A porphyry Cu-Au model – exploration implications

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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

Plate A

Plate B

Nambonga mineralisation

Wafi-Golpu 0.3% Cu Shell
Structure in porphyry systems – localisation

- Pull-apart basin filled with epiclastic sediments
- Normal faults host mineralisation
- Fissure veins
- Splay
- Pull-apart basin
- Epithermal
- Normal faults
- Hot spring and sinter deposits
- Controlling strike-slip structure
- Stratigraphy thickens across growth faults
- Fissure veins
- Intrusion derived from major magma source
- Negative flower structure
- Pull-apart basin and negative flower structure at varying crustal levels

Corbett 1277c
Cadia Valley

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 $f_{O_2}$) to enable Cu-Au partitioned in pyrrhotite and be liberated in aqueous phase.

- **High Cl/H$_2$O ratios** allows transportation of Cu-Au into aqueous phase as chlorocomplexes.

- **High $f_S$** needed to precipitate sulphides.

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

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

Batu Hijah–Gold deportment & Cu:Au ratio

Native and Free Gold Distribution in Thin Sections and Gold (g/t) to Copper (%) Grade Ratios (699 native and free gold grains)

Distribution (%)

- Au:Cu < 1 (143 Au grains)
  - Native Gold in Bornite-Digenite & Bomite
  - Native Gold in Chalcopyrite
  - Free Gold

- 1 < Au:Cu < 2 (228 Au grains)

- Au:Cu > 2 (328 Au grains)

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Arif and Baker, 2012
Gold deportment in bornite

Au vs Cu vs Mo zonation at Wafi

- 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 oxochloride complexes as proposed by Ulrich and Mavrogenes (2008) and Li et al. (2012).
Wafi - Surface geochem zonation
PCA of Wafi surface data

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<th>Eigenvectors:</th>
<th>F1</th>
<th>F2</th>
<th>F3</th>
<th>F4</th>
<th>F5</th>
<th>F6</th>
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<td>Au_ppm</td>
<td>0.276</td>
<td>-0.301</td>
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<td>0.858</td>
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<td>Cu_ppm</td>
<td>0.172</td>
<td>0.630</td>
<td>0.375</td>
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<td>Pb_ppm</td>
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<td>0.016</td>
<td>-0.085</td>
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<td>Zn_ppm</td>
<td>-0.048</td>
<td>-0.064</td>
<td>0.820</td>
<td>-0.084</td>
<td>-0.441</td>
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<td>Ag_ppm</td>
<td>0.505</td>
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<td>As_ppm</td>
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<td>-0.264</td>
<td>-0.002</td>
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<tr>
<td>Mo_ppm</td>
<td>0.170</td>
<td>0.688</td>
<td>0.240</td>
<td>0.196</td>
<td>0.625</td>
<td>0.027</td>
<td>0.105</td>
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</tbody>
</table>

Menzies et al., (2013)
Batu Hijah—surface geochem zonation

Maula and Levet (1996)

Zn ppm

Cu ppm.

Au ppm.

Zn ppm

Mo ppm.
Cu vs Mo vs Au zonation

Stage model for the evolution of porphyry Cu-Au systems

STAGED PORPHYRY Cu-Au EVOLUTION

EARLY

- Intrusion emplacement and heat transfer
- Initiation of A & M quartz vein formation and early mineralization

LATE

- Cooling and collapsing of retrograde alteration.
- Continued collapse, D vein mineralization, & post-mineral features.
Potassic alteration

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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

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Propylitic alteration

- Chlorite
- Epidote
- Actinolite

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Drawdown and phyllic alteration overprint

STAGED PORPHYRY Cu-Au EVOLUTION

**EARLY**

- Structure
- Apophysyes
- Magnetite
- Felsic

**LATE**

- Dilatant structure
- Stockwork
- Chorite
- Lower grade in stockwork

**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 retrograde alteration.**

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

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Phyllic fluid evolution

Cooling and collapsing of retrograde alteration.

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D vein - Wafi-Golpu, PNG
Argillic overprint on phyllic

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Barren shoulders/lithocaps

Corbett (2008)

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

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

Prograde and proximal

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


D vein with Mo from Cu Hill

Corbett and Menzies Consulting www.cmcgeos.com
Pebble dykes

Very Late Post-Mineral Hot Spring Stage
intrusion of latite

advanced argillic alteration
pebble dikes
latite dikes
pyritic mineralization
meteoric hydrothermal solutions

Resurgence
LH stage

Latite porphyry
Braden Breccia
Dacite porphyry
dike and pipes
Marginal Breccia
LH - concentric structures
LH - NE-trending structures
LH - concentric structures
Principal hydrothermal and late hydrothermal domain boundary

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.

- Carbonate-base metal Au
- Mo shell to Cu porphyry
- Quartz sulphide Au+Cu
- Cu-Au porphyry

- Zn: > 200 ppm
- Mo: > 50 ppm
- Au: > 0.5 ppm
- Cu: > 0.1%
- Cu: > 0.3%

Epithermal quartz Au+Ag
Carbonate-base metal Au
Quartz sulphide Au+Cu
Wall rock porphyry Au-Cu
Porphyry Cu-Au

Adularia
Outer propylitic
Inner propylitic
Potassic alteration
Magnetite creation and destruction

STAGED PORPHYRY Cu-Au EVOLUTION

EARLY

Initiation emplacement and local transfer.
Abundant A & M quartz vein formation and early mineralization.

LATE

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

Corbett
Aeromagnetic signatures

SECTION

above intrusion
intrusion exposed

PLAN

spot high
donut high

POTASSIC GRADING TO PROPYLITIC

potassic
propylitic

phyllic/ergillic

high level

at depth

metamorphics

volcanics

OVERPRINTING PHYLIC/ARGILIC

magnetite destruction

magnetite destruction relict magnetic highs in magmatic arc

AEROMAGNETIC SIGNATURES IN PORPHYRY SYSTEMS

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Chargeability highs – retrograde sericite-pyrite alteration


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?