



UNIVERSITY
OF TASMANIA

**A GEOLOGICAL, GEOCHEMICAL AND METALLOGENIC STUDY
OF THE CHATREE EPITHERMAL DEPOSIT,
PHETCHABUN PROVINCE, CENTRAL THAILAND**

by

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**A thesis submitted in fulfilment of the requirements for the
degree of Doctor of Philosophy**



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DECLARATION

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ABSTRACT

The Chatree gold-silver epithermal deposit is located in the central part of the Loei Fold Belt (LFB), which forms an arcuate zone that extends from Laos in the north through central and eastern Thailand into Cambodia in the south. Epithermal gold-silver mineralisation is present as veinlets/veins and stockworks and minor breccia and is hosted in Late Permian volcanoclastic and volcanogenic sedimentary rocks. The current (2011) total resource at Chatree is 81 Mt. at 1.2 g/t Au and 10 g/t Ag. The Chatree volcanic complex has a well-defined volcanic stratigraphic sequence comprised of mafic to intermediate units at the base and felsic units at the top. The andesite dominants at the lower parts of the succession and includes plagioclase-hornblende-phyric andesite, plagioclase-hornblende-phyric basaltic andesite, monomictic breccia and overlying mafic-intermediate polymictic breccia facies, followed by fiamme breccia at the top of the succession.

Geochemically, the host volcanic rocks at Chatree comprise two volcanic suites: (a) Volcanic Suite 1 ranging in age from 258.6 to 250 Ma, characterised by low Ti, P, Mg, Zr, Ce and Y with very low LREE basalt to dacite; and (b) Volcanic Suite 2 ranging in age from 250 to 247 Ma, characterised by slightly higher Ti, Zr, Y, Ce, P and LREE andesite to dacite. This host sequence is intruded by two series of dykes: (a) high-Mg and moderate-Ti xenolithic dykes, and (b) high-Ti basaltic to andesitic dykes.

Gold-silver mineralisation is controlled by a geometric combination of structure (faults) and lithology. Lithologically, Au-Ag mineralisation is best developed in volcanic breccia such as mafic-intermediate polymictic breccia, and volcanogenic sedimentary rock and monomictic plagioclase-phyric andesite breccia. Minor mineralisation also is present in coherent rocks (e.g., plagioclase-phyric andesite) and fiamme breccia. Structurally, mineralisation is mainly present in two major structural orientations, namely: N-S to NNW-SSE and NE-SW trending faults. Based on cross-cutting paragenetic relations and mineralogy, the mineralisation at Chatree occurs in 7 stages which can be divided into pre Au-Ag mineralisation (Stage 1, 2A, 2B and 3), main Au-Ag mineralisation (Stage 4A, 4B and 4C) and post Au-Ag mineralisation (Stages 5, 6 and 7) stages: Infill Stage 1 – microcrystalline quartz + pyrite; Infill Stage 2 – Quartz-chlorite-sericite-pyrite; (Stage 2A – Quartz-chlorite-sericite-pyrite; Stage 2B – Quartz-sericite ± chlorite-chalcopyrite-pyrite-sphalerite ± galena); Infill Stage 3 – Quartz - carbonate - (K-feldspar) ± carbonate ± sulphide; Infill Stage 4 – quartz + carbonate + chlorite + adularia + sulphide + electrum; (Stage 4A – Quartz-chlorite-adularia ± carbonate-sulphide-electrum; Stage 4B – Quartz ± carbonate-adularia-sulphide-electrum; Stage 4C – Carbonate ± quartz-adularia -sulphide- electrum- argentite - tetrahedrite); Infill Stage 5 – Quartz ± carbonate veins; Infill Stage 6 – quartz ± carbonate veins; and Infill Stage

7 – Quartz-zeolite-carbonate. Four alteration zones were identified, namely: (1) Silicic (quartz-illite-adularia-pyrite), (2) Argillic (Illite-quartz-adularia-chlorite-pyrite), (3) Propylitic (chlorite-calcite-pyrite-epidote), and (4) Clay (Kaolinite-montmorillonite-illite).

Adularia from the main Au-Ag mineralisation Stage 4 was dated by laser incremental-heating $^{40}\text{Ar}/^{39}\text{Ar}$ analysis, and yields an age of 250 ± 0.8 Ma (Late Permian). The $^{40}\text{Ar}/^{39}\text{Ar}$ analysis of muscovite from a Au-bearing vein from the nearby (~10 km from Chatree) Khao Phanom Pha gold deposit also yields a similar age of 250 Ma. The minimum age of epithermal mineralisation can be bracketed to be 245–250 Ma by the ages of post-mineralisation dykes which yield LA-ICPMS U-Pb zircon ages of 247–238 Ma. This is further supported by Re-Os dating of molybdenite from sub-economic porphyry-style mineralisation hosted in plagioclase-hornblende diorite porphyry (243 ± 5 Ma) at the ‘N’ Prospect (~1 km south of Chatree), which yields an age of 244 ± 1 Ma (Early Triassic), suggesting it is younger than the Chatree gold-silver epithermal deposit.

Mineral paragenetic studies combined with laser ICPMS analysis (spot analysis and imaging) indicate that at least two generations of pyrite are present in each mineralisation stages. These pyrite generally are characterised by different trace element patterns. Gold is present mostly as stoichiometric substitution in pyrite structure in pre Au-Ag mineralisation stages (Stages 2A, 2B and 3) and wall-rock pyrite. In contrast, Au occurs in the pyrite structure as well as inclusions for the main gold-silver stages (Stages 4A, 4B and 4C). In the pre Au-Ag mineralisation stages, trace element concentrations generally increase from early Stage 2A to late Stage 3, particularly elements such as Au, Ag, As, Sb, Se and Pb. This temporal trend reflects an increase in metal content of the ore fluid prior to the main gold deposition. Comparison of trace elements in pyrite from the ore zone and various alteration zones in this study indicates that significant trends exist for certain elements such as Tl, Sb and Ag decreasing outwards from the ore zone into the wall-rocks. In contrast, Co, Ba and La have values decreasing towards ore zone possibly due to dilution of these elements related to alteration. Other elements such as Pb, Se, K, Rb and Sr show less clear trends. Pyrite tend to have more pronounced trends in many elements particularly in chalcophile elements in comparison to the whole-rock. However, more work need to be done to confirm which of the technique works best at the chatree and more and analyses from regional pyrite distal from the deposit are required for full evolution. The element which has the best potential for use in pyrite chemistry vectoring is Tl and Co. The data from this study shows that this element could be used as a pathfinder for geochemical exploration for similar styles of mineralisation in and around the Chatree area.

The sulphur isotopic values of pyrite from the main gold-silver mineralisation stages (Stages 4A, 4B and 4C) mainly range from 1 to 7 ‰, compatible with a magmatic source. However, some contribution of sulphur derived from other sources such as a biogenic origin is possible, particularly for the data from Q and A lenses which include lighter values (–9 to –1‰). Oxygen isotope variation of quartz at Chatree shows that the lowest oxygen isotope values are spatially confined to the central parts of the major ore zones, in particular along H and D lenses. Variation in oxygen isotopic values likely is due to an isotopic exchange between the mineralised hydrothermal fluids and wall-rocks where heavy oxygen isotopes were leached out of the propylitic and argillic

alteration zones in the wall rock and were deposited in the outer parts of the main vein system. The combined oxygen and hydrogen isotope data of Chatree plots between meteoric water and magmatic water, indicating a mixture between the magmatic and meteoric water. Lead isotope data indicate that the Pb isotopic model ages of the Chatree Au-Ag epithermal deposit plot around 400 Ma on the model Pb growth curve. As the age of mineralisation at Chatree is known to be Late Permian (ca. 250 Ma), this model Pb age is suggestive of unusually old Pb most likely from Paleozoic sediments.

The mineralisation at Chatree is part of an arc system that was emplaced within the LFB during the Late Permian to Early Triassic. Arc formation commenced with the extruding of basalt and andesite and was followed by rhyolite towards the end of the main phases of volcanic activity. This study suggests that the Chatree Volcanic Complex was emplaced in a shallow marine environment. The initial hydrothermal activity at Chatree appears to have been associated with movement along a NW-SE which caused the N-S to NNE-SSE and NE-SW dilational structures. Circulating ore fluid ascended along the dilational structures. Gold-silver mineralisation was initiated by ground preparation due to rapid cooling of silica-rich fluids that lead to precipitation of microcrystalline quartz early in Stage 1, which sealed in the fractures. Fluid pressure then increased from degassing ore boiling of CO₂ and H₂S in the fluids and brecciated the seals, allowing mineralising fluids to enter, leading to the precipitation of metals including gold and silver during the main Au-Ag mineralisation stages, particularly in Stages 4B and 4C. Fluid inclusions in quartz during this process contain high homogenisation temperatures ranging from 190 ° to 348 °C with salinities less than 5.6 wt. % NaCl equiv. The metal was probably derived from a fluid reservoir that was significantly enriched in Pb compared to U for a long period of time, as evidenced by the old Pb signature at Chatree. This suggests that Pb and possibly part of the Au were sourced from older basement rocks beneath the deposit as well as magmatic sources. A component of magmatic fluid was possibly involved during ascent of the ore fluids and mixing with circulating dilute meteoric water occurred as indicated by sulphur, oxygen, hydrogen isotope compositions and fluid inclusion data.

After formation, the Chatree deposit was cross-cut by basaltic to andesite dykes at the same time to the emplacement of plagioclase-hornblende diorite porphyry intrusion at N Prospect which has a weak porphyry-style mineralisation. The altered wall-rocks at Chatree deposit was eroded bringing the landscape to its current level represented by Khao Mo hill (A lens). Throughout the Chatree deposit, acidic fluids were produced by breakdown of pyrite in the oxidised zone leaching carbonate; this process also created significant permeability allowing oxidised ground water to react with the ores and form significant supergene gold enrichment.

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CONTENTS

CHAPTER 1: INTRODUCTION

1.1. INTRODUCTION	1
1.2. HISTORY OF DISCOVERY	1
1.3. AIMS OF THE STUDY	3
1.4. METHODOLOGY	4
1.4.1. Field investigation methods	4
1.4.2. Laboratory research methods	6
1.5. THESIS STRUCTURE AND CONVENTIONS	6

CHAPTER 2: TECTONIC SETTING AND REGIONAL GEOLOGY

2.1. INTRODUCTION	9
2.2. REGIONAL TECTONIC SETTING	9
2.3. GEOLOGY OF THAILAND	13
2.3.1. Lower Palaeozoic rocks (Cambrian-Ordovician)	13
2.3.2. Middle Palaeozoic rocks (Silurian-Devonian)	13
2.3.3. Upper Palaeozoic rocks (Carboniferous-Permian)	13
2.3.4. Mesozoic rocks	15
2.3.5. Cenozoic rocks	15
2.4. LOEI FOLD BELT AND MINERAL DEPOSITS	16
2.4.1. Loei area	17
2.4.2. Phetchabun-Phai Sali area	18
2.4.3. Nakhon Nayok-Sra Kaeo area	18
2.4.4. Mineral deposits	20
2.4.4.1. Skarn deposits	22
2.4.4.2. Epithermal deposits	22
2.5. DISTRICT-SCALE GEOLOGY	22
2.5.1. Carboniferous rocks	22
2.5.2. Middle Permian limestone (Ratchaburi Group)	24
2.5.3. Late Permian volcanic rocks	24
2.5.4. Khorat Group	25
2.5.5. Plutonic rocks	25
2.5.5.1. Dong Khui granite (Carboniferous)	28

2.5.5.2. Khao Rub Chang granite	28
2.5.5.3. Wang Pong intrusive rocks (Early Triassic)	28
2.5.5.4. Khao Chet Lok diorite intrusion (Early Triassic)	28
2.5.5.5. N-prospect intrusion (Early-Middle Triassic)	29
2.5.5.6. Andesite dykes	29
2.5.5.7. Singto intrusion (Late Triassic)	29
2.6. DISTRICT-SCALE STRUCTURE	29
2.6.1. NE-SW structure	32
2.6.2. NW-SE structure	32
2.6.3. Folding	34
2.7. AGE OF MAGMATISM	34
2.7.1. Analytical technique	34
2.7.2. Zircon petrography	35
2.7.3. Geochronological results	35
2.8. DISCUSSION	36
2.8.1. Age of volcanic sequence at Chatree deposit	36
2.8.2. Magmatism in the Chatree district	36

CHAPTER 3: VOLCANIC FACIES, STRATIGRAPHY, ARCHITECTURE AND GEOCHEMISTRY

3.1. INTRODUCTION	41
3.2. VOLCANIC FACIES, STRATIGRAPHY AND ARCHITECTURE	41
3.2.1. Plagioclase-hornblende-phyric andesite facies association	43
3.2.1.1. Coherent plagioclase-hornblende-phyric andesite facies	43
3.2.1.2. Monomictic plagioclase-hornblende-phyric andesitic breccia facies	48
3.2.1.3. Monomictic plagioclase-hornblende-phyric andesitic sandstone facies	48
3.2.2. Plagioclase-phyric andesite facies association	49
3.2.2.1. Coherent plagioclase-phyric andesite facies	49
3.2.2.2. Monomictic plagioclase-phyric andesite breccia facies	49
3.2.3. Polymictic mafic-intermediate breccia facies	49
3.2.4. Volcanogenic sedimentary facies association	55
3.2.4.1. Laminated siltstone-carbonaceous mudstone facies	55
3.2.4.2. Sandstone facies	55
3.2.4.3. Limestone facies	57
3.2.4.4. Sand-matrix polymictic breccia facies	57
3.2.5. Feldspar-phyric rhyolite facies association	57
3.2.5.1. Coherent feldspar-phyric rhyolite and monomictic rhyolitic breccia facies	57
3.2.5.2. Polymictic rhyolitic breccia and sand-matrix rhyolitic breccia facies	59
3.2.6. Fiamme breccia facies association	59
3.2.6.1. Quartz-rich fiamme sandstone and breccia facies	59

3.2.6.2. Lithic-rich fiamme breccia facies	62
3.2.7. Volcanic stratigraphy	64
3.2.8. Facies architecture of Chatree volcanic succession	65
3.2.9. Relationships between volcanic facies and mineralisation	65
3.3. GEOCHEMISTRY	67
3.3.1. Introduction	67
3.3.2. Sampling and analytical methods	67
3.3.2.1. XRF major and trace element analysis	67
3.3.2.2. Low-abundance trace elements and REE analysis by solution ICP-MS	71
3.3.3. Geochemistry of Chatree volcanic rocks	71
3.3.3.1. Major element geochemistry	71
3.3.3.2. Trace element geochemistry	76
3.3.3.3. REE Elements	76
3.3.3.4. Immobile element geochemistry	83
3.3.4. Regional intrusive rock geochemistry	83
3.3.4.1. Major element geochemistry	83
3.3.4.2. Trace element and REE element geochemistry	87
3.3.5. Discussion	88
3.3.5.1. Magmatic suites at the Chatree deposit	89
3.3.5.2. Comparison of volcanism and plutonism in Chatree	90
3.3.5.3. Tectonic setting and magmatic affinity	92

CHAPTER 4: DEPOSIT-SCALE GEOLOGY, STRUCTURE AND NATURE OF ORE LENSES

4.1. INTRODUCTION	95
4.2. DEPOSIT-SCALE GEOLOGY AND STRUCTURE	95
4.2.1. Pre-mineralised structures	95
4.2.2. Syn-mineralised structures	101
4.2.3. Post-mineralised dykes and sills	101
4.2.4. Post-mineralisation shear	106
4.3. CHATREE ORE LENSES	108
4.3.1. A ore lens	108
4.3.2. D ore lens	110
4.3.3. S ore lens	110
4.3.4. Mars ore lens	112
4.3.5. C ore lens	113
4.3.6. H ore lens	114
4.3.7. H-south ore lens	115
4.3.8. H-west ore lens	116
4.3.9. P ore lens	116

4.3.10. J ore lens	116
4.3.11. N Prospect	116
4.4. SUPERGENE MINERALISATION	119
4.5. CONCLUSIONS	120

CHAPTER 5: VEIN AND MINERAL PARAGENESIS, ALTERATION AND AGE OF MINERALISATION

5.1. INTRODUCTION	123
5.2. PARAGENESIS	123
5.2.1. Veins, textures, and timing relationships	123
5.2.1.1. Pre Au-Ag mineralisation stage	123
5.2.1.1.1. Infill Stage 1: microcrystalline quartz + pyrite	124
5.2.1.1.2. Infill Stage 2: Quartz-chlorite-sericite-pyrite	126
5.2.1.1.2.1. <i>Infill Stage 2A: Quartz-chlorite-sericite-pyrite</i>	127
5.2.1.1.2.2. <i>Infill Stage 2B: Quartz-sericite ± chlorite-chalcopyrite-pyrite-sphalerite ± galena</i>	128
5.2.1.1.3. Stage 3: Quartz - carbonate - (K-feldspar) ± carbonate ± sulphide	128
5.2.1.2. Main Au-Ag stage	130
5.2.1.4. Stage 4: quartz + carbonate + chlorite + adularia + sulphide + electrum	130
5.2.1.2.1.1. <i>Stage 4A: Quartz-chlorite-adularia ± carbonate-sulphide-electrum</i>	130
5.2.1.2.1.2. <i>Stage 4B: Quartz ± carbonate-adularia-sulphide-electrum</i>	132
5.2.1.2.1.3. <i>Stage 4C: Carbonate ± quartz-adularia -sulphide- electrum-argentite- tetrahedrite</i>	132
5.2.1.3. Post mineralisation stage	135
5.2.1.3.1. Stage 5: Quartz ± carbonate veins	135
5.2.1.3.2. Stage 6: quartz ± carbonate veins/veinlets	137
5.2.1.3.3. Stage 7: Quartz-zeolite-carbonate	137
5.3. MINERALOGY	137
5.3.1. Sulphide mineralogy	140
Pyrite	140
Sphalerite	140
Chalcopyrite	142
Galena	142
Tetrahedrite-tennantite	142
Electrum	142
Boulangerite	144
Acanthite, arsenopyrite and pyrargyrite	144
Marcasite	145
5.3.2. Gangue mineralogy	145
Quartz and chalcedonic quartz	145

Carbonate minerals	145
Chlorite	147
Adularia	147
K-feldspar	147
5.3.3. Mineralogical and textural variation with depth	148
5.4. ALTERATION	149
5.4.1. Introduction	149
5.4.2. Methodology	149
5.4.3. Chatree alteration	149
5.4.3.1. Silicic alteration	152
5.4.3.2. Argillic alteration	152
5.4.3.3. Propylitic alteration	154
5.4.3.4. Clay alteration	156
5.4.4. Discussion	158
5.5. AGE OF MINERALISATION	159
5.5.1 Introduction	159
5.5.2. Sample preparation and analytical procedures	159
5.5.3. Age of Chatree epithermal mineralisation	161
5.5.3.2. Age of Khao Phanom Pha epithermal mineralisation	162
5.5.3.3. Age of N Prospect porphyry mineralisation	164
5.5.4. DISCUSSION	164

CHAPTER 6: PYRITE CHEMISTRY

6.1. INTRODUCTION	167
6.1.1. Sample selection and preparation	167
6.1.2. Analytical Techniques	169
6.1.3. Precision and detection limits	170
6.1.3. Quantitative multielement analysis of pyrite	170
6.2. PYRITE TEXTURES	170
6.2.1. Pre-Au mineralisation pyrite	171
6.2.2. Gold mineralisation pyrite	171
6.2.3. Wall-rock pyrite	171
6.2.4. Inclusions in pyrite	174
6.3. CHEMICAL COMPOSITION AND ZONING OF PYRITES	177
6.3.1. Pre-Au mineralisation stage	177
6.3.1.1. Composition of Stage 2A pyrite	177
6.3.1.2. Composition of Stage 2B pyrite	177
6.3.1.3. Composition of Stage 3 pyrite	177
6.3.1.4. Chemical distinction of pre-gold stage pyrites (Stages 2A, 2B and 3)	178
6.3.2. Composition of main Au mineralisation Stages	178

6.3.2.1. Composition of Stage 4A and B pyrite	186
6.3.2.3. Composition of Stage 4C pyrite	186
6.3.2.4. Chemical distinctions of the main Au mineralisation Stages	186
6.3.3. Sedimentary pyrite	195
6.3.4. Composition of wall-rock pyrite in volcanic rocks	195
6.3.5. Whole-rock trace elements	197
6.4. DISCUSSION	197
6.4.1. Au in pyrite	201
6.4.2. Gold and trace element content versus pyrite textures	203
6.4.3. Au-As relationships in Chatree pyrite	203
6.4.4. Pyrite geochemistry as a guide to exploration and metallurgy	205
CHAPTER 7: STABLE AND RADIOGENIC ISOTOPES	
7.1. INTRODUCTION	207
7.2. SULPHUR ISOTOPES	207
7.2.1. Previous studies	207
7.2.2. Methods	207
7.2.2.1. Conventional technique	207
7.2.2.2. Laser ablation technique	208
7.2.3. Sulphur isotope compositions	208
7.2.4. Discussion	208
7.3. OXYGEN AND HYDROGEN ISOTOPES	212
7.3.1. Introduction	212
7.3.2. Method of study	214
7.3.3. Oxygen isotopic compositions of quartz and chlorite	214
7.3.4. Hydrogen isotopic compositions of quartz and chlorite	215
7.3.5. Oxygen isotope of altered wall-rock	215
7.3.6. Oxygen isotopic composition of ore fluids	219
7.3.7. Discussion	219
7.3.7.1. Spatial distribution of oxygen isotopes	219
7.3.7.2. Origin of Chatree ore fluids	221
7.3.7.3. Isotopic haloes at Chatree	221
7.4. RADIOGENIC LEAD ISOTOPES	224
7.4.1. Introduction	224
7.4.2. Sampling and analytical procedures	224
7.4.2.1. LA-ICPMS technique	225
7.4.2.2. Aqua regia acid digestion (galena solution method)	225
7.4.2.3. Multi collector ICPMS technique (pyrite solution)	225
7.4.3. Chatree Pb isotope	225
7.4.4. Comparison results from different technique	227

7.4.5. Lead isotope in the district area	229
7.4.6. Discussion	229
7.4.6.1. Unique Pb isotope of the Chatree	229
7.4.6.2. Mixed lead signature	231

CHAPTER 8: FLUID INCLUSIONS

8.1. INTRODUCTION	233
8.2. PREVIOUS FLUID INCLUSIONS DATA	233
8.3. SAMPLING AND LABORATORY WORKS	233
8.4. NATURE OF FLUID INCLUSIONS	234
8.5. MICROTHERMOMETRY	238
8.5.1. Homogenisation temperatures	238
8.5.2. Salinities	238
8.6. DISCUSSION	240
8.6.1. Pressure-depth estimates	243

CHAPTER 9: SUMMARY, GENETIC MODEL AND DISCUSSION

9.1. INTRODUCTION	245
9.2. SUMMARY OF RESULTS	245
9.3. FORMATION OF THE CHATREE DEPOSIT	249
9.3.1. Phase 1: Tectonic setting and igneous emplacement	249
9.3.2. Phase 2: Hydrothermal evolution and ore deposition	252
9.3.3. Phase 3: Post-mineralisation magmatism	256
9.3.4. Phase 4: Uplift, weathering and erosion	257