GEOLGY AND GENESIS OF THE
PERMATA - BATU BADINDING - HULUBAI AND KERIKIL
AU-AG LOW SULFIDATION EPITHERMAL DEPOSITS,
MT MURO, KALIMANTAN, INDONESIA.

by

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Submitted in fulfillment of the requirements for the degree
of
Doctor of Philosophy

University of Tasmania
Australia
June, 2004
DECLARATION AND AUTHORITY OF ACCESS

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Andrew T. Wurst
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DEDICATION

For my grandfathers

Alfred Martin Reichstein
(1920 to 1999)
and
Phillip Wilfred Wurst
(1921 to 1996)
ABSTRACT

The Permata-Batu Badinding-Hulubai (PBH) vein and Kerikil breccia-hosted deposits of Mt Muro, Kalimantan, Indonesia (10.4 Mt at 3.8 g/t Au and 101 g/t Ag) represent two styles of Au-Ag, low sulfidation epithermal deposit. These two systems provide important information on the processes and mechanisms of metal deposition under epithermal conditions.

PBH and Kerikil volcanic host rocks range from andesitic to basaltic in composition and are correlated with Early Miocene Sintang volcanism and Pliocene Metalung volcanism of Kalimantan. PBH and Kerikil exhibit similar structural trends and north-northwest dilational settings that are the result of north-northwest directed compression and dextral movement on major northwest striking basement structures. The different characteristics of the two deposits are attributed to different structural, lithological and hydrological controls that effected the nature of ore deposition.

The PBH deposit is hosted within extrusive and intrusive coherent volcanic rocks with minor volcaniclastic and sedimentary rocks. These units were deposited on the slopes of a stratovolcano and into valleys and pull-apart basins. Structure is dominated by north-northwest, northwest and northeast striking fractures, faults and veins on both a regional and deposit scale. The main deposit at PBH is hosted by a 2.2 km long, mineralized, cymoid structure which strikes north-northwest to north-south and dips steeply. Six stages of vein infill are recognized at PBH: stage 1 jasper; stage 2 microcrystalline quartz; stage 3 microcrystalline quartz + sulfide + sulfosalt; stage 4 base metal sulfide + sulfosalt + quartz; stage 5 amethyst and stage 6 carbonate. Early infill stages are typically fine-grained and microcrystalline with colloform, cockade and crustiform textures. Later infill stages are coarse-grained and crystalline with crustiform, colloform, cockade and dogstooth textures. Infill stage compositions and textures are linked to the dilation history of the vein and Riedel-style mechanics. Gangue mineralogy is dominated by polymorphs of silica (quartz, chalcedony and amethyst) with lesser adularia and clays. Carbonate is only present in the last vein stage. Ore mineralogy consists of pyrite, sphalerite, galena, Ag-Sb sulfosalts, Ag sulfides, Ag tellurides, native Ag and electrum. Jalpaite, freibergite and acanthite are all important hosts of Ag. Electrum ranges from 219 to 761 fine and contains trace amounts of Hg and Cu. PBH exhibits vertical metal zonation, with Au and Ag deposited at bonanza grades at higher elevations with Cu, Pb and Zn deposited below. Alteration is developed principally in the hanging-wall to the deposit and is well zoned, with disruption to zonation occurs where hydrothermal fluids have exploited more permeable and/or reactive beds. Alteration ranges from halloysite + kaolinite + silica assemblages at shallow depths to illite
+ sericite + pyrite + adularia + quartz surrounding the deposit to phengite/sericite +
adularia + pyrite + quartz and chlorite + carbonate + albite + epidote + quartz, both
distal to the deposit and at depth. Evidence for boiling within the hydrothermal system is
recognized from the presence of bladed quartz after carbonate, adularia and two phase
(liquid-vapor) fluid inclusions. Sulfur and carbon isotope data indicate a magmatic source
for sulfur in pyrite and carbon in carbonate. δ18O values of infill stage quartz show a trend
towards lower values with successively later infill vein stages. δ18O values of whole rock
alteration facies have lower values closer to the vein and higher values associated with
younger overprinting alteration assemblages.

Based on these characteristics, PBH can be classified as a sericite/illite-adularia-
quartz, Ag-Au low sulfidation epithermal vein deposit. The distribution and zonation of
alteration, mineral textures, mineral composition and metals within the mineralized
structures are a direct result of the mechanical and physico-chemical processes of
depressurization (through structure dilation) and consequent boiling, mixing and cooling
of the hydrothermal fluids. PBH is a single dilating conduit which effectively focused fluid
flow and boiling is the dominant mechanism of metal deposition. Alternating periods of
boiling produced the banded, colloform, crustiform and cockade vein textures observed at
PBH. The physico-chemical processes of boiling-related mineral deposition resulted in
discrete zoning of metals. Bicarbonate fluids, created above the boiling zone, were
excluded from the system by temperature and buoyancy effects. After the system waned
the bicarbonate fluids were able to migrate down into the system and deposit carbonate in
the last infill stage.

The Kerikil deposit is hosted by coherent volcanic lavas and intrusions of a
stratovolcano vent environment. Kerikil is divided into three main deposits that total over
900 m in length and are confined by north-northwest and north-south striking structures.
Eight vein and breccia stages are recognized within three main periods of mineralization at
Kerikil. During period 1, infill stages 1 to 4 are dominated by quartz gangue. In period 2,
infill stages 5 to 7 are characterized by the presence of rhodochrosite as an important
gangue mineral. In period 3, infill stages 8 and 9 are represented by base metal and pyrite
veins, respectively, which crosscut all earlier infill stages. The main ore stages are stage 2
(microcrystalline quartz + sulfide + sulfosalt), stage 5 (rhodochrosite + sulfide + sulfosalt)
and stage 8 (base metal sulfide + quartz). Ore mineralogy is dominated by pyrite and
chalcopyrite with minor sphalerite, galena, Ag sulfosalts and electrum. Selenian jalpaite,
acanthite, and native Ag are important hosts of Ag. Electrum is 480 to 764 fine and is
typically observed as inclusions in pyrite and association with chalcopyrite. Metal zonation
is poorly developed at Kerikil with Au, Ag, Cu, Pb and Zn precipitating at the same level
within the system. A brecciated system and multiple fluid pathways, allow the downwards migration and mixing of oxidizing ground waters and bicarbonate waters with geothermal fluids, thus favoring both Au and base metal precipitation together. A broad alteration zonation with depth is apparent at Kerikil. Alteration ranges from halloysite + kaolinite + quartz at shallow depths to illite/sericite + adularia + pyrite + quartz proximal to the deposit and chlorite + carbonat[e + albite + epidote + quartz distally and at depth. At Kerikil, there is overprinting of the illite/sericite + adularia + pyrite + quartz assemblages by the kaolinite + halloysite + quartz facies at shallow levels and deeper in the deposit. Evidence for boiling within the conduit comes from the presence of bladed carbonate, adularia and two phase fluid inclusions. Sulfur and oxygen isotope values indicate a magmatic source for sulfur in pyrite and carbon in carbonate. Carbon and oxygen isotope values suggest that rhodochrosite at Kerikil was precipitated from surficial bicarbonate waters. $\delta^{18}O$ values of infill stage quartz are relatively constant indicating a fluid in equilibrium with andesite host rocks. $\delta^{18}O$ values of whole rock alteration facies, display a trend towards lower values with depth and higher values at surface, associated with late stage alteration.

Kerikil is an illite, Au-Ag, quartz-carbonate, low sulfidation epithermal breccia and stockwork deposit. Kerikil consists of breccias, veins, faults and stockwork. Hydrothermal fluids have been able to boil, cool and mix with bicarbonate waters through enhanced permeability facilitated by repeated sealing, brecciation and re-brecciation of the coherent volcanic host rocks. Sealing of multiple fluid conduits and subsequent rupturing gives rise to complex overprinting mineralogical and textural relationships, complex mineral paragenesis, metal and alteration zonation. Boiling is an important process when fluid pathways are open. However, sustained boiling precipitates microcrystalline quartz which seals fluid pathways, allowing the influx of earlier boiling derived bicarbonate fluids into the former up flow zone. Subsequent over-pressurization and seismic rupture leads to seal failure and the direct contact of bicarbonate waters above the seal with boiling hydrothermal fluids from below the seal. Precious metals and base metals then precipitate together due to the combined physico-chemical processes of boiling and mixing.

Study of the volcanological, structural, mineralogical, metallogenic, alteration and isotopic characteristics of the PBH and Kerikil deposits has led to geological and geochemical vectors being established to aid in mineral exploration at Mt Muro.
ACKNOWLEDGEMENTS

Many people have offered advice, assistance, support and friendship over the course of this research and the following list attempts to thank all of these, and I extend a general acknowledgement to any I may have overlooked.

Firstly, I would like to thank my supervisor, Assoc. Prof. Bruce Gemmell who has always provided help, encouragement, and guidance in the course of the research. I have appreciated Bruce's friendship, and he has always been a source of inspiration through his enthusiasm for my project. Dr. David Cooke, my secondary supervisor, was always more than willing to provide support, friendship and guidance whenever it was required. Careful and tedious corrections by Bruce, Dave and Dr. Cari Deyell were invaluable in the final drafts of this thesis. I am also especially grateful to Dr. Stuart Simmons, Prof. Jocelyn McPhie, Dr. Robert Scott, Dr. Robina Sharpe, Wally Hermann and Mike Blake, as part of the Australian Industries Mineral Research Foundation (AMIRA) P588 (Alteration in Low Sulfdation Epithermal Systems) Project Team, who all provided excellent critique towards the research. All the academic staff and researchers at CODES and the School of Earth Sciences under the leadership of Prof. Ross Large, were also a constant source of inspiration. I would like to thank Ross and CODES for the opportunity and financial support to attend conferences and visit many different mineral deposits across several continents during the course of my studies; the experience was invaluable and rewarding.

The initial stages of this project were aided financially and logistically by Aurora Gold Ltd. and Indo Muro Kencana (IMK) Ltd., Mt Muro, Indonesia. IMK staff were always helpful in providing assistance and discussions on aspects of Mt Muro Geology under sometimes trying work conditions. In particular, I am grateful to Trevor Bradley and Peter Brown for the conceptualization and management of the project, as well as the IMK mine development team; Julie Ried, Andrew Grieve, Priyo, Trejanto, Tawoco, Ambung and Avar; and field assistants; Luther, Zubier, and Putuh (who helped lay out core and taxied me to the pits, while simultaneously providing me with Indonesian language lessons), Hugo Hooglievliet and his mine geology team (who provided grade control data and discussions on various aspects of the pits), Dave Hester (for assistance with computing problems and expertise in diamond gemstone evaluation), Donny Eka and his survey team (for help with pit survey pickups), Has and Harry (for arranging and building
boxes for rock transportation back to Australia), Operations Manager; Dave Morrison and Mine Managers; Dean Stewart and Rohan Johnson (for logistical support and accommodation during the course of my stay at Dirung Camp). The final stages of this project were funded through the AMIRA P588 project and an Industry APAI grant, and to this part, I thank Alan Goode as the AMIRA representative.

I gratefully acknowledge Doug Kirwin and Dr. Chris Wilson from Ivanhoe Mines Ltd. for giving me the great experience of working in Mongolia during the closing stages of my studies and also supplying me with a computer to aid in the completion of this thesis.

The CODES and Central Science Laboratory (CSL) support staff are greatly thanked for their role in providing technical and logistical assistance. I would like to thank June Pongratz who was always willing to help in all drafting and publishing matters, Peter Cornish and Di Stephens for logistical support, Simon Stevens and his crew for their thin section and lapidary work, Dr. David Steele for assistance and guidance on the electron microprobe and Dr. Phil Robinson, Kate McGoldrick and Nilar Hlaing for providing timely geochemistry data. I also appreciate Dr. Mark Barton's (University of Arizona) help with oxygen isotope analyses and making my stay in Tucson, Arizona a pleasant one.

Numerous post-doctoral fellows and Ph.D. students at the School of Earth Sciences have been a constant source of inspiration and amusement over the past years while at the same time providing friendship, support and a useful and stimulating academic forum for inspiring discussion (wine tasting nights). To all of them I extend my thanks and heartfelt best wishes for whatever they will do and wherever they may go. I would like to make special mention of Andrew Davies, Kirstie Simpson, Alan Wilson, Mike Buchanan, Glen Masterman, Darryl Clark, Neil Martin, Vanessa Lickfold, Steve Boden, Catherine Reid, Andrew Rae, Kate Bull and Tim Ireland, as well as former room-mates Kieren Howard, Roman Leslie, Rohan Wolfe and Catheryn Gifkins for their camaraderie, friendship and discussions over the years at CODES.

I would also like to thank my parents and family for their love, support and encouragement from afar, during my entire professional and academic career, which has taken me to many exotic places but has often kept me too long away from home.

Finally and utmostly, I am, and always will be indebted to Cari for her patience, love, help, support, companionship, and just for always being there when needed most.
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