GEOLOGY AND GENESIS OF THE KELIAN GOLD DEPOSIT, EAST KALIMANTAN, INDONESIA

by

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ABSTRACT

Kelian is a bulk tonnage, breccia- and vein-hosted, structurally controlled, base metal sulfide-rich low sulfidation epithermal gold-silver deposit. The Kelian mine is located in East Kalimantan, Indonesia on the island of Borneo. Containing ~ 240 metric tonnes of gold, Kelian is a 'giant' gold deposit and Indonesia's largest gold-only resource.

The deposit occurs principally within a structural inlier of felsic volcaniclastic rocks (the Kelian Volcanics) surrounded by Eocene terrestrial and shallow marine sedimentary rocks of the Kutai Basin. A new U-Pb zircon age determination for the Kelian Volcanics indicates an Upper Cretaceous age (67.8 ± 0.3 Ma). The Kelian Volcanics have been uplifted along a dextral strike-slip basement fault (West Prampus Fault) at its intersection with a regional scale northwest-trending crustal lineament. At the surface, this lineament manifests as a series of northwest-striking, strike-slip and oblique-slip faults that were intimately linked with gold mineralisation. The intersection of these two regional-scale structures was a focus for magma emplacement in the Lower Miocene. Feldspar – hornblende-phyric andesite intrusions were emplaced in rhombic, extensional domains defined by northwest- and northeast-striking faults.

In addition to being a magmatic centre during the Early Miocene, the Kelian area was a focus for intense hypogene brecciation. Detailed facies mapping has delineated the subsurface facies and remnants of the eruptive facies of a maar-diatreme complex, and genetically related, mineralised phreatic and hydraulic breccias. Intrusion of quartz-phyric rhyolite (19.8 ± 0.1 Ma) and quartz – feldspar-phyric rhyolite (19.5 ± 0.1 Ma) into an active hydrothermal system at Kelian triggered phreatomagmatic and hybrid phreatomagmatic – phreatic explosions and eruptions. The Kelian Breccia Complex records the effects of magma intrusion into an active hydrothermal system and the ensuing disruption, reorganisation and enhancement of that system. The root zones of the phreatomagmatic explosions are preserved and provide direct textural evidence of magma – water interaction. Widespread phreatic explosions were triggered by the catastrophic disruption of the hydrothermal system caused by magma emplacement and diatreme formation. Seven breccia facies have been defined for the mineralised phreatic breccias based on cement assemblages. The return towards steady state conditions is recorded by the progression from explosive phreatic breccias, to in-situ hydraulic breccias.

Syn-mineralisation faults occur in four main groups: northwest-, northeast-, north- and east-striking. Northwest-striking faults accommodated early, syn-magmatic dextral strike-slip motion followed by

dip-slip motion during syn-mineralisation, whereas all other syn-mineralisation faults were extensional. Structural controls on gold mineralisation are indicated by the parallelism of trends in gold assay data with mapped faults and the spatial distribution of sheeted and conjugate extension and extensional shear veins developed about the syn-mineralisation faults. The 383, Water Tank, Tepu and Sungai Jiu ore zones are localised along major northwest-striking faults zones. The Tepu and 383 ore zones are also associated with east-striking faults that may have controlled late-stage mineralisation. The northeast-trending high-grade core of the deposit consists of the 255, 393 and 394 ore zones. These ore zones are each centred on breccia bodies located at the intersection of multiple fault sets. Vein-hosted mineralisation in the 393 ore zone is strongly related to extensions across north-northeast- and northeast-striking faults. The 255 and Hanging Wall ore zones are localised along northeast faults and at the intersection of northeast -striking faults with southern projection of the West Burung Fault.

Mineralisation occurs as disseminations, in sheeted and conjugate veins and as breccia cement. Unlike many low-sulfidation epithermal gold deposits, quartz is only a minor component and base-metal sulfides are abundant at Kelian. A revised paragenetic sequence consisting of ten mineralisation stages (1A, 1B, 2A, 2B, 3A, 3B, 3C, 3D, 4, 5) has been defined for the Kelian system. There is an overall progression through the paragenetic sequence from pyrite-dominated to base metal-sulfide-dominated and finally sulfosalt dominated mineralisation. Gangue minerals also change from adularia and/or quartz to quartz – illite and finally carbonate dominated through the paragenesis. Stage 1 mineralisation consists of proximal illite – pyrite – quartz cemented veins and breccias and distal calcite – quartz ± epidote veins. Stage 2 mineralisation consists of pyrite – quartz – illite and minor base metal sulfides in the northern Kelian area, and adularia – quartz – pyrite in the south. A transition to abundant base-metal-sulfides (galena, sphalerite, chalcopyrite) occurs between stages 2 and 3A. In addition to base-metal sulfides, stage 3A mineralisation contains ubiquitous pyrite, local sulfosalts and abundant native gold. Stage 3B mineralisation is coeval with stage 3A, but occurs at depth on the flanks of the Kelian system. It consists of base-metal sulfides along with pyrrhotite – marcasite – melnikovite. Widespread boiling is indicated by abundant bladed carbonate in stage 3C. Stage 4 mineralisation consists of sulfosalts and sulfides intergrown with laminated and bladed rhodochrosite. Gold deposition occurred throughout stages 1 to 4, but was most significant during stage 3 and 4. Native gold principally occurs as inclusions within and intergrown with pyrite, sphalerite, galena, arsenopyrite, quartz, bladed carbonate and sulfosalts.

Hydrothermal alteration is zoned about contacts, faults, breccias and veins. Within andesite intrusions, alteration grades from proximal quartz – illite – pyrite (QIP) through illite – carbonate –

pyrite (ICP) and illite – chlorite – carbonate (ICC) to distal chlorite – calcite – illite (CCI) assemblages. Alteration zonation in volcaniclastic host rocks grades from proximal QIP to distal smectite – illite (SMI) alteration. Local, intense adularia – quartz – illite (AQI) and/or carbonate alteration assemblages are spatially associated with adularia and carbonate infill respectively. Alteration distribution is controlled by lithology, structure and host-rock permeability. Variations in illite crystallinity and composition have been qualitatively assessed through the use of a portable short wave infrared mineral analyser (PIMA). Illite crystallinity increases systematically with increasing gold grades.

Fluid inclusion analyses revealed the presence of anomalously saline fluid inclusions, in particular in stages 3A and 3C, during which the bulk of gold and base metals were deposited. The salinity and homogenisation temperature arrays suggest that isothermal mixing of low-salinity (~0 to 2 % eq. wt.% NaCl) with moderate-salinity fluids (10 to 25 % eq. wt.% NaCl), rather than boiling resulted in the spread in salinity values for sphalerite, carbonate and quartz (stage 3). Salinities of ~ 4 to 6 eq. wt.% NaCl for adularia, quartz (stages 2B and 4), rhodochrosite and proustite-pyrargyrite may also reflect a component of mixing with the moderate salinity fluid.

Sulfur and C-O isotopes results from Kelian are consistent with a magmatic source for S and C. Origins for the inferred mineralising brine cannot be confirmed given the data available, but a magmatic source is inferred. Gold was transported as a bisulfide complex, most likely $Au(HS)_2^-$, and Pb and Zn were likely transported as chloride complexes. A reduced, H_2S-rich, saline fluid is inferred to have entered the base of the hydrothermal system at Kelian and to have transported Au, Pb and Zn. Gold deposition at Kelian is inferred to have resulted from a combination of: 1) boiling; 2) desulfidation due to stripping of H_2S by base metal sulfide deposition; 3) isothermal mixing between a reduced, sulfur-rich, saline fluid and a reduced, sulfur deficient, dilute fluid; and 4) wall rock sulfidation.

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