

High Sulphidation Epithermal Deposits



Presented By:

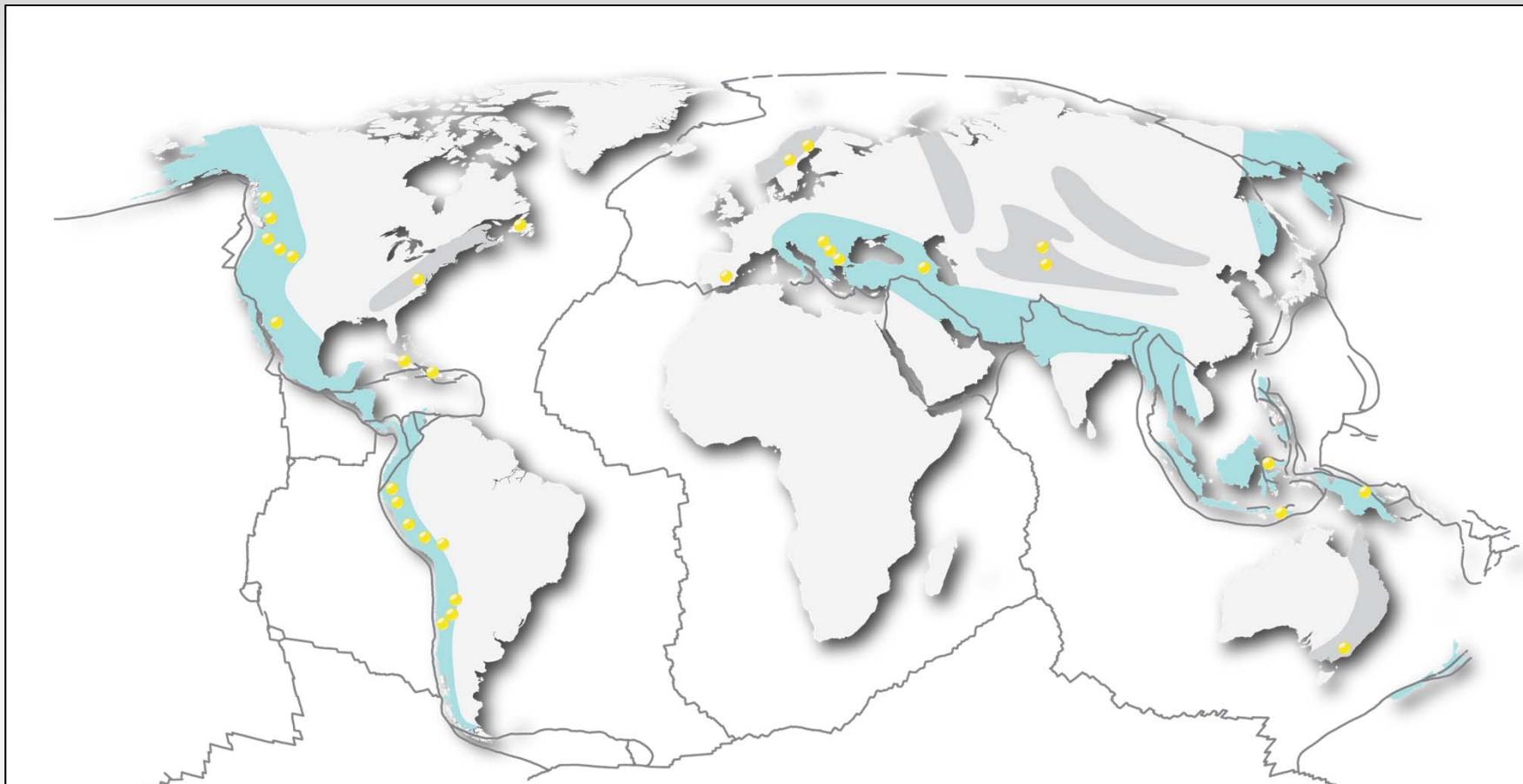
Chris Wilson and Andrew Tunningley
Exploration Alliance



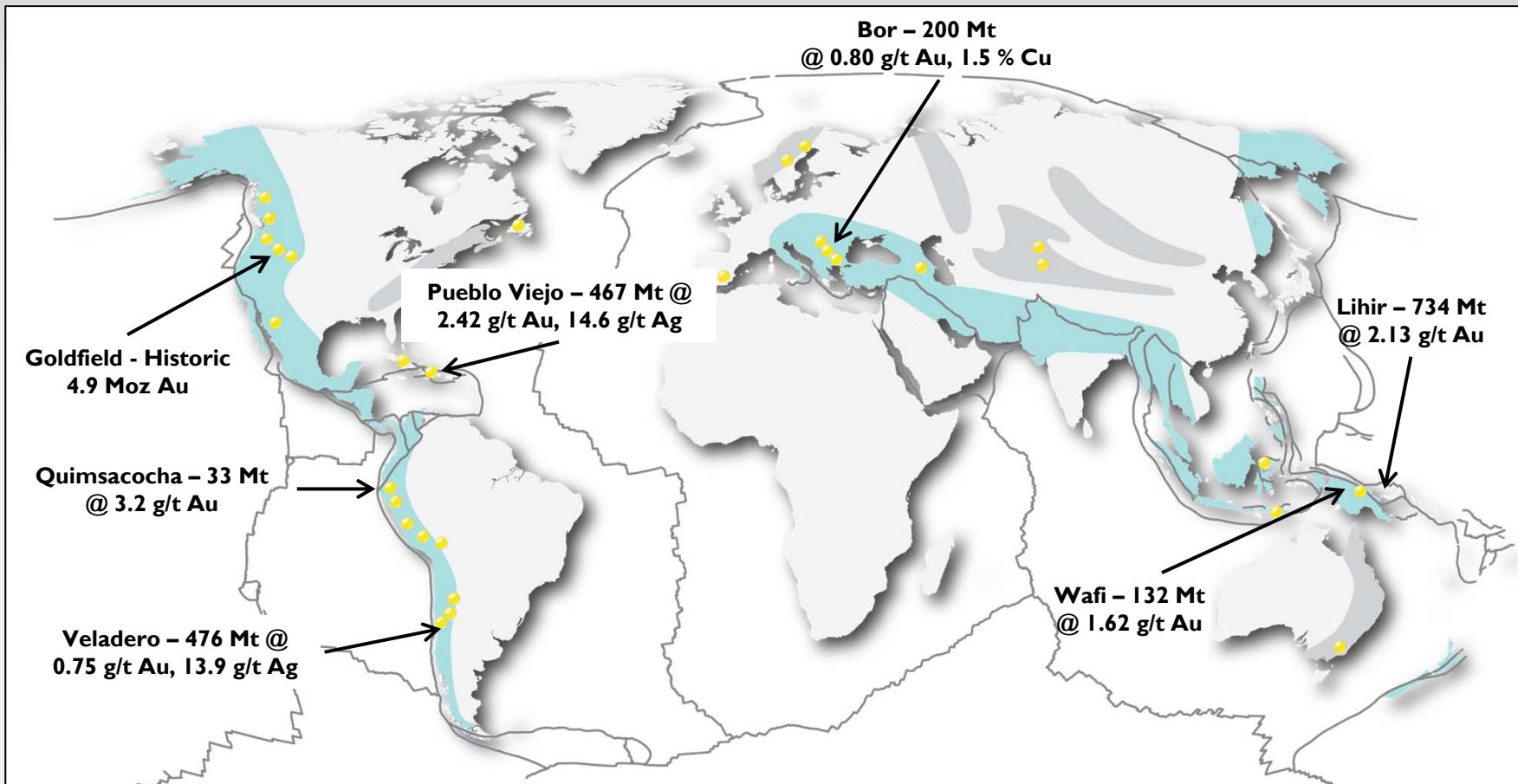
Exploration Alliance

a6
m Association of
Mining Analysts

Global Distribution of High Sulphidation Deposits



World Class Examples



Tonnage (Mt)	Gold (g/t)	Silver (g/t)	Copper (%)	Lead	Zinc
1 to >200	1 to >15	2 to >300	0 to 2	0 to 2	0 to 2



World Class Drill Intercepts

Quimsacocha: 102 m @ 9.2 g/t Au, 46.9 g/t Ag, 0.4 % Cu (IAMGOLD, IQD-122)

Veladero: 170 m @ 1.9 g/t Au (Argentina Gold, Hole 76)

Lihir (Minfie): 40 m @ 8.8 g/t Au (0-40 m),
80 m @ 6.4 g/t Au (40-120 m),
78 m @ 4.2 g/t Au (120 to 197.6 m)

Pueblo Viejo: 86 m @ 3.1 g/t Au (DPV07-74),
133 m @ 3.22 g/t Au (DPV07-86).

Wafi: 20 m @ 8.5 g/t Au, and
70 m @ 11.0g/t Au (WR154),



Geological Setting

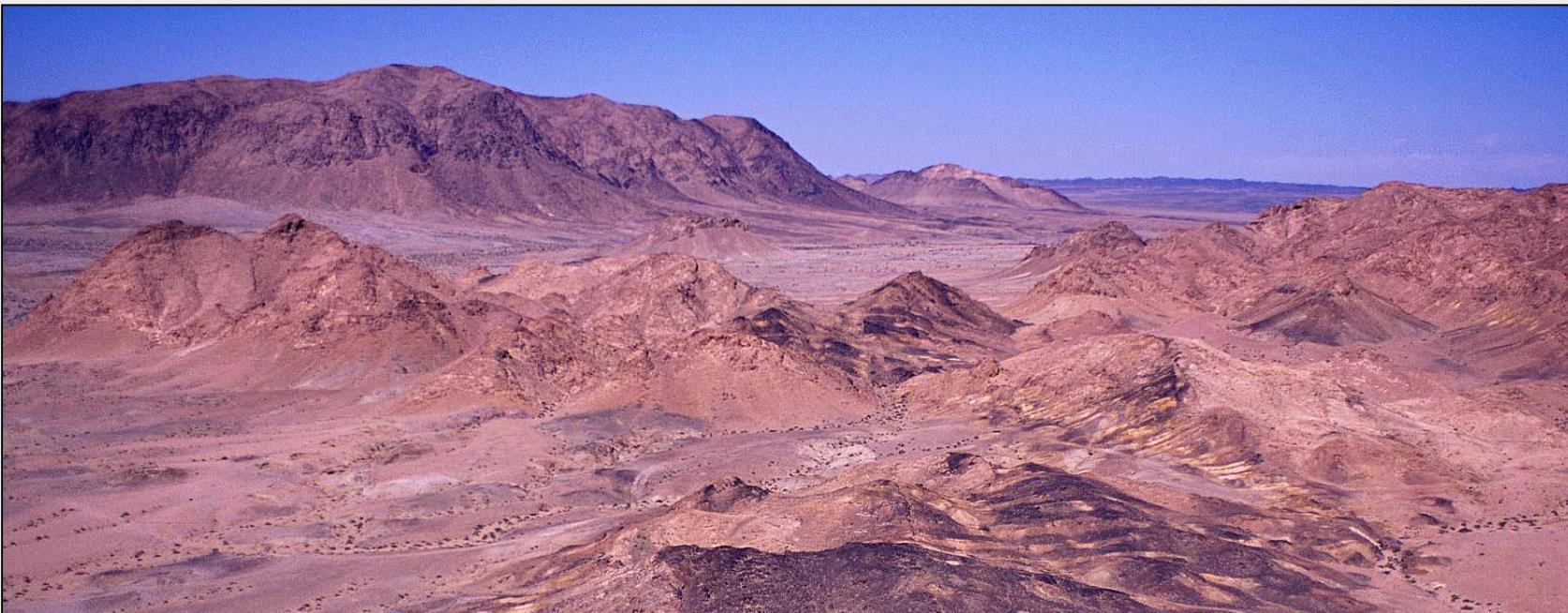
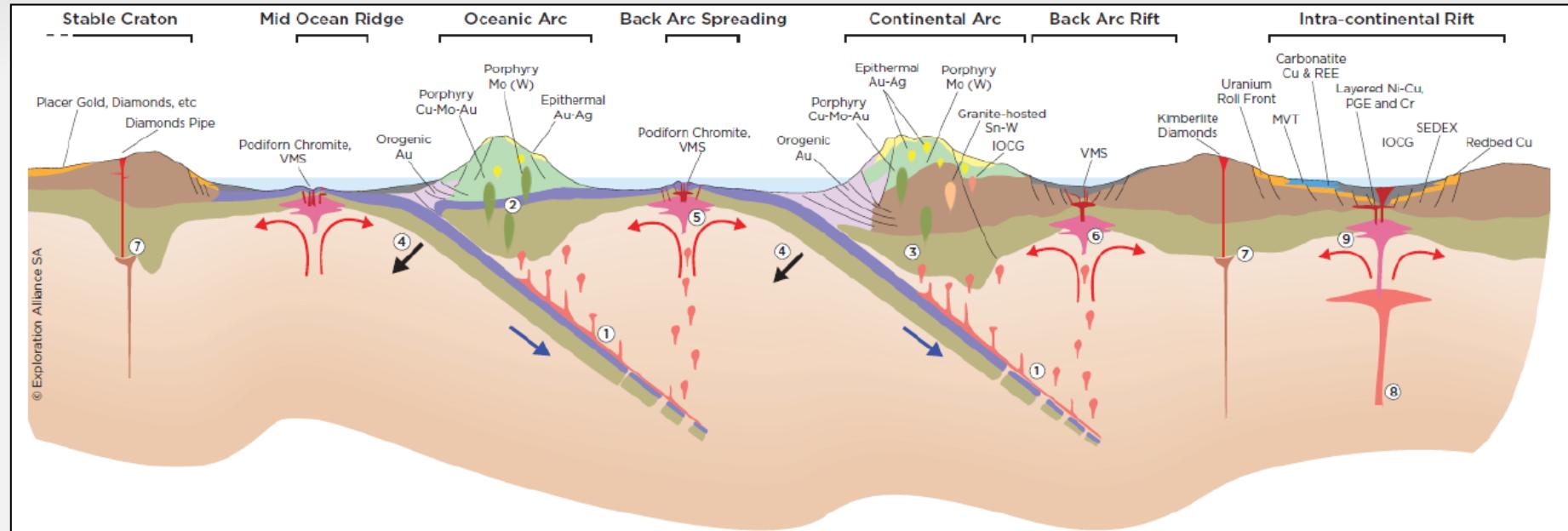


Plate Tectonic Setting



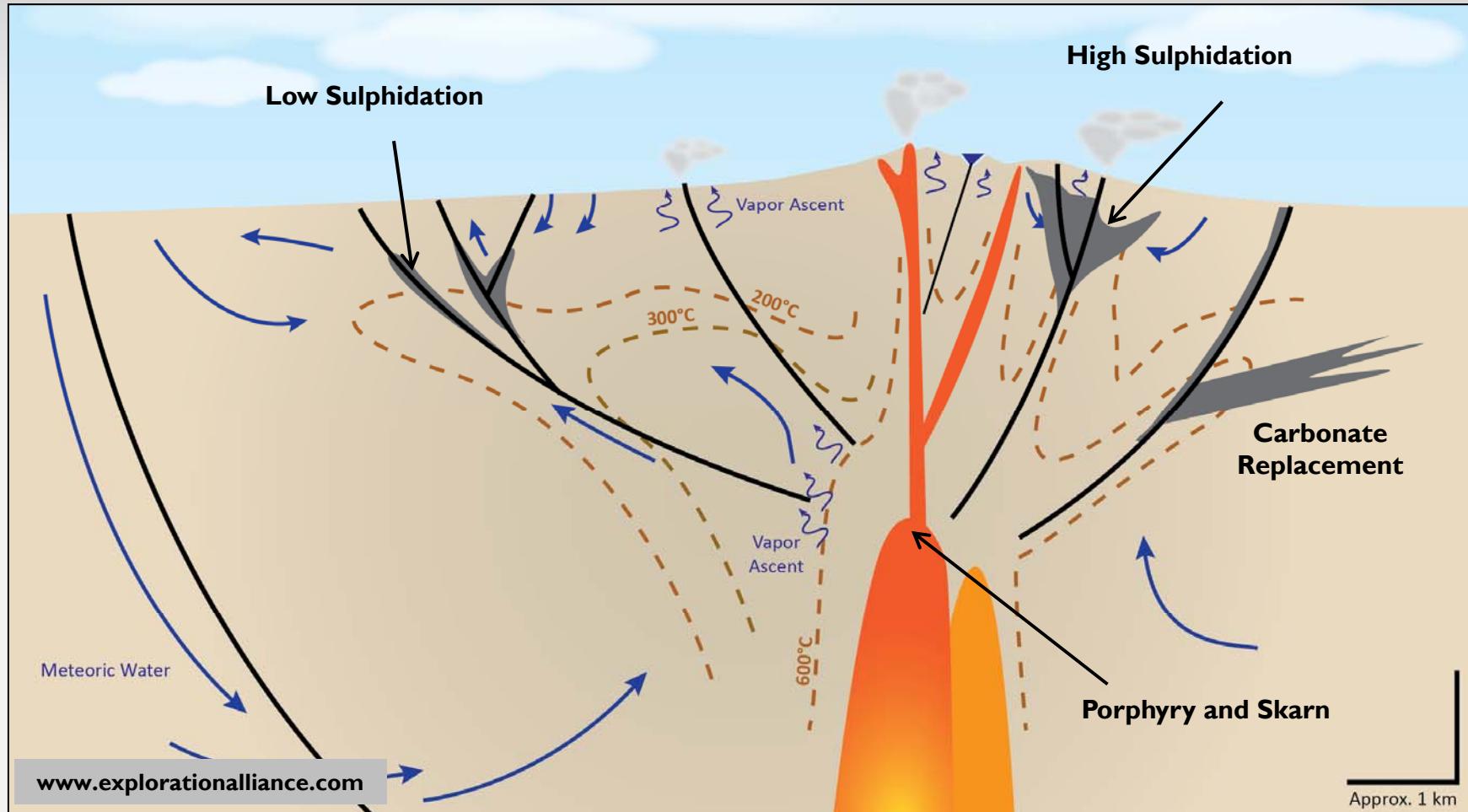
High Sulphidation deposits form in the upper 1 km of the Earth's crust above subduction zones.

Epithermal : Shallow Heat

High Sulphidation: A high metal to sulphur ratio within the sulphide minerals (the sulphidation state). Characterised by minerals such as enargite and luzonite. Alteration indicative of strongly acidic conditions



The Porphyry-Epithermal Hydrothermal System



Hydrothermal deposit types are linked to large cells of circulating magmatic fluids mixed with groundwater centred on an intrusive complex.



Hydrothermal = Hot Water!

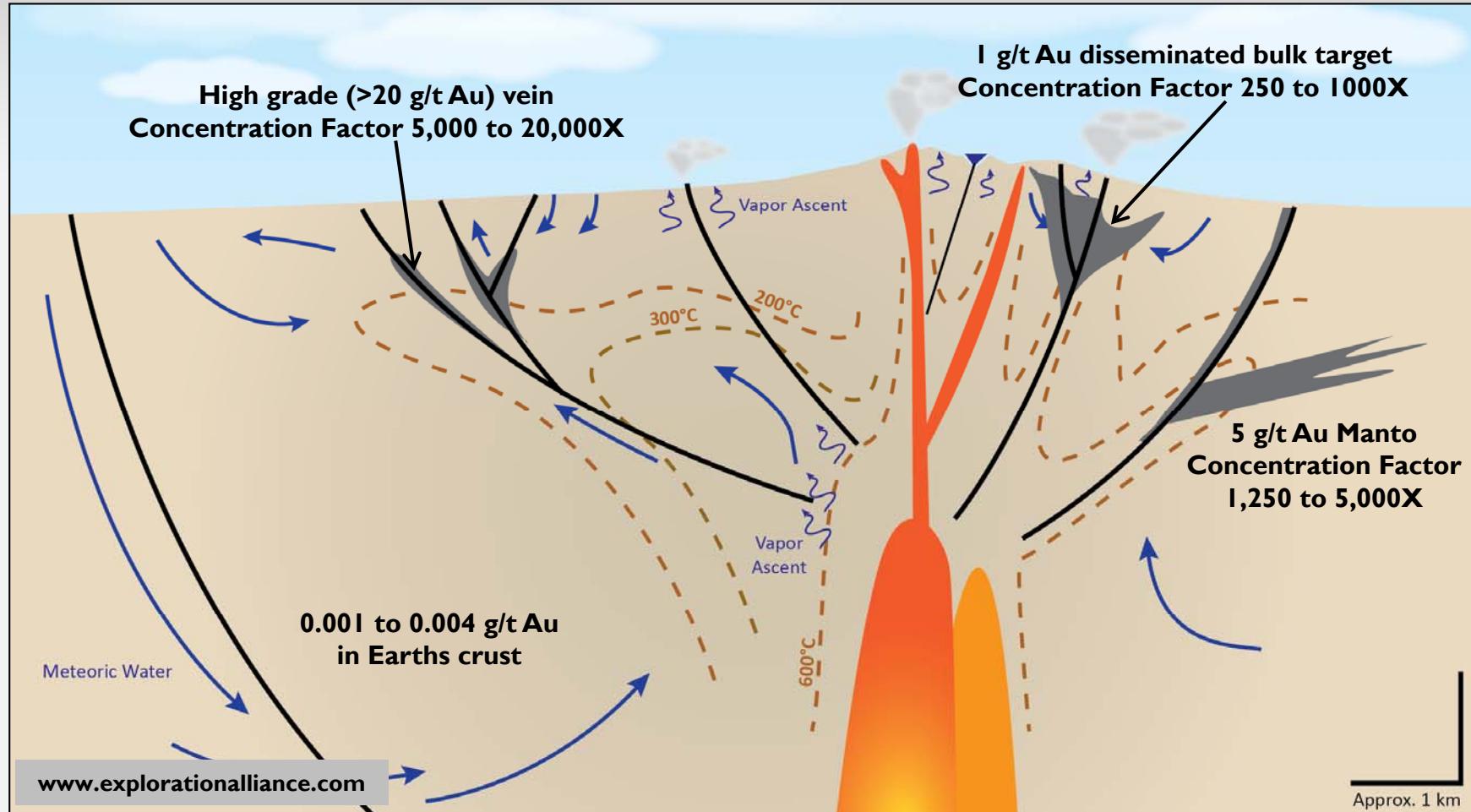


Geysers and Sinter Terraces
New Zealand

Hydrothermal fluids exploit faults, folds and favourable host rocks, depositing minerals as they flow through those spaces.



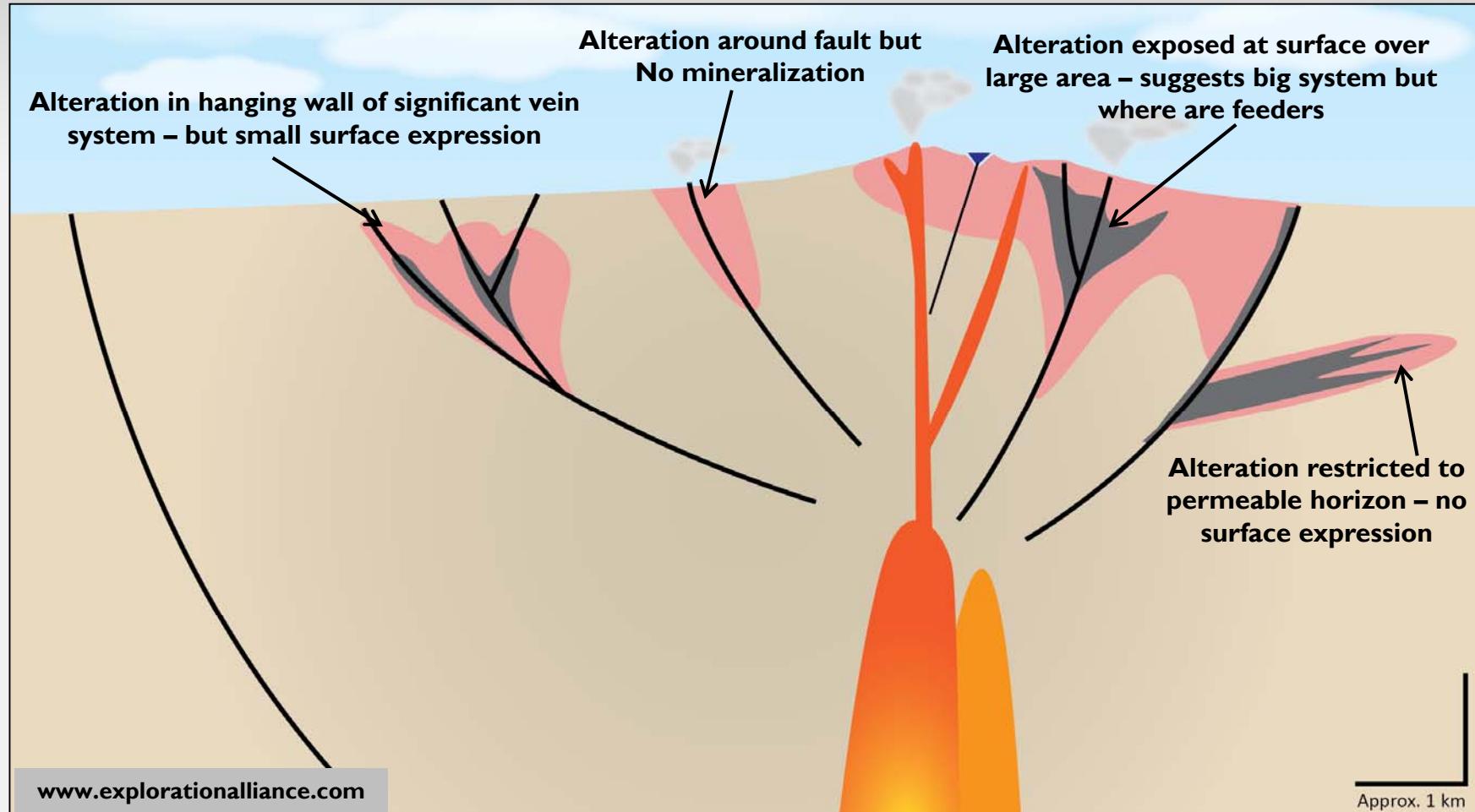
Mineral Deposits – The Product of Multiple Geological Processes



Hot intrusions drive hydrothermal circulation. Fluids leach gold from low abundance crustal rocks – big systems source gold from large volumes of crust. Fluids migrate upwards along faults and permeable horizons. Ascending fluids may boil as they move into low pressure environment, will cool, and may change composition via mixing with near surface fluids – all of which result in deposition of carried metals.



Hydrothermal Fluids Alter Host Rocks



Alteration may be used as a vector to mineralisation but alteration haloes are larger than the ore zones. Large alteration systems may mask high grade feeder zones, alteration associated with high grade veins may have a small surface footprint, buried mineralization may have no surface expression, and many altered systems are barren.

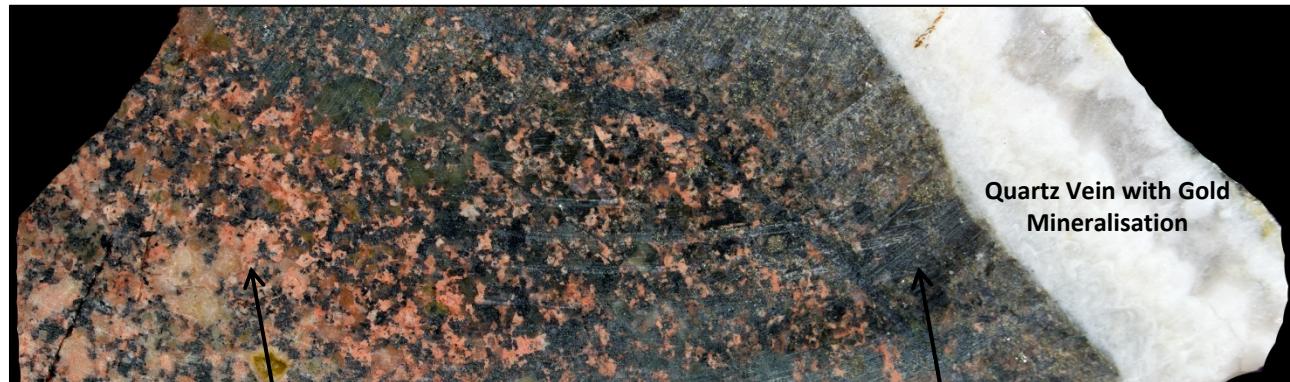


Alteration

Unaltered Host Rock



Altered Host Rock



2 cm

These minerals have been replaced

Texture of rock has been destroyed

Mapping these changes gives information on proximity to mineralisation.

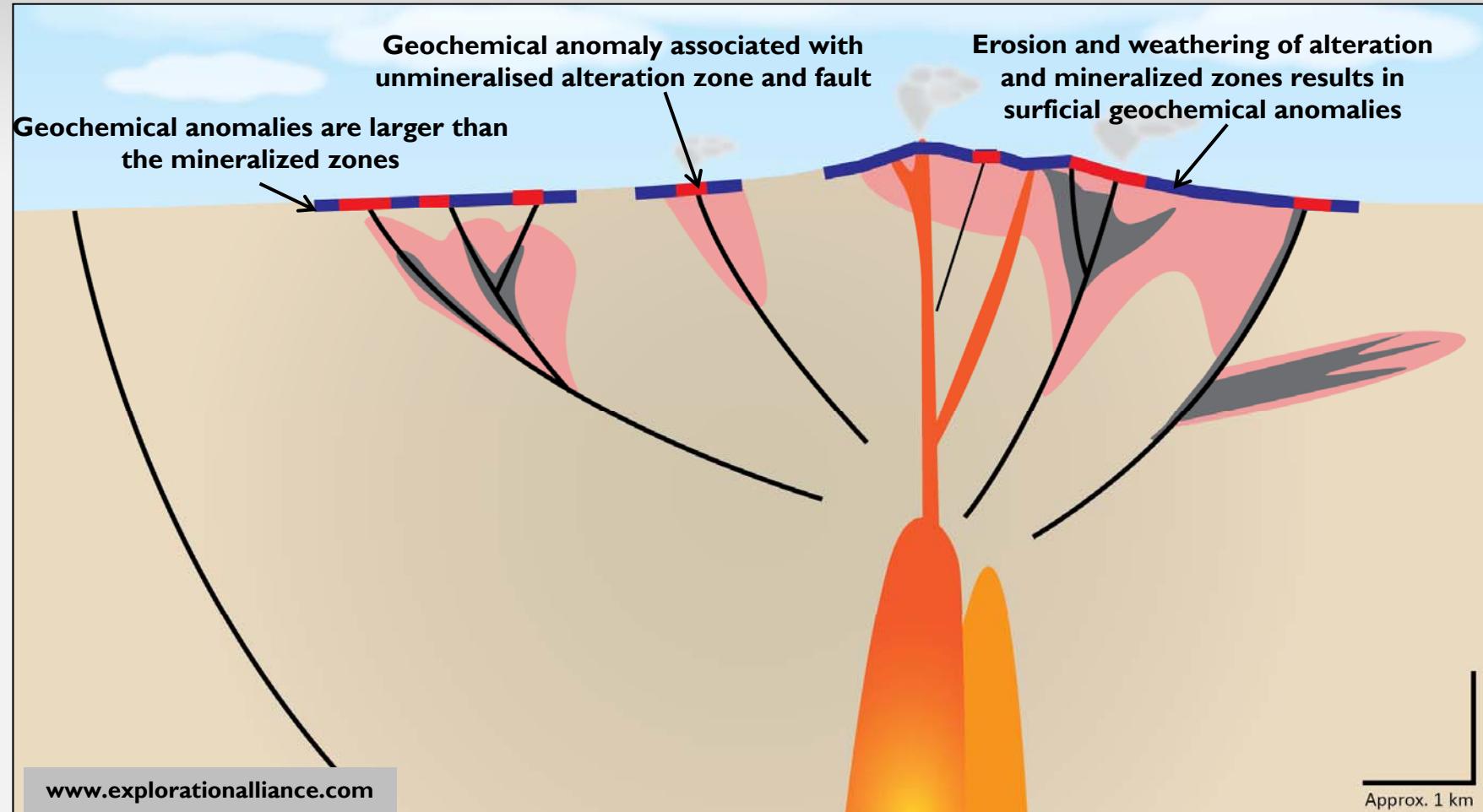
www.explorationalliance.com

Alteration: A term used to describe the chemical response of a rock to hydrothermal solutions causing mineralogical change. Alteration is used as a vector to mineralisation.

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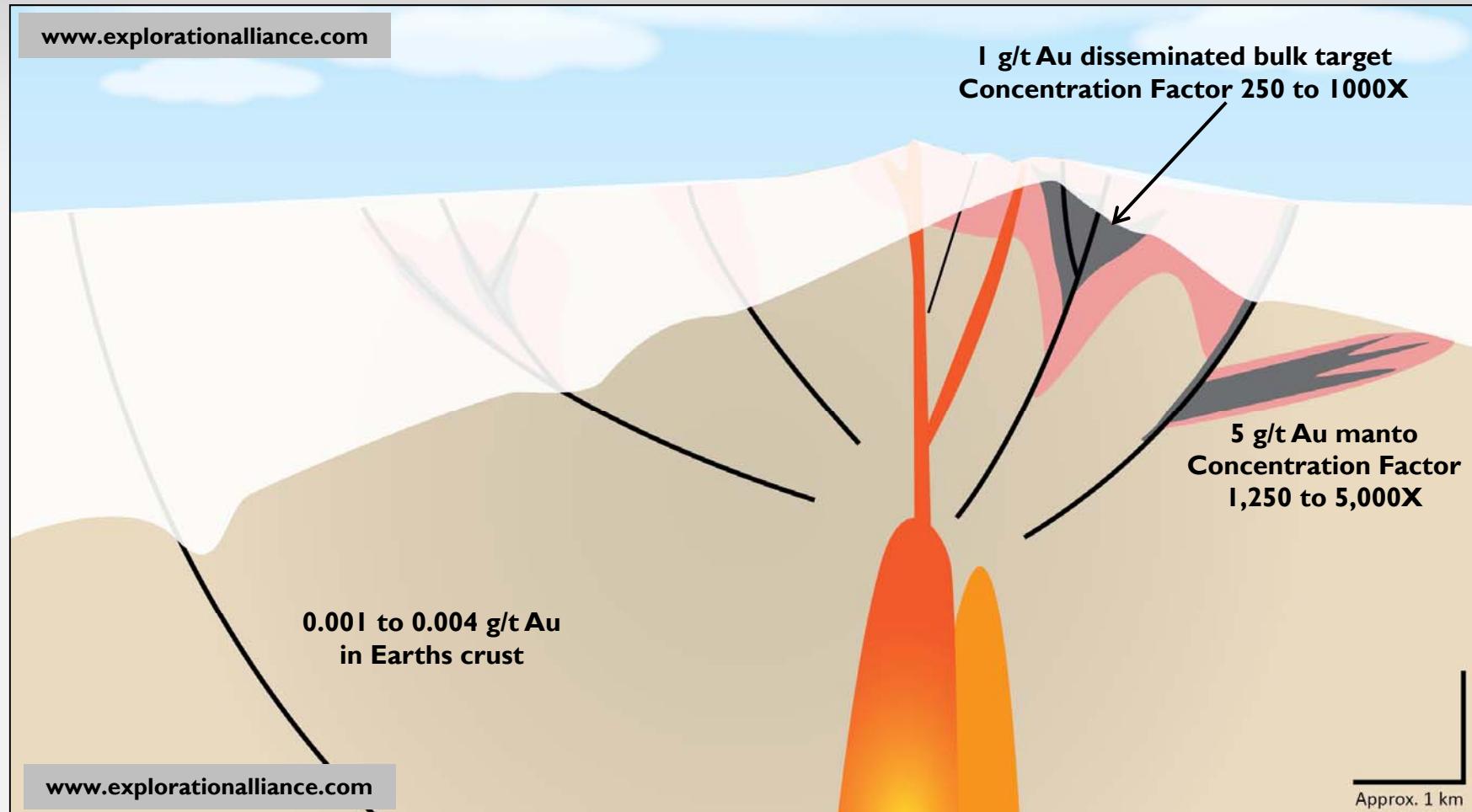
Exposure of Mineralized Systems Creates Geochemical Anomalies



Surficial geochemical anomalies form above and downslope of alteration zones (whether mineralized or not), in association with structures that have acted as fluid conduits, and surrounding areas of exposed mineralization.



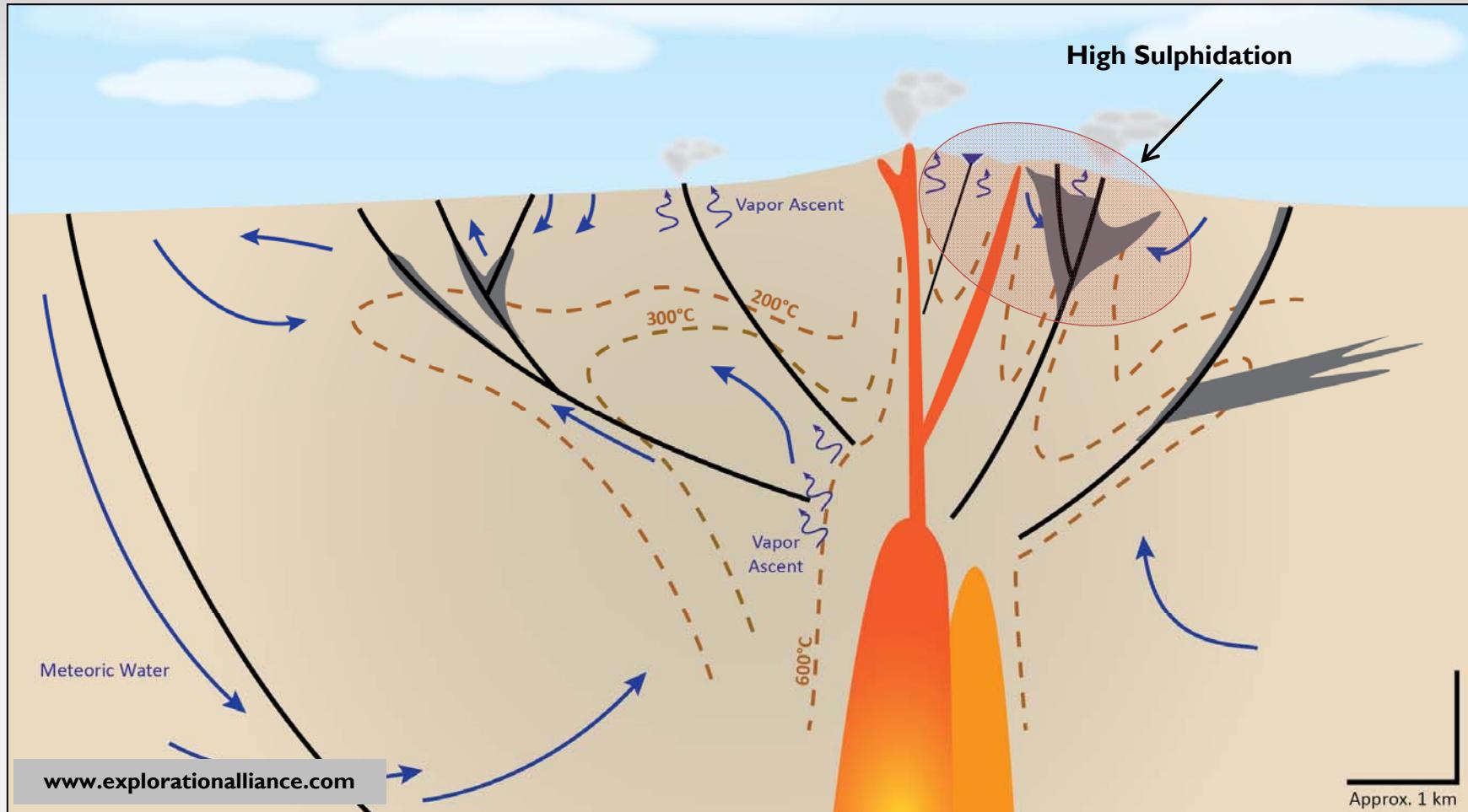
Not All Mineral Deposits are Preserved



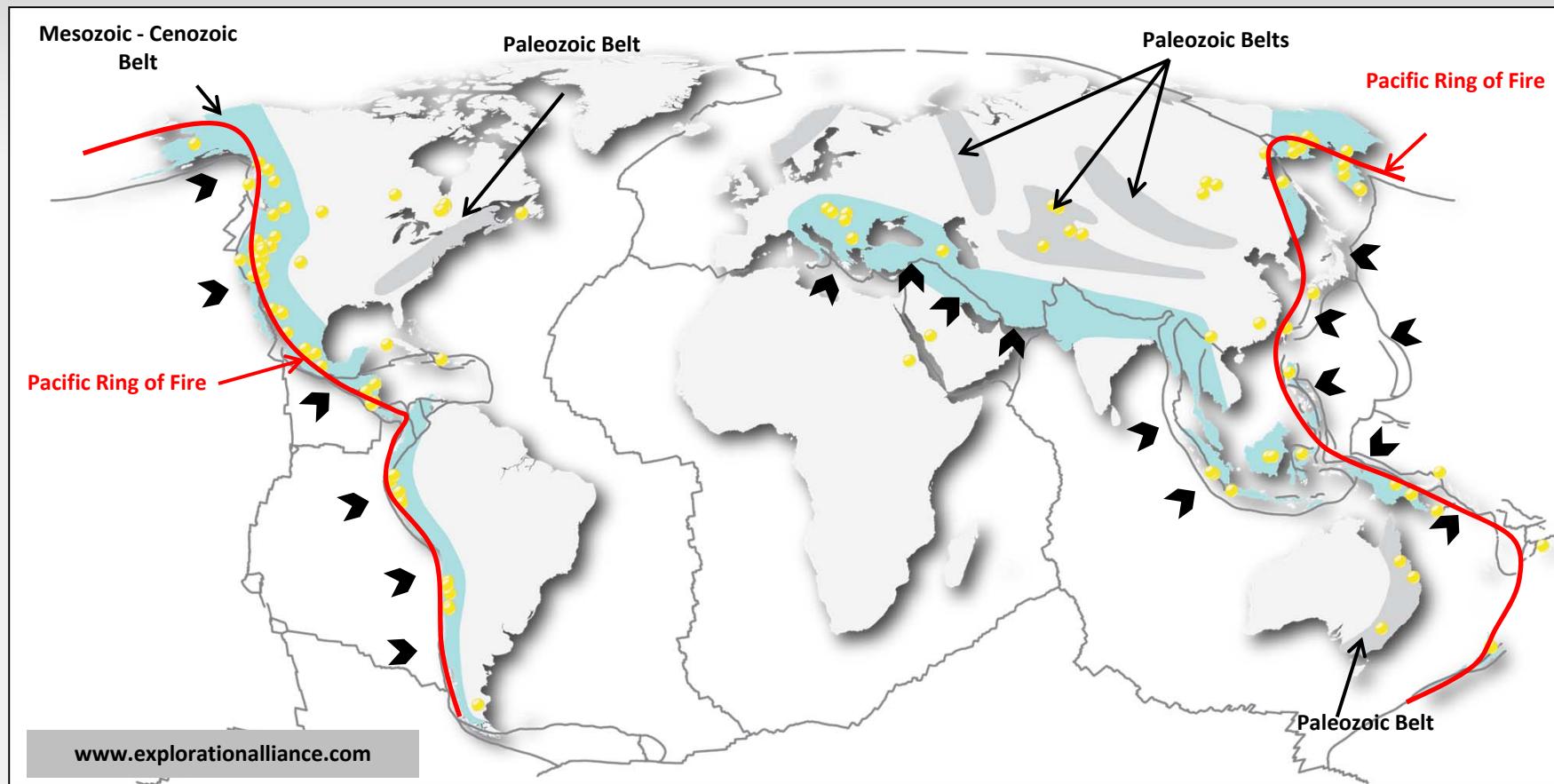
Weathering and erosion of the Earth's surface exposes mineralized systems and will eventually remove them from the geological record. Deposits formed close to surface (such as epithermals) or those formed in rapidly uplifting terrains (such as mountain chains) have poorest preservation potential. The very oldest gold deposits are dominated by orogenic (greenstone-hosted) types which formed at significant (>3-10+ km). Almost all preserved epithermal deposits are <100 Ma.



High Sulphidation Deposits in the Hydrothermal System



Major HS and LS Epithermal Deposits and Plate Tectonic Boundaries



The high and low sulphidation epithermal deposits associated with blue coloured belts are late Mesozoic and Cenozoic in age (generally <120 Ma) and are associated with Late Cretaceous to present day subduction zones.

Deposits located in the middle of plates (grey coloured belts or metallogenic provinces) are associated with Paleozoic age (ca. 542 to 241 Ma) rocks which were formed in ancient subduction zones.



Calderas Host Hydrothermal Systems



The Kikai Caldera is host to the hydrothermal system. The volcanoes post-date the caldera.

Source: Smithsonian Institute



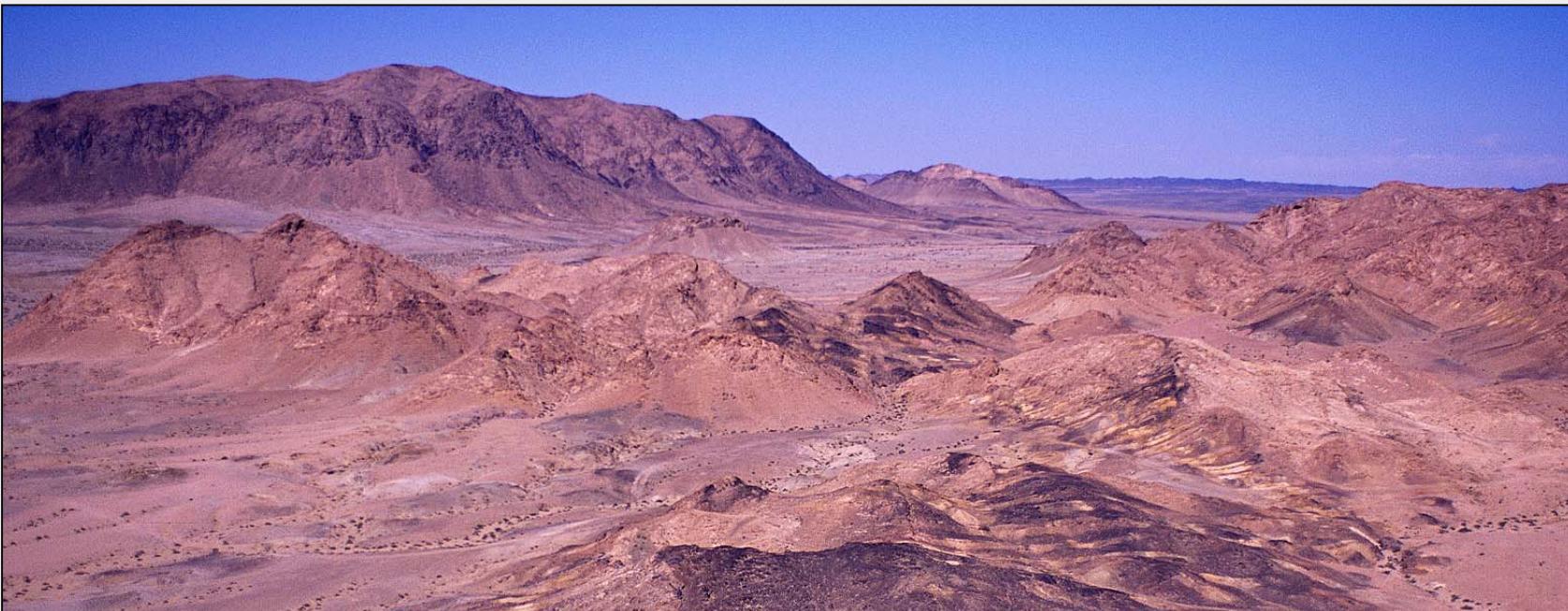
Shallow Crustal Levels of Formation



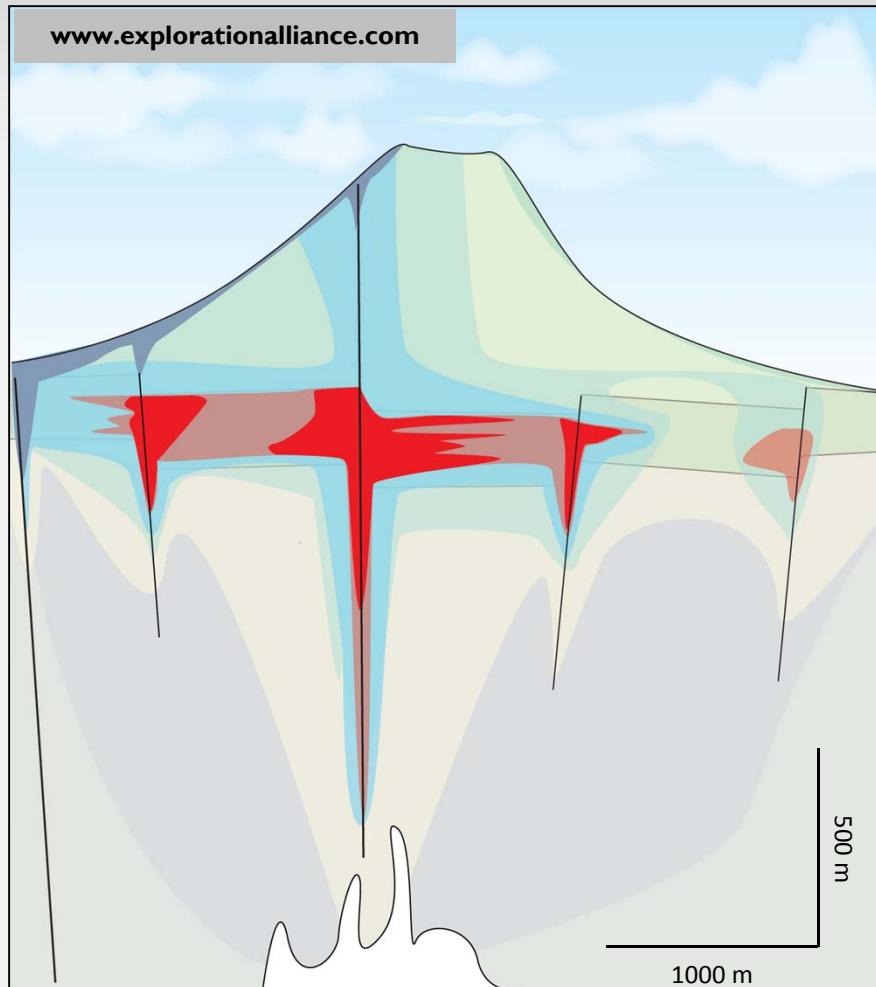
Satsuma-Iwojima volcano, Japan (from Hedenquist, 2002)



Deposit Model



High Sulphidation Deposit Model

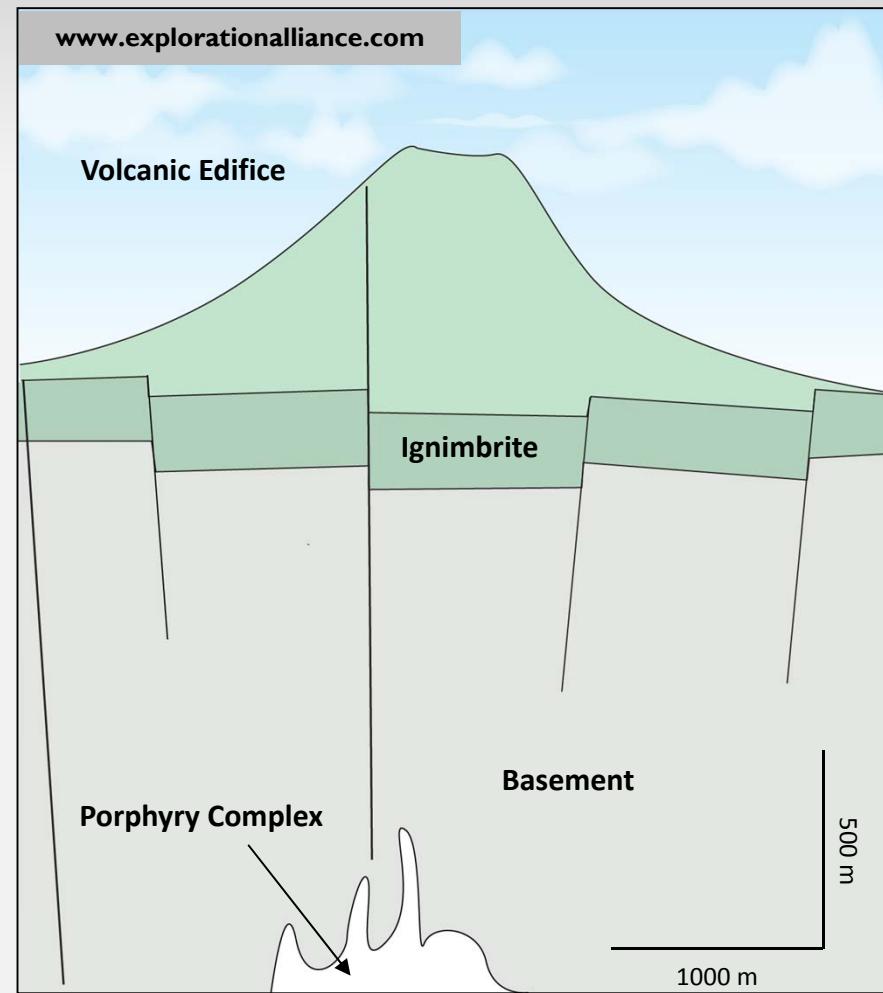


Satsuma Iwojima, Japan.
Photo from Hedenquist, 2002

High Sulphidation deposits are spatially related to volcanic centres and diatremes. They often represent the upper parts of porphyry systems and the two types of mineralisation can often overlap or occur adjacent, for example Bor (Serbia), Lepanto (Indonesia) and Wafi-Golpu (PNG). Note the alteration of the upper parts of the volcano (shown in the photograph) caused by release of acid vapours and fluids.



Structural Control

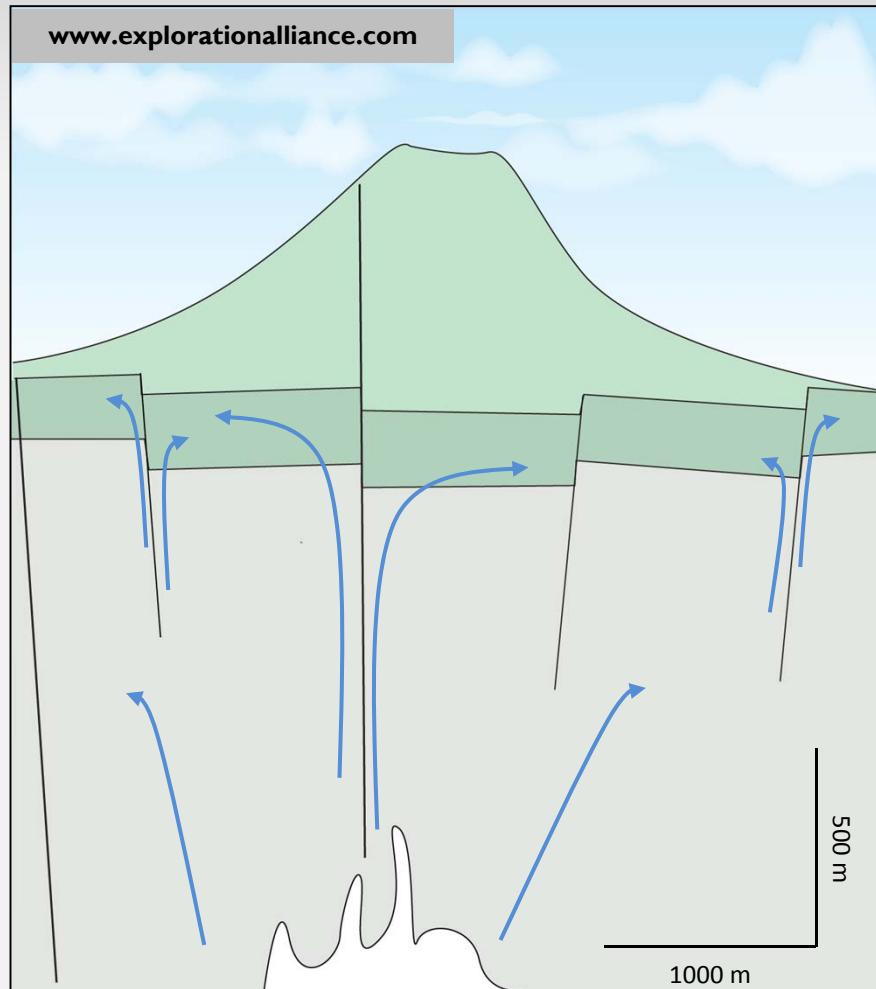


Ignimbrite is a volcaniclastic rock with inherent permeability – with zones of weakness at the contact between fragments and throughout the matrix.

The structural setting of High Sulphidation deposits in volcanic environments lends itself to mineralisation due to the hydrothermal alteration caused by underlying intrusions, and creation of space through extensional faulting in and around the caldera and back-arc basin. Furthermore, permeable volcaniclastic and sedimentary rocks are deposited in the same environment and act as fluid conduits.



Hydrothermal Activity



Fumaroles and acid lakes form at surface

Ascending, highly acidic magmatic vapour condense when mixed with meteoric water

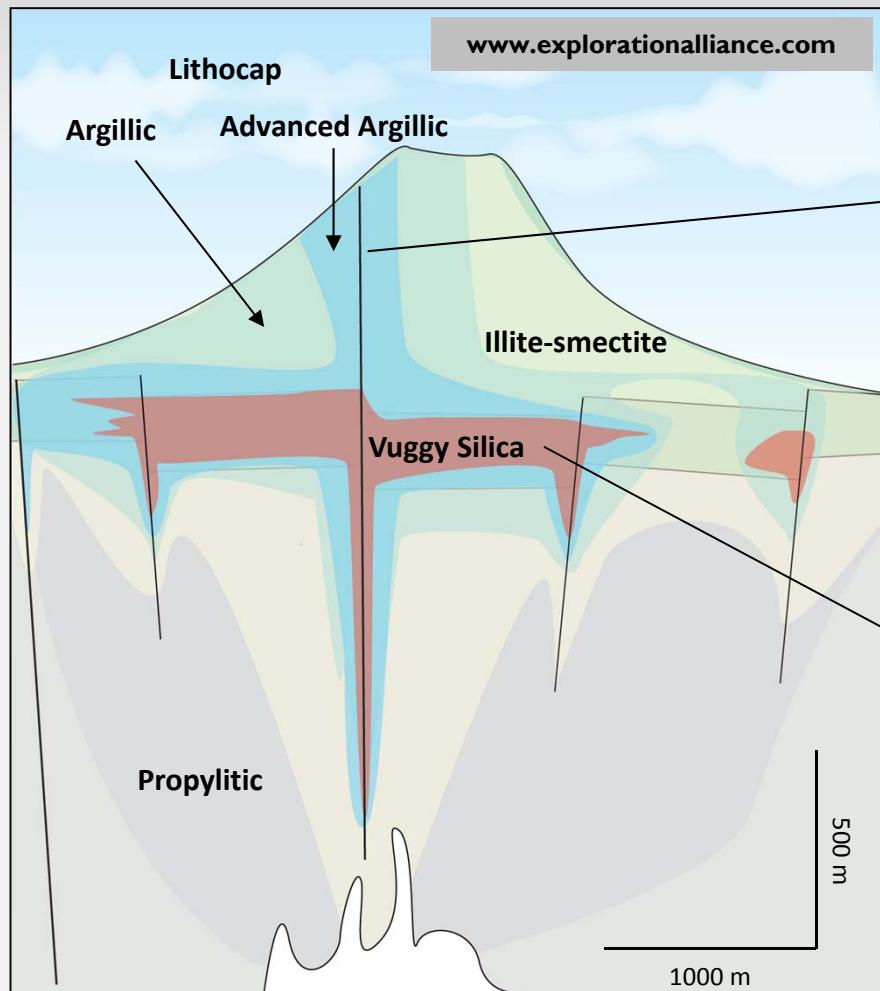
Acidic gases and fluids ascend from the deep magma chamber. The hydrothermal fluids will exploit any weakness such as faults or permeable lithologies. The acidity of the hydrothermal fluid is greatest within the conduits. As the fluid percolates away from the main structures its acidity is neutralised, creating a zoned alteration pattern. Vuggy silica is at the core of the alteration system.



Lihir – An Active Geothermal System



Vuggy Silica and Acid Sulfate Alteration



Kaolin altered feldspars in andesitic volcanic rock. Note also dark sulphidic fractures.

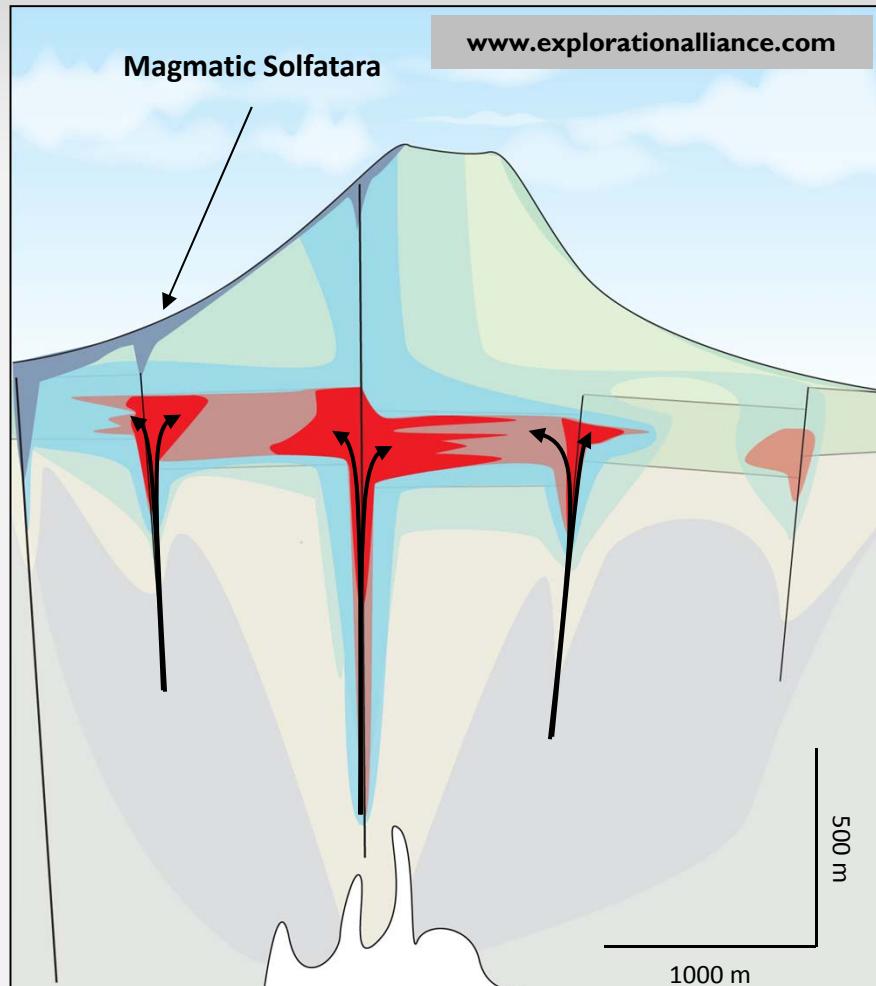


Vuggy Silica, which is formed in the initial hydrothermal stages in sub-vertical fault zones.

Vuggy silica forms in sub-vertical structures and favourable, permeable lithological units, often sub-horizontal. The acid condensate is progressively neutralised away from the source structures, creating a zoned alteration pattern. A lithocap of argillic and advanced argillic alteration forms at surface, which is commonly rich in alunite.



Late Mineralising Event Exploits Pre-Existing Voids



Hydrothermal Breccia comprising angular fragments of tuff cemented with quartz-sulphide

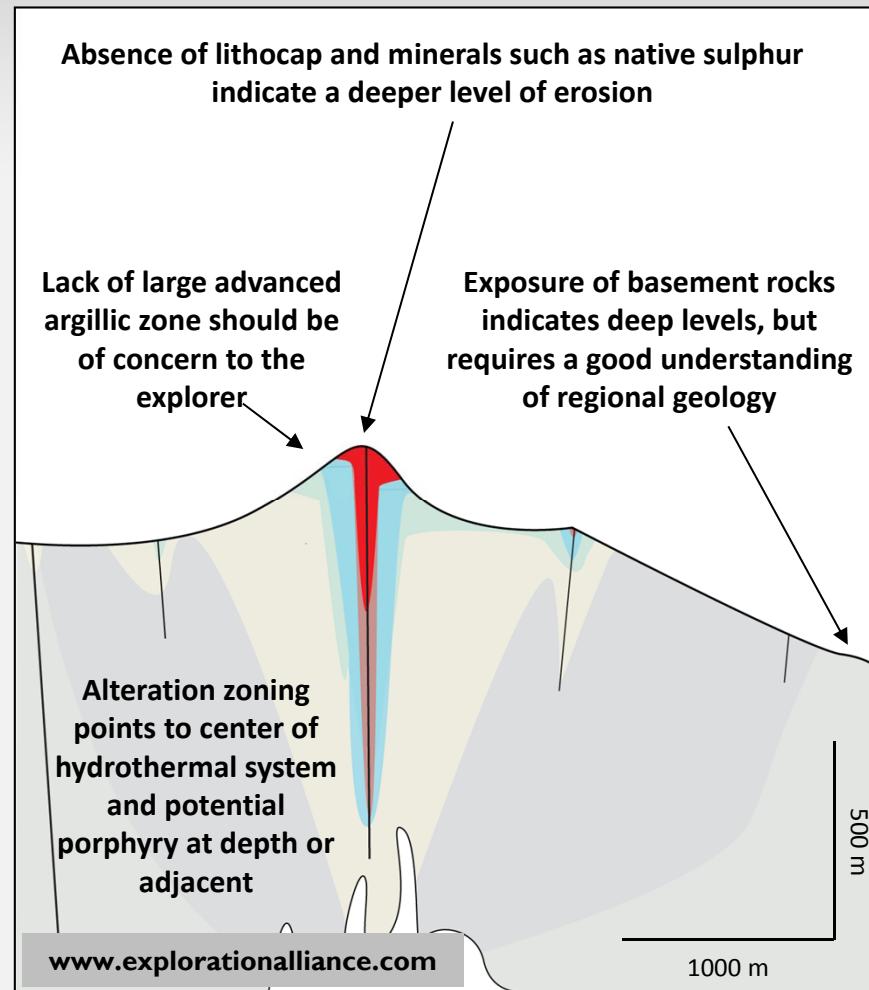


Massive Sulphide vein hosted in advanced argillic altered volcanic.

A later, less acidic but metal endowed fluid ascends from the deep magma chamber. The late fluid rapidly loses temperature and pressure when it reaches the vuggy silica due to the abundant space, causing metals to be precipitated from the oversaturated fluids, introducing gold with pyrite. Ores are often refractory. Late steam-heated alteration forms at surface with native sulphur, and supergene minerals such as jarosite and sulfates.



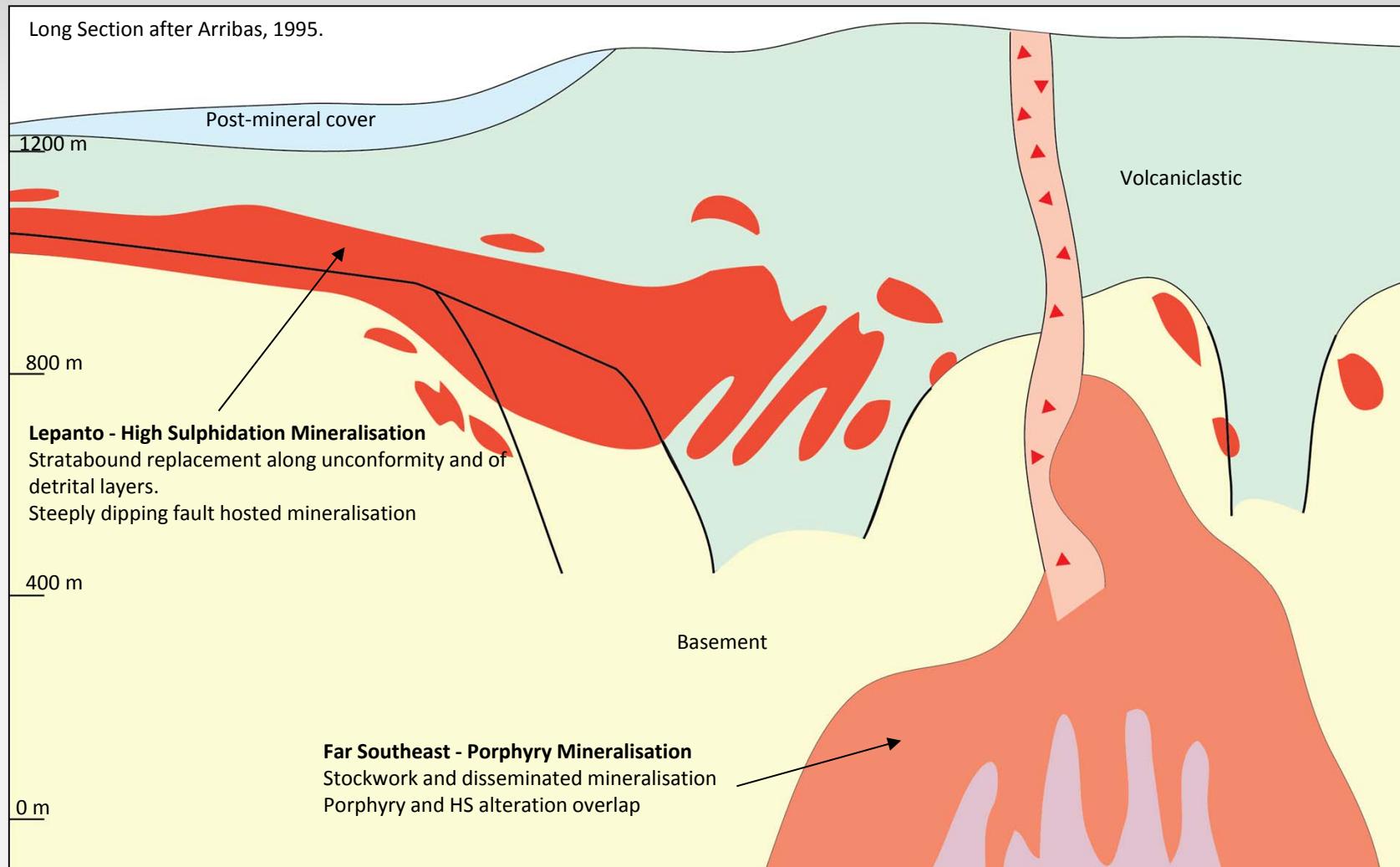
The Link between High Sulphidation and Porphyry



At first glance the ingredients for High Sulphidation mineralisation appear to be present at surface – however the alteration zonation is small and the basement rocks are exposed. There may, however, be an opportunity to explore for associated porphyry mineralisation...



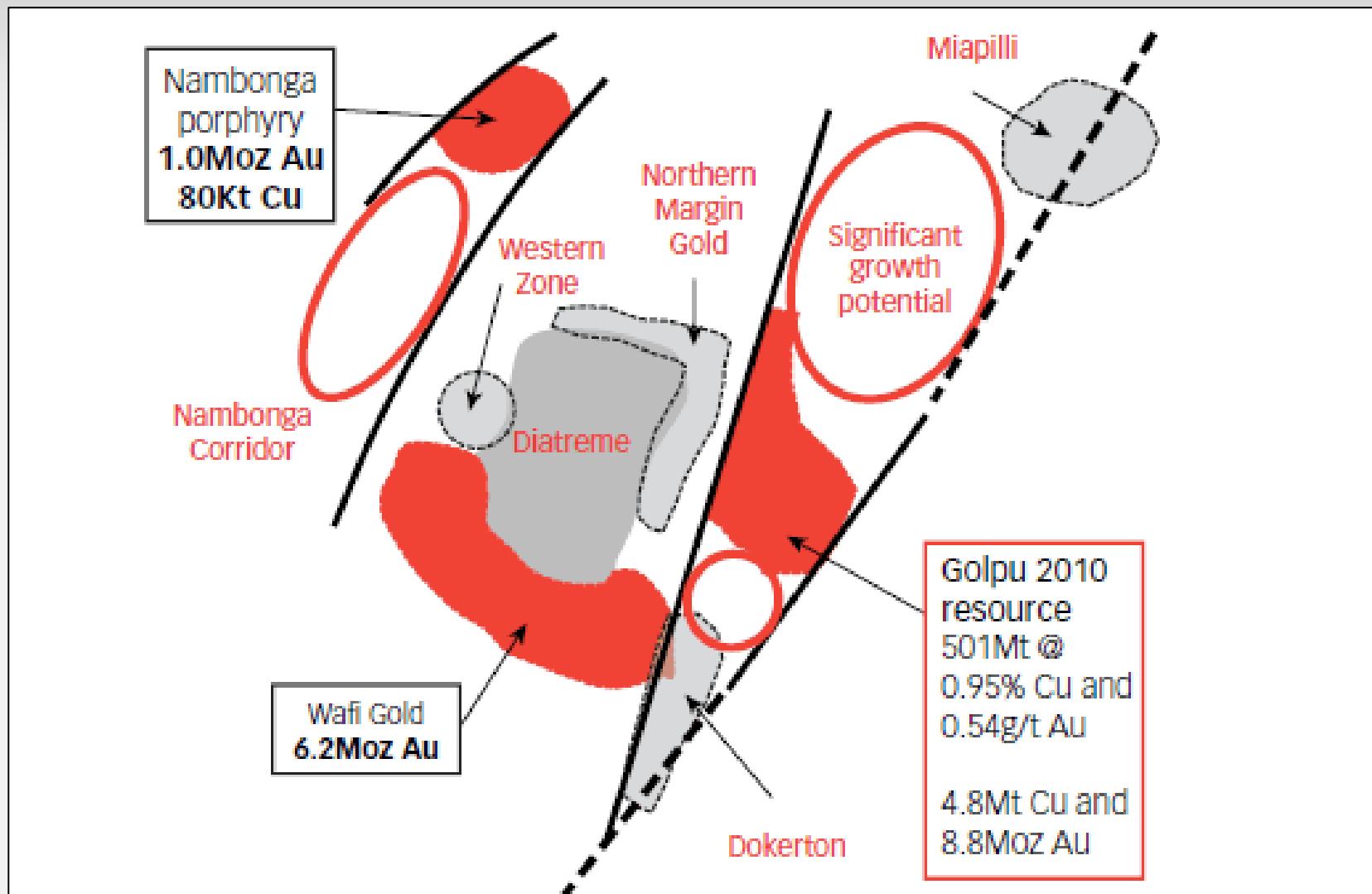
High Sulphidation and Porphyry – Mankayan District



Mankayan District, Phillipines. The Far Southeast porphyry acts as the centre of the hydrothermal system and is the source of hydrothermal fluids and magmatic gases. The Lepanto high sulphidation mineralisation is coeval with the porphyry, and the surface alteration has been shown to be a reliable tool in locating the porphyry (after Hedenquist, 2011).



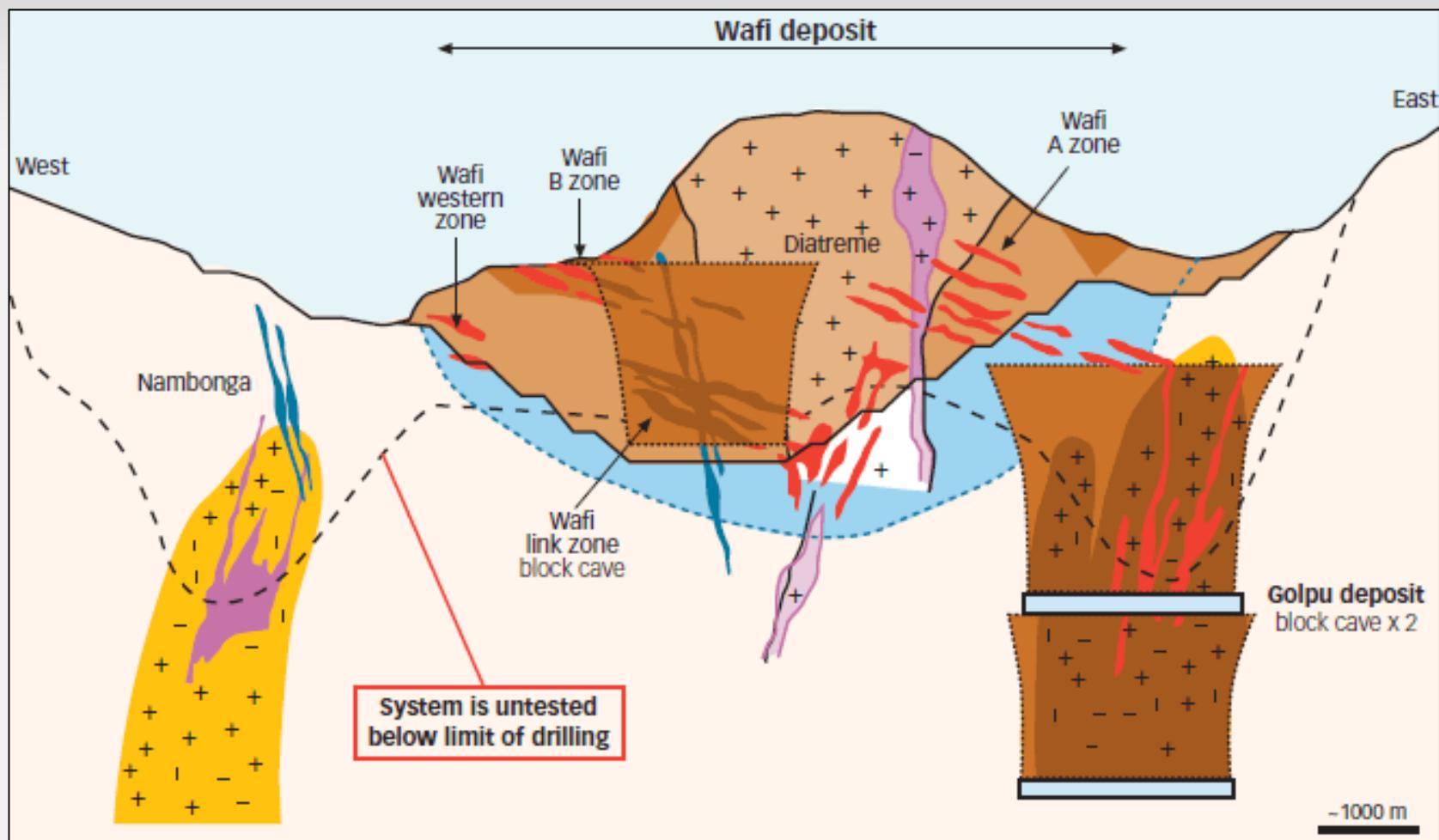
Wafi-Golpu Deposit



Source: www.harmony.co.za



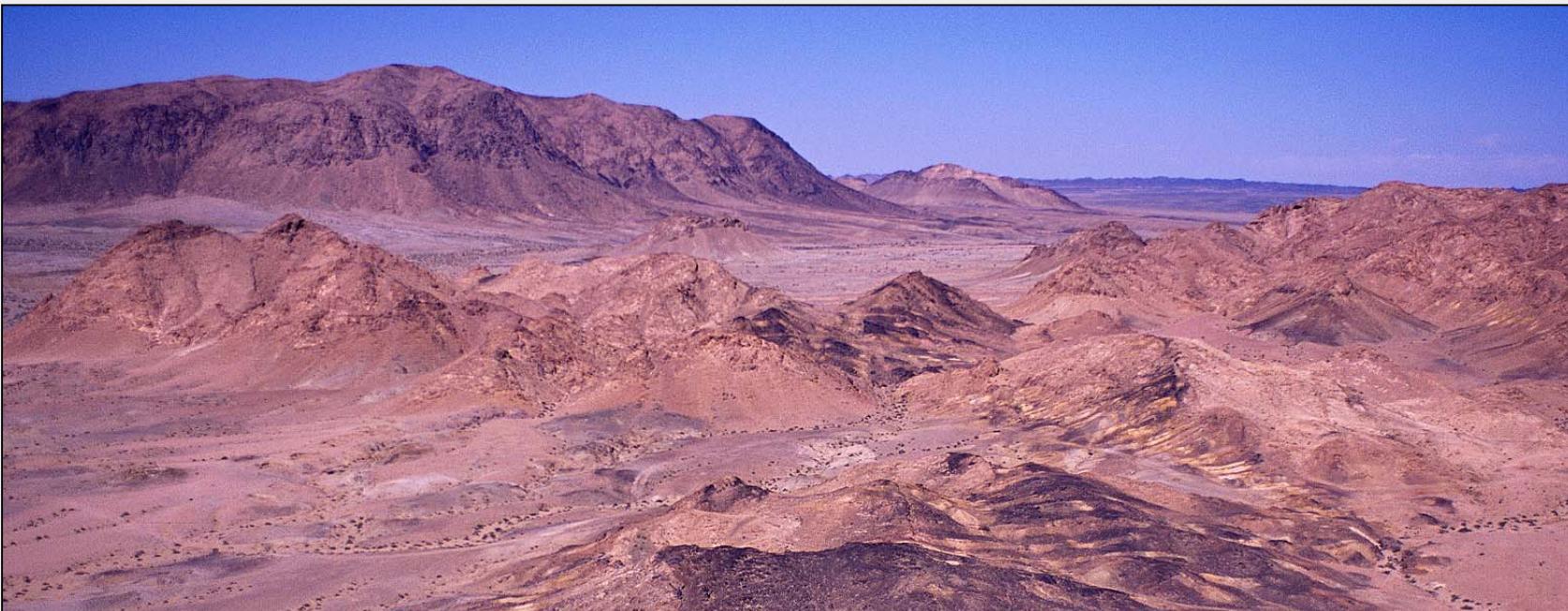
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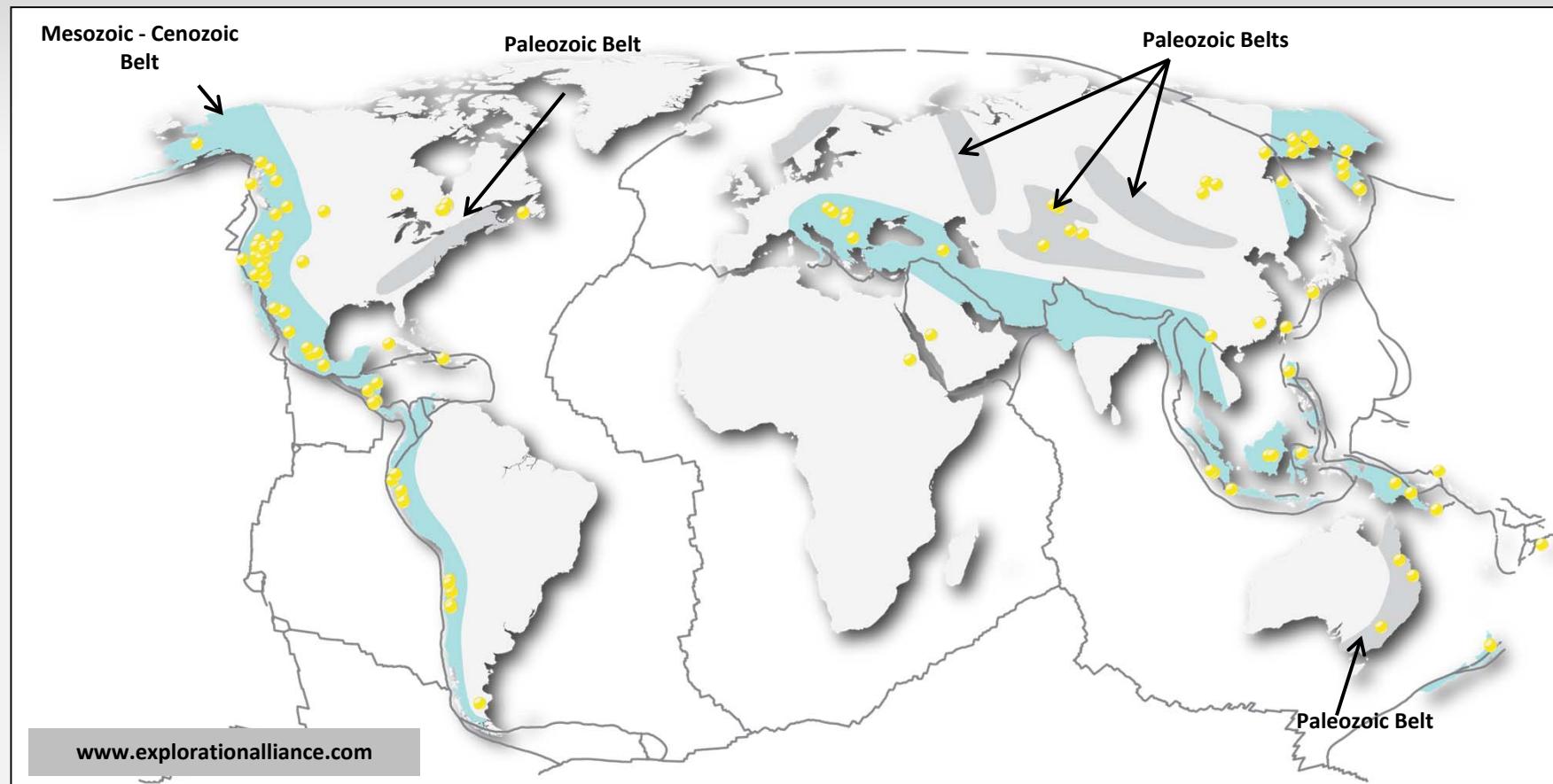
Source: www.harmony.co.za



Exploration Challenges



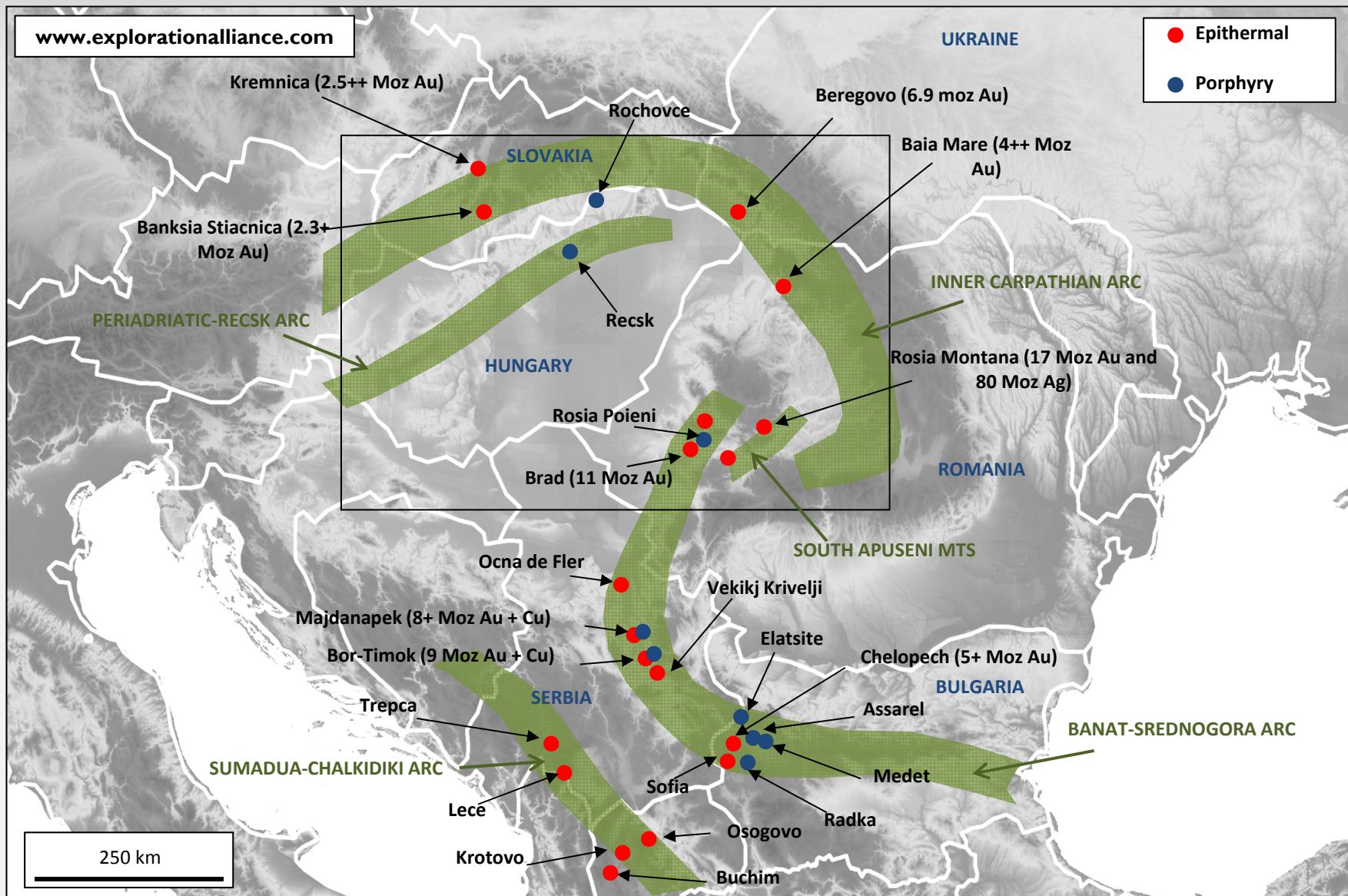
Global Exploration Strategy – Identify Arc Settings



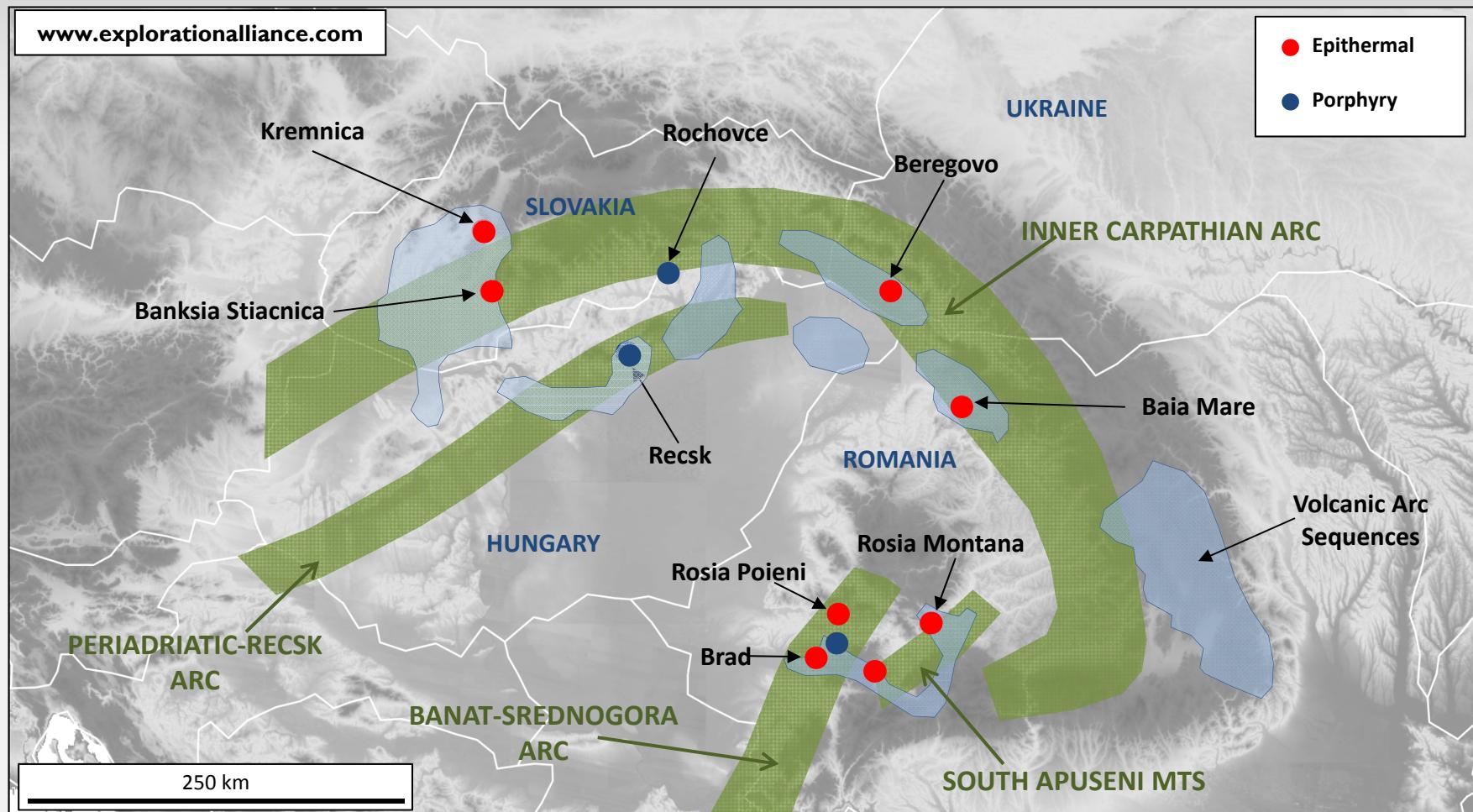
High sulphidation epithermal deposits form in Continental and Oceanic Arc settings as subducting oceanic plates melt and generate large intrusive complexes and associated hydrothermal circulation cells. Correct identification of Continental and Oceanic Arc settings is a pre-requisite for successful exploration.



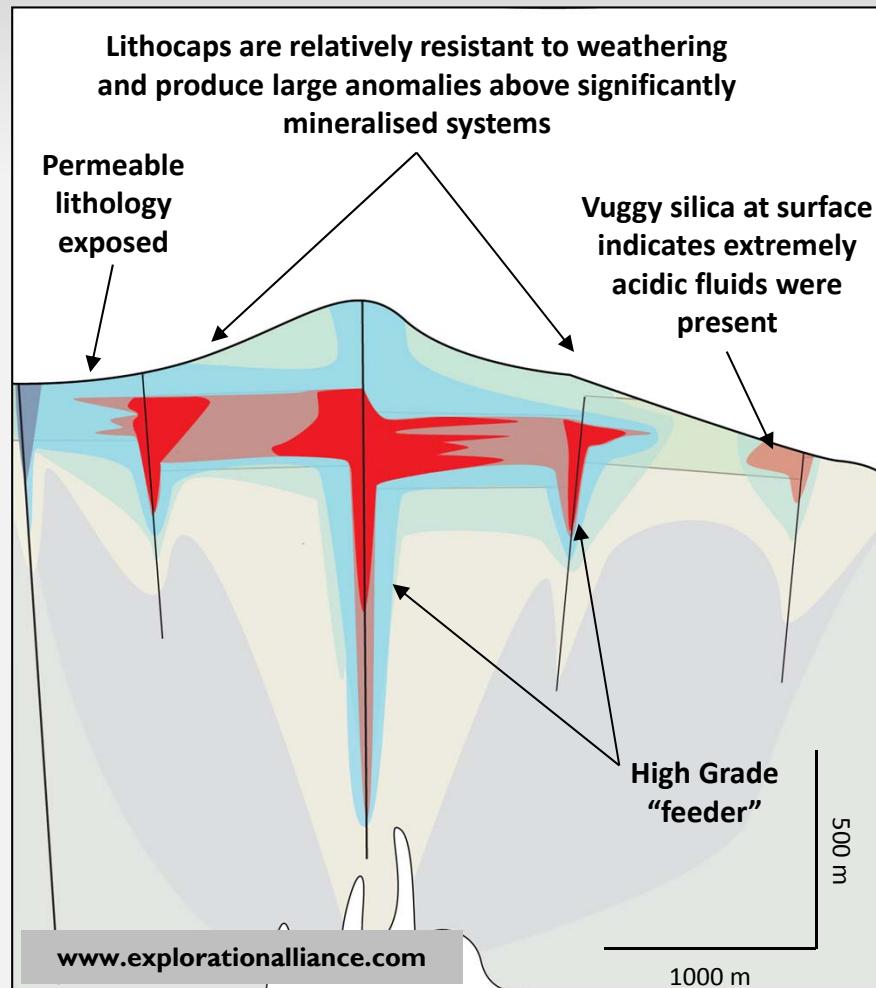
Identify Volcanic Arc and Mineral Occurrences/Mines



Identify Intrusive Centres and Volcanic Rocks



Level of Erosion



Alteration zones are readily identified in areas of good exposure...



...but may be buried under late volcanic cover!

Along with the large alteration zones, many anomalies are created and it can be difficult to vector in on a mineralised system. Remnant lithocaps, zoned alteration and identification of permeable lithologies are important exploration guides.



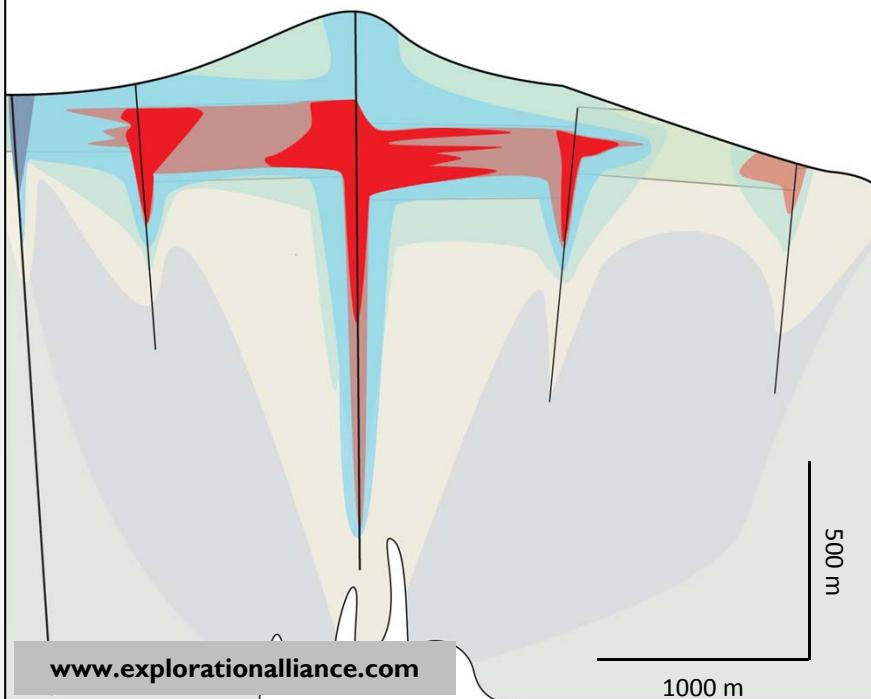
Combining Geology, Geochemistry and Geophysics

Geochemistry

As, Cu, Sb, Bi, Te, Sn, Mo, S – indicative of magmatic source fluids responsible for alteration.

Geophysics

Low resistivity, high chargeability
Magnetite destructive alteration presents as flat response



Surface expression may be low grade or barren



PNG Highlands are densely forested yet host to many world class deposits.



Geochemistry and alteration provide vectors to prospective targets.



High Sulphidation Alteration and Lithocap



A lithocap exposed in northern Iran. Note resistant cap and extensive clay development.



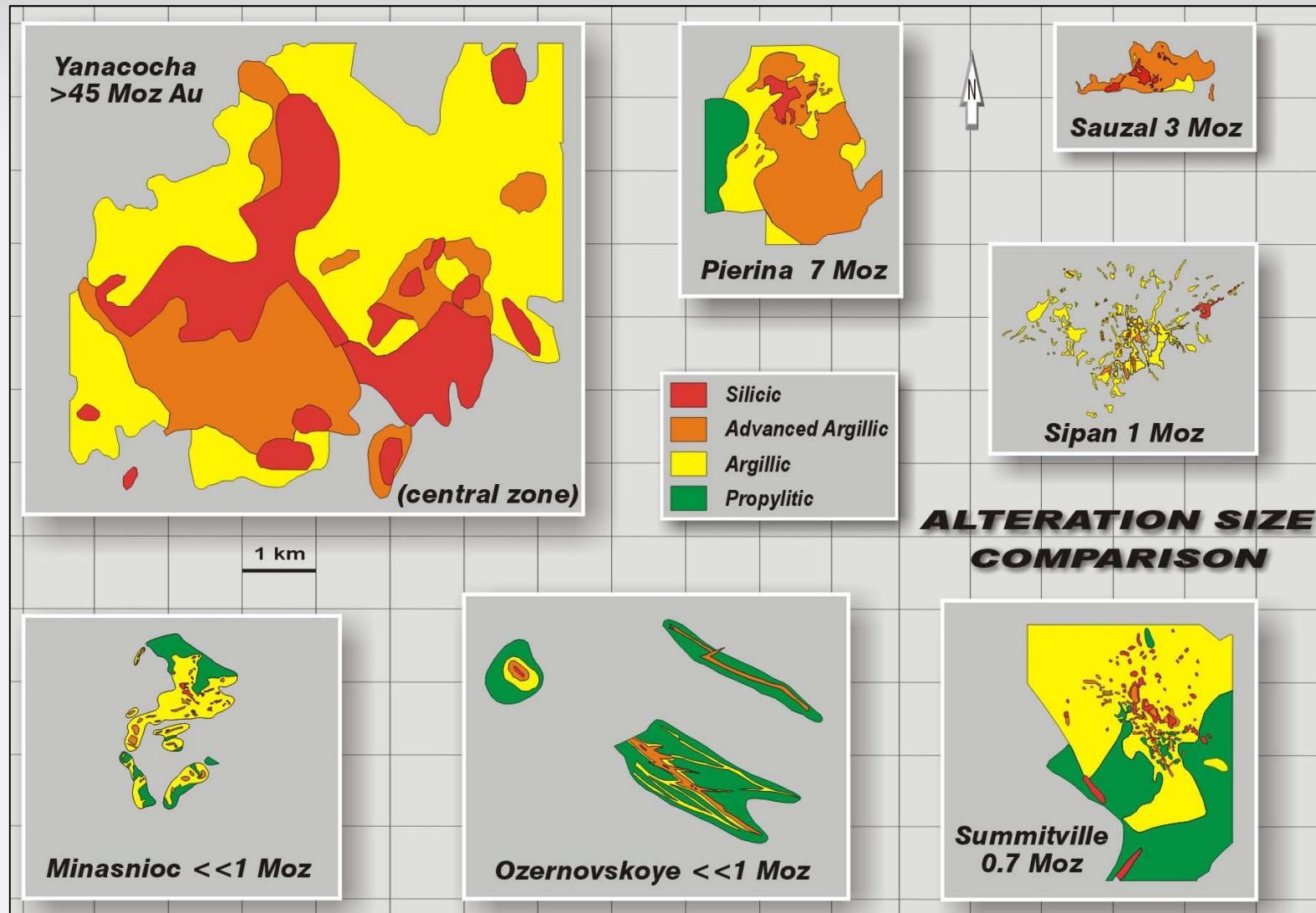
High Sulphidation Alteration and Lithocap



Vuggy Silica forming a ridge at the centre of the lithocap. Northern Iran



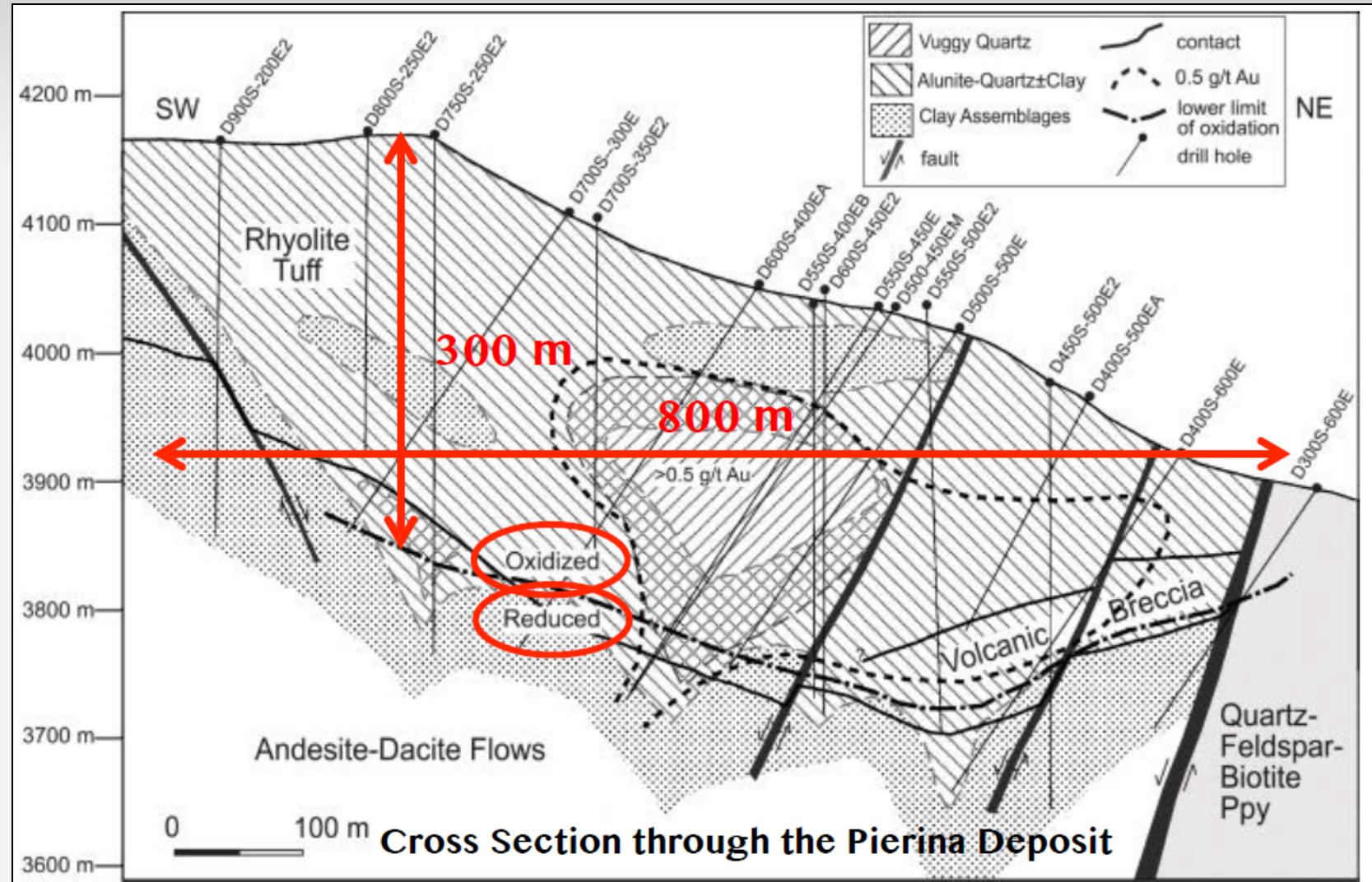
Size of Alteration Zone is Critical



Source: Hedenquist, 2002



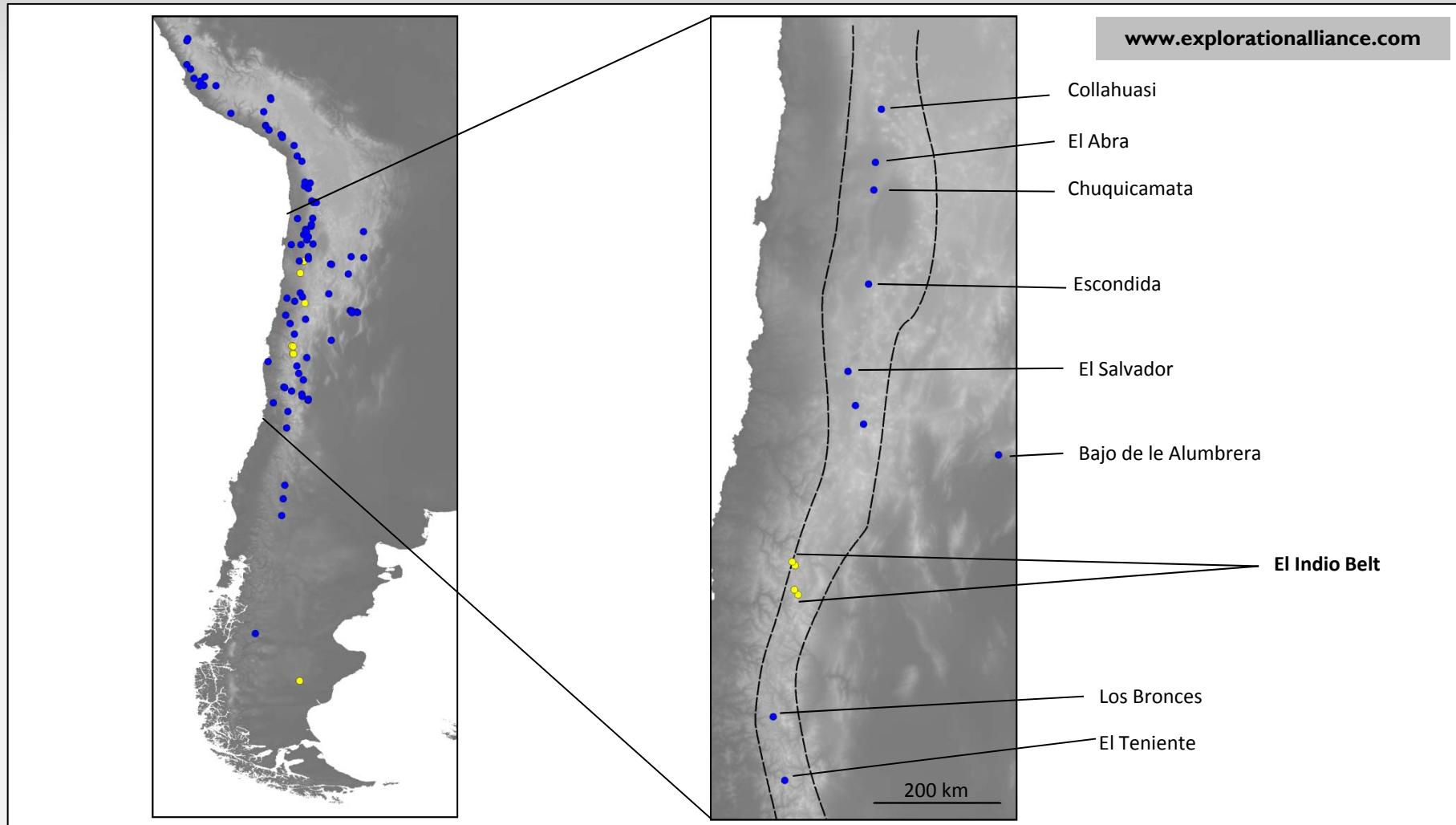
Refractory Ores are Common



Source: Hennigh, 2012



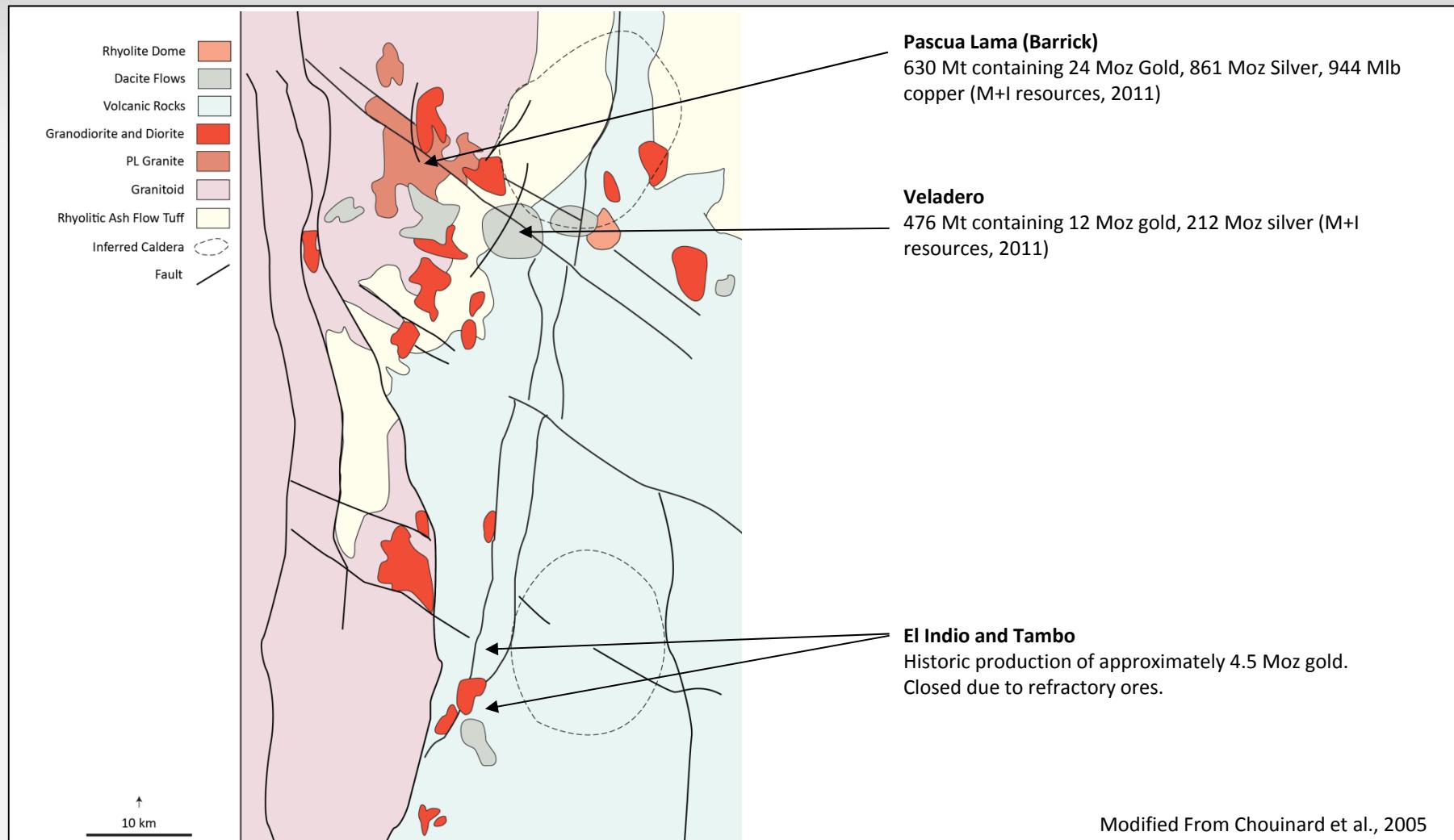
Southern Andes – A Prospective Magmatic Arc



The Southern Andes are host to some of the world's largest porphyry and high sulphidation deposits. They are largely restricted to the magmatic arc and hosted in associated intrusive and volcanic rocks. The El Indio Belt is a high sulphidation district (yellow dots) in a region otherwise dominated by porphyry and IOCG deposits (blue dots).



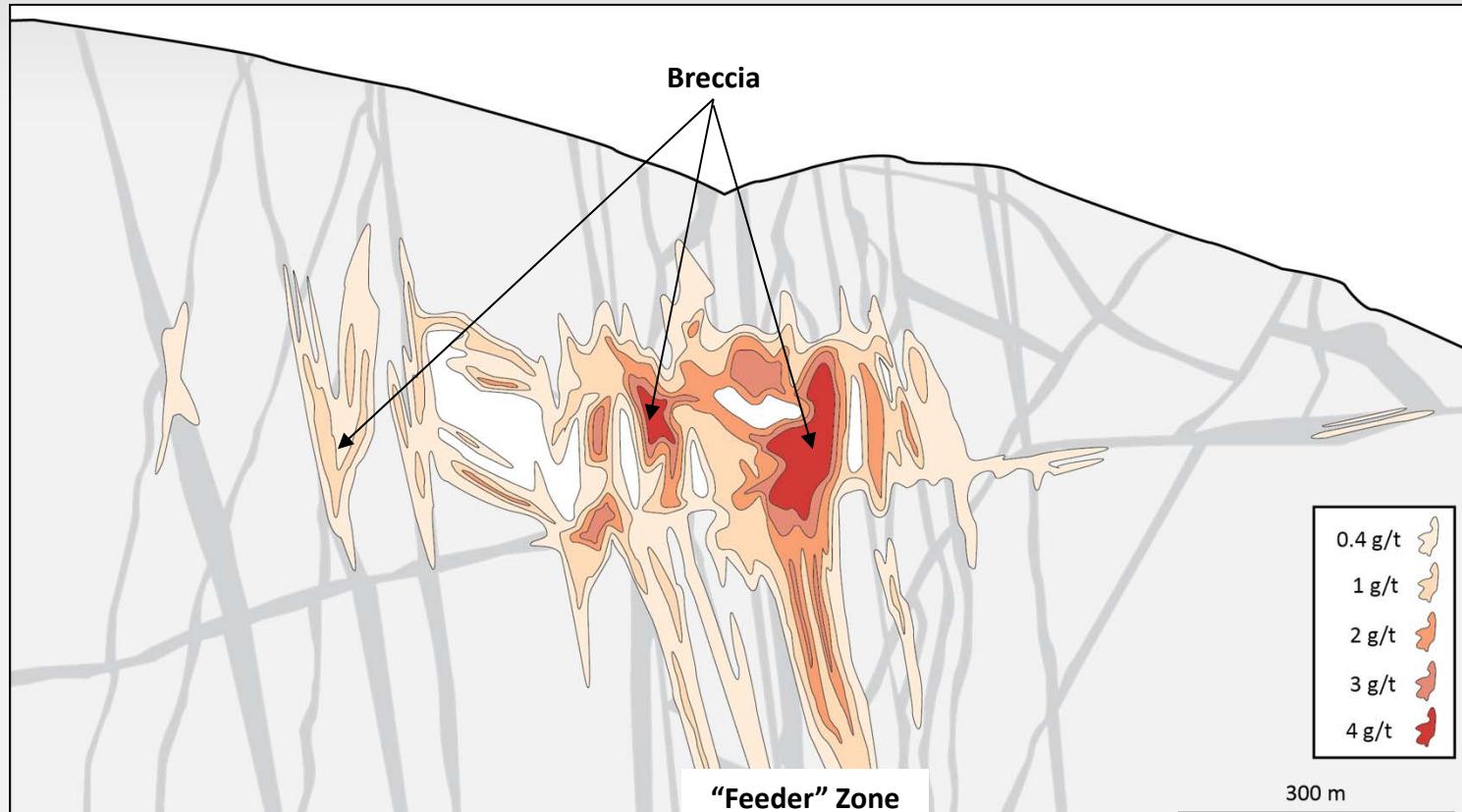
Deposits Occur in Clusters - The El Indio Belt



The El Indio deposit was discovered in 1977 and the region has since become recognised as a major gold-silver-copper district, hosting over 80 Moz gold (Sillitoe, 2008). Economic mineralisation is spatially related to calderas.



Feeder Zones and Structural Controls – Pascua Lama

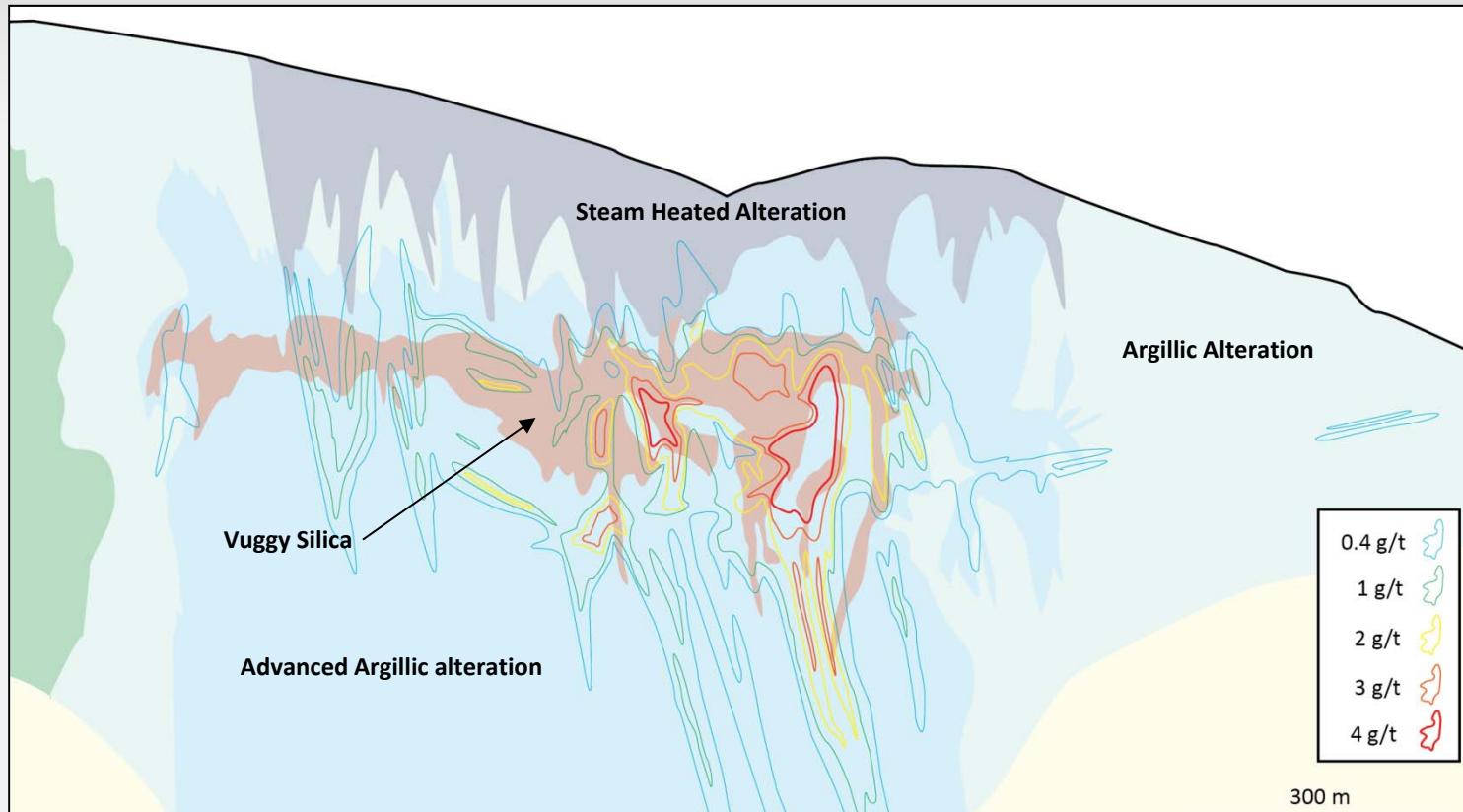


Cross section after Chouinard et al., 2005

Barrick acquired Pascua Lama in 1994 and inherited a resource of 1.8 Moz gold. By 2004 Barrick had increased this to 17.6 Moz gold and 585 Moz silver! Mineralisation is centred on breccias and displays an obvious structural control.



Alteration as a Vector – Pascua Lama



Cross section after Chouinard et al., 2005

Mineralisation is restricted to the advanced argillic envelope, and furthermore displays a close spatial relationship to the less extensive, vertically restricted vuggy silica alteration at the inferred mixing zone.

Deep overburden as very top of system is preserved.



Veladero Discovery History

1980s: Argentine government geologists identify large alteration zone from satellite imagery. Gold anomalies discovered through surface sampling.

1994: Argentina Gold Corp. (AGC) awarded exploration rights. Entered into JV with Barrick (original agreement with Lac Minerals)

1996-1998: Soil surveys, mapping, trenching and drilling.

1999: AGC acquired by Homestake Mining. Aggressive drilling campaign.

2001: Merger between Homestake and Barrick

2005: Production commences

2015: Remaining Reserves 172 Mt @ 0.86 g/t Au (4.7 Moz)

Discovery Hole:
170 m @ 1.90 g/t Au

Follow Up:
193 m @ 1.49 g/t Au
145 m @ 1.06 g/t Au
80 m @ 1.15 g/t Au



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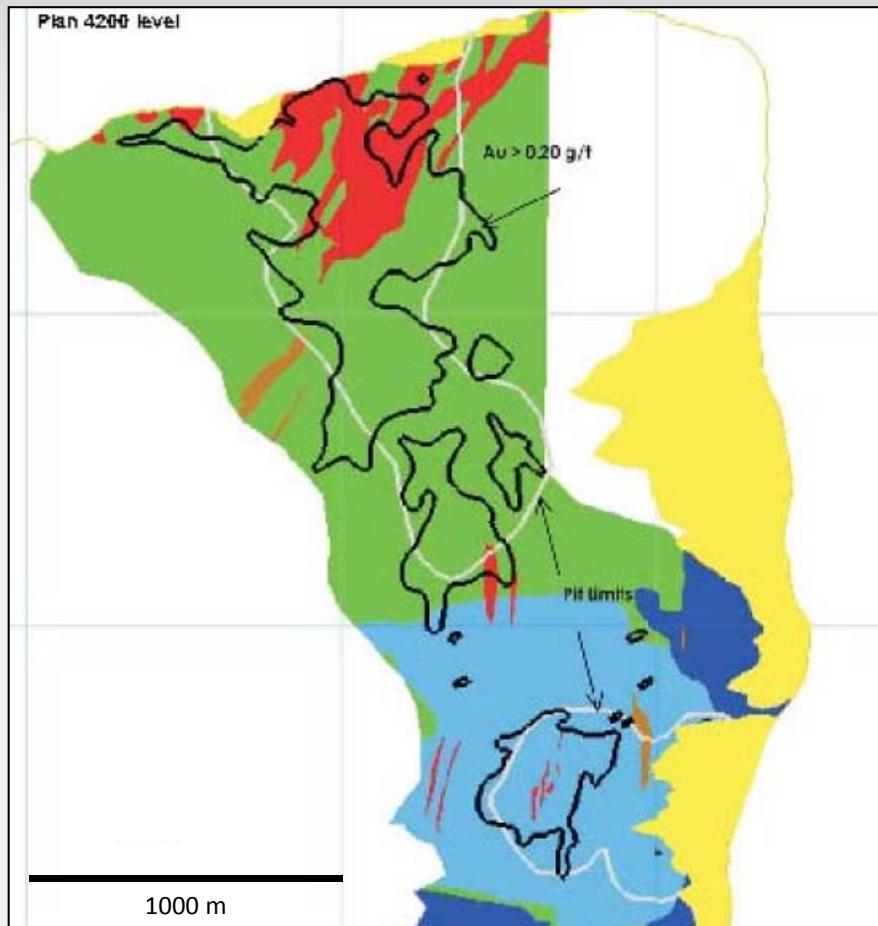
325,284 meters drilled

25 years from prospecting to production

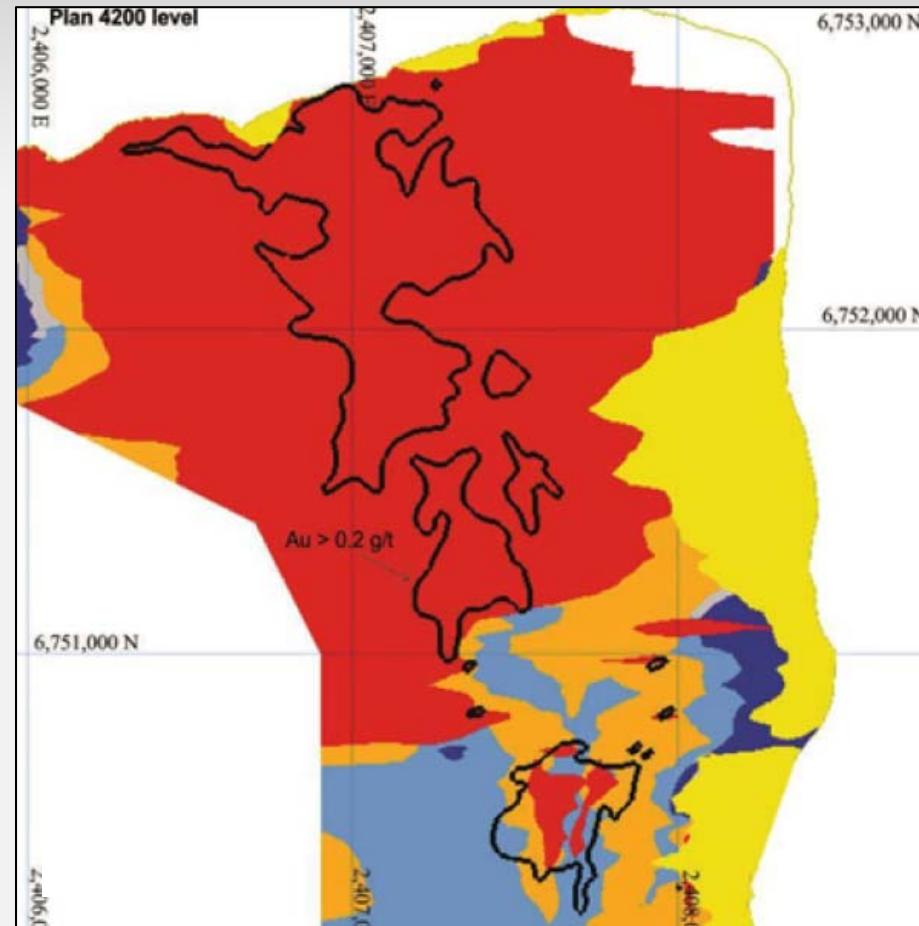
8 years from discovery hole to production



Multiple Mineralised Domains



Geology

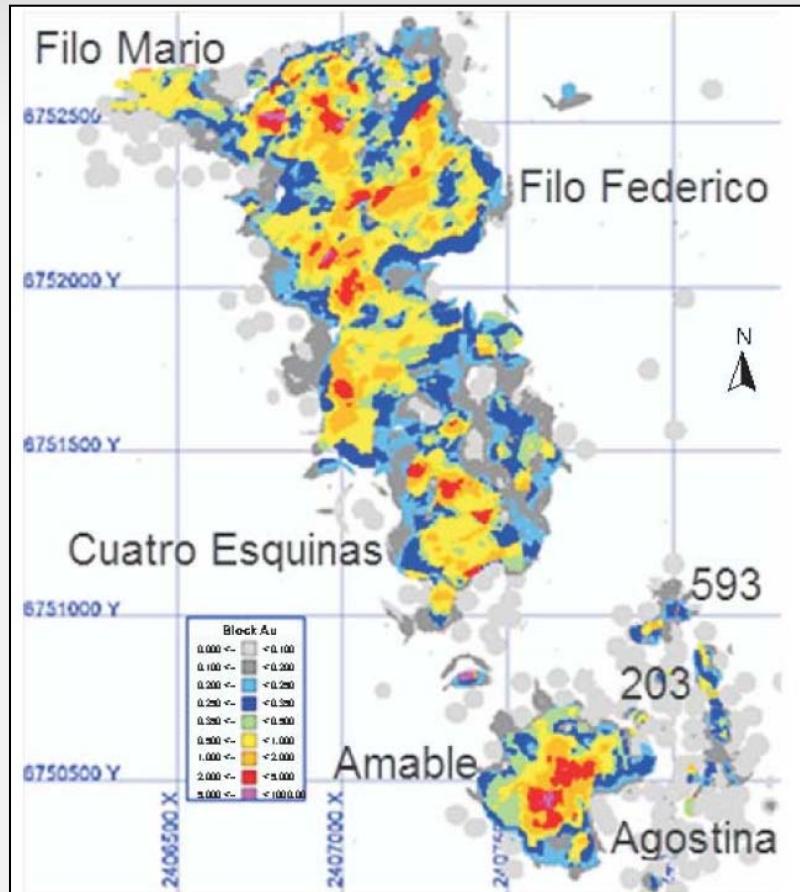


Alteration

Source: Barrick Technical Report



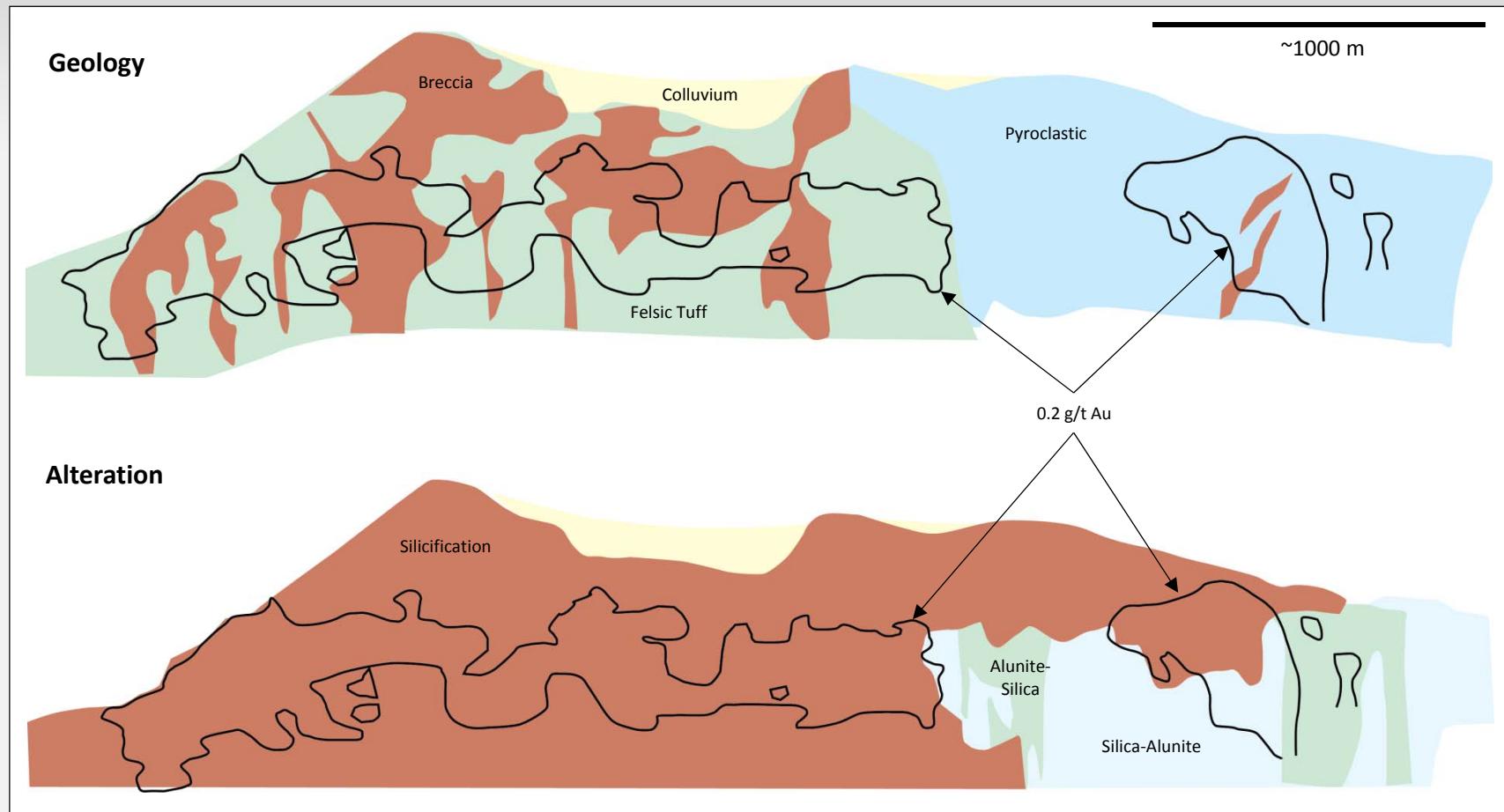
Good Grade Continuity



Source: Barrick Technical Report



Mineralisation Centred on Breccias



Long sections modified from Barrick Technical Report

Mineralisation hosted largely in volcanic explosion breccias and tuffs which are silica altered.



Mineral Processing

Ore Type	Au Grade (g/t)	Recovery Formula (%)
Federico Filo Type 1 (crushed)	Au ≤ 0.3	60
	0.3 ≤ 0.5	38.4 * Au(g/t) + 55
	0.5 ≤ 1.6	2.4 * Au(g/t) + 77
	1.6 ≤ 2.0	10.0 * Au(g/t) + 65
	2.0 ≤ Au < 3.0	2.0 * Au(g/t) + 81
	3.0 ≤ Au	87
Federico Filo Type 2 (crushed)	Au ≤ 0.5	40
	0.5 ≤ Au < 1.0	4.0 * Au(g/t) + 38
	1.0 ≤ Au < 3.0	14 * Au(g/t) + 28
	3.0 ≤ Au	70
Amable Type 1 (crushed)	Au ≤ 0.3	58
	0.3 ≤ Au < 0.5	20.0 * Au(g/t) + 52
	0.5 ≤ Au < 1.0	16.0 * Au(g/t) + 54
	1.0 ≤ Au < 2.0	10.0 * Au(g/t) + 60
	2.0 ≤ Au	80%
Amable Type 2 (crushed)	Au ≤ 0.5	40
	0.5 ≤ Au < 1.0	4.0 * Au(g/t) + 38
	1.0 ≤ Au < 2.0	14.0 * Au(g/t) + 28
	2.0 ≤ Au	56
Federico Filo Type 1 (ROM)		60
Federico Filo Type 2, Amable Type 1 and Type 2		60% of estimated crushed ore recovery

Table from Barrick Technical Report

Ore is heap leached and recovered by Merrill-Crowe cyanide leach.

Federico Type 2 associated with argentojarosite.

Other projects, for example Lihir, utilise pressure oxidation followed by cyanide leaching to improve recovery.



Quimsacocha, Ecuador

1970s: UN exploration program identifies stream sediment anomalies.

1991: COGEMA drilled 2944 metres

1993: Newmont JV with COGEMA - 7581 M drilled. Best intercept 2 metres @ 83 g/t gold, 316 g/t Ag. JV dissolved.

1999: IAMGOLD acquired concessions. Re-interpreted geology using PIMA analysis on drill core. Drilled 74,652 metres through to 2007.

2008: New Ecuadorian Constitution and amendment of mining regulations (2009).

2011: INV purchase agreement with IAMGOLD.

2013: 3684 meters drilled.

2015: INV announce Pre-Feasibility Study – underground lbg hole stoping with drift and fill mining. Sequential flotation to produce pyrite and copper cons.

88,861 meters drilled

~45 years from prospecting to PFS

11 years from discovery hole to Current PFS



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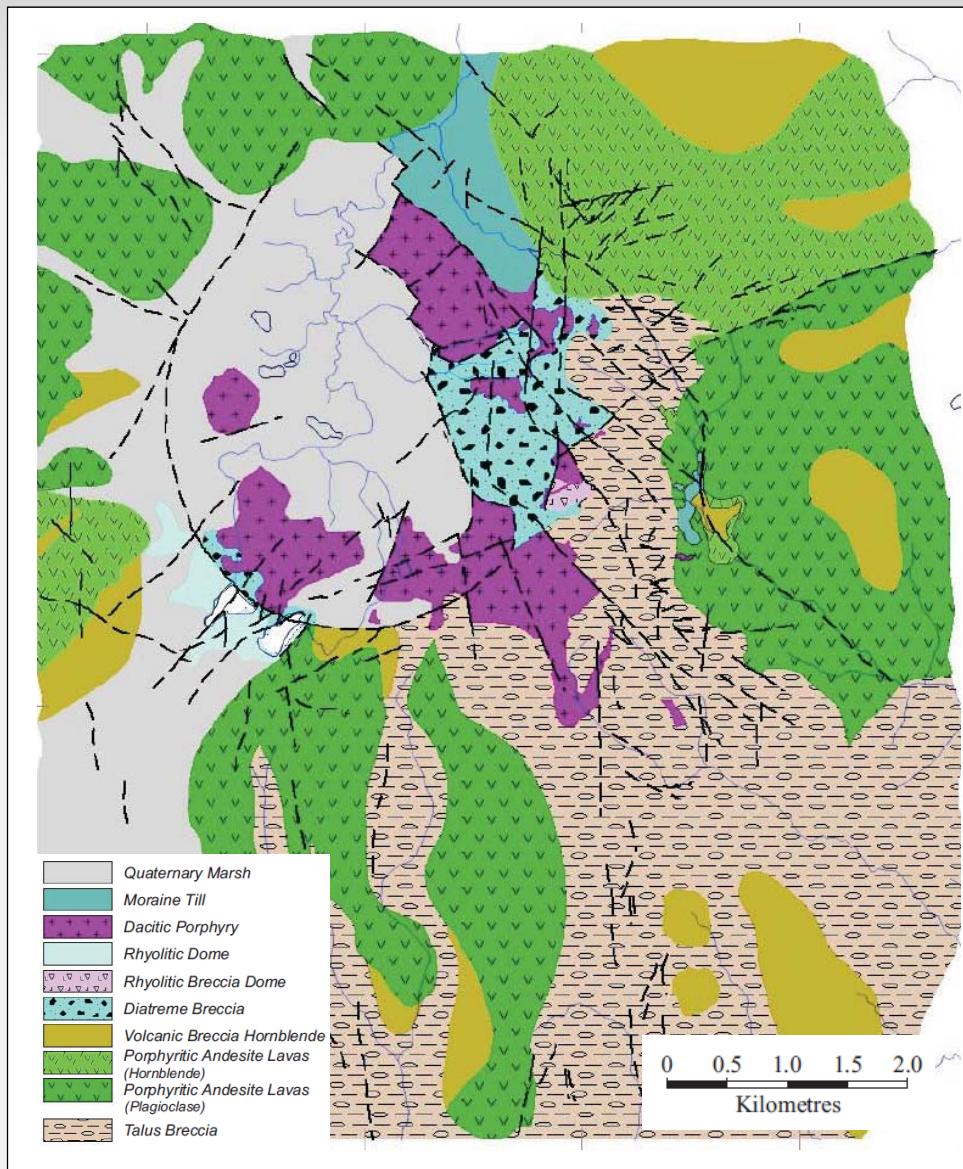
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Discovery Hole:

102 m @ 9.2 g/t Au, 46.9 g/t Ag
0.4 % Cu



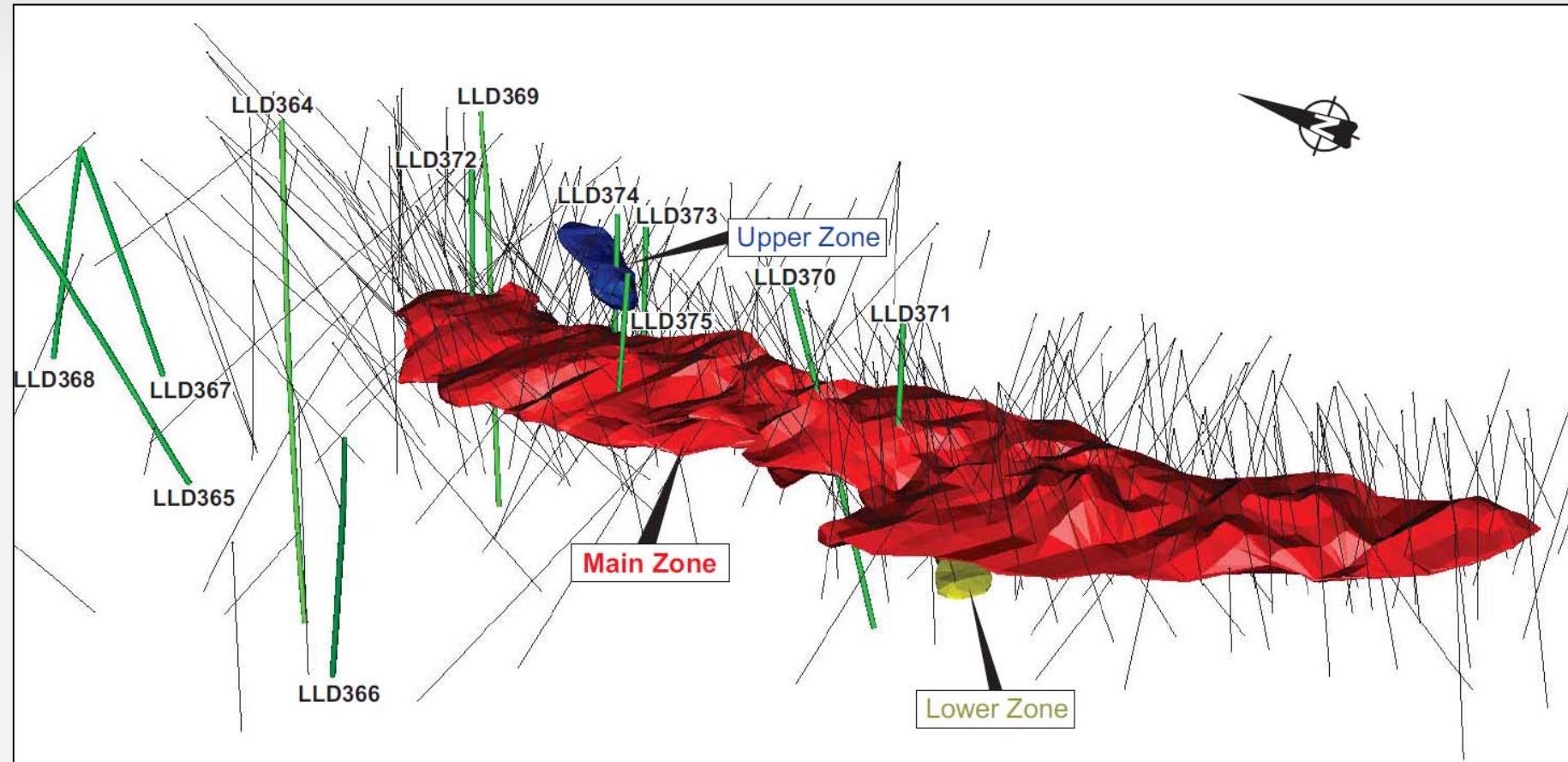
Proximal to Caldera



from IAMGOLD Technical Report



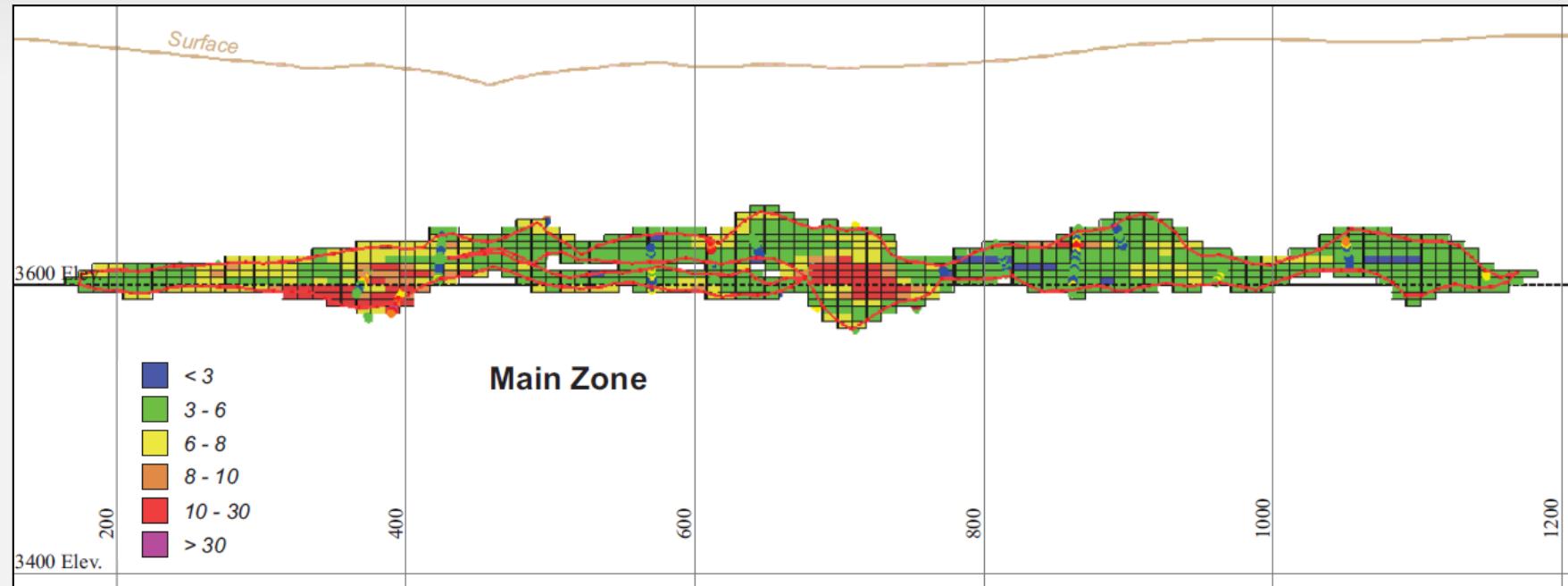
Typical High Sulphidation Morphology



from INV Technical Report



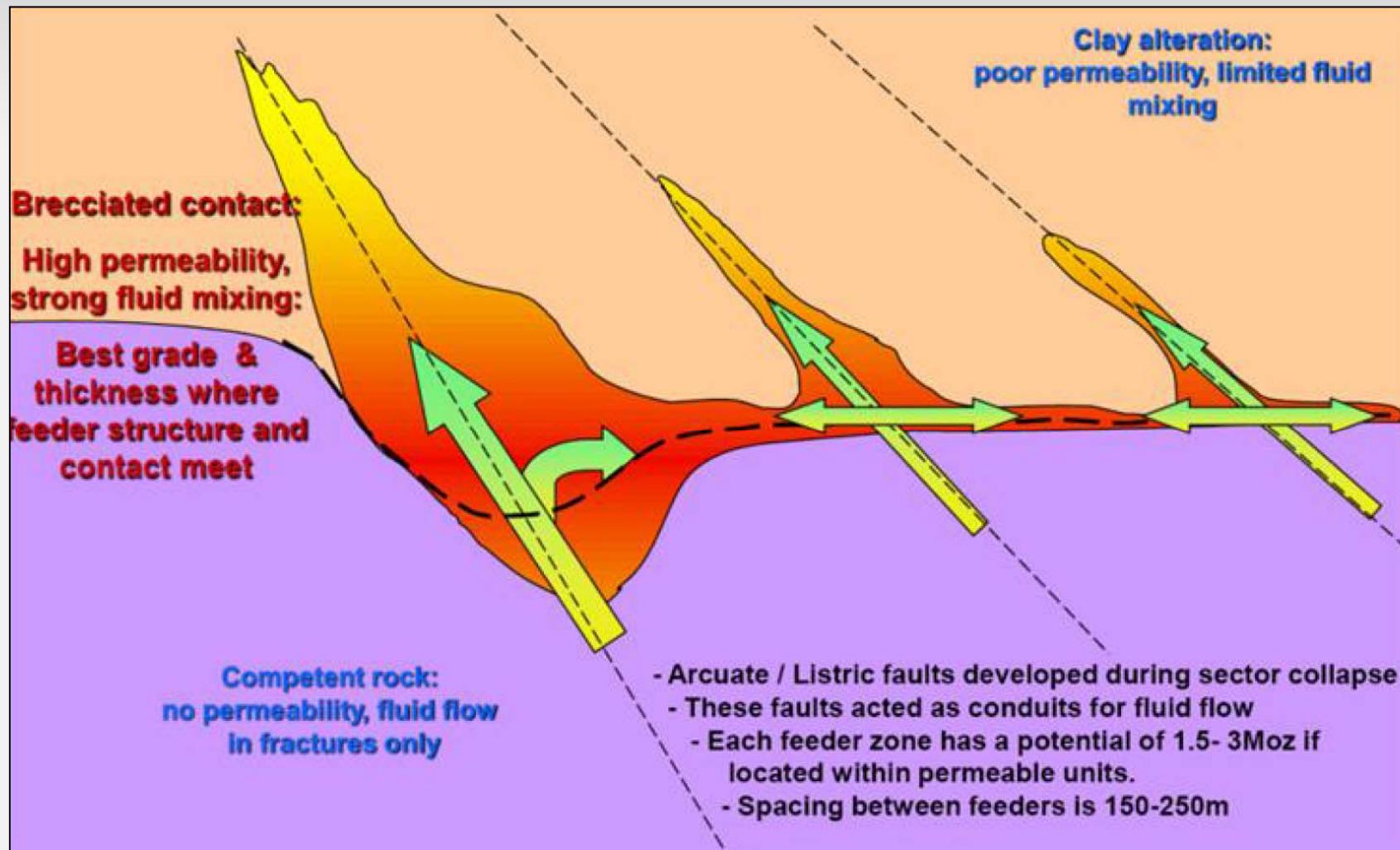
Excellent Grade Continuity



from INV Technical Report



Conceptual Model Led to Discovery



Source: Newcrest Lihir Technical Report



Thank You



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