Geology, Geochemistry and Metallogenesis of Selected Sediment-hosted Gold Deposits in the Central Gold Belt, Peninsular Malaysia

Charles Makoundi

MSc

A research thesis submitted in partial fulfillment of the requirements for the degree of Master of Science

School of Earth Sciences, CODES Centre of Excellence in Ore Deposits, University of Tasmania

April 2012
Abstract

The Tersang, Selinsing, and Penjom gold deposits are located at the east of the Bentong-Raub Suture Zone in the State of Pahang, Central Malaysia. The Tersang gold deposit is hosted in sandstone, breccia and felsic rhyolite of probably Triassic in age. LA ICP-MS U-Pb zircon dating of the host sandstone at Tersang indicates a possible age that ranges from ca.319 Ma to ca.219 Ma. However, the age of the sandstone could be as young as Upper Triassic. The alkali rhyolite, which intruded the host sandstone sequence, yielded a Late Triassic age of 218.8 ± 1.7 Ma. Structural and textural investigation has shown two sets of NNW-SSE and ESE-WNW oriented mineralised veins at Tersang and ore minerals include pyrite, arsenopyrite, sphalerite, galena, geocronite \([\text{Pb}_{14}(\text{Sb, As})_8\text{S}_{23}]\), covellite, and gold. Normalised quantitative analysis of gold grains in veins indicates two generations: high fineness gold (959 to 965) and low fineness gold (769 to 792). The argillic alteration is dominant in the Tersang deposit and characterised by an assemblage of sericite, illite, and montmorillonite.

Detailed paragenetic studies at Tersang revealed four pyrite types including euhedral to subhedral “spongy” pyrite with internal fracturing (pyrite 1), euhedral clean pyrite (pyrite 2) overgrown on pyrite 1, amorphous pyrite with high As and high Au (pyrite 3), crack-fill or vein pyrite with high As and low Au (pyrite 4). LA ICP-MS analysis of different pyrite types indicates that they are enriched in Au, As, Zn, Ni, Co, Sb, Tl, Se and depleted in Cu, Ag, Te, V, Bi, and Ag. Pyrite 1 and Pyrite 3 are particularly enriched in Au, As, Co, Ni, Se, and Tl. Pyrite 1 and pyrite 2 show zoning of
Co, Ni, As, and Se and they have low Ag/Au, and Ni/Co ratios indicating that these pyrites are likely of metamorphic origin.

Sulphur isotope composition of pyrite, arsenopyrite and galena has a range of $\delta^{34}\text{S}$ values from -6 to 2.5 ‰ at Tersang. Additionally, these sulphide minerals are associated with primary hematite indicating that the sulphur may have been derived from the oxidation of a magmatic hydrothermal fluid at Tersang. The Tersang ores contain lead isotope ratios of 18.59 for Pb$^{206}$/Pb$^{204}$ and 15.75 for Pb$^{207}$/Pb$^{204}$ suggesting that lead was probably derived from the lower crust source rocks. At Tersang, fluid-inclusion studies yielded a homogenisation temperature range from 210 to 348 °C with salinities between 2.41 and 8.95 wt % NaCl equiv. indicating magmatic input due to relatively high salinity. Laser Raman Spectrometry analysis indicates the presence of CO$_2$ (98.1 to 100 mol %) in fluids with a minor amount of CH$_4$ (0 to 1.9 mol %).

In comparison, the Selinsing gold deposit is hosted by phyllite, siltstone, cataclasite, mylonite and argillite units of probably Triassic in age. LA ICP-MS U-Pb zircon dating of the host siltstone indicated a maximum Carboniferous age between 324.1 ± 3.5 and 346 ± 6 Ma. Structural and paragenetic studies of quartz veins revealed two vein generations: NS-oriented early veins and NNW-SSE-trending pinch and swell structures formed during D2 extensional regime and later brecciated veins, which resulted from D3 compressional regime.

At Selinsing, ore minerals consist of pyrite, arsenopyrite, galena, sphalerite, chalcopyrite, pyrrhotite and gold. Metal distribution in drill holes shows that economic mineralisation is mostly found in cataclasite and breccia units suggesting a structural control on gold mineralisation. The host sequences are altered to quartz-ankerite
alteration in the high-grade zones in the catalasite units. However, sericite and illite alteration is present in phyllite and siltstone units. Detailed textural and chemical studies revealed seven pyrite types, which include framboidal pyrite (pyrite 1), rounded recrystallised pyrite (pyrite 2), euhedral clean pyrite (pyrite 3), euhedral to subhedral with inclusions (pyrite 4), overgrown pyrite (pyrite 5), euhedral to subhedral overgrown pyrite (pyrite 6), and euhedral overgrown on pyrite 6 (pyrite 7).

LA ICP-MS analysis of the pyrite types indicates that they are enriched in Au, Pb, As, Zn, Ni, Co, and Sb and depleted in Mo, Te, V, Bi, and Ag relative to the Tersang pyrites. Pyrite 1 and pyrite 2 have almost the same trace element assemblages. Compared to pyrite 1, pyrite 2 shows slight enrichment in Bi, Te, and Se and depletion in Co and Mo. However, Pyrite 3 and pyrite 6 are particularly enriched in Au, As, Cu and Ni, whereas pyrite 7 is enriched in Pb and Mo. Sulphur isotope composition of ores from the Selinsing deposit ranges from 1.5 to 9.2 ‰. In addition, Pb isotope values of pyrite range from 18.94 to 19.10 for Pb$^{206}$/Pb$^{204}$ and from 15.72 to 15.73 for Pb$^{207}$/Pb$^{204}$ suggesting a high uranium source rock of the lead. Fluid-inclusion in quartz at Selinsing yielded a homogenisation temperature range from 194 to 348 °C and salinities between 1.23 and 9.98 wt % NaCl equiv. Similar to Tersang, Laser Raman Spectrometric analysis revealed CO$_2$-rich (95 to 100 mol %) inclusions with minor amount of N$_2$ (0 to 5 mol %).

A limited study was undertaken at the Penjom gold deposit. This deposit is hosted in Permian tuffaceous siltstone, carbonaceous shale, and tuffaceous conglomerate sequence that is intruded by rhyodacitic and trachyandesitic igneous rocks. LA ICP-MS U-Pb zircon dating of the host tuffaceous siltstone and tuffaceous breccia indicated ages ranging from 264.9 ± 2.6 to 259.8 ± 4.9 Ma (Permian). Gold mineralisation occurs in
carbonate-rich zones hosted within dilated quartz veins, which contain disseminated pyrite and arsenopyrite. These veins are found in NS and NE trending shears which dip 60-75° to the east. Sulphur isotope composition at the Penjom deposit ranges from -8.4 to -3.9 ‰. The Pb isotope composition from galena ranges from 18.54 to 18.57 for Pb\(^{206}/\)Pb\(^{204}\) and 15.70 for Pb\(^{207}/\)Pb\(^{204}\). This Pb isotopic signature is less radiogenic indicating a lower crust source rock. Fluid inclusion studies at Penjom yielded a homogenisation temperature range from 260 to 300 °C and salinities between 6.30 and 8.68 wt % NaCl equiv.

The geological, structural, geochemical and isotopic data together with mineral paragenesis, pyrite chemistry and ore fluid characteristics of the Tersang, Selinsing and Penjom gold deposits indicate that they are comparable to Bendigo and Meguma type deposits. The geochemical and isotopic evidence also suggests that the ore fluids have been predominantly derived from a mixture of magmatic and metamorphic sources with a minor meteoric fluid. The ore fluids ascended and deposited in structurally favorable traps, such as shear zones, saddle reefs, and fold hinges during metamorphism and deformation. The source of Au is still conjectural; however, LA ICP-MS pyrite geochemistry indicates multiple stages of Au enrichment and remobilisation from diagenetic conditions. The enrichment of VAMSNAZ (V, As, Mo, Se, Ni, Ag and Zn) metals implies a possibility of diagenetic origin of the gold. Pyrite chemistry, alteration, Pb isotopes and structural setting at Tersang, Selinsing, and Penjom provide exploration guides. Elements such as As, Sb, Pb, Ag, Co, Ni, Tl, Te, Se, Zn, Mo, U and V occurring together with Au can be used as pathfinders and vectoring tools. Occurrences of quartz-ankerite and quartz-illite-chlorite alteration assemblages are also indicative of potentially
Au enriched geological terrains. Additionally, Pb isotope ratios for \( \text{Pb}^{206} / \text{Pb}^{204} \) that varies from 15.72 to 19.10 are useful geochemical criteria to search for gold.
Declaration of Originality

This thesis contains no information that has been accepted for the award of any other degree or diploma in any tertiary institution around the world. To the best of my knowledge and belief, it contains no material pre-published or written by another individual, apart from due reference made in the text of the paper.

Signed

Charles Makoundi
B.Sc. M.Sc (UMNG), M.Sc (UM)
(April, 2012)

Authority of access

This thesis may be made available for loan and limited copying in accordance with the Copyright Act 1968.

Signed

Charles Makoundi
B.Sc. M.Sc (UMNG), M.Sc (UM)
(April, 2012)
# TABLE OF CONTENTS

ABSTRACT ...............................................................................................................................ii
DECLARATION ..........................................................................................................................vi
CONTENTS ...............................................................................................................................vii
LIST OF FIGURES ..................................................................................................................xi
LIST OF TABLES .......................................................................................................................xviii
ACKNOWLEDGEMENTS ...........................................................................................................xx

Chapter 1: Introduction
1.1 Prelude ...............................................................................................................................1
1.2 Location, topography and climate ....................................................................................1
1.3 Exploration and mining history .......................................................................................3
1.4 Aims ..................................................................................................................................6
1.5 Thesis organisation ...........................................................................................................7

Chapter 2: Tectonic and district-scale setting
2.1 Introduction .......................................................................................................................10
2.2 Tectonic setting ................................................................................................................10
   2.2.1 Sibumasu terrane .......................................................................................................11
   2.2.2 Indochina, South China and East Malaya terranes .....................................................12
   2.2.3 West Sumatra terrane ..............................................................................................13
   2.2.4 West Burma terrane and the Mogok belt ..................................................................13
   2.2.5 Woyla terrane .........................................................................................................14
   2.2.6 Medial Sumatra Tectonic Zone (MSTZ) ..................................................................14
   2.2.7 Bentong-Raub Suture Zone ....................................................................................14
   2.3 Metallogenic belts of Malaysia ......................................................................................18
   2.3.1 The Western tin belt ...............................................................................................18
   2.3.2 The Central gold belt .............................................................................................18
   2.3.3 The Eastern tin belt ...............................................................................................20
2.4 District-scale geology ......................................................................................................21

Chapter 3: Local geology and geochronology
3.1 Introduction ......................................................................................................................25
3.2 Methods of study ............................................................................................................25
   3.2.1 Fieldwork ..............................................................................................................25
   3.2.2 Laboratory methods ...............................................................................................27
3.3 Geology of the Tersang deposit .....................................................................................30
   3.3.1 Sandstone unit .......................................................................................................30
   3.3.2 Felsic intrusion unit ...............................................................................................30
   3.3.3 Breccia unit ..........................................................................................................34
3.4 Geology of the Selinsing deposit ...................................................................................34
   3.4.1 Phyllite unit ..........................................................................................................34
   3.4.2 Siltstone unit .........................................................................................................37
   3.4.3 Fault-related rocks ...............................................................................................37
Chapter 6: Pyrite geochemistry
6.1 Introduction.................................................................116
6.2 Method of study..........................................................116
6.3 Processing of trace element maps.....................................117
6.4 Pyrite geochemistry at the Tersang gold deposit.....................118
   6.4.1 Pyrite trace element mapping at Tersang.......................118
   6.4.2 Trace element distribution at Tersang.........................125
6.5 Pyrite geochemistry at the Selinsing gold deposit...................128
   6.5.1 Trace element distribution at Selinsing........................136
6.6 Comparative trace element distribution at Tersang and Selinsing....141
6.7 Discussion.......................................................................146
6.8 Conclusions...................................................................148

Chapter 7: Sulphur and lead isotopes
7.1 Introduction...................................................................149
7.2 Sulphur isotopes............................................................149
   7.2.1 Previous studies.......................................................150
   7.2.2 Methods.................................................................150
   7.2.3 Sulphur isotope compositions.....................................151
      7.2.3.1 Tersang..........................................................151
      7.2.3.2 Selinsing.........................................................151
      7.2.3.3 Penjom..........................................................154
   7.2.4 Discussion.............................................................154
7.3 Lead isotopes.................................................................158
   7.3.1 Methods.................................................................158
LIST OF FIGURES

Chapter I

1.1 Location of the Tersang, Selinsing and Penjom gold deposits in mainland Southeast Asia…………………………………………………2

1.2 Location of gold deposits in the State of Pahang, Peninsular Malaysia………………………………………………………………………4

Chapter II

2.1 Distribution of continental blocks and suture zones in Southeast Asia region. …11

2.2 Hypothetical plate tectonic reconstruction of the distribution of the continents between 280 and 210 million years ago………………16

2.3 Cross-section illustrating plate tectonic evolution of the Malay Peninsular and Singapore……………………………………………………………17

2.4 Map of the metallogenic belts of Peninsular Malaysia………………………19

2.5 District-scale geological map showing location of the gold deposits, Central Malaysia………………………………………………………………22

Chapter III

3.1 Geological map of the Tersang gold deposit showing the main lithologic units…………………………………………………………………31

3.2 Field view and outcrop photographs at Tersang……………………………32

3.3 Lithological characteristics of Host rock and intrusion at the Tersang gold deposit………………………………………………………………33

3.4 Geological map of the Selinsing gold deposit showing the main lithologies, Central Malaysia………………………………………………………….35

3.5 Lithological characteristics of host sequence at the Selinsing gold deposit……36

3.6 Lithological characteristics of host sequence and limestones at the Selinsing gold deposit……………………………………………………39

3.7 Characteristics of the orebody at the Selinsing gold deposit. ………………41
Chapter IV

4.1 Structural features of Host rock and vein assemblages at Tersang gold deposit..............................58
4.2 Structural setting at Tersang..........................................................59
4.3 Structural features of Host rock at the Selinsing gold deposit.........................61
4.4 Structural features of Host rock and vein assemblages at the Selinsing gold deposit..............................................62
4.5 Structural features of barren quartz veins at the Selinsing Gold deposit........................................................63
4.6 Vein stages at the Tersang gold deposit..............................................65
<table>
<thead>
<tr>
<th>Chapter V</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.1 Alteration mineral assemblages at the Tersang gold deposit ..................................................78</td>
</tr>
<tr>
<td>5.2 Alteration assemblages at the Selinsing gold deposit ............................................................79</td>
</tr>
<tr>
<td>5.3 Textural characteristics of different types of pyrite at the Tersang gold deposit .............................83</td>
</tr>
<tr>
<td>5.4 Gold occurrence at the Tersang deposit .........................................................................................85</td>
</tr>
<tr>
<td>5.5 Gold occurrence at the Tersang deposit .........................................................................................86</td>
</tr>
<tr>
<td>5.6 Gold occurrence at the Tersang deposit .........................................................................................87</td>
</tr>
<tr>
<td>5.7 SEM images showing morphology of alluvial gold grains at the Tersang deposit ..................................89</td>
</tr>
<tr>
<td>5.8 Ore minerals at the Tersang deposit ...............................................................................................91</td>
</tr>
<tr>
<td>5.9 Back-scattered electron images of ore and gangue minerals at the Tersang gold deposit ..................94</td>
</tr>
<tr>
<td>5.10 Textural characteristics of pyrite at the Selinsing gold deposit .....................................................97</td>
</tr>
<tr>
<td>5.11 Ore minerals at the Selinsing deposit ............................................................................................100</td>
</tr>
<tr>
<td>5.12 Gold occurrence at the Selinsing gold deposit ..............................................................................103</td>
</tr>
<tr>
<td>5.13 Ore and gangue minerals at the Selinsing deposit ..........................................................................104</td>
</tr>
<tr>
<td>5.14 Lithologic log of the drillhole SEL-DD0001 .................................................................................107</td>
</tr>
<tr>
<td>5.15 Lithologic log of the drillhole SEL-DD0002 ...............................................................................108</td>
</tr>
</tbody>
</table>
Chapter VI

6.1 LA-ICPMS images of trace elements in pyrite 1 and pyrite 2 (Sample No. TER-R007) at the Tersang gold deposit

6.2 LA-ICPMS images of trace elements in vein-hosted pyrite 1 (Sample No. TER-R039) at the Tersang gold deposit

6.3 LA-ICPMS images of trace elements in wallrock-hosted pyrite 1 and pyrite 2 (Sample No. TER-R007B) at the Tersang gold deposit

6.4 LA-ICPMS images of trace elements intrusion-hosted pyrite (pyrite 2) (Sample No. TER-R033) at the Tersang gold deposit

6.5 LA-ICPMS images of trace elements in pyrite 1, pyrite 3 and pyrite 4 (Sample No. TER-R007B) at the Tersang gold deposit

6.6 Attribute map of pyrite grains and gold solubility diagram at Tersang

6.7 Periodic table of chemical elements

6.8 Normalised quantitative analysis of trace elements for all pyrite types at the Tersang gold deposit, Central Malaysia

6.9 Trace element ratios at the Tersang gold deposit

6.10 Framboidal pyrite textures and LA ICP-MS spot analysis at Selinsing

6.11 LA-ICPMS images of trace elements in pyrite 3 (Sample No. SEL-R039) at the Selinsing deposit

6.12 LA-ICPMS images of trace elements in pyrite 4, pyrite 5, and pyrite 6 (Sample No. SEL-R006) at the Selinsing deposit

6.13 LA-ICPMS images of trace elements in pyrite 5, pyrite 6 (Sample No. SEL-R006) at the Selinsing gold deposit, Central Malaysia
6.14 LA-ICPMS images of trace element of zoned hydrothermal Pyrites (pyrite 4, pyrite 5, pyrite 6, and pyrite 7) at the Selinsing gold deposit…………………..133

6.15 LA-ICPMS images of trace elements in pyrite 4 and pyrite 5 (Sample No. SEL-R054C) at the Selinsing gold deposit, Central Malaysia…………………………….134

6.16 LA-ICPMS images of trace elements in pyrite 4 and pyrite 5 (Sample No. SEL-R009) in black shale at the Selinsing gold deposit……………………………..135

6.17 Attribute map of pyrite grains and gold solubility diagram at Selinsing……….136

6.18 Normalised quantitative analysis of trace elements for all pyrite types at the Selinsing gold deposit………………………………………………………………137

6.19 Normalised quantitative analysis of framboidal pyrites (pyrite 1 and pyrite 2) at the Selinsing gold deposit, Central Malaysia………………………………………………….137

6.20 Binary plot of Au against Bi (A) and Te (B) in all pyrite types at the Selinsing gold deposit, Central Malaysia………………………………………………………………….138

6.21 Ratio of trace elements at the Selinsing gold deposit, Central Malaysia…….139

6.22 Line ablation line across pyrite 4 and pyrite 5 at the Selinsing gold deposit…….140

6.23 Box plots showing mean concentrations of Au, Co, and Ni in pyrite for both the Tersang and Selinsing gold deposit………………………………………………….141

6.24 Box plots showing mean concentrations of Cu, Zn, and Se in pyrite for both the Tersang and Selinsing gold deposits…………………………………………………….142

6.25 Box plots showing mean concentrations of Sb, Tl, and Pb in pyrite for both the Tersang and Selinsing gold deposits…………………………………………………….143

6.26 Box plots showing mean concentrations of Bi, Ti, and Ag in pyrite for both the Tersang and Selinsing gold deposits…………………………………………………..144

6.27 Point density maps of main Au-As concentration ……………………………145
Chapter VII

7.1 Histograms showing the $\delta^{34}S$ compositions of sulphides from the Tersang, Selinsing and Penjom deposits, Malaysia.................................153

7.2 Sulphur isotope composition at the Tersang, Selinsing and Penjom deposits, Central Malaysia.................................................................156

7.3 Pb isotope ratio for pyrites from the Selinsing, Tersang and Penjom gold deposits, Malaysia.................................................................161

7.4 Plot of lead isotopic compositions for Pb$^{208}$/Pb$^{204}$ versus Pb$^{206}$/Pb$^{204}$ from the Tersang, Selinsing, and Penjom deposit...................................................161

7.5 Pb isotope compositions for Pb$^{207}$/Pb$^{204}$ versus Pb$^{206}$/Pb$^{204}$ for the Tersang, Selinsing, and Penjom deposits, Central Malaysia..........................162

Chapter VIII

8.1 Photomicrographs of fluid inclusions at the Tersang gold deposit, Central Malaysia.................................................................168

8.2 Photomicrographs of fluid inclusions in quartz veins at the Selinsing gold deposit.................................................................169

8.3 Photomicrographs of fluid inclusions at the Penjom gold deposit, Central Malaysia.................................................................170

8.4 Histogram of homogenisation temperature of Type I inclusions at the Tersang gold deposit, Central Malaysia.................................174

8.5 Histogram of salinities of Type I inclusions at the Tersang gold deposit, Central Malaysia.................................................................174

8.6 Histogram of homogenisation temperature of Type I inclusions at the Selinsing gold deposit, Central Malaysia.................................175

8.7 Histogram of salinities of Type I inclusions at the Selinsing gold deposit, Central Malaysia.................................................................175

8.8 Histograms of homogenisation temperature at the Penjom gold deposit, Central Malaysia.................................................................176

8.9 Histogram of salinities for the Type III fluid inclusions from the Penjom gold deposit, Central Malaysia.................................................................177
8.10 Plot of molar percent of H$_2$O against homogenisation temperature at the Tersang gold deposit……………………………………………………………………..181

8.11 Plot of molar percent of H$_2$O against homogenisation temperature at the Selinsing gold deposit……………………………………………………………………..181

8.12 Plot of molar percent of H$_2$O against homogenisation temperature at the Penjom gold deposit……………………………………………………………………..182

8.13 Plot of homogenisation temperatures and salinities for the Tersang, Selinsing and Penjom deposit, Central Malaysia…………………………………………………………184

Chapter IX

9.1 Cartoon showing a simplified ore deposit model of the Tersang gold deposit, Malaysia……………………………………………………………………...195

9.2 A two-stage genetic model of the Selinsing gold deposit, Central Malaysia……………………………………………………………………...197

9.3 Deposit model of the Penjom gold deposit, Central Malaysia …………………199
LIST OF TABLES

Chapter IV
4.1 Deformation history at the Selinsing gold deposit, Central Malaysia……………70

Chapter V
5.1 Mineral paragenesis at the Tersang gold deposit, Central Malaysia……………..81
5.2 Normalised quantitative analysis of gold in veins at Tersang……………………88
5.3 Normalised quantitative analysis of alluvial gold at Tersang…………………90
5.4 Mineral paragenesis at the Selinsing gold deposit, Central Malaysia…………96

Chapter VII
7.1 Sulphur isotope composition for the Tersang, Selinsing, and Penjom deposits…152
7.2 Lead isotope composition for the Selinsing, Tersang, and Penjom deposits……159

Chapter VIII
8.1 Summary of homogenization temperature and salinity at the Selinsing, Tersang, and Penjom deposits…………………………………………………..172
8.2 Laser Raman Spectrometry Results for the Tersang gold deposit……………..178
8.3 Laser Raman Spectrometry Results for the Selinsing gold deposit…………….178
8.4 Laser Raman Spectrometry Results for the Penjom gold deposit………………179

Chapter IX
9.1 Comparison of the Selinsing, Tersang, and Penjom Au deposits in Central Malaysia……………………………………………………………………….193
9.2 Comparison of the gold deposits in Malaysia with other deposits……………..194
ACKNOWLEDGMENTS

Special thanks to my supervisor Assoc. Prof. Dr. Khin Zaw, who tirelessly guided me right from choosing the research project and methods for my research, from the data collection to writing and completion of this thesis. I also strongly thank him for his advice and constructive criticism during my study. In my weak moments, he motivated me to keep going and be strong regardless of what I could face. He also taught me to be consistent in the process of tiding up my thesis. I had many fruitful discussions with my co-supervisor Prof. R.R. Large, in particular on pyrite geochemistry. His ideas were a driving force that made me enjoyed writing on various aspects of pyrite chemistry.

During my field work, exploration and mine geologists of Monument Mining Ltd, Malaysia gave me a hand through sampling, sample preparation, and packaging. To these folks I am indebted. I am grateful to Mr. Zaidi Harun, Managing Director of Monument Mining Ltd Company who permitted me to carry out my project at the Selinsing gold mine.

Thanks to Dr. Teh Gua Hoe, Research Fellow at the University of Malaya, who played an important role of motivating me in the early days of my field work in Malaysia. My gratitude also goes to Dato’s Andrew Kam, CEO of Peninsular Gold Ltd Company for allowing me to get access into the Tersang mine area. Thanks to the staff of Penjom gold mine for granting me permission to collect hand specimen samples at the Penjom mine-site.

I am also thankful to Dr. Sebastien Meffre who provided me with new ideas on how to write a good piece of pyrite chemistry by processing pyrite mapping data using ioGAS software. He also reviewed my research work on structural geology and
facilitated the dating of my samples. Christine Cook and Karsten Goemann at the Central Science Laboratory are thanked for the sulphur isotope conventional analysis and SEM and microprobe analysis. Many thanks to Dr. Zhaoshan Chang with whom I spent quite a bit of time on analyzing clay minerals using PIMA instrument. This study is financially supported by CODES Scholarships, Monument Mining and CODES Industry funded “Ore Deposits of SE Asia” Project.

I also thank Phil Robinson and Katie McGoldrick for their work on XRF analysis. This study was undertaken with financial and logistical support from Monument Mining Ltd, CODES Scholarships and Ore Deposits of SE Asia” Project. During my candidature at CODES, many colleagues have been a source of psychological support such as Takayuki Manaka, Matthieu Agenau, Jeff Steadman, Abhisi Salam, Mohd Basril, Kit, Yungu, and Hugo Galvan to name a few. Thanks to Christian McKenzie and his team for helping on technical issues related to information technology.

Many thanks also go to the administrative staff at CODES, University of Tasmania: Nilar Hlaing, Sarah Gilbert, Simon Stephens, Peter Cornish, Isabella von Lichtan, Christine Higgins, Karen Mollross, Deborah Macklin, Helen Scott, and Rose Pongratz.