The Wafi-Golpu porphyry Cu-Au deposit, Papua New Guinea: Exploration history, mineralisation alteration zonation, surface geochemical expression and paragenesis.

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Introduction

The Miocene Wafi-Golpu gold-rich porphyry Cu-Au deposit and associated high sulphidation epithermal Au mineralisation is located in the Morobe Province of PNG and has a currently published total inclusive gold equivalent Mineral Resource of 19.03Moz Aueq which includes 9500Mlb of copper, 17Moz of silver and 81Mlb of molybdenum (Harmony website, 2022). The Wafi-Golpu porphyry Cu-Au system is bounded by a NE to NNE trending fault zone known as the Wafi Transfer and intrudes a basement sequence of weakly metamorphosed well-bedded siltstones and conglomerates of the Oligocene Langimar Formation (previously interpreted to be the Owen Stanley Metamorphics). The Langimar Formation dipping between 50-80° to the E-NE has been intruded by several copper-gold mineralised hornblende phyric to feldspar phyric diorite porphyry bodies (Harris, 2010, 2011) and a late phase phreatomagmatic diatreme breccia. The diatreme breccia is 800 x 600m in diameter, bounded by pebble dykes, and is inferred to have vented due to the presence of accretionary lapilli in layered bands at surface.

Exploration history

The Wafi Project area was originally discovered CRA Exploration (CRAE) as part of a SW Pacific island reconnaissance exploration program, called CRAE Star, facilitated from a fishing trawler with an assay lab on board. Sampling by CRAE geologists of float in Wafi River in 1977 yielded the first significant Au assay in the area of 22g/t Au and 89g/t Ag (Shedden, 1979; Erceg et al., 1991). Follow up surface rock-chip and soil samples, along with approximately 8500m of drilling by CRAE, identified multiple centres of Au mineralisation (Zones A, B, C and others). Drill data indicated that the gold resources were small and metallurgically challenging, and the project was farmed out to Elders Mining PNG. Drilling by Elders defined a high sulphidation epithermal gold resource of 18Mt at 2.5g/t Au, using a 1.0g/t cutoff (Erceg et al., 1991). Drilling focussed on a zone of higher temperature quartz-alunite-dickite hydrothermal alteration, identified from petrographic and XRD analysis, which were interpreted elsewhere to be indicative of the Au-rich core of high sulphidation epithermal deposits ie El Indio style target (Leach and Erceg, 1990; Corbett, 1990). Additionally, Corbett (1990) identified an NNE trending photo-lineament interpreted to represent the feeder-structure for hydrothermal fluids, and recommended the zone be drill tested. In 1991 drill hole WR95 intercepted the porphyry Cu-Au style mineralisation (263m at 1.86% Cu and 0.27g/t Au within 446m at 1.44% Cu and 0.73g/t Au, Hayward et al., 2011) which was named the Rafferty's Porphyry after the captain of a WW11 Superfortress bomber that crashed nearby. In the early 1990's Elders were acquired by Carter Holt Harvey which elected to sell the 40% stake in Wafi back to CRAE. Between 1991 and 1997 drilling by CRAE defined a resource of 100Mt at 1.3% Cu and 0.6g/t Au and the high grade "Linked Zone" Au zone (Tau-loi et al, 1996; Hayward et al., 2011), after which the project remained under care and maintenance till 2001. In 2002 the project was acquired by Aurora Gold, who later merged with Abelle Pty Ltd, which was acquired by Harmony Gold in 2004. Between

2004 and 2008, drilling by Harmony Gold into high sulphidation epithermal zones A, B, C and Linked Zone and the porphyry resource at Golpu (renamed from Rafferty's), upgraded the Golpu resource to 163Mt at 0.6g/t Au and 1.1% Cu (Habermann, 2007). In 2007 the Nambonga Porphyry was discovered with a resource of 1Moz Au and 80Kt Cu (Hayward, et al., 2011). In 2008 the Wafi-Golpu JV was established, a 50:50 joint venture between Harmony Gold and Newcrest Mining Limited. A review of historical drill hole WR93 by Greg Corbett recognised the occurrence of porphyry-related M veins and that Cu anomalism increased with depth, which led to the targeting of deeper hole WR321 (331m at 0.51g/t Au and 0.93% Cu) that rediscovered the project.

Mineralisation and alteration zonation

Four discreet mineralising systems have been identified to date including: the Golpu porphyry Cu-Au system; the Nambonga porphyry Cu system; the Wafi Zones A and B high sulphidation Au mineralisation; and later Au-bearing Mn-Carbonate veined and Au-rich, As-bearing pyrite epithermal mineralisation within Link Zone. The Golpu porphyry mineralised system exhibits a concentric alteration zonation consisting of a K-feldspar rich core (330 x 760m in diameter), grading out into a biotite–magnetic rich zone (650 x 1000m in diameter), an actinolite rich zone (640 x 1030m in diameter), grading out into a chlorite dominated zone. Strong sericite alteration overprint occurs at the eastern and western edges of the Golpu porphyry and centrally within cross cutting fault/shear zones. The first appearance of actinolite alteration correlates with the first appearance of chalcopyrite and is coincident with the 0.1% Cu shell. A zone of intense silicification and quartz veining occurs on the upper north-western margin of the Golpu porphyry mineralised system, where pyrite is dominant over chalcopyrite mineralisation. This zone also displays minor crenulated and layered quartz veining exhibiting unidirectional solidification texture as reported by Seedorff et al. (2005), who proposed this texture represents the transition between magmatic and hydrothermal conditions and demonstrates that fluids accumulated in the apex of a porphyry stock during crystallisation. The Golpu porphyry Cu-Au sulphide species have a concentric zonation from a bornite rich core grading out into chalcopyrite rich then pyrite rich zones. Au:Cu ratios are typically 0.6:0.9, and in several drill holes (WR416, WR426) Au has a positive correlation with observed bornite mineralisation (r=0.21, n=1890). This relationship is consistent with experimental work by Simon et al. (2000) who proposed bornite can accommodate one order of magnitude more gold than chalcopyrite. However, hand-specimen samples show evidence to suggest that Cu and Au may have been remobilised in zones of intense sericite alteration, where chalcopyrite is observed rimming bornite with appreciable Au grades, a relationship similar to that reported at Batu Hijau by Arif and Baker (2004). Molybdenite mineralisation is typically found on the margins and lower portions of the porphyry Cu-Au systems often associated with potassic alteration within quartz-anhydrite veins and occurs strongly in K-feldspar altered zones with later sericite overprint. Statistically analysis of drill core assays demonstrates a strong positive Pearson correlation between Cu and Au (r= 0.607, n=32653), a negative correlation between Mo and Au (r=-0.024, n=32653) and a neutral correlation between Cu and Mo (r=0.031, n=32653). Similarly, the Golpu block model shows Cu + Au rich zones off-set from Mo-rich zones. On the south-eastern margin the Golpu porphyry A and B stockwork mineralisation is overprinted by a telescoped high sulphidation covellite-enargite-pyrite epithermal mineralisation and associated advanced argillic alteration. This high sulphidation epithermal Au-Cu mineralisation exhibits a zonation from a vuggy (or residual) quartz-alunite bearing core, out to alunite-dickite, dickite-kaolinite with lesser pyrophyllite and diaspore, then illite-smectite alteration. Advanced argillic alteration dips to the east, sub-parallel to dominant bedding,

is indicative of a lithological control to the alteration and mineralisation producing fluids (Erceg et al, 1991). This style of mineralisation exhibits sulphide species zonation from enargite-luzonite, to tennantite-tetrahedrite, covellite and As-bearing pyrite (Erceg et al, 1991). This high sulphidation mineralisation is cut by later Au-bearing Mn-carbonate bearing (Zhang et al., 1997) and As-bearing pyrite veins, interpreted to have affinities with Carbonate Base Metal Au mineralisation as defined by Corbett and Leach (1998). Zhang et al. (1997) interpret the occurrence of Au associated with Mn-carbonate (rhodochrosite) in the Link Zone core to be indicative of Au deposition associated with the mixing of bi-carbonate bearing meteoric waters with pregnant Au-bearing magmatic fluids.

Surface Geochemical Expression

Surface geochemical data describes a broad annulus 2.94km x 2.7km which contains >140ppm Zn rimming the entire system, centred on the diatreme and is broadly coincident with the propylitic alteration zone. Zone A and B high sulphidation epithermal Au mineralisation is manifests at surface as a zone of anomalous Au values in soil samples (1.0 x 0.4km @ > 0.48 g/t Au). The southern portion of the Golpu porphyry Cu-Au mineralisation is identified at surface by spotty Cu (>150ppm) and Mo (>35ppm) anomalism in soil samples.

Paragenesis of Wafi-Golpu mineralisation

Wafi-Golpu porphyry Cu-Au and associated epithermal Au mineralisation are localised within a zone of extension associated with a left stepping sinistral fault jog, as part of the Wafi transfer structure as described by Corbett (1994). The porphyry mineralisation is interpreted to have been introduced by a two-phase fluid as proposed by Fournier (1999) comprising a hypersaline liquid rich in Fe, K and Cl and a low-density S-rich and Cu-Au-bearing phase (Sillitoe 2010, Corbett and Leach, 1998). The negative correlation between Mo and Au-Cu is indicative of a separate transportation method for Mo into the system. It is believed the diatreme intruded and vented due to a phreatomagmatic eruption resulting from the ingress of meteoric water onto a high level intra/late mineral porphyry during rapid uplift (Corbett and Leach, 1998). Drill hole WR457 shows a transition from hydrothermal breccia (diatreme) to a more magmatic-hydrothermal breccia with an aplitic-quartz-silica matrix, and eventually to a quartz lacking feldspar-biotite-hornblende phyric porphyry at depth below the diatreme. The lithologically controlled Zone A and B high sulphidation epithermal Au mineralisation (Erceg et al., 1991) then overprinted both the Golpu porphyry mineralisation and the diatreme and were followed by later Au-bearing carbonate-base-metal and Au-As pyrite epithermal mineralisation commonly known as the Link Zone (Ryan and Vigar, 1999; Erceg, 2008). Cross-cutting relationships and petrological analysis of core from the Link Zone by Zhang *et al* (1997) and discussions by Ryan and Vigar (1999), as well as core from the recently discovered Northern Diatreme Gold Zone (WR392) suggest this is the latest mineralising event to have resulted from the mixing of pregnant metal bearing fluids with bi-carbonate bearing meteoric waters (Zhang et al., 1997; Corbett and Leach, 1998). Post-mineral thrust faulting is believed to be part of a Pliocene (5.0 - 2.5Ma) E-W compressional event (Reid, 2012, and Cloos et al., *2010)*) and has offset the Golpu porphyry mineralisation to the NW. Copper mineralisation has undergone later supergene enrichment forming a chalcocite-rich zone with associated supergene kaolinite and alunite.

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