Influence of magmatic arc geothermal systems on porphyry-epithermal Au-Cu-Ag exploration models

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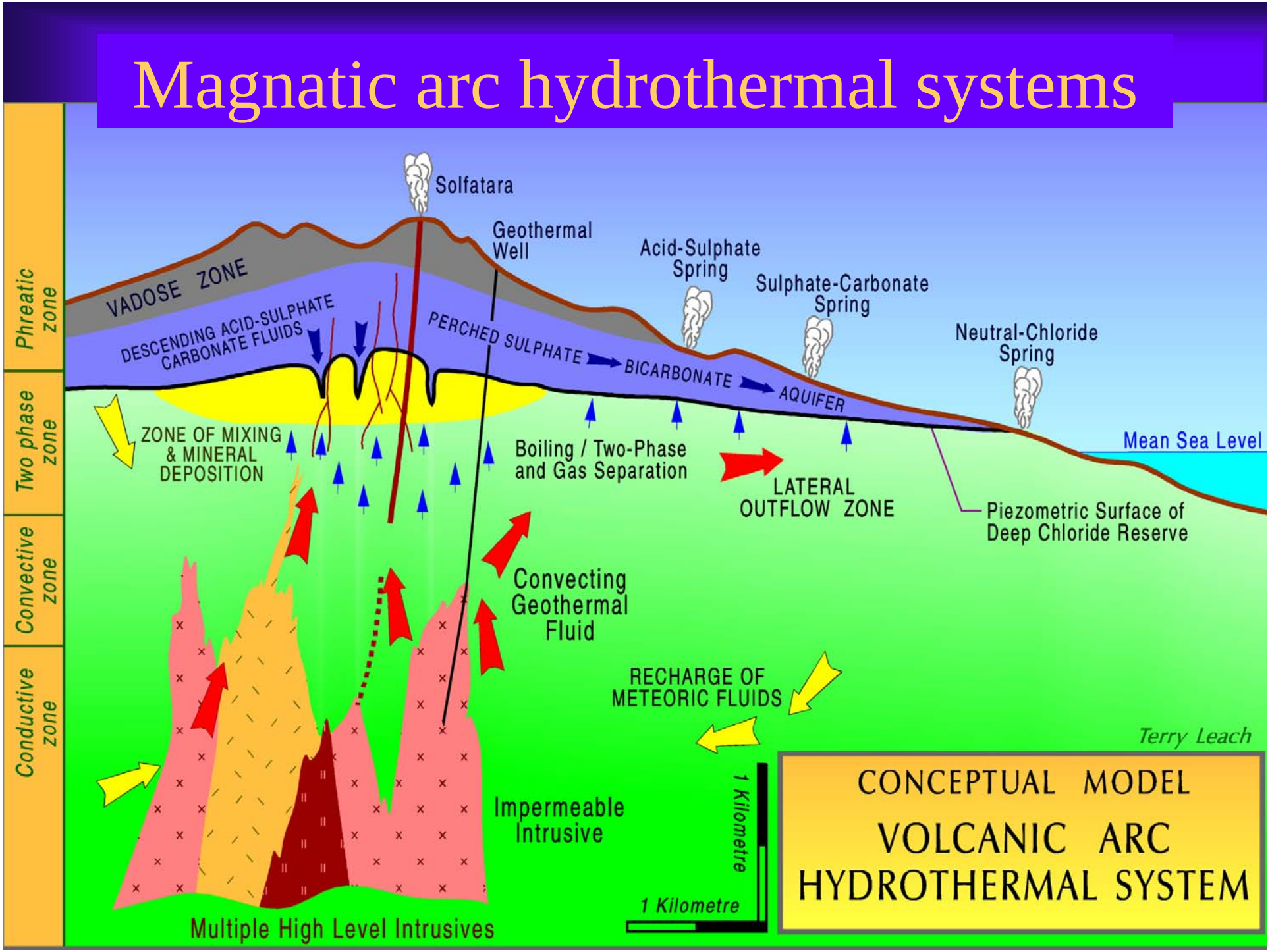
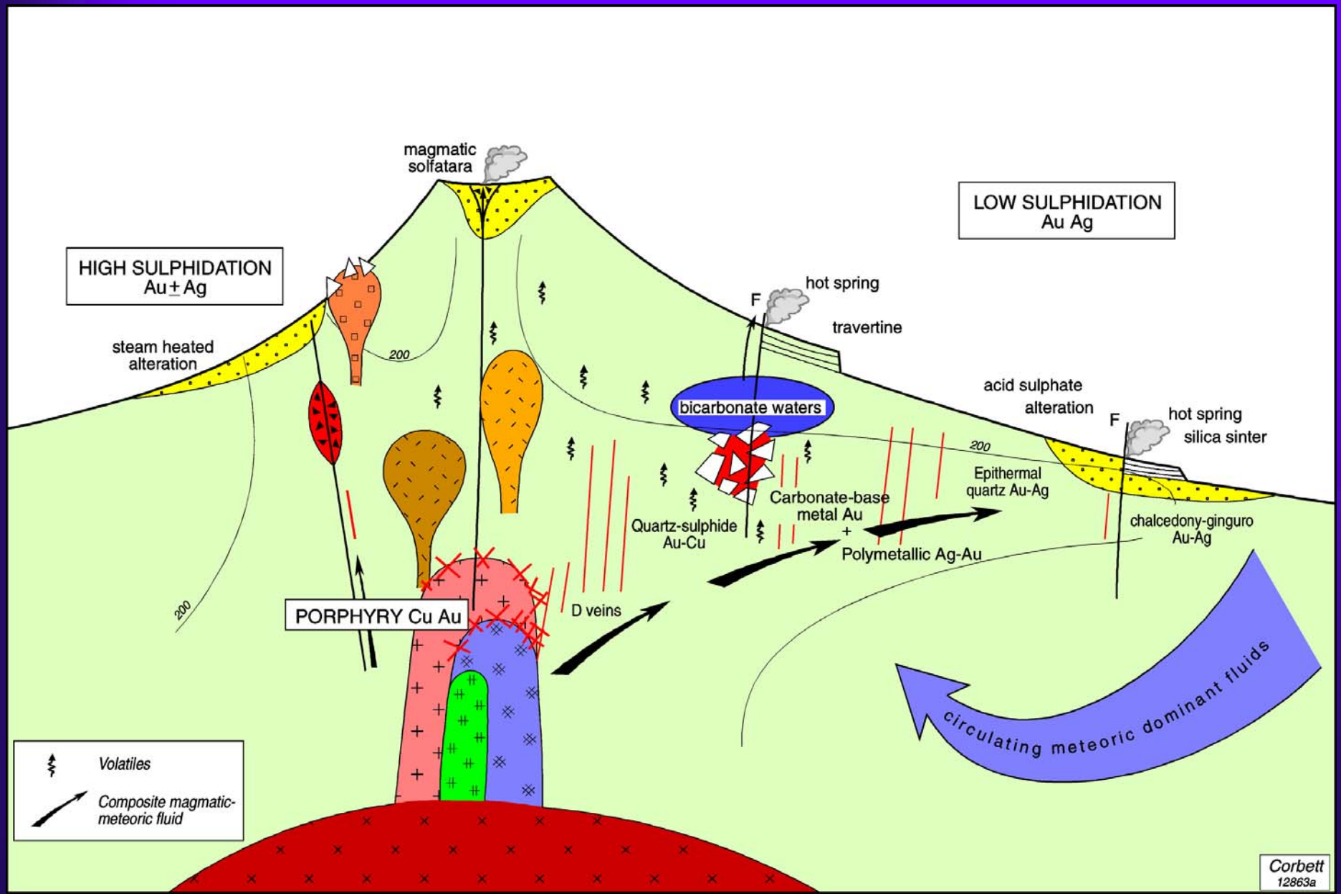
Geothermal environments

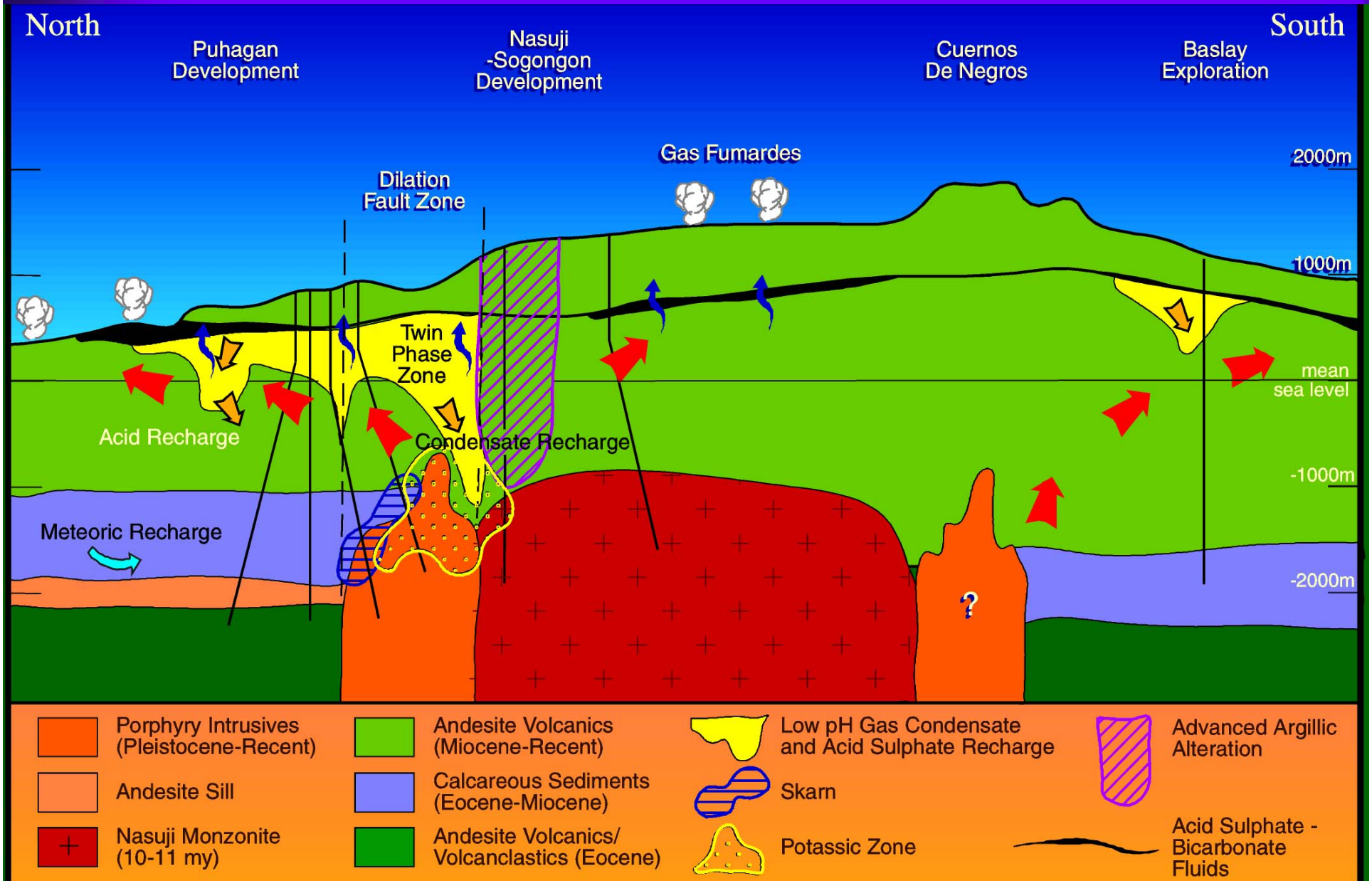
Magnatic arc hydrothermal systems



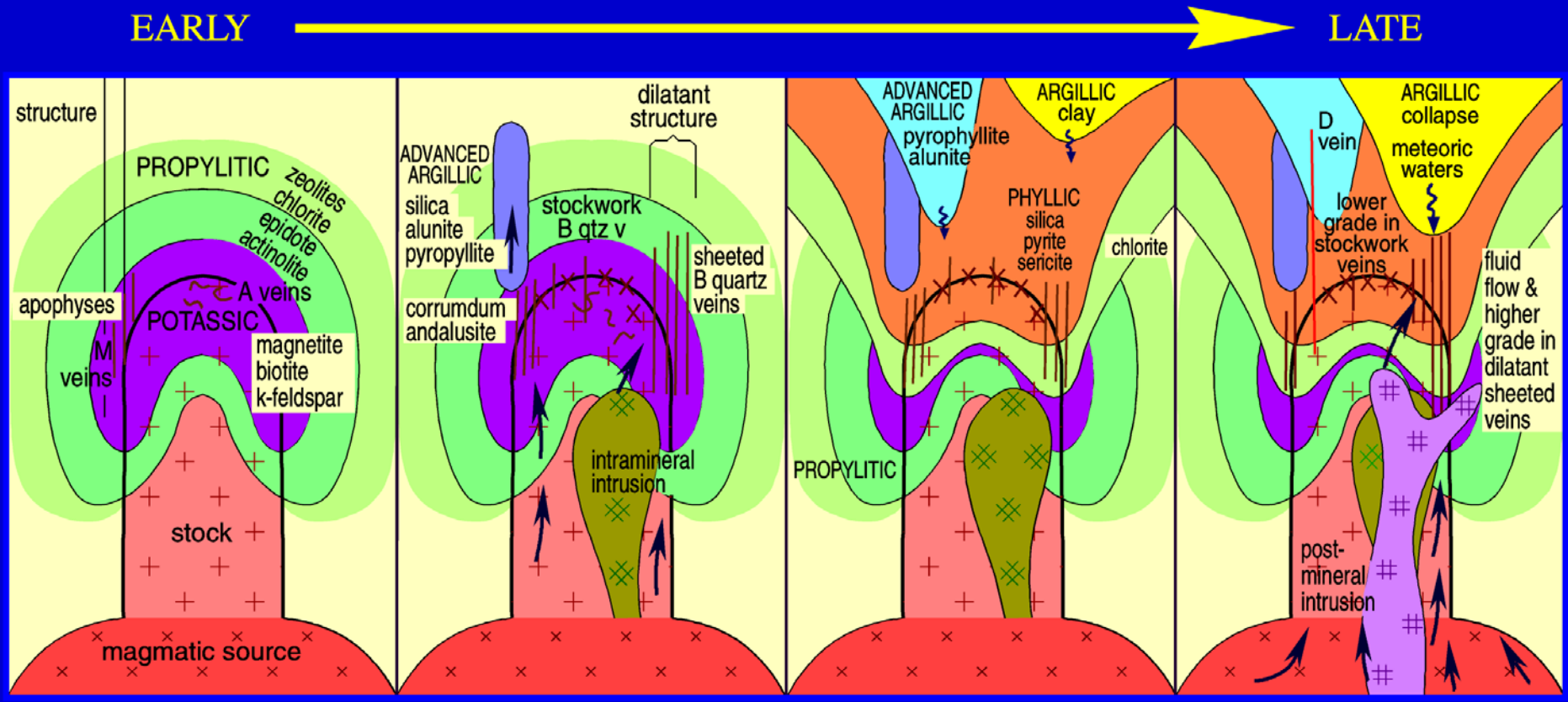
Magmatic arc porphyry to epithermal



Southern Negros Geothermal Field



Time in porphyry Cu-Au evolution



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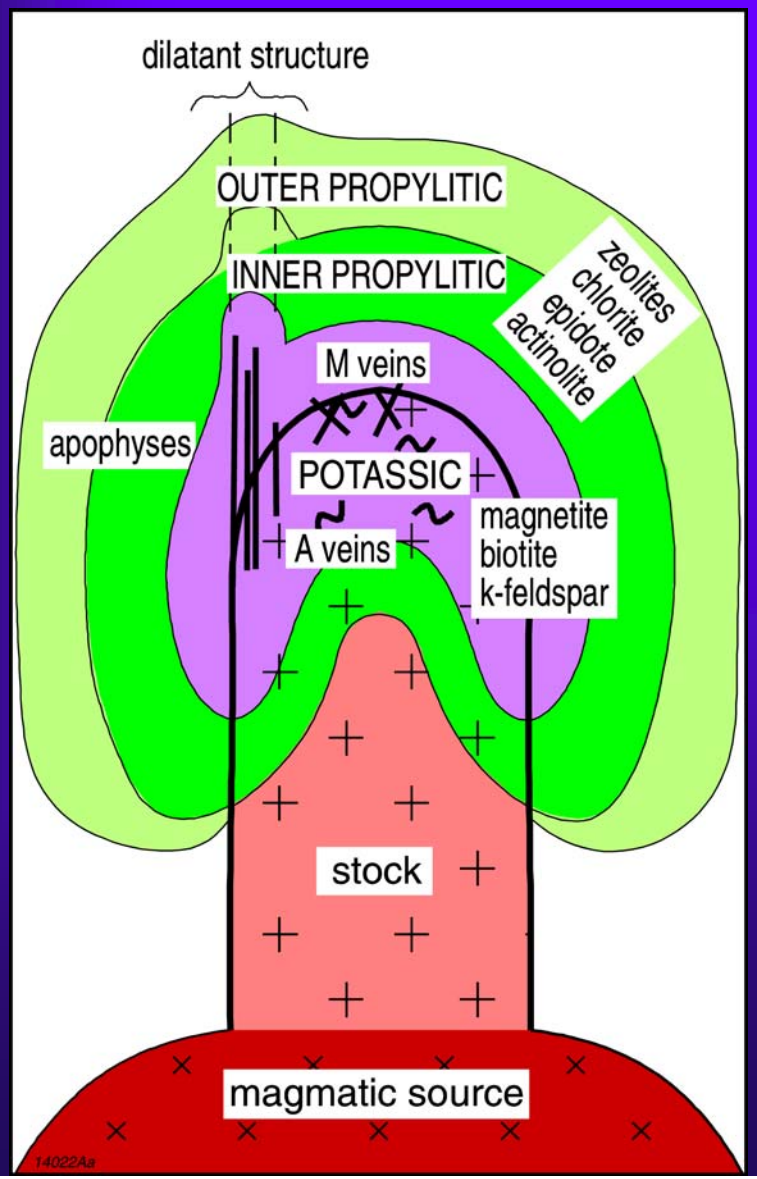
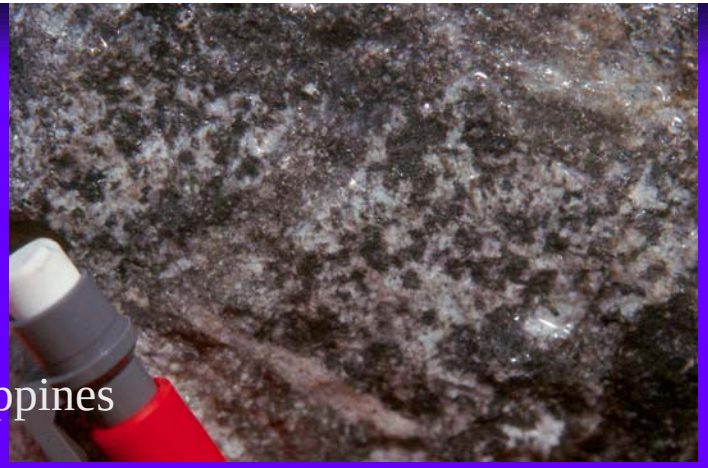
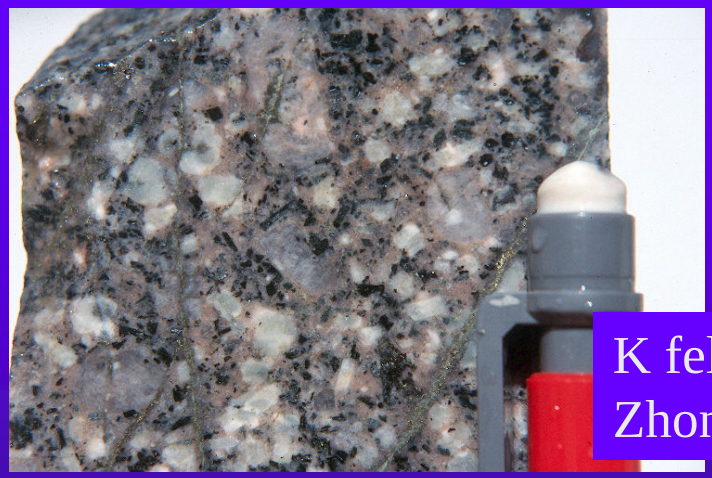
Porphyry emplacement, prograde alteration





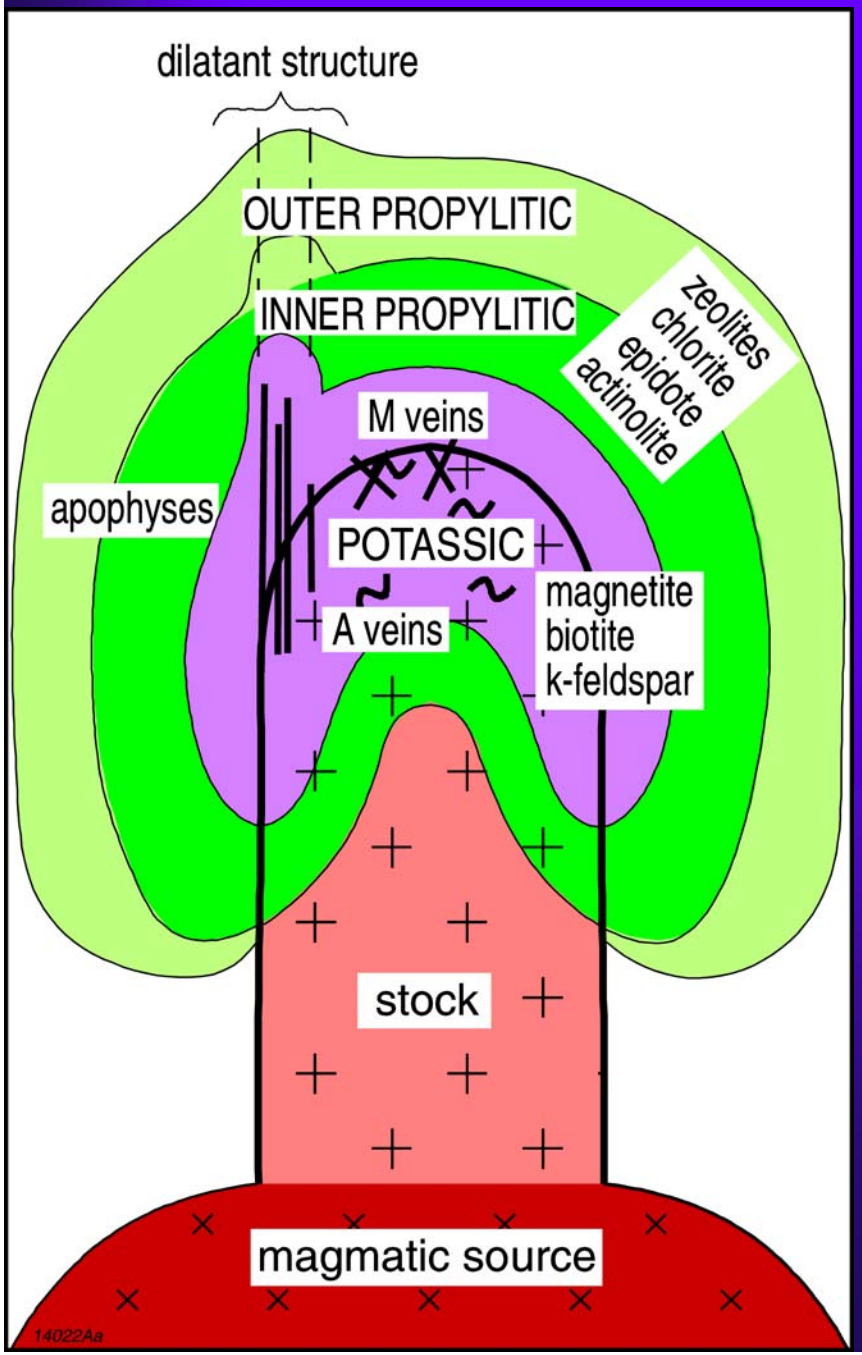
Biotite
St Tomas, Philippines



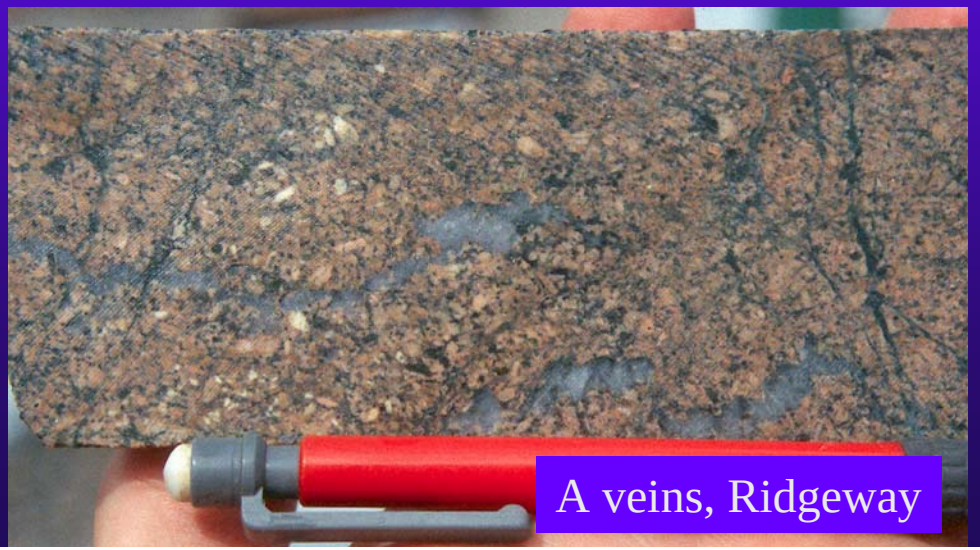
K feldspar flooding
Zhongdian, China

Magnetite
Ridgeway, Australia

Porphyry style A and M veins

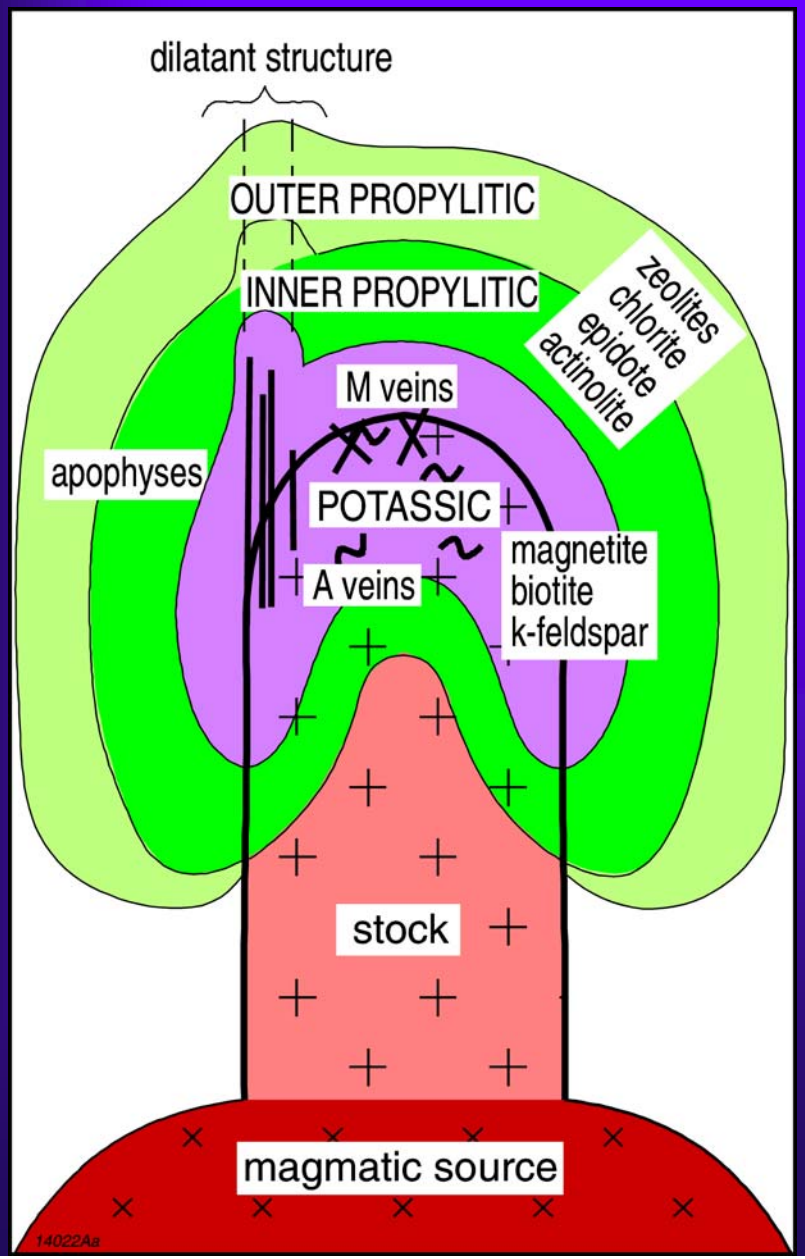


M veins Copper Hill



A veins, Ridgeway

Propylitic alteration

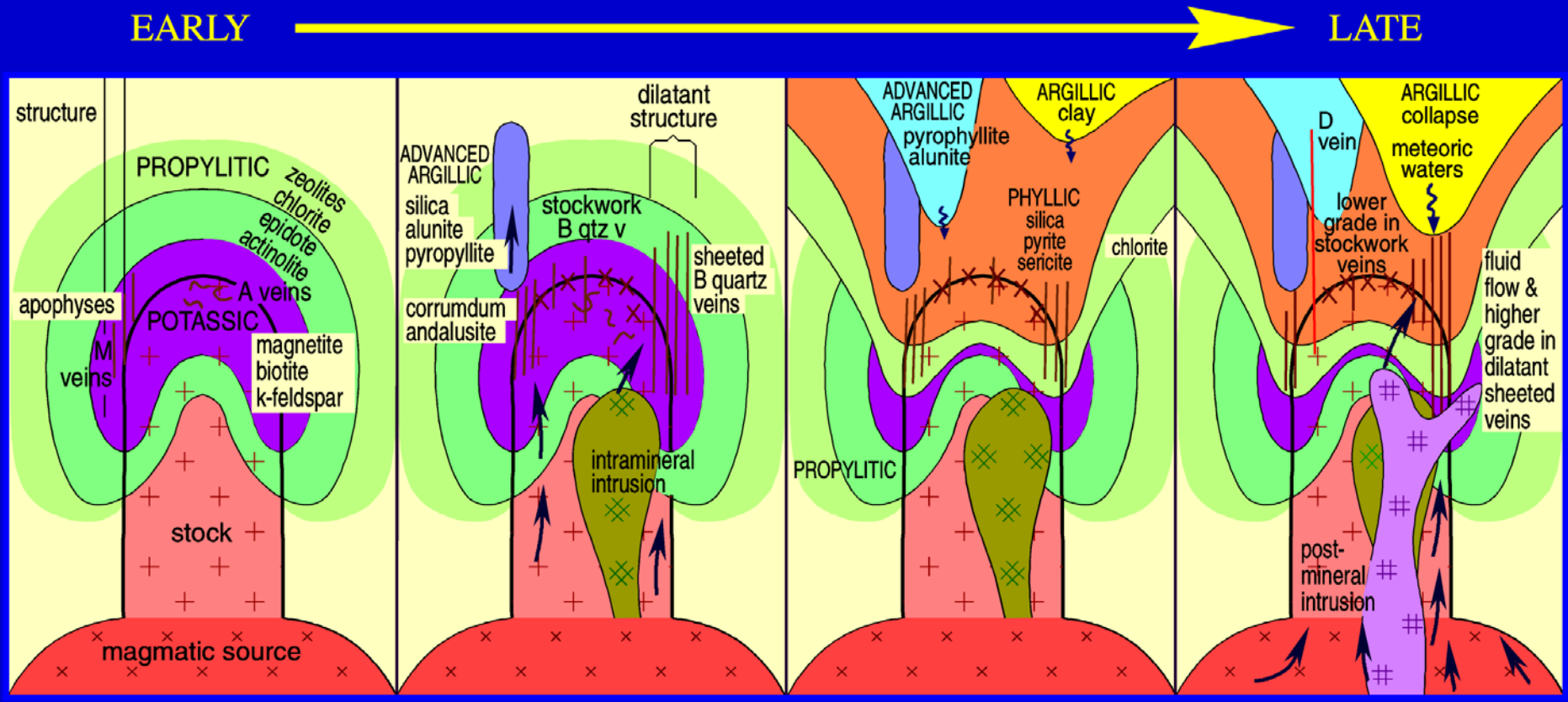


chlorite

epidote

actinolite

Time in porphyry Cu-Au evolution



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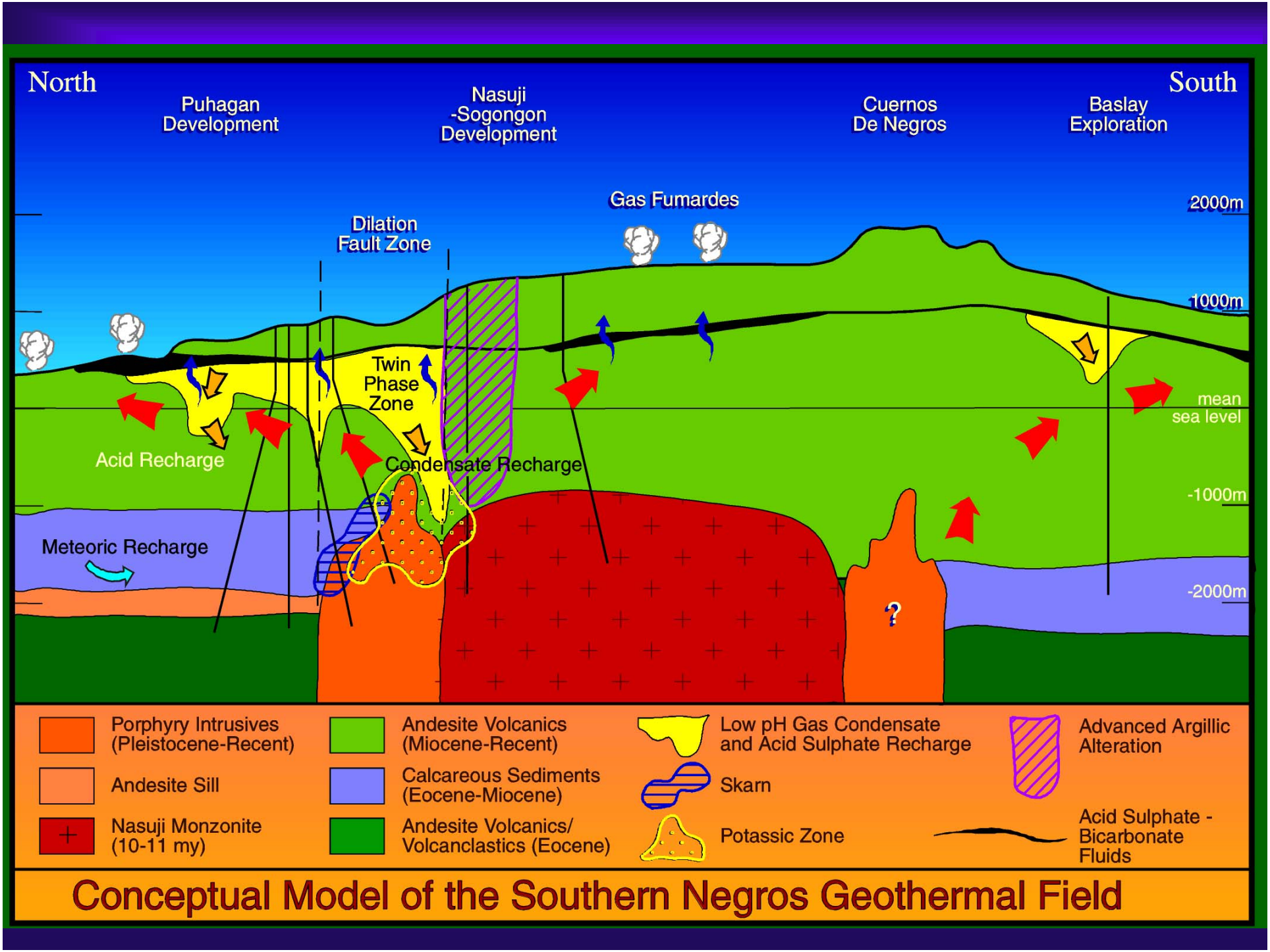
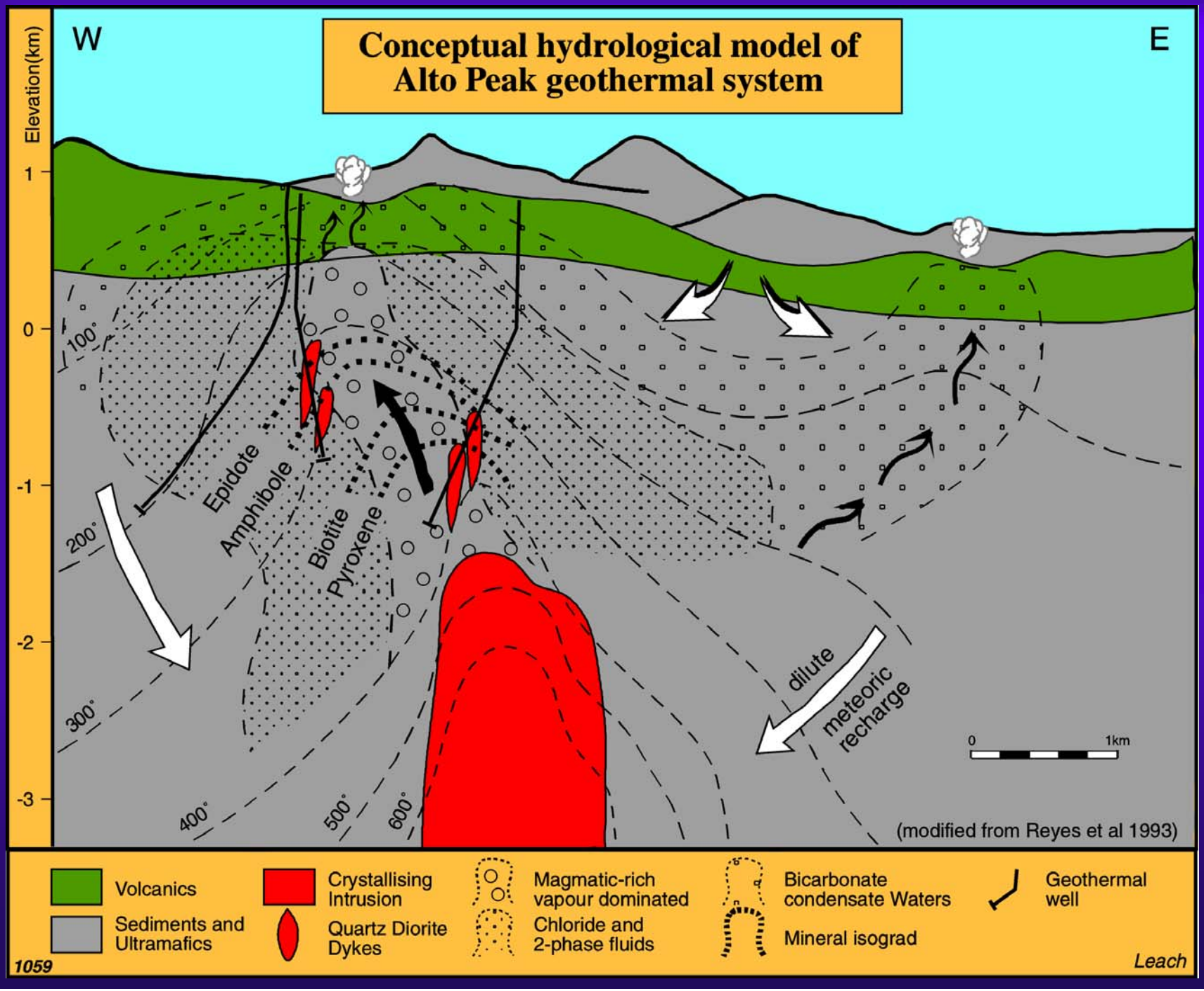
Barren shoulders to porphyry Cu-Au

Lookout Rocks, New Zealand

Ekwai Debom, Frieda River, PNG


North
South
Puhagan Development
Nasuji -Sogongon Development
Cuernos De Negros
Baslay Exploration
Gas Fumardes
Dilation Fault Zone
2000m
1000m
mean sea level
-1000m
-2000m
Twin Phase Zone
Acid Recharge
Condensate Recharge
Meteoric Recharge
?
Porphyry Intrusives (Pleistocene-Recent)
Andesite Sill
Nasuji Monzonite (10-11 my)
Andesite Volcanics (Miocene-Recent)
Calcareous Sediments (Eocene-Miocene)
Andesite Volcanics/ Volcanclastics (Eocene)
Low pH Gas Condensate and Acid Sulphate Recharge
Skarn
Potassic Zone
Advanced Argillic Alteration
Acid Sulphate - Bicarbonate Fluids
Conceptual Model of the Southern Negros Geothermal Field


Conceptual hydrological model of Alto Peak geothermal system
W
E
Elevation(km)
1
0
-1
-2
-3
100°
200°
300°
400°
500°
600°
Epidote
Amphibole
Biotite
Pyroxene
dilute
meteoric
recharge
0
1km
(modified from Reyes et al 1993)
Volcanics
Sediments and Ultramafics
Crystallising Intrusion
Quartz Diorite Dykes
Magmatic-rich vapour dominated
Chloride and 2-phase fluids
Bicarbonate condensate Waters
Mineral isograd
Geothermal well
1059
Leach

Early magmatic volatiles – Rocks

Negros Is., Phillipines

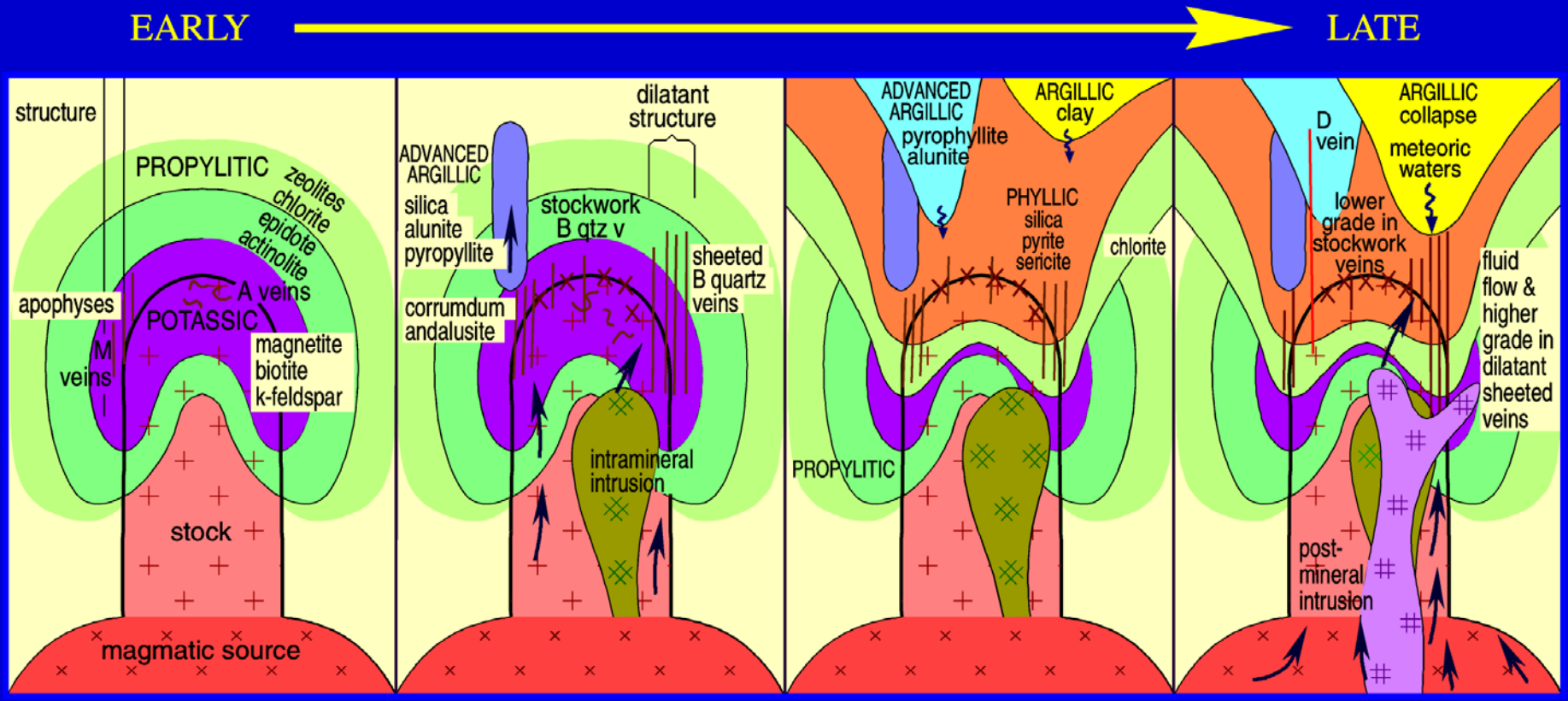
Vuda, Fiji

Peak Hill, Australia

Bulahdelah, Australia

Pyrite-rich AAA, Quimsacocha, Ecuador

Time in porphyry Cu-Au evolution



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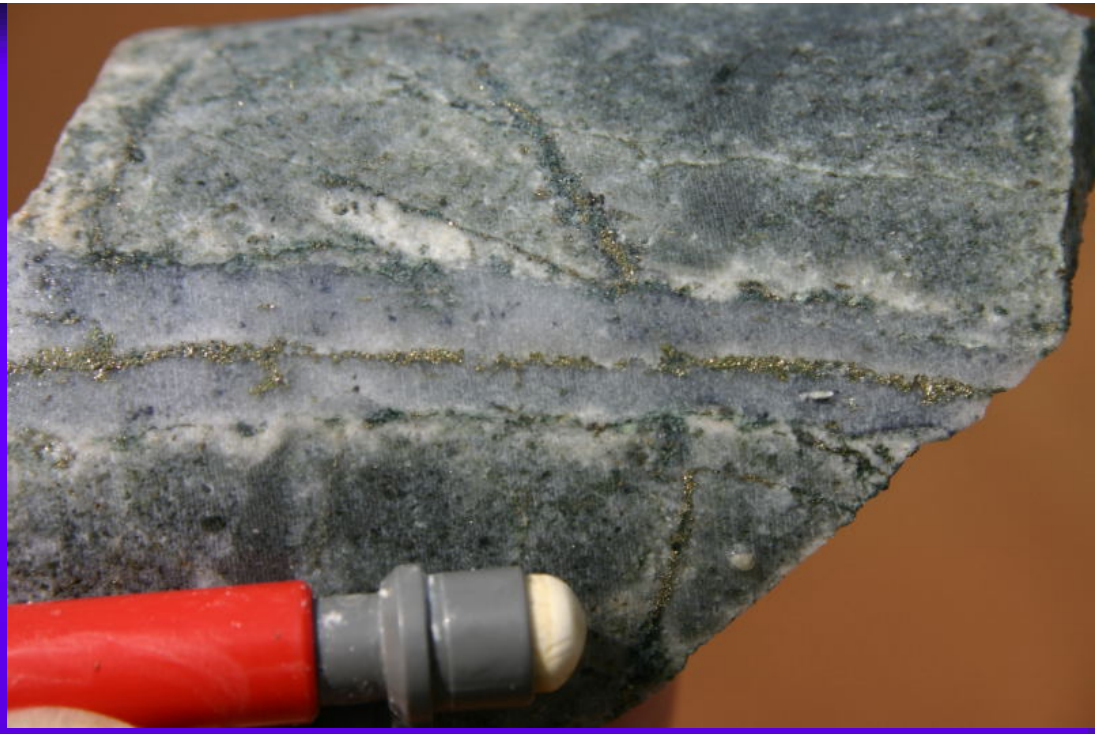
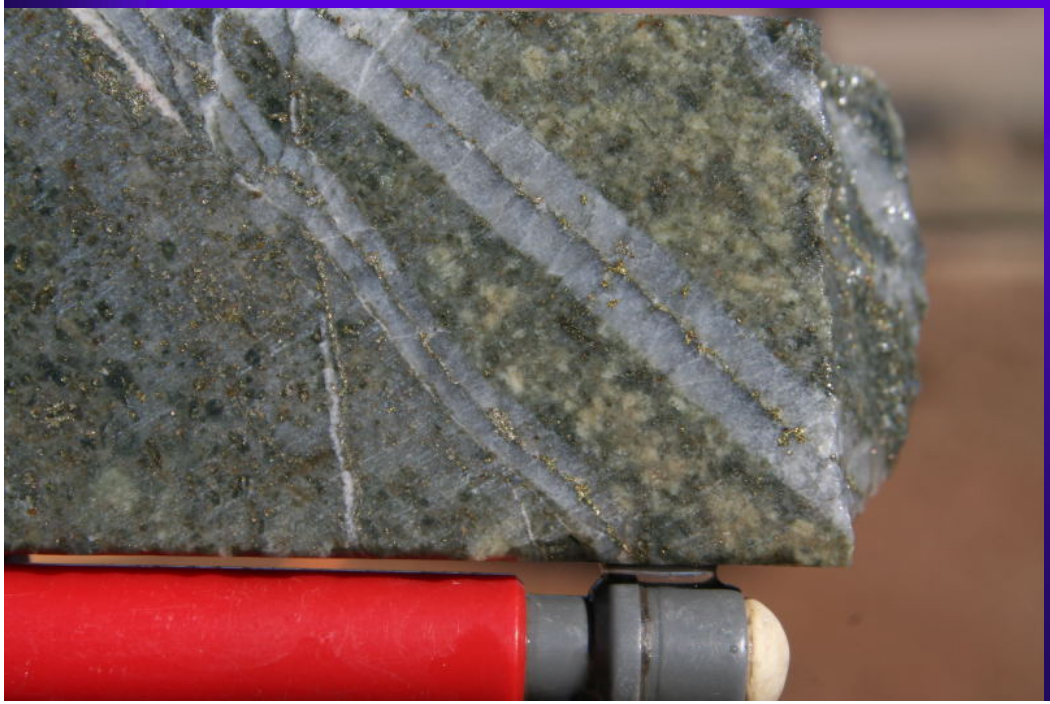
B veins

Chatree,
Thailand





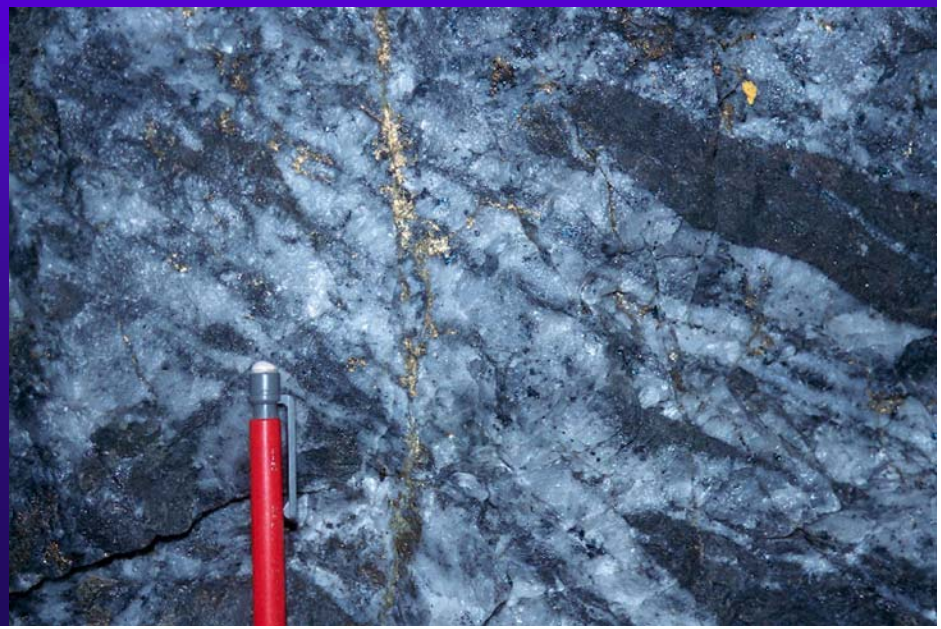
Copper Hill,
Australia

C veins

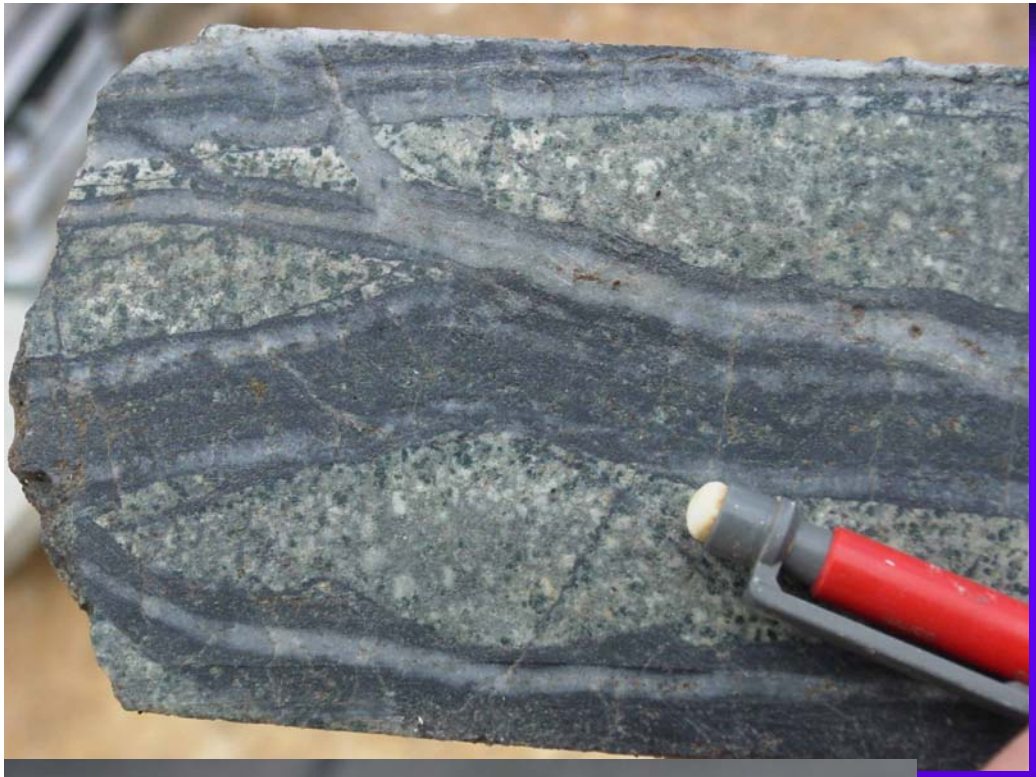
Grasberg, Indonesia

Copper Hill

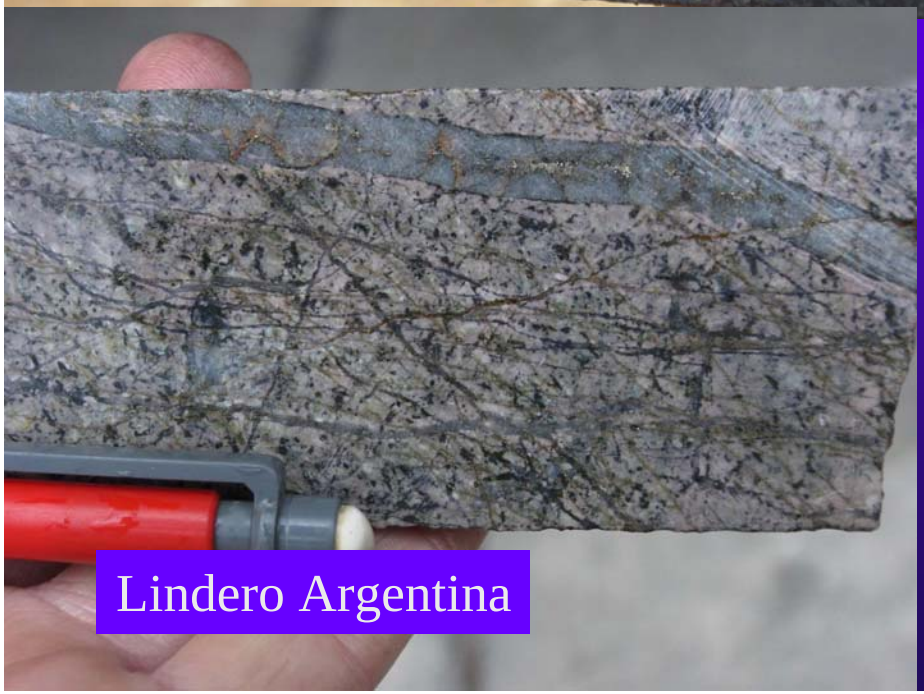
Ridgeway



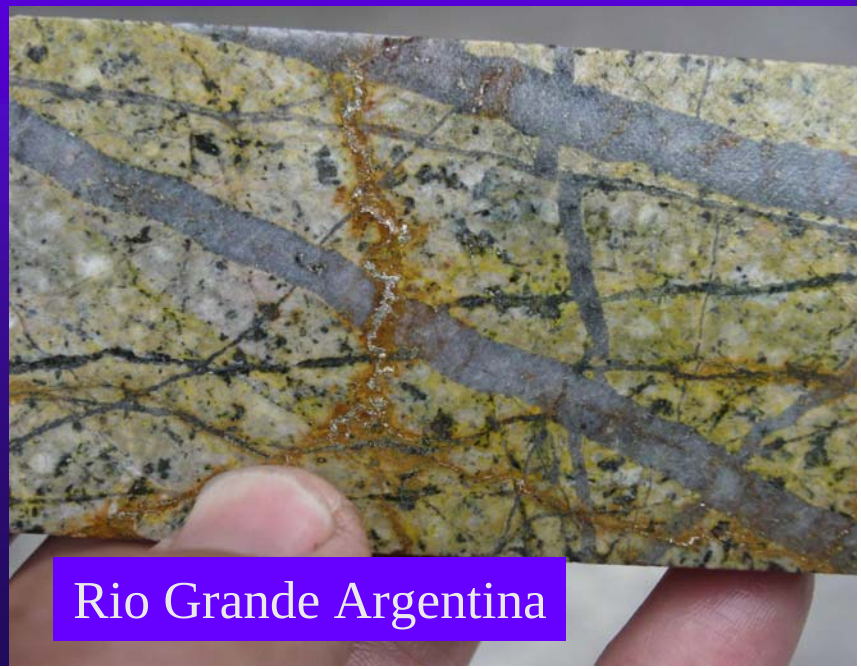
B veins cut M veins



Namosi Fiji

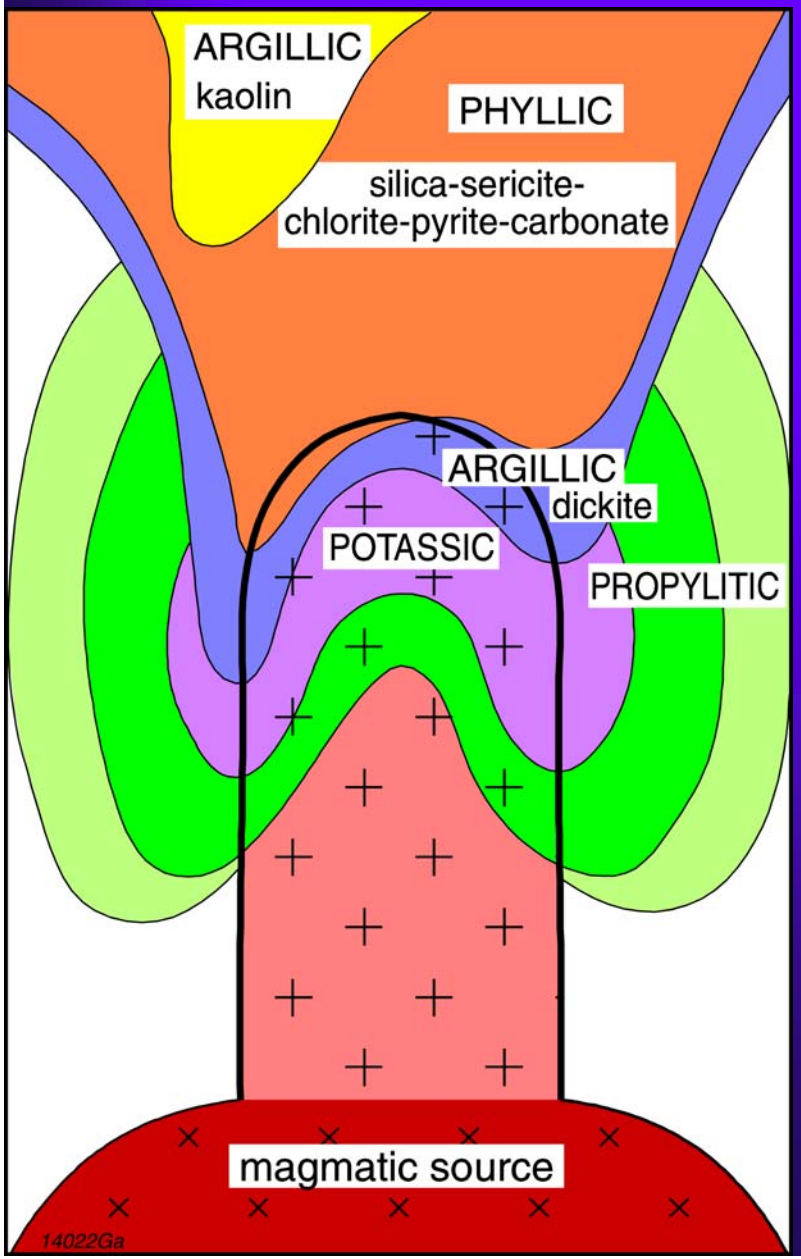


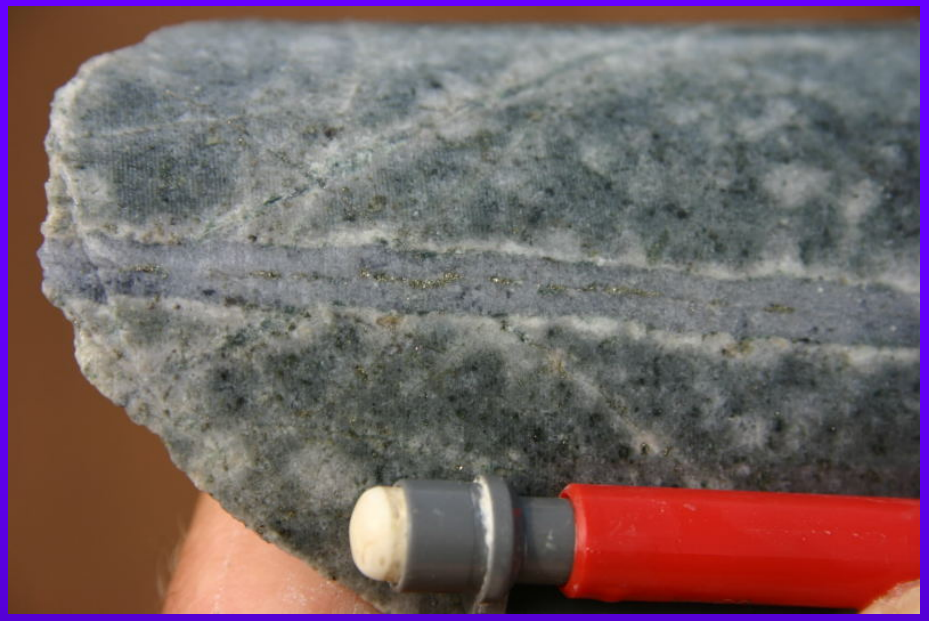
Lindero Argentina

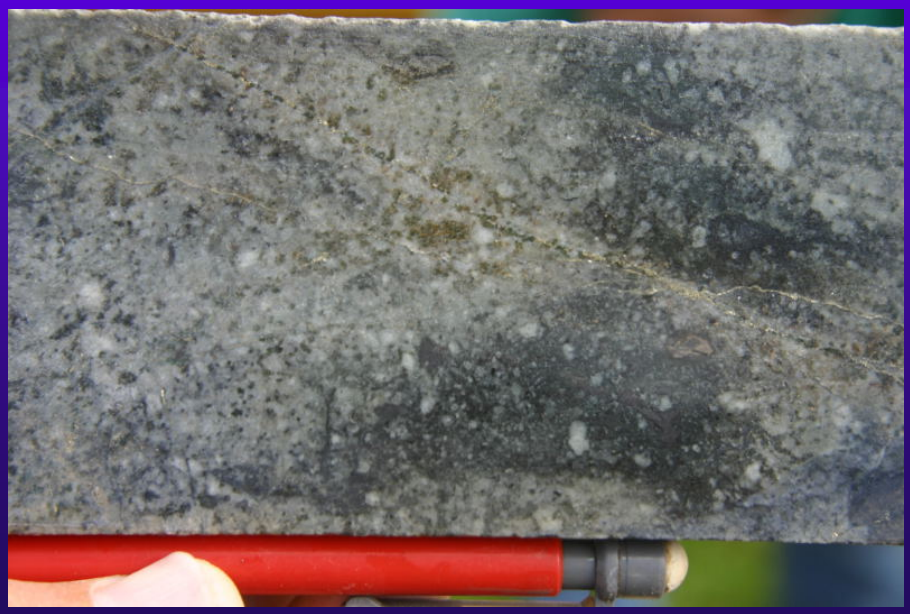


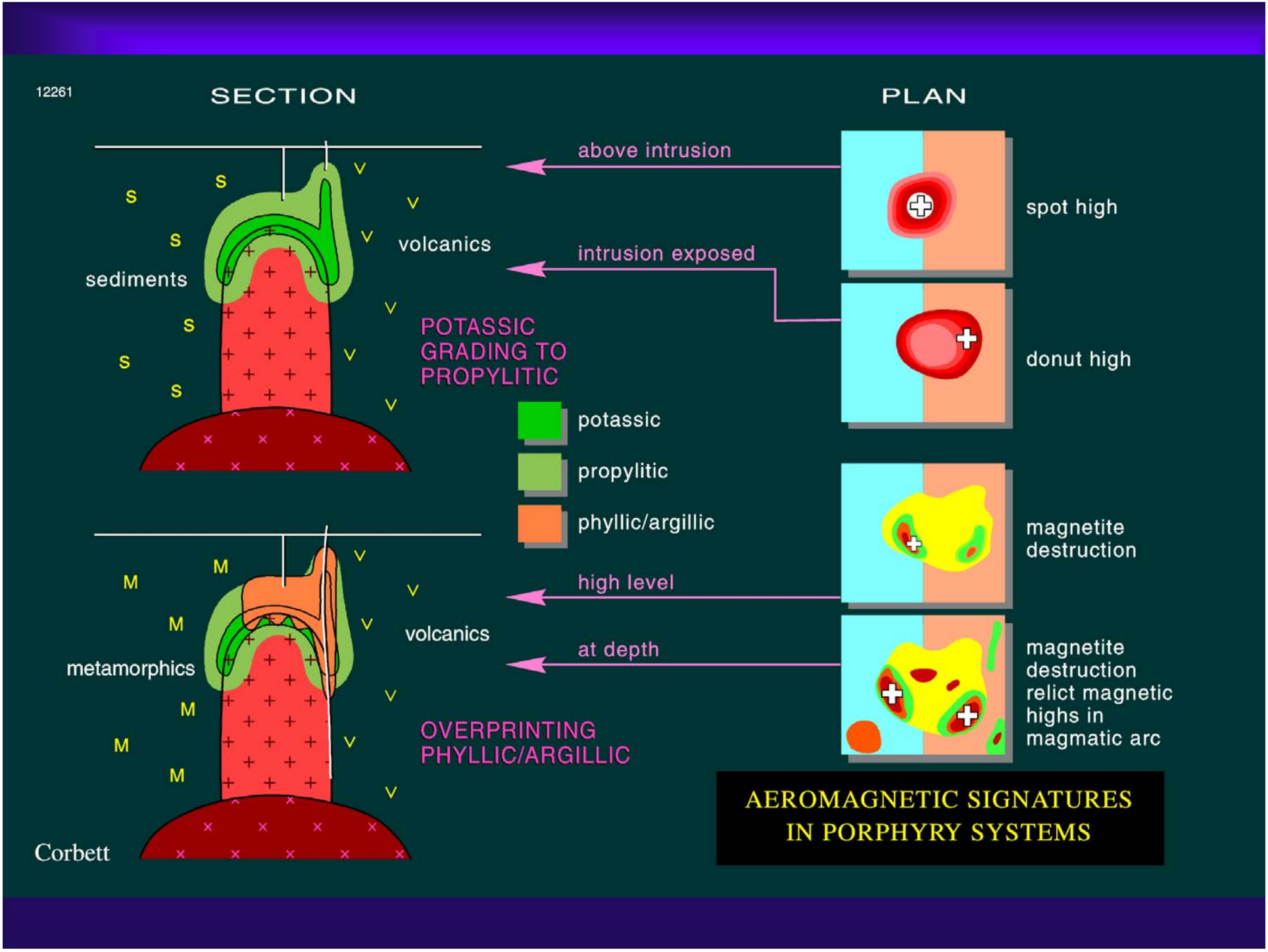
Rio Grande Argentina

Retrograde alteration








12261
SECTION
PLAN
above intrusion
intrusion exposed
spot high
donut high
volcanics
sediments
POTASSIC
GRADING TO
PROPYLITIC
potassic
propylitic
phyllic/argillic
magnetite
destruction
high level
at depth
volcanics
metamorphics
OVERPRINTING
PHYLLIC/ARGILLIC
magnetite
destruction
relict magnetic
highs in
magmatic arc
AEROMAGNETIC SIGNATURES
IN PORPHYRY SYSTEMS
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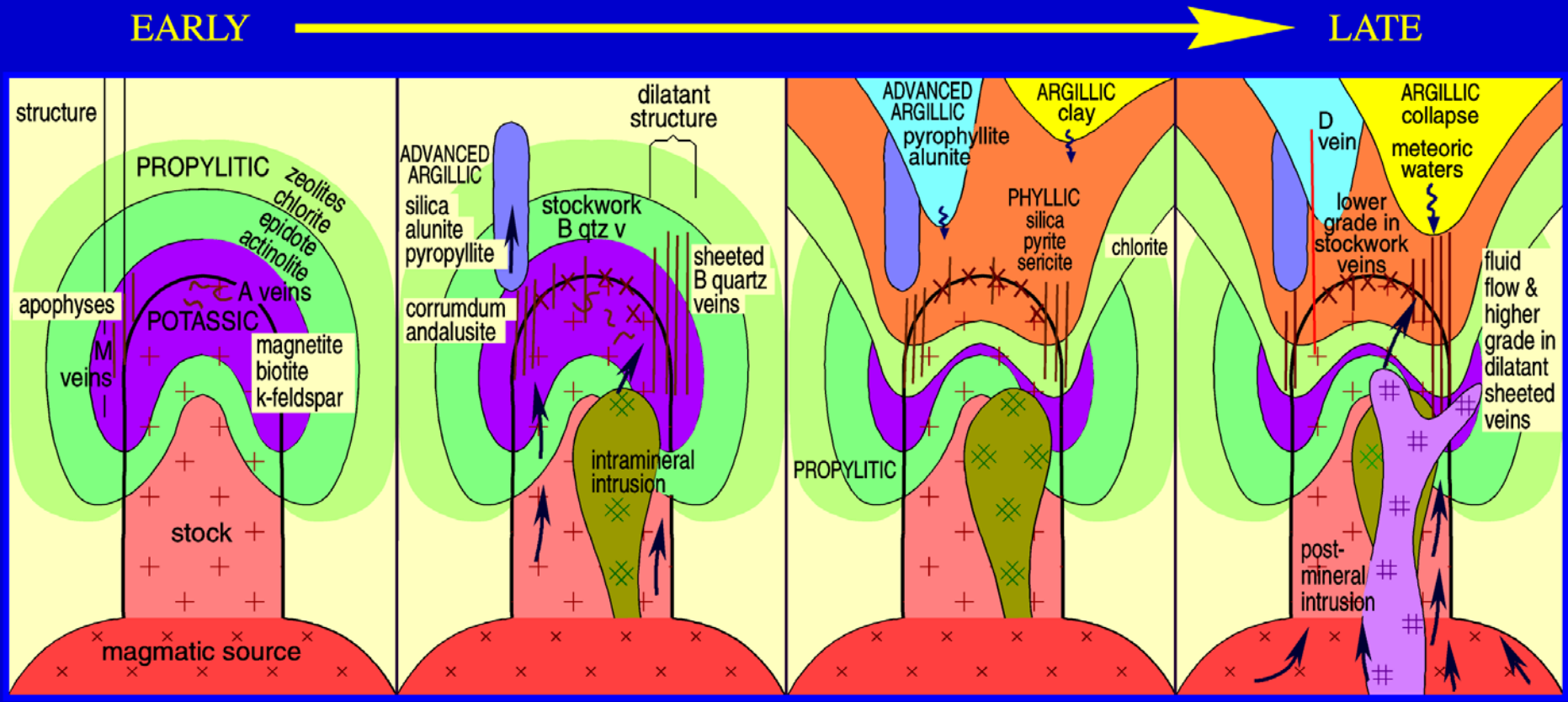
Time in porphyry Cu-Au evolution



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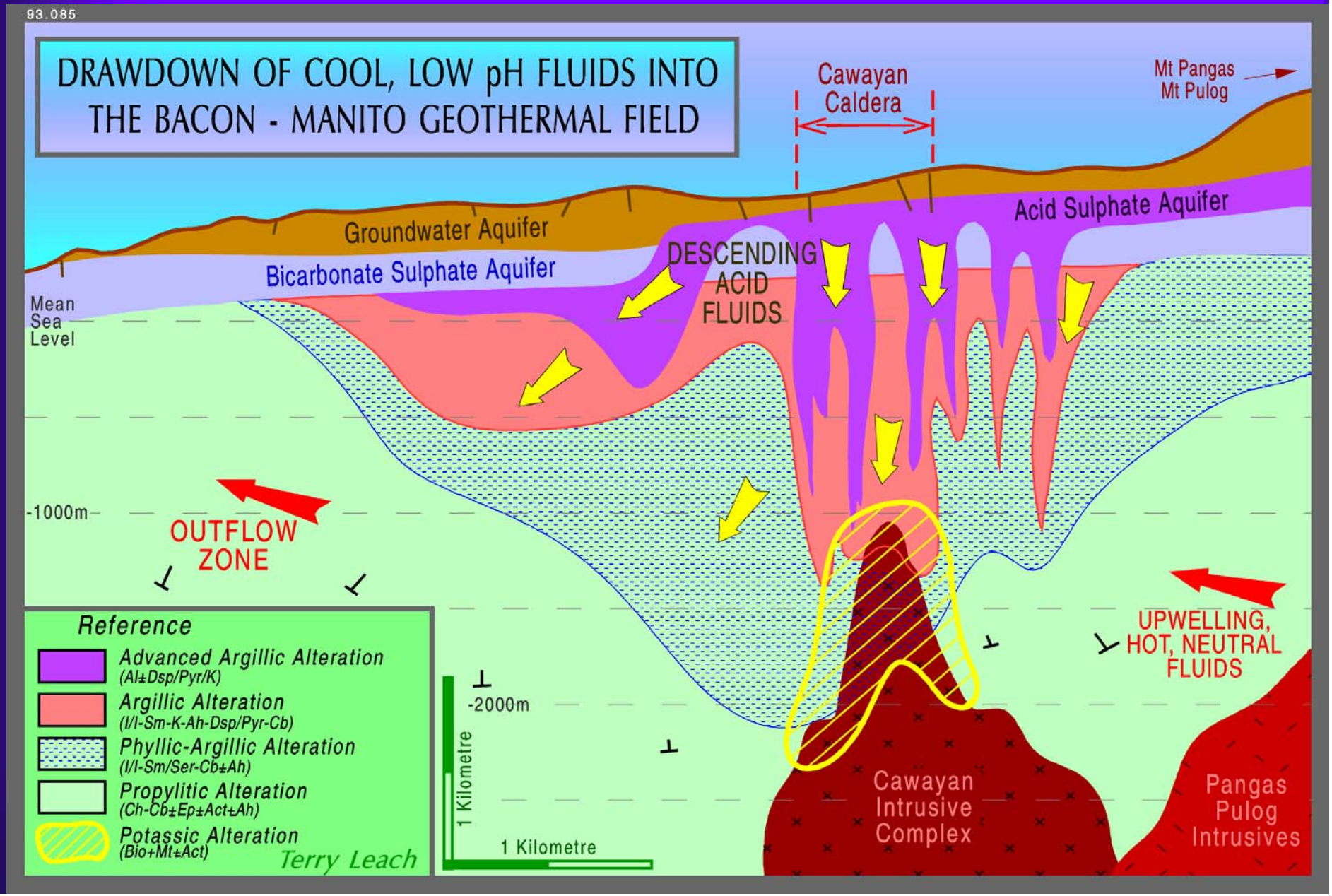
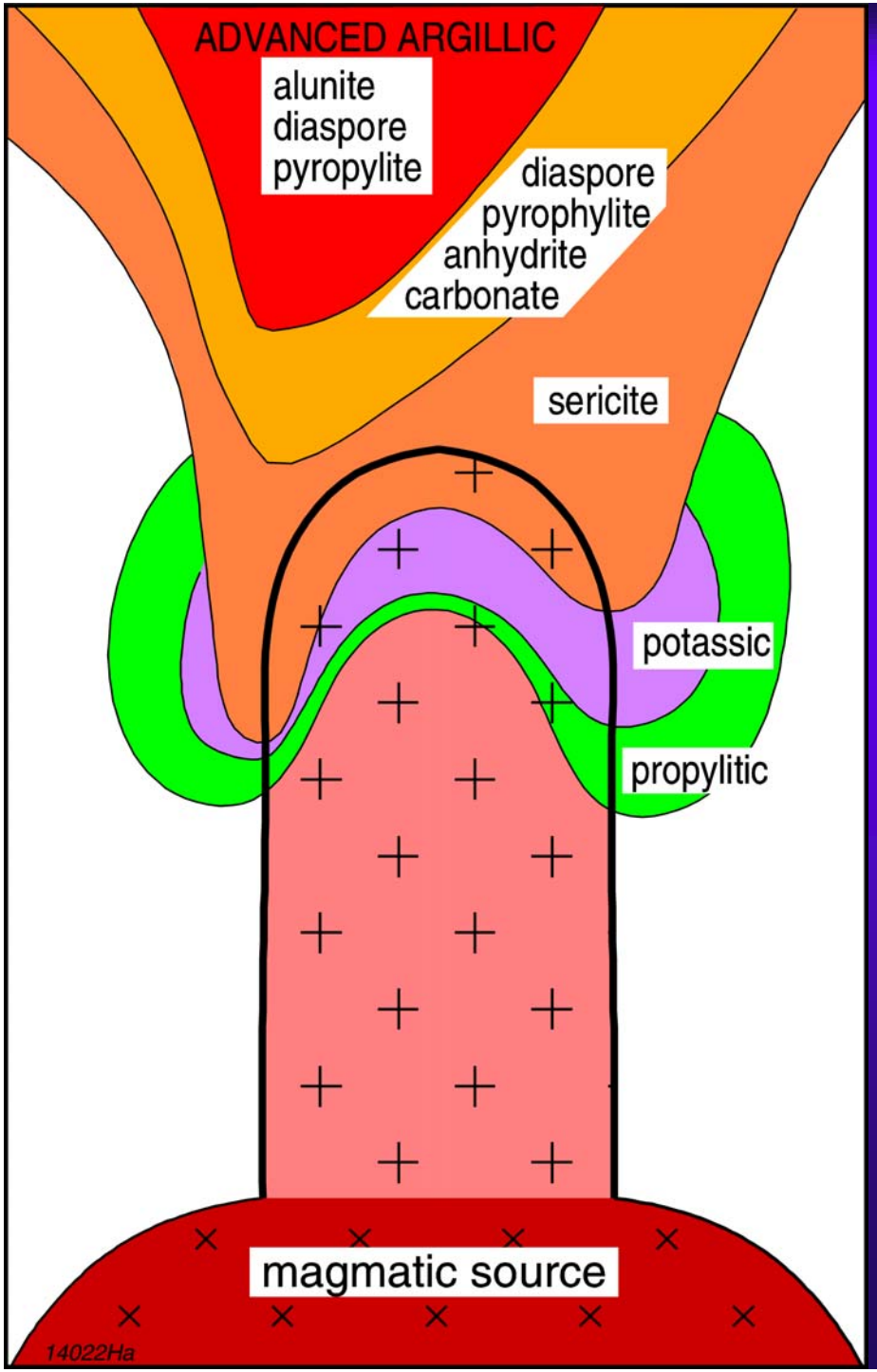
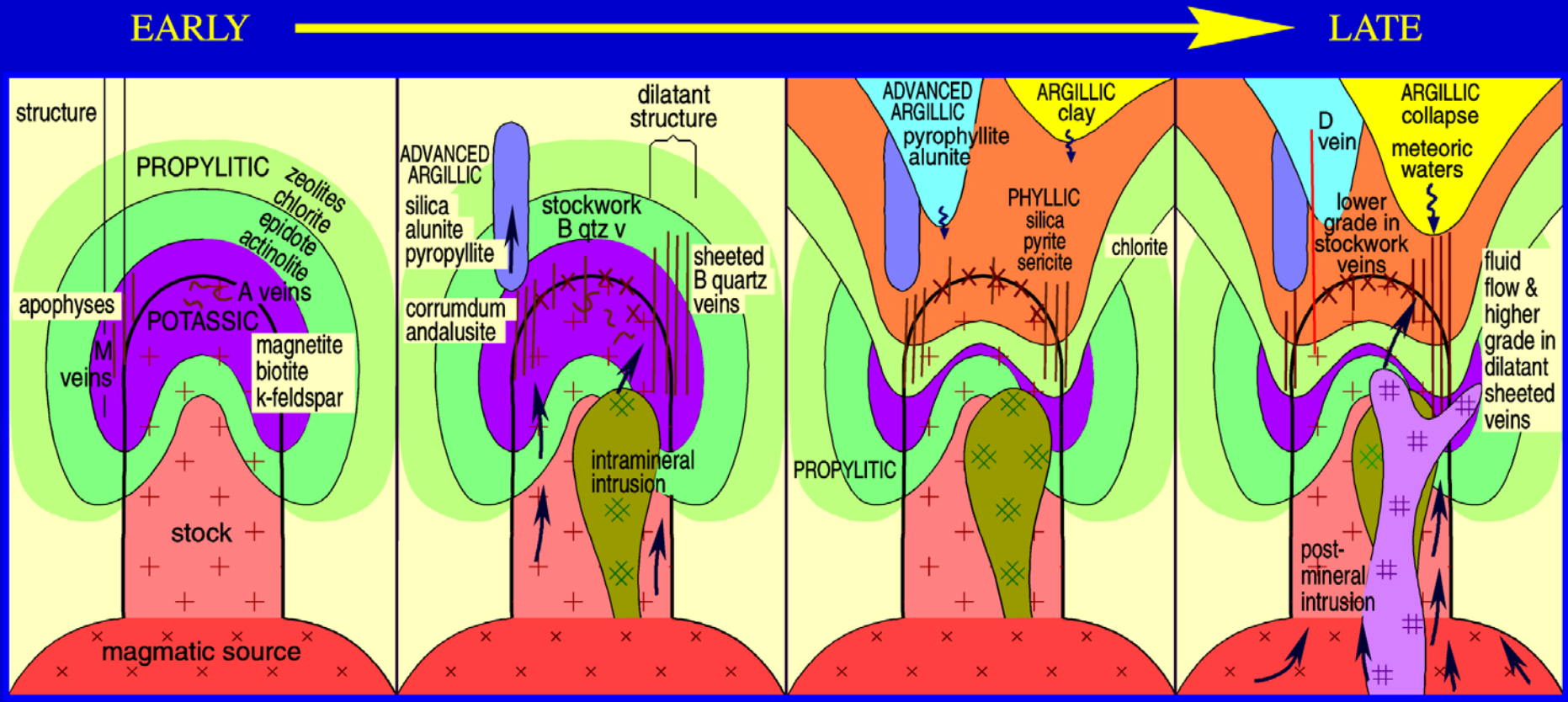
Collapse of Acid waters





Collapsing advanced argillic alteration

Time in porphyry Cu-Au evolution



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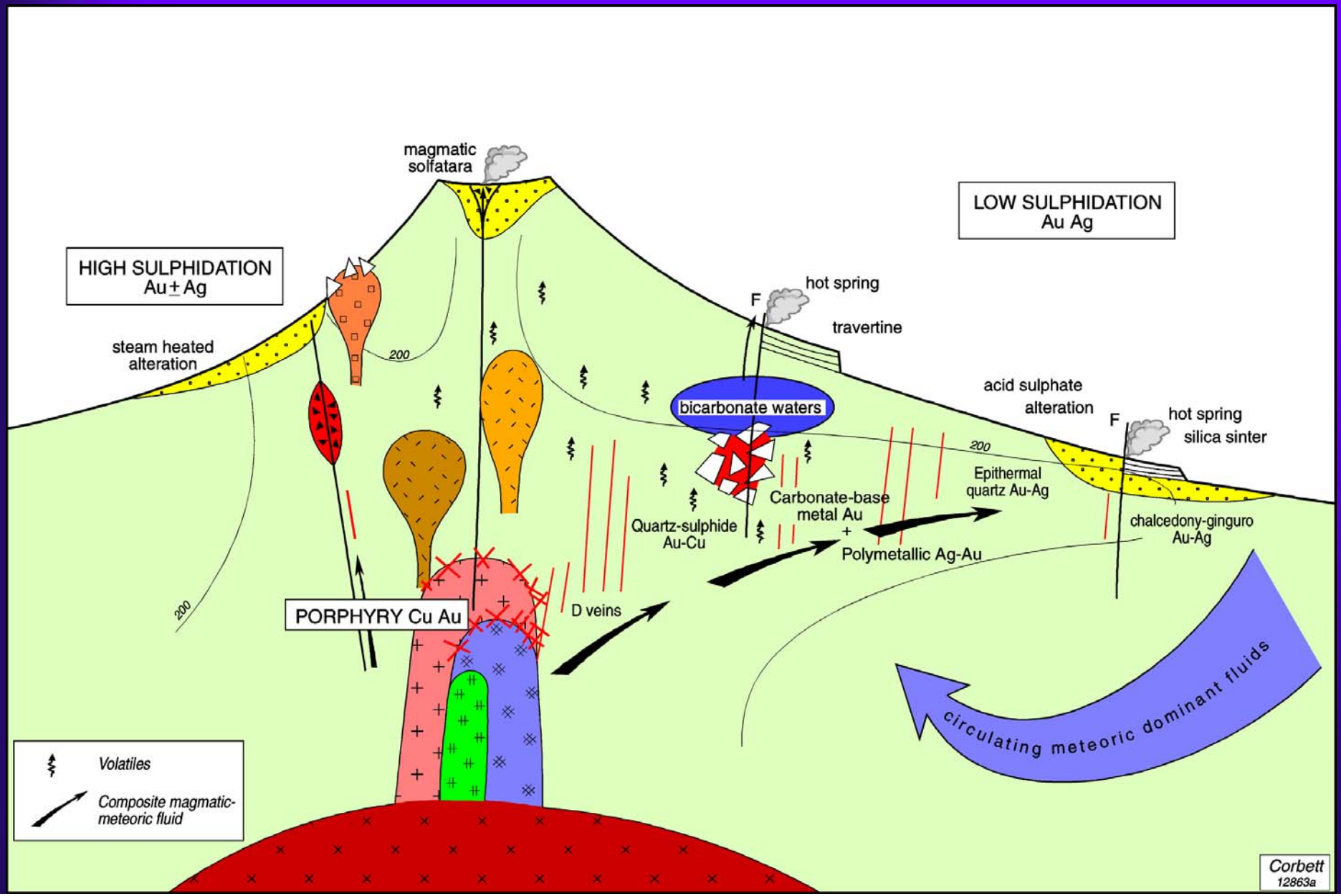
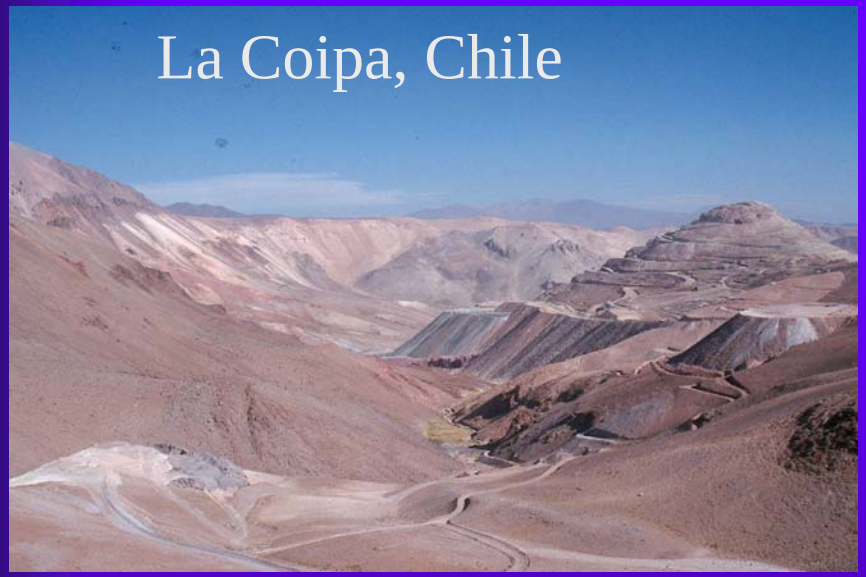
Magmatic arc porphyry to epithermal

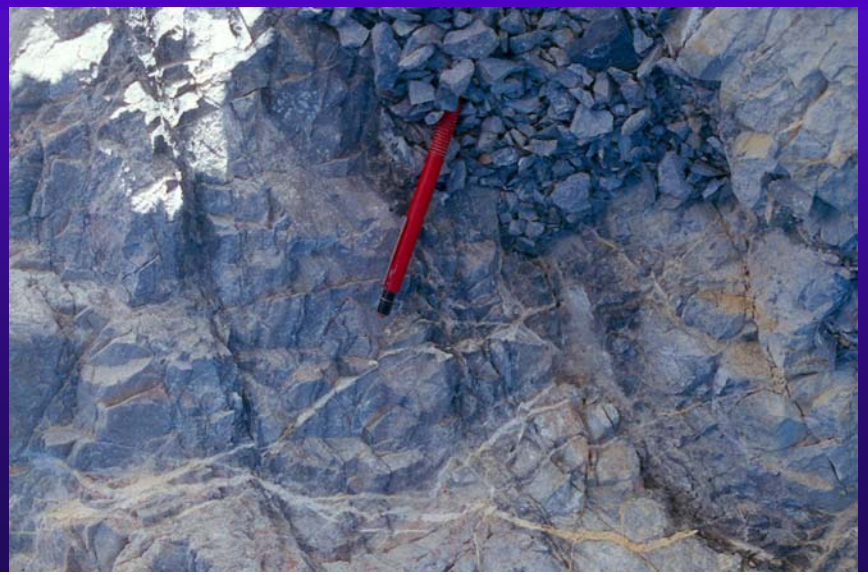


D veins in porphyry-high sulphidation

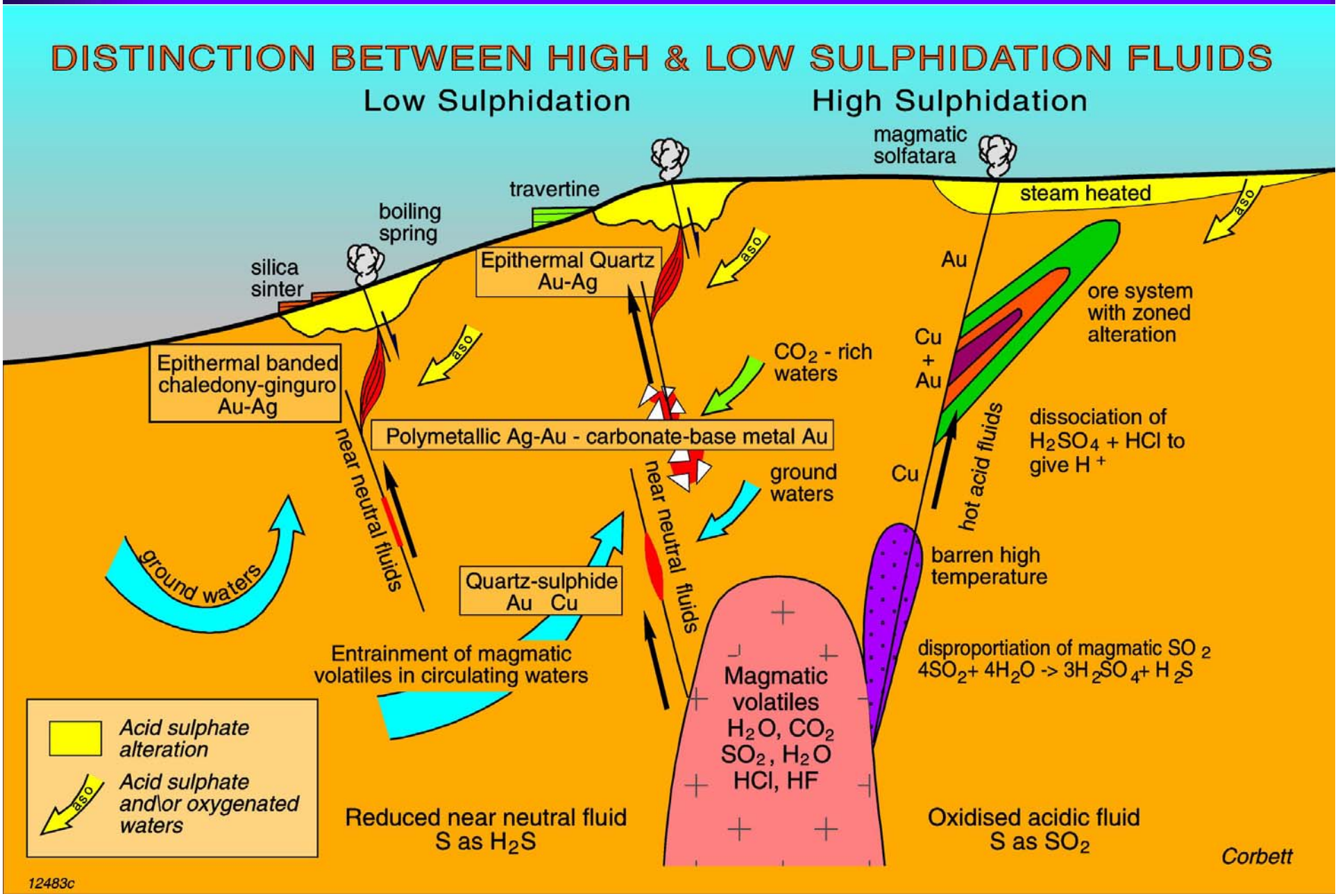
La Coipa, Chile



Poposa, Argentina

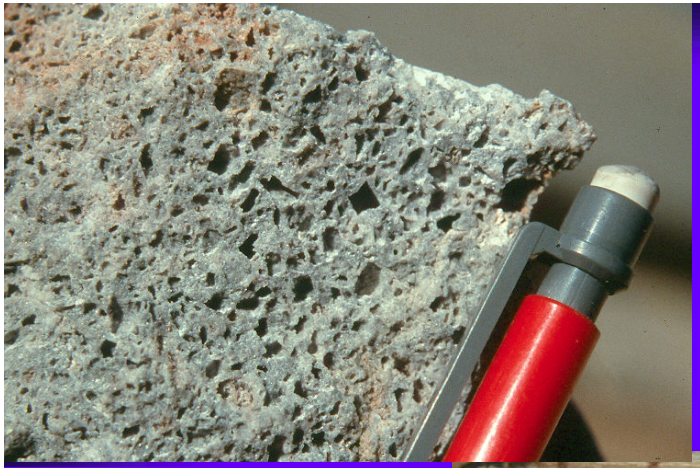


Formation of high sulphidation



MOST
HOT ACID

High sulphidation zoned acid alteration



Vughy or
residual silica

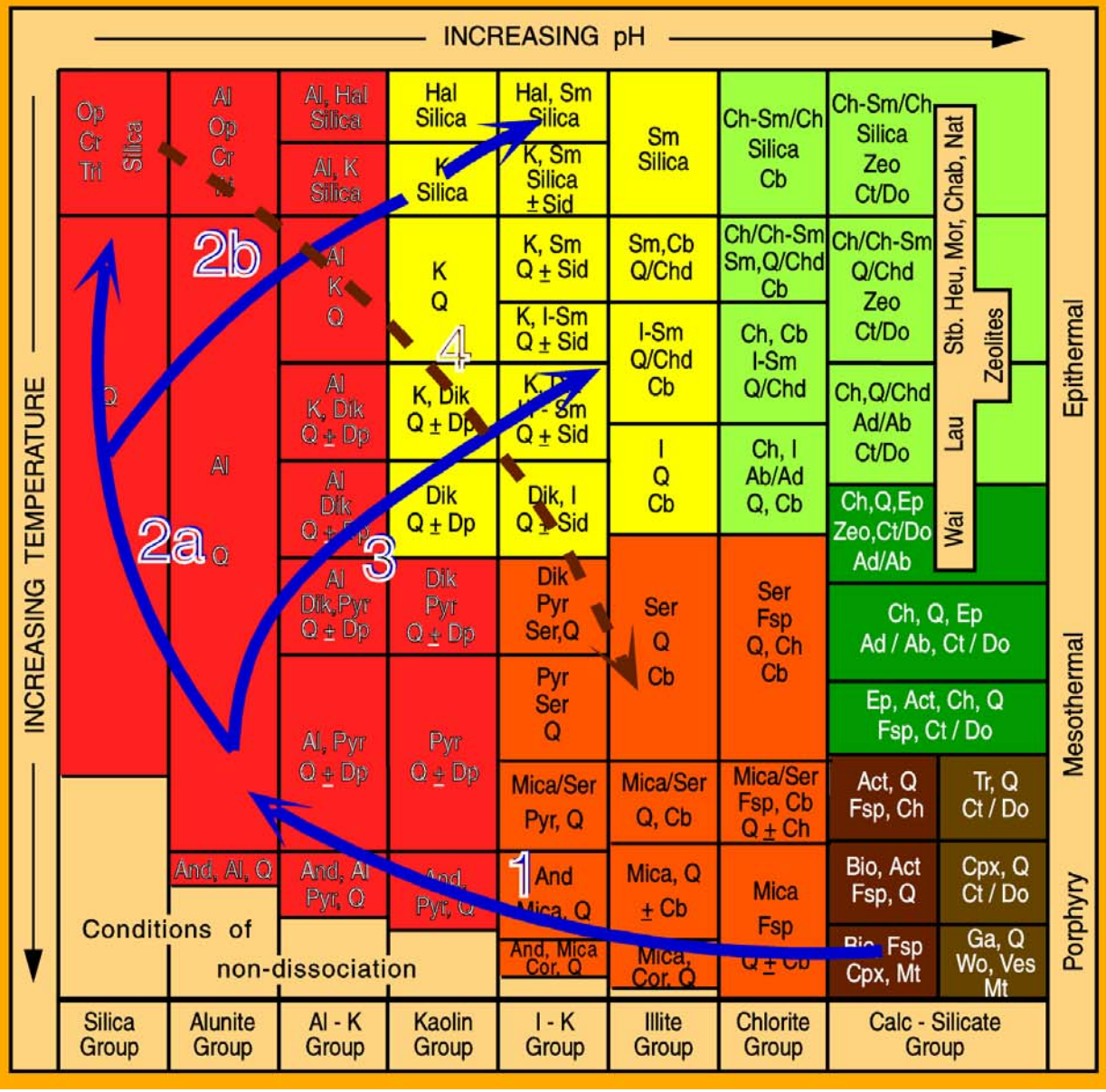
Alunite

LESSER
HOT ACID

Pyrophyllite-diaspore

Dickite-kaolinite

High sulphidation at different levels



High Sulphidation Systems

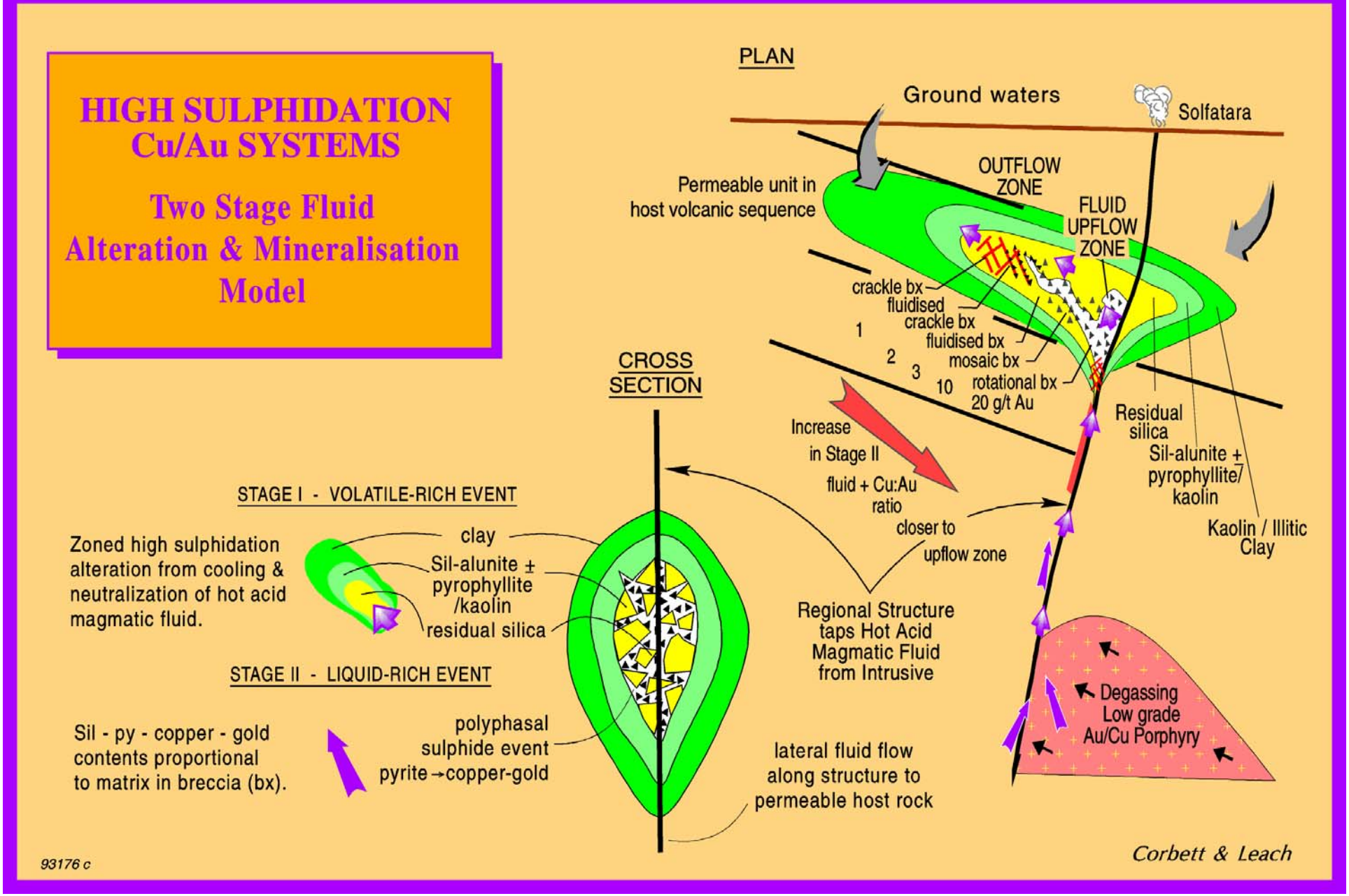
Alteration Mineralogy

1. Porphyry high sulphidation systems
2. Structural high sulphidation systems
   a. Silica core
   b. Peripheral zones
3. Lithological high sulphidation systems
4. Descending cool acid sulphate fluids

Leach

94485

High sulphidation epithermal Au



Mineralization

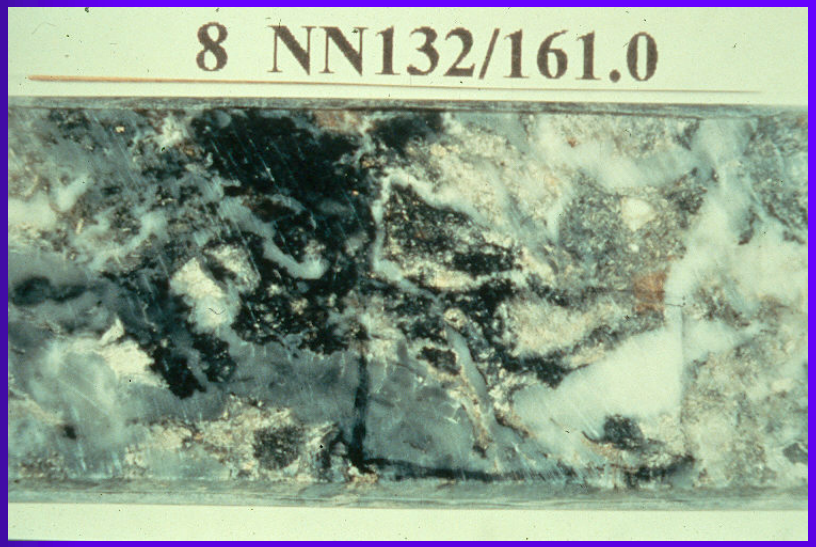
Mt Kasi, Fiji

Maragorik, PNG

El Indio, Chile

Yanacocha, Peru

Gangue



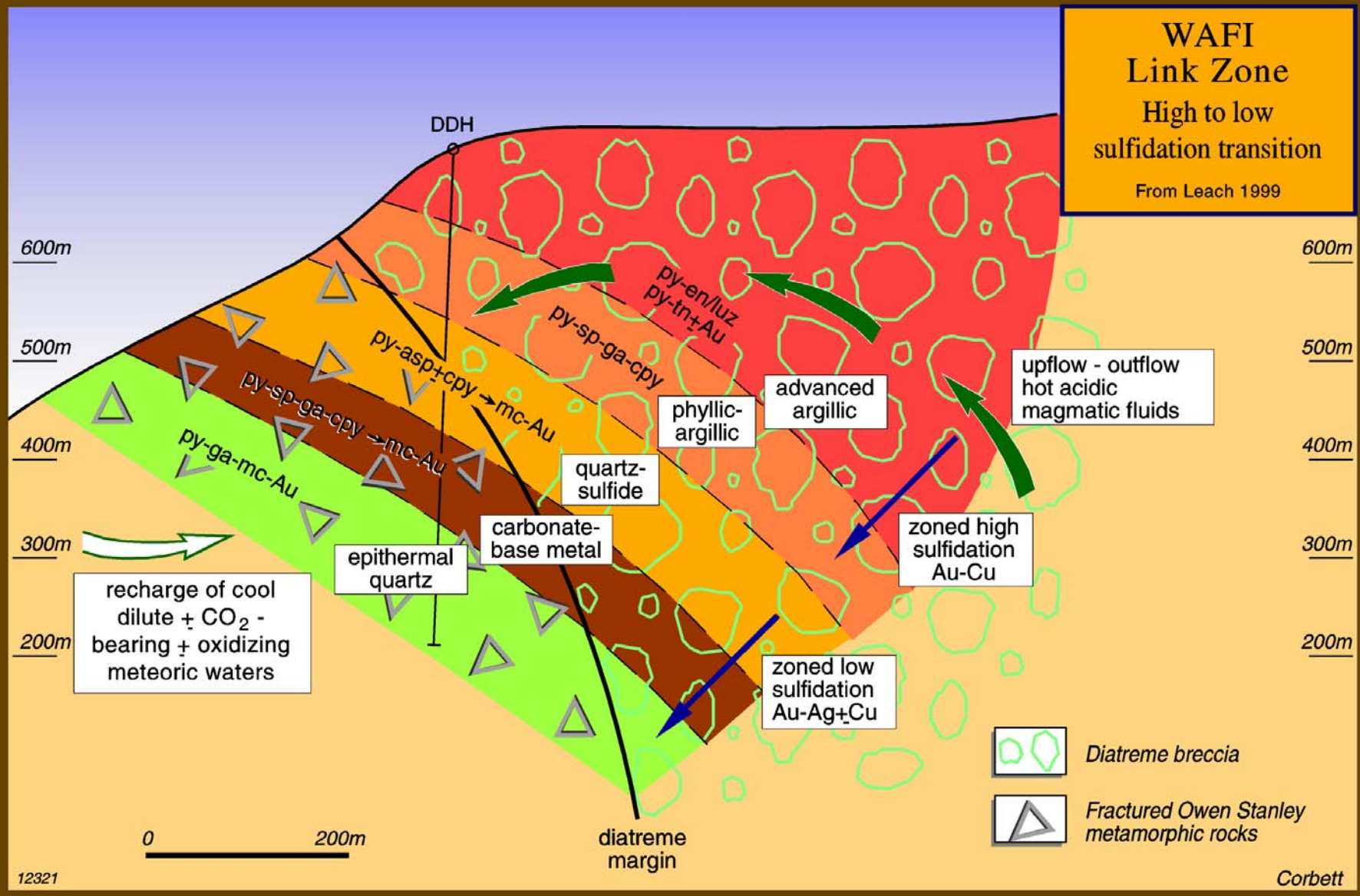
Nena, PNG

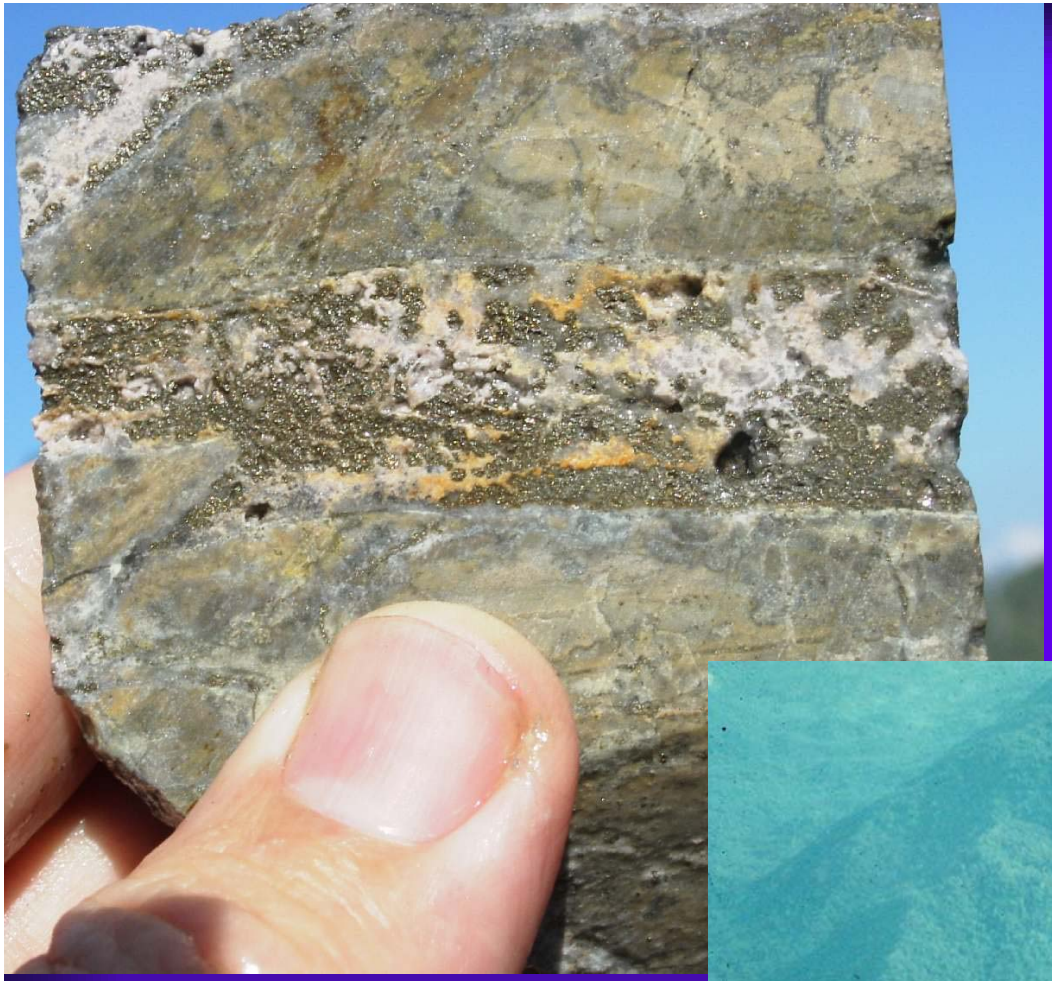
Lama, Argentina

Tambo, Chile

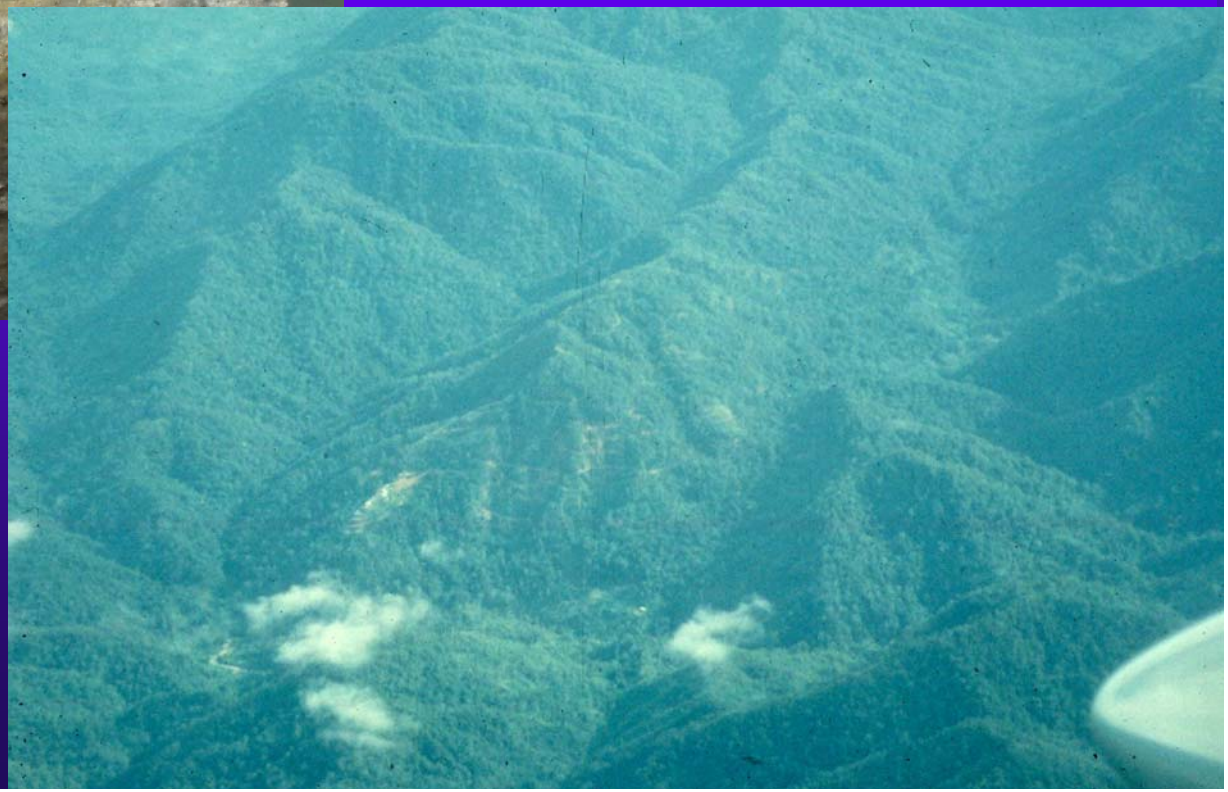
Nansatsu Deposits, Japan

Wafi fluid evolution





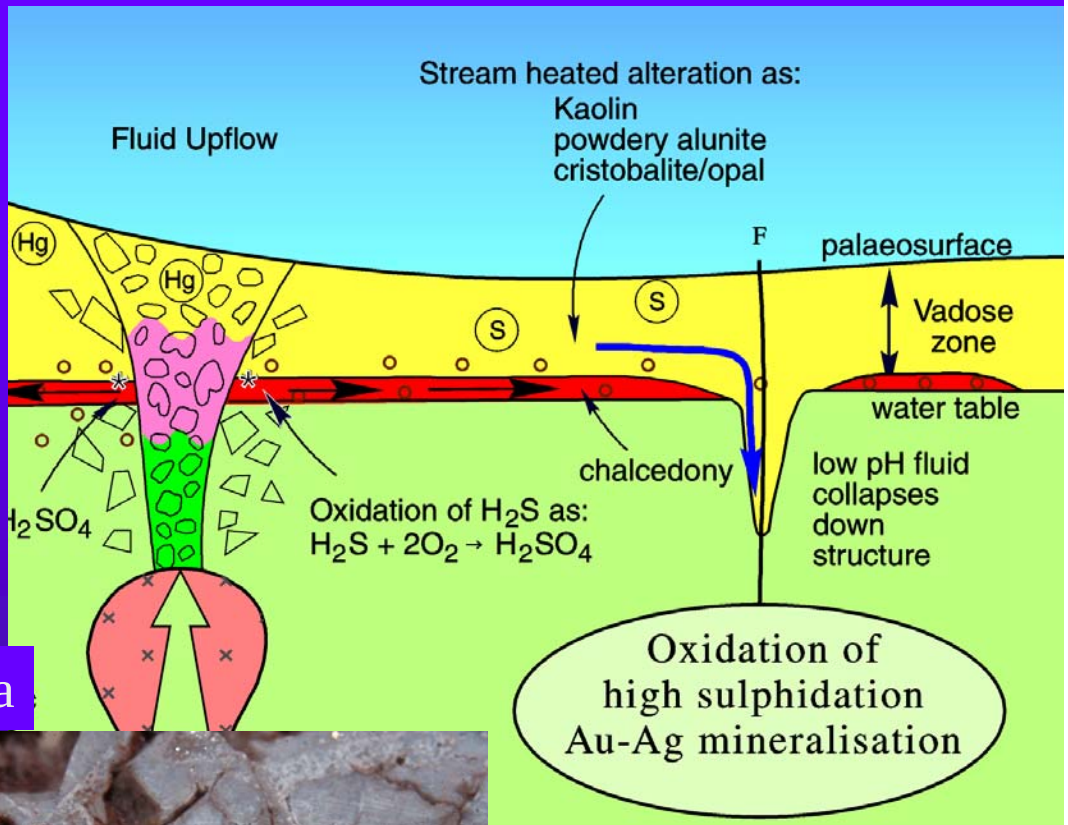
Wafi – low sulphidation Au



Steam heated alteration

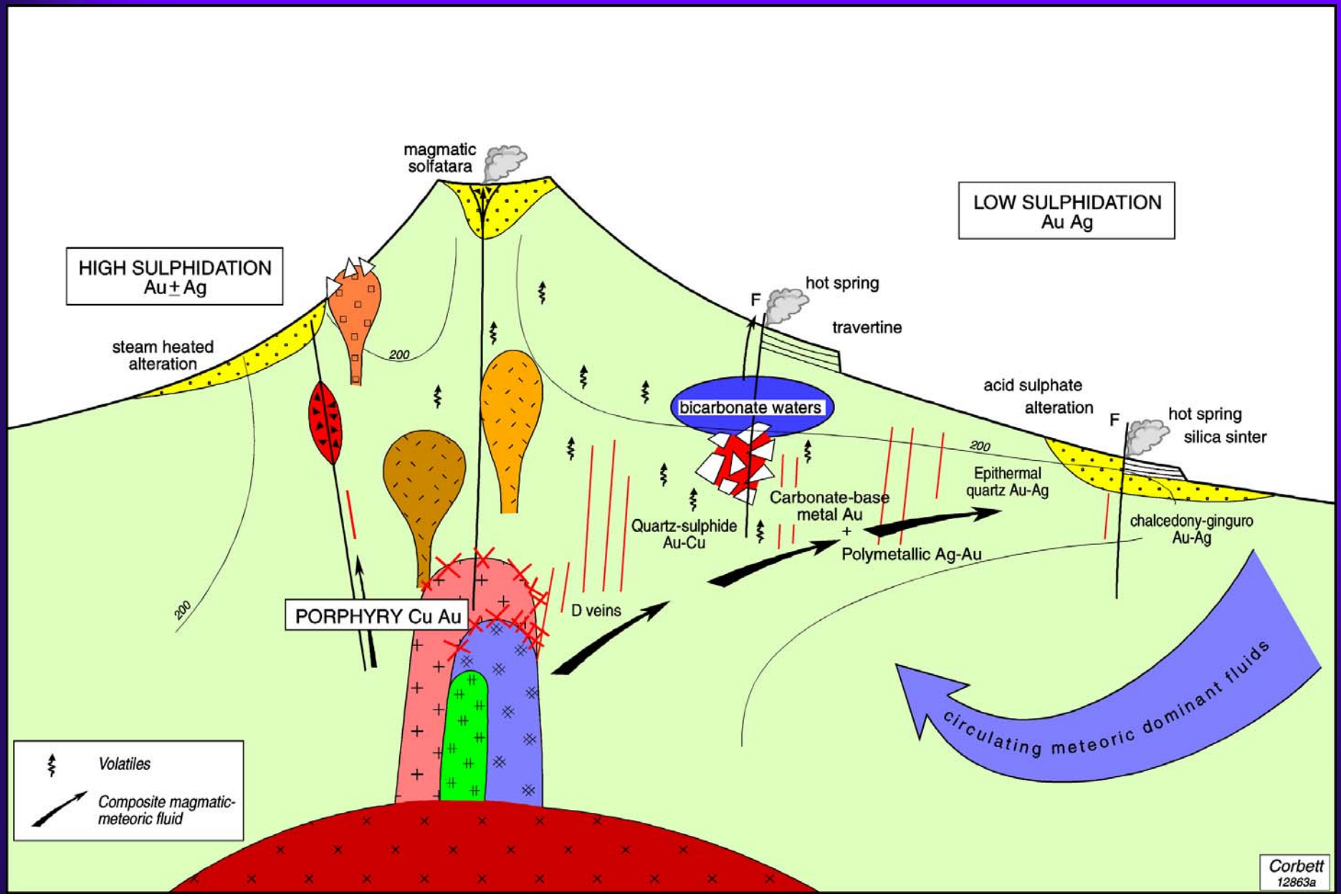
Hypogene oxidation in high sulphidation epithermal systems

Pierina, Peru

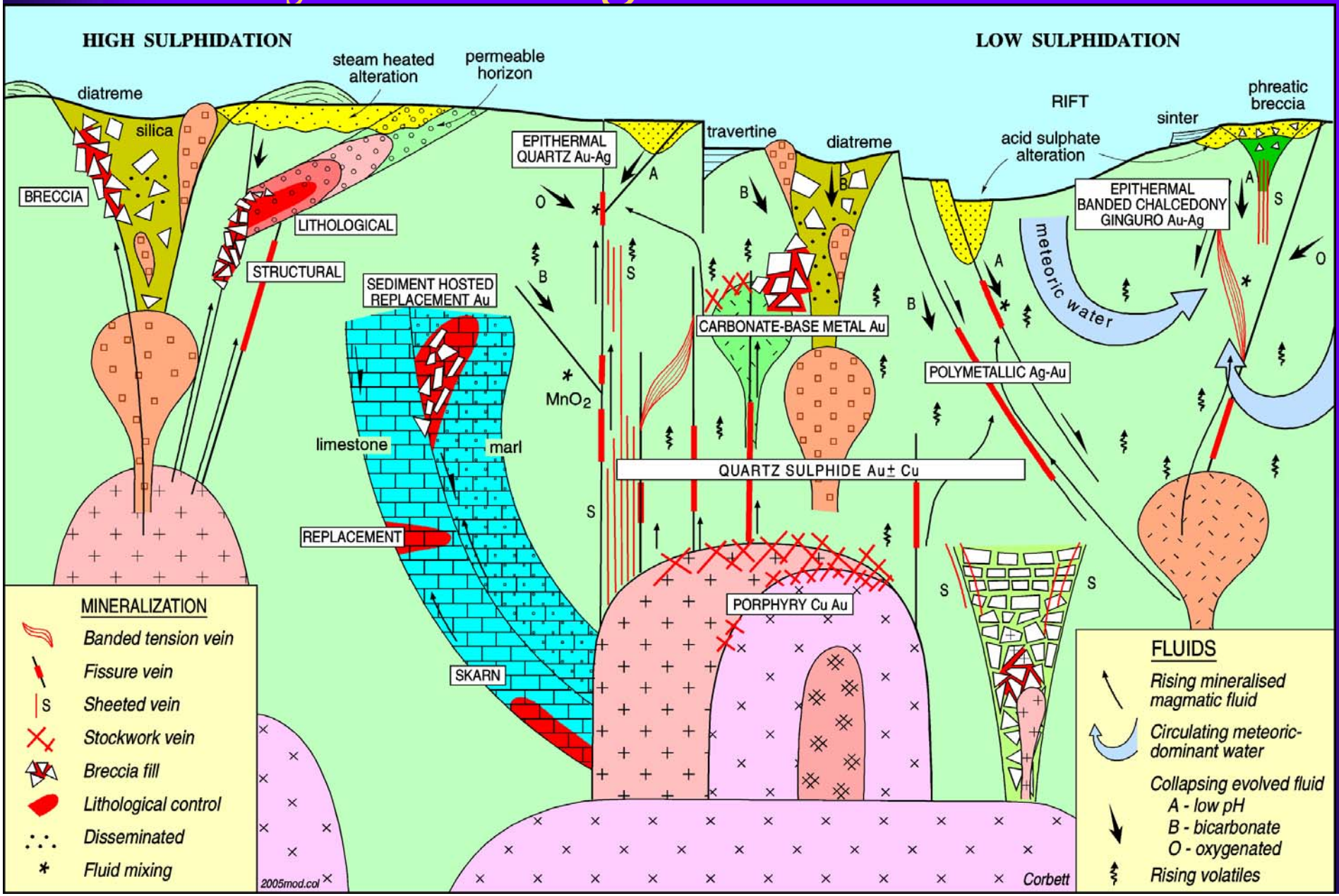


Veladero, Argentina

Magmatic arc porphyry to epithermal



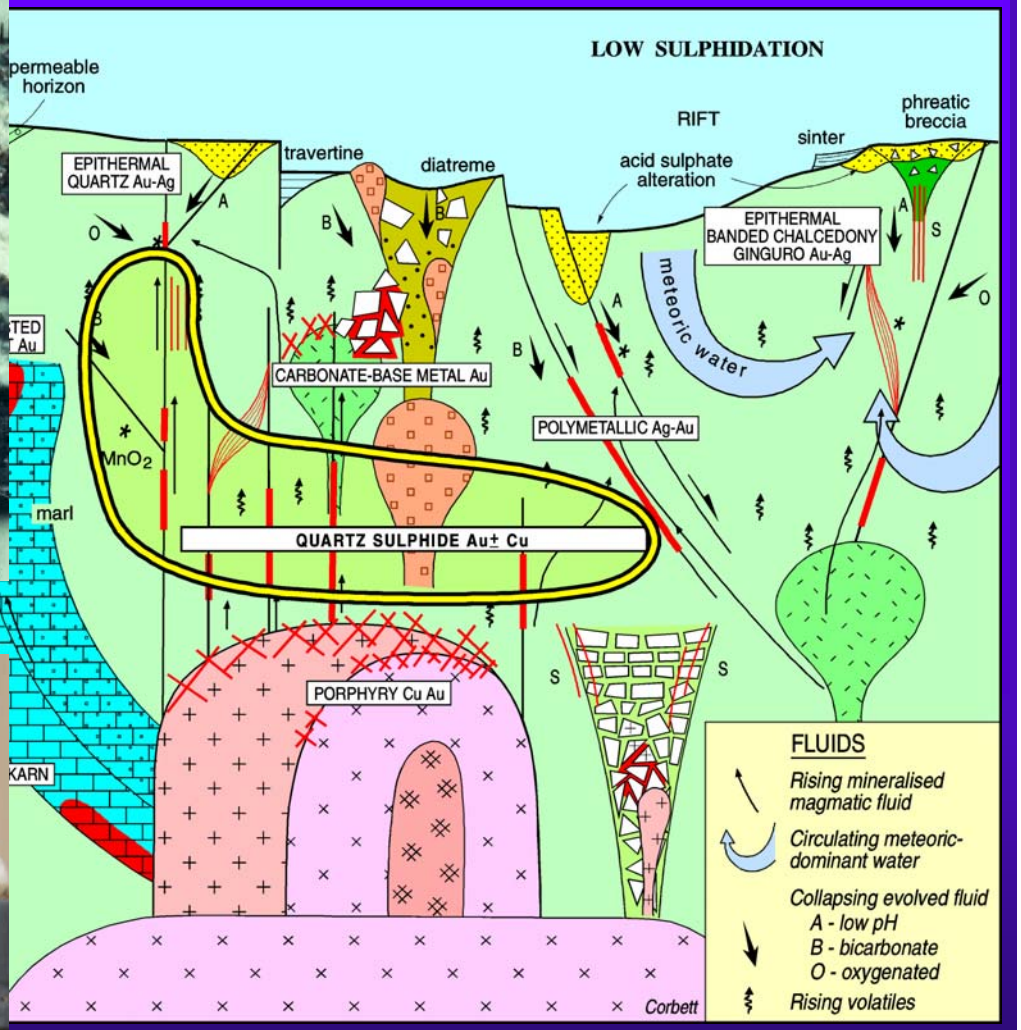
Styles of magmatic arc Cu-Au



Low sulphidation Quartz-Sulphide Au ± Cu

Bilimoia Papua New Guinea

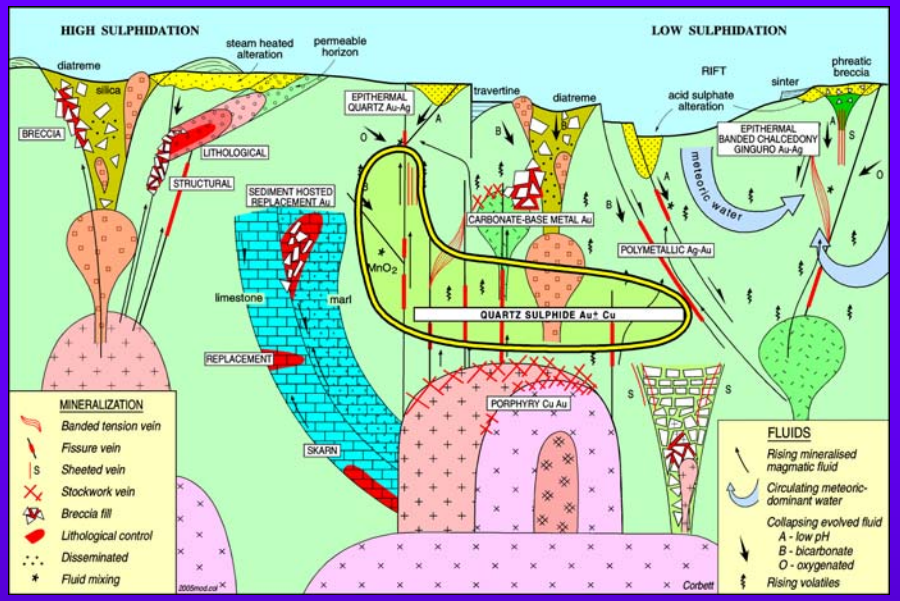
Lake Cowal, Australia



Round Mountain, Nevada

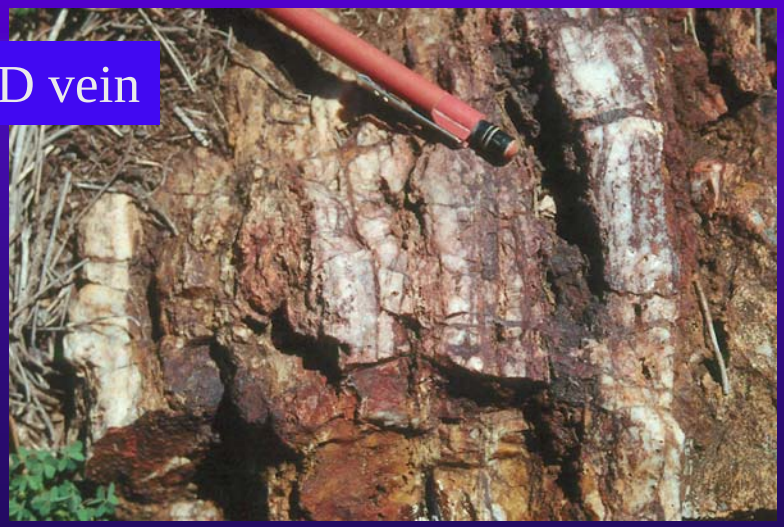
Transition to porphyry Cu-Au

Sheeted veins - Maricunga Belt, Chile

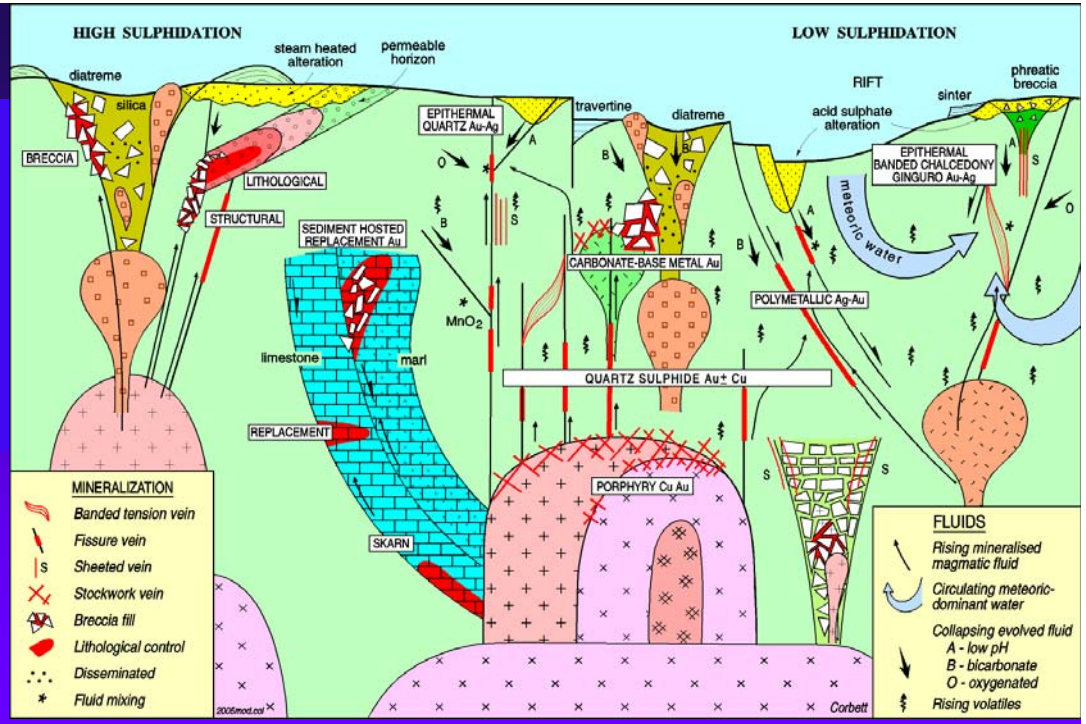


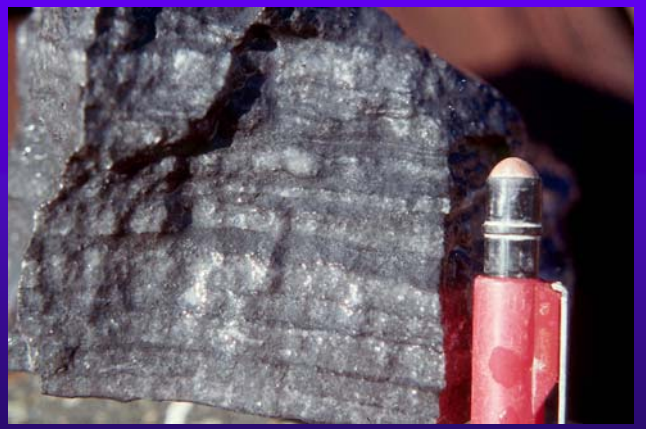
Sheeted veins - Cadia,Australia

D vein

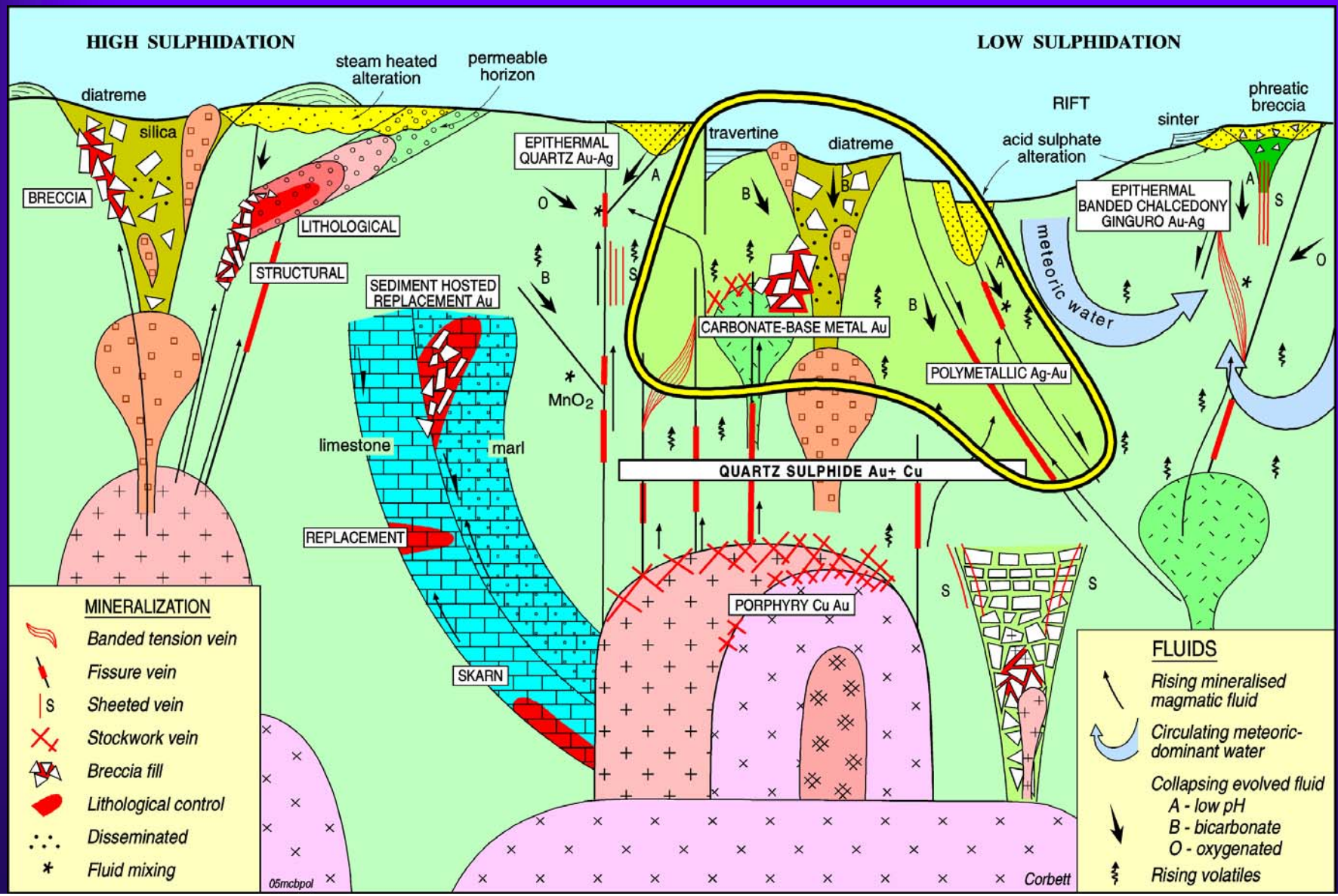


Sediment Hosted Replacement Gold

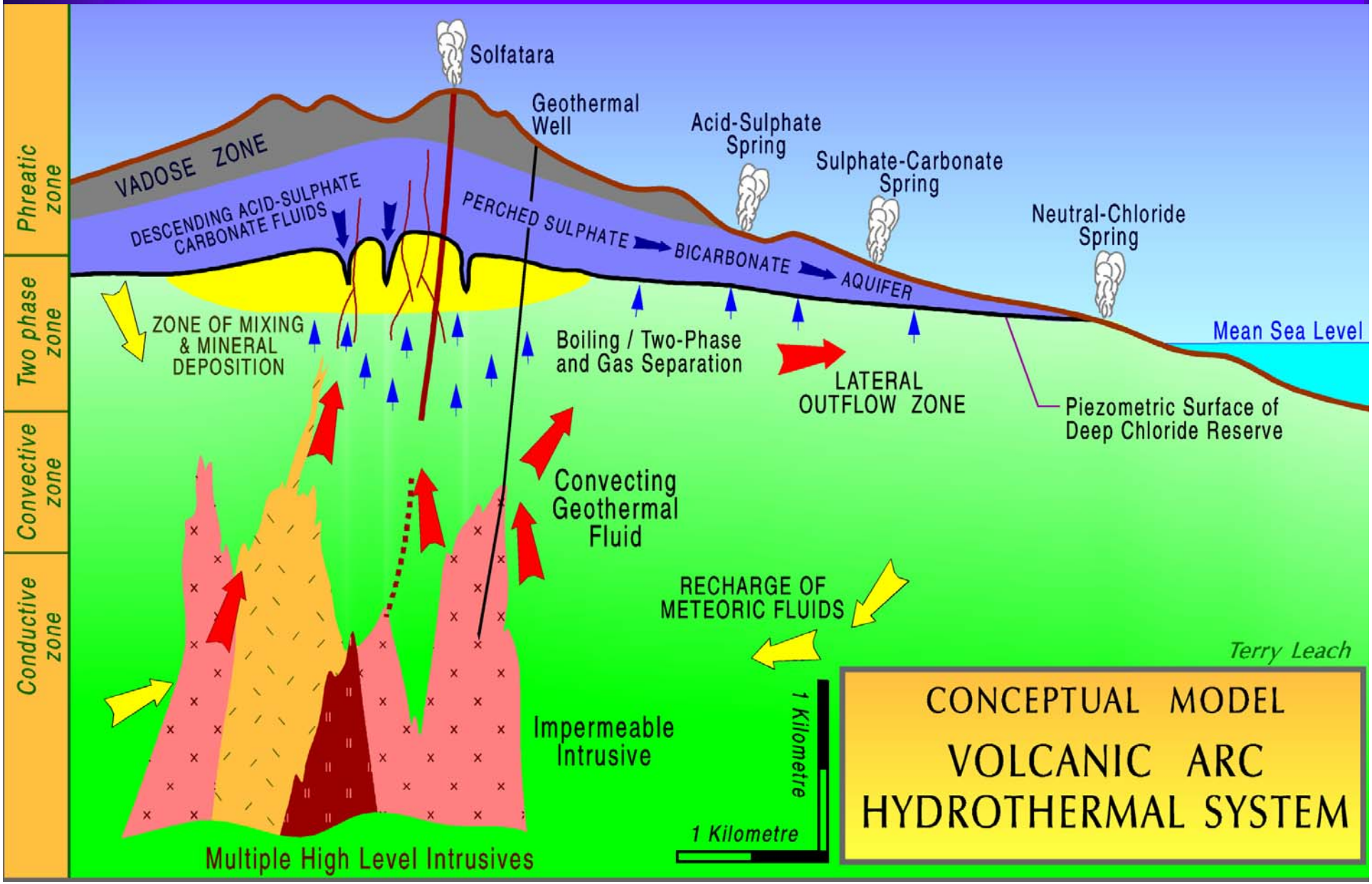




Polymetallic Au-Ag
Carbonate-base metal Au



Bicarbonate waters



Carbonate-base metal Au –

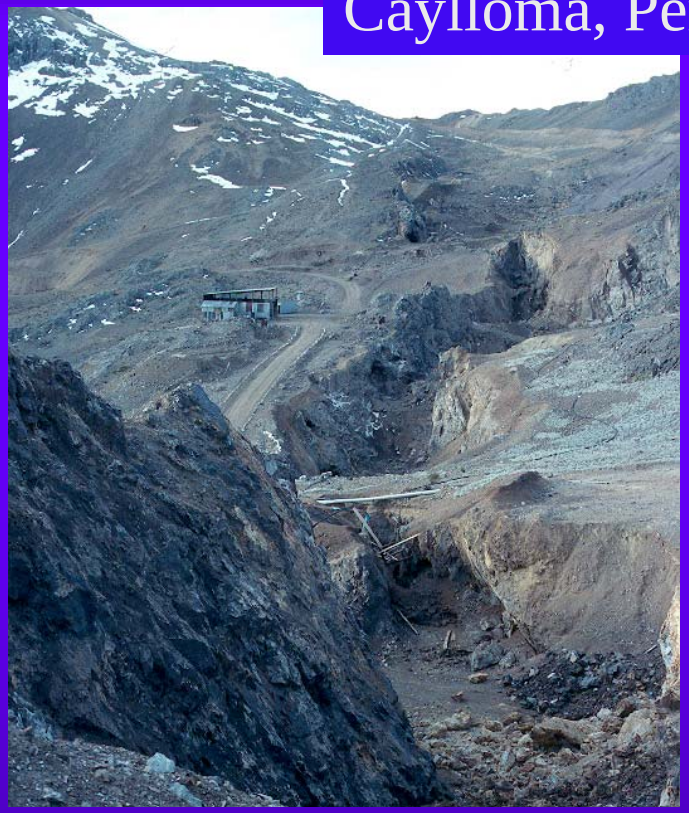
Leach and Corbett, 1993, 1994, 1995; Corbett and Leach, 1998

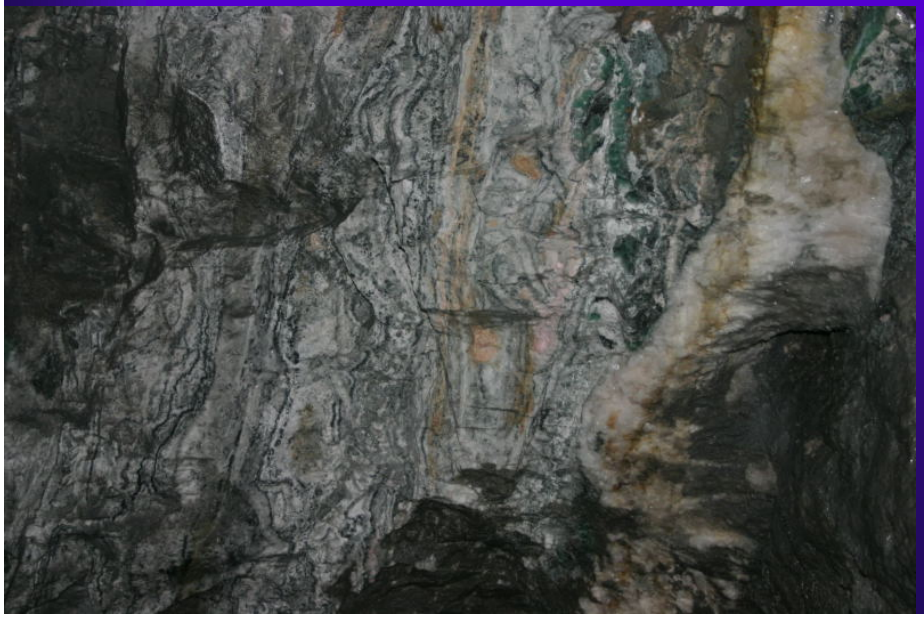
Porgera

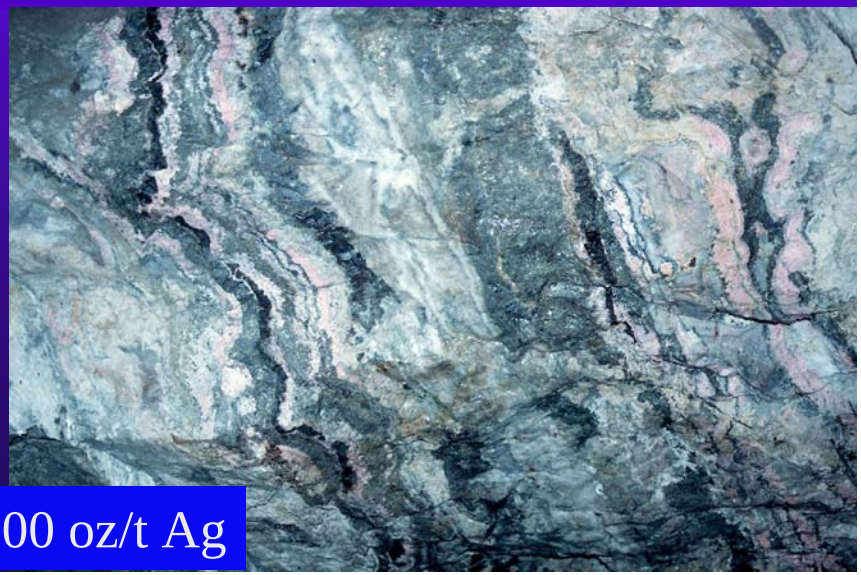
Andean Polymetallic Au-Ag

Arcata, Peru

Caylloma, Peru





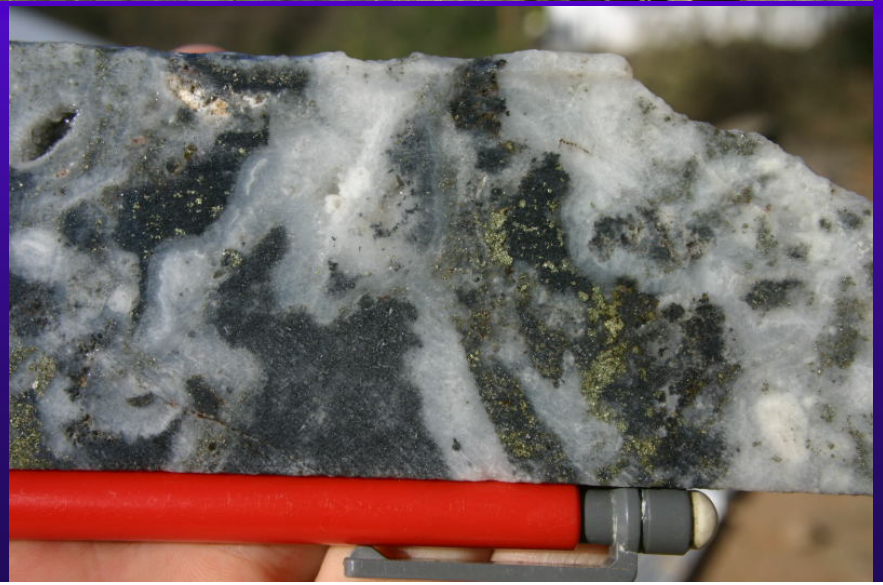


1000 oz/t Ag

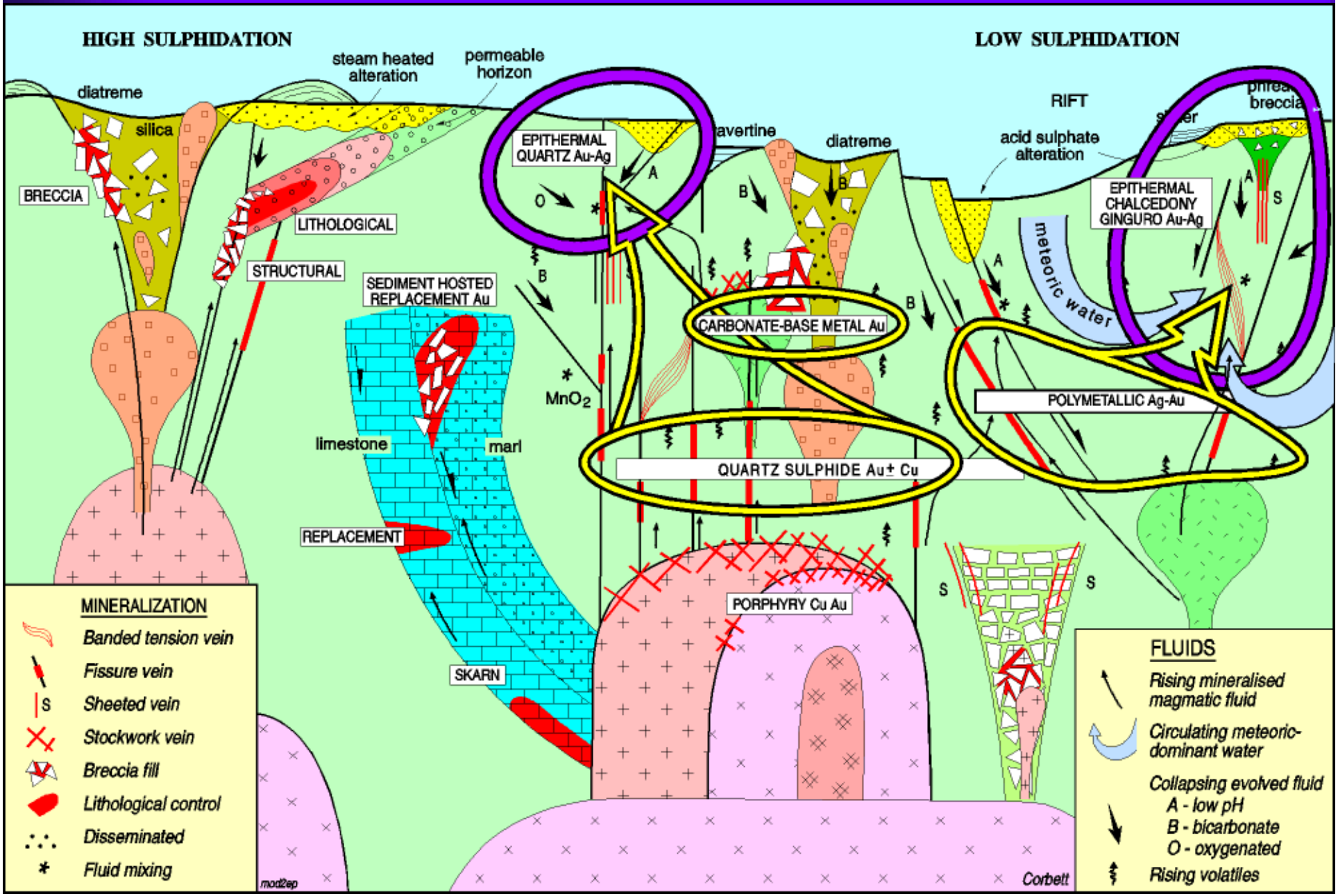
Polymetallic Ag-Au Mexico

Fresnillo

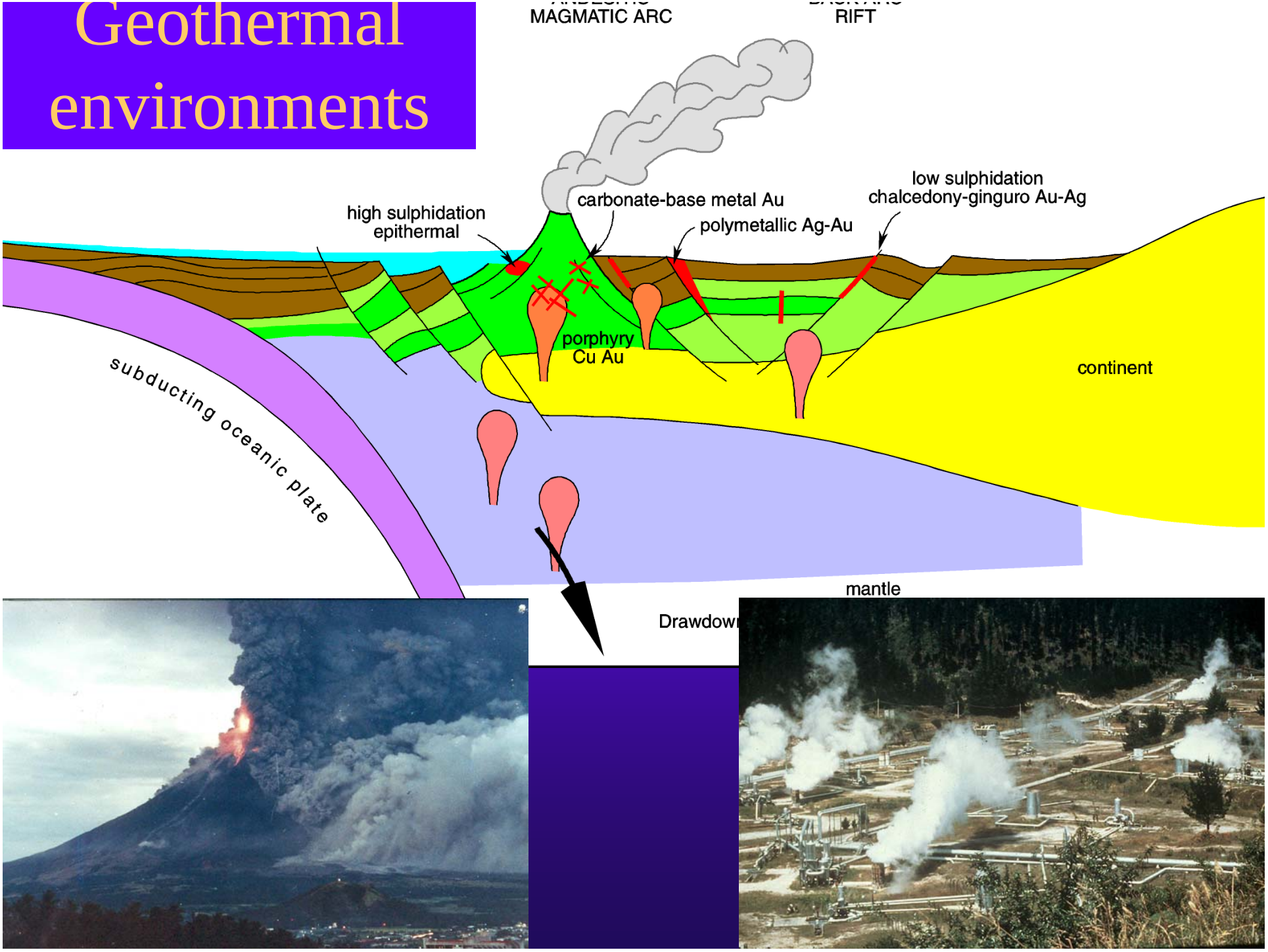
Palmarejo



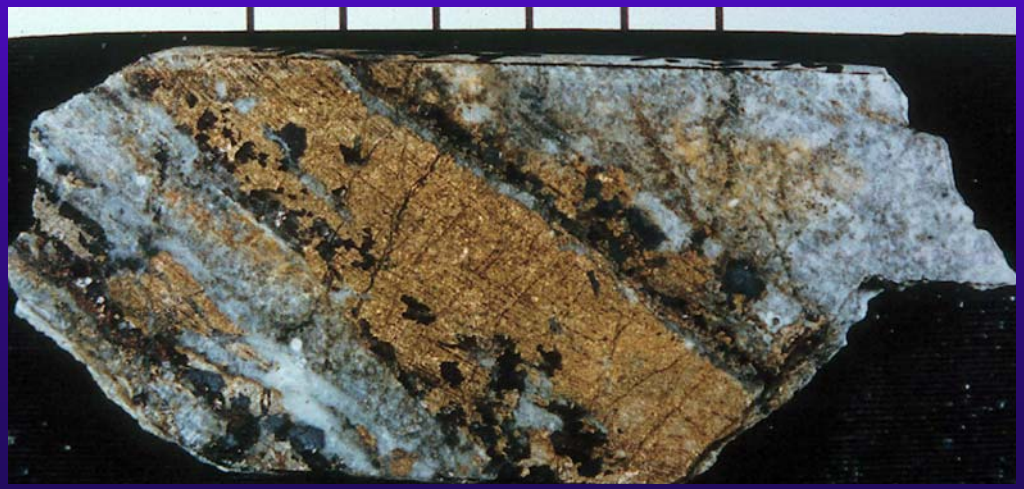
Two epithermal Au-Ag end members

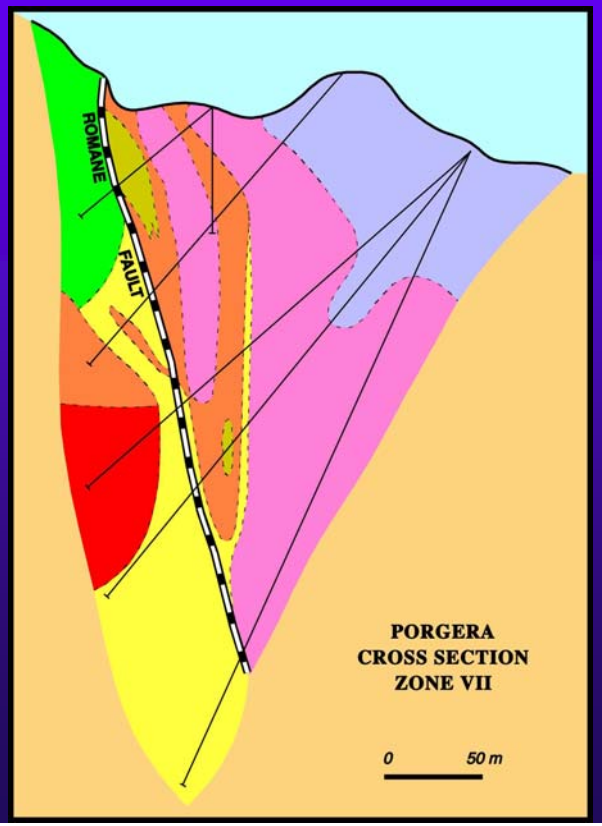


Geothermal environments

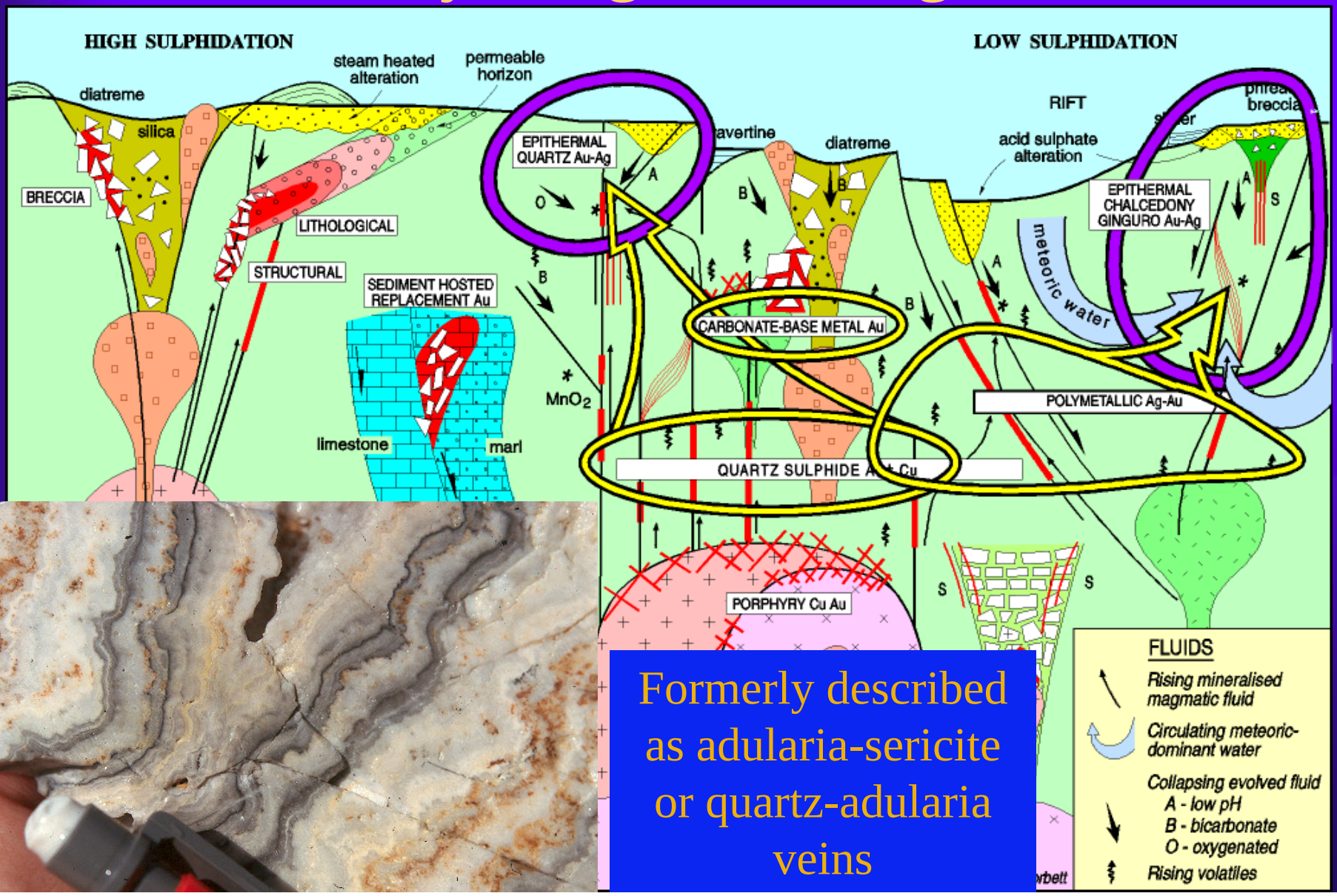


Porgera Zone VII





Low sulphidation Epithermal Chalcedony-Ginguro Au-Ag veins



Formerly described as adularia-sericite or quartz-adularia veins

Banded chalcedony-ginguro Au-Ag veins

-El Peñon..

Cracow

Banded quartz vein - Golden Cross

Quartz pseudomorphing platy carbonate

Vera Nancy

Adularia

Hishikari

Ginguro bands

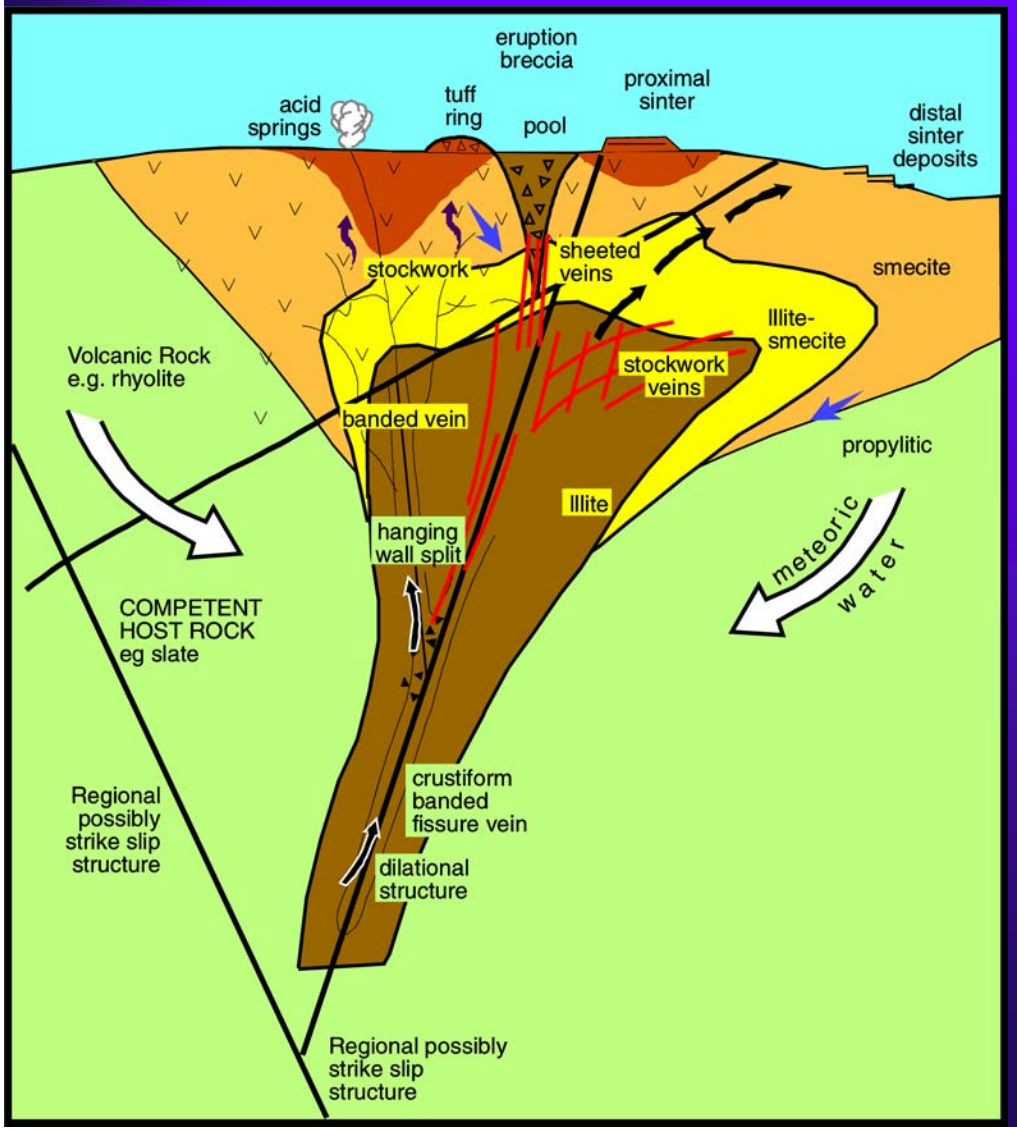
Visible Au
Asacha, Kamchatka

Midas, Nevada

Vera Nancy, Aust

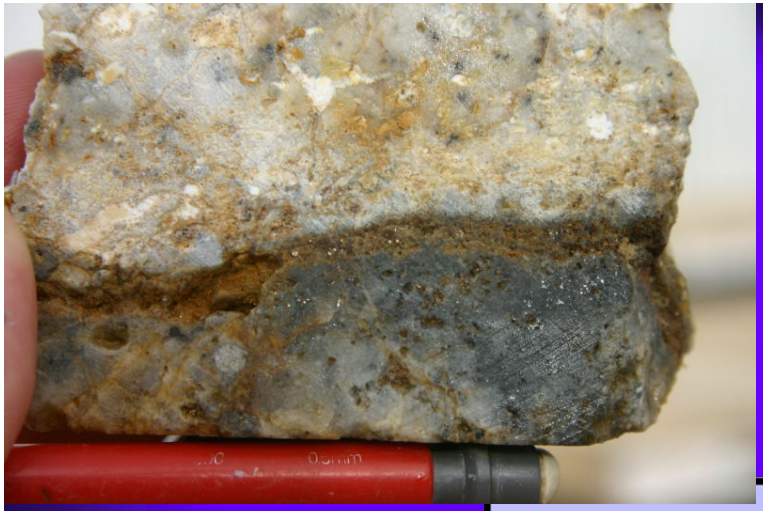
Hishikari, Japan

Acid sulphate caps



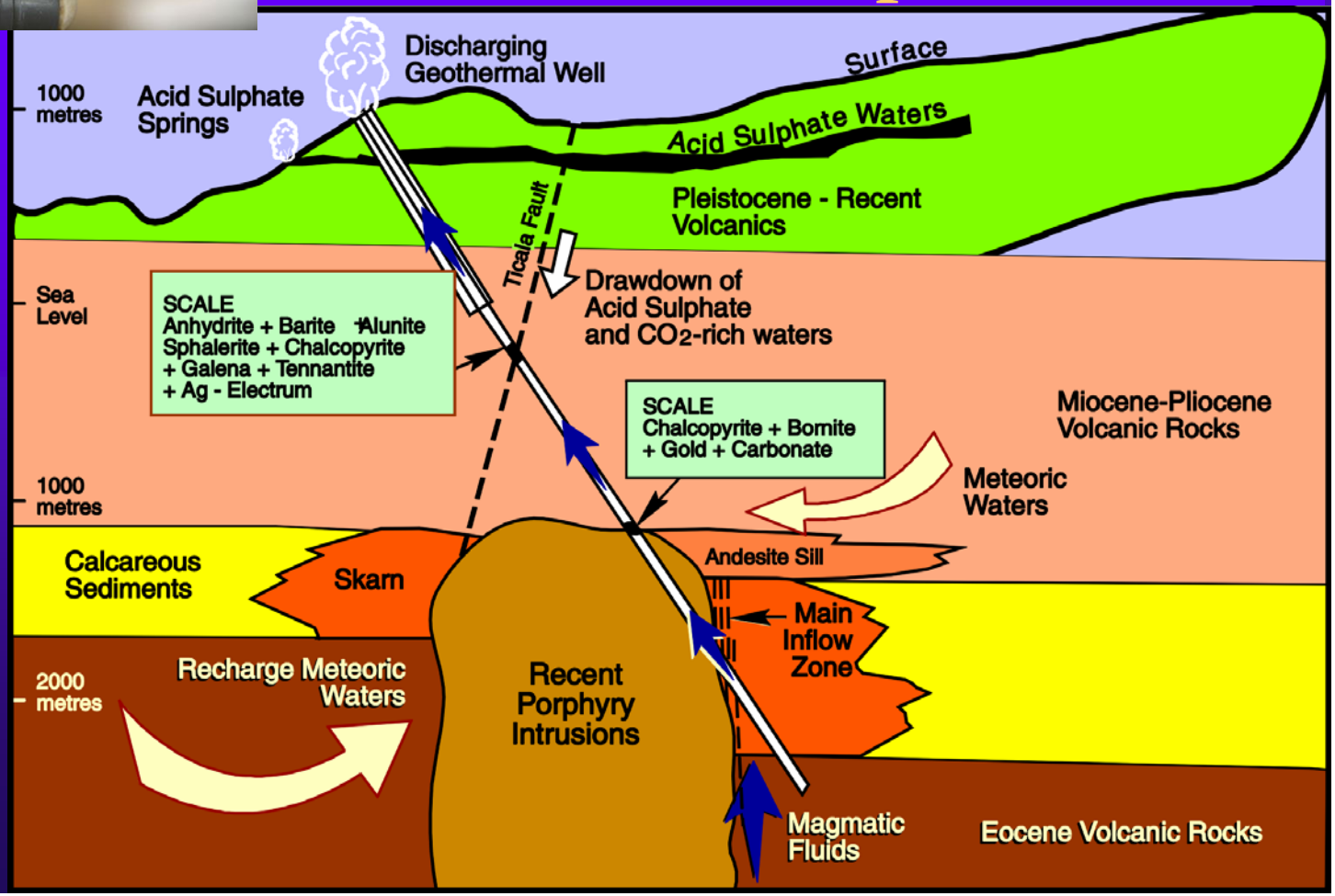
Chanpamge Pool, New Zealand

Arcata, Peru



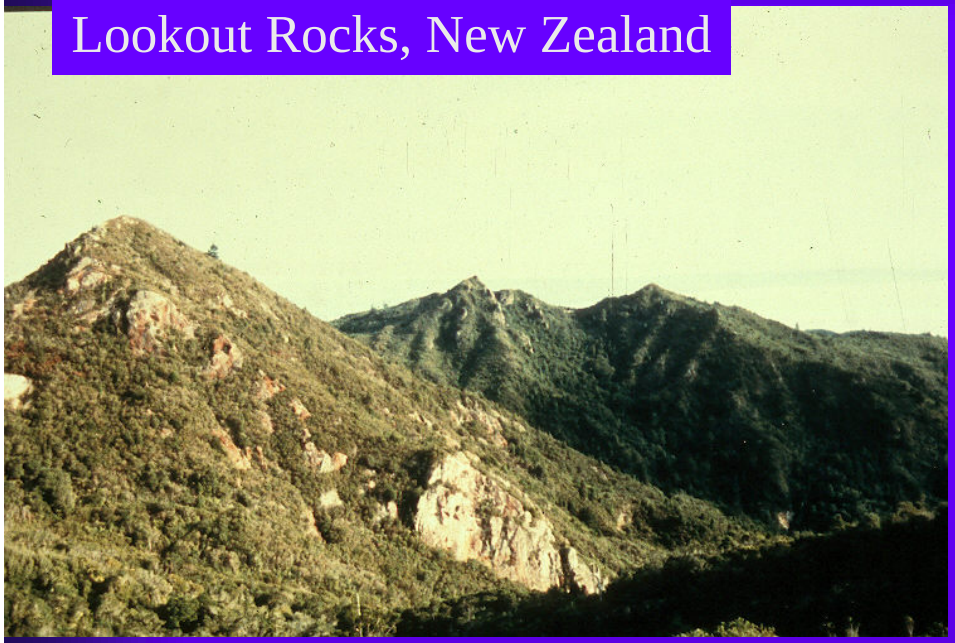
223 g/t Au &
17,642 g/t Ag

Au deposition by mixing of ore fluids with low pH waters



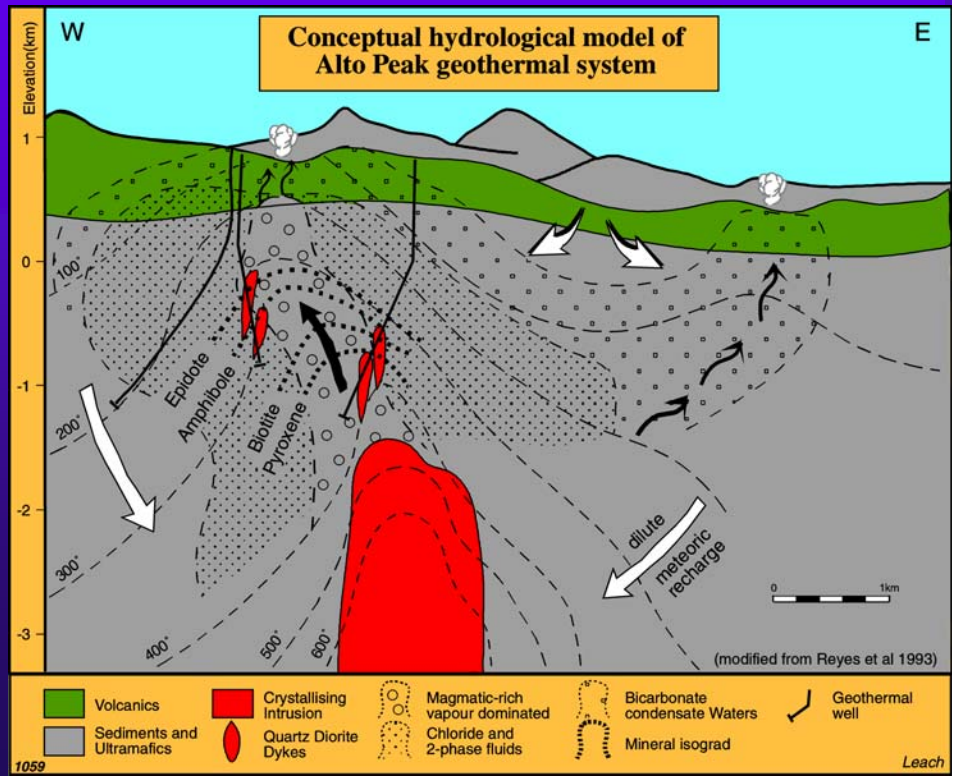
Andean Lithocaps

Lookout Rocks, New Zealand



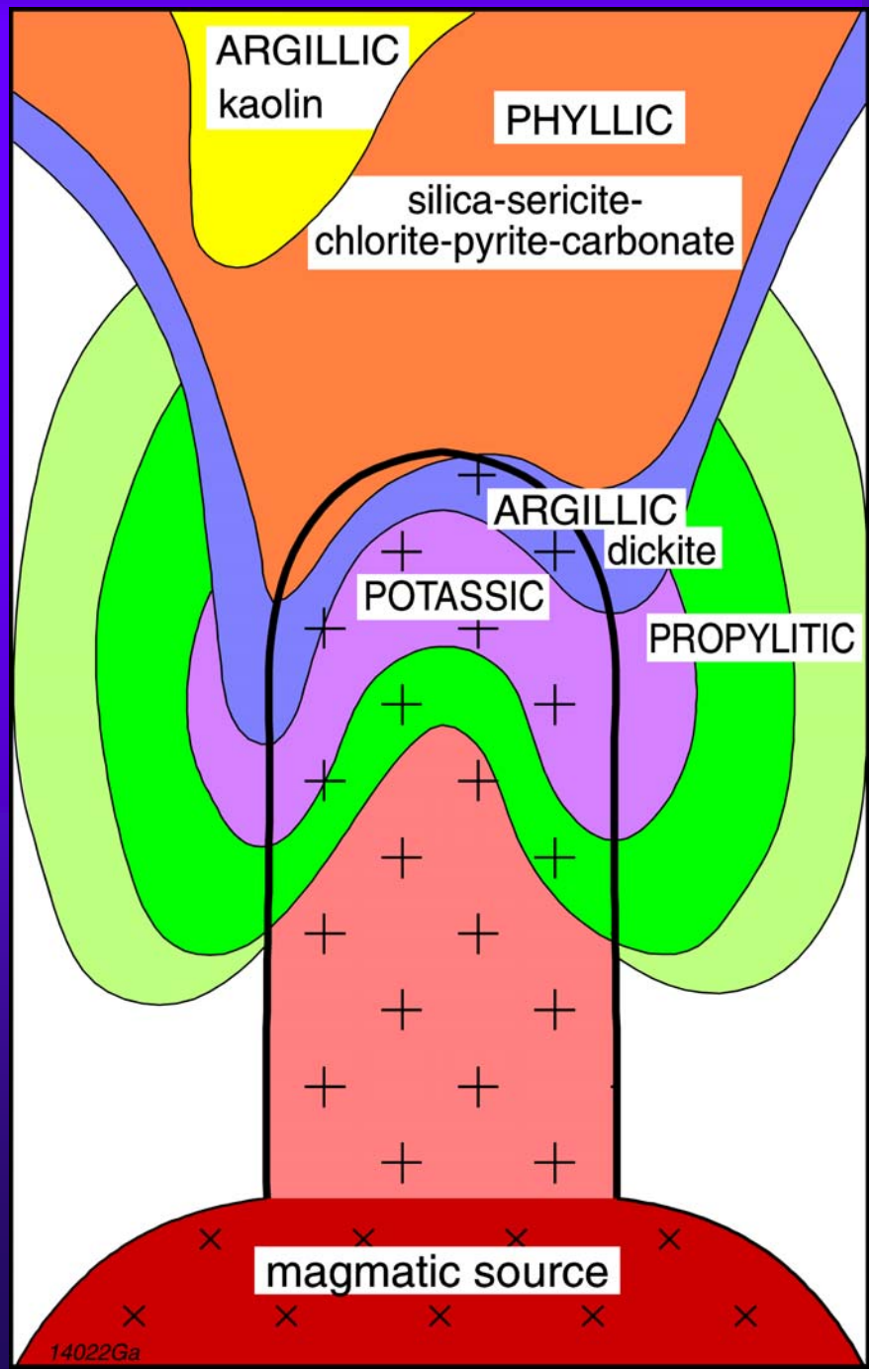
Rising magmatic volatiles – barren shoulders

Bulahdelah

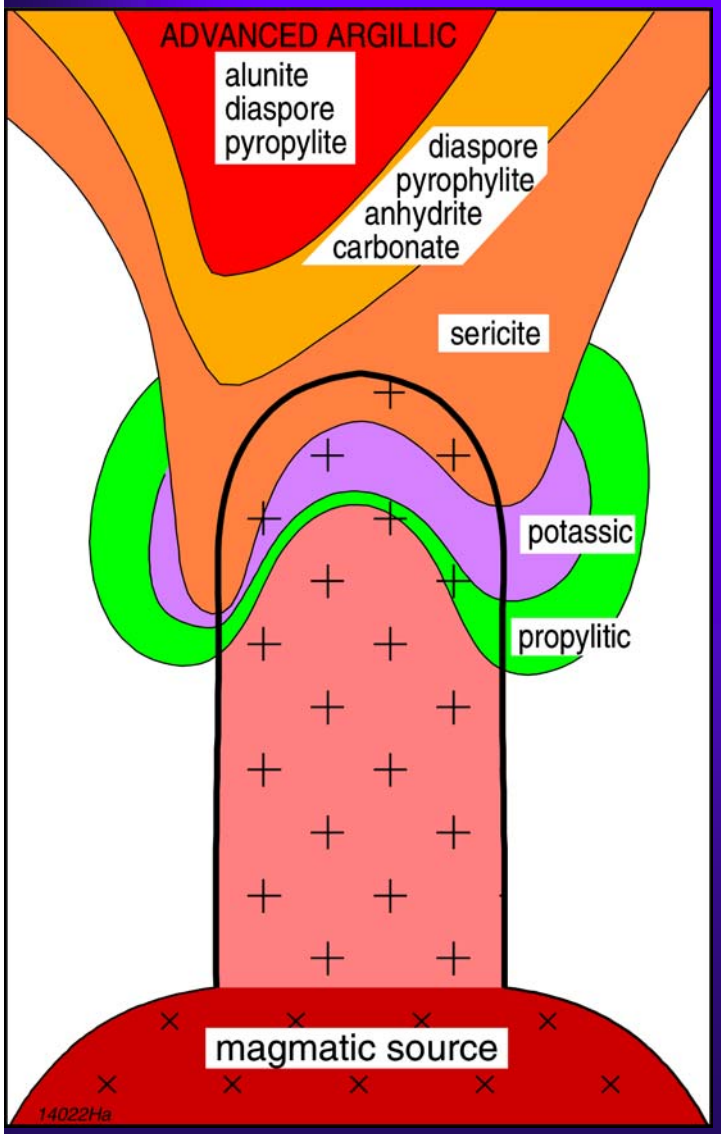


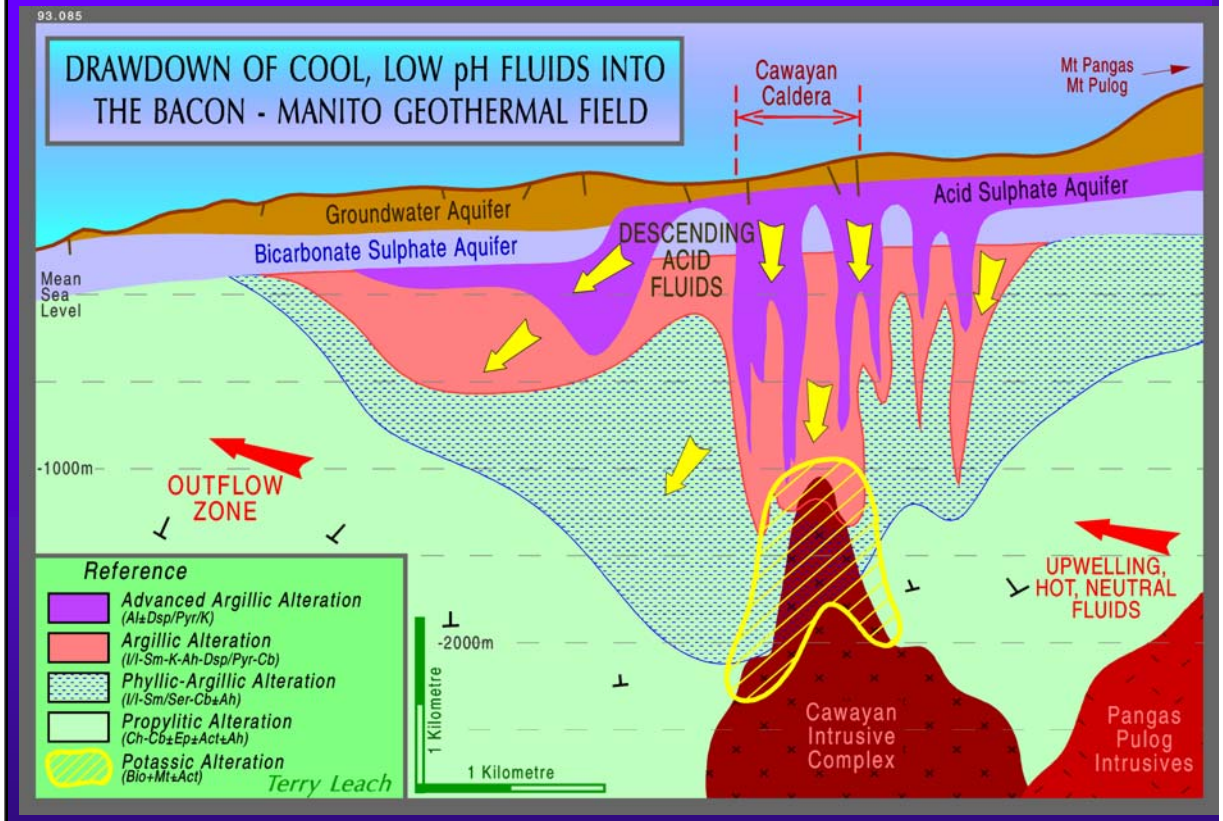
Collapsing condensate waters

Mineral Hill



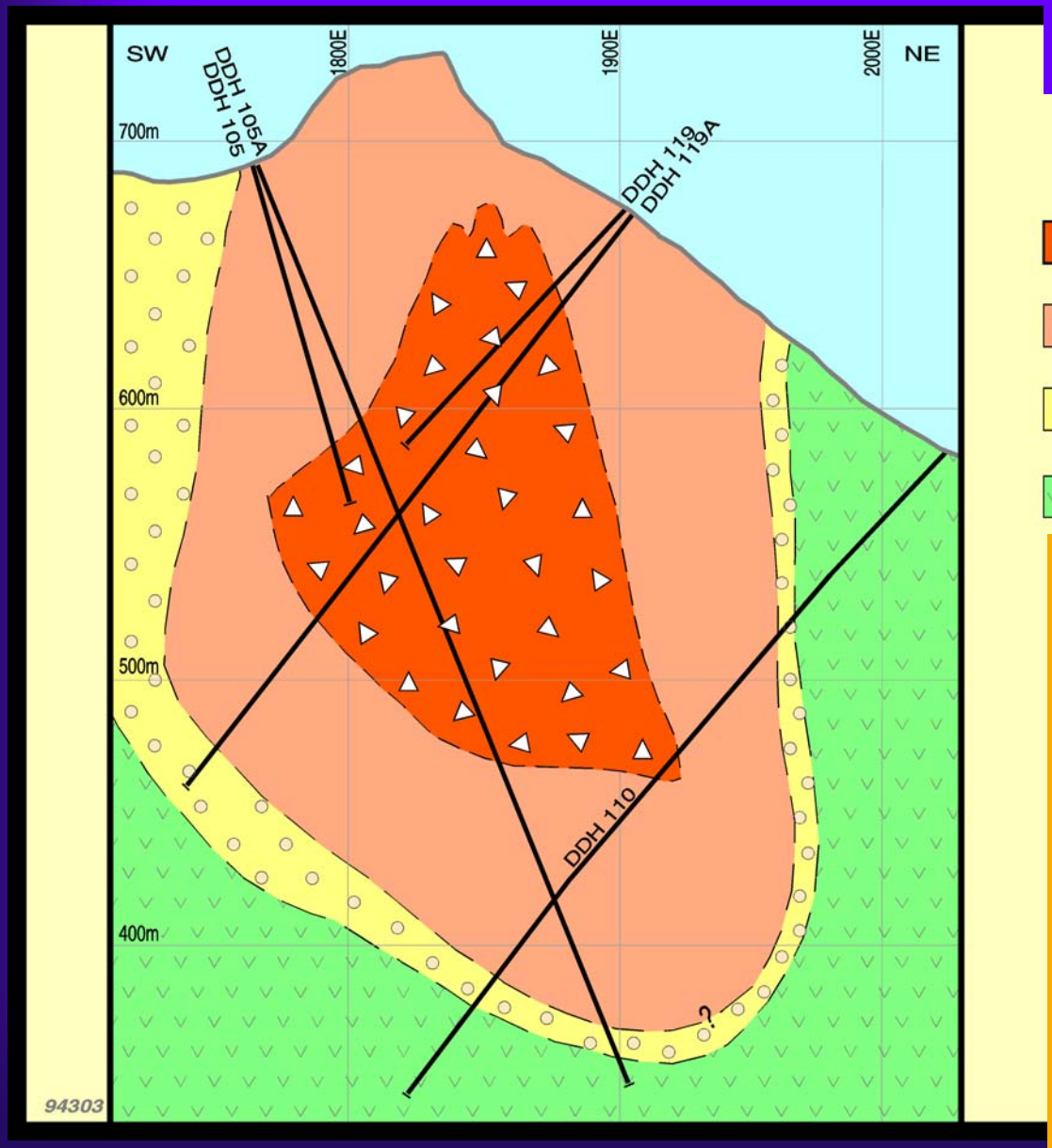
Collapsing advanced argillic alteration





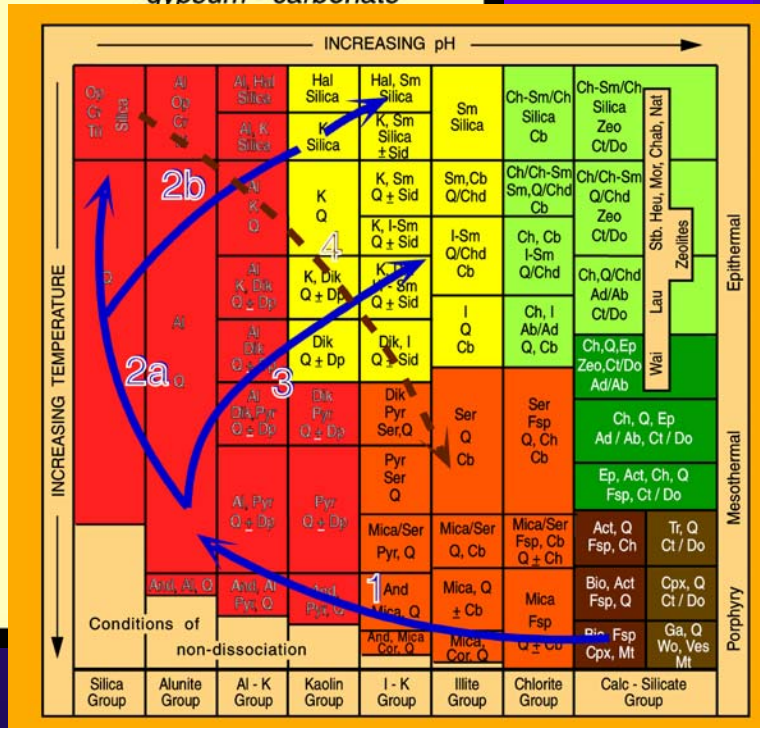
High sulphidation epithermal Au

Nena, Papua New Guinea



ALTERATION

- *Vughy quartz - pyrite*
- *Quartz - alunite - pyrite ± sulphur*
- *Clay - pyrophyllite - dickite - illitic clay*
- *Propylitic chlorite - illitic clay -gypsum - carbonate*



Steam heated alteration

Quimsacocha, Ecuador

Acid Sulphate alteration zones

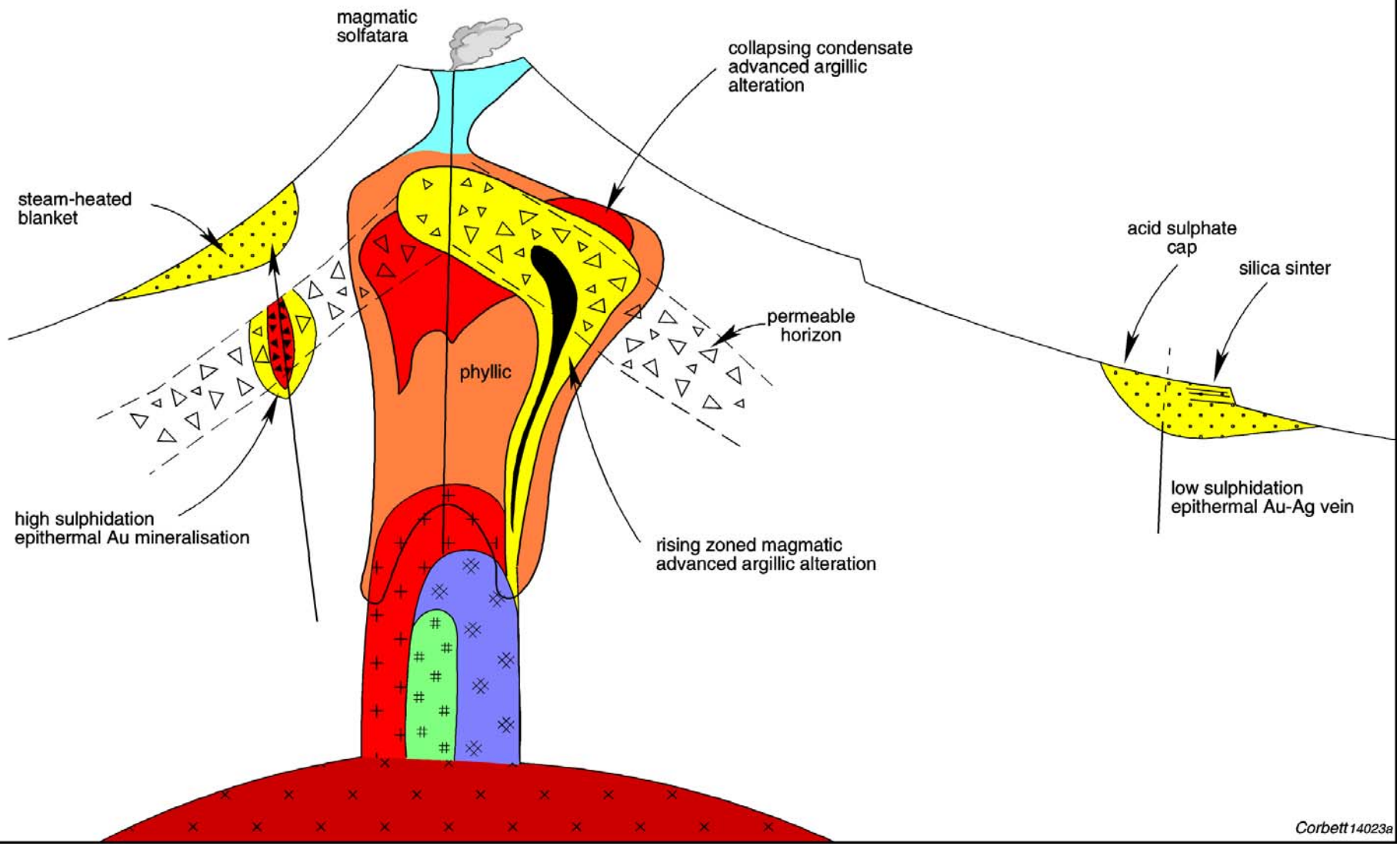
186 g/t Au, 3720 g/t Ag

Guadalupe, Palmarejo Mexico

Styles of acid alteration

- Rising magmatic volatiles (barren shoulders)
- Collapsing condensate waters (phyllic alteration)
- Strongly acidic collapsing condensate waters (advanced argillic alteration)
- High sulphidation epithermal (zoned advanced argillic to argillic alteration)
- Steam heated above high sulphidation epithermal
- Acid sulphate above low sulphidation epithermal

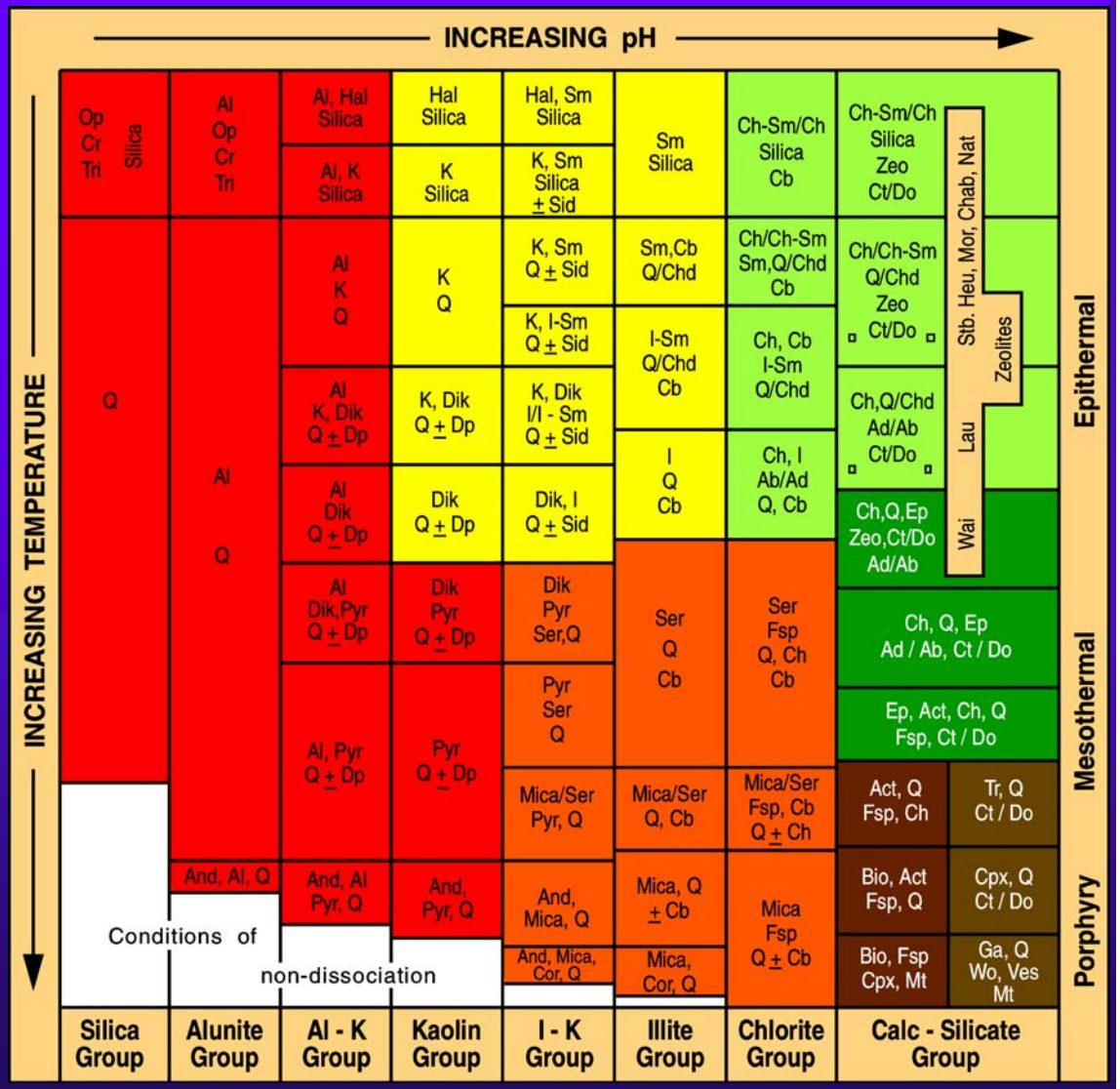
Styles of acid alteration



Conclusion

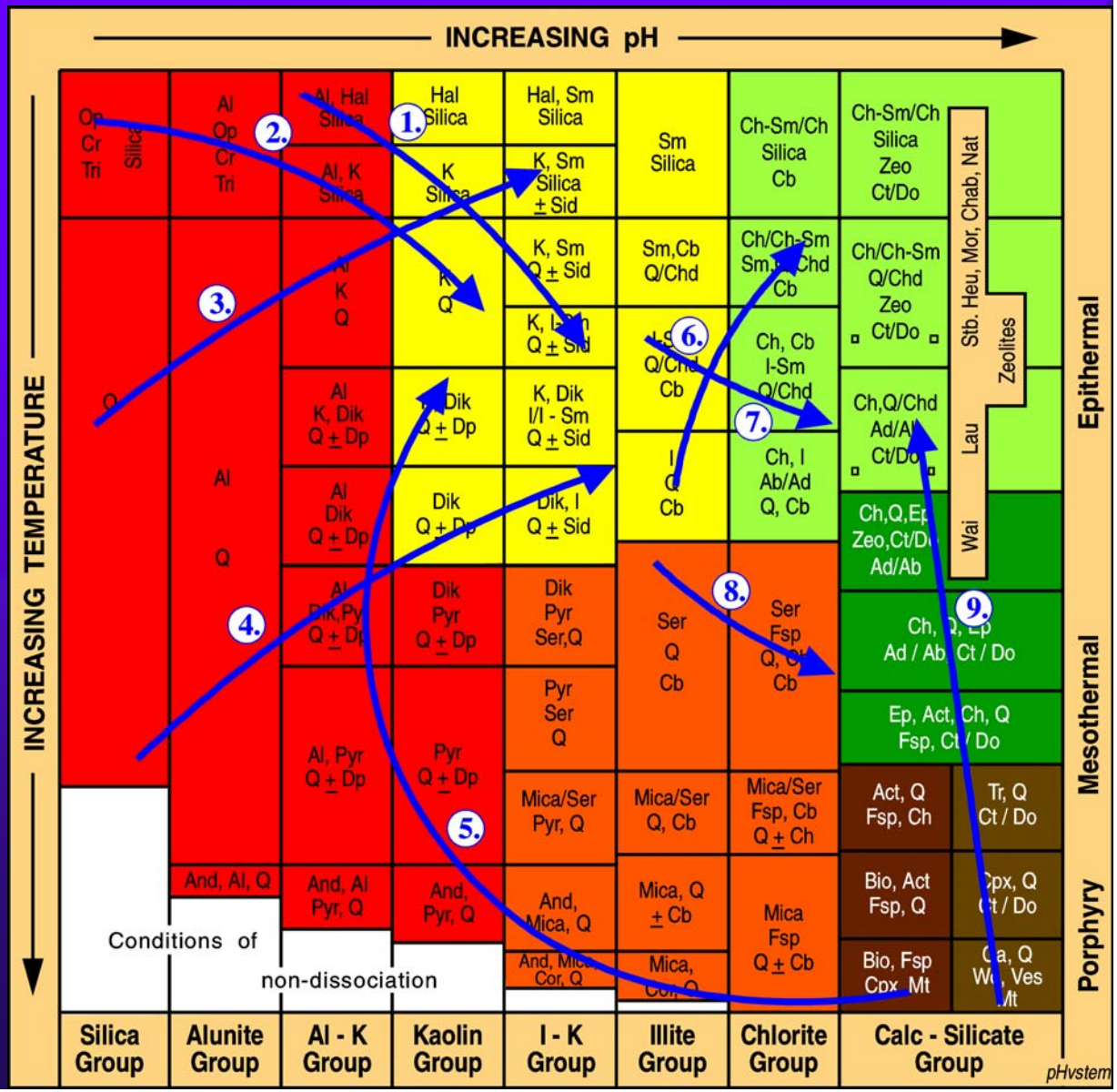
- Magmatic arc geothermal systems are analogous to porphyry Cu-Au, high sulphidation and intrusion-related low sulphidation ores
- Geothermal and petrological studies have aided in and understanding of the:
  - Evolution of ore systems and setting of mineraliation
  - Distinguish between varying styles advanced argillic-argillic alteration with different relationships to mineralisation
  - Conceptual geological models as an aid to the categorisation of ore systems and exploration
  - Zoned alteration and its relationship to mineralisation using the pH vs temp figure

Terry's pH vs temperature figure

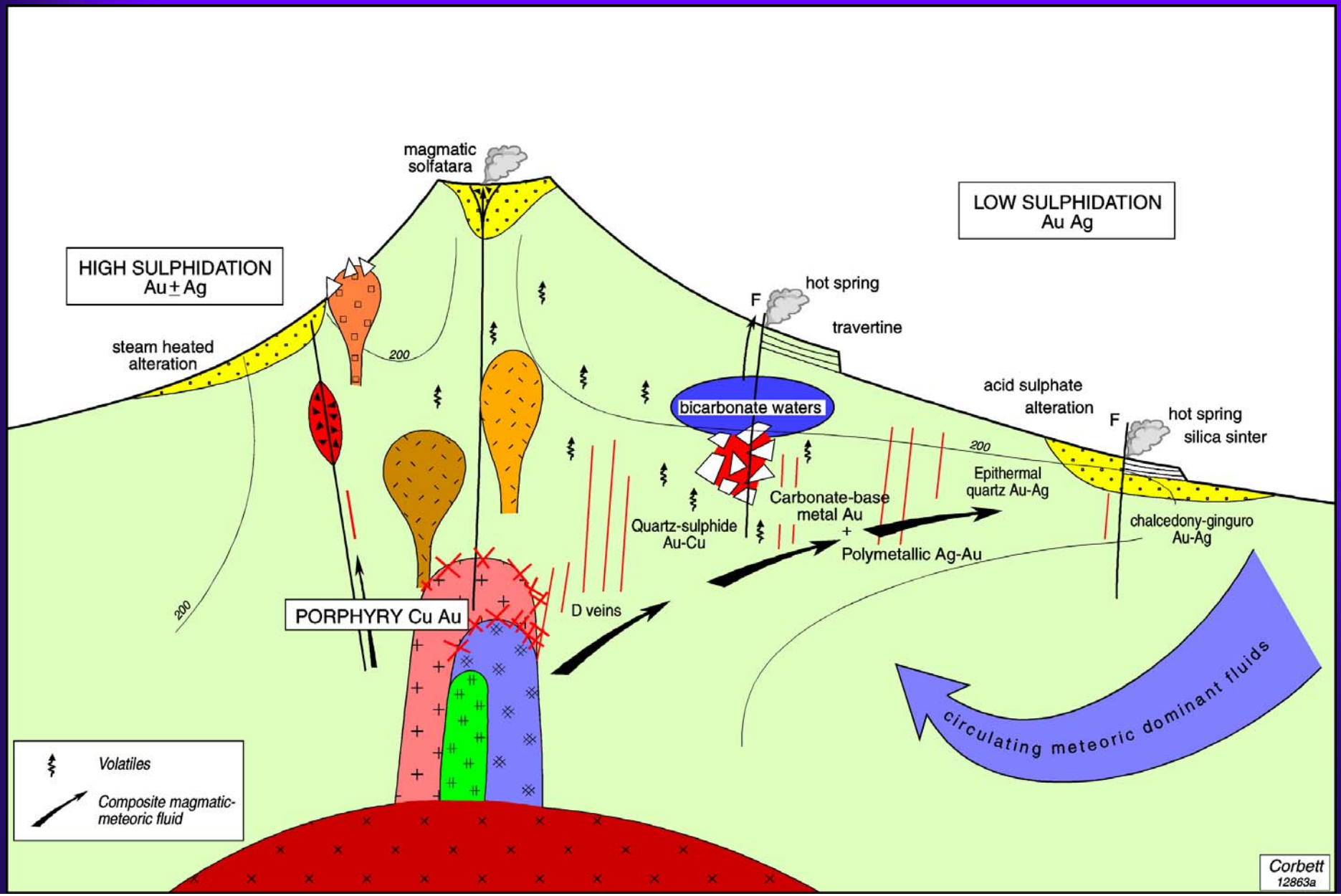


Some alteration zonation patterns

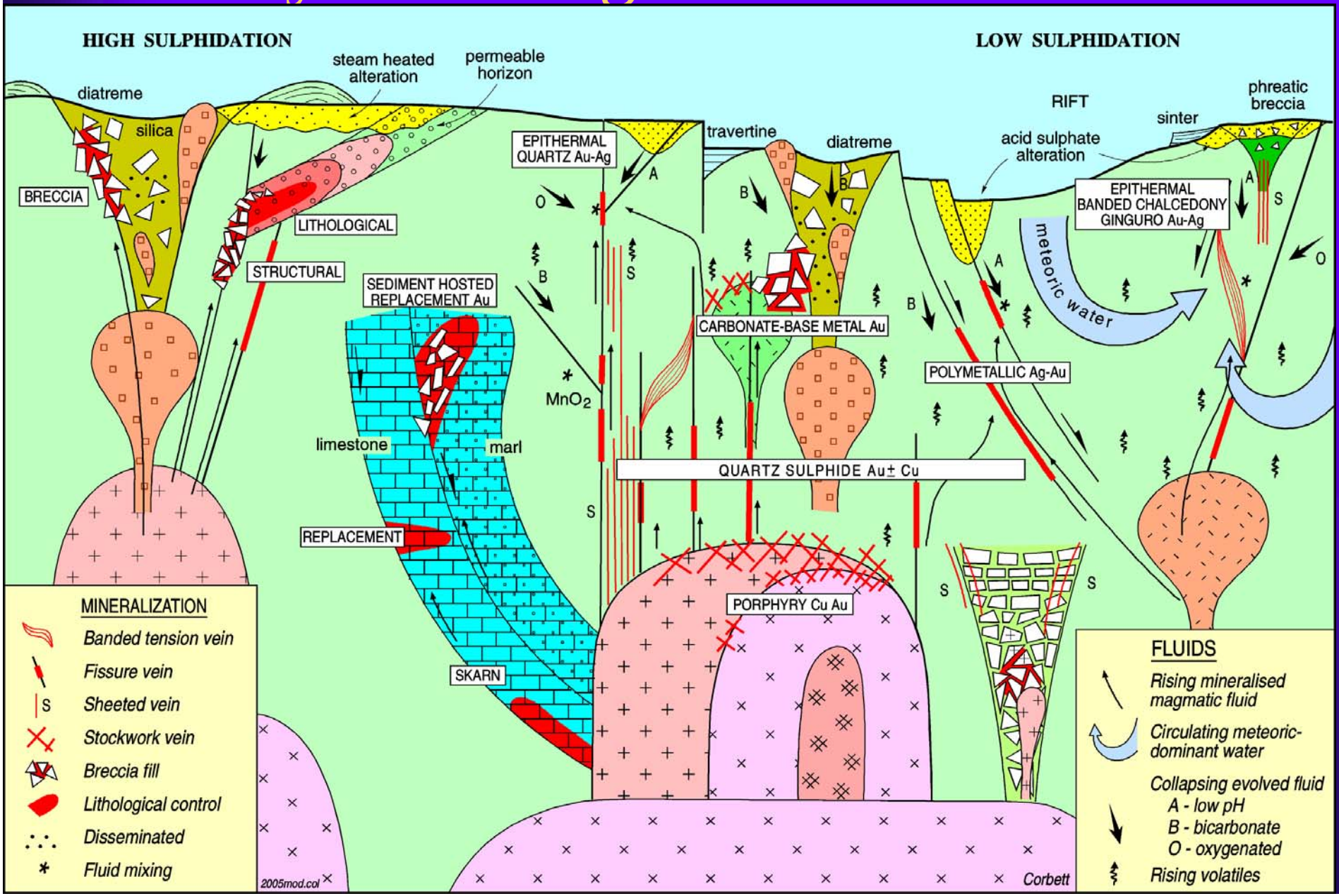
- 1. Low sulphidation acid sulphate cap
- 2. High sulphidation steam heated cap
- 3. High sulphidation high level structurally controlled
- 4. High sulphidation deep level permeability controlled
- 5. Rising early magmatic volatiles (barren shoulder)
- 6 Low sulphidation argillic vein halos
- 7. Porphyry related argillic
- 8. Porphyry related phyllic
- 9. Evolving potassic propylitic



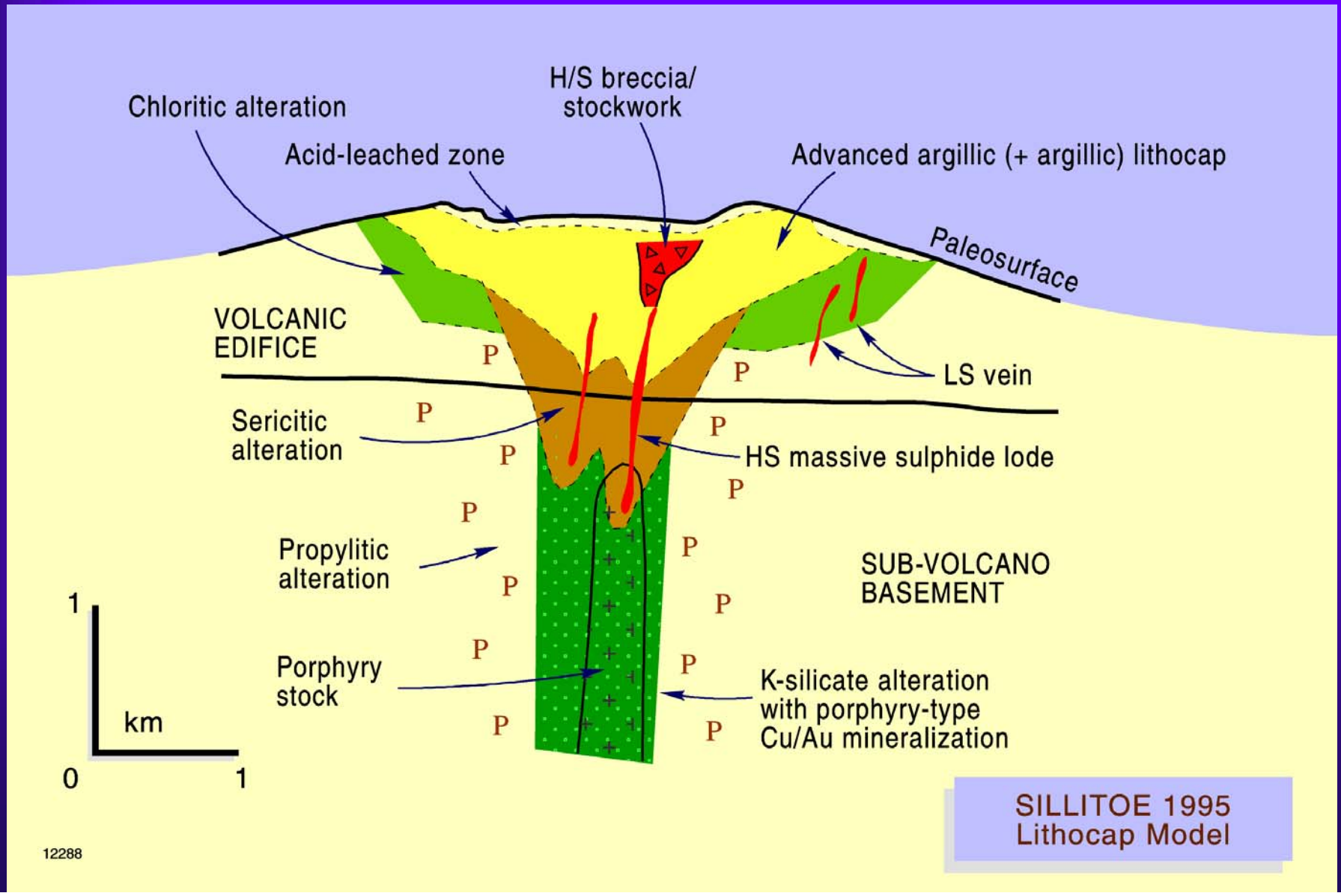
Magmatic arc porphyry to epithermal



Styles of magmatic arc Cu-Au



Lithocaps


Chloritic alteration
H/S breccia/
stockwork
Acid-leached zone
Advanced argillic (+ argillic) lithocap
Paleosurface
VOLCANIC
EDIFICE
LS vein
Sericitic
alteration
HS massive sulphide lode
Propylitic
alteration
SUB-VOLCANO
BASEMENT
Porphyry
stock
K-silicate alteration
with porphyry-type
Cu/Au mineralization
1
km
0
1
12288
SILLITOE 1995
Lithocap Model