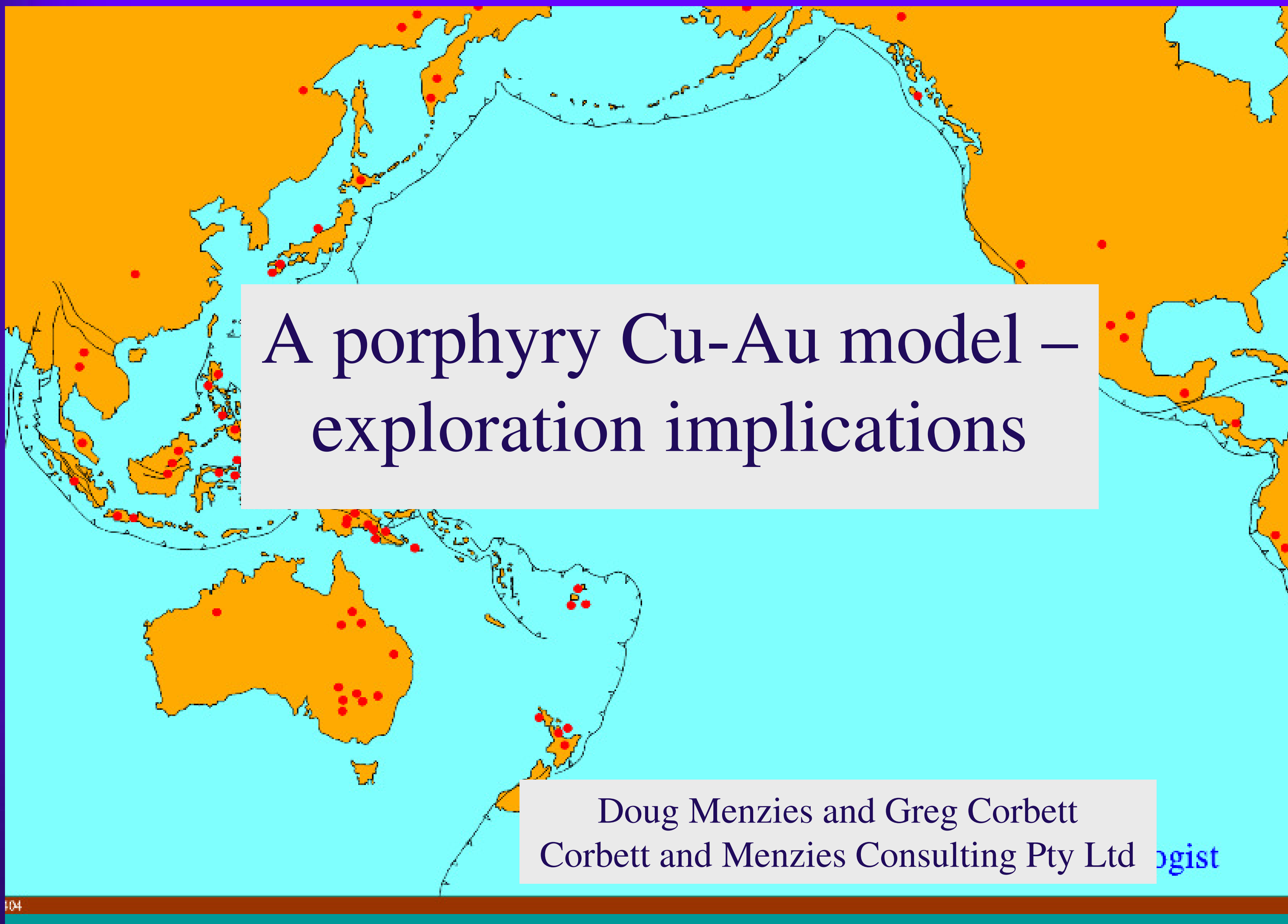
A porphyry Cu-Au model – exploration implications



Doug Menzies and Greg Corbett
Corbett and Menzies Consulting Pty Ltd

Thanks – porphyry mapping course

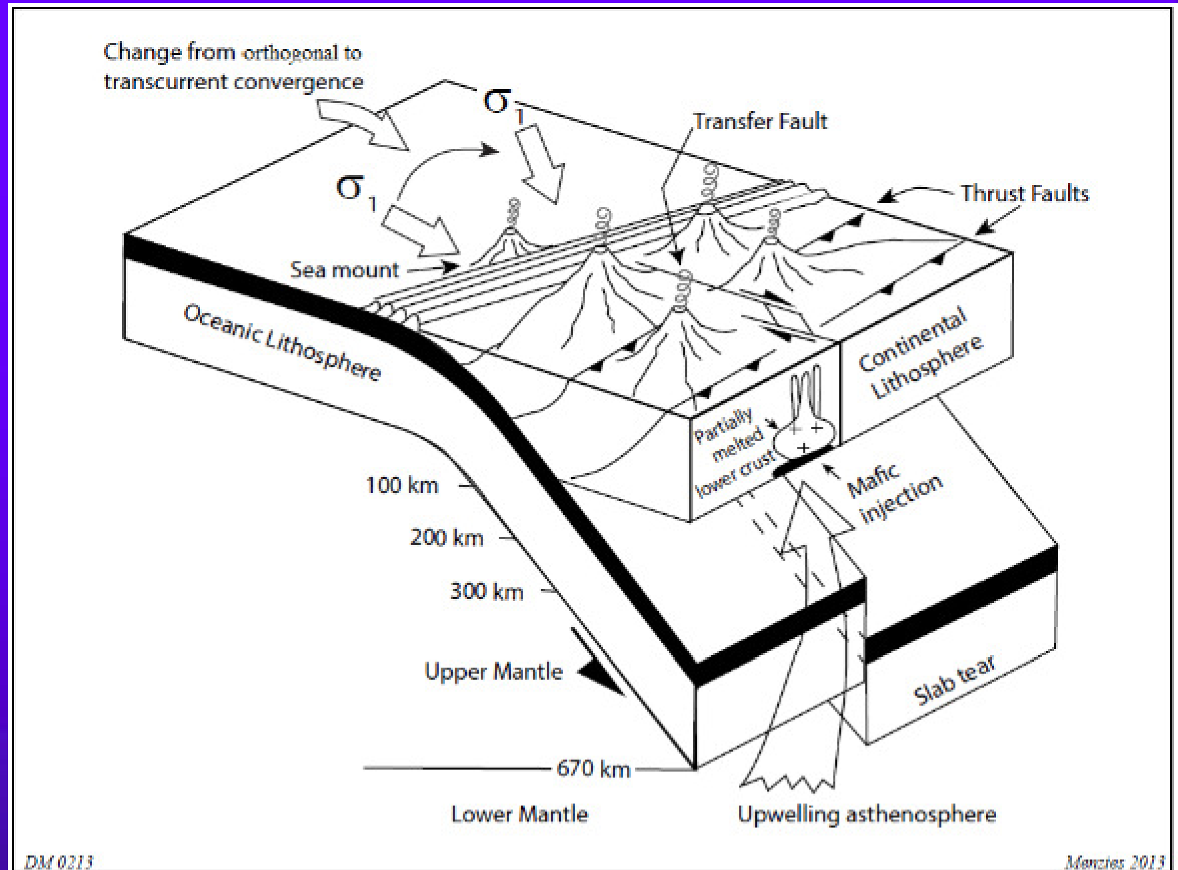
- Golden Cross Resources
- Newcrest Mining Limited
- North Parkes Mine
- Mel Quigley – Minerals Matter
- Hanne Paulsen

Agenda

- Localisation of porphyry Cu-Au deposits (PCD)
- Factors that contribute to the high Cu-Au grades in porphyry deposits and metal zonations
- Stage model for the evolution of porphyry Cu-Au deposits incorporating time.
- Field based vectors used to explore for porphyry Cu-Au deposits.

Localisation of porphyry Cu-Au systems

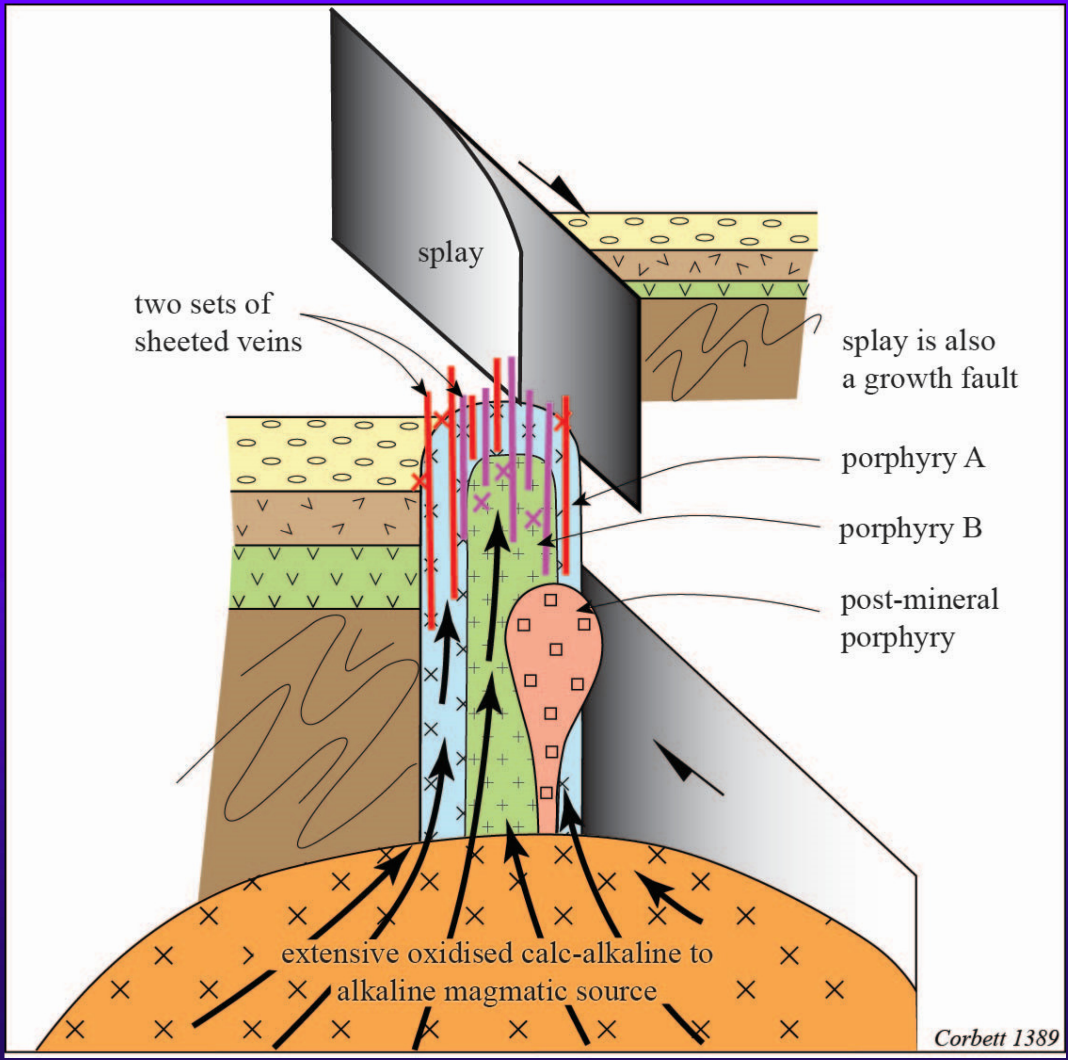
- Associated with subduction related magmatic arc.
- Emplaced during a change in convergence from orthogonal to transcurrent convergence
- Partial melting of lower crust emplaced in dilational transfer structures



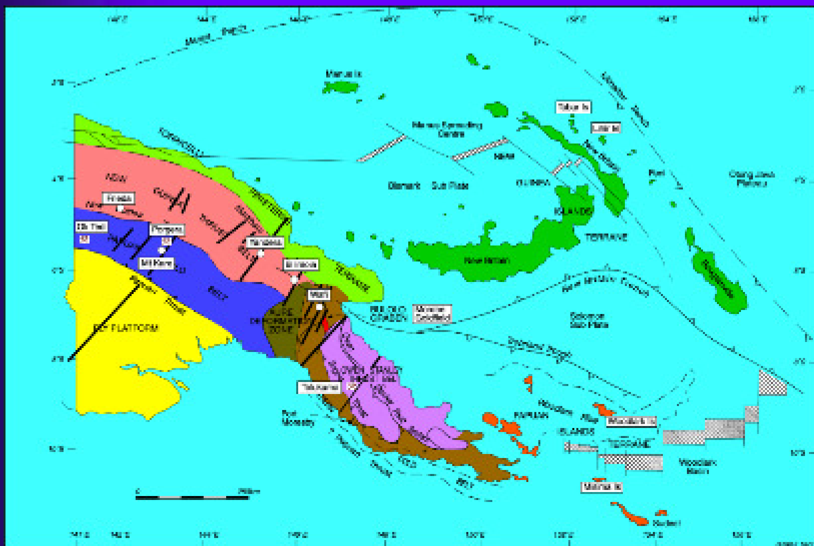
- Slab tear facilitates upwelling of mafic magmas from asthenosphere to increasing Cu-Au endowment

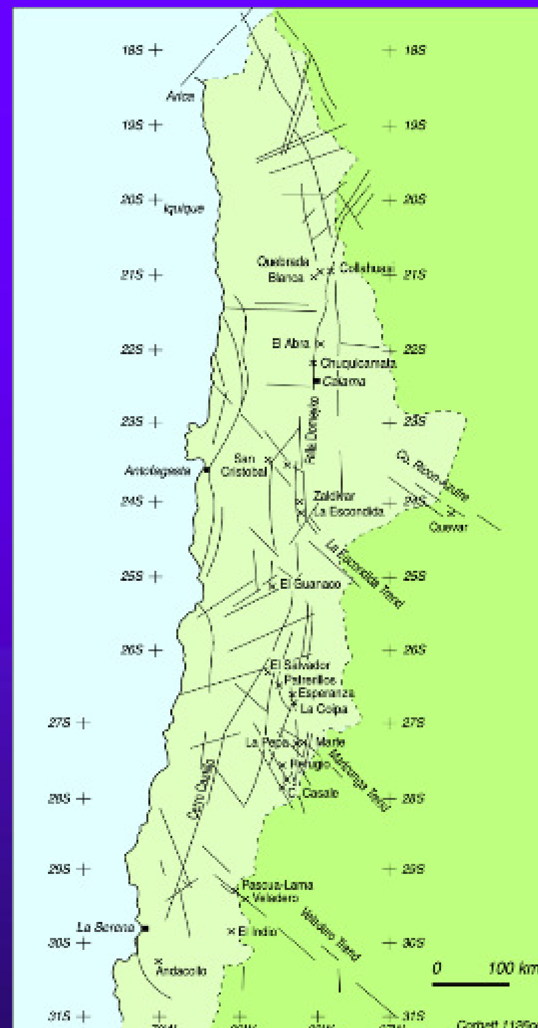
Controls to porphyry Cu-Au-Mo mineralisation

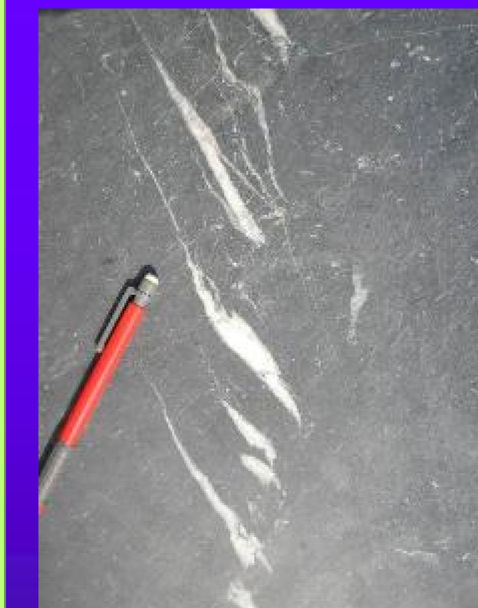
- Fertile magmatic source
- Trigger provided by change in convergence
- Dilatant setting eg splay
- Sheeted veins
- Competent host rock
- Polyphasal intrusions
- Only minor post-mineral porphyry

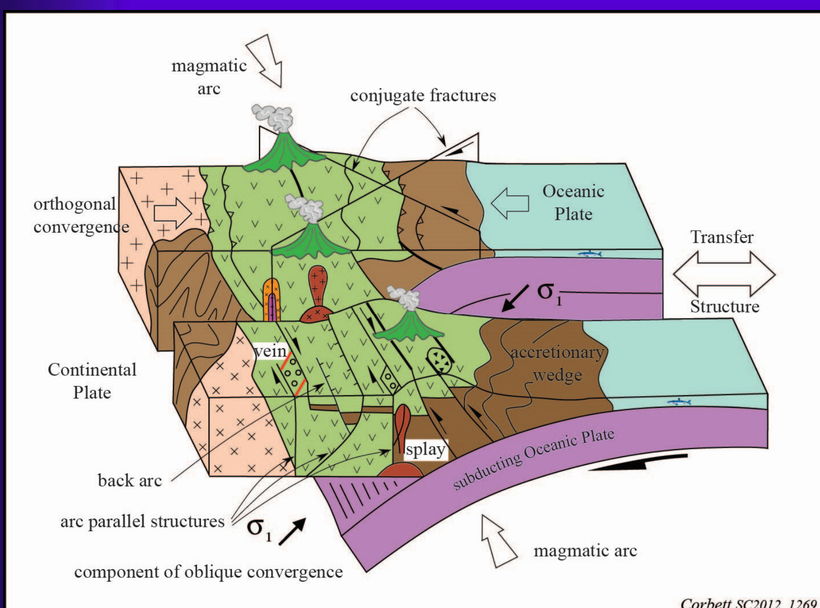


Major structures



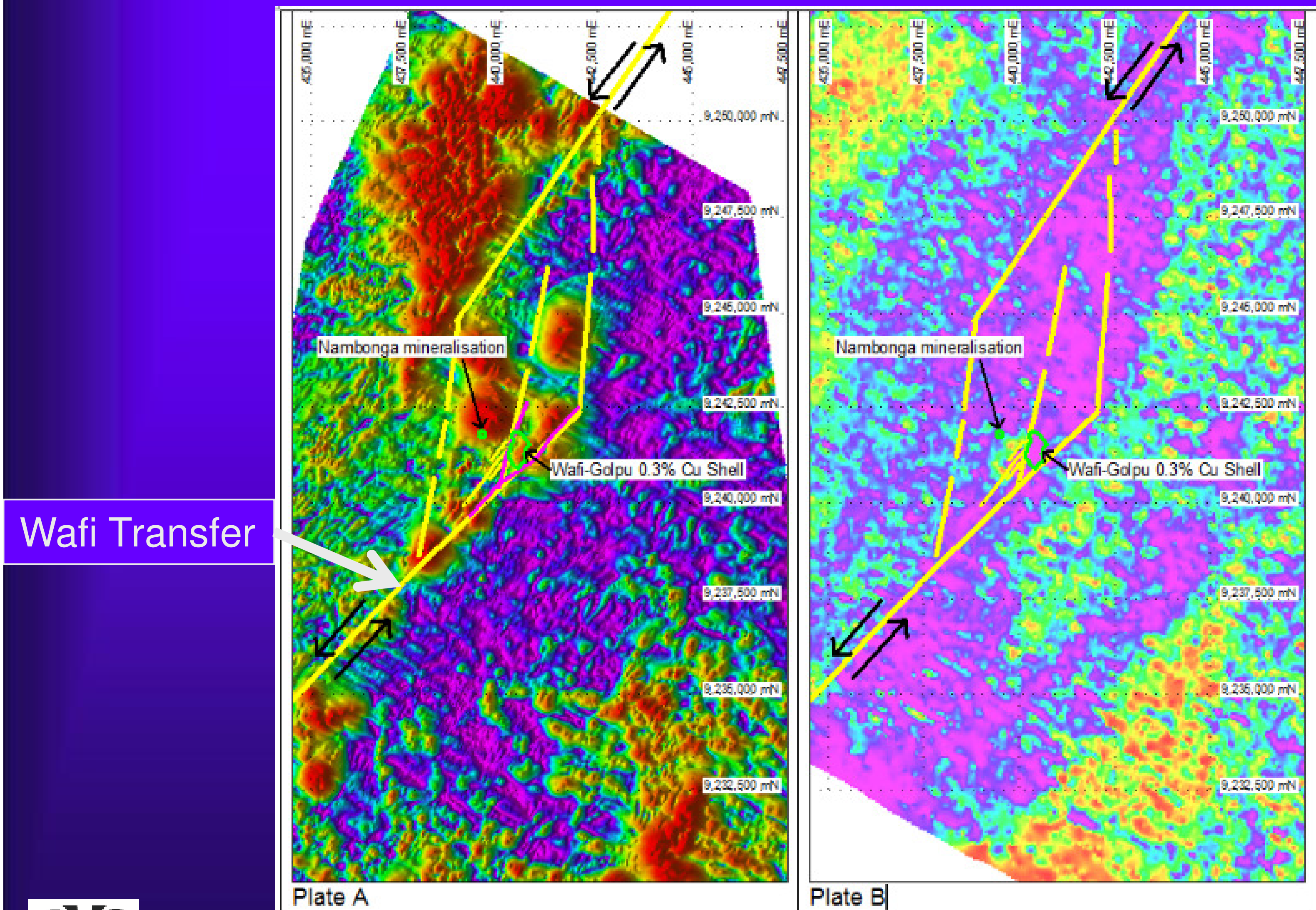






Corbett (in prep)

Wafi-Golpu



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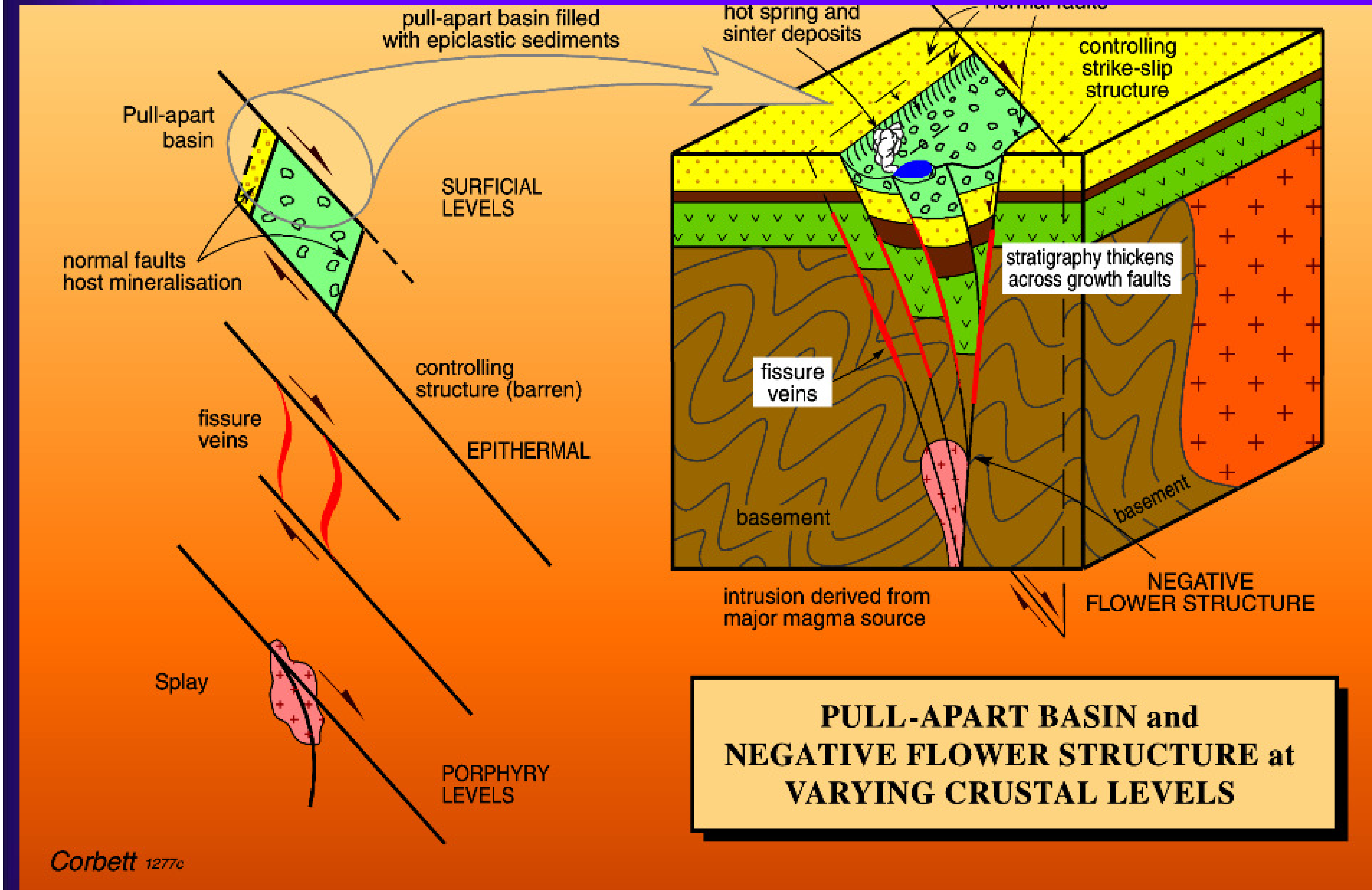
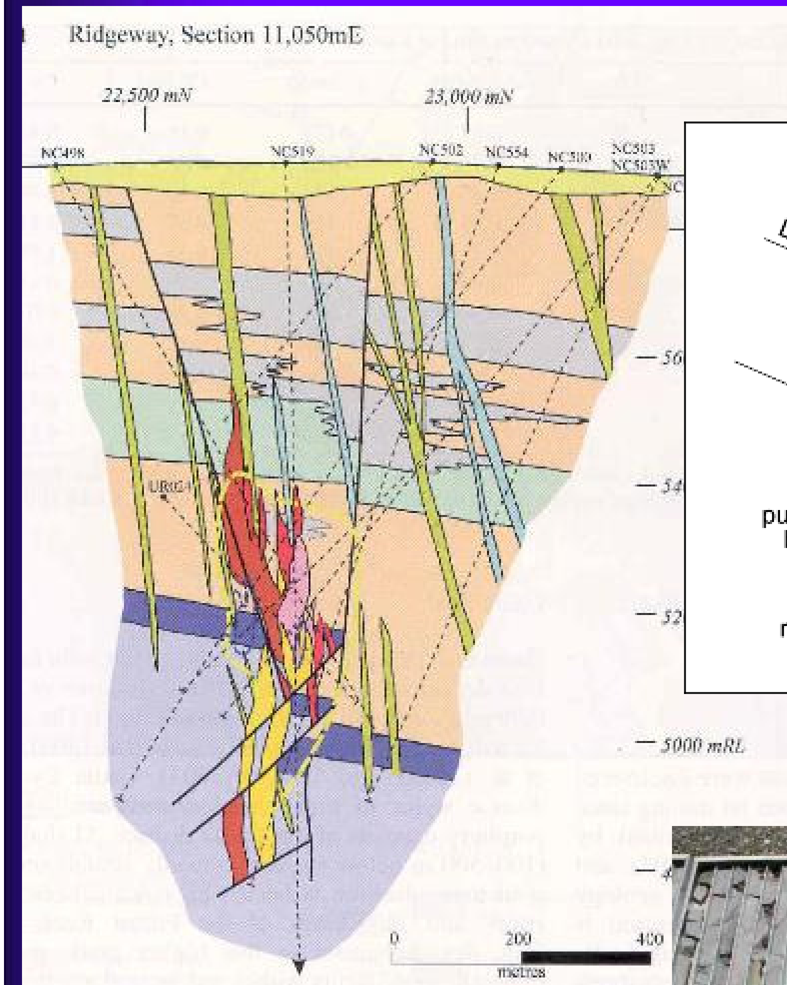
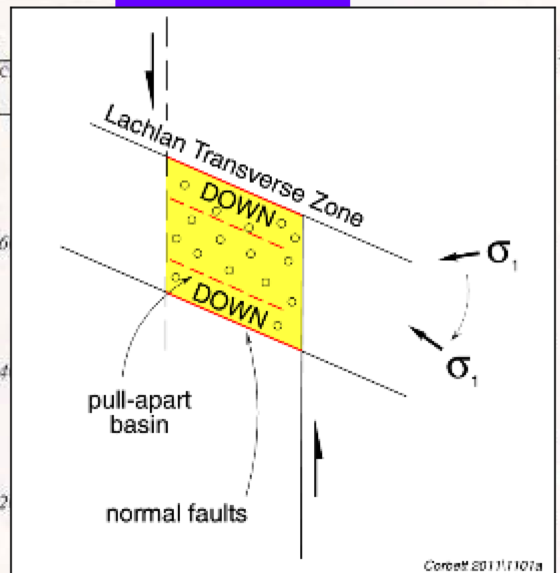
Menzies et al., (2013)

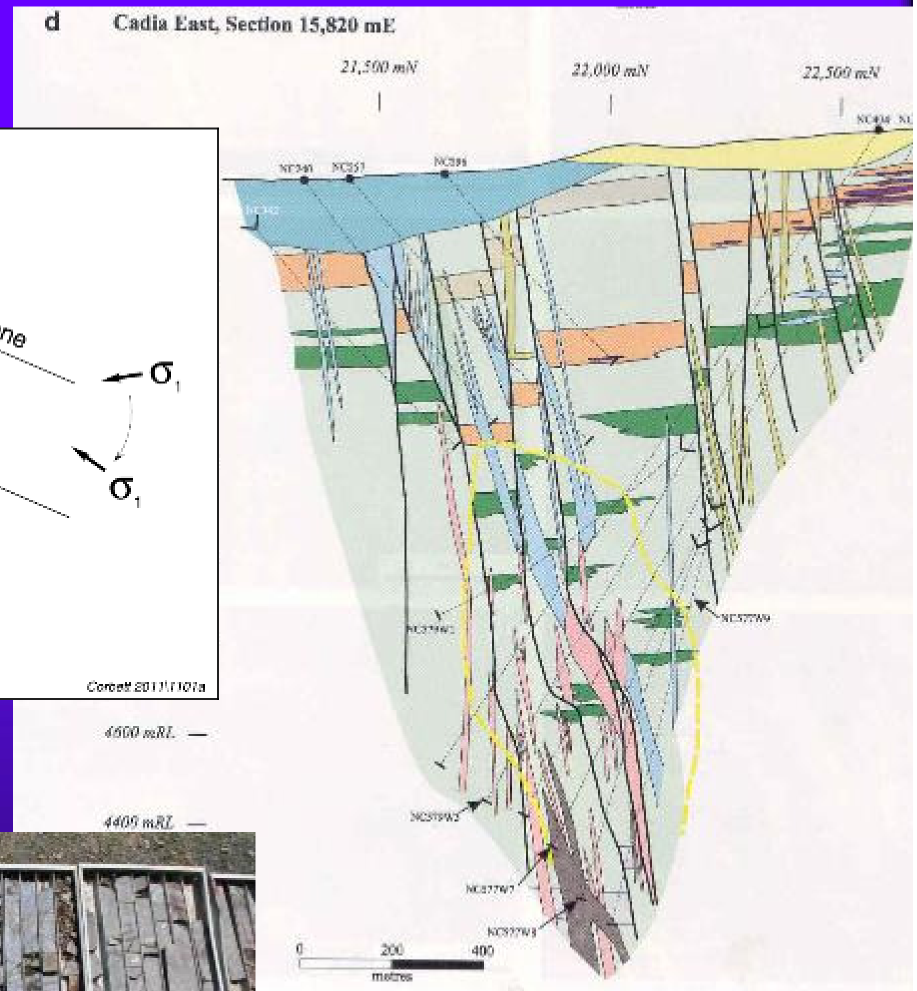
Structure in porphyry systems – localisation



Cadia Valley







Ridgeway

Cadia East

Corbett and Menzies Consulting

Wilson et al., (2005)

Porphyry Cu-Au system magmas

- Calc-alkaline to alkaline in composition.
- **High water content** to promote volatile exsolution and fracturing at depths of 2-8km.
- **High oxidized (high $f0_2$)** to enable Cu-Au partitioned in pyrrhotite and be liberated in aqueous phase.
- **High Cl/H_2O ratios** allows transportation of Cu-Au into aqueous phase as chlorocomplexes.
- **High fS** needed to precipitate sulphides.

Using work by Candela (1989), Candela (2005), Jenner et al, (2010)

CMC

Factors contributing high Cu-Au grades

- High Cu-Au content is associated with bornite mineralisation

Ridgeway, NC498, 688m stock worked quartz-cpy-bornite veins 31.0g/t Au + 1.93% Cu within 84m from 821m at 7.40g/t Au and 1.27% Cu

Wafi-Golpu WR377 - 883m @ 2.15% Cu and 2.23g/t Au

References: Holliday et al (1999) Smedge; Harmony gold website

Factors contributing high Cu-Au grades

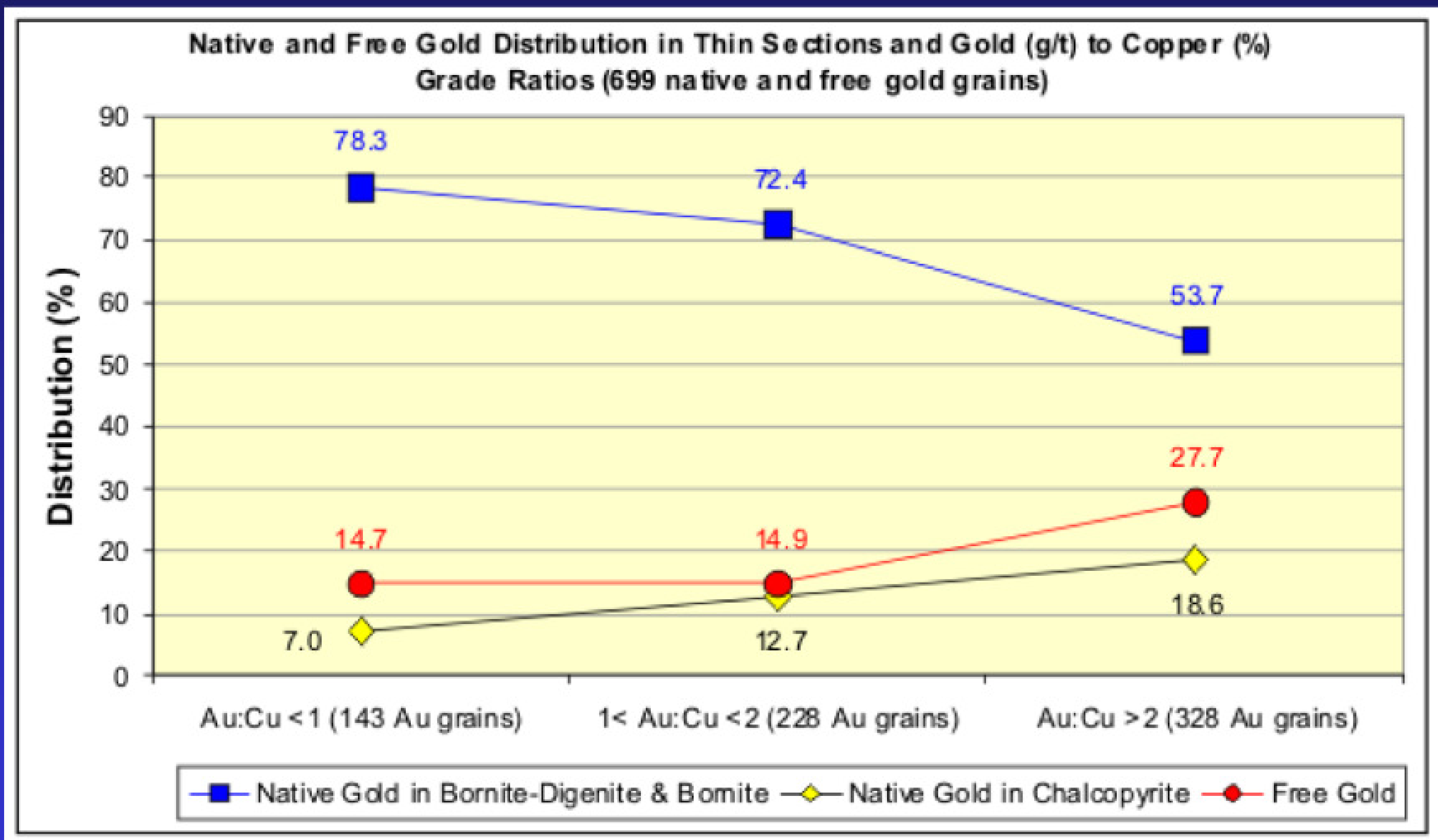
- Wafi-Golpu - later epithermal quartz-carbonate-base metal veins overprinting the system produced by the mixing of magmatic fluids with bi-carbonate bearing meteoric fluids

Wafi- 85m at 3.2 g/t Au.

WR444 – Wafi free gold in quartz-carbonate-galena-sphalerite vein reporting 1m of up to 110 g/t Au

Ref: Newcrest quarter report, June 2013; Harmony 3rd quarter report, 2013

Batu Hijah–Gold deportment & Cu:Au ratio



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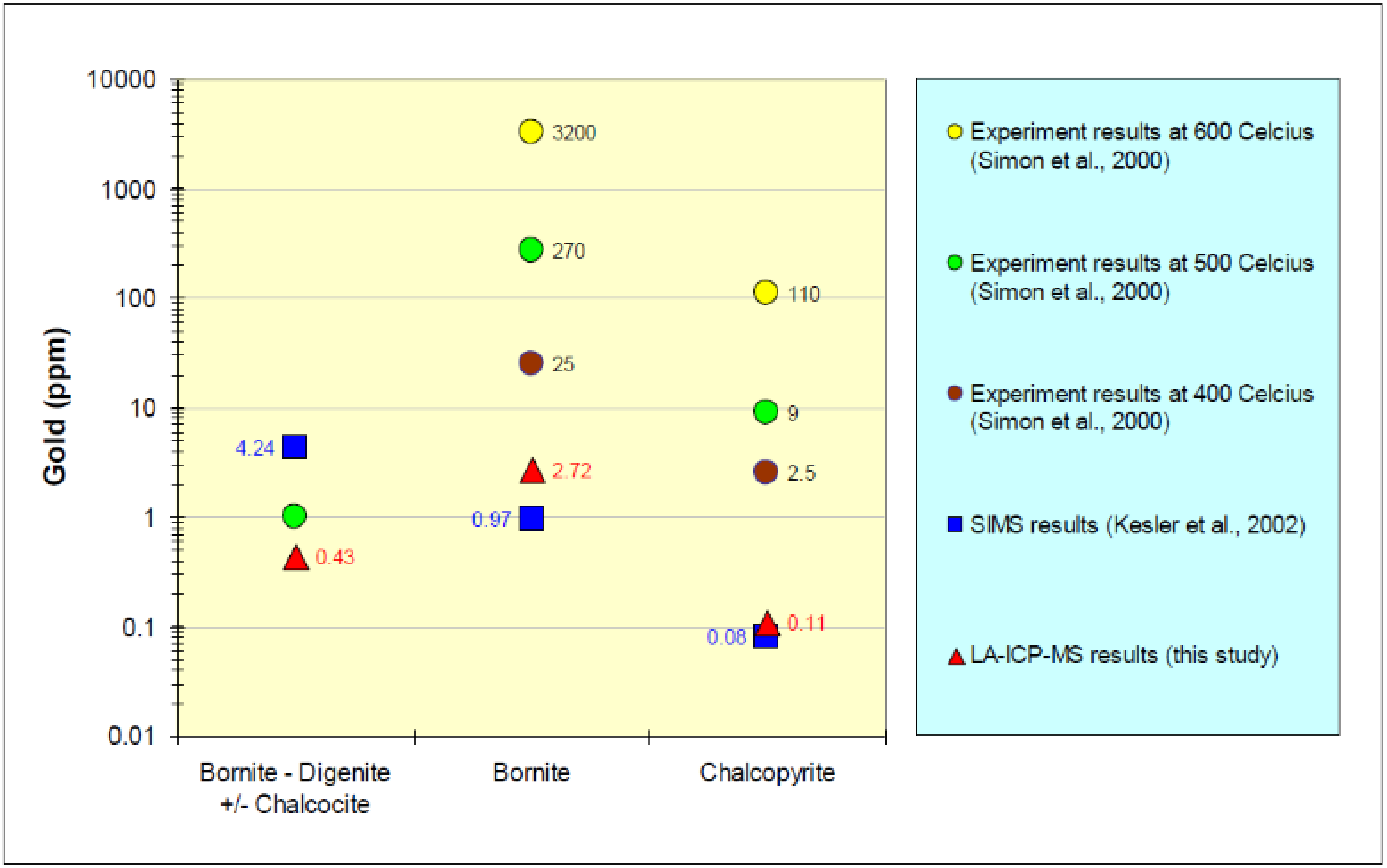
Arif and Baker, 2012

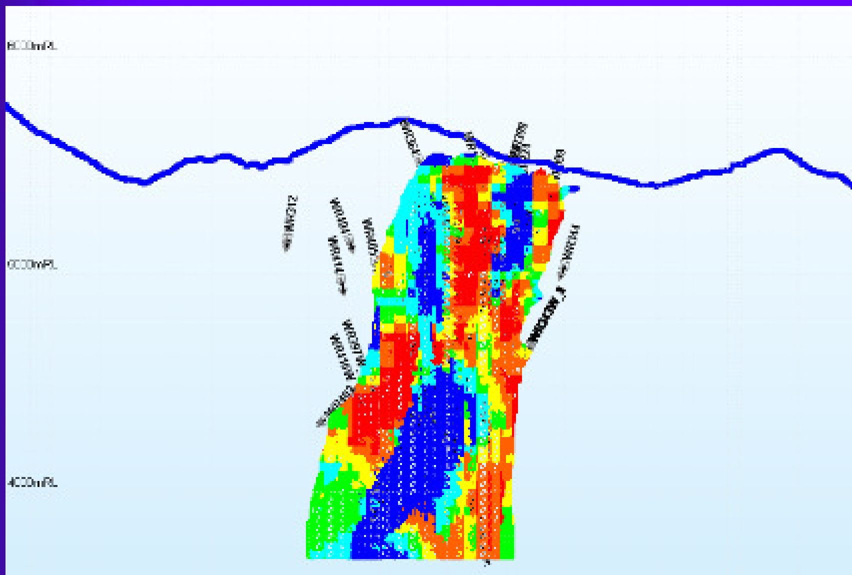
Gold deportment in bornite



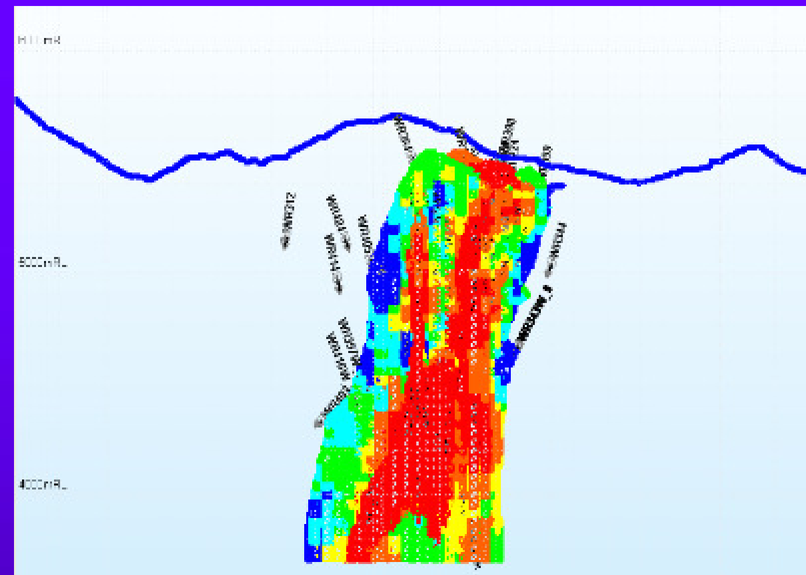
Arif and Baker, 2012 after Simon et al, 2000 and Kesler et al, 2002)

Au vs Cu vs Mo zonation at Wafi

Golpu Long section - Mo in block model



Golpu Long section - Au in block model

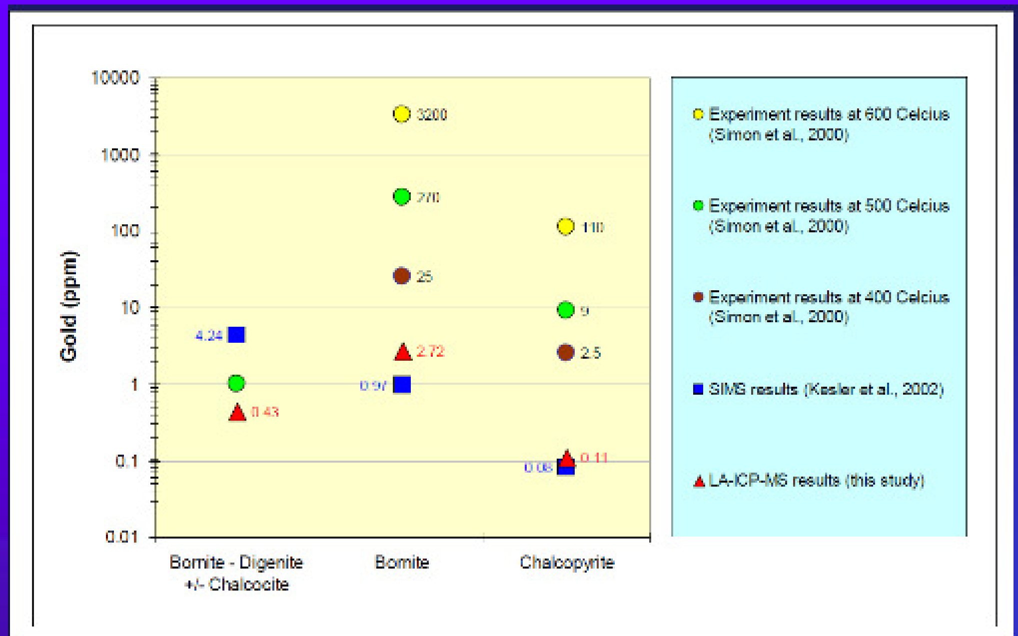


- Au:Mo Pearson correlation r = -0.024, n=32653 **(negative correlation)**
- Cu:Au Pearson correlation r = 0.607, n=32653 **(positive correlation)**
- Au:bornite Pearson correlation r = 0.21, n = 1890 **(positive correlation)**
- Cu:Mo Pearson correlation r = 0.031, n=32653 (neutral correlation)

Menzies et al., (2013)

Interpretation

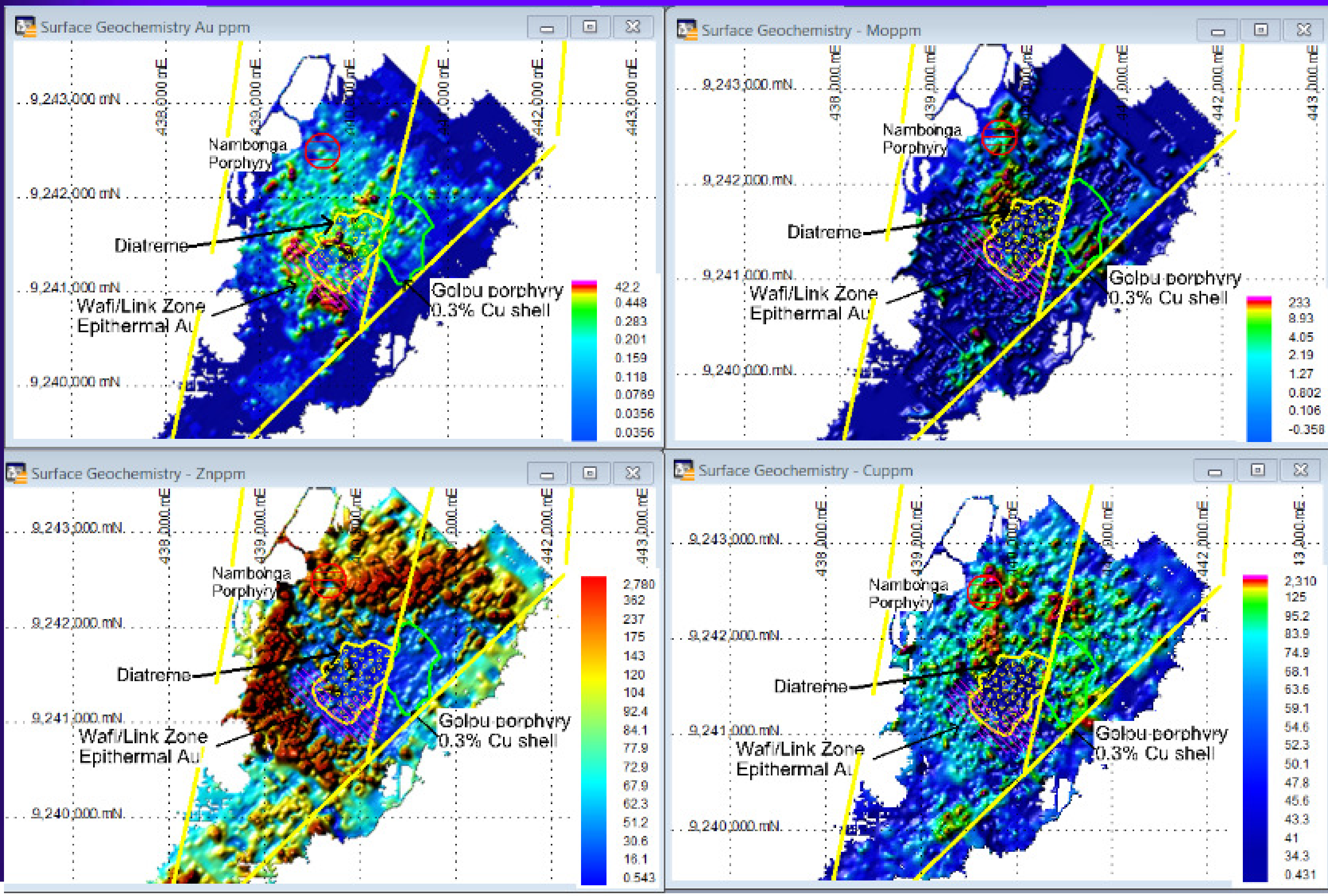
- Greater Au deposition associated with bornite as proposed by Simon *et al.* (2000) and Kesler et al (2002).



- Separate metal deposition event for Mo vs Cu/Au. Molybdenite possibly deposited by hypersaline Fe, K, Cl rich brine as oxochochloride complexes as proposed by Ulrich and Mavrogenes (2008) and Li *et al.* (2012).

Menzies et al., (2013)

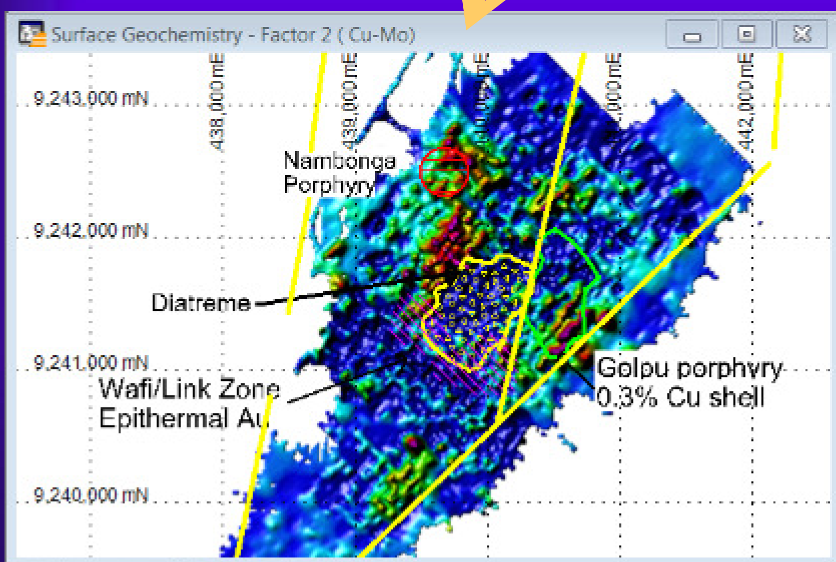
Wafi - Surface geochem zonatation

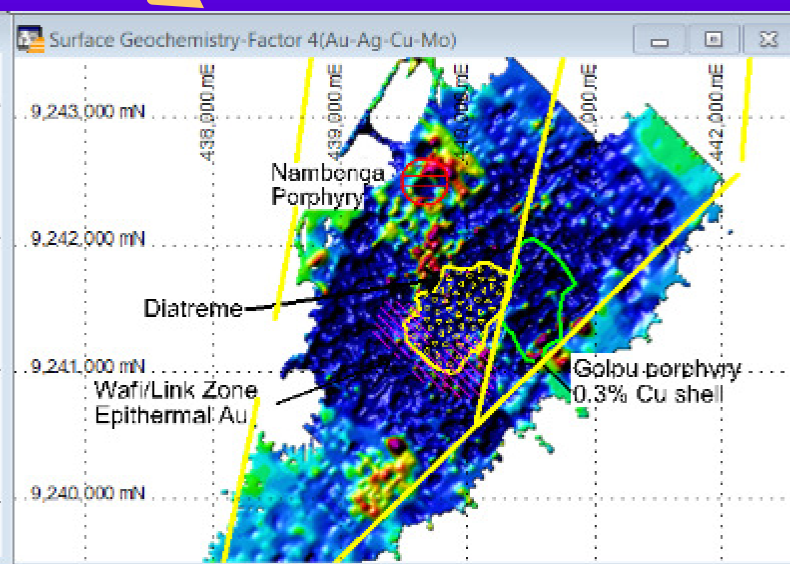


Menzies et al., (2013)

PCA of Wafi surface data

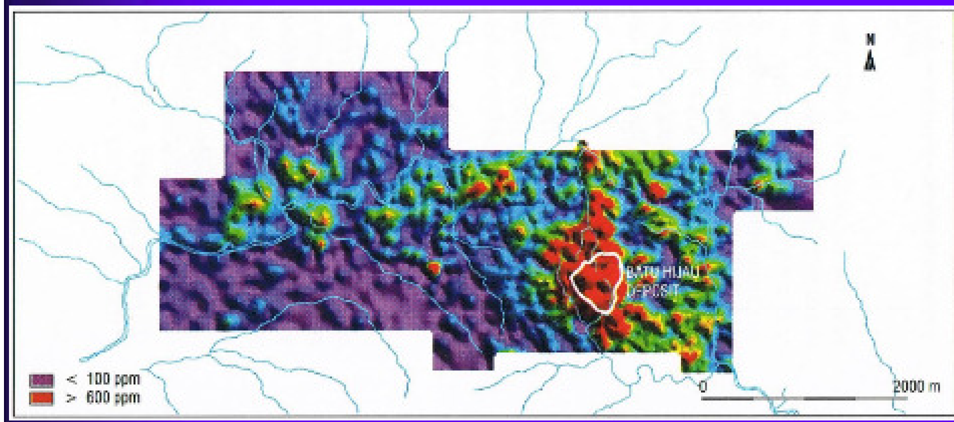
Eigenvectors:							
	F1	F2	F3	F4	F5	F6	F7
Au_ppm	0.278	-0.301	-0.019	0.858	0.027	-0.286	0.111
Cu_ppm	0.172	0.630	0.376	0.117	0.639	-0.090	0.055
Pb_ppm	0.553	-0.147	-0.051	-0.356	0.016	-0.085	0.732
Zn_ppm	-0.048	-0.064	0.829	-0.084	-0.441	-0.322	0.013
Ag_ppm	0.505	-0.115	0.285	0.090	-0.079	0.756	-0.252
As_ppm	0.548	-0.011	-0.172	-0.264	-0.002	-0.475	-0.612
Mo_ppm	0.170	0.688	-0.240	0.196	-0.625	0.027	0.105



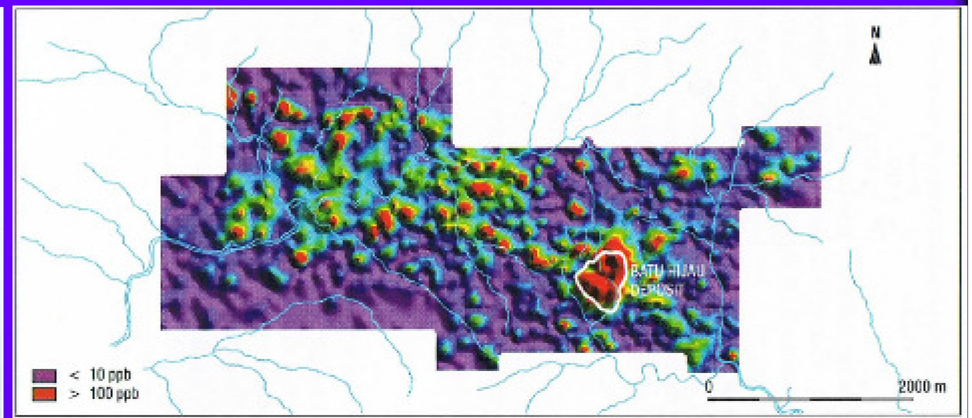


Menzies et al., (2013)

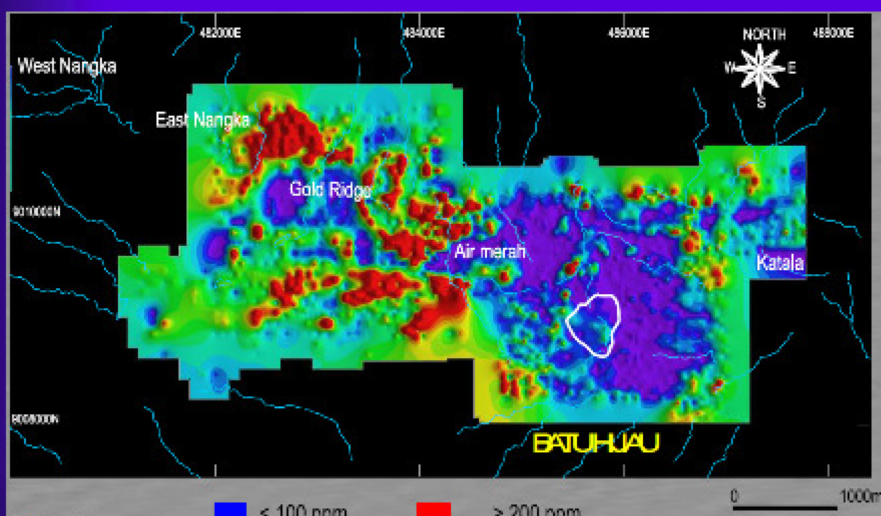
Batu Hijah–surface geochem zonation



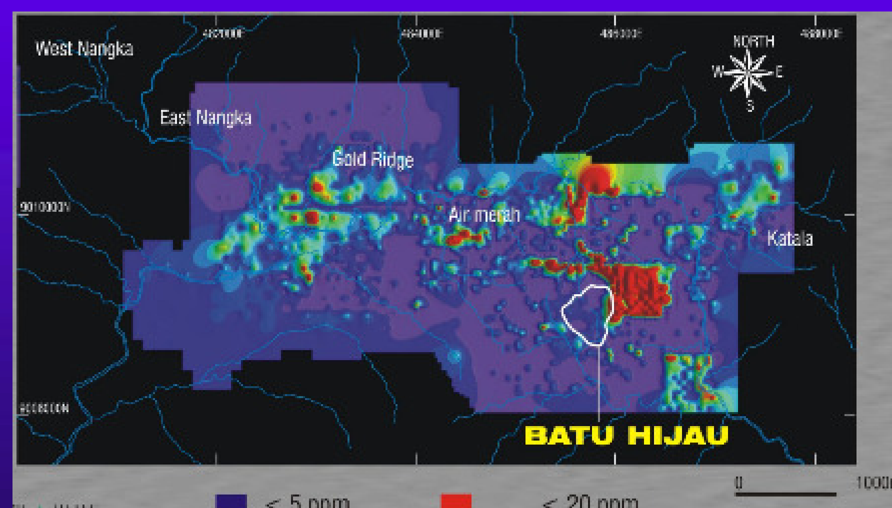
Cu ppm.



Au ppm.



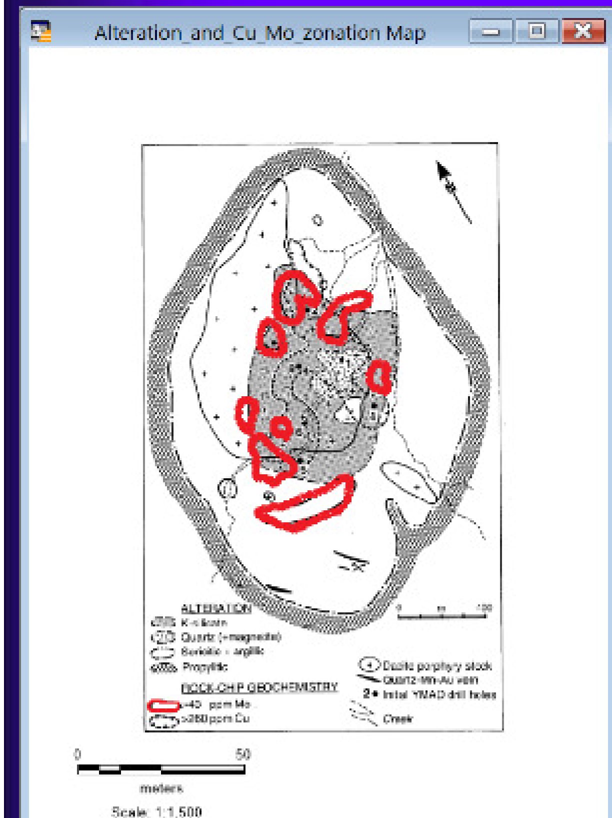
Zn ppm.



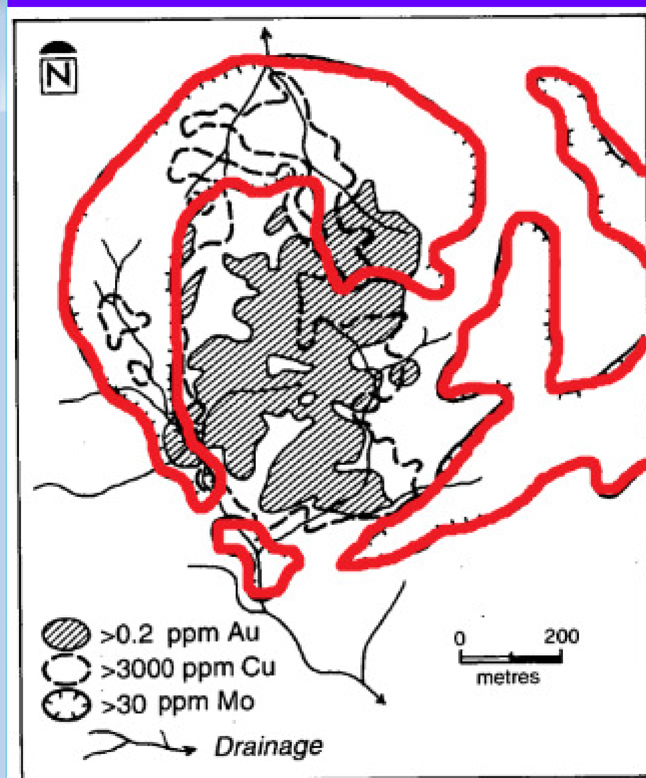
Mo ppm.

Maula and Levet (1996)

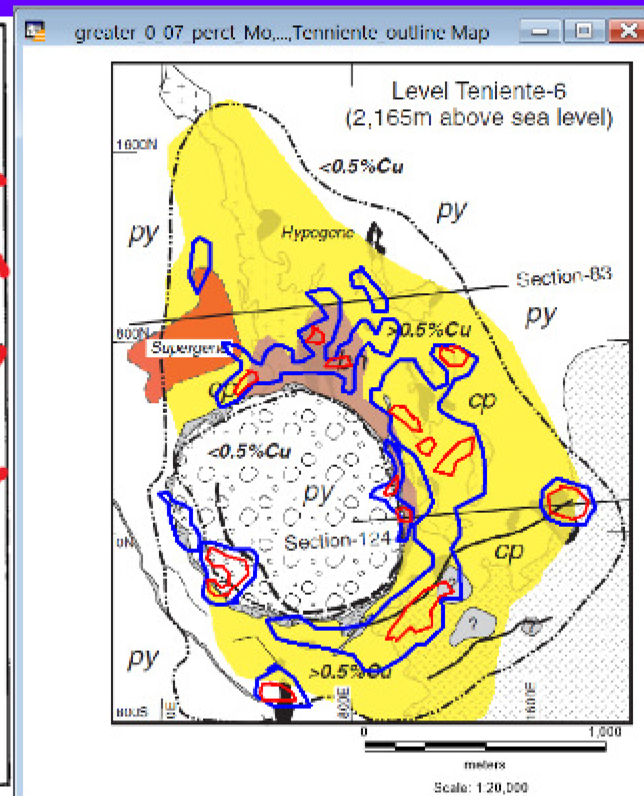
Cu vs Mo vs Au zonation



Bajo de La Alumbrera



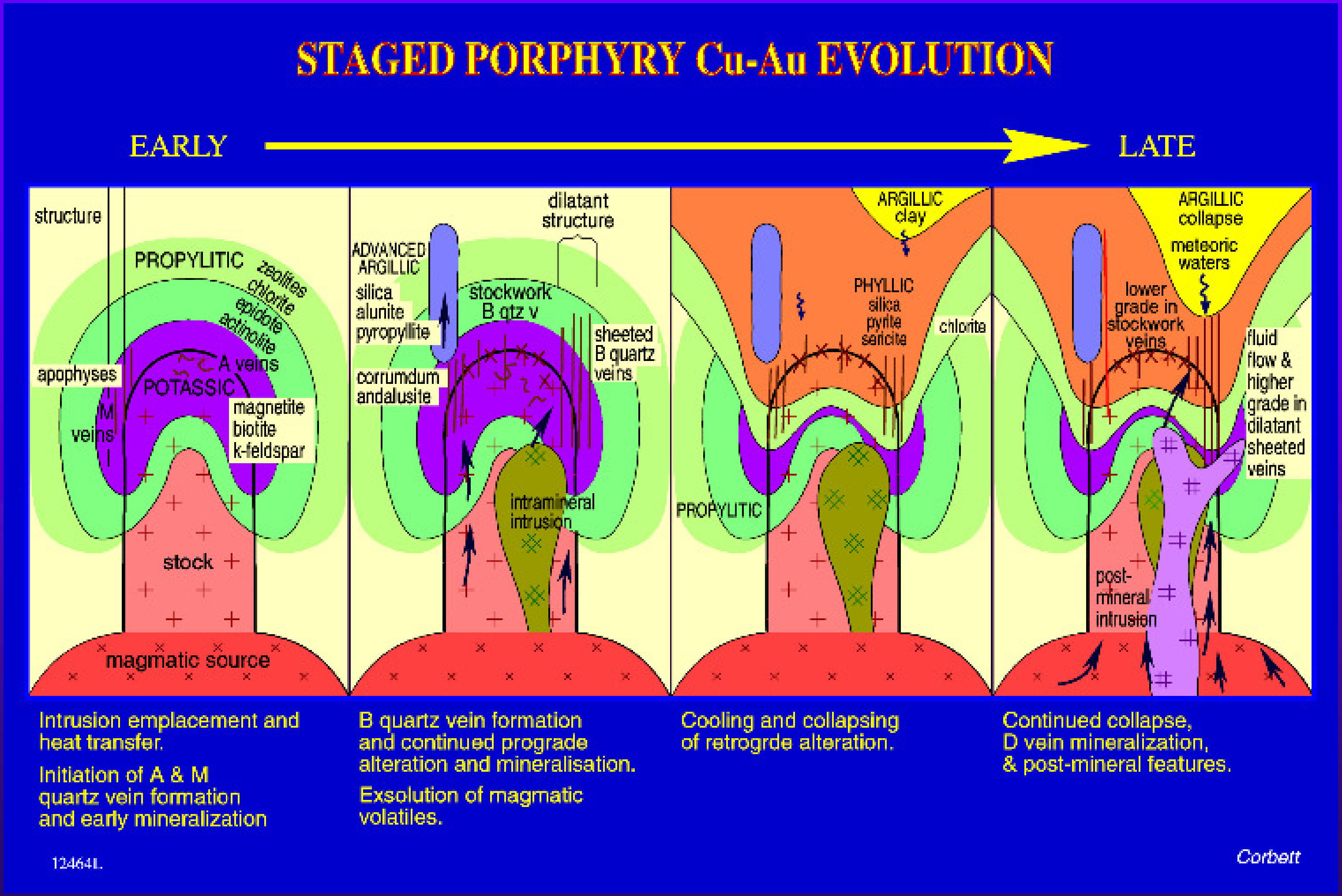
Batu Hijah



El Tenniente

References: Sillitoe, (1995), Meldrum, *et al*., (1994), Cannell et al., (2007)

Stage model for the evolution of porphyry Cu-Au systems



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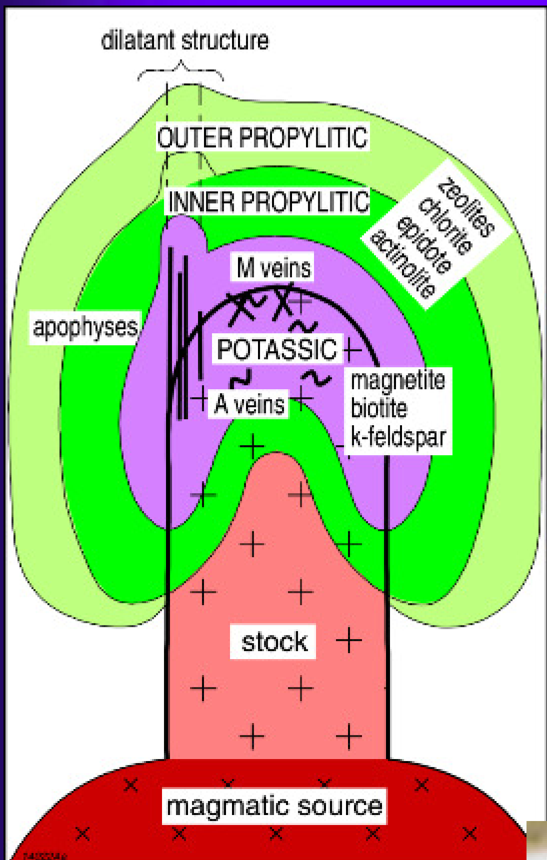
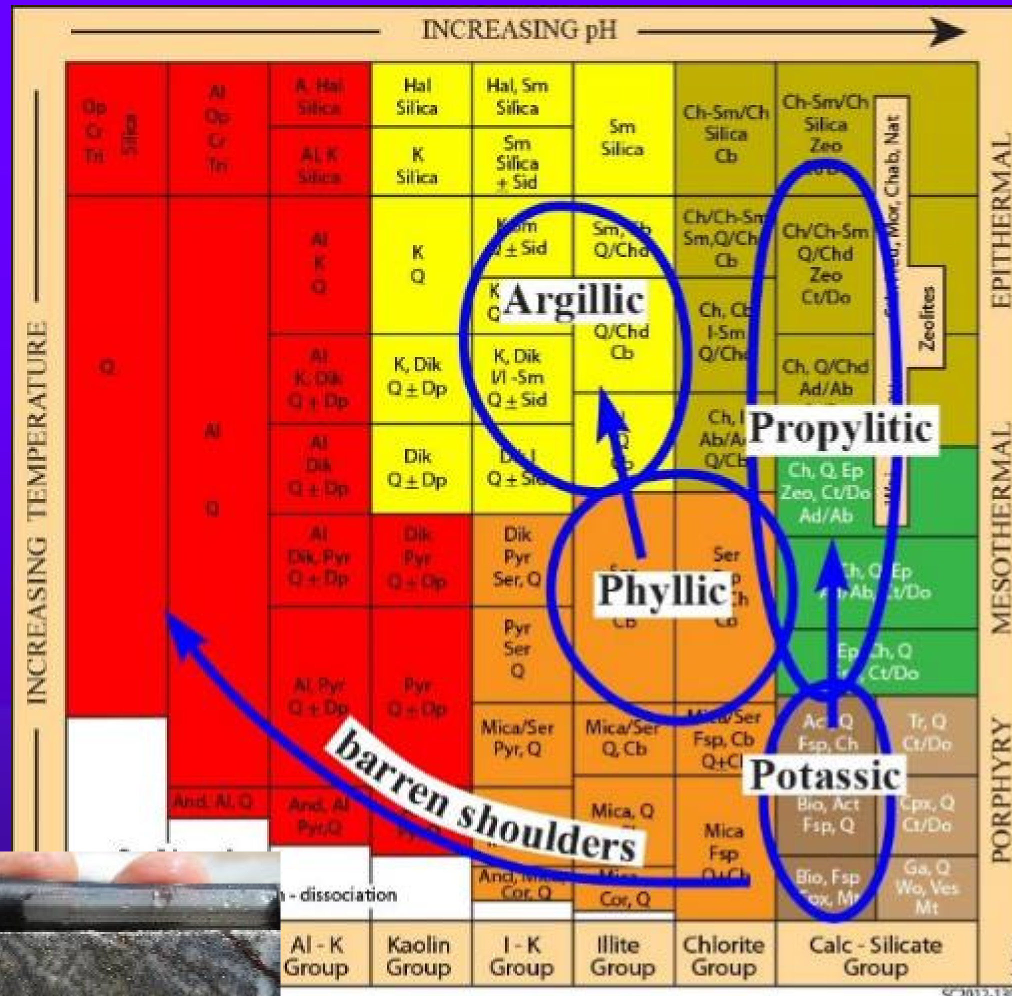
Potassic alteration





Corbett in prep

Potassic alteration

Qtz-cpy-mo vns in bio altd sed Wafi-Golpu

Bio altd porphyry bxa OK Tedi, PNG

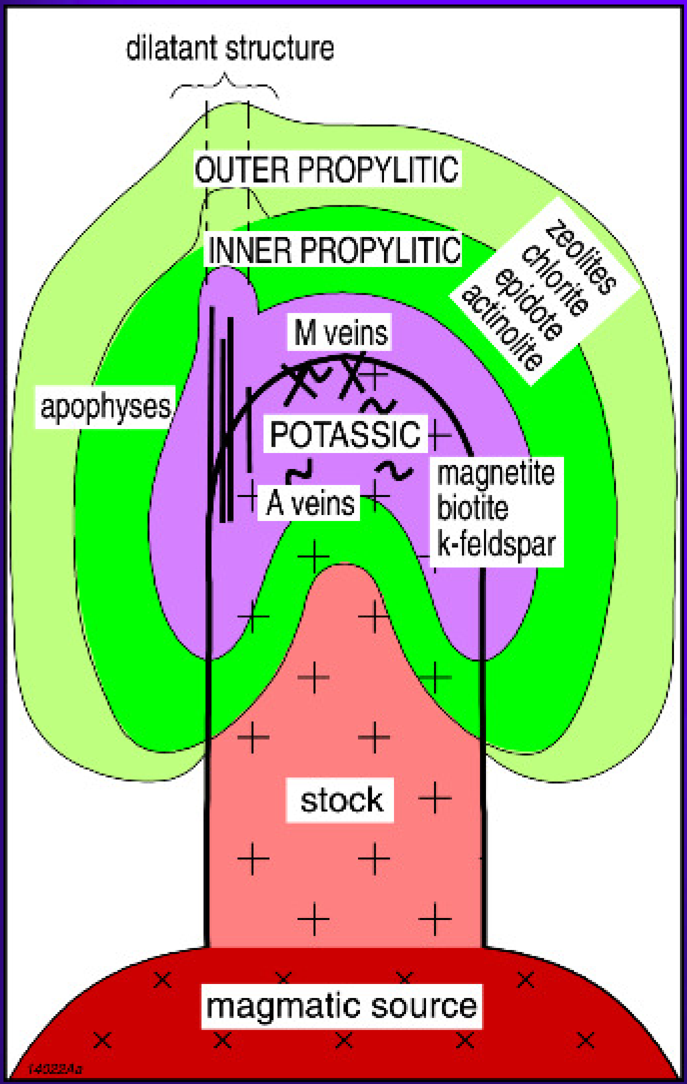
A veins Goonumbla, NSW

K-feldspar altd porphyry Goonumbla

K-feldspar altd volc Cadia, NSW

M veins Ridgeway, NSW

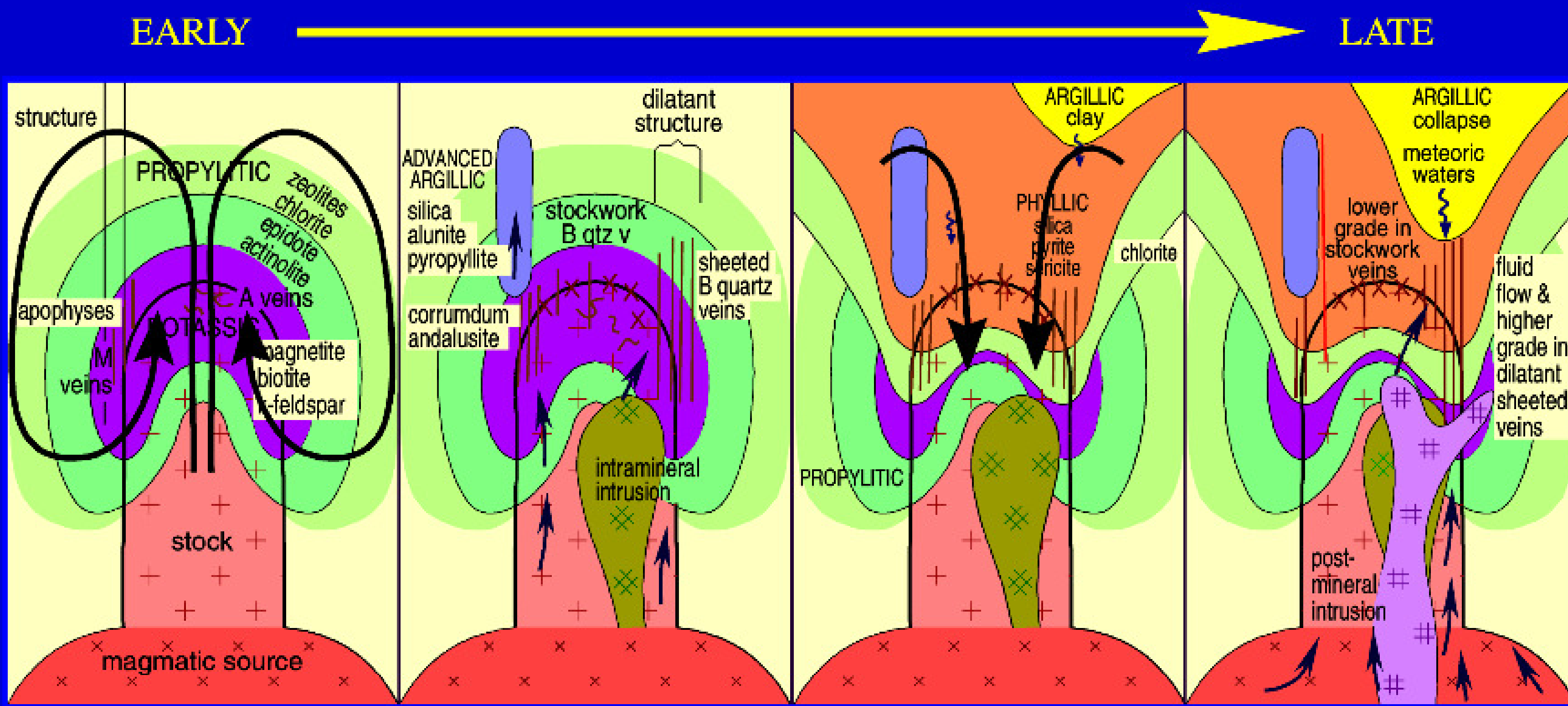
Propylitic alteration



Corbett in prep

Drawdown and phyllic alteration overprint

STAGED PORPHYRY Cu-Au EVOLUTION



Intrusion emplacement and heat transfer.

Initiation of A & M quartz vein formation and early mineralization

B quartz vein formation and continued prograde alteration and mineralisation.

Exsolution of magmatic volatiles.

Cooling and collapsing of retrogrde alteration.

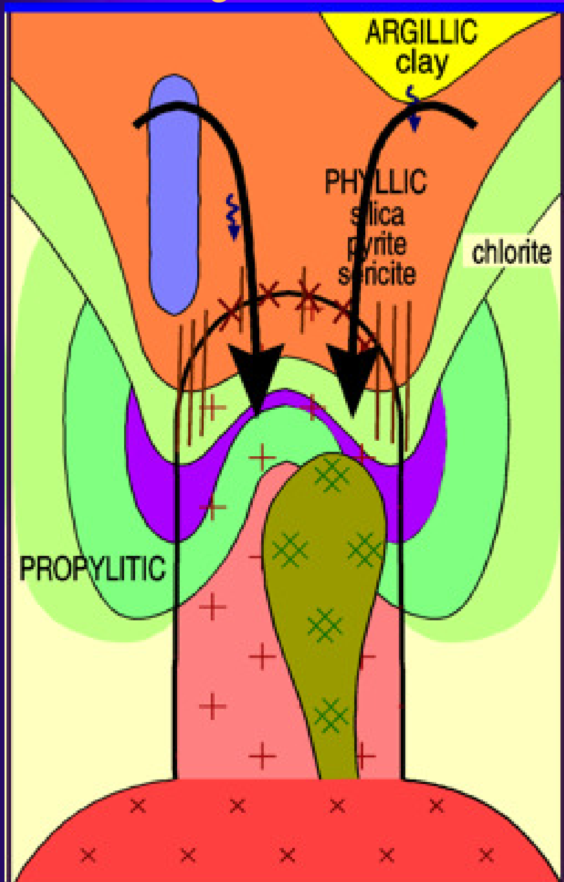
Continued collapse, D vein mineralization, & post-mineral features.

12464M

Corbett

Corbett in prep

Phyllic fluid evolution



Cooling and collapsing
of retrogrde alteration.

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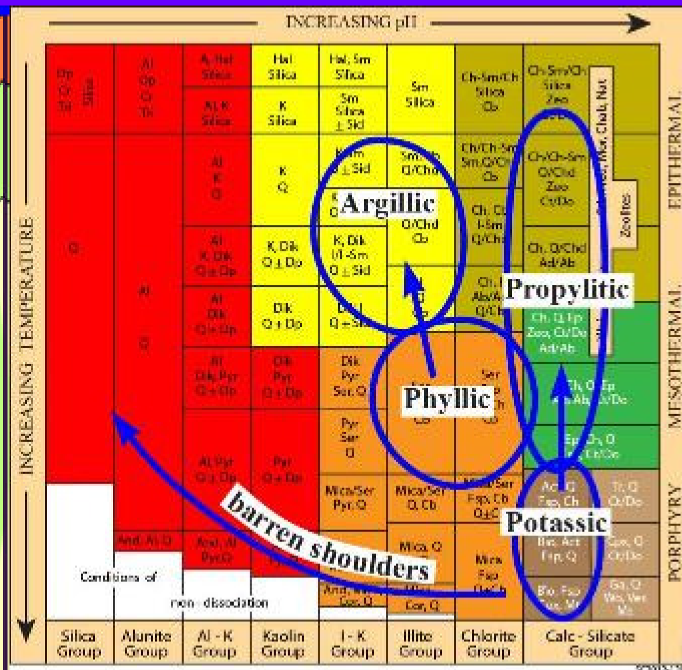
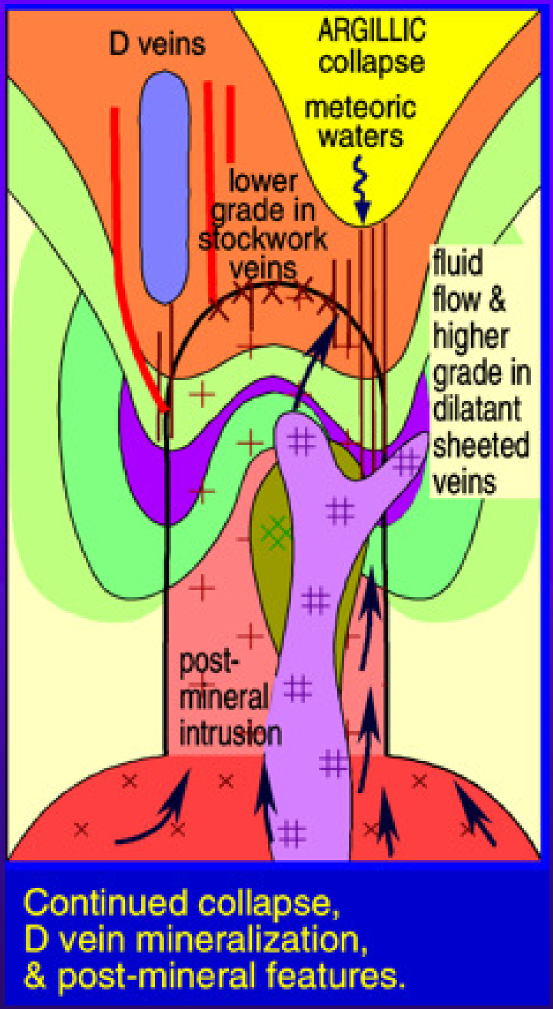


D vein -Wafi-Golpu, PNG

Argillic overprint on phyllic



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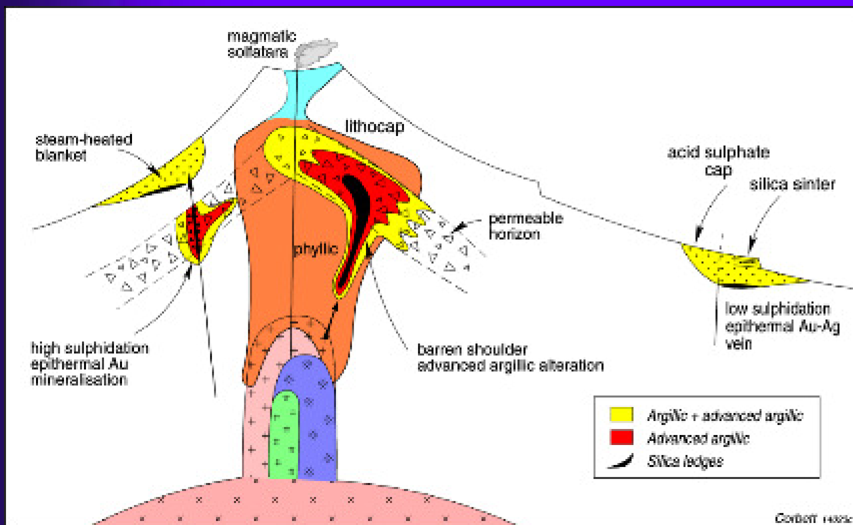
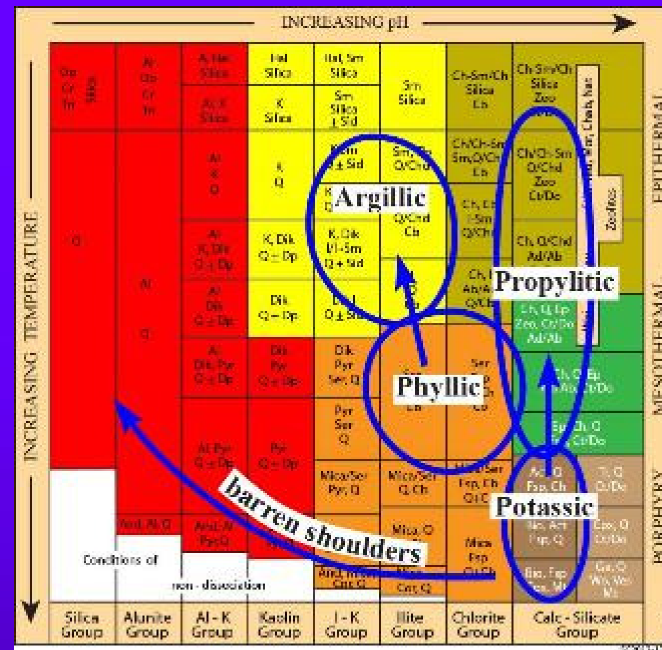
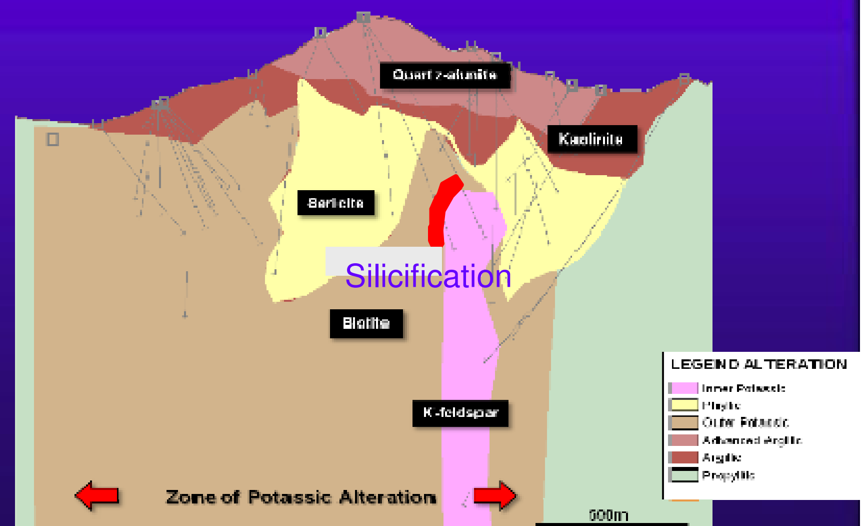
Barren shoulders/lithocaps



Corbett (2008)





Corbett and Menzies Consulting www.cmcgeos.com

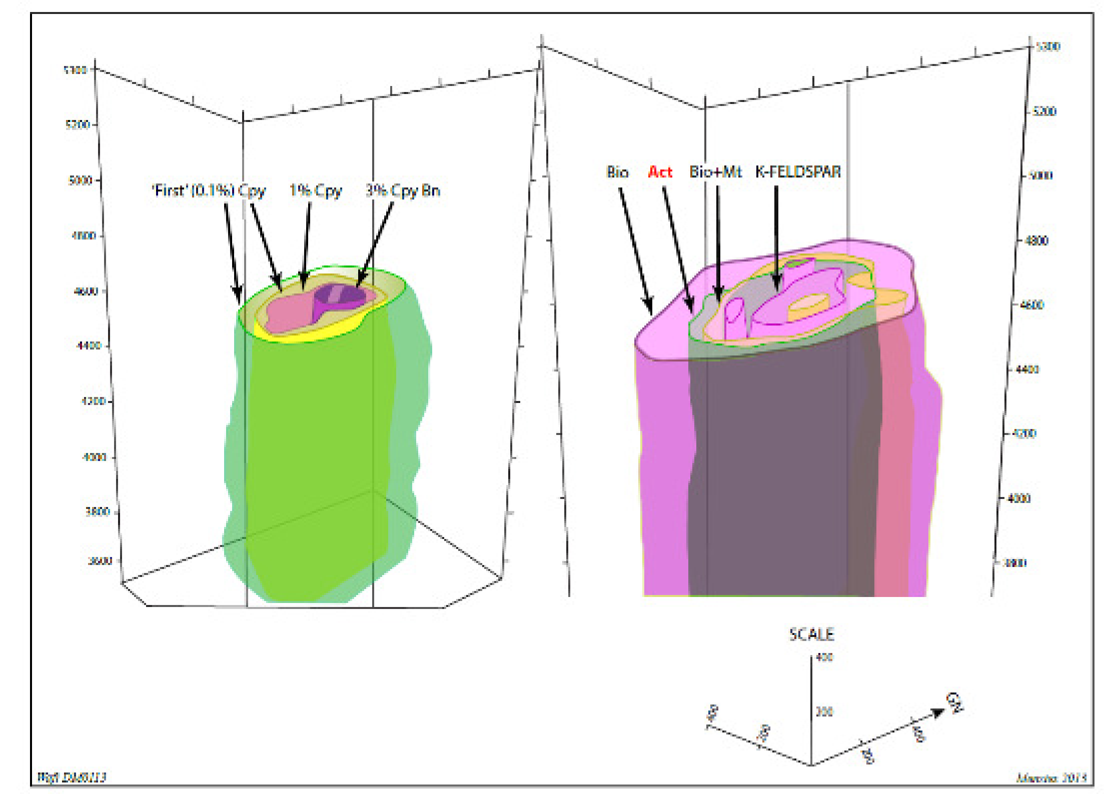
Menzies et al, (2013) redrafted from Muller et al (2011)

Vectors for porphyry exploration

- Prograde alteration zonation and actinolite
- Porphyry veins styles including D veins
- Pebble dykes
- Metal zonation
- Mag highs prograde alteration, mag lows retrograde
- Chargeability anomalies
- Skarn mineralisation or float.

Golpu Alteration/mineralisation zonation

- Alteration shells of Kf - Bi+Mt - Act - Bi - Chl
- Sulphides shells of Bn - Cpy – Py
- First Cpy is coincident with first actinolite



Redrawn from Menzies et al., (2013)

Porphyry vein styles

Prograde and proximal

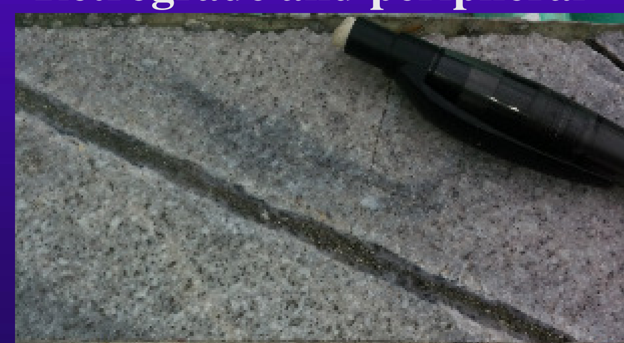
Wormy **A veins** Wafi-Golpu PNG (Muller et al, 2012.

A veins with Kspar selvage cut by later **B Vein-** Ridgeway

C vein -Wafi-Golpu, PNG

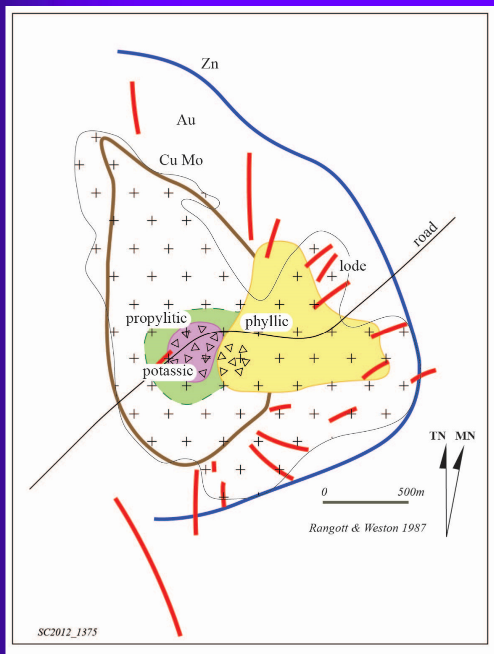
M veins - Qtz-mag-cpy-born veins.

Retrograde and peripheral

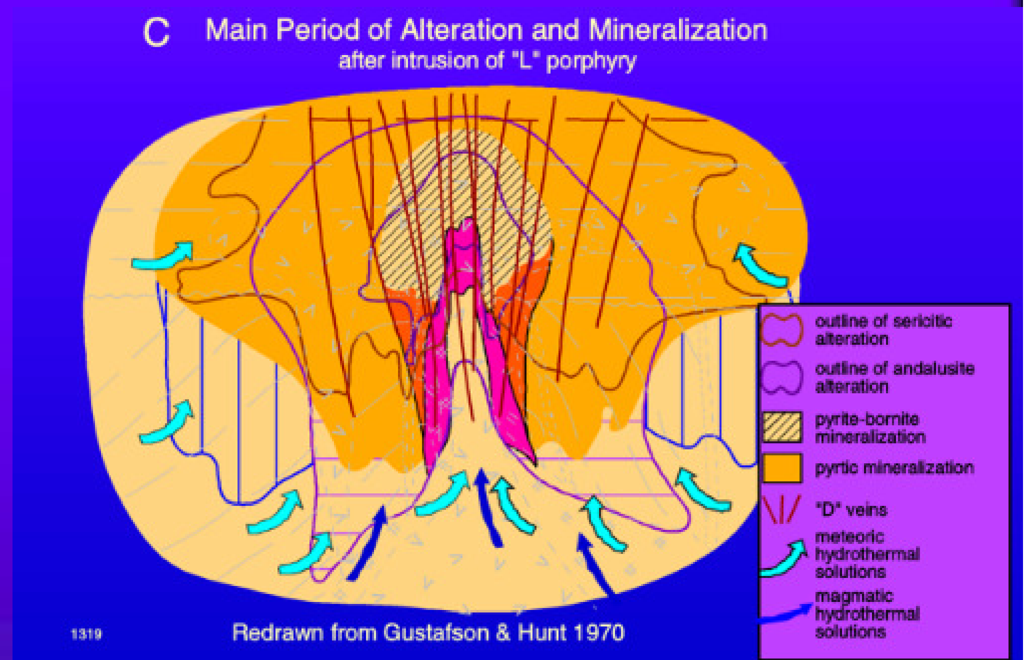


D vein -Wafi-Golpu, PNG

D veins – retrograde and peripheral



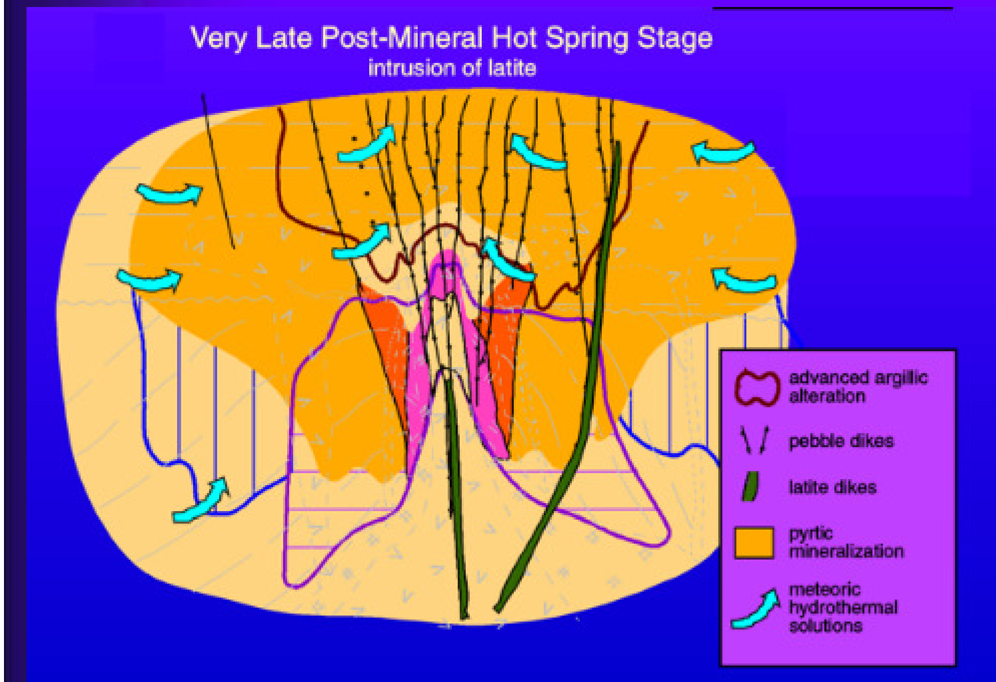
Cargo -Rangott and Wilson 1987



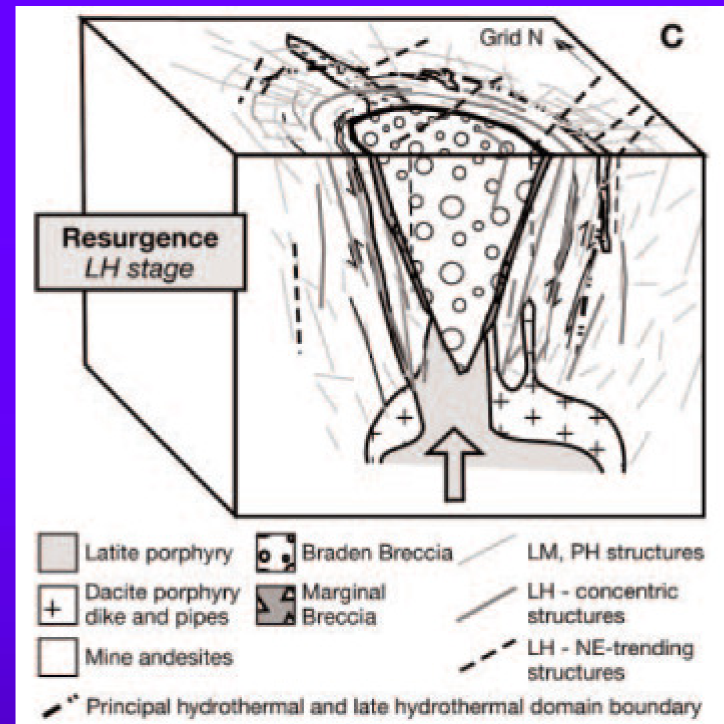
El Salvador porphyry - Redrawn by Corbett in prep from Gustafson and Hunt, (1970)

D vein with Mo from Cu Hill

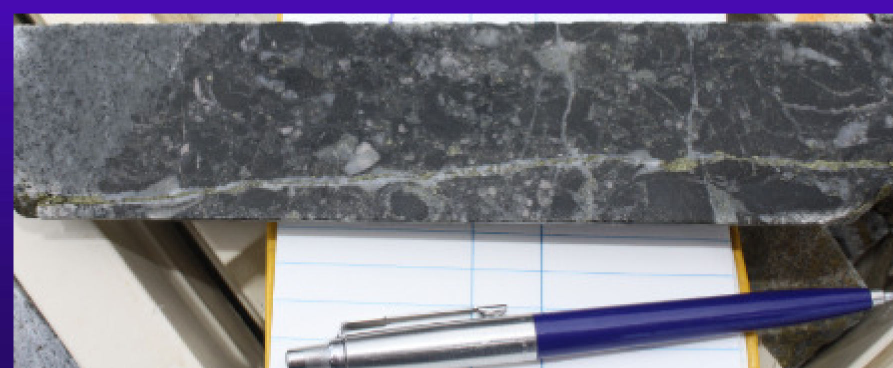
Pebble dykes



El Salvador porphyry - Redrawn by Corbett in prep from Gustafson and Hunt, (1970)

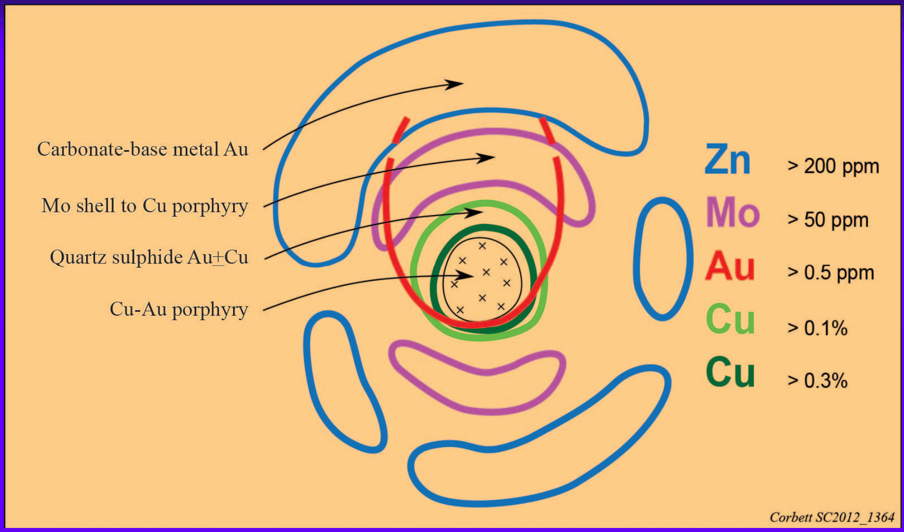


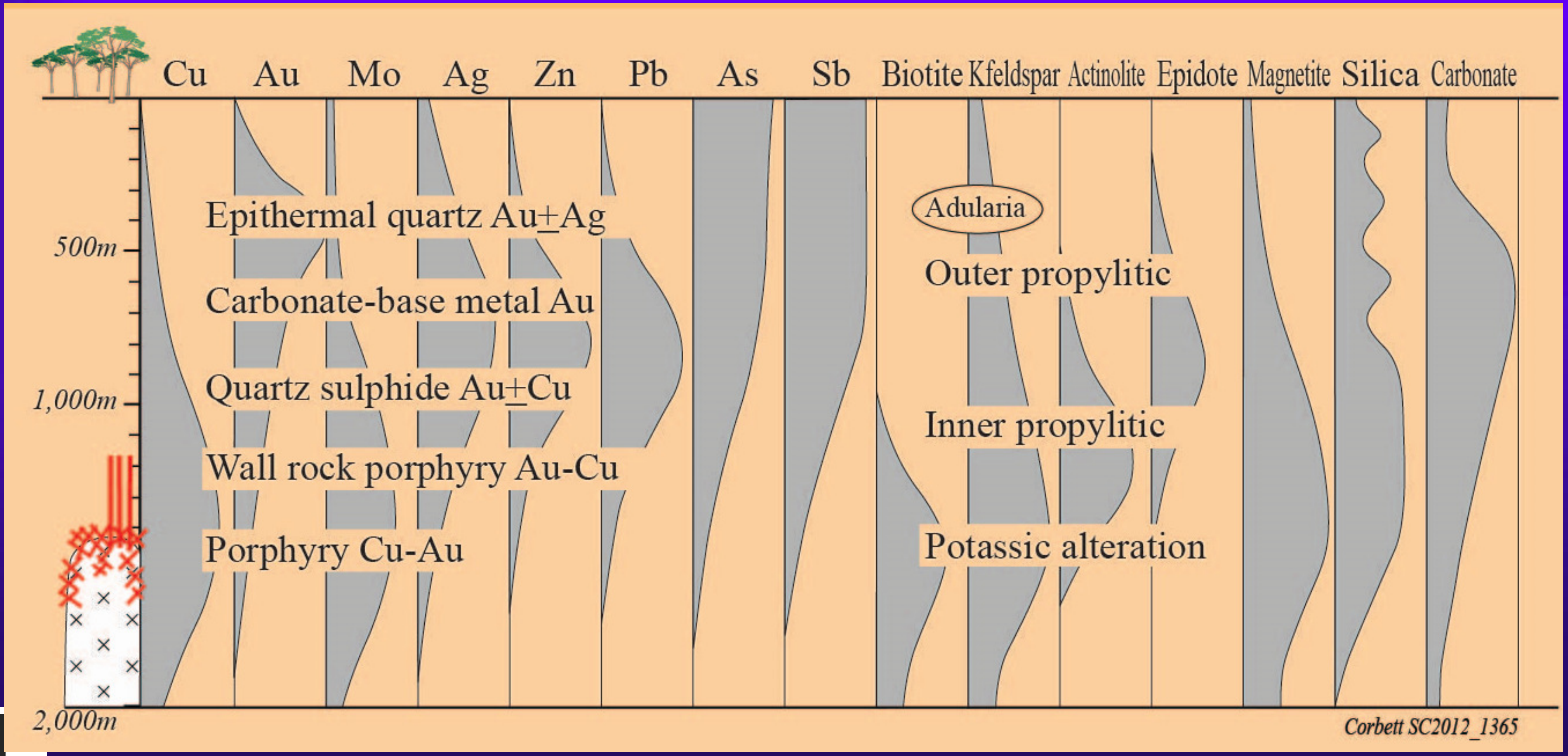
El Tenniente Cannell et al., (2005)



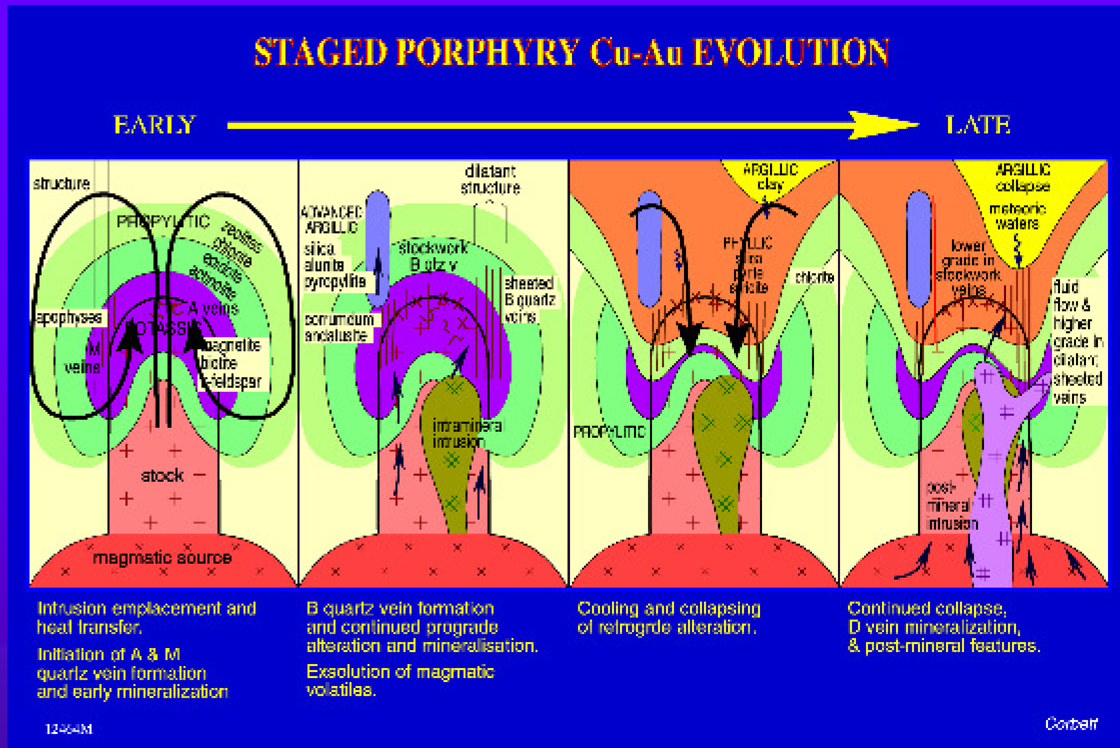
Pebble dyke Wafi-Golpu, PNG

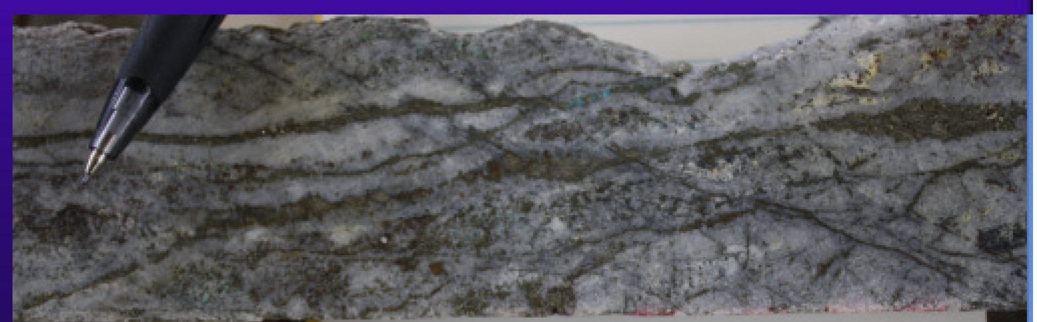
General metal zonation.



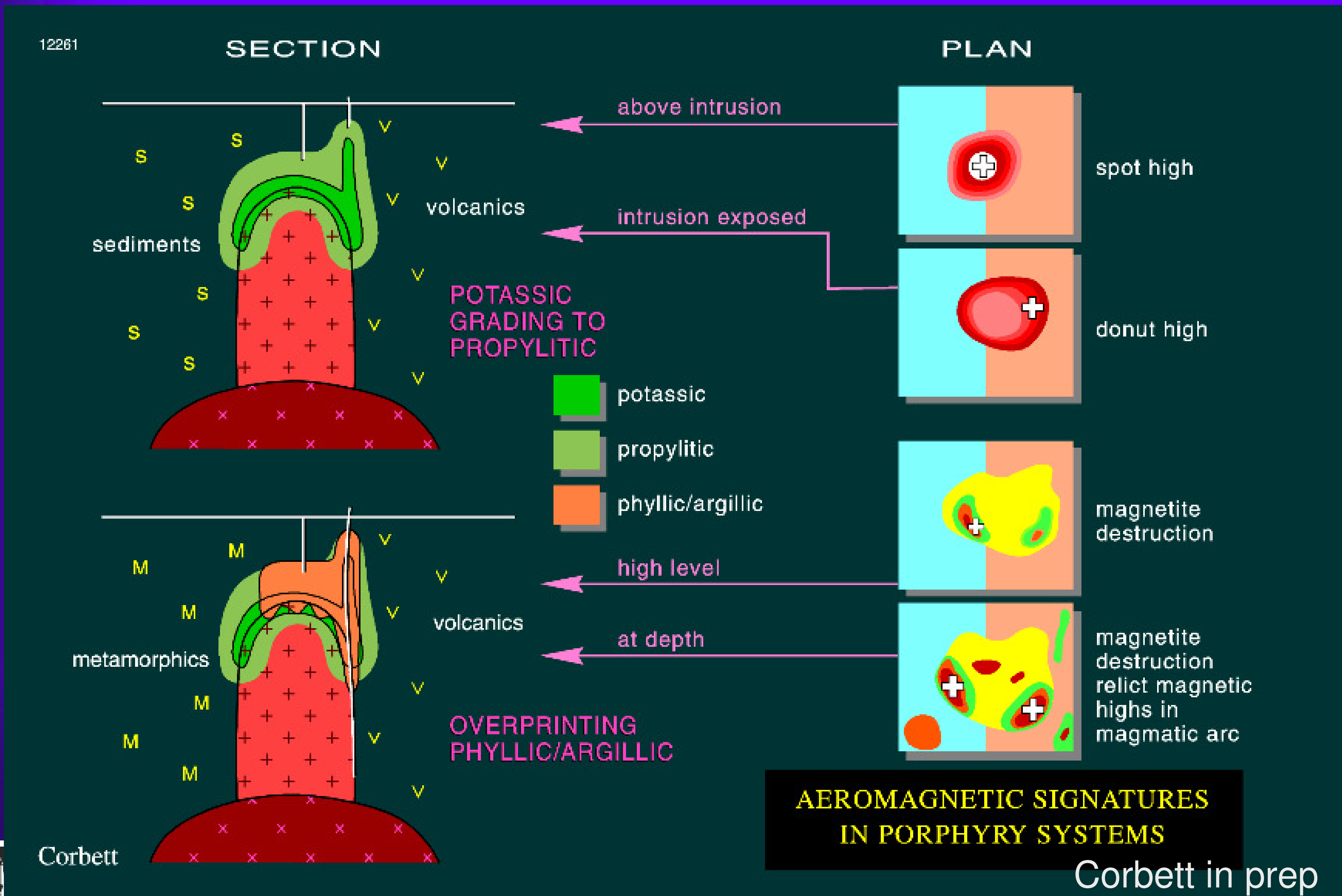


Magnetite creation and destruction



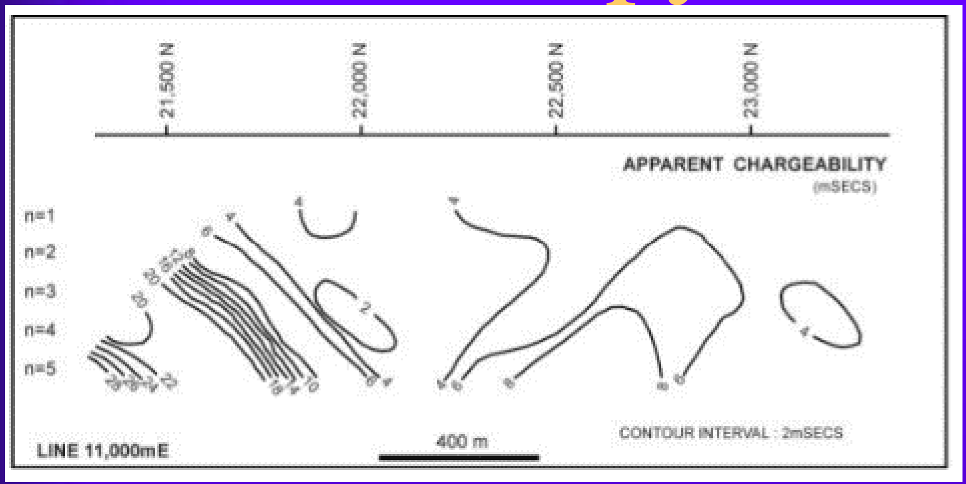


Aeromagnetic signatures

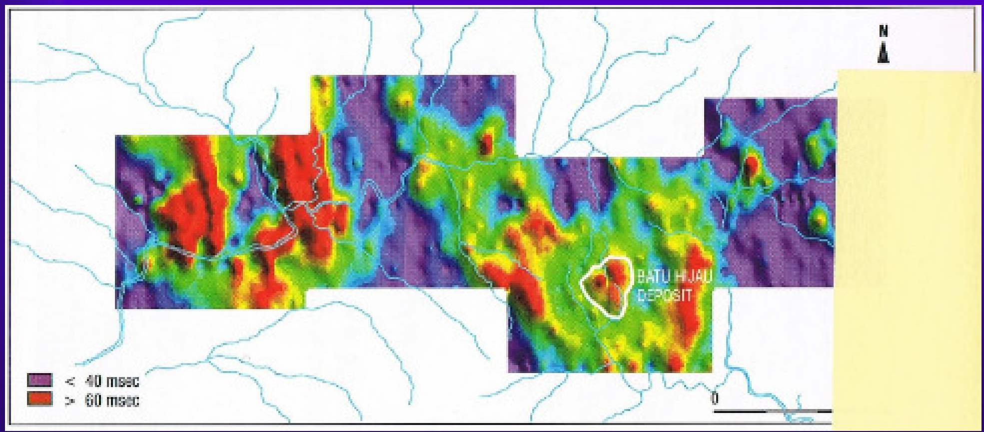


Corbett in prep

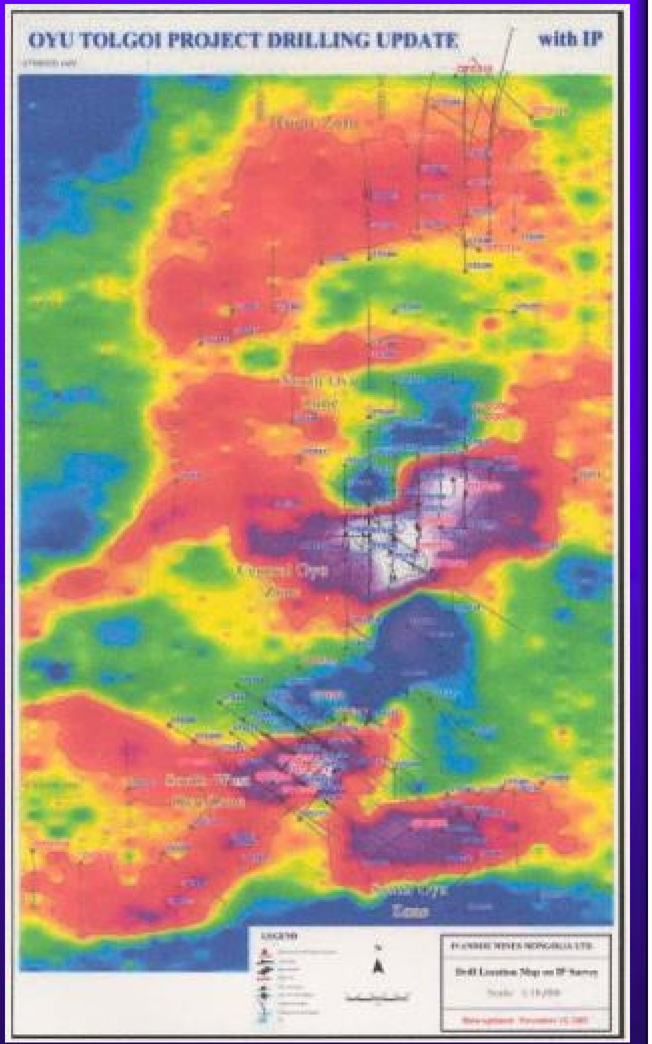
Chargeability highs – retrograde sericite-pyrite alteration



Ridgeway- Holliday et al (1999)



Batu Hijah - Maula and Levet (1996)



Oyu Tolgoi - Kirwin 2003

Skarns

Big Cadia skarn

Ok Tedi skarn

Summary/ implications for exploration

- PCD emplaced in extensional crustal scale structures where slab tears facilitating mafic injection into felsic magmas to increase Au-Cu endowment.
- Magmas are oxidised with high water, Cl and S contents
- Au-Cu deportment is increased by deposition with bornite which can precipitate an order of magnitude more Au than chalcopyrite.
- Porphyry Cu-Au mineralisation deposited separate phase to Mo mineralisation. Mo appears to be immobile and a good indicator of system margins.
- Later Au associated with quartz-carb-base metal veins produced by mixing with bi-carbonate waters
- Actinolite is a good indicator to proximity to chalcopyrite mineralisation
- Vectors include: D veins, pebble dykes, Cu-Mo anomalism at surface, mag low/highs, chargeable zones associated with sericite-pyrite (phyllic) alteration.

Questions?