The geology and genesis of the Kencana epithermal Au-Ag deposit, Gosowong Goldfield, Halmahera Island, Indonesia

by
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MSci

Submitted in fulfilment of the requirements
For the degree of Doctor of Philosophy

UNIVERSITY OF TASMANIA
Australia
August, 2012
This thesis is dedicated to my parents

Gavin and Helen Clark

who encouraged me to study the Earth
while reaching for the stars
STATEMENT

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The Kencana Au-Ag low-sulfidation epithermal deposit, situated in the Neogene magmatic arc of Halmahera, Eastern Indonesia, has an estimated resource of 4.4 Mt @ 27.9 g/t Au, containing 4 Moz Au. The deposit, forming part of the Gosowong Goldfield, is the third, and most recently discovered (2002) deposit in the goldfield, after the Gosowong and Toguraci deposits.

The Gosowong goldfield is situated on the eastern side of the NW arm of Halmahera, which is composed of four superimposed volcanic arcs, produced as a result of subduction of the Molucca sea plate beneath Halmahera since the Palaeogene. Lithologies are dominated by andesite to basaltic andesite volcanic and volcaniclastic rocks and diorite intrusions.

Epithermal mineralization is hosted by the upper Miocene Gosowong Formation, a series of interbedded volcaniclastic rocks, ignimbrites and coherent andesitic volcanic flows and diorite intrusions. Andesites and diorites are closely temporally related, with andesite emplacement at 3.73 ± 0.22 Ma followed by diorite intrusion at ~3.50 Ma. Epithermal mineralization post-dates andesite and diorite emplacement with \[^{40}\text{Ar}/^{39}\text{Ar}\] dating of hydrothermal adularia giving a mean age of 2.925 ± 0.026 Ma for the Kencana deposit.

The deposit is hosted by two main sub-parallel NW-trending fault structures, (namely K1 and K2) with a strike length of 400 m, a vertical extent of 200 m and dipping ~46°E; joined by link structures, such as K-Link (KL). Bonanza Au-grade zones are located in dilational zones above hematitic volcaniclastic mudstone packages. The deposit does not crop out, but displays a weak surface expression represented by carbonate veining and faults filled with clay and pyrite.

Kencana (K1 vein) shows a complex, multiphase history of formation with numerous brecciation and opening events. Eleven infill types are recognized at Kencana, including

**ABSTRACT**
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Wallrock (1), quartz stockwork (2), wallrock breccias with crystalline quartz cement (3), red chalcedony infill (4), massive crystalline quartz (5), massive crystalline quartz breccias (6), cockade-banded quartz-chlorite breccias (7), banded quartz-chlorite (8), banded quartz-adularia (9), grey cryptocrystalline quartz stringer veins (10) and black quartz-molybdenite infill (11). Infill types 1, 2 and 3 are distributed throughout the deposit and are particularly prevalent on the margins of the vein. Types 7, 8 and 9 are the main ore-bearing stages and form the bulk of the central section of the vein. Type 11 infill is most prevalent to the north. Types 4, 5, 6 and 10 are variably and sporadically distributed across the vein.

Ore assemblages are dominated by high-fineness electrum and sulfides, with selenides and lesser tellurides and sulfosalts. Chalcopyrite is the most common sulfide mineral, with selenian-galena, sphalerite, bornite and pyrite in order of decreasing abundance. Other accessory minerals include aquilariite and molybdenite, with trace tennantite, arsenian-pyrite, silver and lead tellurides, naummanite and rare bismuth minerals. Gangue minerals are crystalline, microcrystalline and cryptocrystalline quartz, adularia, chlorite and calcite.

Ore deposition is interpreted to be the result of a combination of processes (mixing, boiling and cooling), with mixing processes inferred to be of particular importance, based on the presence of high-fineness electrum and selenium-bearing minerals. Evidence for boiling processes is present at Kencana after deposition of infill type 5, including bladed carbonate pseudomorphs and abundant adularia. A general transition from early coarse crystalline quartz to micro- and cryptocrystalline quartz is observed in the paragenetic sequence of the K1 vein, reflecting an increase in the rate of silica precipitation in silica-saturated fluids.

Fluid inclusion data indicate that early crystalline quartz (type 2c) was precipitated from near-neutral, hot, low salinity, low CO₂ (203.0 to 248.8°C, 0.1 to 0.5 wt% NaCl (equiv.), <0.015 m CO₂) fluids. Temperatures and salinities increase during formation of the main ore-bearing stages of the deposit. Fluids associated with precious metal deposition in type 7 and 8 infill are 202.7 to 306.9°C, 0.0 to 1.0 wt% NaCl (equiv.), <0.015 m CO₂, with fluids in quartz-adularia (type 9) mineralization forming at 95.8 to 258.7°C, 0.0 to 0.8 wt% NaCl (equiv.), and <0.015 m CO₂. Pressure estimates used to calculate minimum depth of
entrapment infer that most fluid inclusions were trapped 50 to 200 m deeper than their current location.

Mineralizing fluids are strongly dominated by meteoric water, with a marginally increased magmatic input during formation of type 7 and 8 infill. Gold hydrosulfides (in particular, Au(HS)$_2$) are most significant in terms of gold transport at Kencana. Metal-bearing fluids were sourced from the down-dip extension of the K1 vein, flowing upwards through the dilating structure. Metal distribution is vertically and laterally zoned at the Kencana deposit, with precious metals enriched at shallow levels of the system, and base metal values increasing systematically with depth. Lateral zonation implies a hydrothermal fluid temperature gradient with a metal source to the north of the Kencana deposit.

Ten alteration facies are recognized: SCG (Argillic 1) facies, ISP (Argillic 2) facies, IC (Argillic 3) facies, QAS (Phyllic) facies, EC (Propylitic 1) facies, CEP (Propylitic 2) facies, P (Sub-propylitic) facies, BM (Calc-potassic) facies, IDP (Intermediate-advanced argillic) facies, and KH (Advanced argillic) facies. Zonation is also observed in the distribution of alteration facies: (1) phyllic alteration (QAS facies) in the form of pervasive silicification and quartz-adularia-sericite alteration in the immediate vein zone, (2) argillic alteration (IC facies) enveloping the vein zone, (3) high-temperature propylitic alteration (CEP facies) filling fractures, extending up to 50 m from the vein, and (4) low-temperature argillic alteration and regional propylitic alteration (SCG, ISP and IC facies) distal to the vein. Supergene advanced argillic alteration (KH facies) blankets the top 5 m of stratigraphy at Kencana and represents intense tropical surface weathering. The geochemical signature of altered rocks hosting the Kencana deposit is variable depending on position relative to the mineralized structure, either within the vein, in the upflow zone, in the outflow zone or in the alteration halo.

It is proposed that a sub-class of low sulfidation epithermal deposits (Se-rich low sulfidation epithermals), characterized by bonanza-grade Au, bimodal volcanism and a Se-rich ore mineral assemblage, such as Midas (USA), Hishikari (Japan), and Broken Hills (New Zealand), be considered, and that Kencana is a classic example of such a deposit. It
is suggested that as well as similarities in their general geological setting, these deposits may form under similar physiochemical conditions, including the relatively more oxidized conditions than typical for low sulfidation systems.

The volcanic-hydrothermal evolution of the Kencana deposit is relevant to understanding the genesis of, and exploring, for other low sulfidation epithermal gold deposits in volcanic settings. Several geological and geochemical features observed in the Kencana deposit may be useful for helping to vector towards mineralized zones in the Gosowong Goldfield, and other low sulfidation epithermal districts, including zonation of chlorite chemistry from Fe-rich to Mg-rich with increasing proximity to mineralization, lateral metal zonation from high to low temperature assemblages, elevated Pb and Sb values in altered host rocks with strong zonation around the ore zone, and the quantitative increase of potassium metasomatism (represented by $mK/(2Ca+Na+K)$ values) towards the Kencana deposit. High As and Sb values relative to $mK/(2Ca+Na+K)$ values can be used as distal pathfinders to ore mineralization, as these elements are enriched at low $mK/(2Ca+Na+K)$ values, where precious metals (e.g. Au) are enriched at higher $mK/(2Ca+Na+K)$ values.
ACKNOWLEDGEMENTS

I have benefited greatly from the knowledge, assistance, support and friendship of many people over the course of this research and the following list attempts to thank all of those involved. I extend my gratitude to any that I may have overlooked.

First and foremost, I would like to thank my principal supervisor Prof. Bruce Gemmell, who has been unrelenting in his guidance, enthusiasm and belief in me over the course of this project. Bruce spent hours translating my thoughts and questions into expressions and theories fit for a thesis. Thank you Bruce for imparting so much knowledge on epithermal geology and for your patience, constructive help and advice - we’ve come a long way from the first week when I asked you what “epithermal” meant! Not to mention keeping me well supplied with Bombay Sapphire through many long months in the jungle.

I would also like to thank my secondary supervisor Prof. Dave Cooke, who was always willing to provide advice and support whenever it was required, and my research advisor Dr. Steven Mickethwaite.

To all the academic staff and researchers at CODES and the School of Earth Sciences at UTAS for many insightful discussions, inspiration and for opening my eyes to the world of ore deposits. I would also like to thank all the researchers and staff at CODES and the Central Science Laboratory who aided my project, took care of administrative and financial matters and taught me many new techniques in analysis: Karsten Goemann, Sandrin Feig, Sarah Gilbert, Marcel Guillong, Katie McGoldrick, Ian Little, Phil Robinson, Zhaoshan Chang, Huayong Chen, Izzy von Lichtan, Peter Cornish, Karen Mollross, Rose Pongratz, Helen Scott, Christine Higgins, Caroline Mordaunt, Claire Rutherford, Deborah Macklin and Nilar Hlaing. Thanks to June Pongratz for her assistance with printing and to Keith Dobson for IT and technical support.

This project was supported logistically and financially by Newcrest Mining Ltd., and thanks go to all those who were involved in setting up this project and for giving me the
opportunity to study such an incredible ore deposit. Special thanks to Dean Collett, Kylie
Braund, Trinity Gilmore and Chris Chambers for many meetings, helpful discussions and
direction. To all the geologists and staff on site at Gosowong, thank you for your assistance,
friendship, badminton matches and all logistical support I received whilst in Indonesia. I’m
eternally grateful for all the extra work put in to get me to the places I needed to be, and
for putting up with my dubious Bahasa Indonesia. Thanks to Dadan Wardiman, Daud Sil-
tonga, Sidik Purnama, Junita Siregar, Ketut Suyadnya, Joko Nugroho, Keke, Yulastriani
Aci, Sanjaya Bekti, Fintje Mangalo, Rachel Benton, Jeremy Simpson, Brian Koster, Nick
Fitzgerald, Colin McMillan and Mark Menzies.

Thanks for financial support provided to this project by the Society of Economic
Geologists in the form of research grants and fellowship awards.

To all the friends I have made at CODES over the past 4 years, thank you for all the
great times and for being there during the harder ones. I have had the opportunity to meet so
many wonderful people and I am certain that our friendships will only continue to grow over
the years. To Jamie and Clara Wilkinson, for endless advice, guidance, a beautiful friendship
and bubbling (in all its forms). To Victoria Braniff, for all the tea breaks and for keeping me
British. To Sarah Quine and Martin Jutzeler, for being our family away from home. To my
family and friends at home for understanding when I decided to uproot myself to the other
side of the globe and for always being there when I needed you. Thank you so much for the
countless emails and calls, for keeping me going and for always telling me I could do it.

To Mathieu, without whom this thesis would not have been finished. I do not know
how you managed to help get me across the line whilst writing your own thesis and yet
remaining your calm and collected self. Your patience and encouragement have been unwa-
vering and I cannot tell you how much I have valued your love, advice, friendship and your
ability to always make laugh these past years. This thesis isn’t for you, it’s because of you.

And finally, to Bun. I cannot wait to share with you all the beauty in the world, and
the magic in how it was made.
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