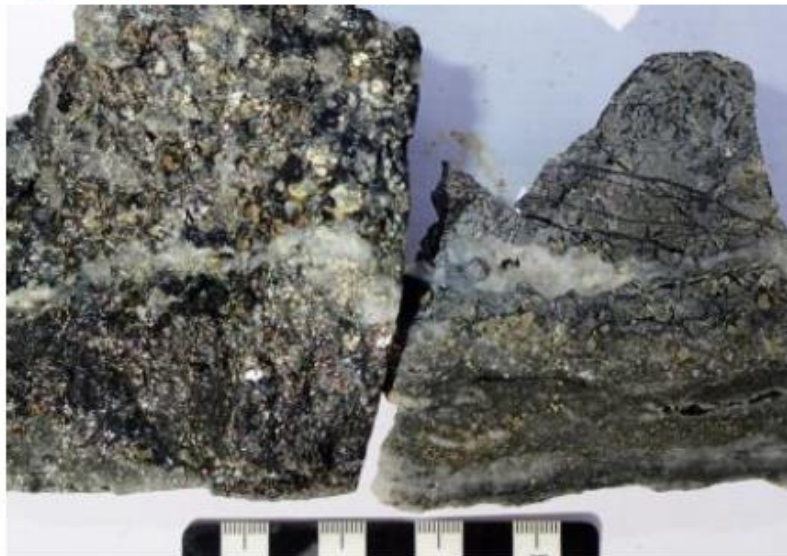
**Vein 225
crustiform
banded
quartz**



Victoria zone 4, Cu, Zn-rich



5.01 g/t Au, 86.43g/t Ag, 4.20 %Cu, 0.40 %Pb, 5.33 %Zn



5.83g/t Au, 77.08g/t Ag, 0.36% Cu, 2.49% Pb, 16.02% Zn

Victoria zone 0, 205, Mn-rich



26.40g/t Au



17.57g/t Au

Teresa veins, 108, Au-rich

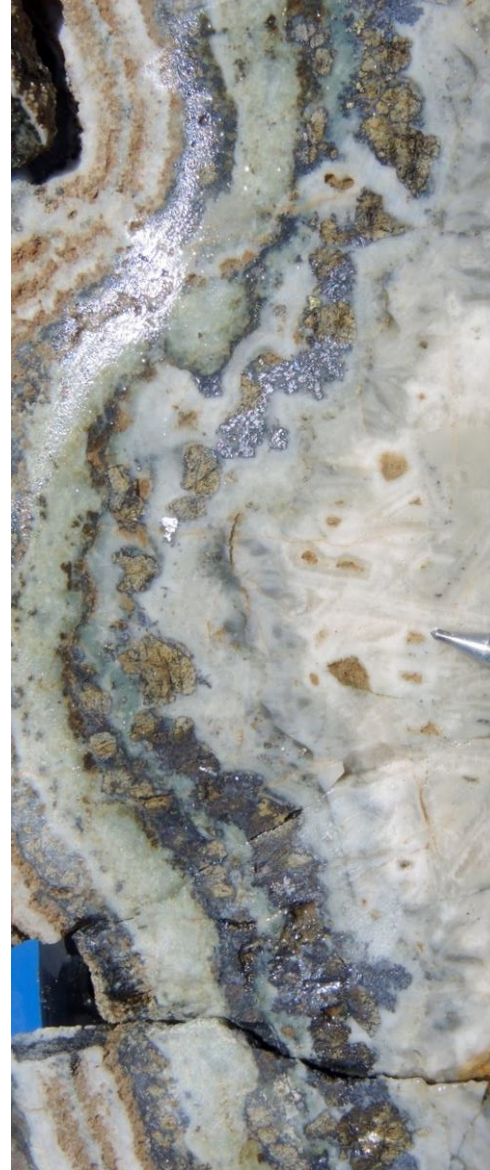


36.92g/t Au, 8.75g/t Ag, 0.005% Cu

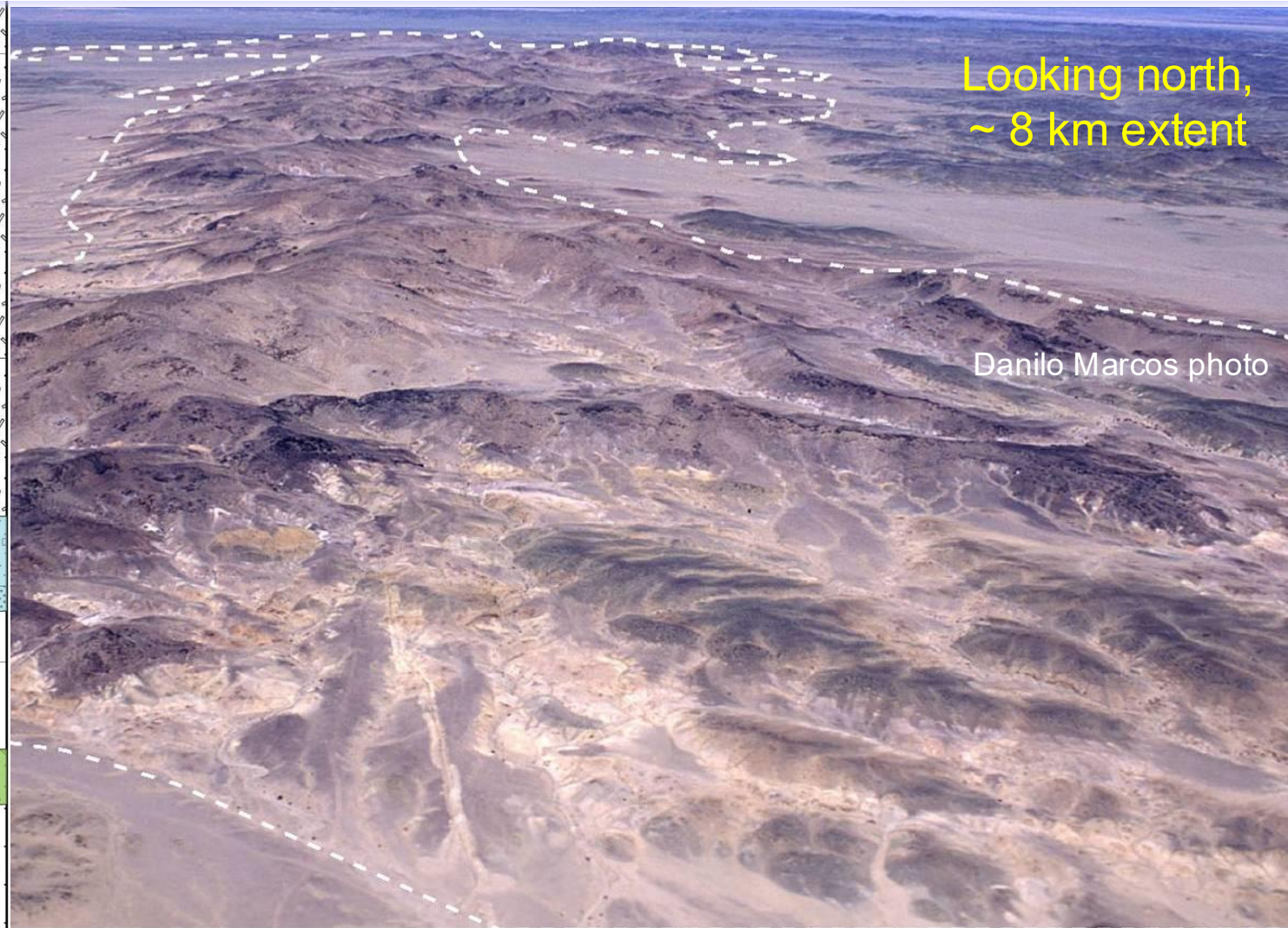
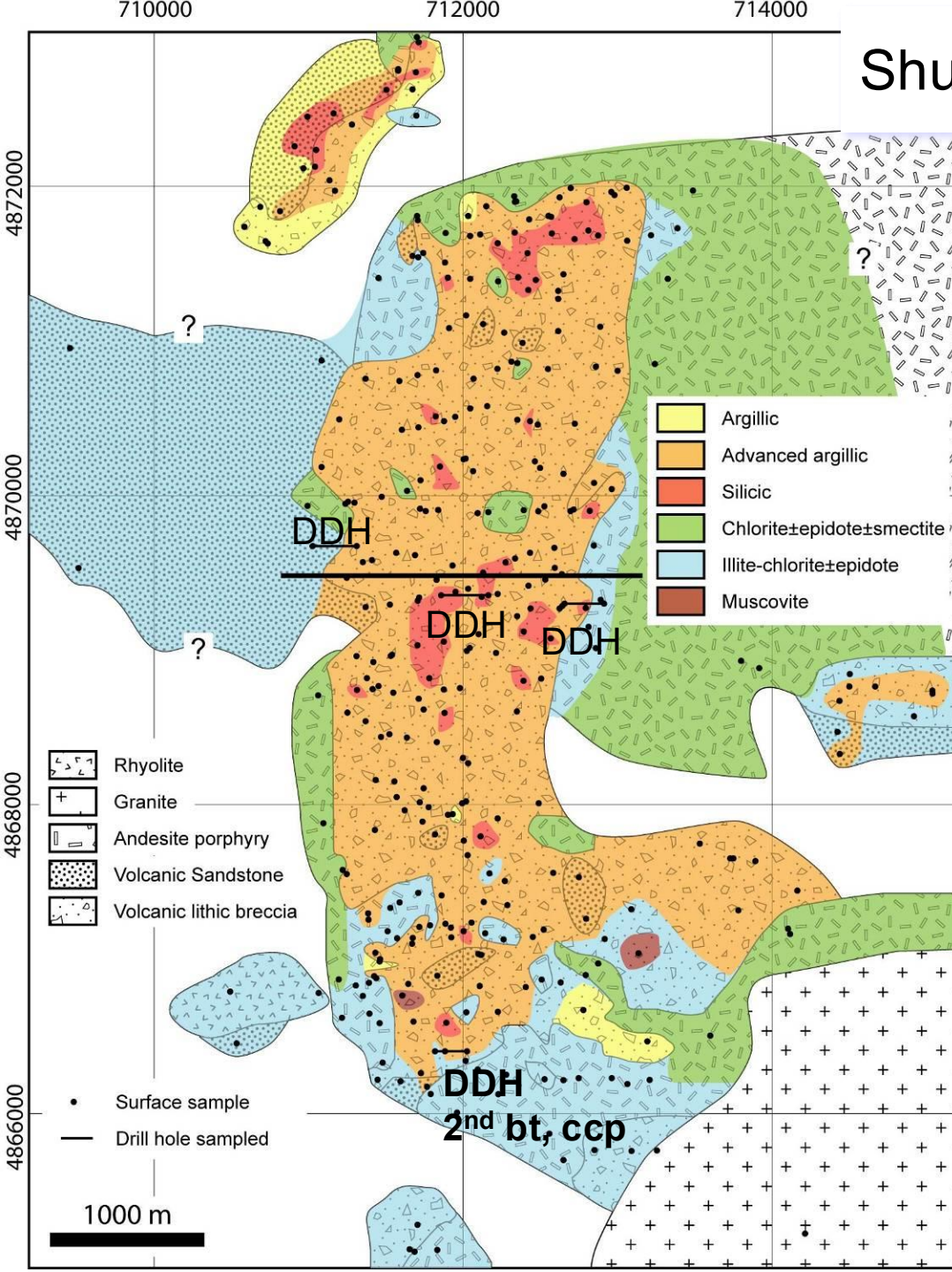


310.43g/t Au, 9.74g/t Ag, 0.05% Cu

Altan Nar drill core – epithermal quartz – adularia (310 Ma) – Fe-Mn carbonate veins: strong banding, quartz after bladed calcite – plus sphalerite, galena; 43-101 resource, 2018: 5 Mt @ 2.8 g/t Au equivalent (Au, Ag, Pb, Zn)



Shuteen barren lithocap & porphyry prospect, Mongolia



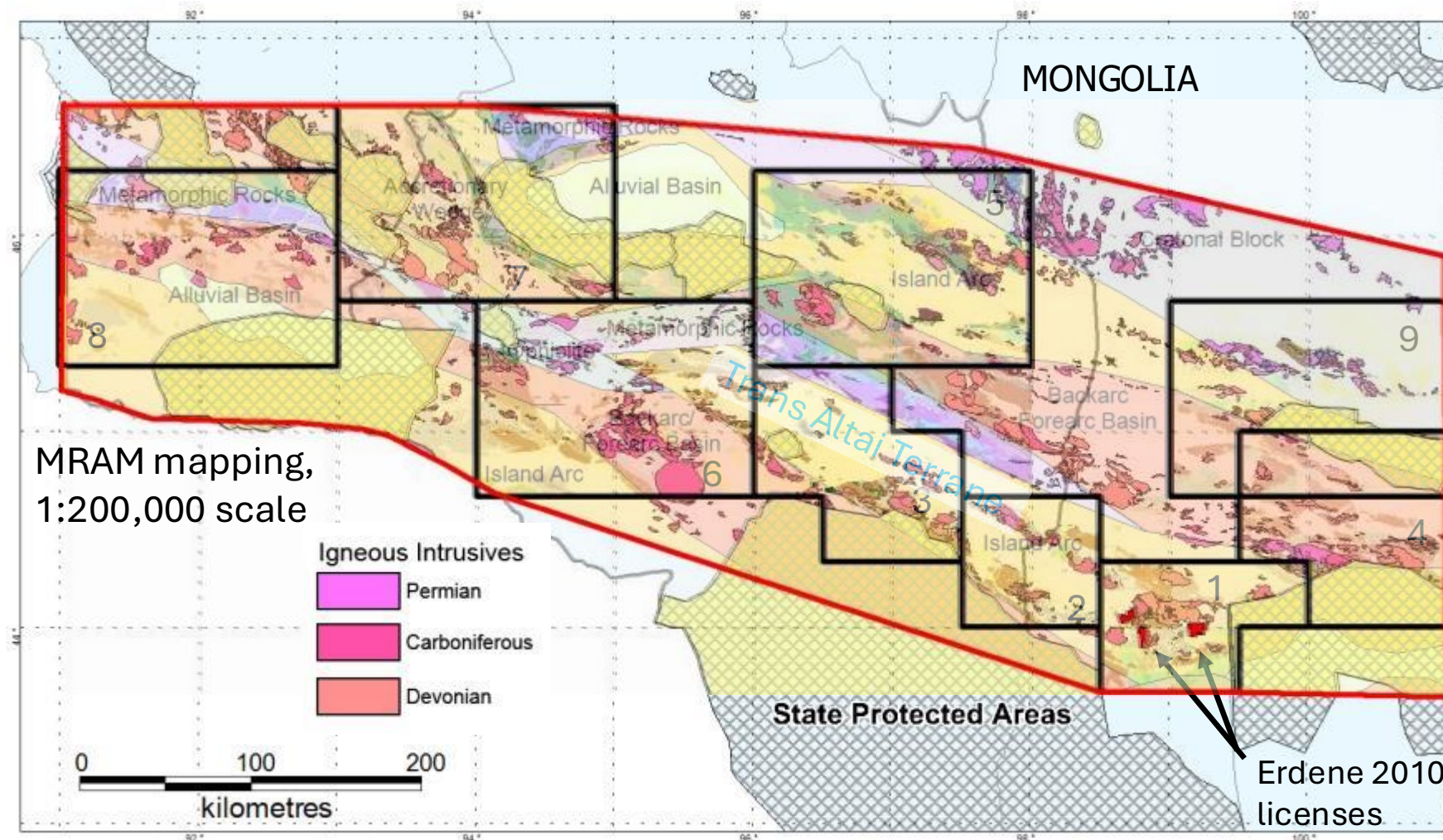
Ivanhoe, 1549 samples: Au: < 10 ppb, Cu: 5 – 500 ppm (avg. 53 ppm)
4 DDH, 300-550 m deep

AMIRA P765, 122 samples <8 ppb Au

Chang et al., 2010

Trans Altai and adjacent terranes – Island arcs, basins

2009: Regional compilation



MRAM mapping,
1:200,000 scale

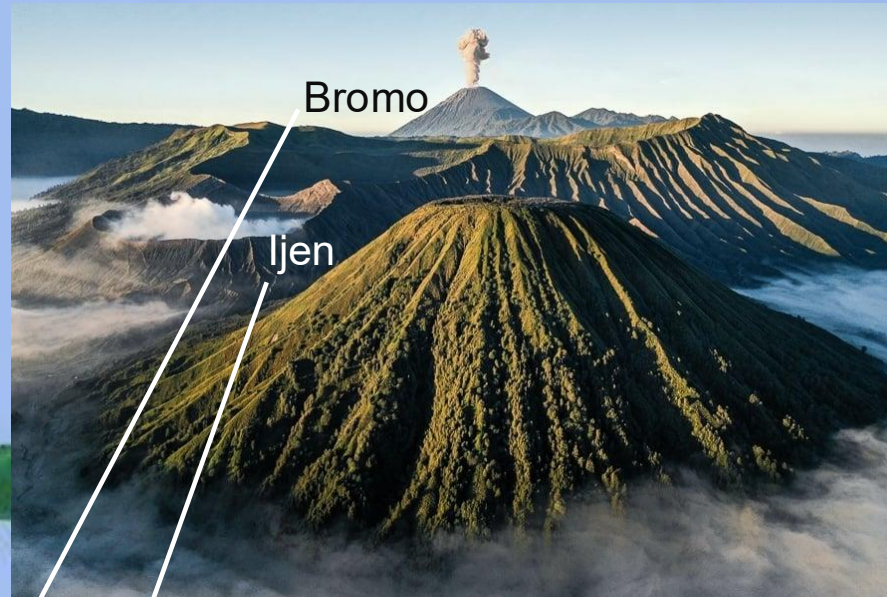
SW Mongolia:
Island arcs plus backarc/
forearc basins,
metamorphosed and folded,
with slivers of ophiolite.
Various levels of erosion (fault
blocks, etc.), with epithermal
levels preserved at Bayan
Khundii, Altan Nar, etc.

*Erosion level is key to
epithermal preservation*

after Badarch et al., 2002;
their Edren Terrane =
Trans Altai Terrane



Merapi

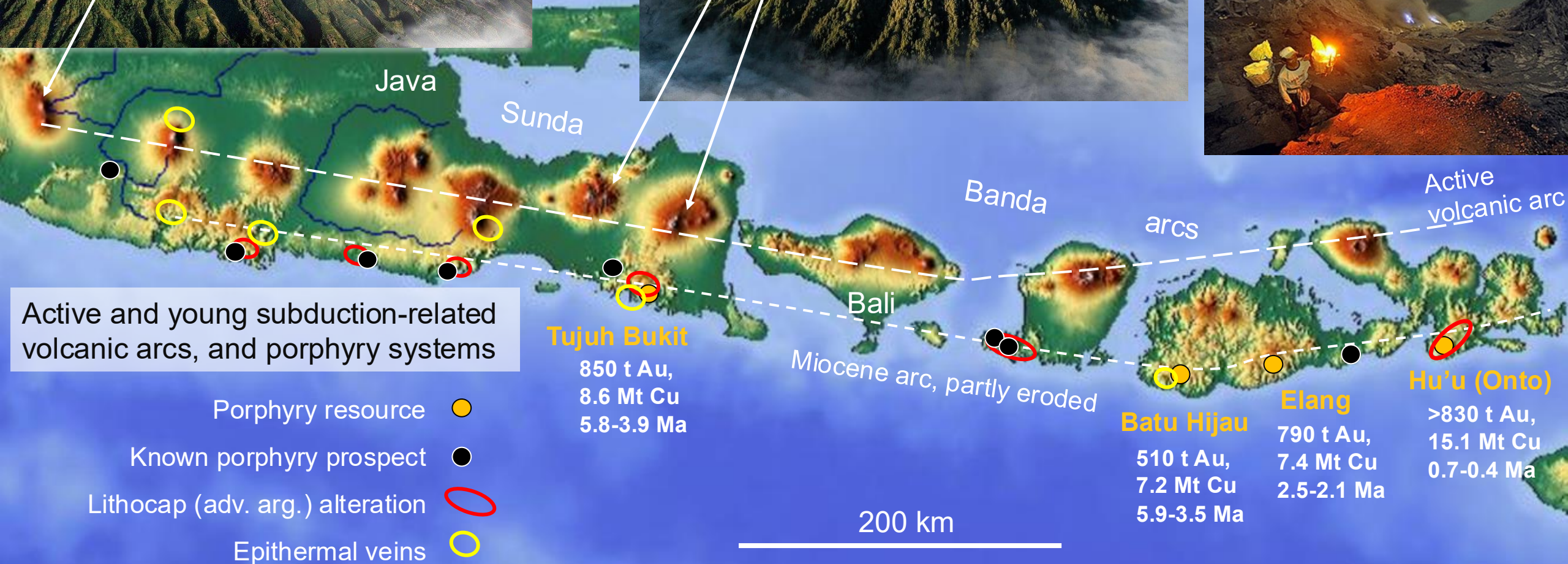


Bromo

Ijen



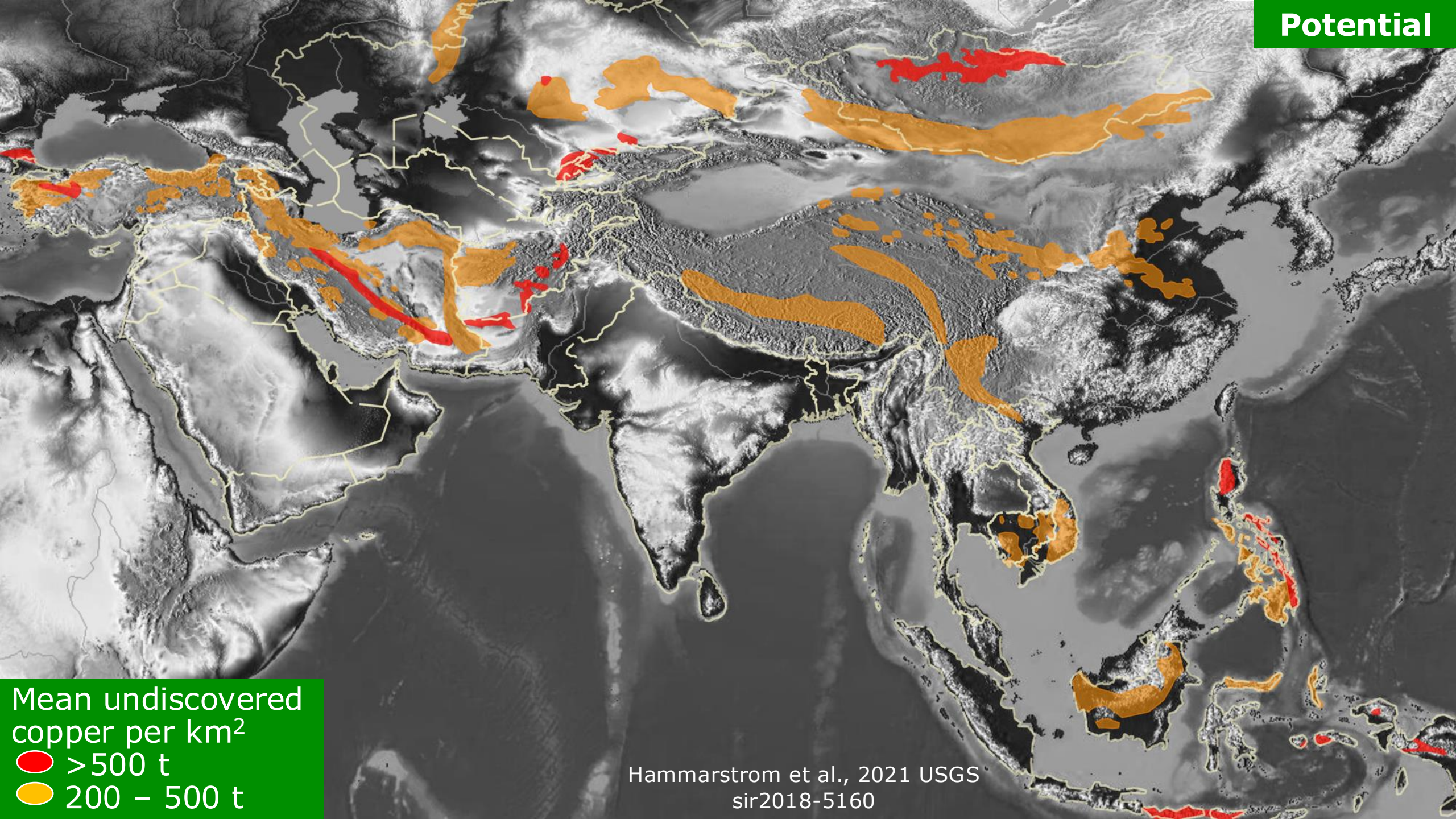
Kawah Ijen (pH <1)



Exploration for epithermal deposits in Mongolia: general guidelines



- Preservation of volcanic package from erosion (< 20-30 % intrusions)
- Erosion level <1 below paleosurface
 - Paleosurface indicators? (True sinter, watertable opaline ± kaolinite horizon; unlikely...)
 - Shallow erosion: Alteration mineralogy – smectite, interstratified clays (<200 m), illite - ISM
- 1. Sulfide-poor veins: several km-wide systems, multiple centers in districts
- 2. Recognition of lithocaps
 - ASTER or WV3: aluminosilicates + alunite
 - Silicic cores + quartz-alunite, most resistant to erosion; best grades in **silicic cores**
 - Vein potential on margins, up to 5+ km distal
 - *If barren lithocap, deeper porphyry potential*
- Range of tectonic settings in SW Mongolia (**island arcs**, and backarc/forearc basins)
 - Potential for range of epithermal styles in downdropped fault blocks (preserved by burial)
 - Uplifted blocks, near-surface potential for deeper styles, including porphyry deposits:
area of intrusive rocks similar or > area of volcanic rocks



Mean undiscovered
copper per km²
● >500 t
● 200 – 500 t

Hammarstrom et al., 2021 USGS
sir2018-5160

Biga region, NW Türkiye:
Wide variety of epithermal styles (of different ages), in ~100 x 100 km region

Intrusive Rocks

Oligo-Miocene		Granitoid
Eocene		Granitoid
Upper Cretaceous		Granitoid

Deposits or Prospects

-  Epithermal HS
-  Epithermal IS
-  Epithermal LS
-  Epithermal/Style not known

>60 epithermal prospects,
~10 porphyry prospects:
Half a dozen epithermal
deposits are now mines

