Epithermal Au-Ag – The Magmatic Connection Comparisons between East and West Pacific rim

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Introduction

Epithermal Au-Ag deposits are distinguished as high and low sulphidation (HS & LS) on the basis of ore and gangue mineralogy, derived from distinctly different fluid typess, and for the LS deposits there is a further distinction between the group of base metal rich deposits which commonly display a relationship with intrusion source rocks, and the banded adularia-sericite style quartz veins (Figure 1; Corbett 2002, and references therein). Characteristics of the distinctly different fluids which form these variable deposit types result from the relationship to the magmatic source and degree of evolution leading to ore deposition.

Metal distribution

Metal abundance and distribution vary according to tectonic setting, deposit type, crustal level of formation, distance from magma source, and the mechanism of metal deposition.

Crustal composition influences metal contents. Many Western Pacific magmatic arcs are underlain by oceanic crust, whereas those in the eastern Pacific overlie thick continental crustal segments. Consequently, HS deposits (below) in the SW Pacific (Nena & Wafi, PNG; Lepanto, Philippines; Peak Hill & Gidginbung, NSW; Mt Kasi, Fiji) are Ag-poor (generally totally free of Ag), whereas Ag is an important economic component of HS ores in the Americas (La Coipa, Chile;Yanacocha & Pierina, Peru; Veladero, Argentina; Pascua-Lama, Chile-Argentina). Similarly, the LS deposits of varying styles tend to be more Ag rich in the Americas. The polymetallic Au-Ag ores of Mexico, Bolivia and Peru, are important sources of Ag, but may contain very low Au, whereas similar ores in the SW Pacific are commonly Au and not Ag rich (Hadleigh Castle, Qld; Parkers at Mineral Hill, NSW). While, SW Pacific LS quartz-sulphide Au deposits contain low fineness Au, Ag as argentite is a significant part of the ore at the Ocampo district Mexico and taken to be representative of others in the region.

Similarly, porphyry deposits in the SW Pacific occur as Cu-Au porphyry systems, whereas most in the Americas are Cu-Mo bearing, again reflecting the influence of crustal metal content. Some gold rich porphyry systems of the Americas conform to the alkaline intrusion class (below), while others such as some at the Maricunga Belt, Chile, are interpreted by this author to be of the LS quartz-sulphide class (below), formed outside the source intrusion.

Tectonic setting may also play a role in magma composition and hence metal abundances and content. During the Miocene, southward subduction of the Pacific oceanic plate under the Indo-Australian plate was jammed by the thick Otong Java portion of oceanic crust. Consequently, by the Pliocene a new northward facing subduction zone extended from Papua New Guinea and Fiji, to the south of the Miocene north dipping subduction zone. Solomon (1990) proposed that remelting of previously melted oceanic crust has led to the development of the Au-rich alkaline shoshonitic melts, which although occupying only 2% of the igneous rock suite, could account (Sillitoe, 1997) for in 20-30% of the SW Pacific Au content (Lihir & Porgera, PNG; Emperor, Fiji). In each case major crustal structures have acted as conduits to aid the formation of significant magma bodies at high crustal levels. While Porgera crops out as an apophysis to a major magmatic source evident on aeromagnetic data, failure of extrusive volcanic edifices provided the impetus for re formation at Lihir and Emperor ore systems. The quenched LS quartz-sulphide ores at Lihir are As-rich.

Although epithermal Au deposits associated with alkaline magmatism display some distinct metal abundance characteristics, mainly Te enrichment (Emperor, Tavatu Fiji; Cripple Ck, US), they should not be classed as a separate deposit style, but occur as a range of documented deposit types (Corbett and Leach, 1998) derived from a different magma type (Emperor, Porgera, Lihir).

Many alkaline magmatic systems are located more towards back arc portions of the overall magmatic environment; examples include Didipio, Philippines; Bajo de la Alumbrera, Argentina, Porgera and Mt Kare in PNG, and possibly Grasberg in West Papua. The tectonic setting of the Ordovician alkaline complexes of the Lachlan Orogen remains less clearly defined.

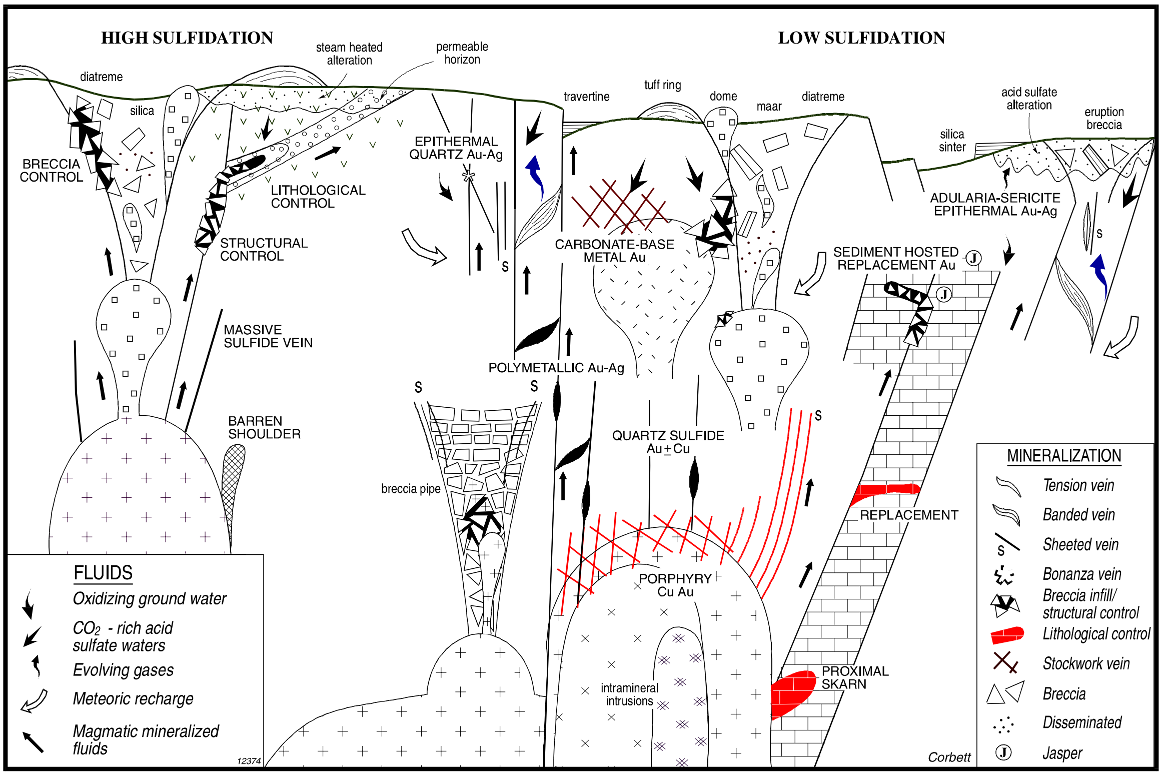

Figure 1. Conceptual model for different styles of magmatic arc Cu-Au-Ag mineralisation (from Corbett 2002).

Deposit Type

Low sulphidation

Low sulphidation Au-Ag deposits develop from cells of circulating dilute meteoric-dominated waters driven by magmatic heat sources within dilational structural settings. These deposits are divided into the group of Arc (ALS) and Rift (RLS) styles, although some transitional relationships are discerned.

The <u>adularia-sericite epithermal Au-Ag</u> deposits (ASED) form banded quartz vein ores common in intra-arc or back-arc rifts and so constitute the Rift LS deposits. These regions are commonly characterised by bimodal volcanism comprising sequences of andesitic flows local basalt and felsic pyroclastic deposits or subvolcanic intrusions. Host rock competency plays an important role in fissure vein formation and so many deposits are more likely to occur within basement shales (Hishikari & Konami, Japan) or andesitic flows (Waihi, Karangahaki, Golden Cross in New Zealand), while andesitic (Chitose, Japan) or felsic (Sado, Japan or Sleeper, US) domes are less common vein hosts. Only rarely (Cerro Vanguardia, Argentina) are felsic volcanic sufficiently brittle to host fissure veins.

While these banded quartz vein ores comprise minerals deposited from rapidly cooling and boiling circulating meteoric waters (chalcedony, adularia, platy calcite replaced by quartz), the metals deposited by fluid mixing (Corbett and Leach, 1998) within black sulphidic ginguro vein portions, may ultimately be derived from distal felsic intrusion source rocks. Felsic domes, dykes and extrusive rocks of similar ages are common in the vicinity of many adularia-sericite deposits (eg, Hishikari).

Furthermore, there are common transitional relationships between (ASED) and the (ALS) deposits, as some RLS deposits become base metal sulphide rich at depth (Waihi) while others contain ore of a LS carbonate-base metal (Karangahake; Misima, PNG) or LS quartz-sulphdie (Rawas, Indonesia) association. Indeed many ASED, particularly in the Jurassic systems of Patagonia, contain early low gold grade quartz-sulphide mineralisation, which is commonly subject to surficial supergene enrichment.

The pattern of Ag significantly greater than Au, is more pronounced in western than eastern Pacific examples, while both display vertical zonation with anomalous Hg, As, Ba in the upper levels.

The Arc Low Sulphidation Au-Ag deposits (Corbett, 2002) are subdivided (Corbett and Leach, 1998) from deeper to higher levels as: quartz-sulphide Au + Cu (QS), carbonate-base metal Au (CBM), and epithermal quartz Au-Ag (EQ). The CBM ores, which are the most prolific gold producers in the SW Pacific, are transitional to the polymetallic Au-Ag fissure veins of the Americas (Arcata, Caylloma, Peru), here Ag-rich, while the CBM deposits also occur as Au>Ag (by value) in the SW Pacific as fissure veins (Acupan, Antamok, Philippines) or fracture/breccia (Kelian, Indonesia; Porgera) ores.

Metals within ALS deposits are derived from intrusion source rocks, entrained within circulating meteoric waters which become progressively more dilute with respect to the magmatic component as they rise to higher crustal levels and mix with more ground waters (eg, QS). Buried magma source rocks are inferred to drive the circulating heat cells. Other gangue minerals such as the carbonate in the CBM deposits is derived from the mixing or ore fluids with evolved bicarbonate waters, inferred to ultimately have been derived from magmatic source rocks. The EQ ores are gangue poor, but contain bonanza gold grades formed by the mixing of ore fluids with condensate (low pH) or oxygenated groundwaters. and occur overprinting CBM (Porgera) or QS (Emperor) and peripheral to porphyry Cu-Au systems (Thames, New Zealand), as an indication of the magmatic derivation.

The magmatic association is most clearly evident in the deeper QS ores some of which are transitional to wall rock porphyry Cu-Au deposits (Cadia, Australia; Maricunga Belt, Chile; La Arena, Peru) while others exploit early structures at higher crustal levels than subjacent porphyry C-Au manifestations (Bilimoia, PNG; Mineral Hill). Many occur within intrusion-related breccia systems (Kidston, Australia; San Cristobal, Chile). These ores are therefore Cu rich at depth and Au rich at higher crustal levels, and where quenched may be anomalous in As (Lihir), and locally Sb and Ba.

CBM Au-Ag deposits occur in association with high level intrusions (Porgera) or diatreme-flow dome complexes developed as clear evidence of felsic magmatism (Kelian, Indonesia; Wau, PNG; Cripple Creek & Montana Tunnels, US). Felsic domes recognised in association with may polymetallic Au-Ag ores in the Americas may be derived from the same magmatic source at depth as the mineralisation.

The more enigmatic sediment hosted replacement Au (SHR) ores, although best developed in the Carlin and Battle Mountain Trends of Nevada, are recognised in other magmatic arcs (Bau, Malaysia; Mesel, Indonesia). These deposits typically form by the replacement of favourable impure limestone in extensional structural settings, and vary from lower metal grade lithologically controlled ores at higher crustal levels, to higher metal grade structurally controlled ores at deeper levels, but commonly do not easily demonstrate direct associations with intrusion source rocks. However, the pyritic ores are interpreted to have been derived from a fluid similar to the QS deposits with a distal relationship to the magma source within the characteristic extensional structural settings. Here, and in QS deposits, these fluids deposit Au in association with As bearing pyrite (commonly encapsulated) and with anomalous Ba, Hg and Sb. Recent work (Chakurian, 2001) suggests that the Carlin Trend SHR Au deposits are of the same age (38 m.y.) as porphyry Cu magmatism in that region, and magmatism is also recognised in other districts where these deposits occur (Mesel).

High Sulphidation Au ± Ag

In brief, high sulphidation deposits develop in settings where volatile rich magmatic fluids rise to higher crustal levels without significant interaction with the host rocks or ground waters. Volatiles (SO_2) evolved from the depressurising fluids oxidise to form a two stage hot acid fluid, the initial stage of which reacts with the host rocks to produce the characteristic zoned acidic alteration at epithermal crustal levels (Corbett and Leach, 1998). A later liquid dominated fluid phase deposits sulphides which are characterised by pyrite with enargite, or the latter's low temperature polymorph luzonite. These deposits are generally Cu-rich at depth, and Au-rich, locally with anomalous Hg, Sb, and Te, at higher crustal levels. HS deposits in the SW Pacific are Ag-poor while those in the Americas are Ag-rich. Many sulphide ores are refractory and low grade and so mined only where oxidised.

Magmatic rocks are interpreted to represent the ultimate source of ore fluids as demonstrated by the commonly association of HS deposits with felsic domes (Yanacocha, Mt Kasi) and phreatomagmatic breccias within flow-dome complexes (Pascua, Veladero, Wafi, Lepanto). Many HS deposits display associations with porphyry Cu-Au systems of similar ages (Nena), or are collapsed upon and form part of the porphyry ores (Monywa, Burma). Fluids responsible for the formation of HS deposits rarely evolve to Au- rich lower sulphidation style ores (Wafi; El Indio, Chile).

Conclusion

In magmatic arcs metals concentrate within intrusive rocks and form porphyry Cu-Au-Mo deposits at the apophyses to larger magmatic sources, and at higher crustal levels evolve to epithermal levels. Whereas HS ores develop from saline fluids with little interaction with circulating waters, the LS deposits develop where metals are entrained within circulating dilute meteoric-dominated waters, and are classed as ALS for the group with closest association with intrusion rocks, or the RLS where the magmatic association, although interpreted herein, is less obvious. Variations in metal contents are apparent from the crustal and tectonic setting as well as crustal level and distance from magmatic source. Epithermal deposits of all classes tend to be significantly more Ag-rich in eastern Pacific magmatic arcs which are underlain by continental rather than oceanic crust.

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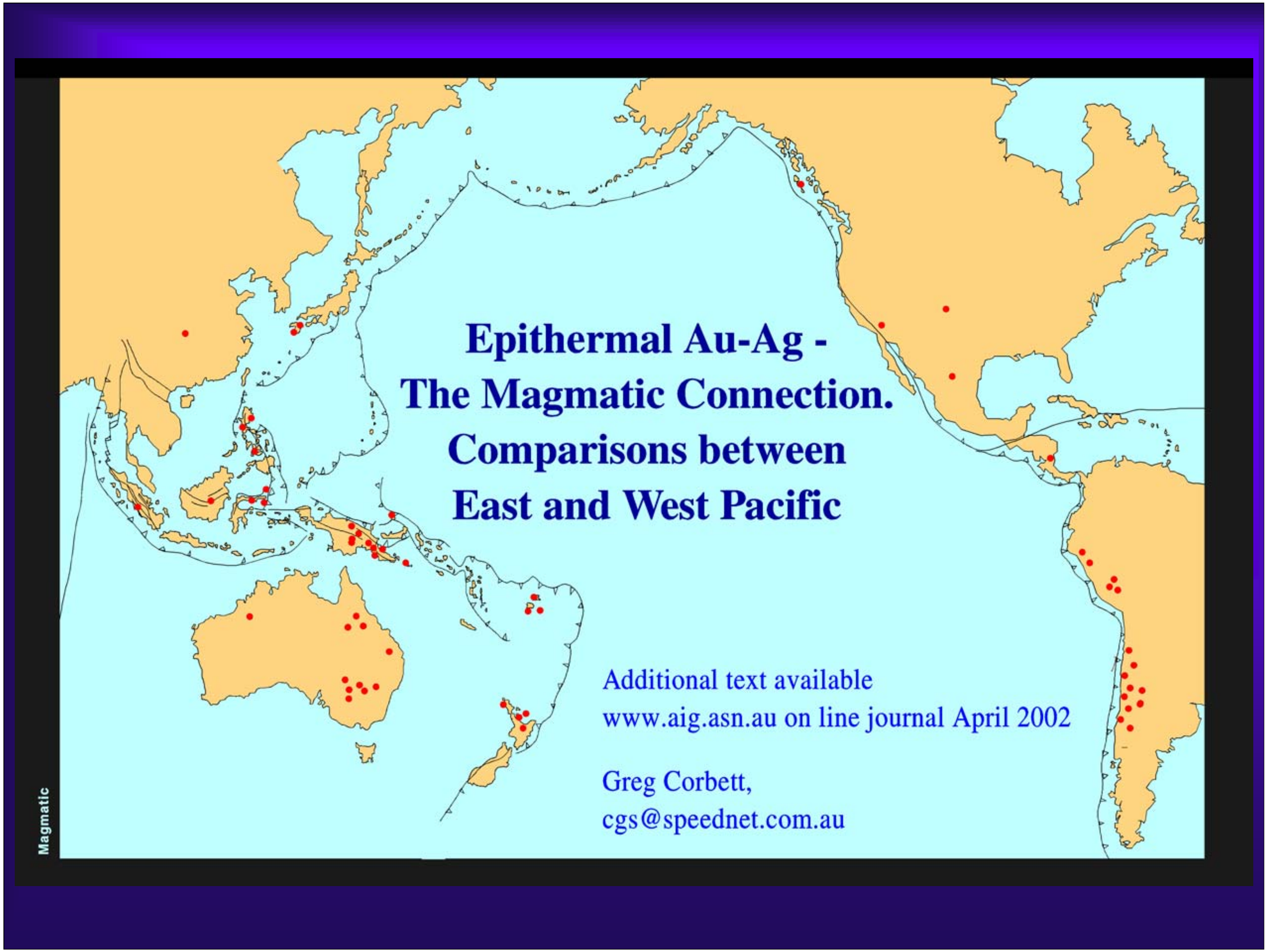
Corbett, G.J. 2002, Epithermal Gold for Explorationists: AIG Presidents Lecture, AIG On Line Journal April 2002, AIG website www.aig.asn.au

Corbett, G.J., and Leach, T.M., 1998, Southwest Pacific gold-copper systems: Structure, alteration and mineralization: Special Publication 6, Society of Economic Geologists, 238 p.

Sillitoe, R.H., 1997, Characteristics and controls of the largest porphyry copper-gold and epithermal gold deposits in the circum-Pacific region: Australian Journal of Earth Sciences, v. 44, p. 373-388.

Solomon, M., 1990, Subduction, arc reversal, and the origin of porphyry copper-gold deposits in island arcs: Geology, v. 18, p. 630-633.



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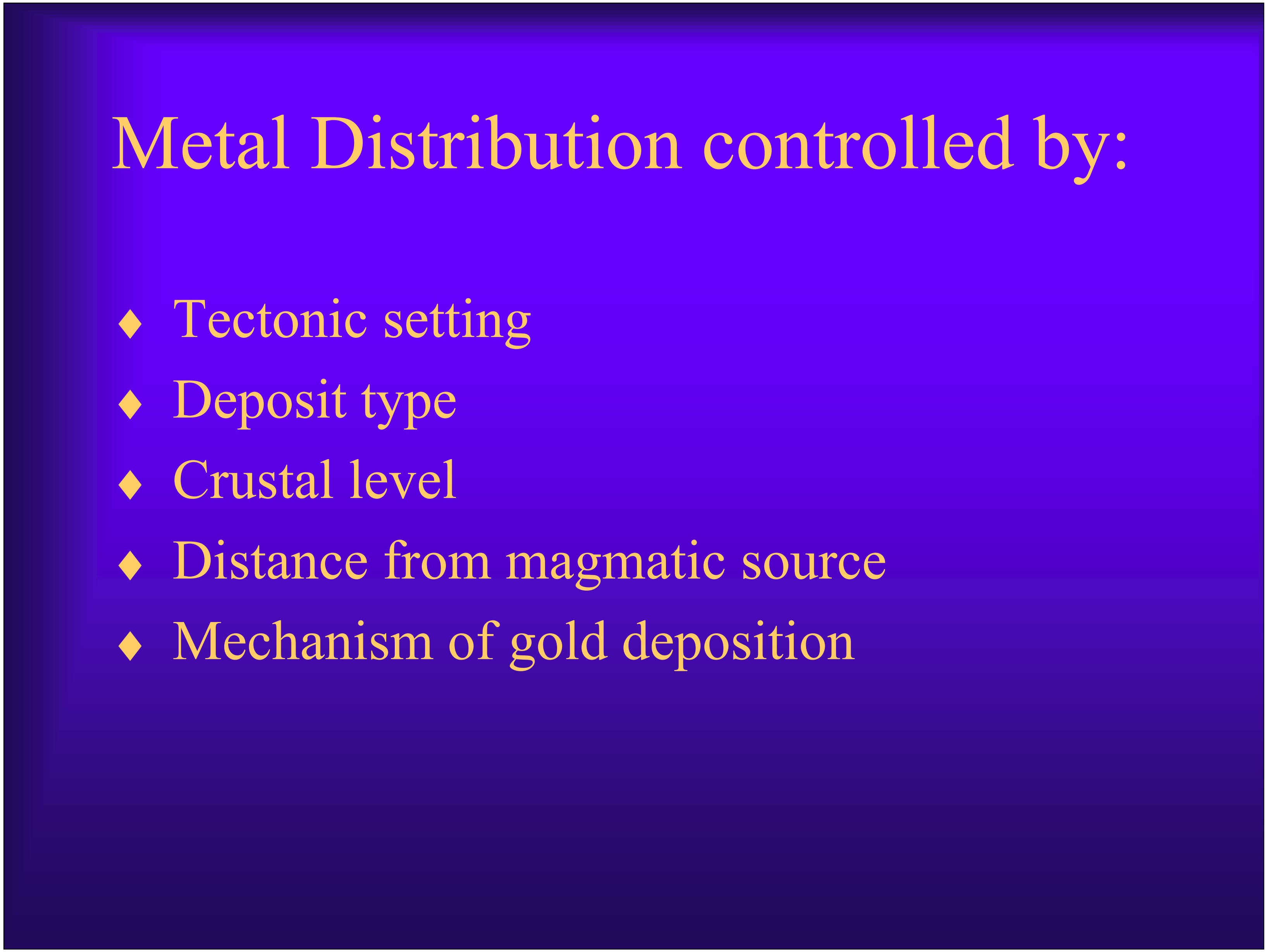
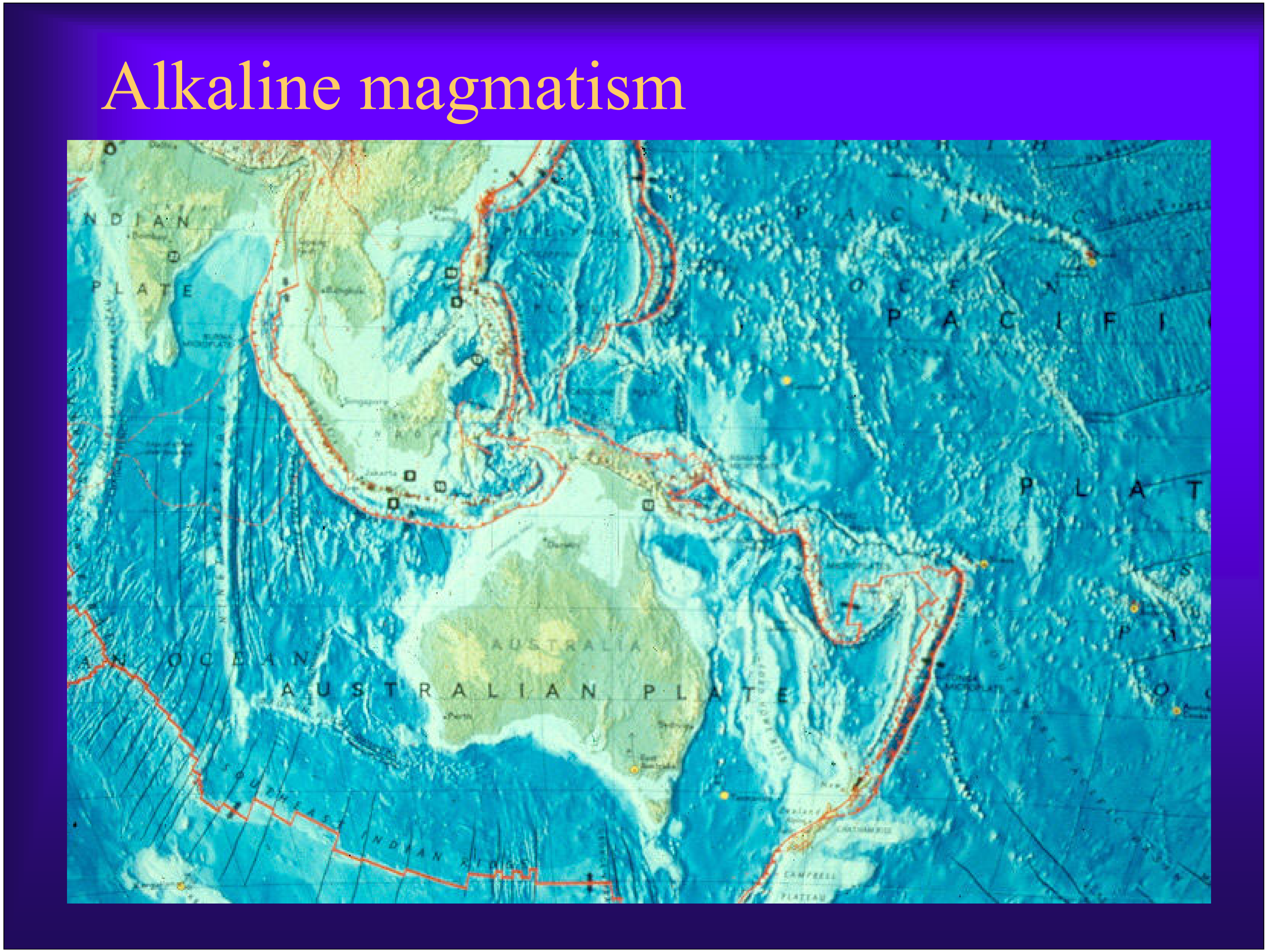
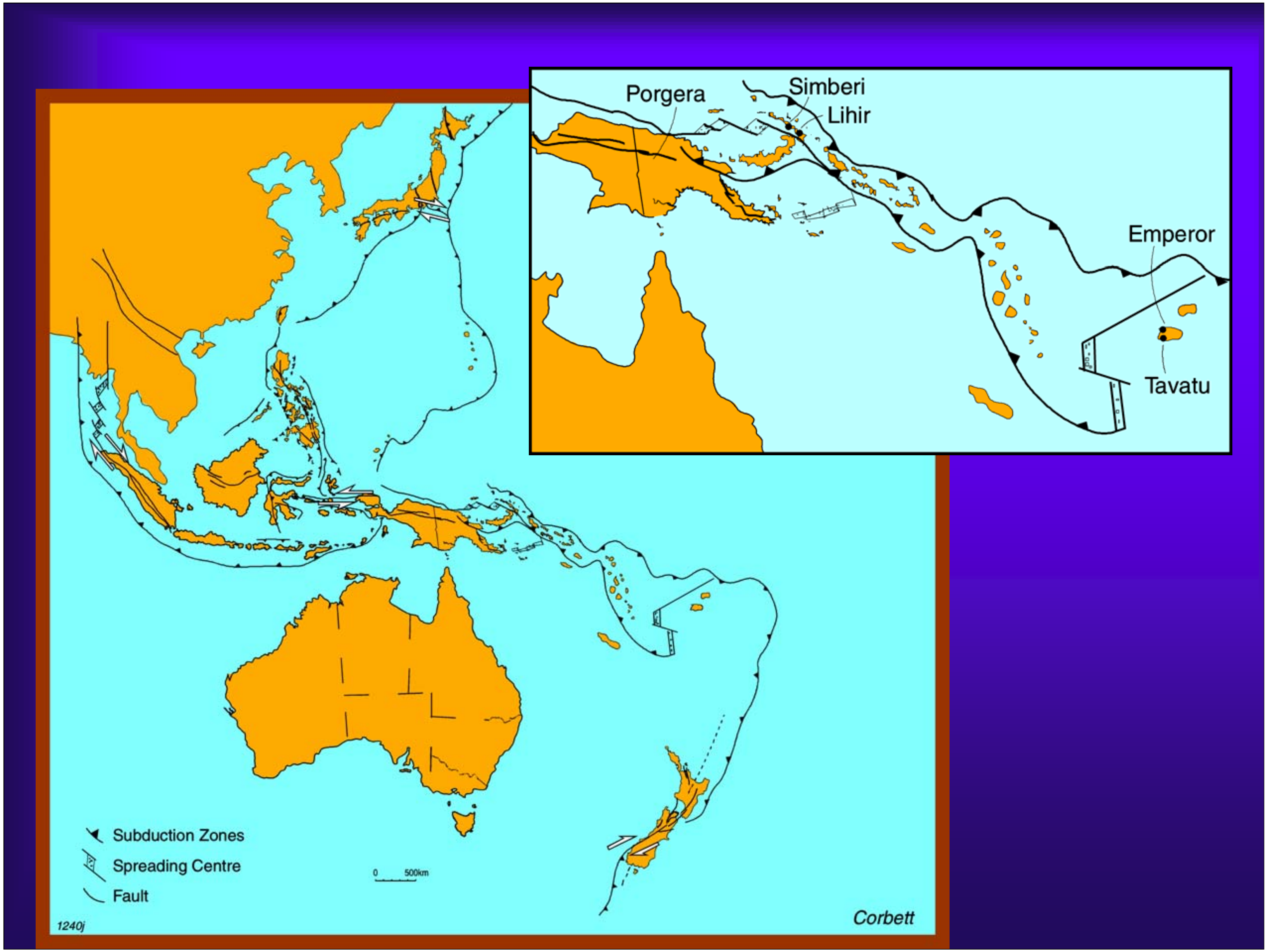


Metal Distribution controlled by:

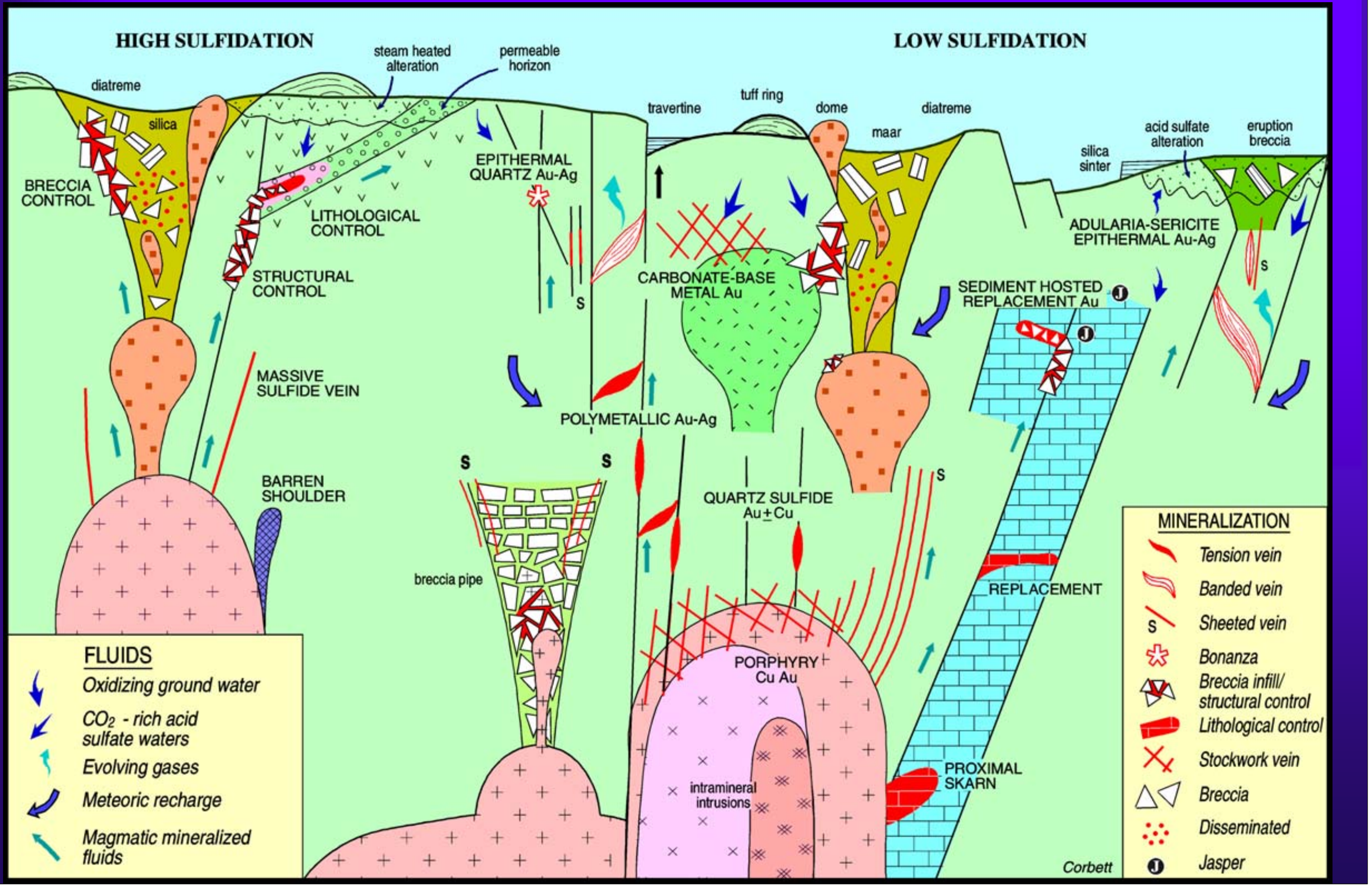
- Tectonic setting
- Deposit type
- Crustal level
- Distance from magmatic source
- Mechanism of gold deposition



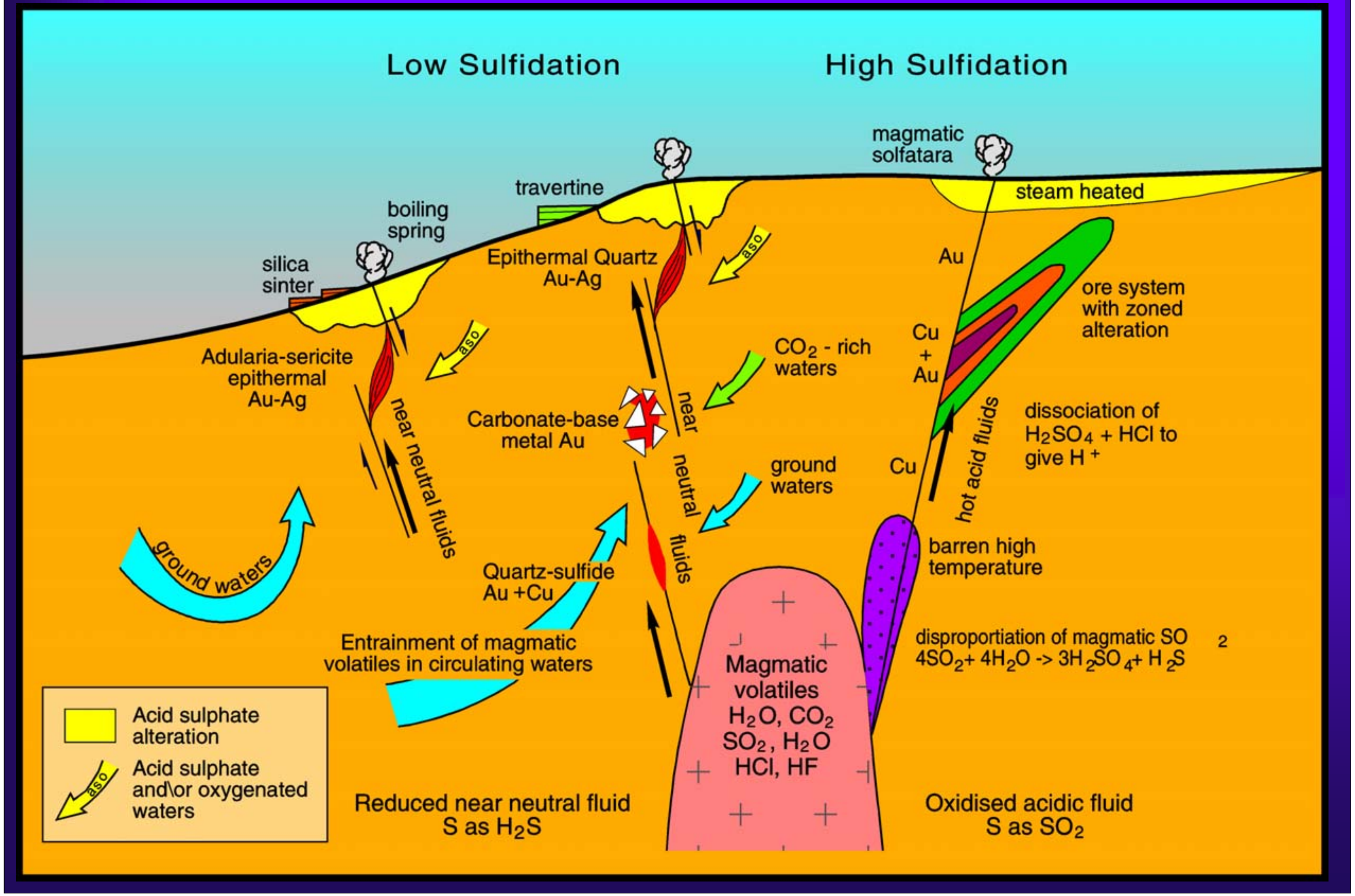
Alkaline magmatism

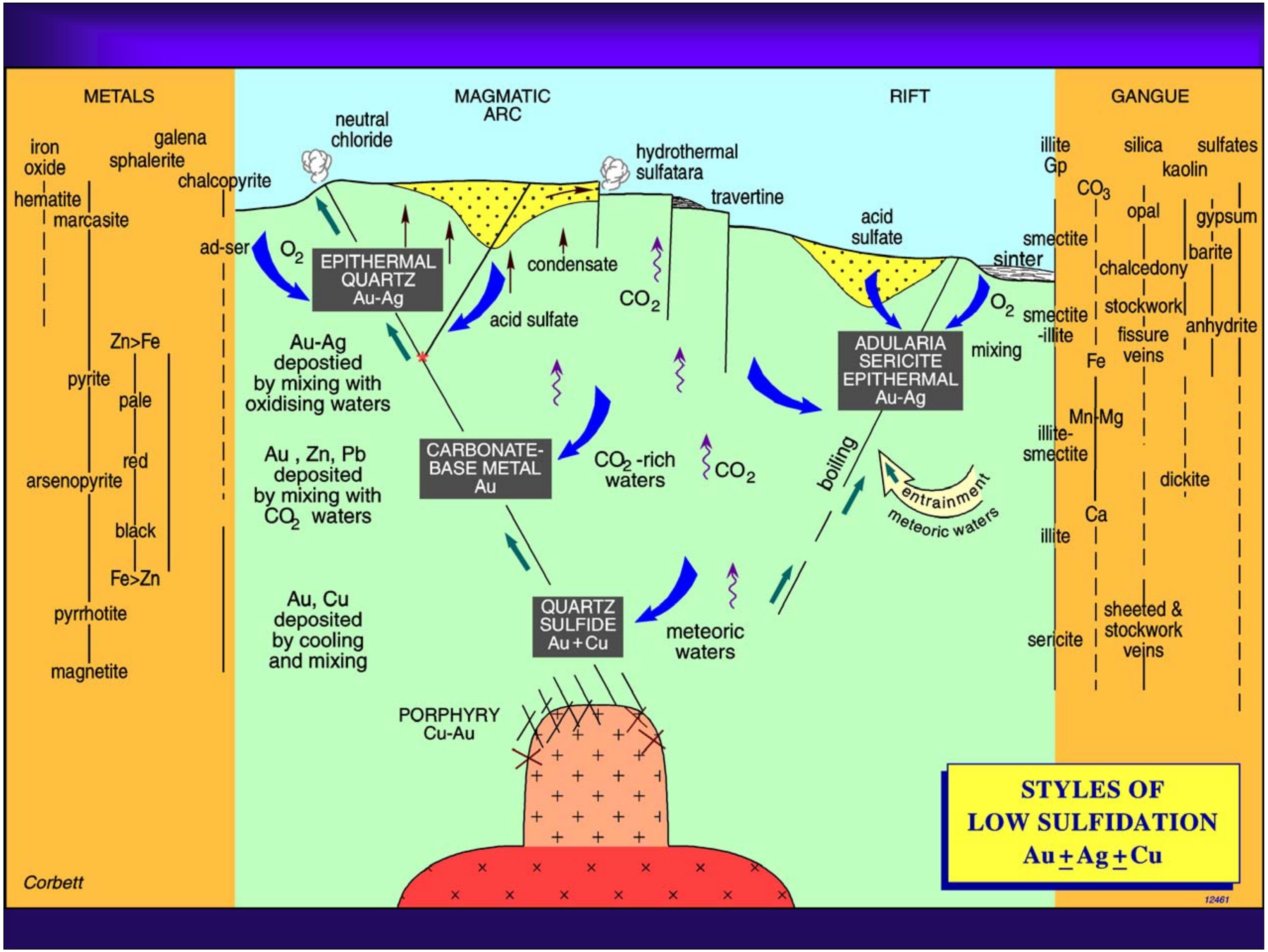

Porgera
Simberi
Lihir
Emperor
Tavatu
Subduction Zones
Spreading Centre
Fault
0 500km
1240j
Corbett

Conceptual model for Magmatic Au-Cu



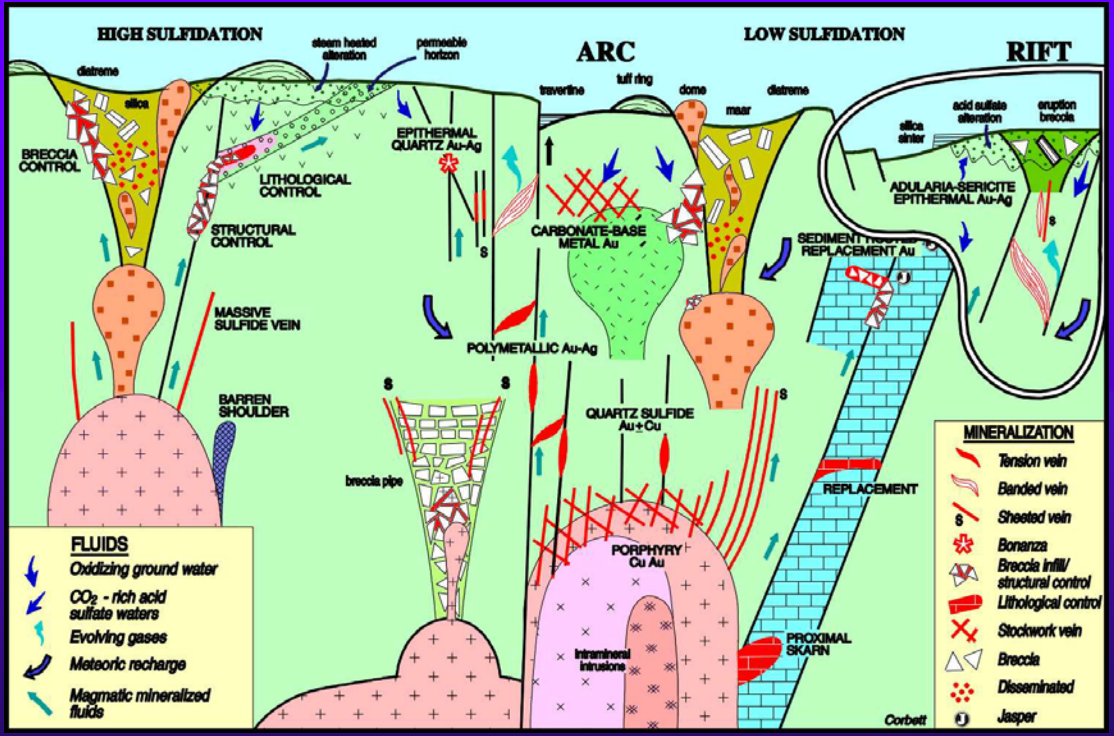
High versus Low Sulphidation





STYLES OF LOW SULFIDATION
Au ± Ag ± Cu

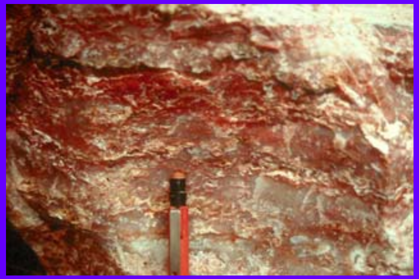
Low Sulphidation
Adularia-sericite epithermal Au-Ag



Adularia-Sericite Epithermal Gold-Silver

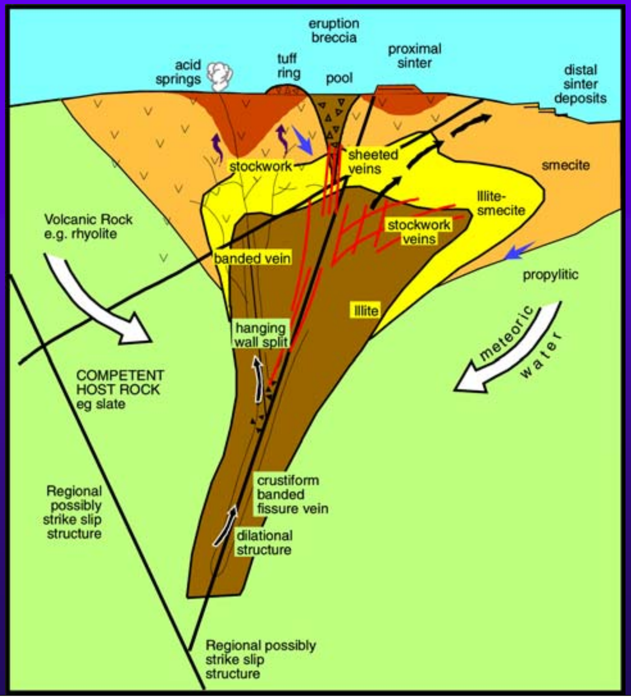
Adularia-Sericite Au-Ag Vertical Zonation

Acid Sulphate alteration
Waitapu, New Zealand



Sinter
Puhi Puhi, New Zealand

Eruption breccia
Toka Tindung, Indonesia



Sheeted veins
McLaughlan California

Banded vein
Golden Cross, NZ

Adularia-Sericite Epithermal Au-Ag

Banded quartz vein -
Golden Cross

Quartz pseudomorphing platy carbonate
-El Peñon and Vera Nancy

Quartz and adularia -
Cracow and Hishikari

Bonanza Au-Ag

Ginguro with kaolin from mixing with low Ph fluids

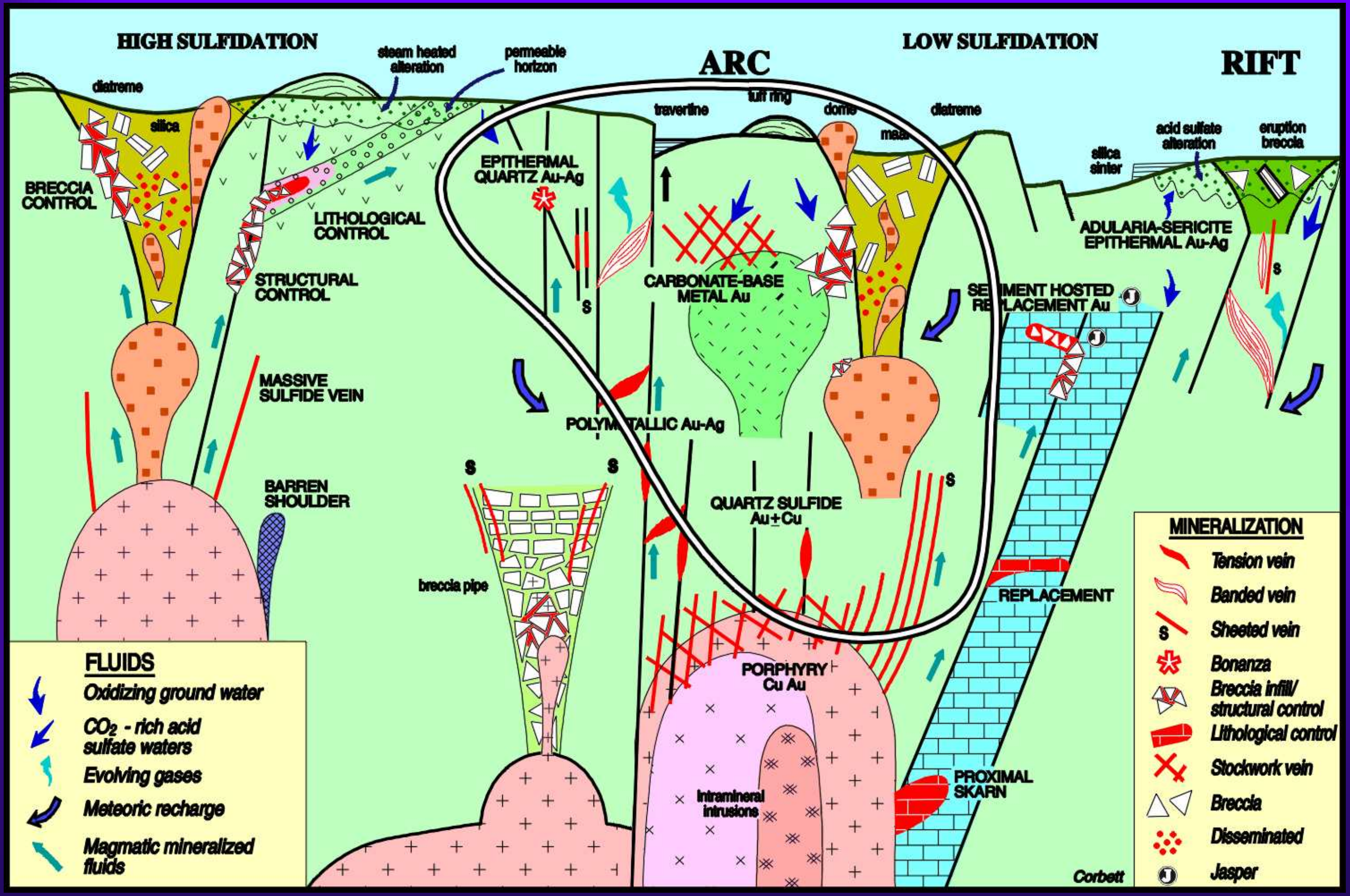
Patagonia

Au-Ag Ore
Yamada Deposit, Hishikari Mine
Au: 948g/t, Ag: 3,720g/t
Sumitomo Metal Mining Co., Ltd.

Hishikari, Japan

Ginguro with hypogene haematite and jarosite from mixing with oxygenated groundwaters

Conceptual Model for Styles of Epithermal Gold-Silver and Porphyry Copper Mineralisation



Quartz-sulphide gold ± copper

Bilimoia, PNG

Rawas, Indonesia

Kelian, Indonesia

Jacks Hut Lode, Mineral Hill, NSW

Ladolam Gold Deposit

Lihir Island, Papua New Guinea

Offshore seismic

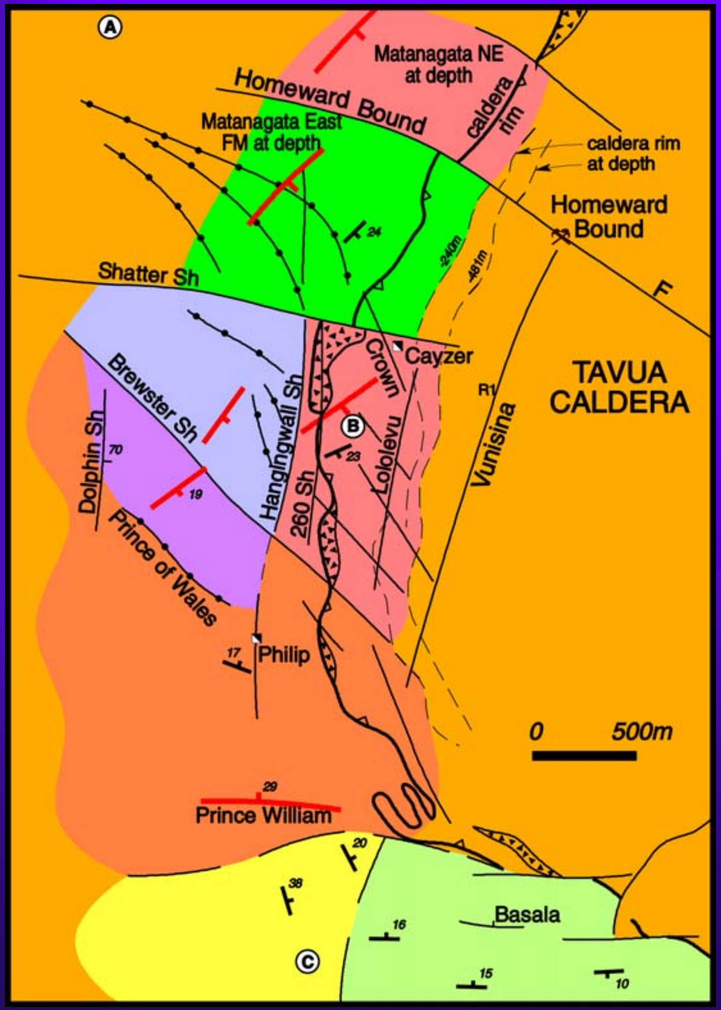
Luise Caldera 1984

Sulphide filled structure 20 g/t Au

Porphyry gold mineralisation 3g/t Au

Lithological permeability 13g/t Au

Emperor Gold Mine

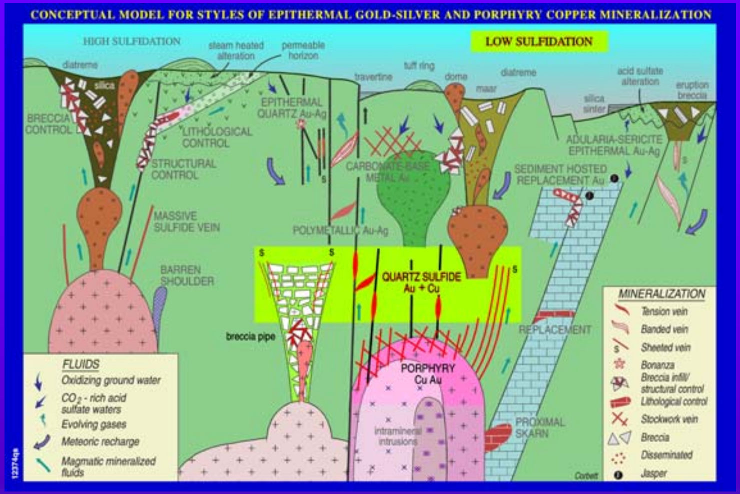


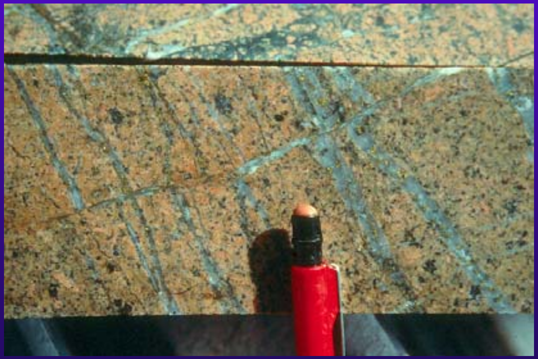
Tavua Caldera

Matanagata Flatmake

Transition to porphyry Cu-Au

Maricunga Belt, Chile

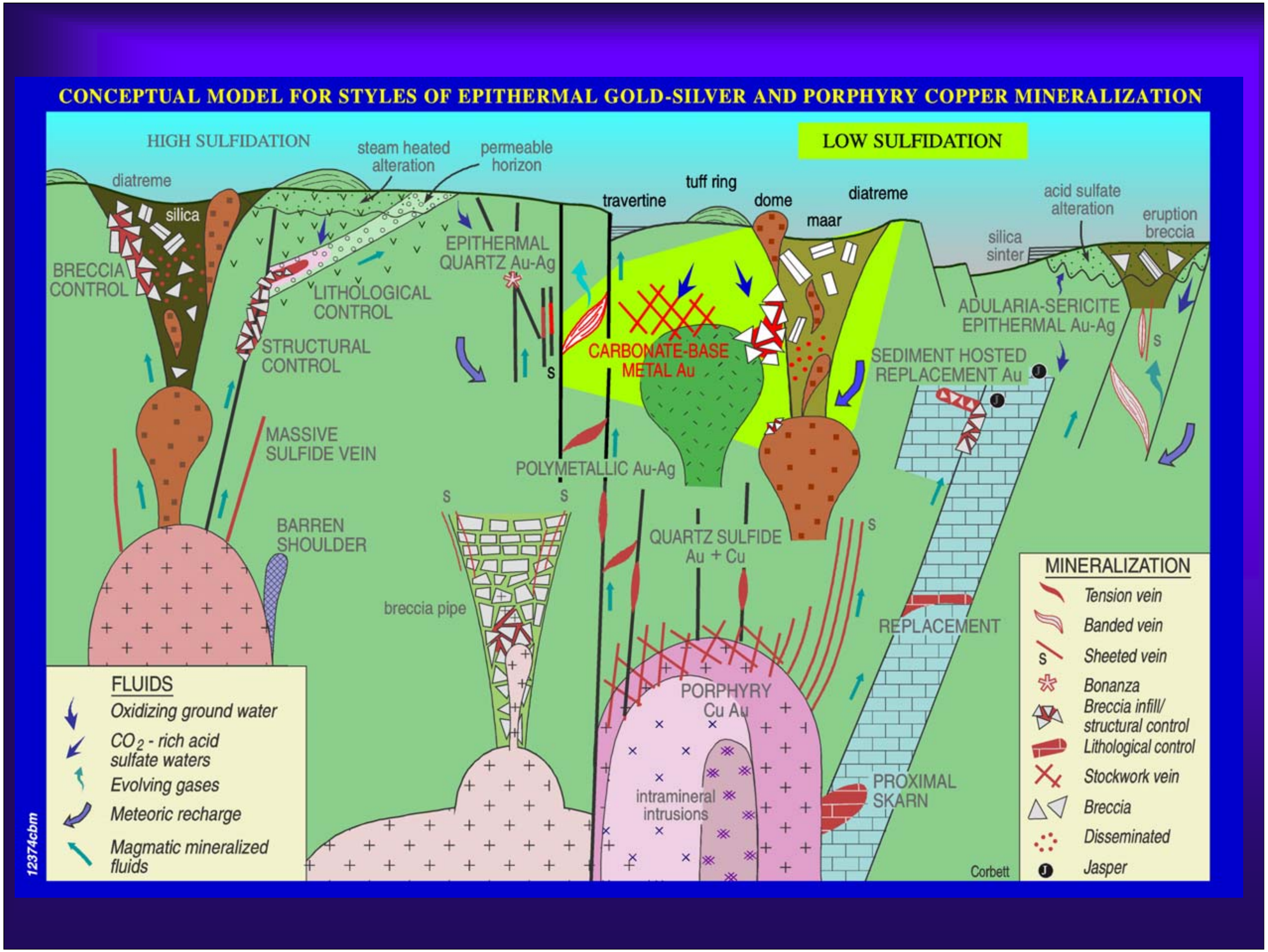




Cadia,Australia

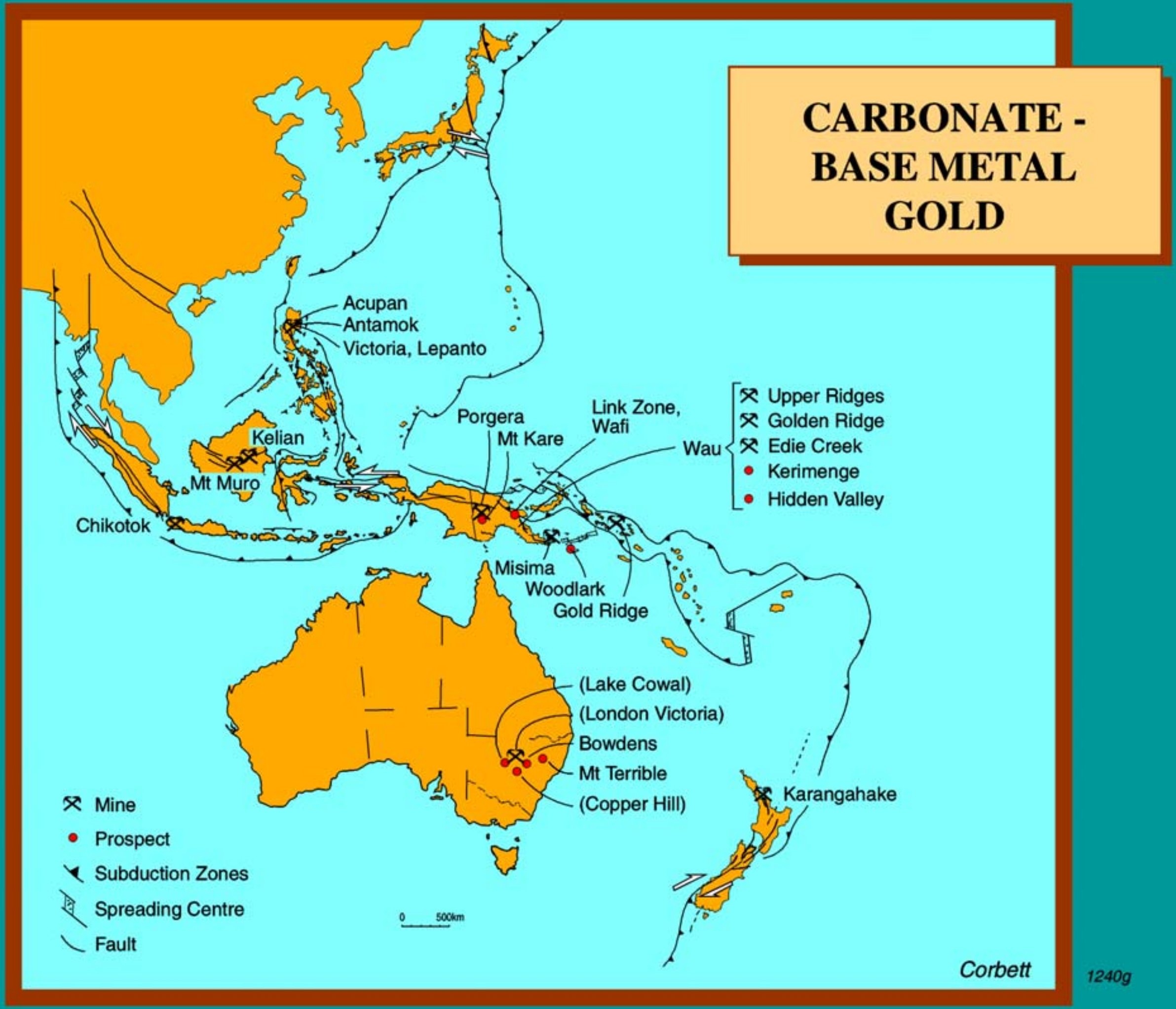
D vein

Quartz-sulphide Au
La Arena, Peru

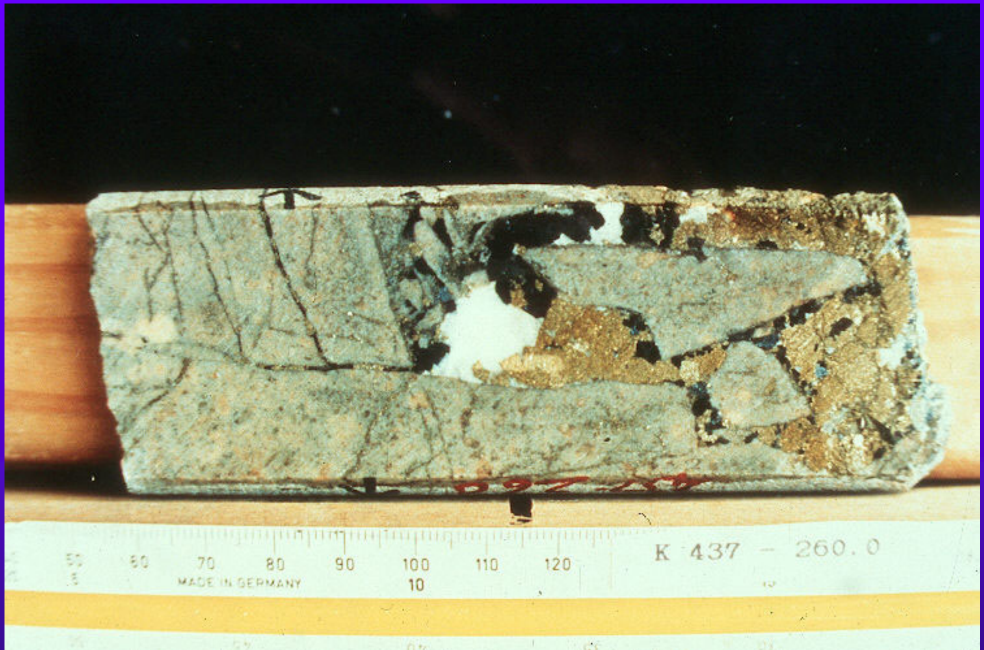


CONCEPTUAL MODEL FOR STYLES OF EPITHERMAL GOLD-SILVER AND PORPHYRY COPPER MINERALIZATION

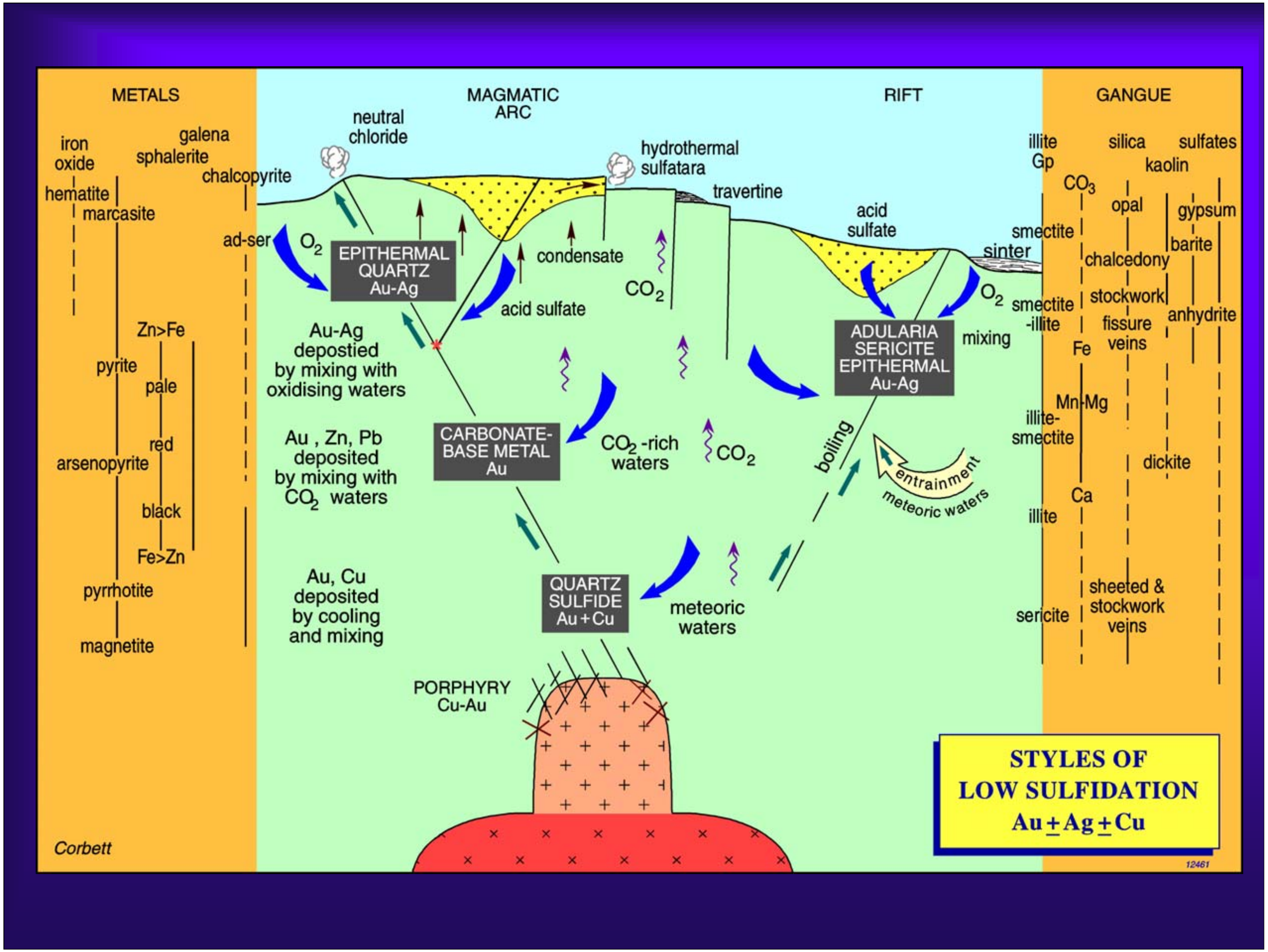
CARBONATE - BASE METAL GOLD



CBM - mineralogy



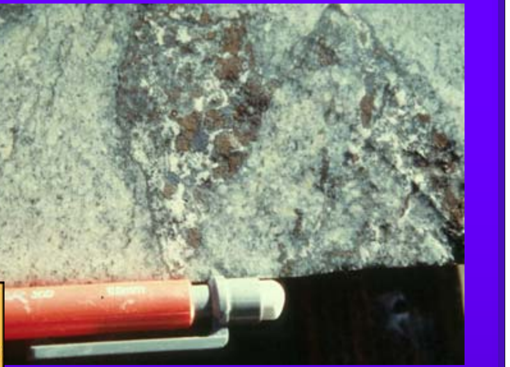
Kelian Indonesia



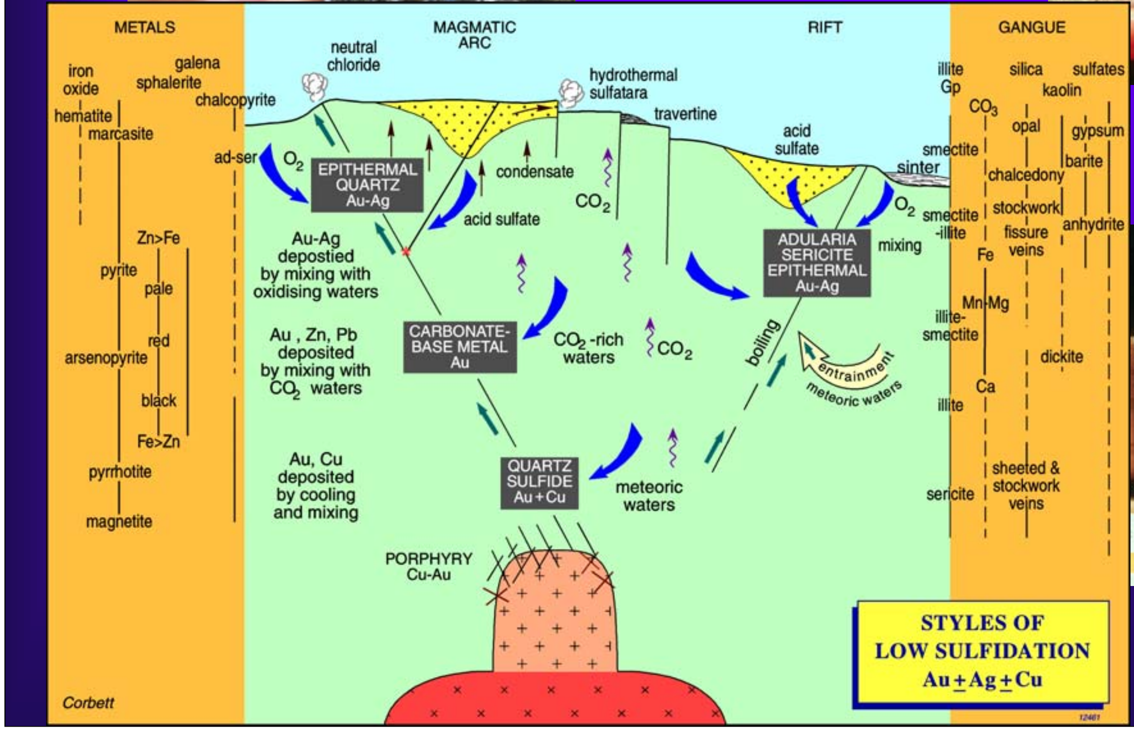
STYLES OF LOW SULFIDATION Au$\pm$Ag$\pm$Cu

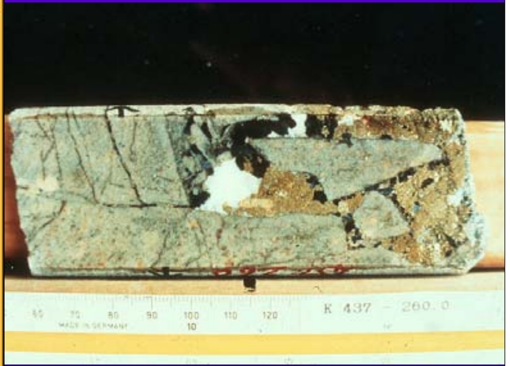
CBM - sphalerite zonation

Caylloma, Peru



Bowdens, Australia



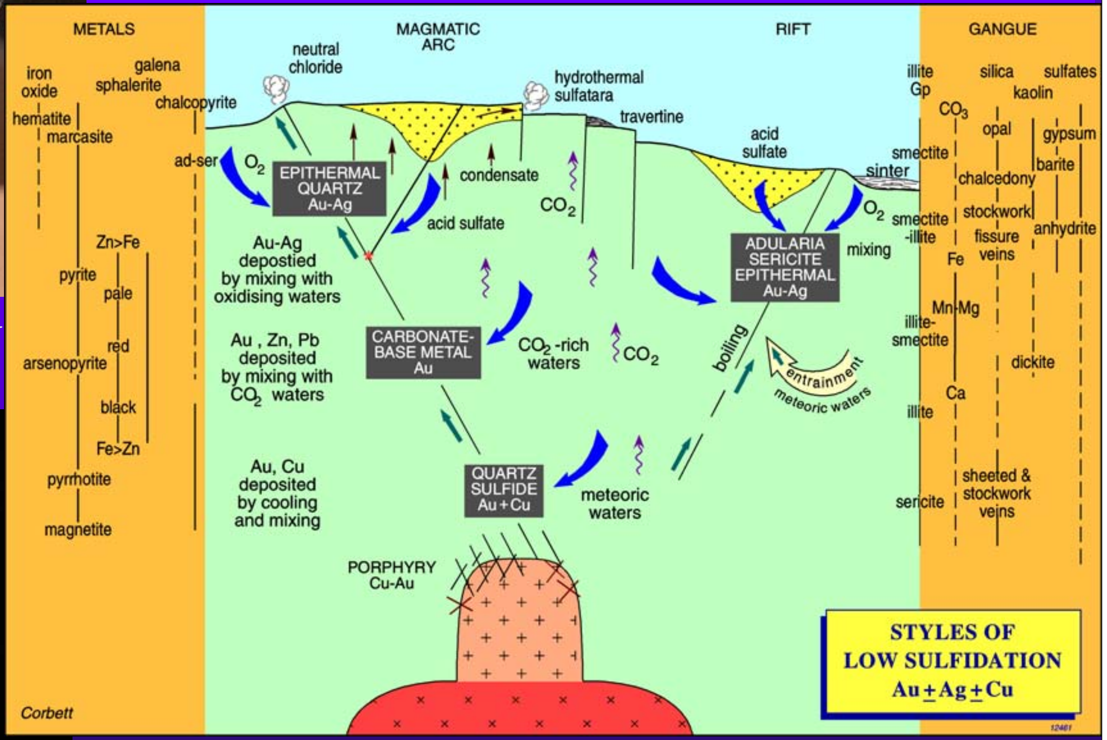


Kelian, Indonesia

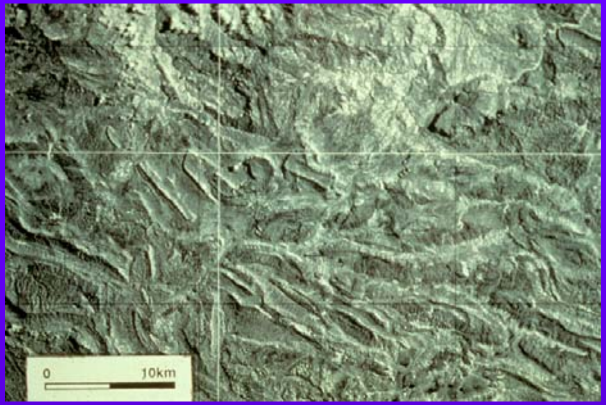
CBM – carbonate types

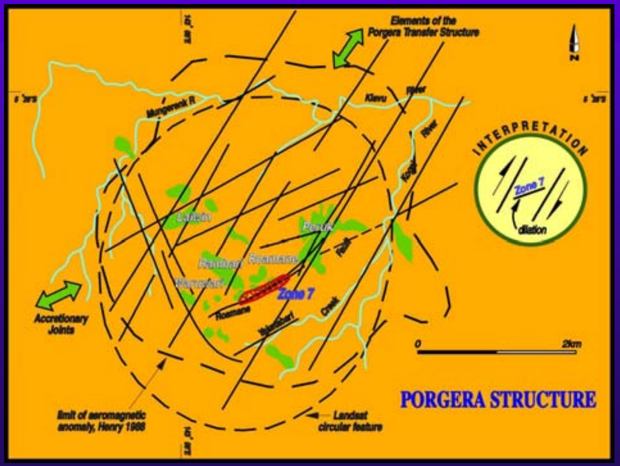
Upper Ridges, Wau, PNG

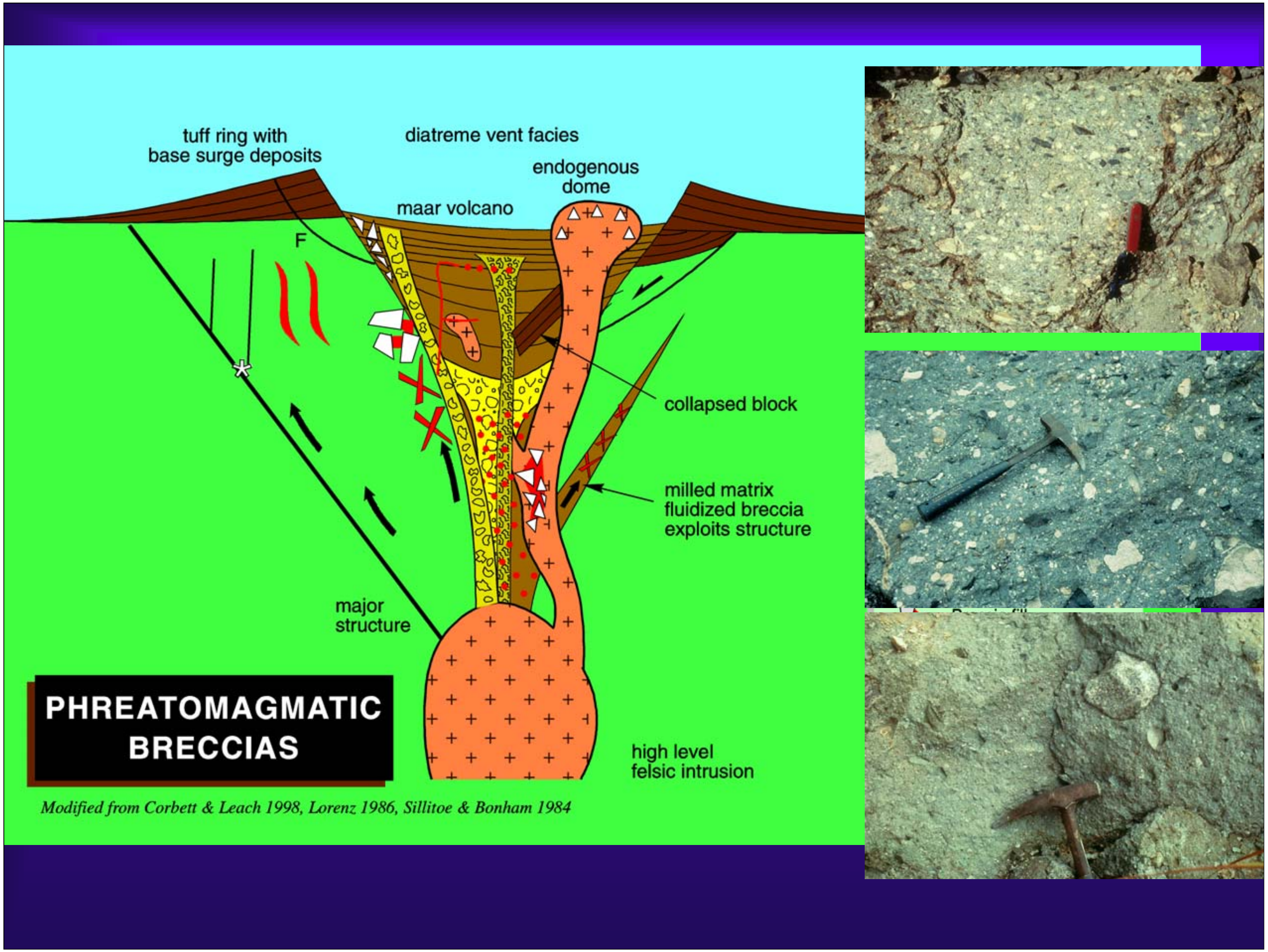
Mt Kare, PNG



Porgera


0
10km

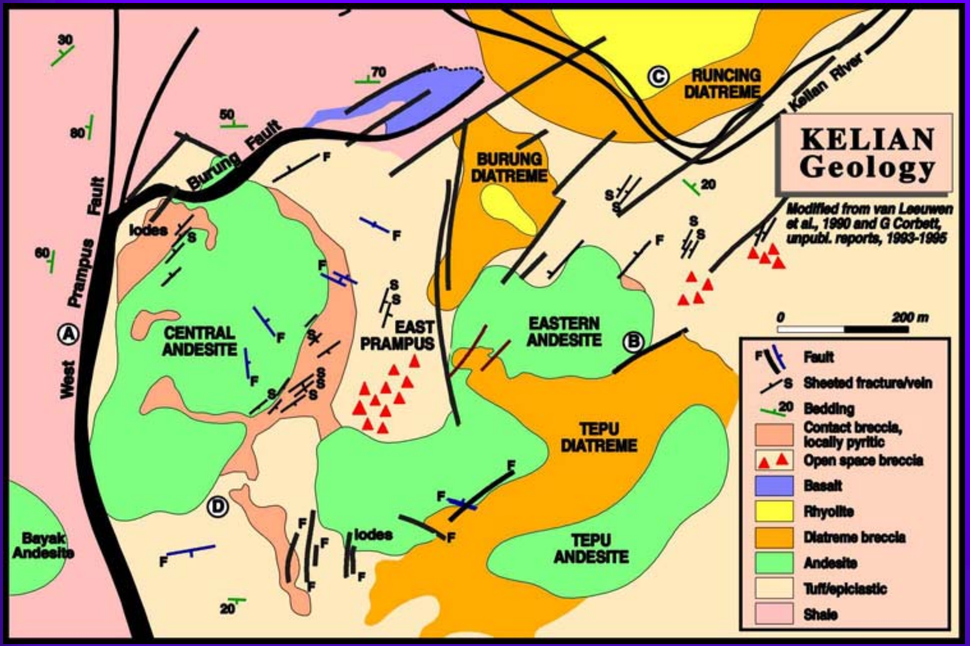

Elements of the Porgera Transfer Structure
Mungarenk R
Klavu River
Kogai River
INTERPRETATION
Zone 7
dilation
Waruwari
Roamane
Zone 7
Roamane
Yakatabari Creek
Fault
Accretionary Joints
0
2km
PORGERA STRUCTURE
limit of aeromagnetic anomaly, Henry 1988
Landsat circular feature

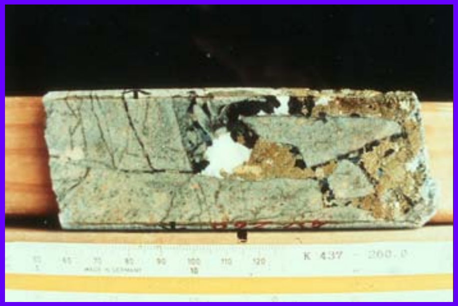


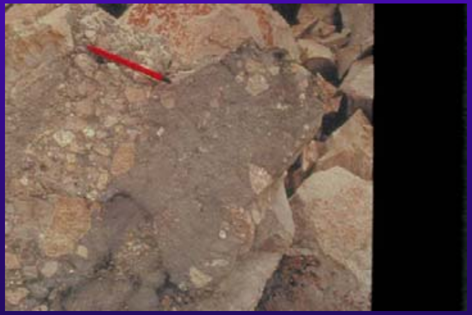
PHREATOMAGMATIC BRECCIAS

Modified from Corbett & Leach 1998, Lorenz 1986, Sillitoe & Bonham 1984

Kelian

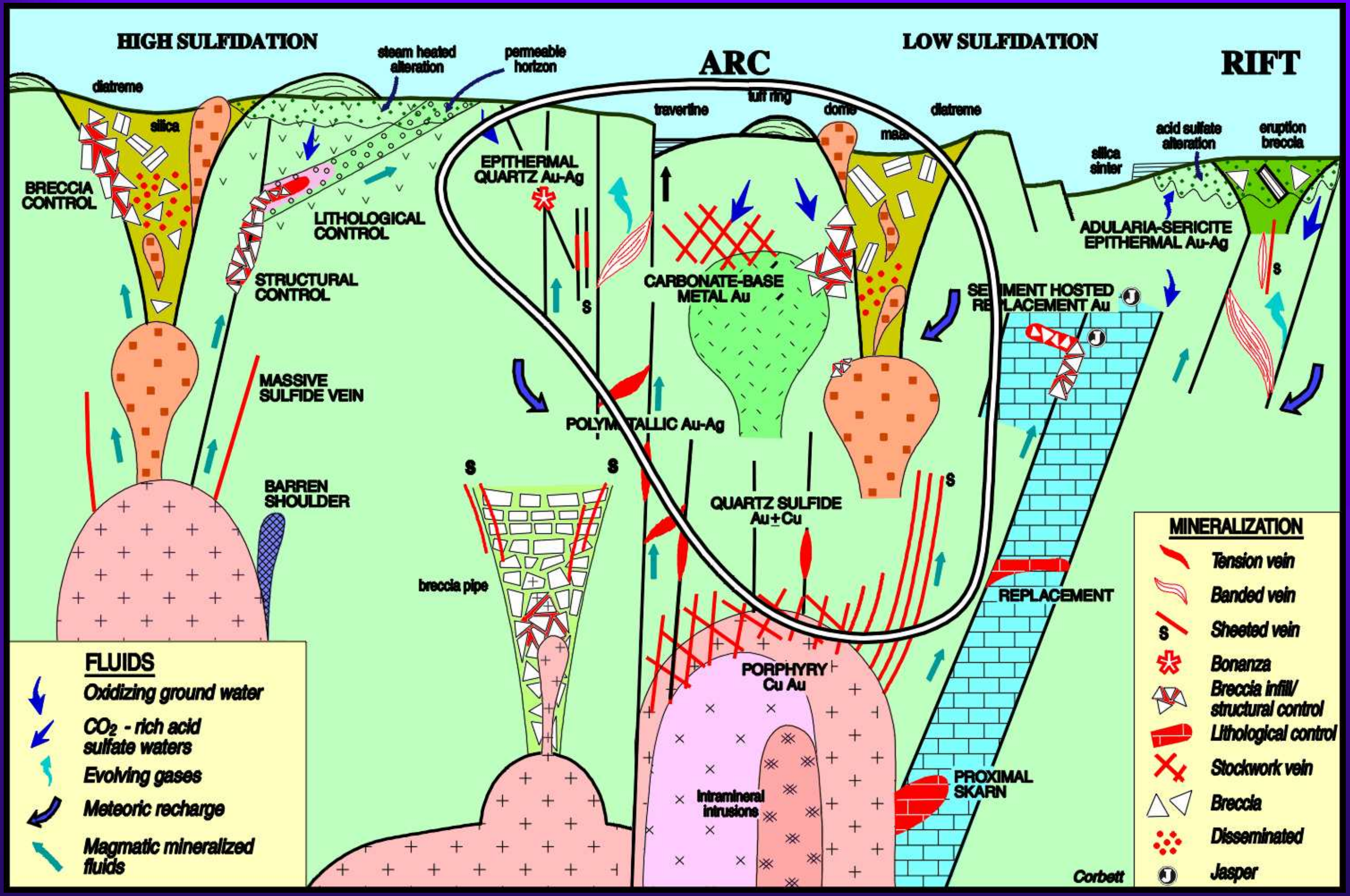






Sheeted veins at depth pass upwards to open space breccia

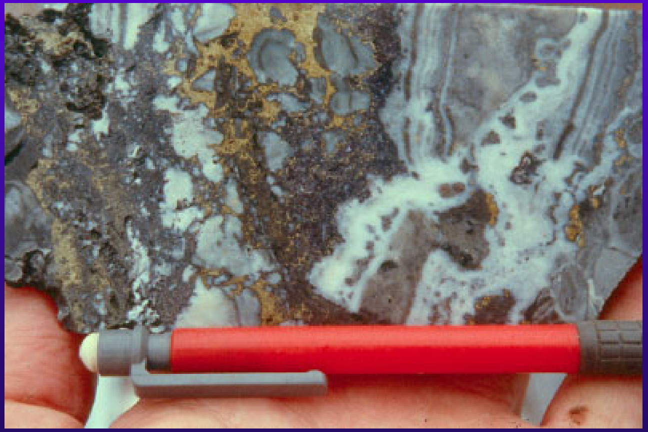
Conceptual Model for Styles of Epithermal Gold-Silver and Porphyry Copper Mineralisation



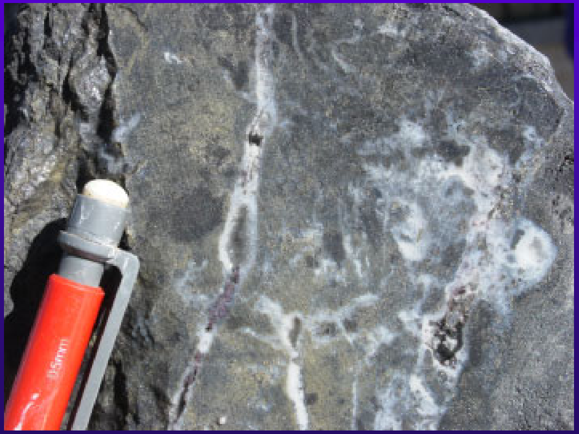
Polymetallic Au-Ag

Hadleigh Castle, Queensland

Caylloma, Peru



Parkers, Mineral Hill, NSW



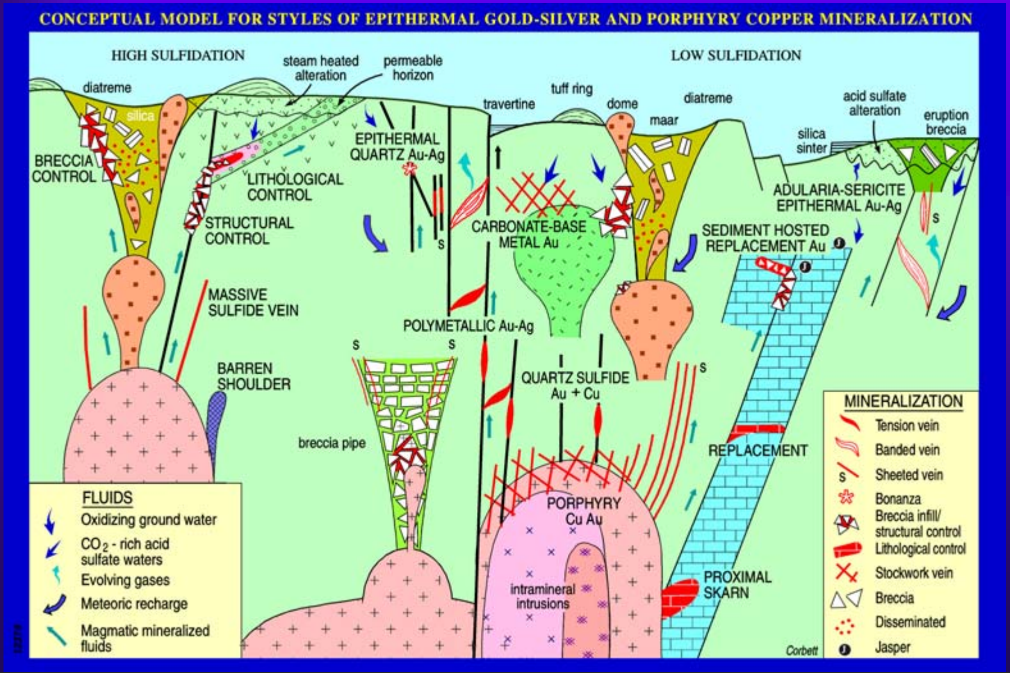
Arcata, Peru

Polymetallic Au-Ag

Banded Adularia-sericite versus Polymetallic

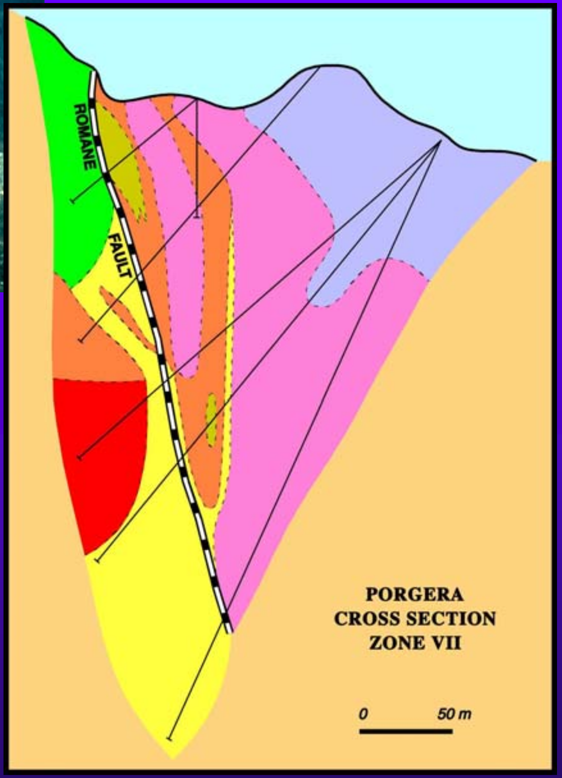
Golden Cross, NZ,
Adularia-Sericite

Peru, Polymetallic Veins

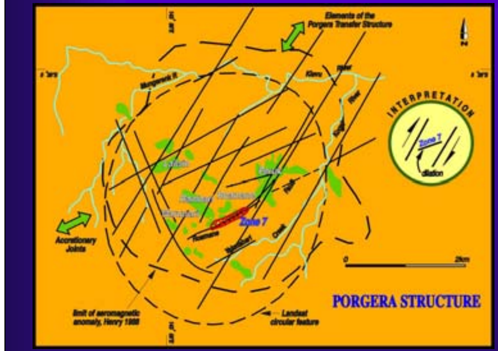


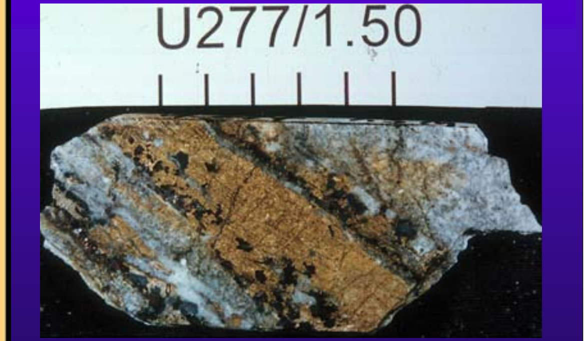
Epithermal Quartz Au-Ag

Porgera Zone VII



Bonanza gold

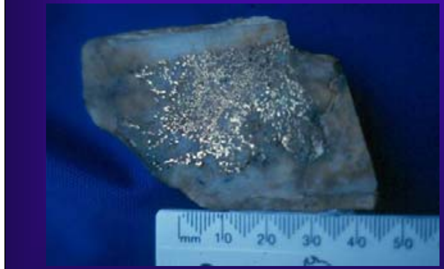




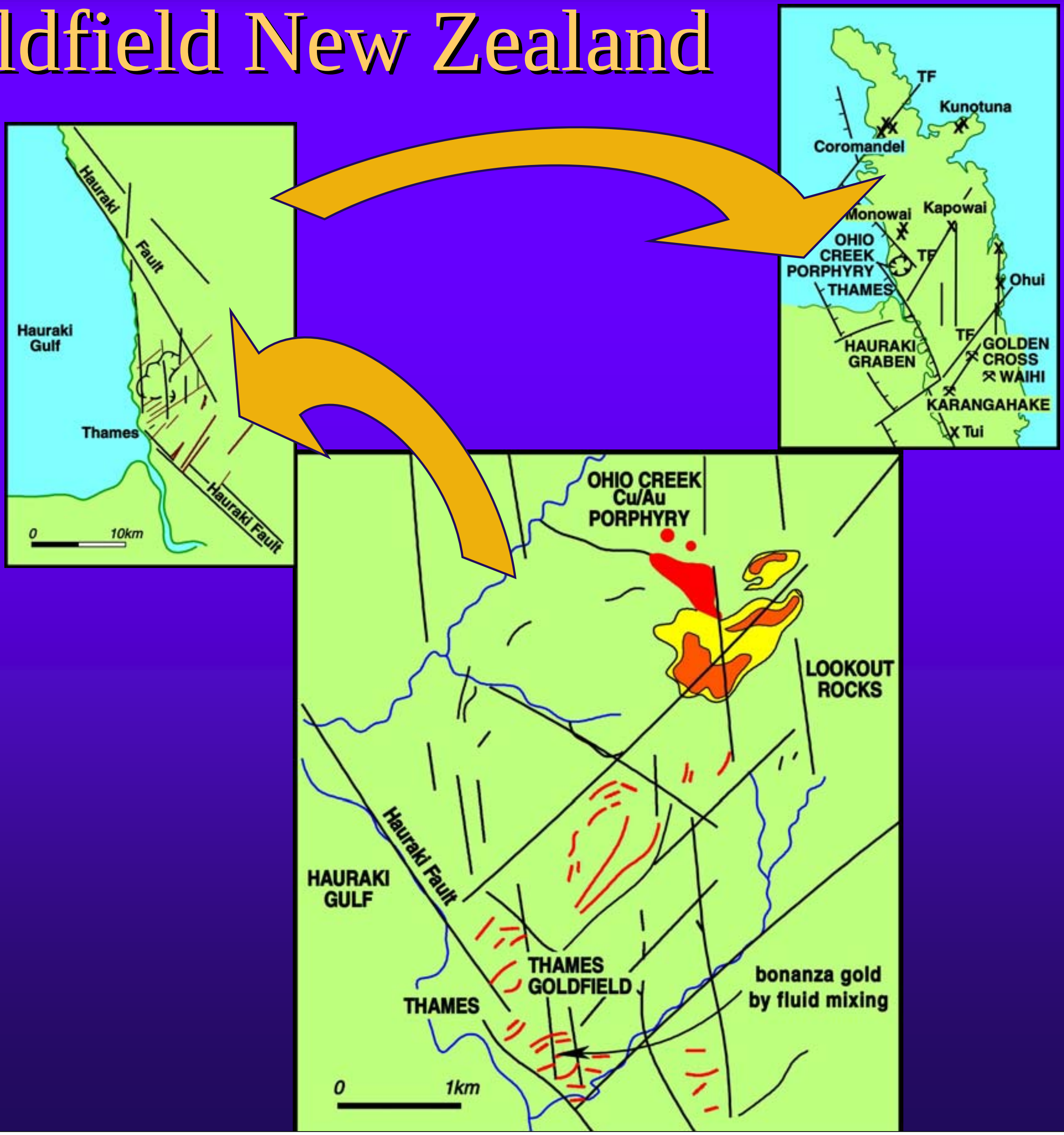
Thames Goldfield New Zealand

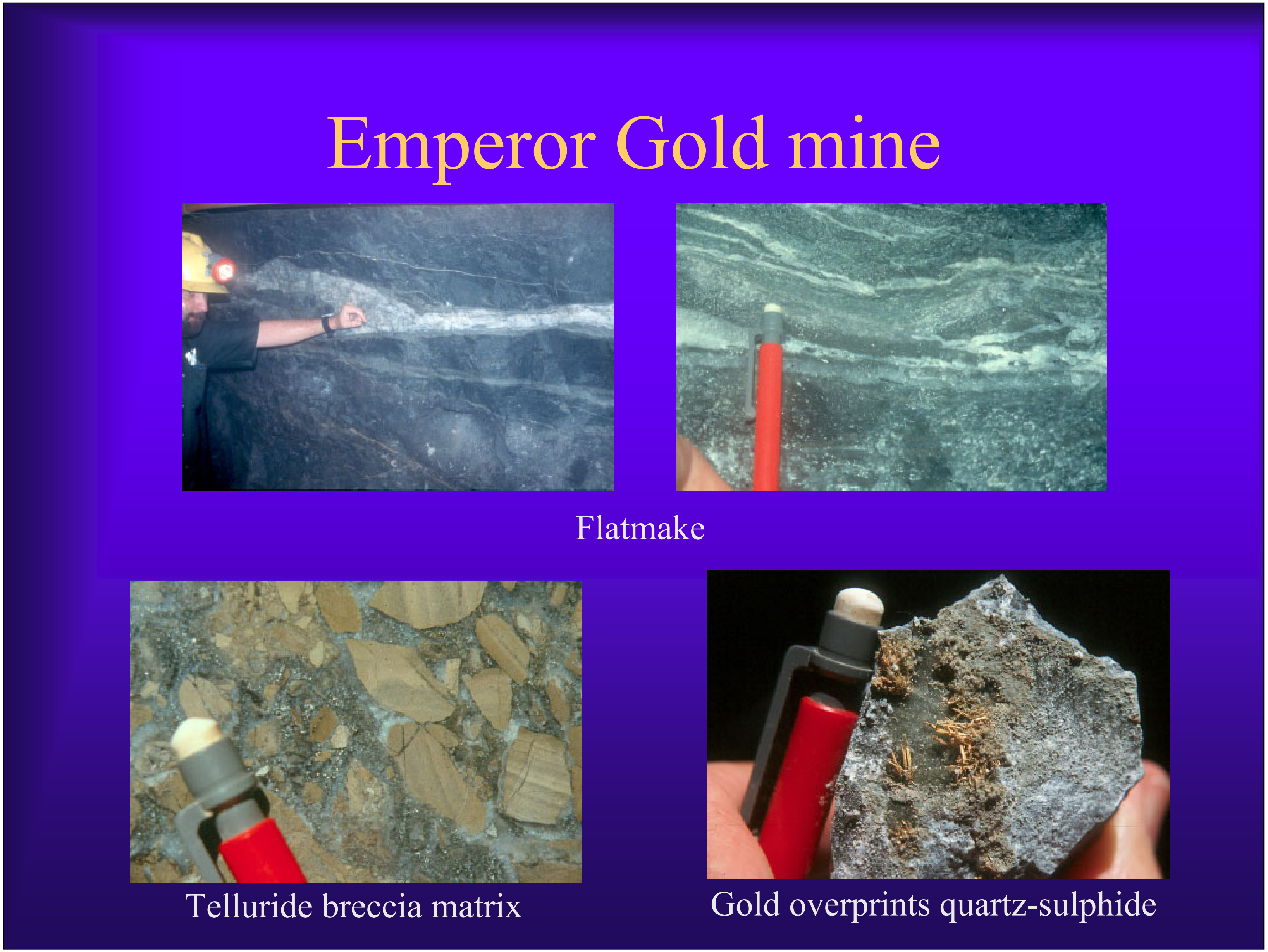
Quartz reefs and faults

Quartz vein breccia



Bonanza gold





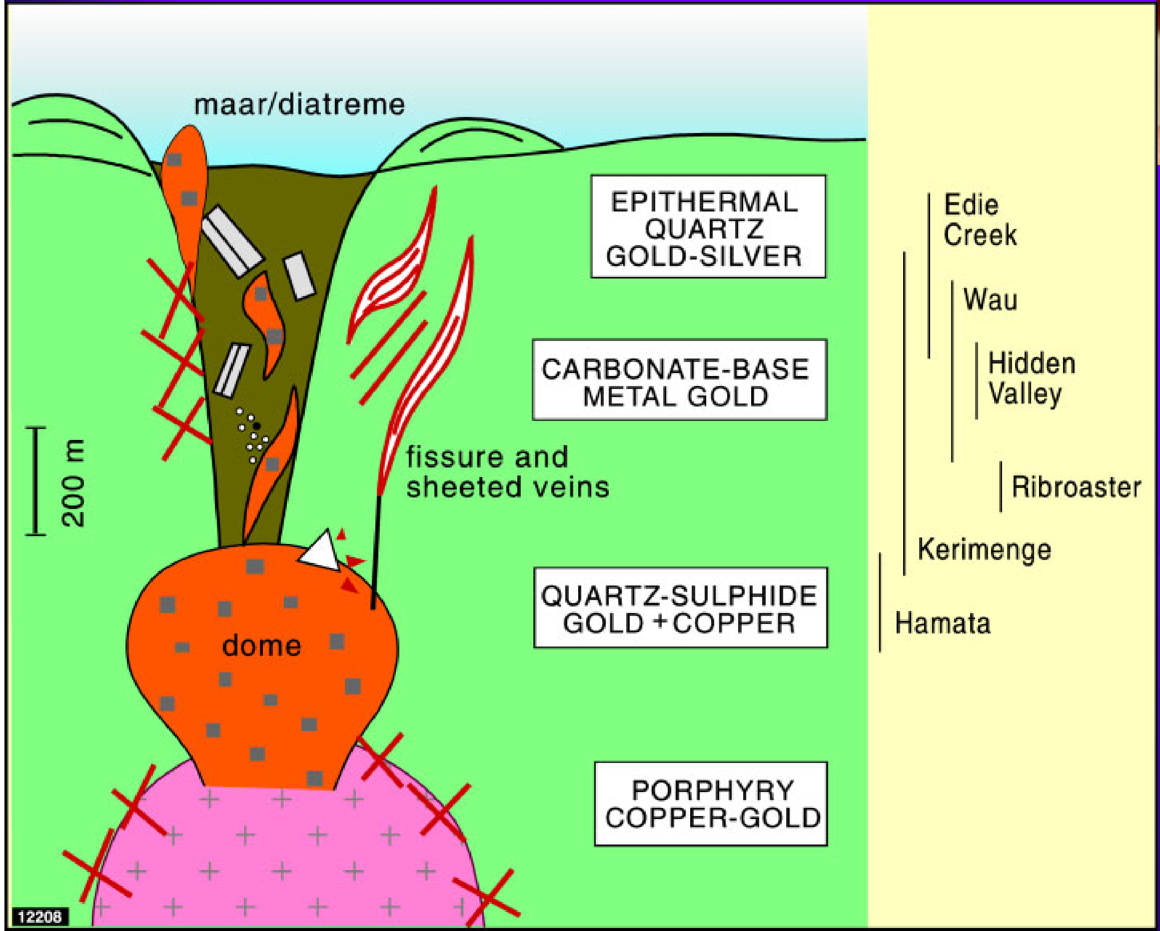
Emperor Gold mine

Flatmake

Telluride breccia matrix

Gold overprints quartz-sulphide

Edie Creek

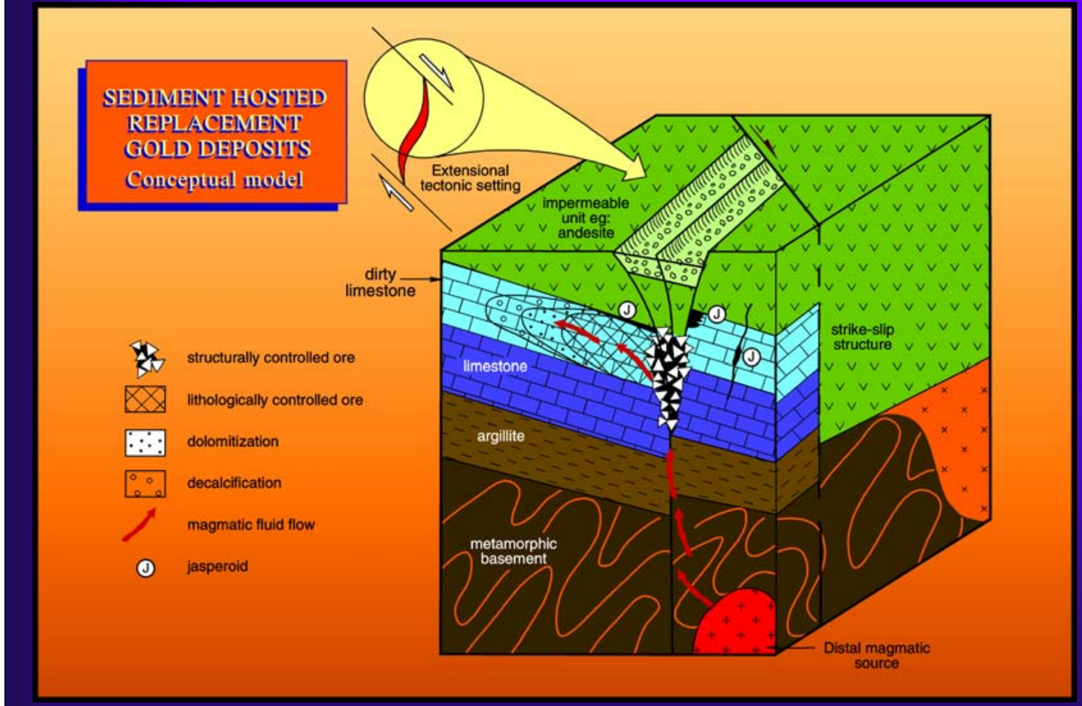


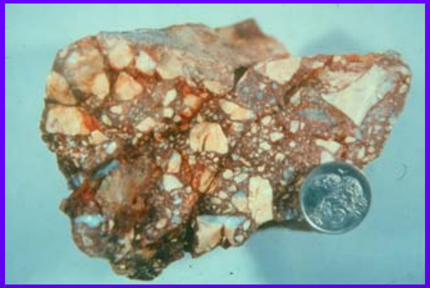

Edie Creek

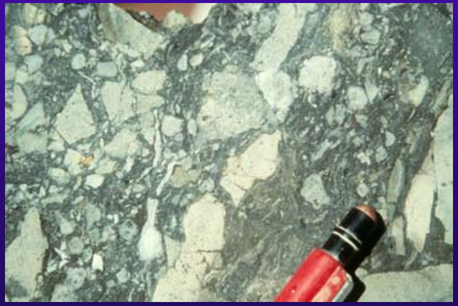

Upper Ridges, Wau


Hamata

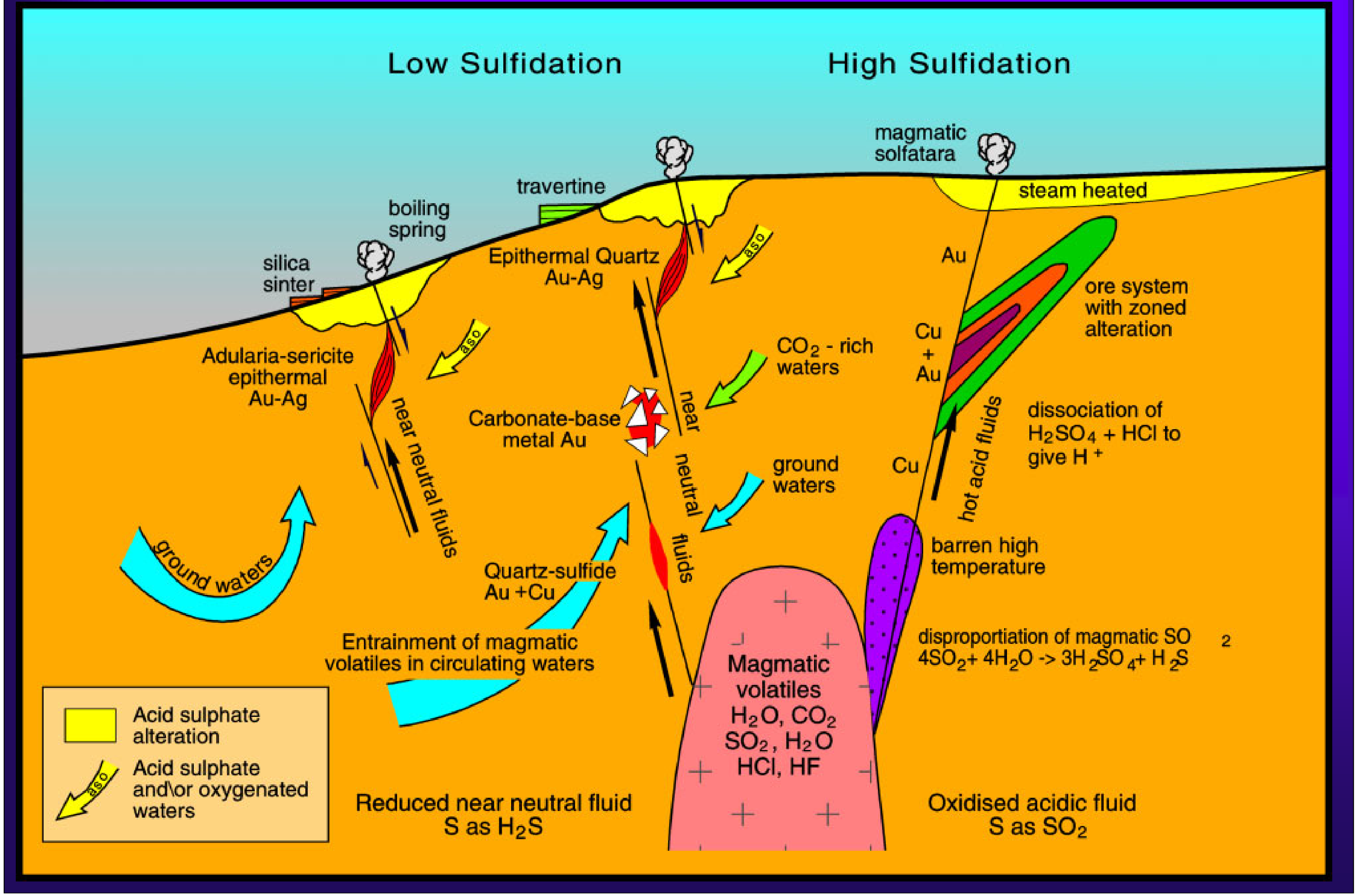
Sediment Hosted Replacement Gold Structural and Lithological Control







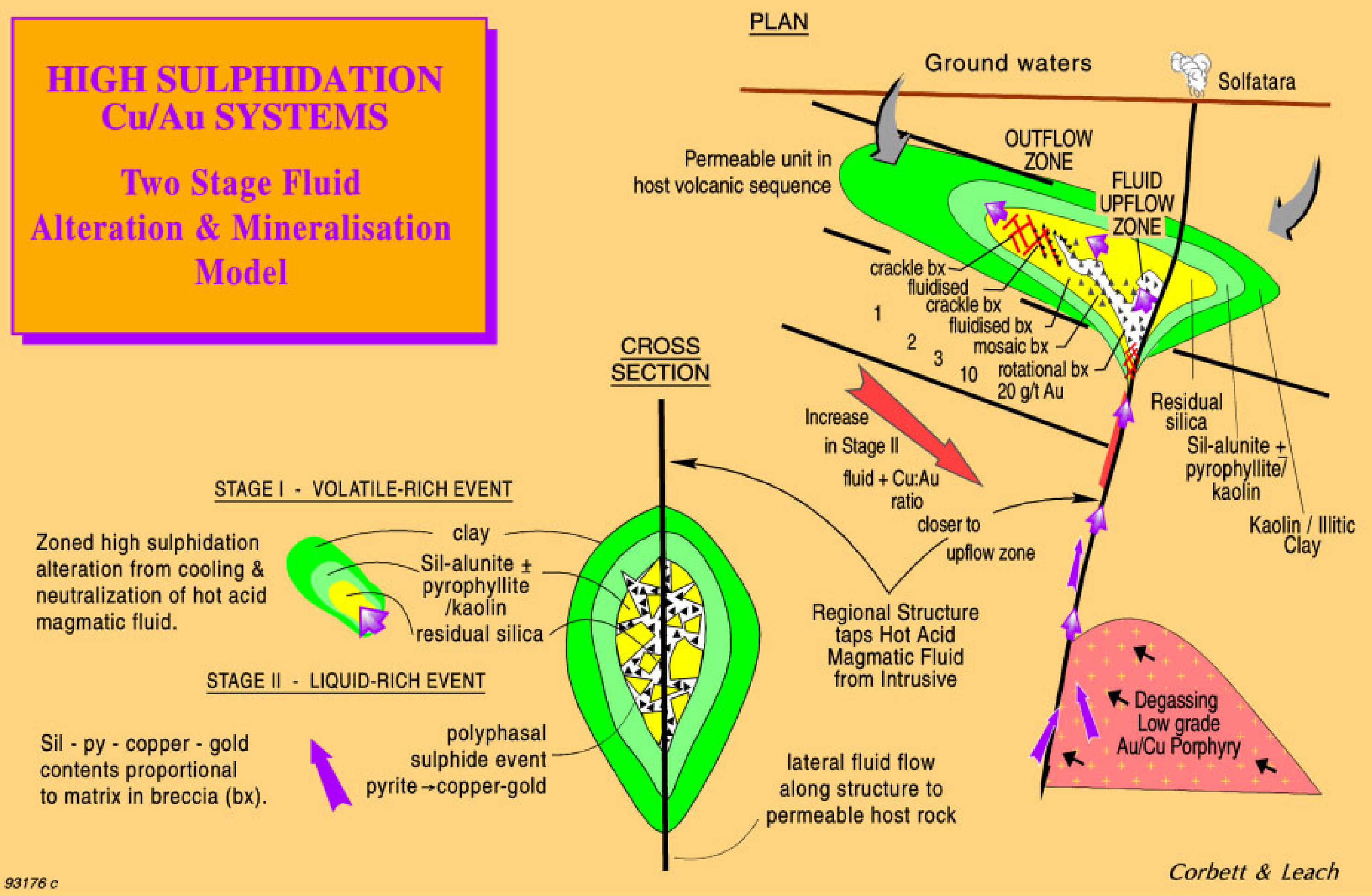
High versus Low Sulphidation



Two phase fluid flow model

HIGH SULPHIDATION
Cu/Au SYSTEMS

Two Stage Fluid
Alteration & Mineralisation
Model



Zoned high sulphidation alteration from cooling & neutralization of hot acid magmatic fluid.

Sil - py - copper - gold contents proportional to matrix in breccia (bx).

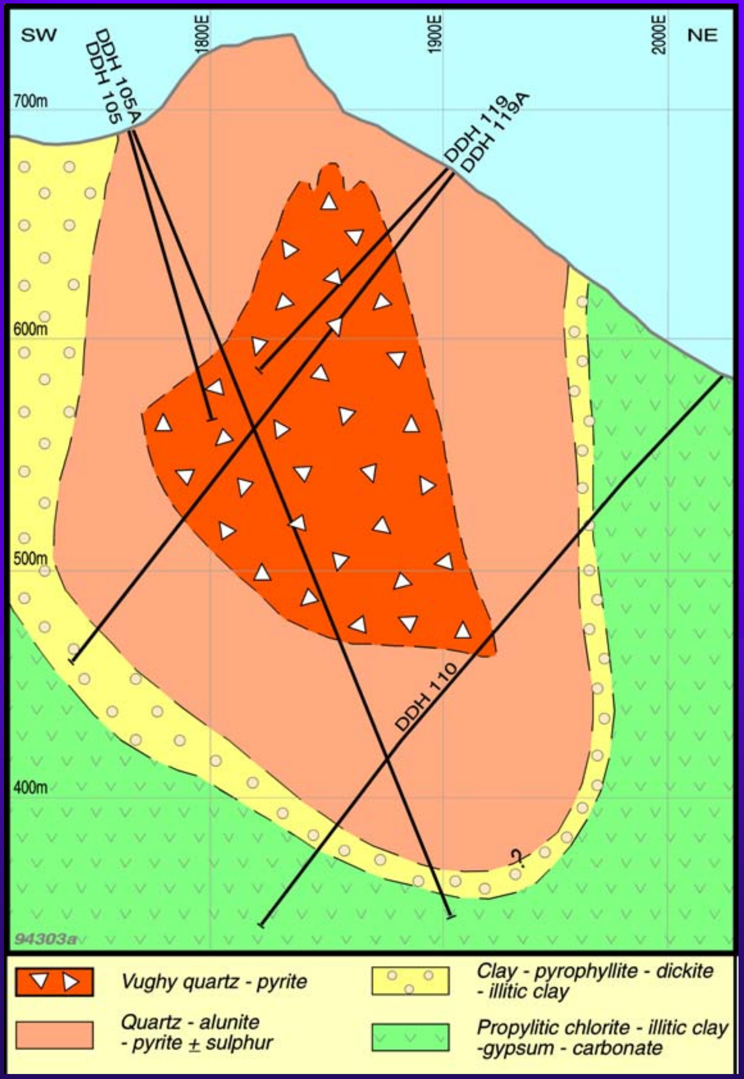
Zoned acid alteration

Del Carmen, Argentina

El Indio, Chile

Sappes, Greece

Alteration cross section - Nena



Mineralization

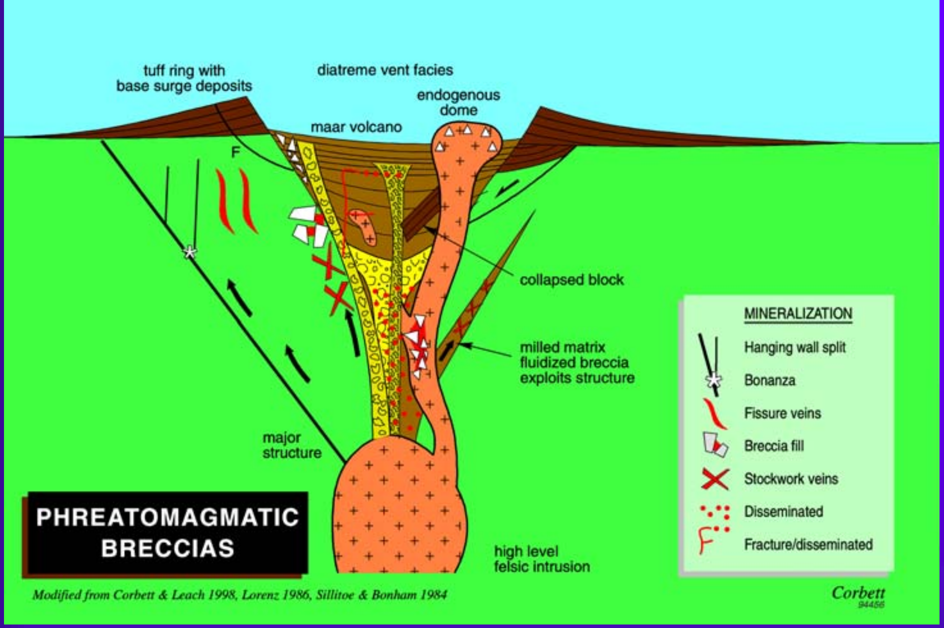
Mt Kasi, Fiji

El Indio, Chile

Maragorik, PNG

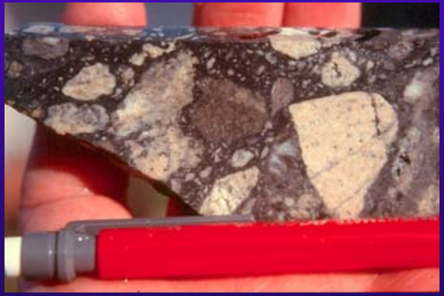
Yanacocha, Peru

Breccia



Modified from Corbett & Leach 1998, Lorenz 1986, Sillitoe & Bonham 1984

Pascua, Chile



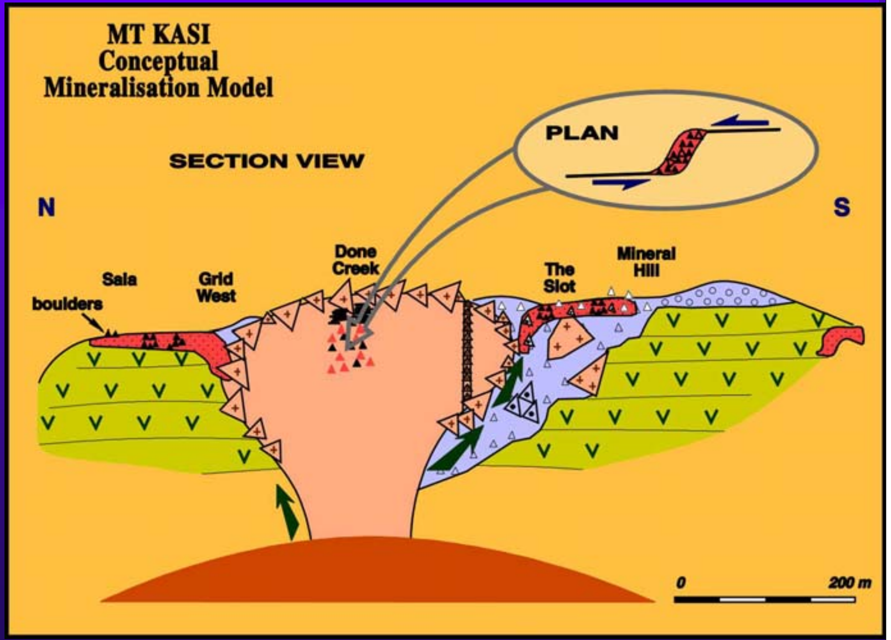
Lepanto, Phillipines

Yanacocha, Peru

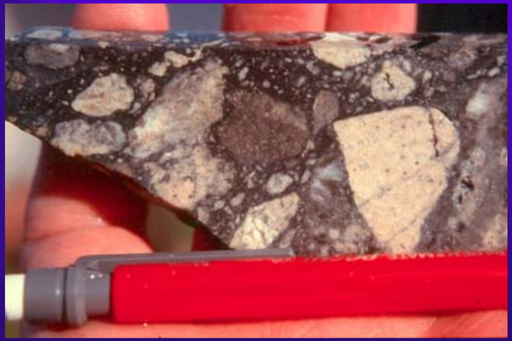
Veladero, Argentina

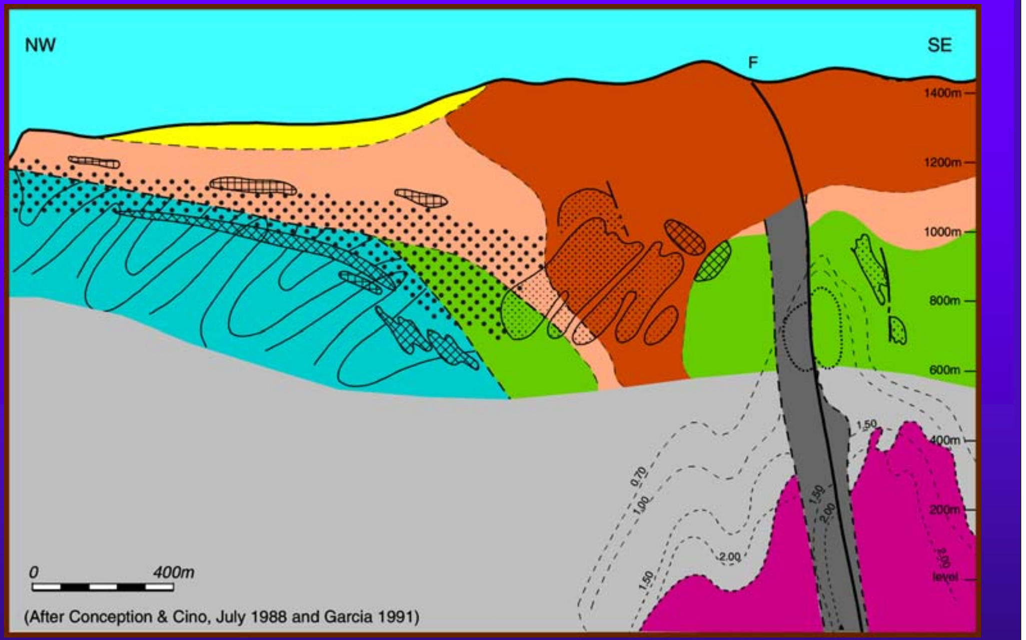
High Sulphidation Cu-Au±Ag

Mt Kasi – Dome Association



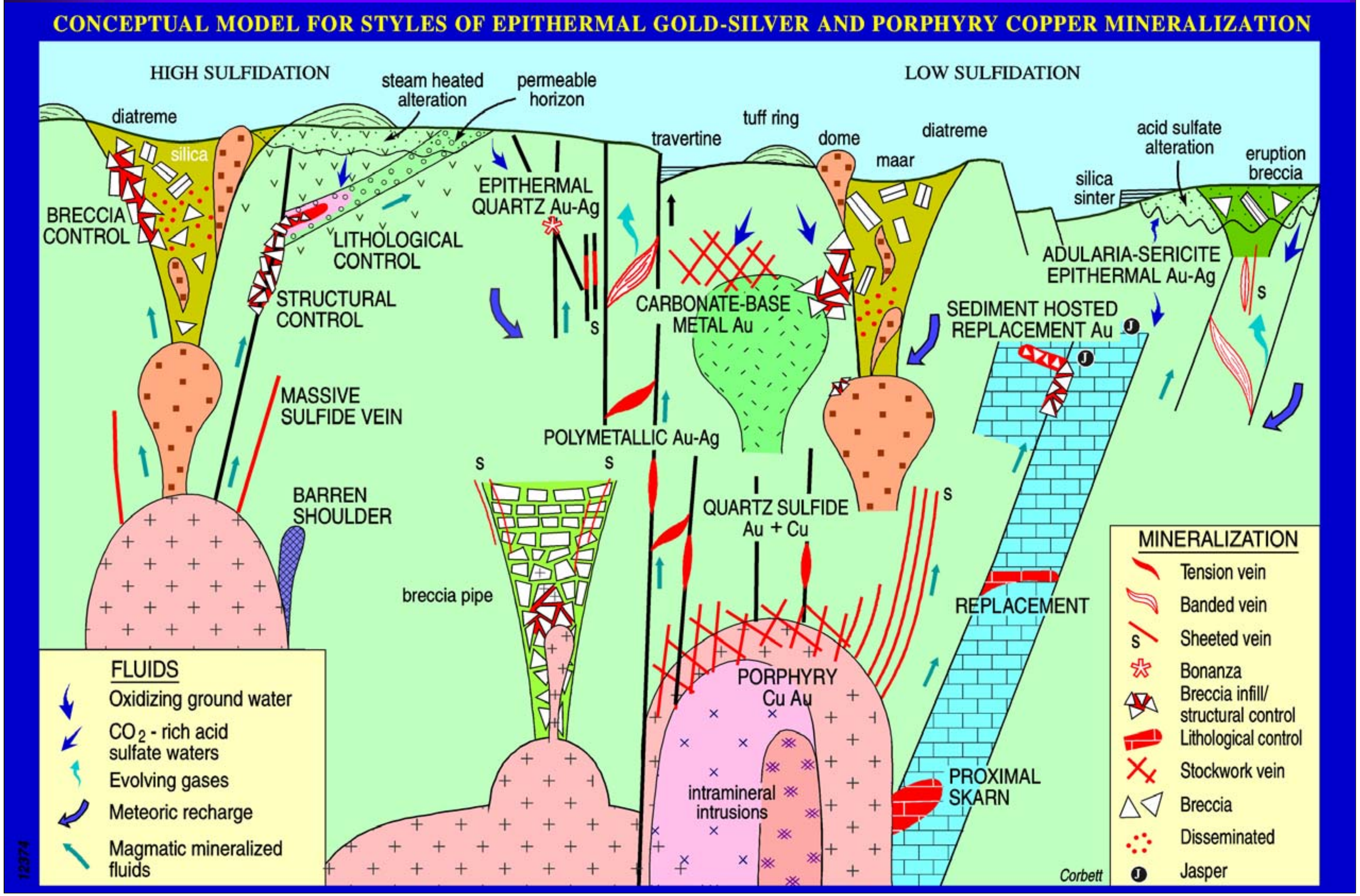
Lepanto





(After Conception & Cino, July 1988 and Garcia 1991)

Conclusion


CONCEPTUAL MODEL FOR STYLES OF EPITHERMAL GOLD-SILVER AND PORPHYRY COPPER MINERALIZATION