Epithermal Gold Deposits : their characteristics & modeling

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Ore deposits: Classification vs Modeling

- Each ore deposit is unique like a person's finger print
- This uniqueness arises out of :
  - fundamental differences in processes and environments
  - local, site-specific geologic variations
- And produces an extremely large variation in characteristics
  - If we group the deposits according to their characteristics, we get a *Classification.*
  - If we specify which characteristics are essential to belong to a group, we have the basis of a *model.* A model provides the much-needed element for decision making, especially in exploration and resource assessment

A mineral deposit model is a systematically arranged body of information that describes the essential attributes of a mineral deposit type.

- Empirical (Descriptive) model: where the various attributes are recognised as essential but their relationship is unknown
- Grade-tonnage model
- Theoretical (Genetic) model: where the attributes are interrelated through some concept
- Quantitative process model (e.g, numerical analysis of flow, chemistry and thermal behaviour of fluids around a cooling pluton)
- Occurrence - probability model

Lithotectonic classification of gold deposits

- **Lode gold deposits**

  Epigenetic vein deposits of gold in metamorphic terranes (Kerrich, 1993). (Also termed as **greenstone- hosted gold deposits, orogenic gold deposits, shear gold deposits, gold-only deposits)**

- **Intrusion related deposits**

  Deposits having spatial and genetic relationship with igneous intrusions. The intrusions related deposits are further subdivided (Sillitoe, 1991) as:

  - **Skarn Au: Replacement deposits in skarn and carbonate rocks**

  - **Porphyry Cu-Au: Porphyry gold and gold-copper deposits: associated with multidirectional stockwork mineralization and K-silicate alteration**

  - **IOCG: structurally controlled, epigenetic deposits, formed in extensional environments within co-eval anorogenic granitoids or older volcano-sedimentary metamorphic rocks**

- # Epithermal deposits (volcanic-associated)

Formed at low temperatures (less than 200º C) and at shallow depth (Lindgren,1933)

- # Sediment-hosted Au deposits
  - **Disseminated deposits (Carlin type)**

    Sediment-hosted, very finely disseminated Au-Ag deposits
  - **Banded Iron-Formations (BIF)**

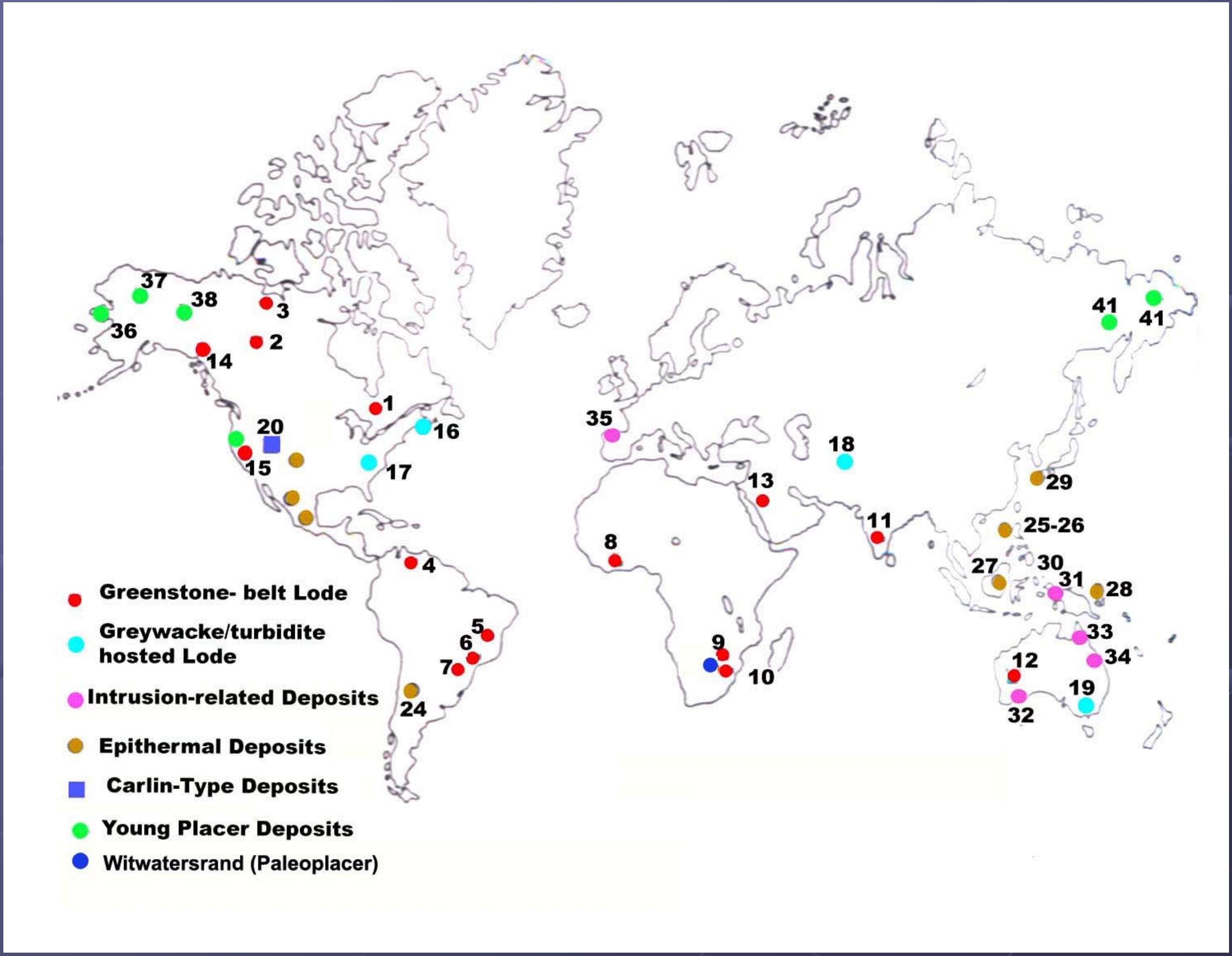
    Stratabound orebodies within thick sequences of iron-rich metasediments or BIF and volcaniclastics. Also in derived laterites

- # Placer deposits

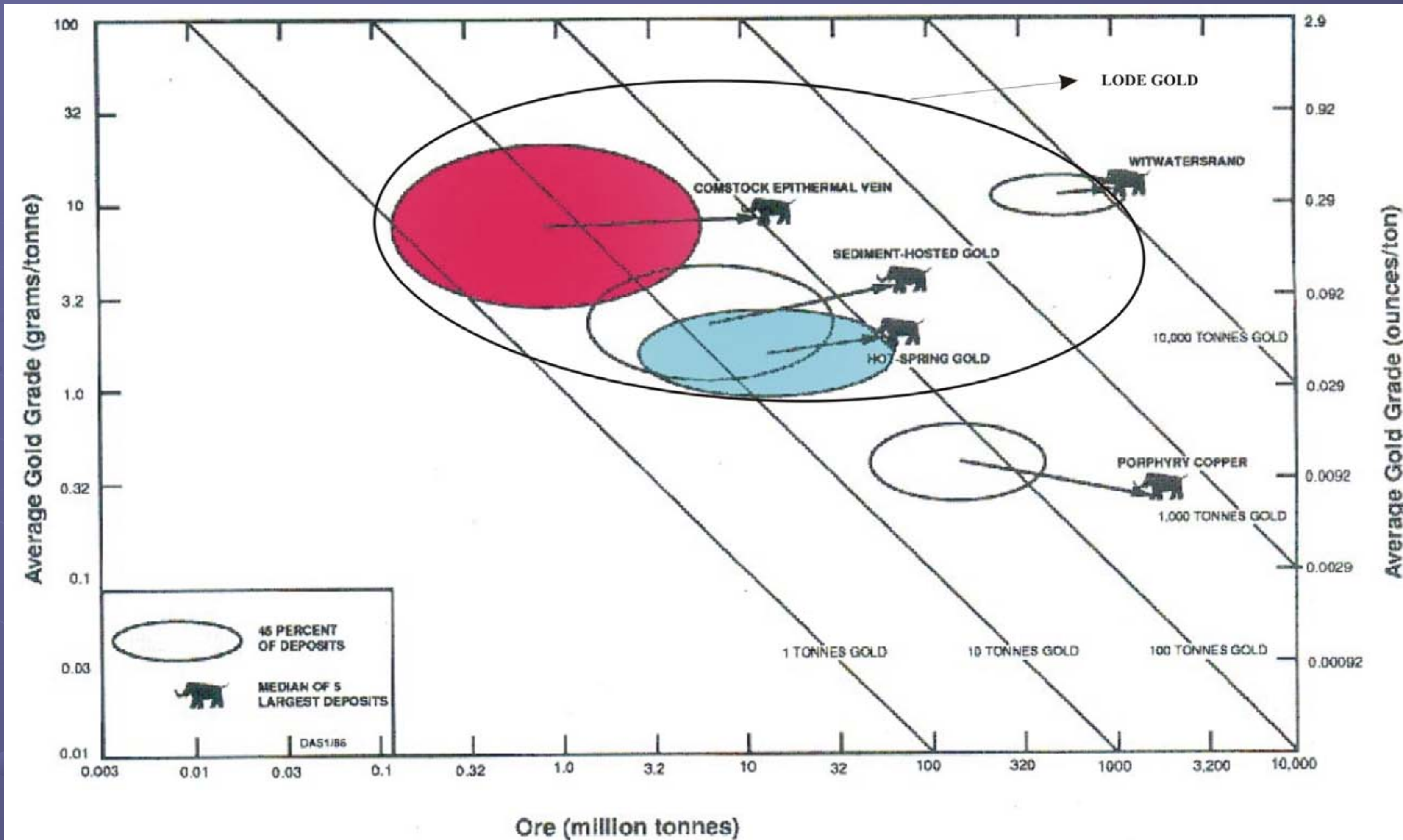
Formed by the mechanical accumulation of economic important,detrital and resistate minerals.

  - **Paleoplacer deposits**
  - **Young placer deposits**

Major gold deposits



Grade and Tonnage relationship in gold deposits



(a) Paleoplacer Deposits (b) Lode gold deposits (c) Epithermal vein type deposits
(d) Sediment hosted deposits, (e) Hot spring deposits and (f) Porphyry deposits

Epithermal Gold Deposits

- The term **'Epithermal'** defined by Lindgren (1922, 1933) includes a broad range of precious metals ($\pm$ tellurides or selunides), base metals, Hg and Sb deposits, formed by aqueous fluids charged with igneous emanations at low T (< 200° C) and moderate pressure

- Now it is considered that predominantly meteoric fluids at slightly higher T (200-300°C) and at P less than a few hundred bars, and depths within $\pm$ 1.5 km, formed these deposits

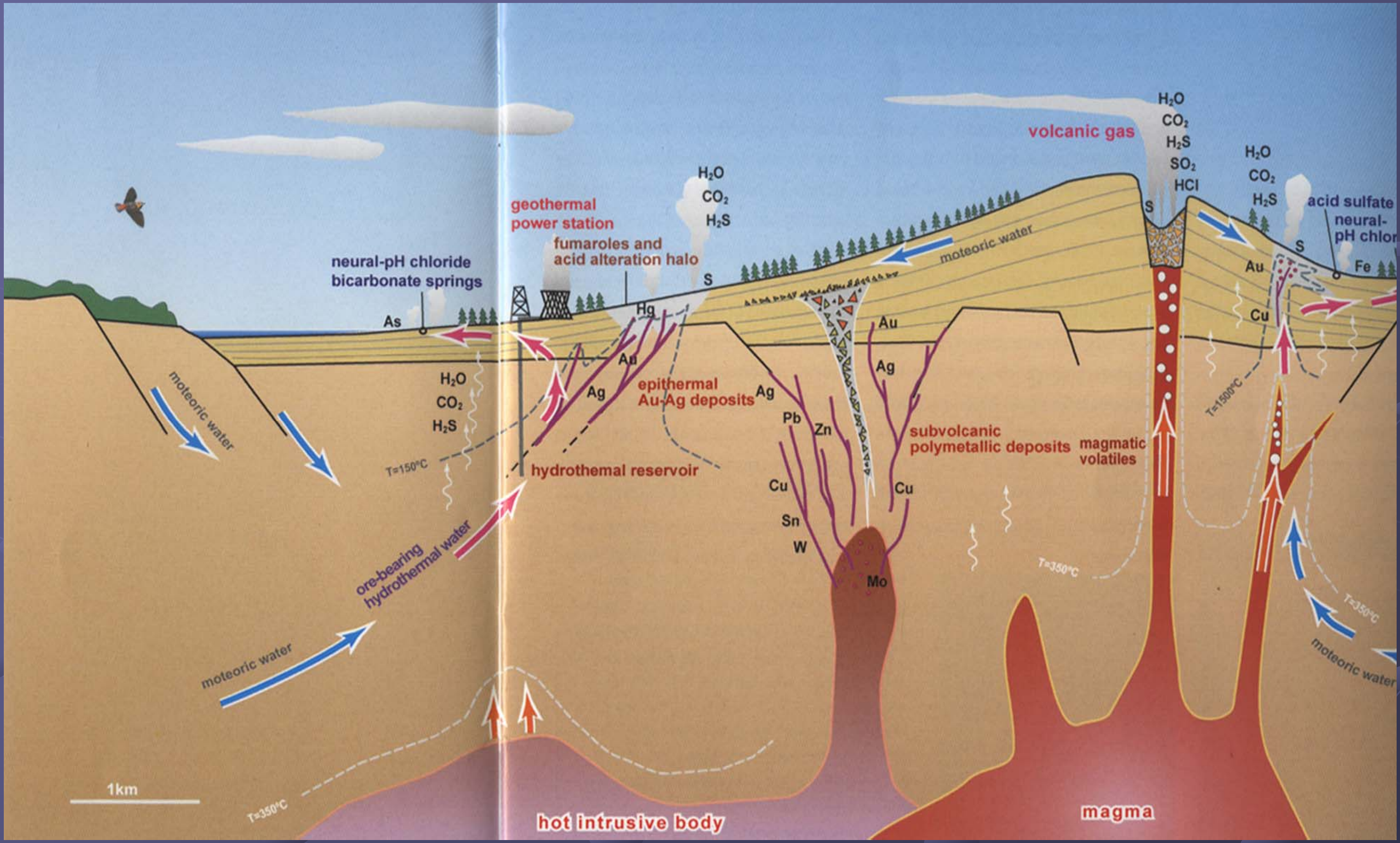
- The following aspects of the epithermal precious metal deposits in volcanic environments are of particular interest to exploration geologists
    - Genetic types
    - Tectonic setting
    - Alteration
    - Geometrical controls
    - Origin

First order genetic classification of epithermal deposits, based on alteration and mineralogy:

- **High sulfidation (HS) or Acid sulfate type**
  - High sulfur/metal ratio (enargite, luzonite, covellite)
  - Advanced argillic assemblage, dominated by alunite and pyrophyllite at deeper levels
  - Formed by acid, S-rich, oxidized fluids

- **Low sulfidation (LS) or Adularia-sericite type**
  - Low sulfur/metal ratio (sphalerite, galena, tetrahedrite, chalcopyrite)
  - Sericite, intermediate argillic and chloritic alteration with adularia
  - Formed by near neutral, S-poor and reduced fluids

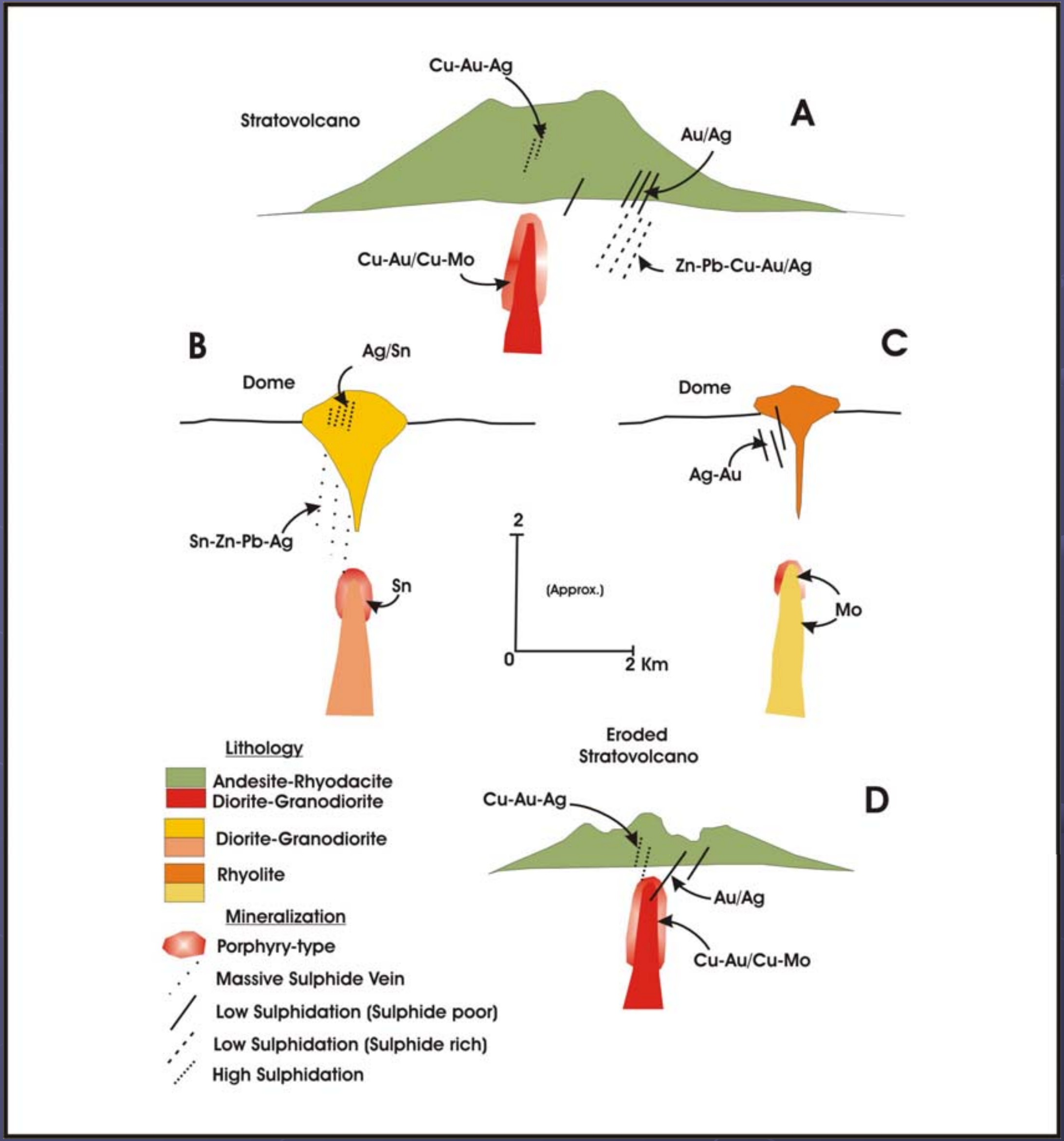
Strato-volcano and epithermal mineralization



Reduced neutral pH fluids

High oxidation state of acidic hypogene fluids

Relation between volcanic-hosted epithermal and sub-volcanic types of mineralization

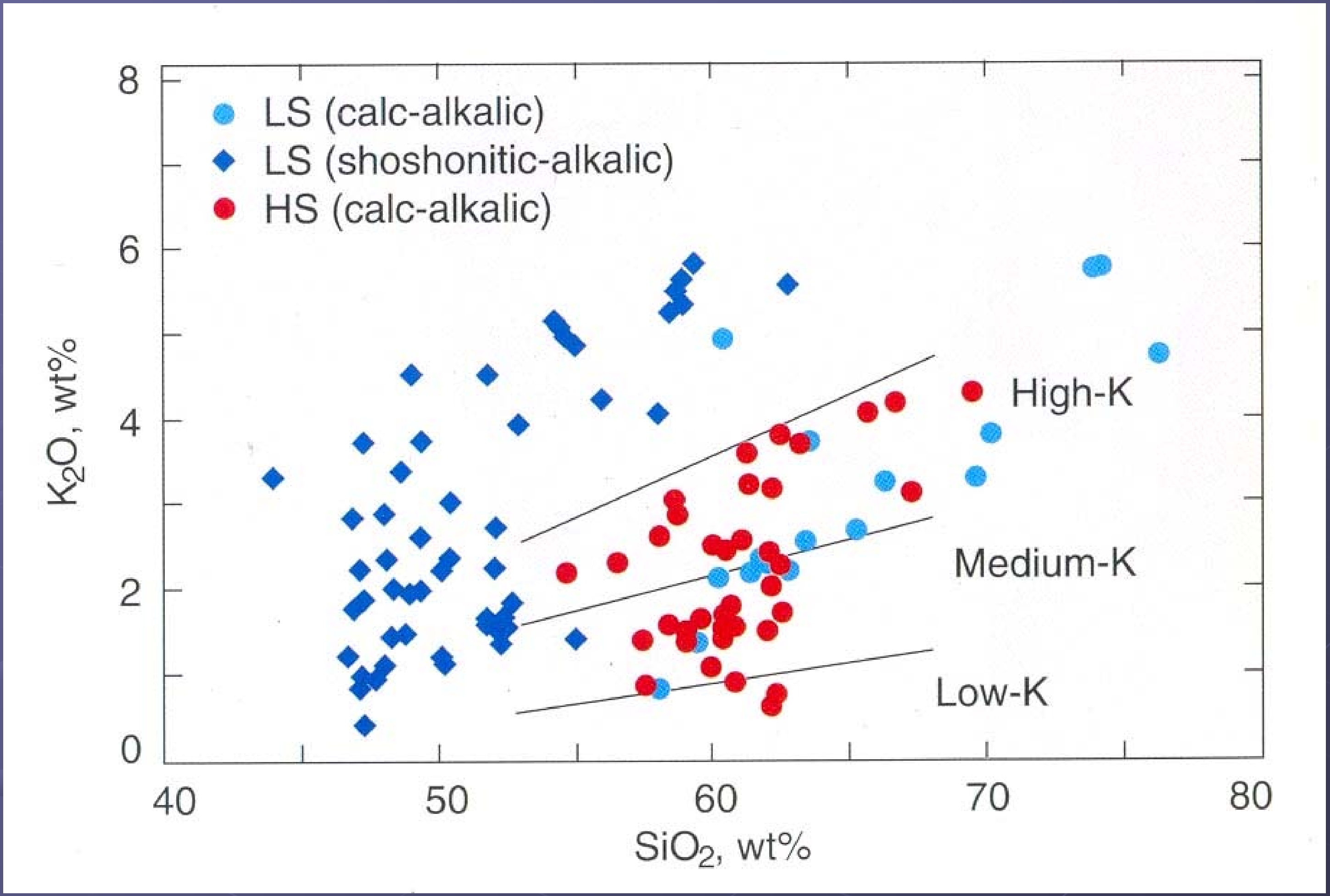


Field characteristics for distinguishing genetic types of

Epithermal gold deposits

	High sulfidation (HS)	Low sulfidation (LS)
Genetically related volcanic rocks	Mainly andesite-rhyodacite	Andesite-rhyodacite-rhyolite
Deposit form	Disseminated: dominant, replacement: common, stockwork: minor	Open-space veins: dominant, stockwork: common, disseminated & replacement: minor
Alteration Zone	Areally extensive & visually prominent	Commonly restricted and visually subtle
Quartz gangue	Fine-grained, massive, mainly replacement origin; residual, slaggy (vuggy) quartz commonly hosts ore	Chalcedony &/or quartz displaying crustiform, colloform, bladed, cockade & carbonate-replacement textures; open space filling
Carbonate gangue	Absent	Ubiquitous, commonly managanoan
Other gangue	Barite widespread with ore; native sulfur commonly fills open spaces	Barite & (or) fluorite present locally; barite commonly above ore
Sulfide abundance	10-90 vol% mainly fine-grained, partly laminated pyrite	1-20 vol%, but typically <5 vol%, predominantly pyrite
Metals present	Cu, Au, As (Ag, Pb)	Au and (or) Ag (Zn, Pb, Cu)

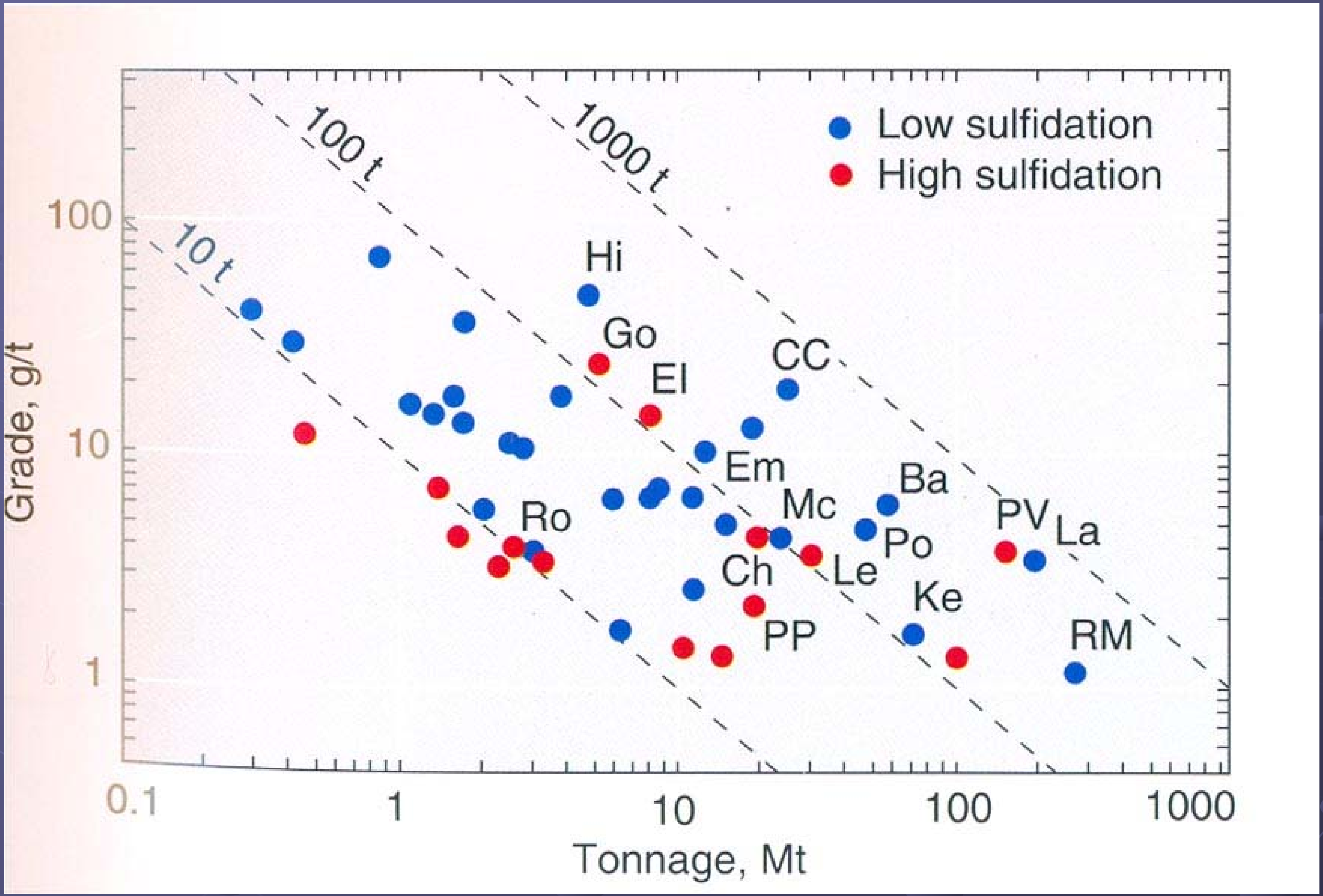
Volcanic rock association



HS: associated with dacite and andesite

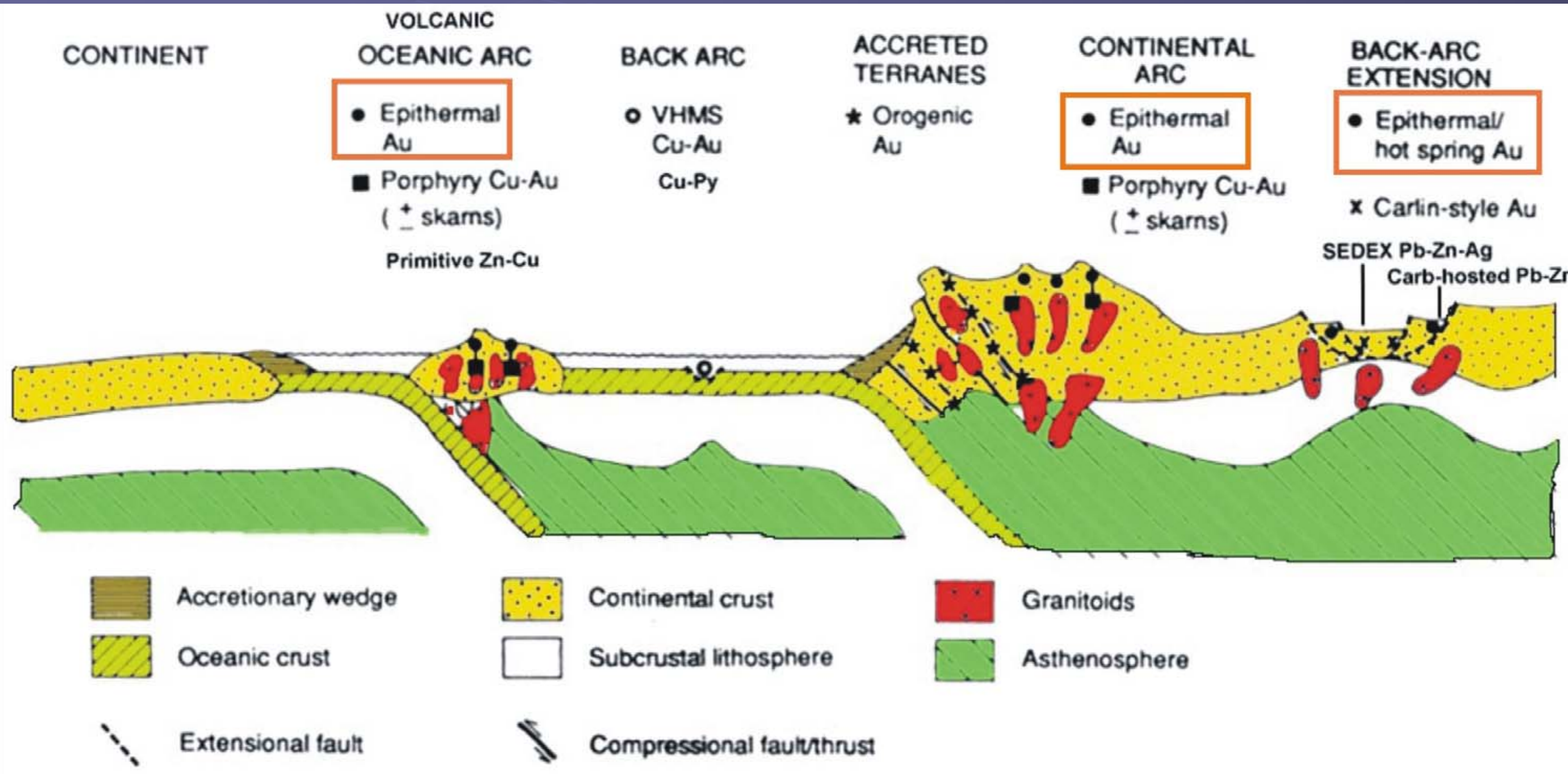
LS: associated with andesite and rhyolite, where major deposits such as Ladolam, Porgera and Cripple Creek are associated with shoshonitic and alkalic rocks

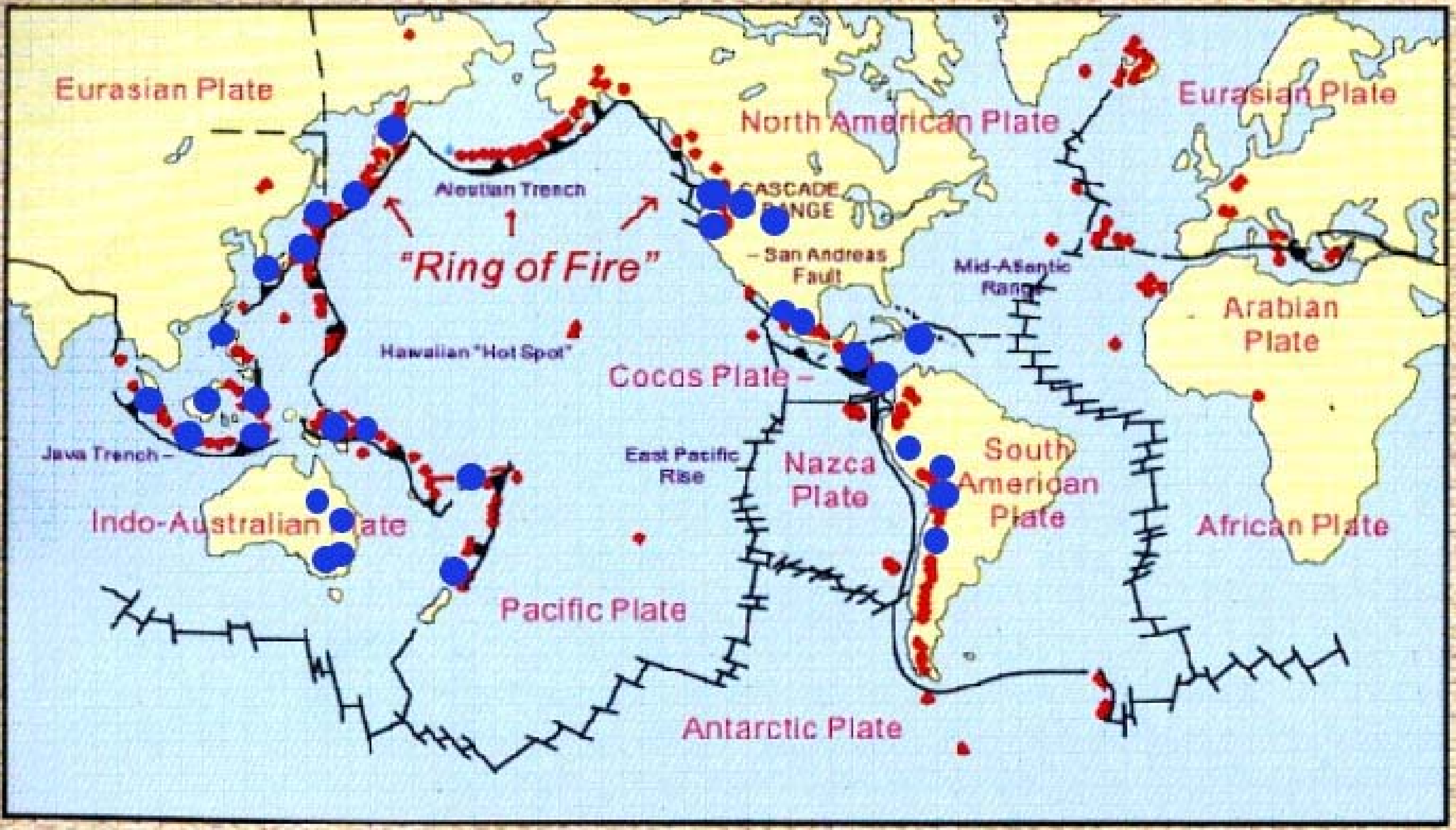
Grade-tonnage plot for epithermal Au deposits



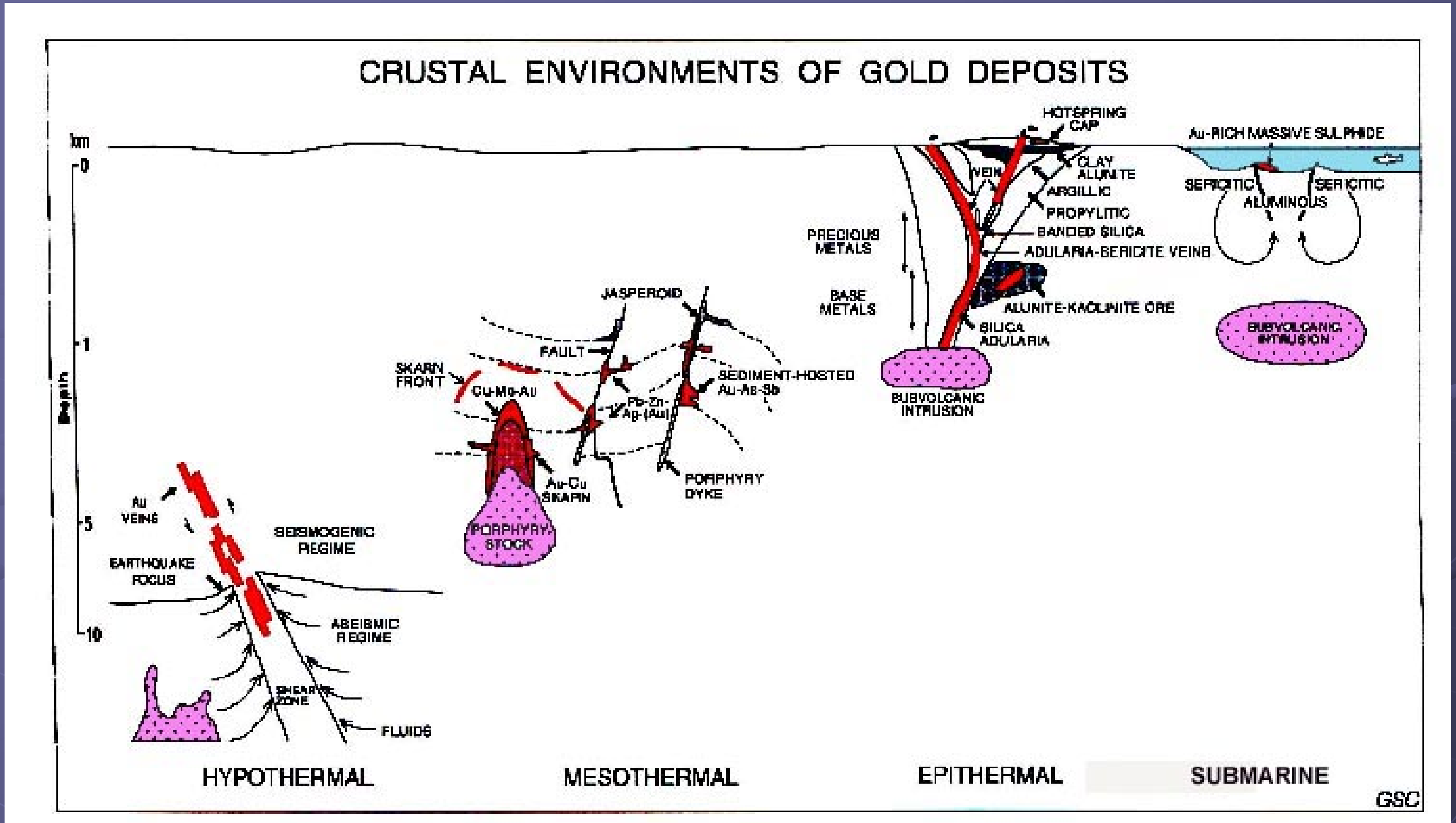
Tectonic settings

Tectonic settings of gold-rich epigenetic mineral deposits (after Groves et al., 1998)





Distribution of world’s active volcanoes and epithermal gold deposits



A steep shear zone is shown to transect the boundary between the seismogenic and aseismogenic crust and controls the fluid movement (shown by arrow) (Sibson et al., 1988)

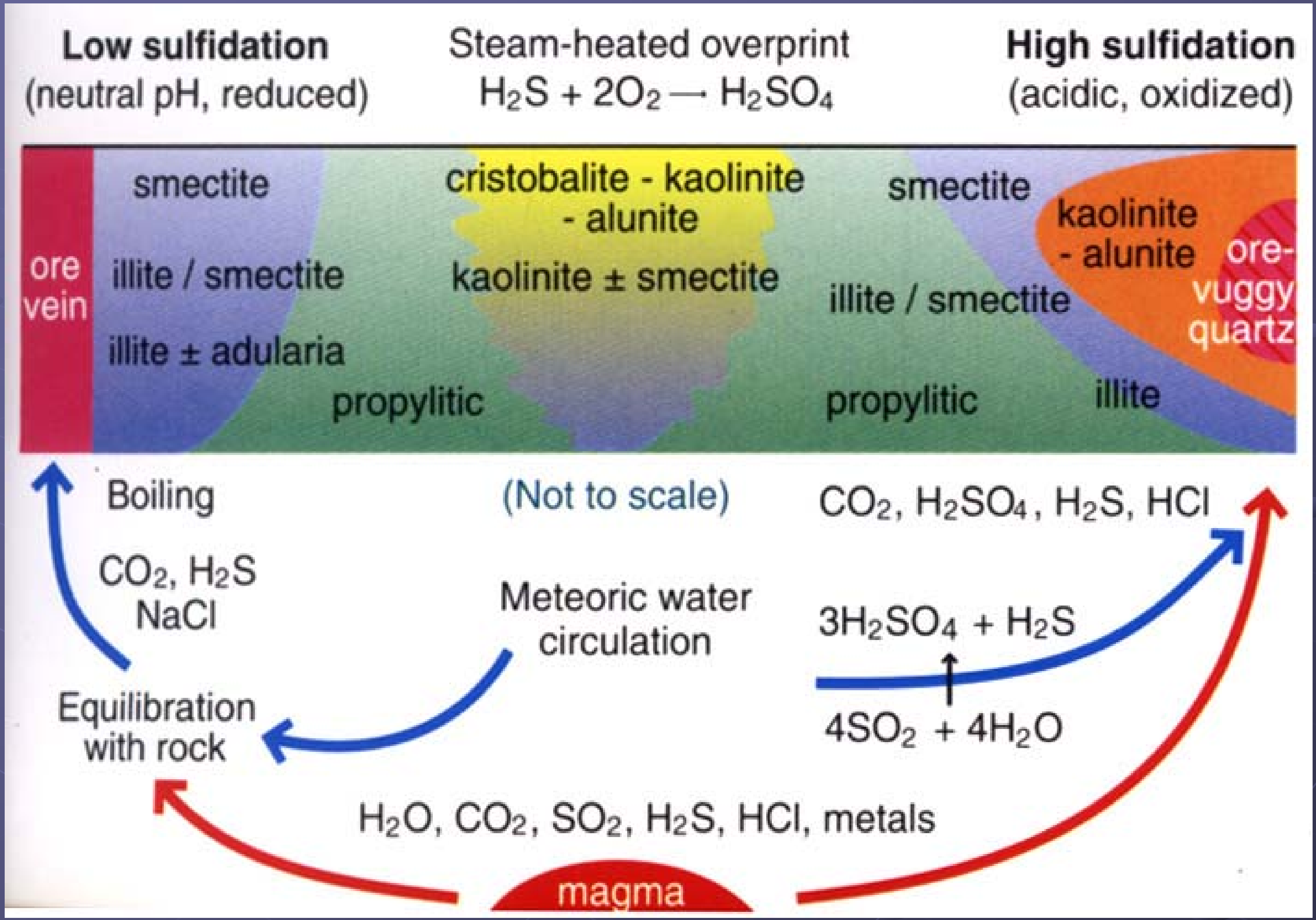
The relative positions of Cu-Mo-Au, Au skarn, and distal Carlin-type Au-AsSb mineralization are noteworthy (Sillitoe and Bonham, 1990

Relative position of subaerial hotspring mineralization with respect to deeper epithermal veins is noteworthy (Panteleyev, 1986

Formation of Au-rich volcanogenic massive sulphides on the sea floor is illustrated

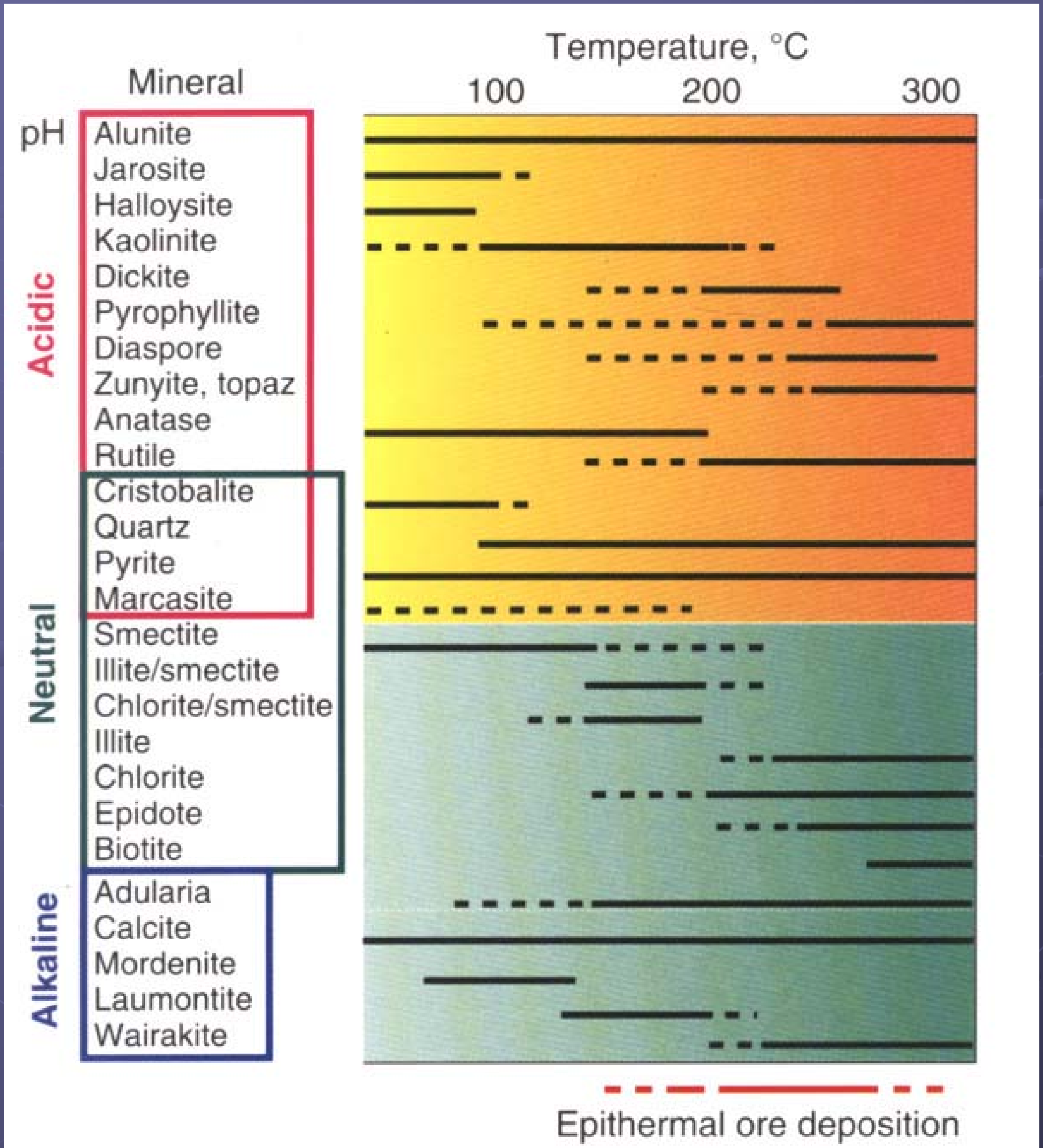
Alteration

Schematic distribution of hydrothermal alteration around LS and HS epithermal deposits



Quartz is stable throughout; propyllitic alteration occurs outside conduit zones (i.e., low water-rock ratio)

Temperature stability of hydrothermal minerals in the epithermal environments



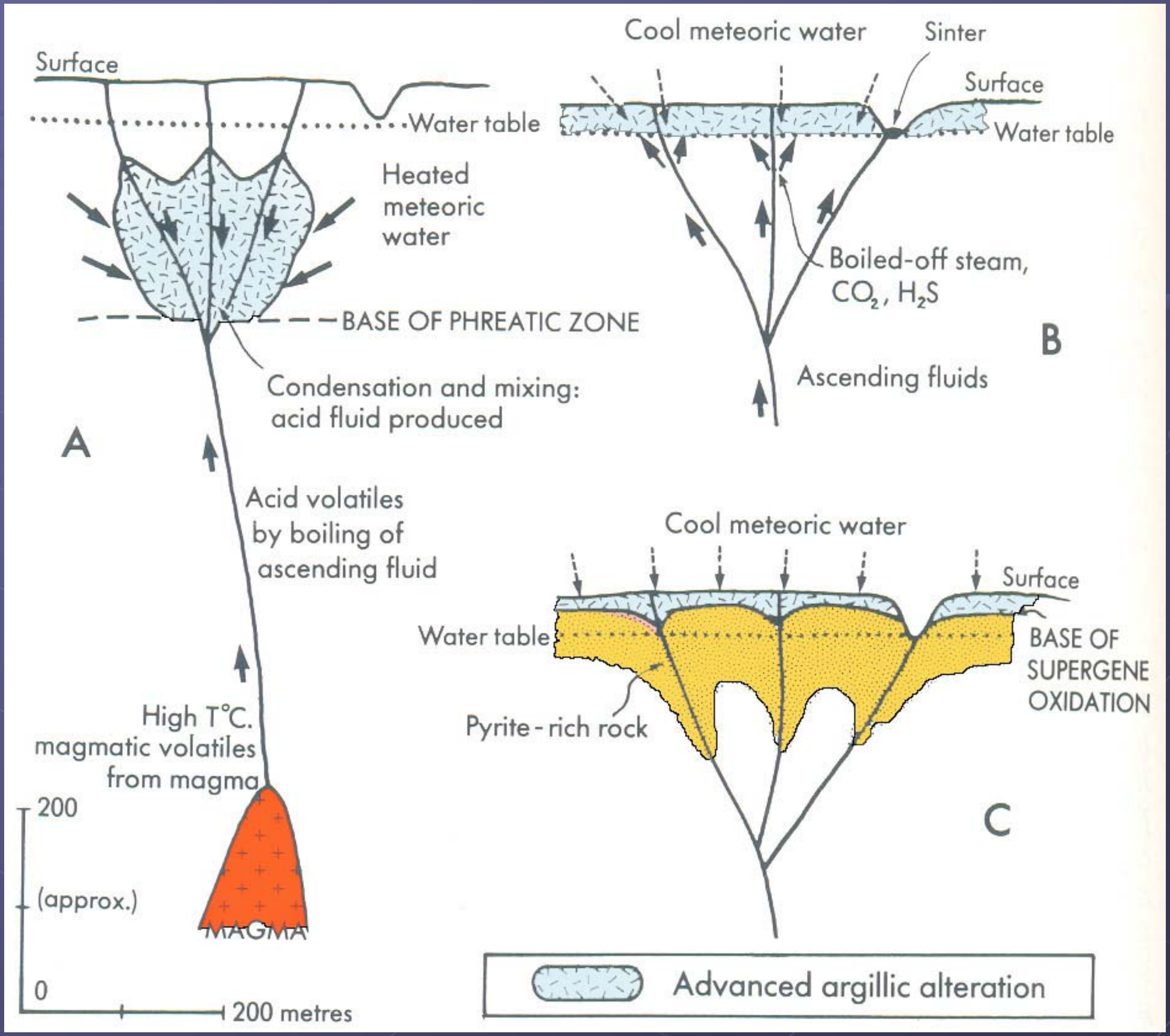
Minerals are arranged by their stability with respect to pH

Origins of three types of advanced argillic alteration

A: Deep Hypogene

B: Shallow hypogen

C: Supergene



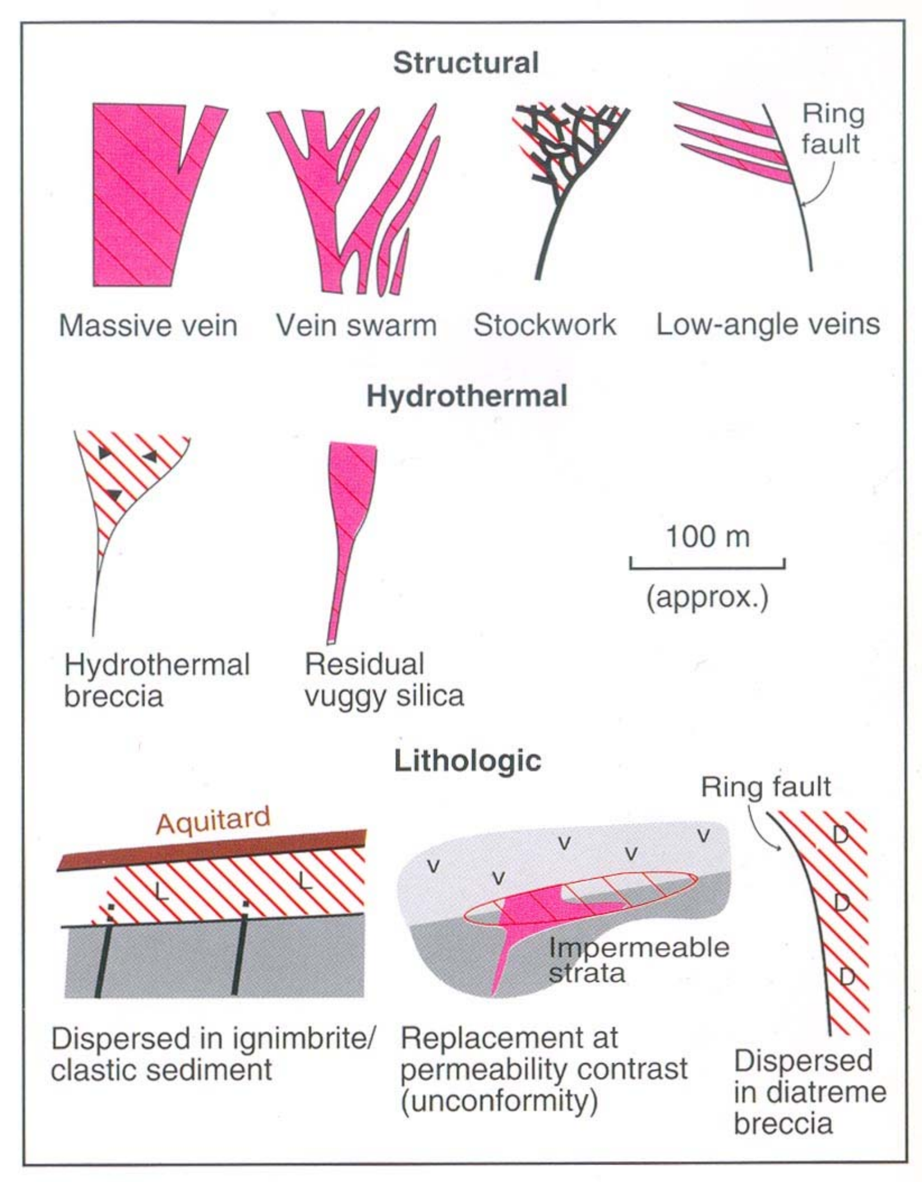
Mineralisation

Low sulfidation	High sulfidation
Ubiquitous	
Pyrite (a)	Pyrite (a)
Quartz (a)	Enargite-luzonite (±)
	Quartz (a)
Common	
Electrum (±)	Native gold (vm)
Native gold (vm)	Tellurides (vm)
Chalcopyrite (vm)	Covellite (m)
Sphalerite (±)	Tennantite (±)
Galena (±)	Tetrahedrite (±)
Tetrahedrite (vm)	Chalcopyrite (m)
Arsenopyrite (m)	Sphalerite (±)
Tellurides (vm)	Galena (±)
Pyrargyrite (vm)	Barite (m)
Chalcedony (±)	Alunite (±)
Adularia (±)	Kaolinite (m)
Illite (a)	Pyrophyllite (±)
Calcite (±)	Diaspore (vm)
Smectite (m)	Illite (m)
Uncommon or rare	
Selenides (vm)	Electrum (vm)
Stibnite (vm)	Selenides (vm)
Cinnabar (vm)	Pyrargyrite (vm)
Enargite-luzonite (vm)	Arsenopyrite (vm)
Tennantite (vm)	Cinnabar (vm)
Covellite (vm)	Stibnite (vm)
Barite (vm)	Chalcedony (m)
Kaolinite (vm)	Smectite (m)
Absent except as overprint	
Pyrophyllite	Calcite
Diaspore	Adularia
Alunite	

Frequency and abundance of ore (red) and gangue (blue) minerals in Au-rich epithermal deposits

A: Abundant; m: minor; vm: very minor and ±: variable

Styles and geometries of epithermal deposits illustrating the influence of structural, hydrothermal and lithologic controls on permeability, i.e., fluid conduits (Sillitoe, 1993)



Ore and gangue mineral textures of the two styles of deposits are distinct

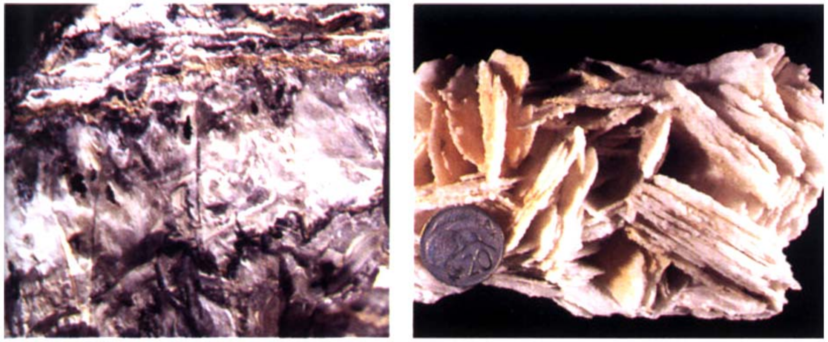


Fig. Banded botryoidal quartz vein from the Sleeper LS deposit, Nevada [44]; note electrum bands and quartz after bladed calcite (photo by J. Saunders). **(r.)** Coarse bladed calcite from the Martha Hill LS deposit, New Zealand (photo by S. Simmons).

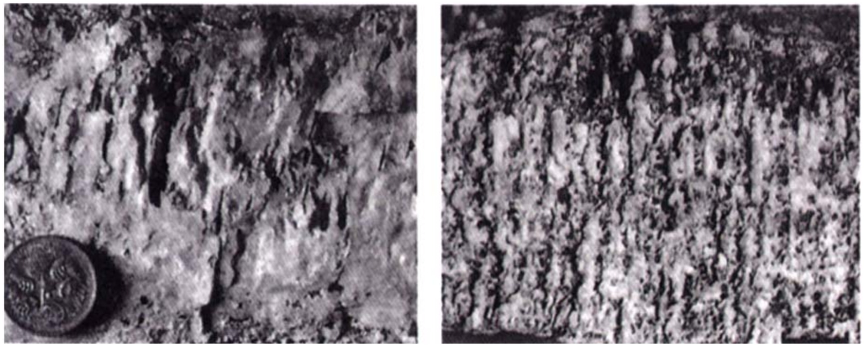


Fig. Diagnostic textures of silica sinter [61]. **(l.)** Columnar growth structures perpendicular to sinter laminations, Devonian Durah Creek sinter, Queensland (coin, 19 mm). **(r.)** Columnar structure formed by bacterial stromatolite, Broadlands geothermal system, New Zealand (photo 6 cm wide).

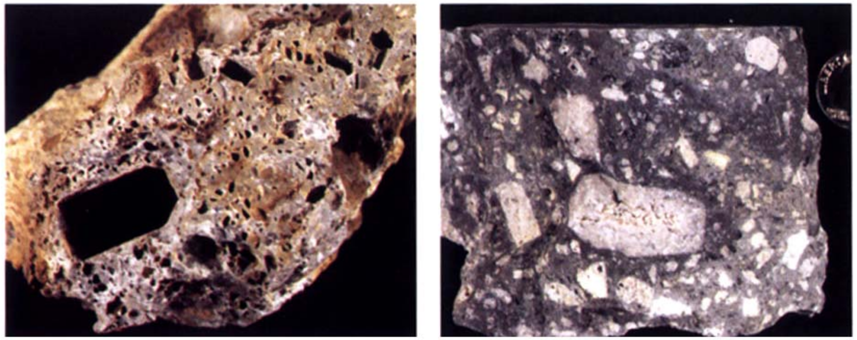


Fig. Diagnostic textures of HS epithermal deposits. **(l.)** Vuggy quartz caused by leaching of sanidine phenocrysts (≤4 cm long) by acidic fluid (pH <2 [55]). **(r.)** Same rock (quartz latite porphyry) altered to alunite-kaolinite in the alteration halo to vuggy quartz ore zone of Summitville deposit.

High Sulfidation
or
Alunite-Kaolinite type

High-sulfidation deposits = volcanic-hydrothermal environment

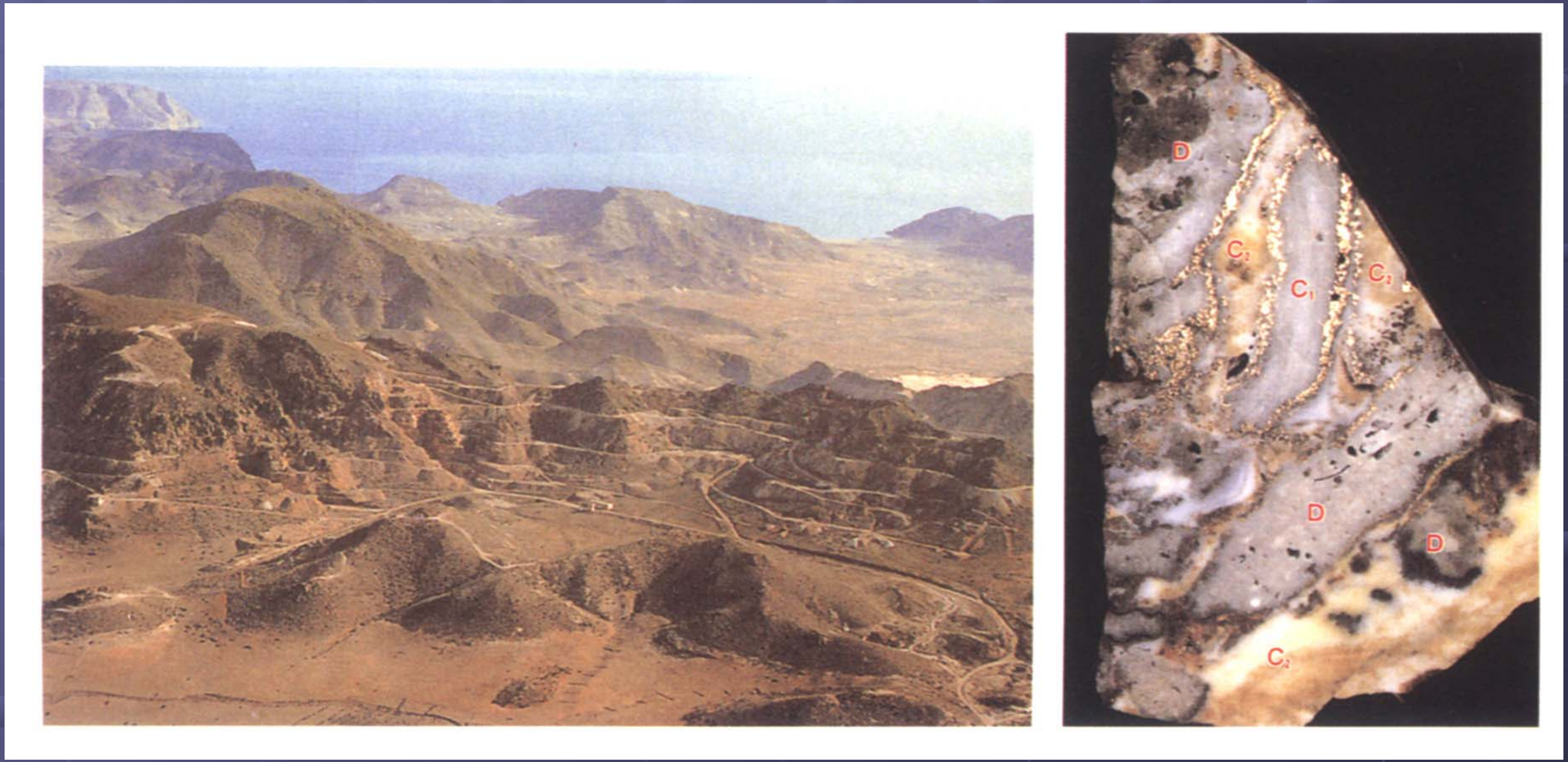
Fig. **(top)** Kasuga high-sulfidation deposit, Nansatsu district, Japan. Products of hypogene acidic alteration include Au-mineralized residual silica (>95% SiO_2) in sharp contact with alunite-kaolinite halo (downwards and to right)[21].

Fig. **(bottom)** Volcanic-hydrothermal system, Satsuma Iwojima, Japan. 870°C fumaroles vent from summit of rhyolite dome; acidic (pH 1.5) hot springs, rich in Fe and Al leached from host rock, discharge from volcano flanks to the sea [22].

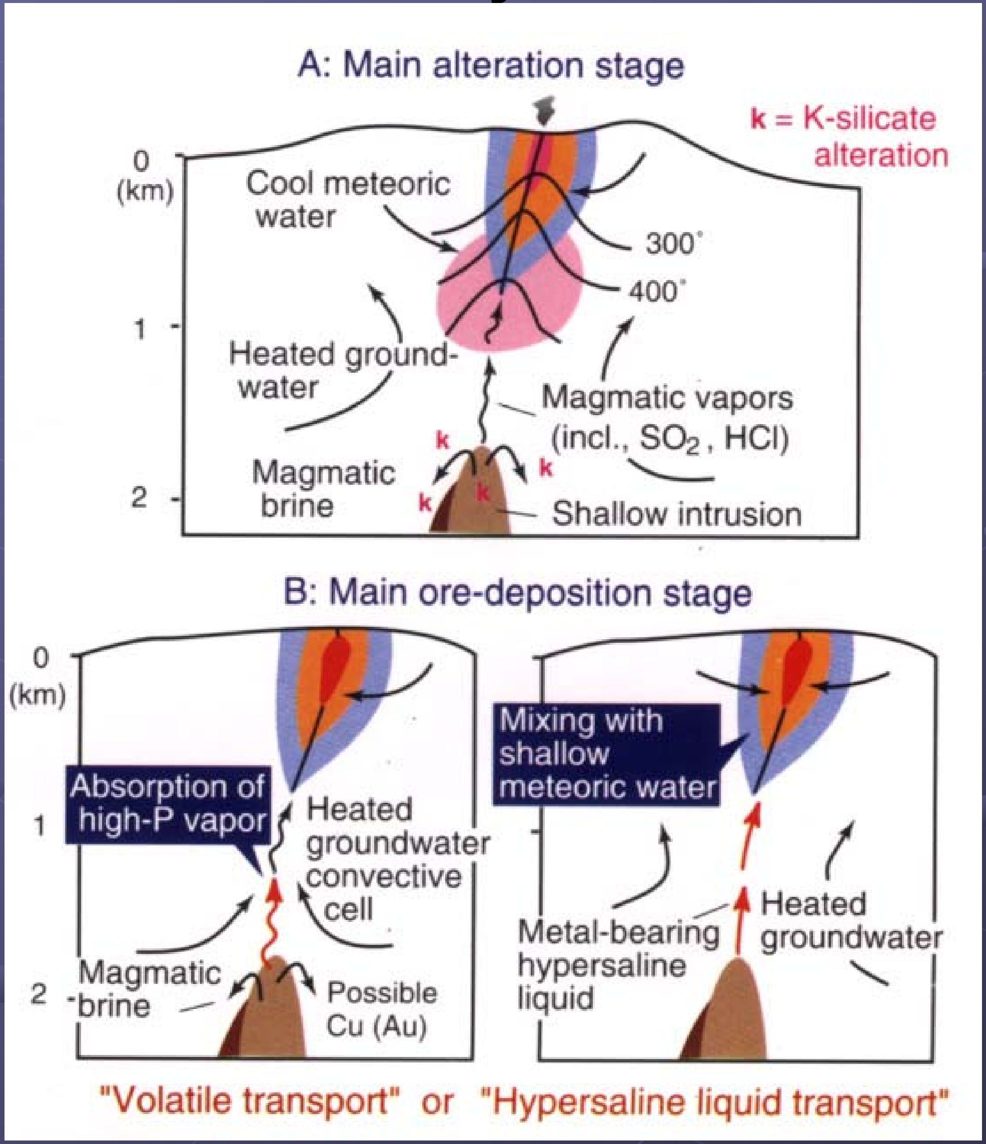
High sulfidation epithermal deposits

High sulfidation deposit: Rodalquilar Au deposit, SE Spain

Hydrothermal vein breccia



Model for the evolution of HS epithermal ore system



Low Sulfidation
or
Adularia-Sericite Type

Low sulfidation epithermal deposits

Fig. 6.4 Vein formation at Hishikari was influenced by unconformity between basement sedimentary rocks and overlying volcanic rocks. A clear example is shown here where the Zuisen 1 vein in the Honko system splays and feathers out on passing from the Shimanto graywacke basement to the overlying volcanic rocks (photo by K. Ibaraki).

Low-sulfidation deposits = geothermal environment

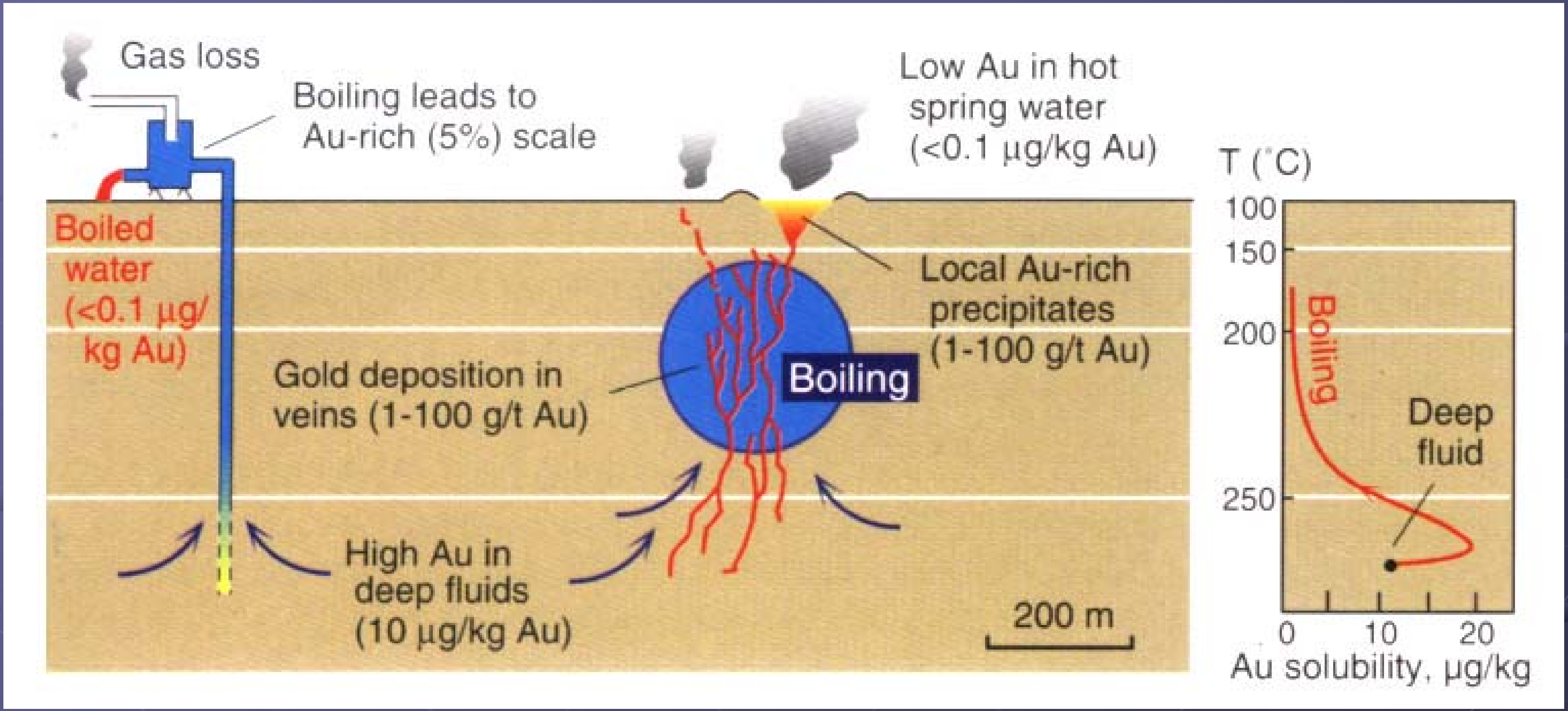
Fig. **(left)** High-grade, low-sulfidation quartz-adularia veins, Hishikari deposit, Japan [28] (photo by K.Ibaraki).

Fig. **(right)** Champagne Pool, Waiotapu geothermal system, New Zealand. Neutral-pH hot spring rimmed by sinter with orange As-Sb-Au-Ag-Hg-Tl-rich precipitates. Steam-heated acid-sulfate water forms kaolinite alteration in craters adjacent to hot spring

Texture of LS epithermal Au deposit: McLaughlin mine, California

Typical texture of LS epithermal gold vein, McLaughlin mine, California (natural size) (photo by Y. Matsuhisa).

Boiling is the critical process to deposit high concentration of Au in LS epithermal deposits

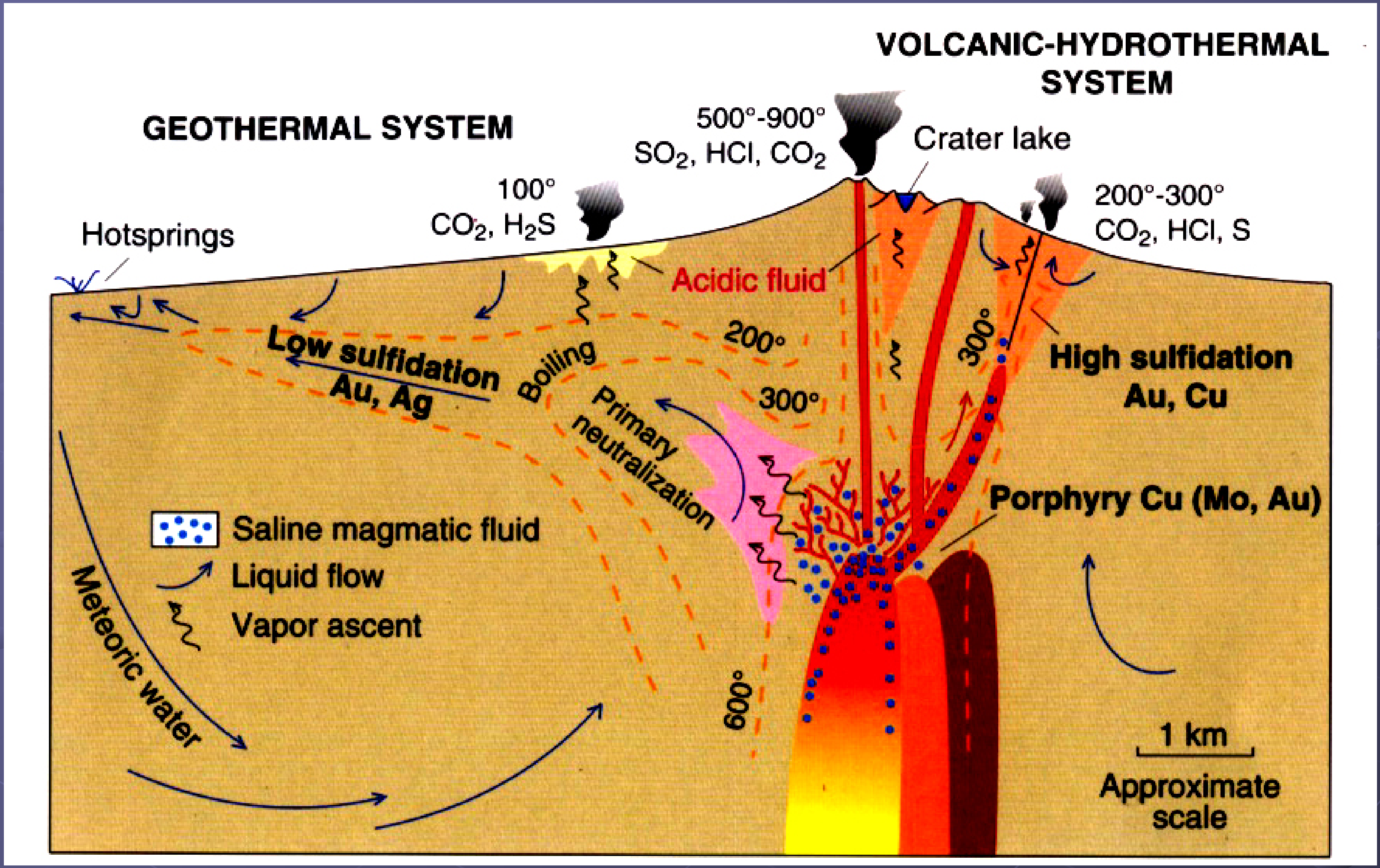


Au concentration in deep water (prior to boiling and gas loss): 10µg/kg

Au concentration in hot spring waters: < 0.1µg/kg

Au precipitates during ascent and boiling

Generalised model of Porphyry and epithermal deposits associated with shallow sub-volcanic intrusions and strato-volcano



Active volcanic-hydrothermal systems extends from degassing magma to fumaroles and acidic springs, and incorporate **porphyry and/or high-sulfidation** ore environments

Geothermal systems: **Low sulfidation**; characterized by neutral pH water that may discharge as hot springs

Solubility aspects of ore formation

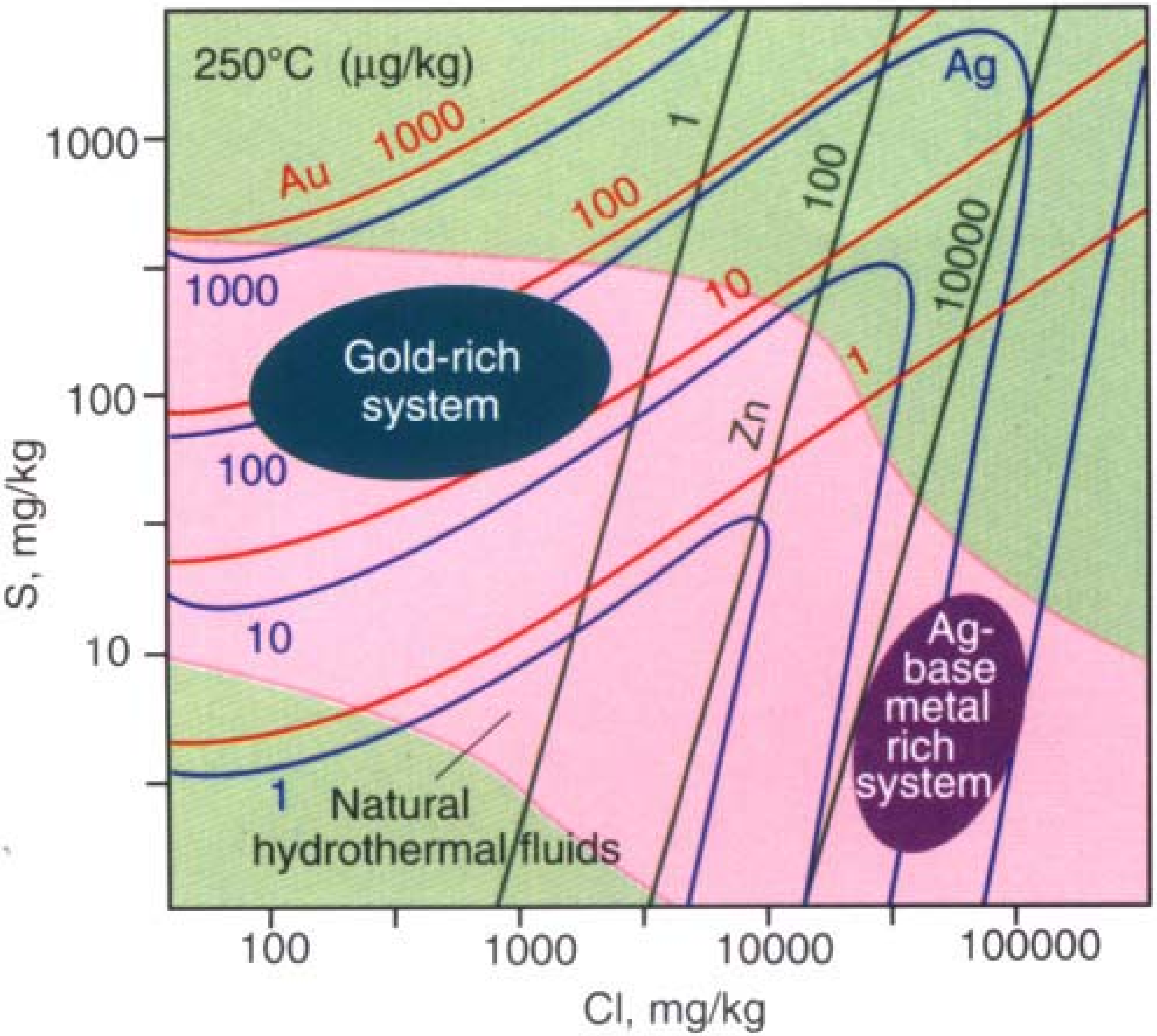
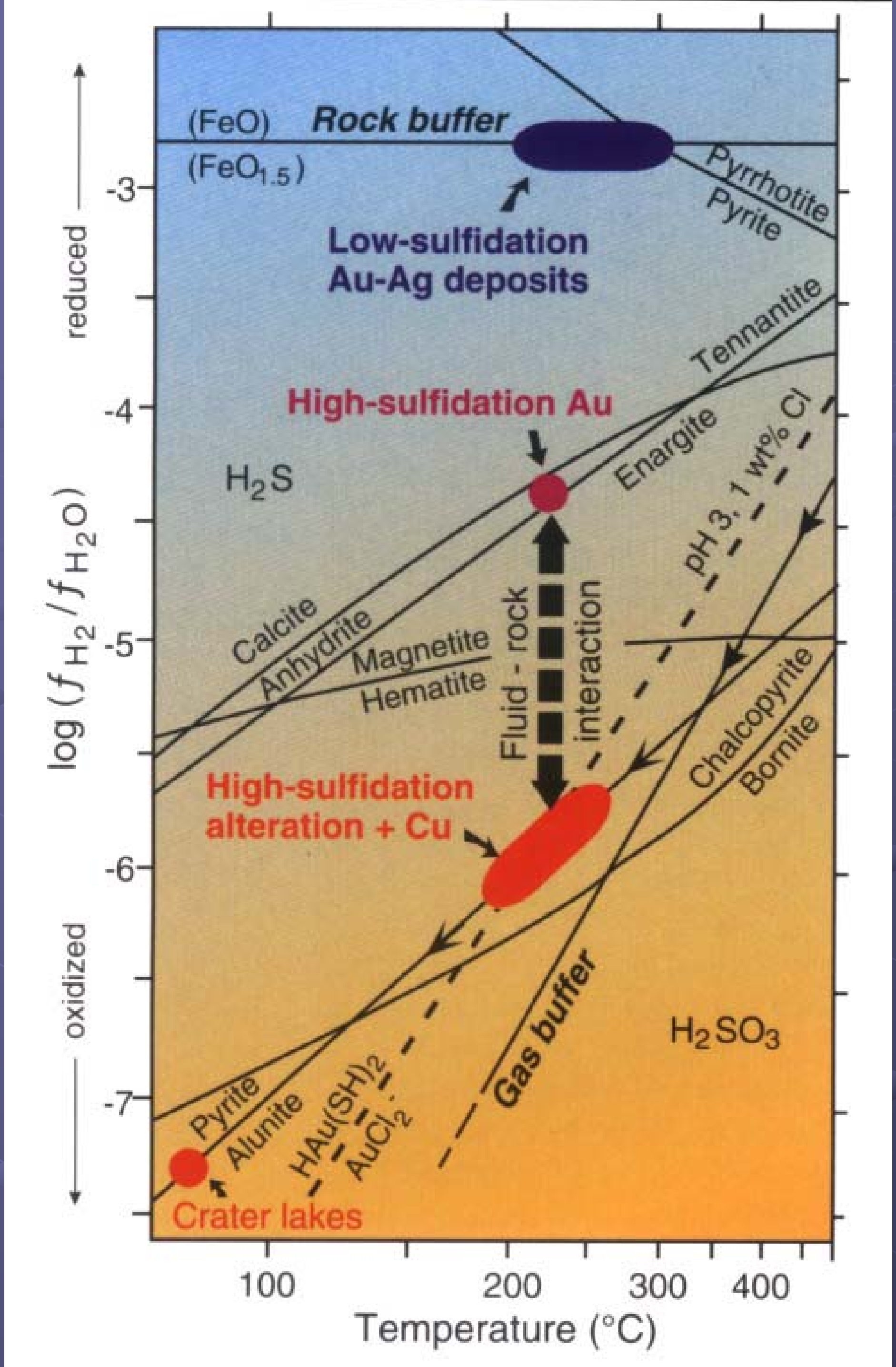


Fig. Solubility of Au, Ag, and Zn as a function of S and Cl concentration at pH and redox of LS mineral assemblages [24]. Cl-poor solutions typical of Au-rich LS ore deposits [19] transport Au as bisulfide complexes, but cannot transport much chloride-complexed base metals [24].



- Redox potential vs temperature for fluids limited by oxidised volcanic rock buffer and reduced rock buffer
- Ore fluids evolve with time to less acidic and more reduced conditions

Exploration guides

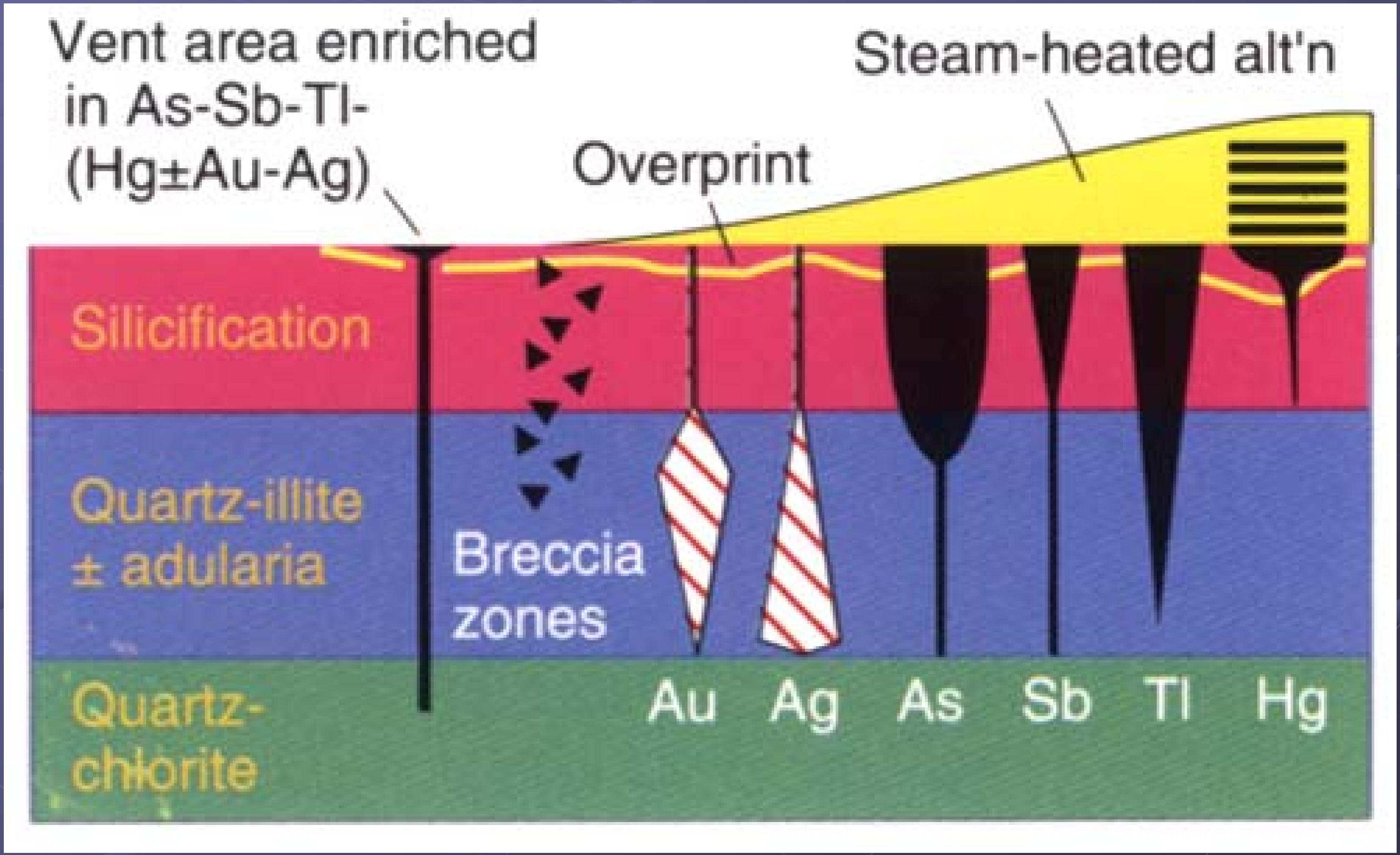
Relative importance of different methods at different stages of Exploration

Method	Regional scale	Project scale	Prospect scale
Geology	***	***	***
Geochemistry			
Stream sediment	***	***	
Soil		***	***
Alteration mapping	*	***	***
Geophysics			
Remote sensing	**	*	
Magnetics	***	*	
Induced polarization			**
Resistivity		*	**
Electromagnetics		*	**
Radiometrics	***	*	
Gravity		*	

Effective exploration methods for epithemal gold deposits

Method	Response
Geology	• Recognition of veins & hydrothermal alteration patterns • Vein texture and mineralogy • Geologic understanding is the basis for all interpretations
Geochemistry	• SHALLOW: Indicator elements important • DEEP: Anomalies related to mineralized structures
Geophysics (a) Induced polarization (b) Resistivity (c) Electromagnetics	Both at shallow and deep levels Effective in prospects scale

Typical variation of LS epithermal indicator elements as function of depth below paleo-surface and alteration zoning



Thank you for your

patience