PETROGRAPHY OF IRON SKARN

AT KHAO LEK, AMPHOE NONG BUA, CHANGWAT NAKHON SAWAN

PHATCHARAPORN RATCHAWONGSA

A REPORT SUBMITTED IN PARTIAL FULFILLMENT OF THE

REQUIRRMENT FOR THE DEGREE OF

THE BECHELOR OF

SCIENCE DEPARTMENT OF GEOLOGY CHULALONGKORN

UNIVERSITY

2009

Date of submit……/……./…….

Date of approval……/……/……

……………………………………………..

(Assoc. Prof. Dr. Visut Pisutha-Arnond)

Senior project advisor

บทคัดย่อ

หัวข้อ (ภาษาไทย): ศิลาวรรณาของหินสกาณร์นที่ให้สินแร่เหล็ก ที่เขาเหล็ก อ.หนองบัว จ. นครสวรรค์

หัวข้อ (ภาษาอังกฤษ): PETROGRAPHY OF IRON SKARN AT KHAO LEK, AMPHOE NONG BUA, CHANGWAT NAKHON SAWAN

นิสิต: นางสาวพัชรภรณ์ ราชวงษา เลขประจำตัวนิสิต 4932719923

อาจารย์ที่ปรึกษา: รองศาสตราจารย์ ดร. วิสุทธิ์ พิสุทธอานนท์

ในการออกภาคสนามครั้งที่สองที่บริเวณเขาเหล็ก อำเภอหนองบัว จังหวัดนครสวรรค์ พบว่าบริเวณนี้มีการเปิดหน้าเหมืองทิ้งไว้ และมีการเกิดแร่เหล็ก รวมทั้งแร่ มาลาไคต์ และ อะซูไรต์ ทำให้พื้นที่บริเวณนี้น่าสนใจในการศึกษาในขั้นรายละเอียด โดยการศึกษาจากแท่งหินที่มีความยาว 60 เมตร ซึ่งประกอบด้วยหิน อัคนีภูเขาไฟ หินสการ์น แร่เหล็ก และหินอ่อน

การศึกษาครั้งนี้มุ่งเน้นศิลาวรรณาของหินแอนดิไซต์ หินอ่อน รวมถึง ชนิดของหินสการ์นและการเกิดแร่โลหะ จากการศึกษาแท่งหินสามารถจำแนกชนิดหินได้เป็น 4 ชนิด ได้แก่ หินทัฟฟ์ หินอิพิโดต์สการ์น หินการ์เนตสการ์น และหินอ่อน ลักษณะของหินทัฟฟ์ที่พบประกอบด้วยแร่ เพลคจิโอเคลส และ เศษหินที่มีขนาดตั้งแต่ 0.1-3 ซม หินอิพิโดต์สการ์นประกอบด้วยแร่ไพรอกซีนซึ่งถูกแทนที่ด้วยแร่แอมฟิโบ และแร่คลอไรต์แทนที่แร่อิพิโดต์ หินการ์เนตสการ์นประกอบด้วยแร่การ์เนต และหินอ่อนประกอบด้วยแร่แคลไซต์ ที่มีลักษณะขนาดเล็กถึงขนาดใหญ่ การเกิดสการ์นบริเวณเขาเหล็กนี้จัดอยู่ในแหล่งแร่แบบแคลสิก ไอรอนสการ์น คาดว่าการเกิดแร่เหล็กมีความสัมพันธ์กับช่วงการแปรรสภาพย้อนหลัง

Abstract

Title (Thai):	ศิลาวรรณาของหินสการ์นที่ให้สินแร่เหล็ก ที่เขาเหล็ก อ.หนองบัว จ.นครสวรรค์
Title (English):	PETROGRAPHY OF IRON SKARN AT KHAO LEK, AMPHOE NONG BUA, CHANGWAT NAKHON SAWAN
Name:	Miss Phatcharaporn Ratchawongsa ID: 4932719923
Avisor:	Assoc. Prof. Dr. Visut Pisutha-Arnond

The occurrence of iron and secondary copper minerals (malachite and azurite) at Khao Lek area at Amphoe Nong Bua, Changwat Nakhon Sawan has attracted my attention during the Fieldwork II course work in 2009. This iron occurrence was partly open-cut at the foot of a hill and was reportedly penetrated by a series of vertical diamond-drilled holes for mineral exploration and evaluation by a private company. It was found that one drilled-hole intersecting the section of volcanics, skarn, iron mineralization and marble at a total depth of 60 meters is rather interesting and suitable for this senior project research.

The objective of this project is to study petrography of the andesitic rocks, marble and type of skarn and mineralization. From logging of the drilled-core samples, four types of rocks can be separated in the field; andesitic lapilli tuff, marble, garnet skarn and epidote skarn. Andesitic lapilli tuff is greenish grey, hard and contains abundant rock fragments of andesite, rhyolite, and silicified shale varying in size from 0.1-3 cm in fine-grained plagioclase-dominated groundmass. Marble is characterized by mosaic interlocking grains of mainly subhedral calcite with minor clinopyroxene suggesting that it was transformed from a rather pure carbonate rock. Garnet skarn is composed mostly of garnet with minor pyroxene and formed earlier as prograde alteration. Two generations of garnet formation were recognized, the early isotropic garnet and late zoned anisotropic garnet overgrowth on the early isotropic garnet. Epidote skarn is the characterized by epidote, actinolite-tremolite, chlorite, calcite, and occurs as replacement or crosscutting of garnet skarn. The epidote skarn is therefore

the retrograde alteration of early garnet skarn. The skarn at Khao Lek can be classified as calcic iron (magnetite) skarn deposit. The formation of iron probably took place during prograde alteration stage as indicated by the occurrence of magnetite in association with garnet.

ACKNOWLEDGMENTS

The author wishes to express this deep gratitude to her advisor Professor Dr. Visut Pisutha-arnond for his invaluable supervision thought out this senior project. The author deeply thanks Mr. Chanwit Premgamone for his kindness to give core sample and some data to make this senior project study.

The author would like to thank Mr. Prajin Thongprachum and Miss Sopit Poompuang for make thin-section and polish-section. The author is greatly Miss Adcharobon Laokun for her assistance during field work. Thanks are also extended to her teachers and friends in Department of Geology, Chulalongkorn University. Finally, the very sincere thankfulness is expressed to the other sponsors whose names are not mentioned herein.

Contents

	Page
Abstract in Thai	A
Abstract in English	B
Acknowledgement	C
Content	
List of Figures	D
List of Tables	H
Chapter I: INTRODUCTION	
1.1 Introduction	1
1.2 Location and accessibility of the study area	2
1.3 Objectives	5
1.4 Scope of work	5
1.5 Method of study	5
1.6 Literature reviews	7
Chapter II: GEOLOGY OF THE STUDY AREA	
2.1 Volcanic rocks	9
2.2 Intrusive igneous rocks	9
2.3 Sedimentary rocks	10
2.4 Contact metamorphic rocks	11
Chapter III: RESULT	
3.1 Core logging	13
3.2 Petrography	15
Chapter IV: DISCUSSION AND CONCLUSION	
4.1 Discussion	37
4.2 Conclusions	38
Reference	39

List of figures

Page

Figure 1-1: Index map of Thailand showing locality of the study area in Amphoe Nong Bua, Changwat Nakhon Sawan, Central Thailand. 3

Figure1-2: Topographic map showing the location of the study area at Khao Lek, Amphoe Nong Bua, Changwat Nakhorn Sawan (Series L7017 Sheet 5140I KHAO PHRA , RTSD, 1993). 4

Figure 1-3: Flow chart of the methodology 6

Figure 2-1: Geological map of the Khao Lek area, Amphoe Nong Bua, Changwat Nakhorn Sawan (after Premgamone, 2005). 13

Figure 3-1: Core logging of a 60m diamond-drilled hole for mineral exploration showing four main rock types, namely, marble, epidote skarn, garnet skarn and andesitic lapilli tuff, and iron ores associated with epidote-garnet skarns. 14

Figure 3-2: A slabbed core sample showing large patches of clinopyroxene in coarse-grained, light grey calcite. 16

Figure 3-3: Photomicrography of marble in figure 3-2 showing interlocking grains of subhedral calcite (ca) with associated clinopyroxene (cpx) 16

Figure 3-4: A slabbed core sample of light grey marble containing fine-grained calcite and patches of dark minerals. 17

Figure 3-5 Photomicrograph of marble in figure 3-4 showing interlocking, coarse-grained, subhedral calcite (ca) with associated clinopyroxene (cpx). 17

Figure 3-6: A slabbed core sample of marble showing fine to medium-grained calcite with patches of dark minerals. 18

Figure 3-7: Photomicrograph of marble in figure 3-6 showing coarse-grained calcite (ca) and fine-grained quartz (qtz) 18

Figure 3-8: A slabbed core sample of marble showing coarse-grained, light grey calcite with large patches of garnet skarn replacement. 19

Figure 3-9: Photomicrograph of marble in figure 3-8 showing calcite (ca) and 19

chlorite (ch) with opaque minerals (op).
Figure 3-10: A slabbed core sample of light grey marble crosscut by garnet skarn vein (left). 20
Figure 3-11 Photomicrograph of garnet skarn-marble contact showing garnet partly alterated to epidote and pyroxene? altered to actinolite –chlorite. 20
Figure 3-12: A slabbed core sample of garnet skarn showing greenish brown, medium to coarse-grained garnet with pale green epidote and quartz. 21
Figure 3-13: Photomicrograph of garnet skarn showing anisotropic garnet (gr) replaced by epidote (ep) with related opaque minerals. 21
Figure 3-14: A slabbed core sample of garnet skarn showing greenish brown, medium to coarse-grain garnet with pale green epidote and quartz. 22
Figure 3-15: Photomicrograph of garnet skarn in figure 3.14 showing two generations of garnet formation; early isotropic garnet core and late anisotropic zoned garnet intergrowth with poikilitic quartz. 22
Figure 3-16: A slabbed core sample of garnet skarn showing greenish brown, medium to coarse-grained garnet and pale green epidote. 23
Figure 3-17: Photomicrograph of garnet skarn in figure 3-16 showing anisotropic zoned garnet (gr) partly replaced by epidote (ep). Note the isotropic garnet to the right. 23
Figure 3-18: A slabbed core sample of reddish brown garnet skarn crosscut by epidote vein?. 24
Figure 3-19: Photomicrograph of garnet skarn showing finely zoned anisotropic garnet (gr) partly replaced and crosscut by epidote veinlets?(ep) and reaction rim of garnet. 24
Figure 3-20: A slabbed core sample of garnet skarn showing coarse-grained garnet and pyroxene? altered to chlorite – actinolite. 25
Figure 3-21: Photomicrograph of garnet skarn showing zoned anisotropic garnet (gr) partly replaced by epidote. 25
Figure 3-22: A slab core sample of garnet skarn showing coarse-grained garnet. 26
Figure 3-23: Photomicrograph of garnet skarn showing coarse-grained garnet 26

(partly replaced by epidote) with interstitial quartz.
Figure 3-24: A slabbed core sample of yellowish green epidote skarn and dark green chlorite. 28
Figure 3-25: Photomicrograph showing epidote (ep), actinolite (an) and chlorite (ch). 28
Figure 3-26: A slabbed core sample of epidote skarn crosscutting fine-grained garnet skarn. 29
Figure 3-27: Photomicrograph showing coarse-grained garnet (gr) replaced by chlorite (ch) and actinolite 29
Figure 3-28: A slabbed core sample of epidote skarn containing of pale green, fine-grained epidote and dark green, fine-grained chlorite and calcite vein. 30
Figure 3-29: Photomicrograph showing epidote-chlorite replacing garnet with associated opaque minerals. 30
Figure 3-30: A slabbed core sample of green epidote skarn replacing and crosscuting fine- grained garnet with associated opaque minerals. 31
Figure 3-31: Photomicrograph showing coarse-grained garnet (gr) replaced and crosscut by chlorite (ch)–epidote (ep) and calcite vein. 31
Figure 3-32: A slabbed core sample of andesitic lapilli tuff showing dark green to black, fine-grained rock and containing fragments varying from 0.1-3 cm. 32
Figure 3-33: Photomicrograph of andesitic lapilli tuff showing amphibole (amb) altered to epidote (ep) and actinolite (ac). 32
Figure 3-34: A slabbed core sample of andesitic lapilli tuff containing angular rock fragments. 33
Figure 3-35: Photomicrograph of andesitic lapilli tuff showing coarse plagioclase containing rock fragments (plg, 0.01-0.05 mm) in microcrystalline plagioclase groundmass 33
Figure 3-36: A slabbed core sample of andesitic tuff containing fine-grained rock fragments. 34
Figure 3-37: Photomicrograph of altered andesitic tuff showing a volcanic rock fragment containing large altered phenocryst in fine-grained groundmass. 34
Figure 3-38: An exposure of secondary copper minerals (malachite and azurite) at the foot at Khao Lek area. 35

Figure 3-39: A slabbed core sample of massive magnetite in garnet skarn. 36
Figure 3-40: Photomicrograph of Garnet skarn showing euhdral to subhedral magnetite crystal aggregate closely associated with garnet. 36

List of table

Page

Table 4-1: Ore-gangue paragenetic sequence of the Khao Lek mineralization. 37

CHAPTER I

Introduction

1.1 Introduction

Most skarn deposits generally form as a result of metasomatism at or near the contact between predominantly carbonate-rich rocks and intrusions, or in carbonate veins along faults or fractures (Meinert et al., 2005). Typically, they are characterized by two main alteration styles based on the separate precipitation of calcsilicate minerals: (1) early prograde assemblage (garnet and pyroxene) and (2) later retrograde assemblage (epidote, chlorite and amphibole). Skarn can be subdivided according to several criteria. Endoskarn is indicated igneous and Exoskarn is indicated sedimentary rocks. Magnesian and calcic skarns can be used to describe the composition of skarn.

The occurrence of iron ore and secondary copper minerals (malachite and azurite) at Khao Lek in one of the Fieldwork II areas of the year 2009 has attracted my attention. This iron occurrence was partly open-cut at the foot of a hill during the student field visit in April 2009 and was reportedly penetrated by a series of diamond-drilled holes to explore and evaluate the grade and tonnage of this deposit by one of a private company (Premgamone, 2005). After investigation the drilled cores with the courtesy of Mr. Charnwit Premgamone, a free lance geologist, it was found that one deepest drilled-hole (60 m.) penetrated volcanics, skarn and iron mineralized zones, and carbonates. Both volcanic-carbonate section and the mineralized skarn are rather interesting; because there is a good possibility that this section could represent Permian-Triassic boundary, and the mineralized skarn itself has not been subjected to any detailed study before. It is therefore my intention to carry out the work here.

1.2 Location and accessibility of the study area

The location of Khao Lek, Amphoe Nong Bua, Changwat Nakhorn Sawan is shown in Figure 1-1. The area is bounded by vertical grid from 690200 E to 691800 E and horizontal grid from 1748600 N to 1757200 N as shown in the topographic map scale 1:50,000, series L7017 Sheet 5140I KHAO PHRA, RTSD, 1993. The area is accessible conveniently from Bangkok heading north along the Phahonyothin highway (Highway no. 1) to Rangsit – Wang Noi – Saraburi then further northeast to Changwat Phetchabun and further west to Amphoe Nong Bua, Changwat Nakhonsawan. It is about 200 kilometers from Bangkok to the study area.

Figure 1-1: Index map of Thailand showing locality of the study area in Amphoe Nong Bua, Changwat Nakhon Sawan, Central Thailand.

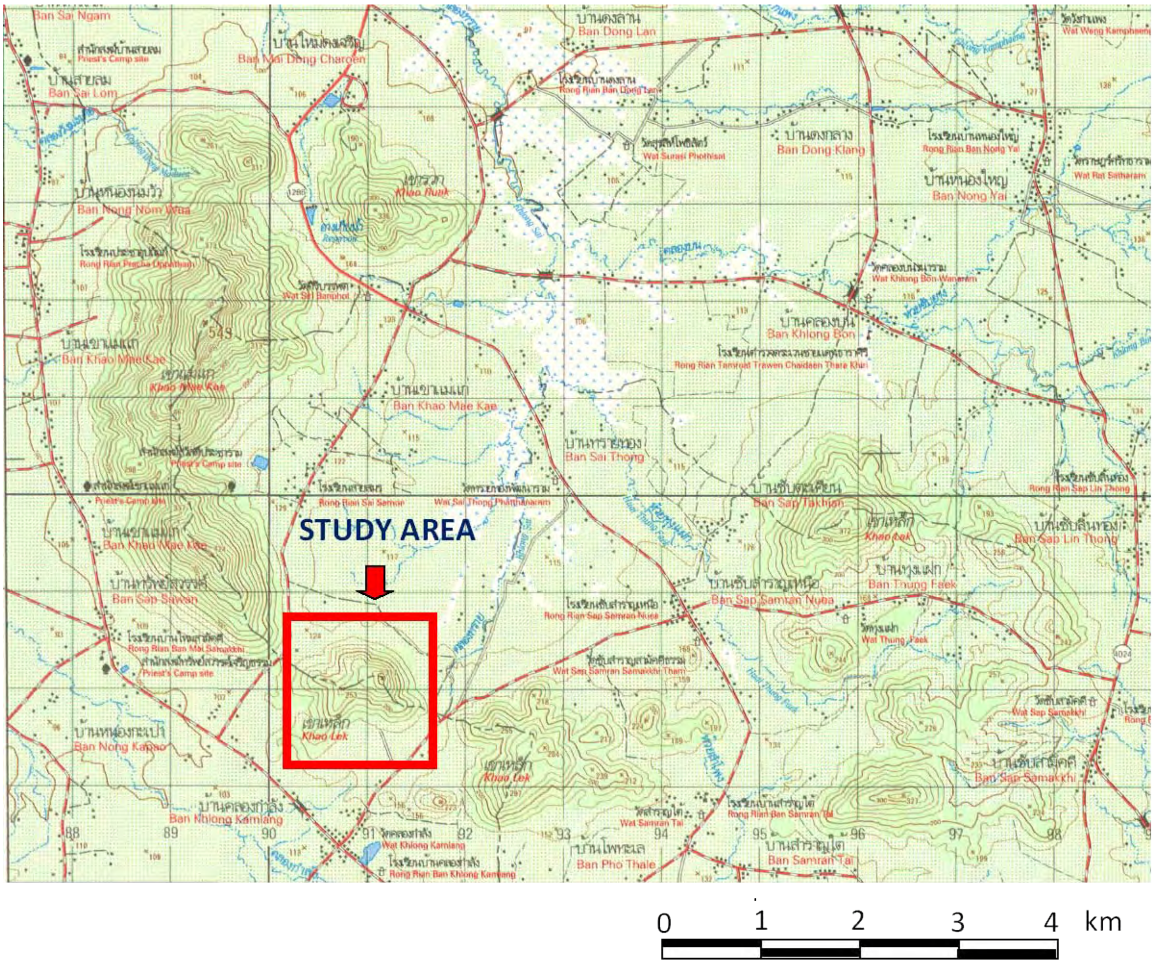


Figure1-2: Topographic map showing the location of the study area at Khao Lek, Amphoe Nong Bua, Changwat Nakhorn Sawan (Series L7017 Sheet 5140I KHAO PHRA , RTSD, 1993).

1.3 Objectives

The objectives of this project are to carry out a detailed study on (1) petrography and mineralogy of the volcanic, carbonate and skarn rocks from a drilled core; and (2) Iron and copper mineralization relating to the skarn formation; and (3) paragenetic sequence of iron and copper mineralization; and type of skarn.

1.4 Scope of work

The project covers only a petrographic study of a drilled core (depth 60 m.) that intersects the country rocks and mineralized skarn section of the area.

1.5 Method of study

The method of this study is summarized in Figure 1-3. The main goal of this project is to carry out the petrographic study of host rocks, skarn and iron ore. After compile and study on relevant researches on some mineralized skarn deposits. Then, the field investigation was conducted to obtain field data, core logging and specimens for laboratory work. Next, the laboratory works includeed thin-sectioning, petrography of skarn, related with host rocks and mineralization. The final step was the interpretation, discussion, conclusion, report writing and project presentation.

Petrography: After specimens were collected from fieldwork. They were cut and prepared in the form of regular thin-sections (with about 0.03 mm. thick) and polished sections. These thin-sections were examined by a polarizing microscope to identify minerals and their textural relationship.

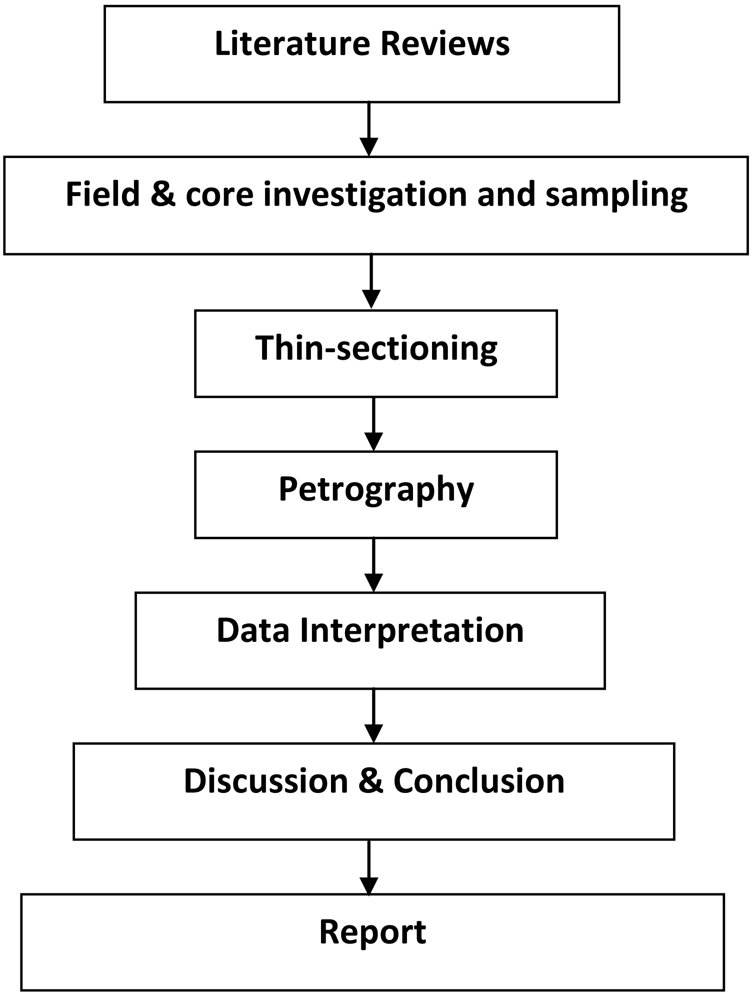


Figure 1-3: Flow chart of the methodology

1.6 Literature reviews

Intayot (2000) studied mineralogy, petrography and mineral chemistry of skarn in Khao Phra Ngam area. The result of chemical analysis indicated that the clinopyroxene (diopside – hedenbergite series) and garnet (grossular – andradite series) was the major prograde skarn formation and occurred as narrow shell parallel to intrusive rocks and with less retrograde skarn alteration. It was suggested that this skarn was formed in deeper part of the intrusion. The skarn was classified as calcic iron ± copper skarn deposit in which the Iron mineralization took place during the prograde skarn.

Pisutha-Arnond et al. (1992) found that the dioritic rocks were the major intrusive in the Phu Lon area and were responsible for the transformation of marble with intercalated calcsilicate hornfels of contact metamorphism and for the subsequent of garnet-pyroxene skarn. The prograde garnet-pyroxene skarn was associated with iron mineralization. The result of chemical analysis of copper and iron-rich skarn gave the contents of gold between 0.25 – 0.28 gram/ton and average 0.98 gram/ton, silver between 5.9 -27.1 gram/ton and average 11.5 gram/ton, copper between 0.91 – 5.74% and average 2.11%, molybdenum between 0.001 – 0.061% and average 0.008%. The Phu Lon was classification as a porphyry-related copper-iron skarn deposits.

Premgamone (2005) reported on geologic and geophysical exploration and drilling at the Khao Lek area. The result revealed the magnetite with minor chalcopyrite and digenite mineralization in skarn and contacted metamorphosed hard and dense rocks. The XRF analyses of four mineralized samples gave 33 to 62.55%, total Fe, 0.25-0.48% total Cu.

Yaemned (1998) investigated the types of rocks and mineralography of Tungkum deposit, Amphoe Mueng, Changwat Loei. Four kinds of skarn zone were determined; garnet skarn, garnet clinopyroxene skarn, magnetite skarn and pyrrhotite – chalcopyrite skarn. Paragenetic investigation revealed that magnetite formed earlier with subsequent crystallization of pyrrhotite, pyrite and arsenopyrite, and chalcopyrite was the latest ore. Skarn formed as a result of hydrothermal alteration by fluids derived from intrusive bodies and interaction with metasediments.

CHAPTER II

GEOLOGY OF THE STUDY AREA

The geologic map covering the study area based on those of Premgamone (2005) and data collected during the course of this study (Figure 2-1). The Khao Lek is situated at a contact metasomatic zone. A series of skarn rock was developed along this contact zone which gave rise to minor iron mineralization. The geology of the study area consists of various rock types which can be described as follows:

2.1 Volcanic rocks

2.1.1 Basaltic andesite and Basaltic andesite porphyry of Permo-Triassic (PTr band)

They are dense, fine-grained, dark grey to black, consisting of plagioclases and pyroxenes in both phenocrysts and groundmass. Some of them are agglomeratic with fragments of green older andesite.

2.1.2 Andesite of Permo-Triassic ages (PTr and)

Andesite is the most extensively distributed rock within the whole area of Khao Lek. It is generally older than the described basaltic andesite. It is green, olive green or greenish grey. It probably occurs as a lower flow showing tuffaceous or agglomeratic textures or forms as co-precipitation of andesitic tuff in carbonate-rich water with limy characteristic on weathering surface. The lava andesite is generally porphyritic with plagioclase or hornblende or both minerals as phenocrysts, usually hydrothermal altered with feldspar changing to clay and sericite and altered to chlorite and magnetite or epidotized with accompanying garnet minerals in contact metamorphic zone. The agglomeratic type is more sensitive to hydrothermal alteration because of more permeability than dense lava flow bed. The calcareous andesitic tuff is good for precipitation of mineralization from hydrothermal.

2.2 Intrusive igneous rocks

2.2.1 Triassic hornblende-biotite-albite granite (Trgr)

These units cover mostly on eastern and northern parts of the study area. The rock is light grey, fine- or medium-grained (equigranular), consisting of albite (subtransparent and nearly colorless) and plagioclase (70-80%) and hornblende-biotite

(25%). They occur as dike intruded in fault zone in volcanic rocks in northeast direction. It is not the exact type of intrusive for making skarnitization. The rock is locally spotted epidotized in plagioclase suites locally in some place 0.5 kilometers east of the eastern mining lease.

2.2.2 Triassic pyroxene diorite (Trdi prx)

the rock is generally found as dike or very small stocks in eastern and southeastern parts of the eastern mining lease. It is dark and dark brownish black pyroxene. The rock genesis is related to andesite and basaltic andesite, and probably the most important intrusive for hydrothermal source for Cu-Fe contact metamorphism / skarnitization within the area. The metamorphism of white limestone into pure marble, the epidote-garnet exoskarn of andesite and impure limestone with chalcopyrite disseminated and Triassic diorite possibly effects magnetite deposit.

2.2.3 Triassic diorite (Trdi)

the rock generally occurs as small dike in northeastern and eastern parts of the area. The rocks in northeastern part have texture which is generally porphyritic with biotite, quartz, hornblende and pyroxenes (35-40%) and plagioclase feldspar (60-65%). This rock is not important for mineralixation. Eastern part of the area, the rock consists of feldspars (50%), hornblende or pyroxene (50%) and sometime grading into pyroxene dolerite or diabase. It is also one of the important rocks in the same pyroxene andesite in forming contact metamorphic skarnitization in andesite and impure limestone, and pure marble from white limestone. Sulfides also disseminated within this diorite.

2.3 Sedimentary rocks

2.3.1 White tuffaceous limestone of Permain age (Ptf pn_w)

It is the only sedimentary rock discovered in the area very close to the eastern corner of eastern mining lease. It is very fine grained dense, recrystalline fine grained with white felsic tuff co-precipitated and diagenetically replaced by $CaCO_3$ (This rock is called by Thai DMR as Permian Tak Fa Formation in Map sheet 5140I and Pha Nok Khao formation in Map sheet 5141II and now call tuffaceous limestone of Permian age).

2.4 Contact metamorphic rocks

2.4.1 Marble (PTr marble)

marble occurring in Triassic by contact metamorphism of white tuffaceous Permian limestone by heat and pressure. The original rock is nearly pure limestone with syndeposited felsic volcanic tuff diagenetically replaced by lime. The different in grain size ranging from 1-2 milimeters. The marble is not skarnitization because of only CaCO3 in composition except some tuffaceous layers developed andesite garnet ($Ca_3Fe_2(SiO_4)_3$) or grossularite ($Ca_3Al_2(SiO_4)_3$). Marble usually associated/close to exoskarns.

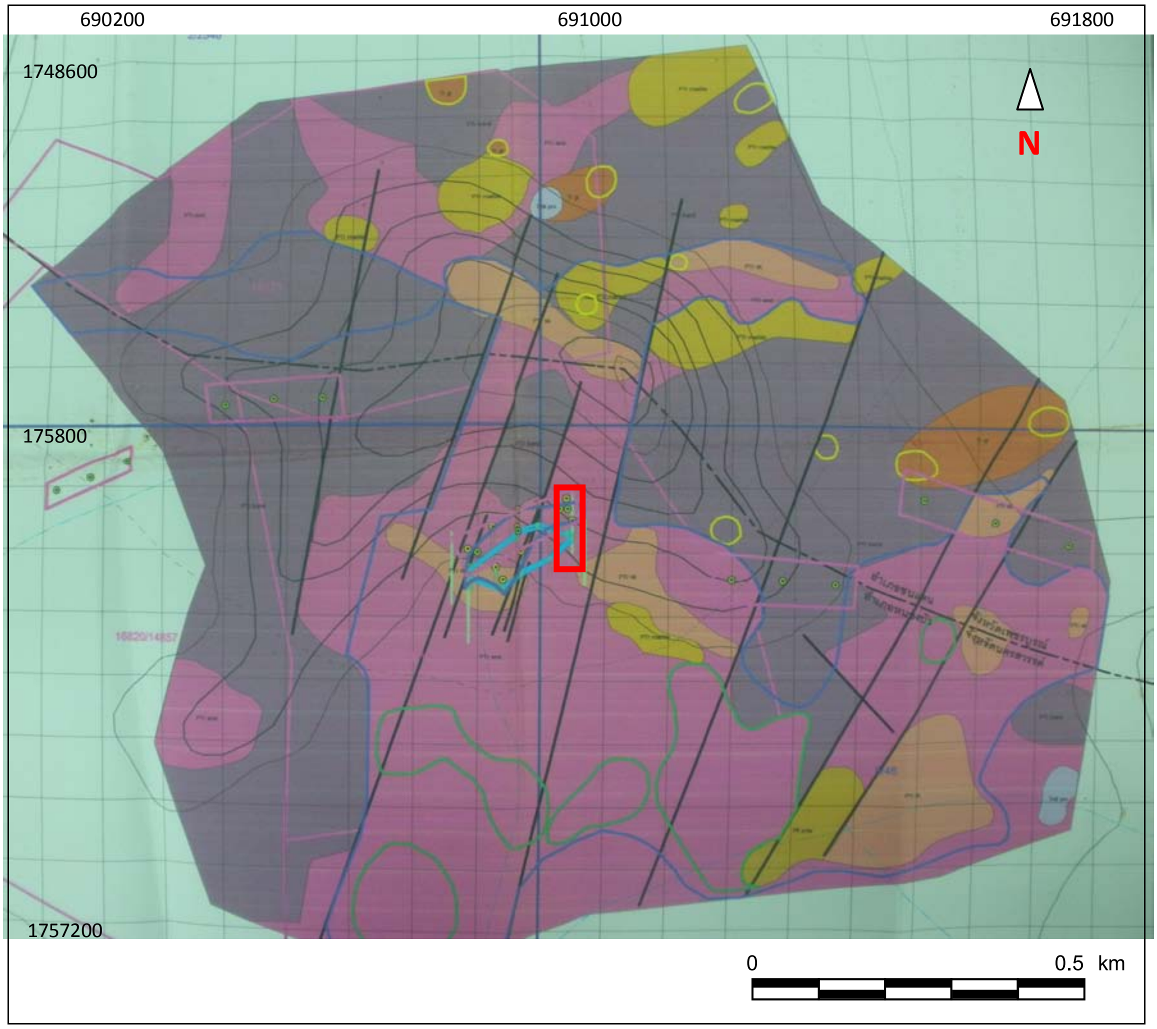


Figure 2-1: Geological map of the Khao Lek area, Amphoe Nong Bua, Changwat Nakhorn Sawan (after Premgamone, 2005).

EXPLANATION

PTr band	Basaltic andesite and basaltic andesite porphyry of Permo-Triassic
PTr and	Andesite of Permo-Triassic ages
Tr gr	Triassic hornblende-biotite albite granite
Trdi prx	Triassic pyroxene diorite
PTr sk	Skarn
PTr marble	Marble
	Drill hole study area

CHAPTER III
RESULT

3.1 Core logging

From a vertical diamond-drilled core for mineral exploration of about 60 m depth (Figure 3-1), four rock types can be recognized megascopically: 1) marble (56.30-60.00m, 51.63-54.75m, and 44-97-45.64m), 2) epidote skarn (50.70-50.95m, 33.57-44.97m, 28.43-29m, 26.00-28.00m, and19.30-23.83m), 3) garnet skarn (33.26-33.57 m, 29.00-29.28 m, 28.00-28.43 m and 23.83-26.00 m), 4) andesitic lapilli tuff (0-19.30m). Iron ores appear to associate with epidote-garnet skarns at 31.30-33.90 m depth.

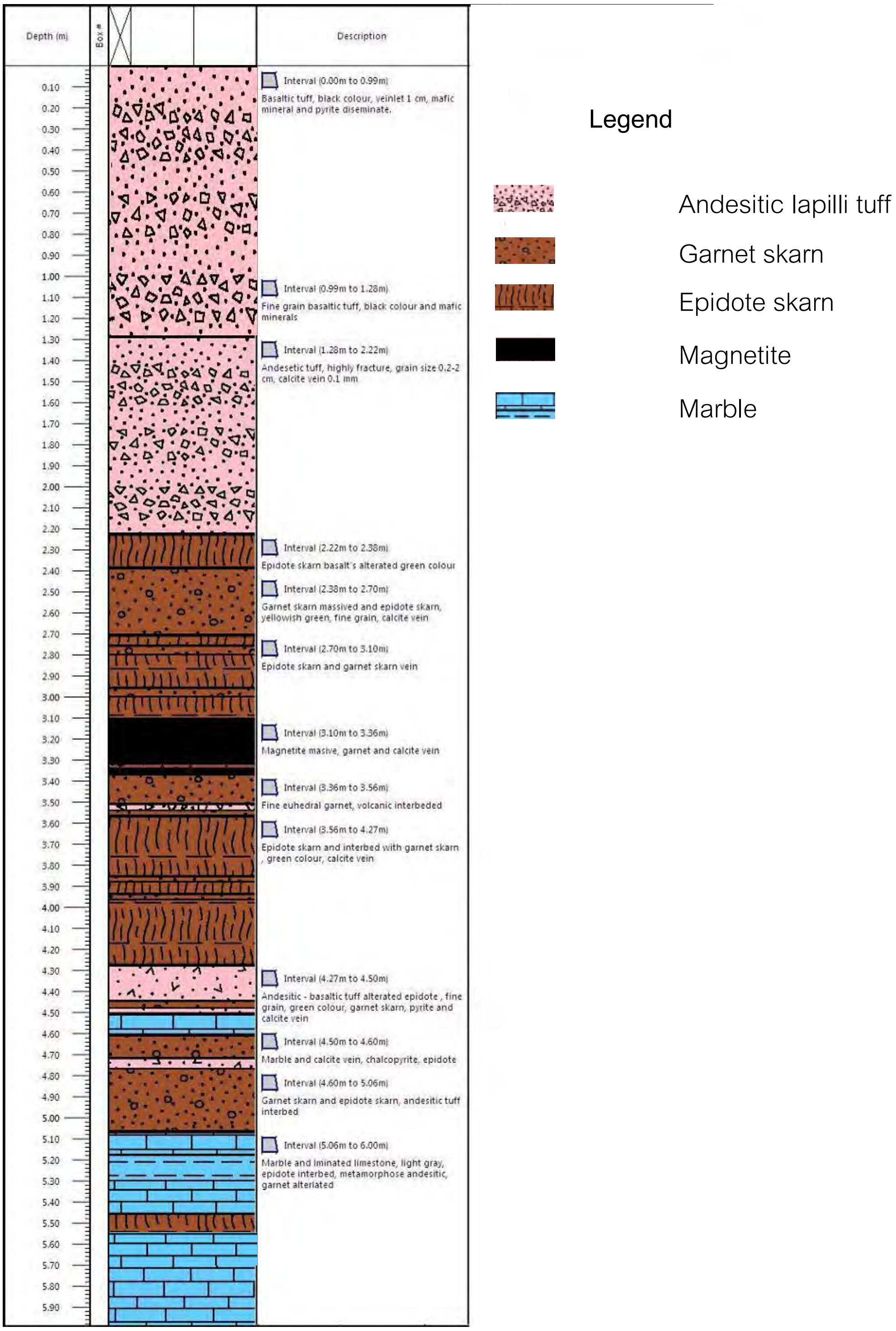


Figure 3-1: Core logging of a 60m diamond-drilled hole for mineral exploration showing four main rock types, namely, marble, epidote skarn, garnet skarn and andesitic lapilli tuff, and iron ores associated with epidote-garnet skarns.

3.2 Petrography

3.2.1 Marble

At 50.79-59.90 m depth, marble is medium to coarse-grained, light to dark gray, consist mostly of calcite with patches of clinopyroxene and garnet (Figures 3-2 to 3-11)Microscopically marble shows equigranular interlocking grains of anhedral to subhedral calcite and minor pyroxene.

3.2.2 Garnet skarn

At 44 – 50 m depth, garnet skarn is brownish green, medium to coarse grained, containing 80-90% garnet, 1-2% calcite, 1-2% quartz, minor opaque minerals and calcite vein (2 mm). Garnet is relatively large in size and euhedral to subhedral in shape. Two types of garnet have been recognized; the type I garnet is early reddish brown, isotropic; the type II garnet is green, late anisotropic zoned overgrowth (Figures 3-12 to 3-23).

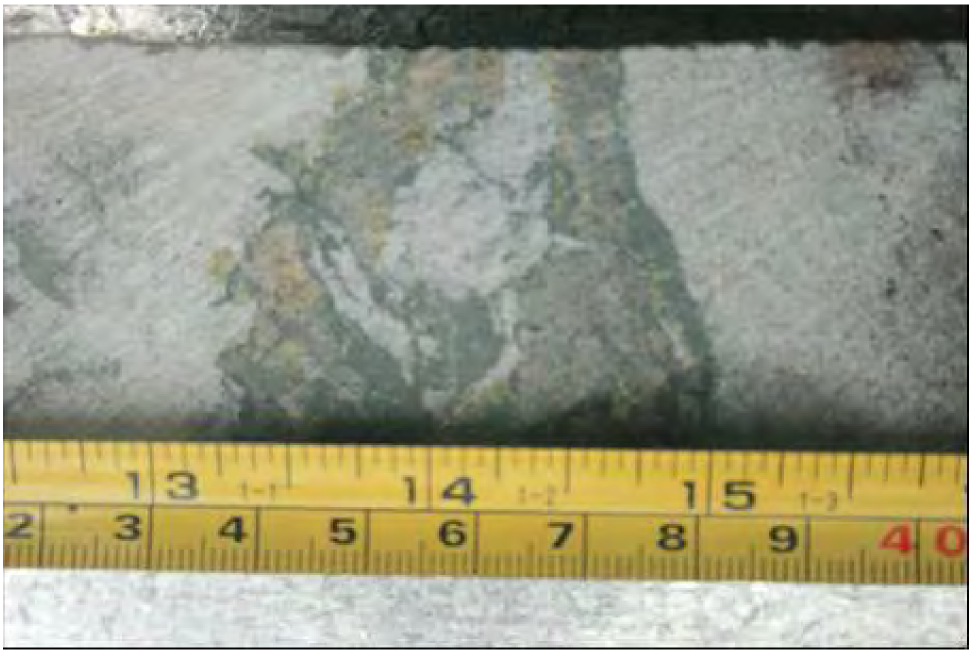
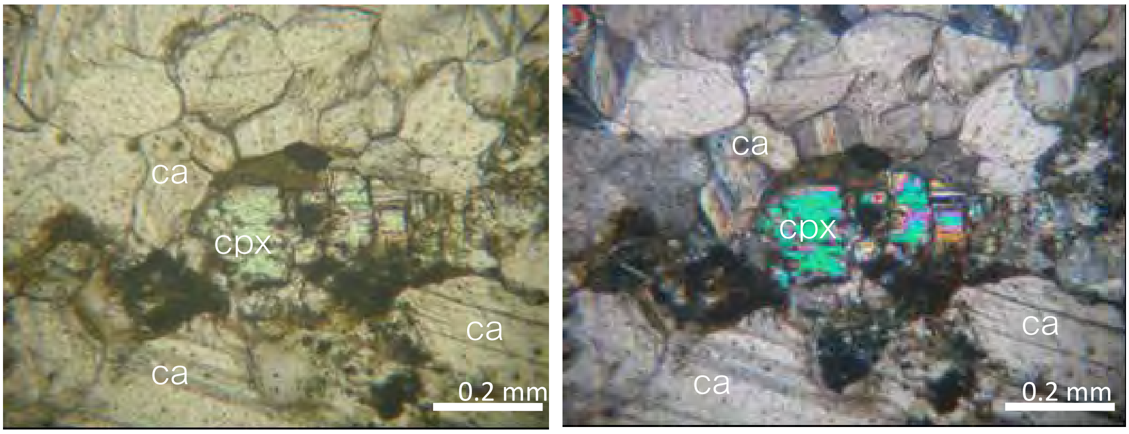


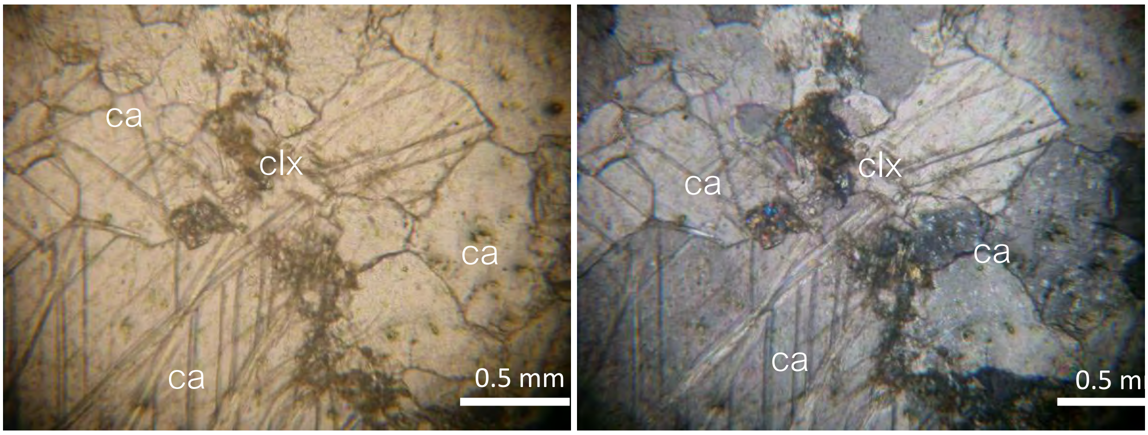
Figure 3-2: A slabbed core sample showing large patches of clinopyroxene in coarse-grained, light grey calcite.



A B

Figure 3-3: Photomicrography of marble in figure 3-2 showing interlocking grains of subhedral calcite (ca) with associated clinopyroxene (cpx) (A: plane-polarized light. B: crossed nicol, 10X).

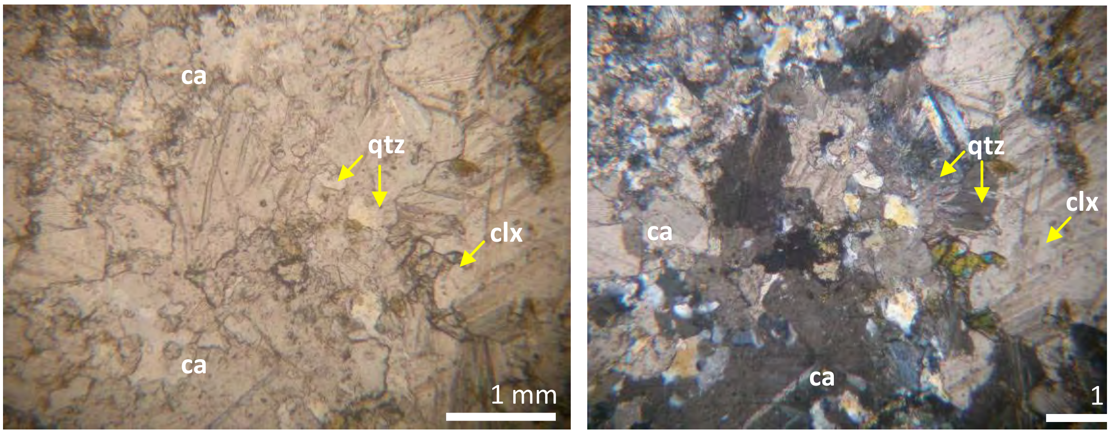
Figure 3-4: A slabbed core sample of light grey marble containing fine-grained calcite and patches of dark minerals.



A B

Figure 3-5 Photomicrograph of marble in figure 3-4 showing interlocking, coarse-grained, subhedral calcite (ca) with associated clinopyroxene (cpx). (A: plane polarized light. B: crossed nicol, 10X).

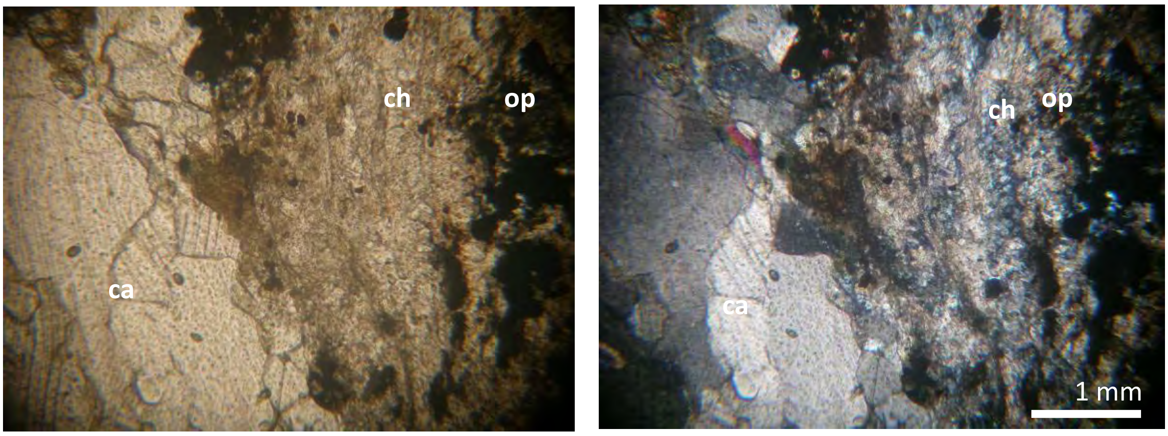
Figure 3-6: A slabbed core sample of marble showing fine to medium-grained calcite with patches of dark minerals.



A B

Figure 3-7: Photomicrograph of marble in figure 3-6 showing coarse-grained calcite (ca) and fine-grained quartz (qtz) (A: plane-polarized light. B: crossed-nicol, 5X).

Figure 3-8: A slabbed core sample of marble showing coarse-grained, light grey calcite with large patches of garnet skarn replacement.



A B

Figure 3-9: Photomicrograph of marble in figure 3-8 showing calcite (ca) and chlorite (ch) with opaque minerals (op). (A: plane-polarized light. B: crossed-nicol, 5X).

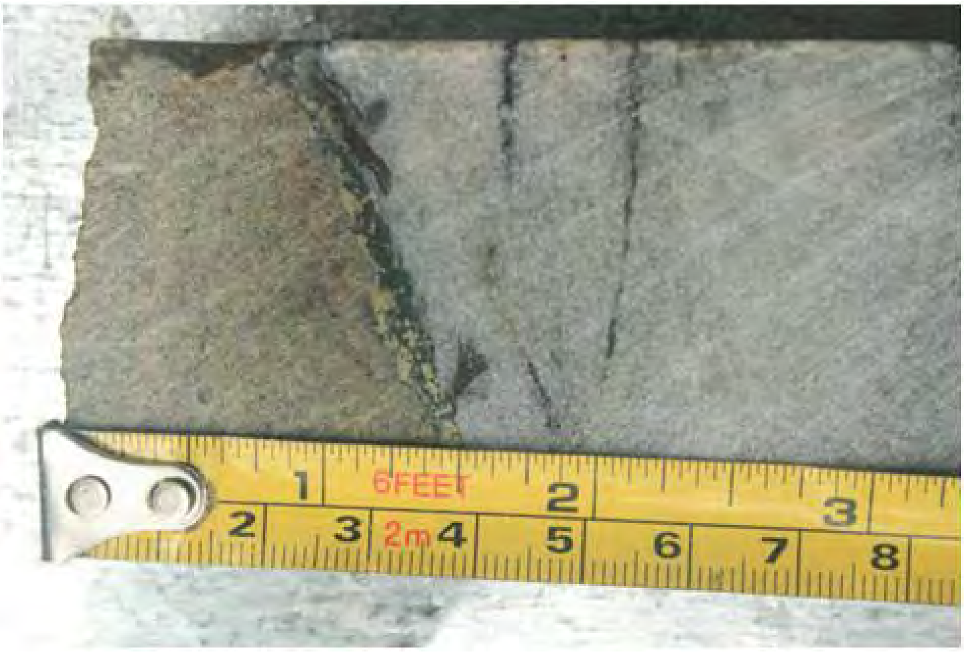
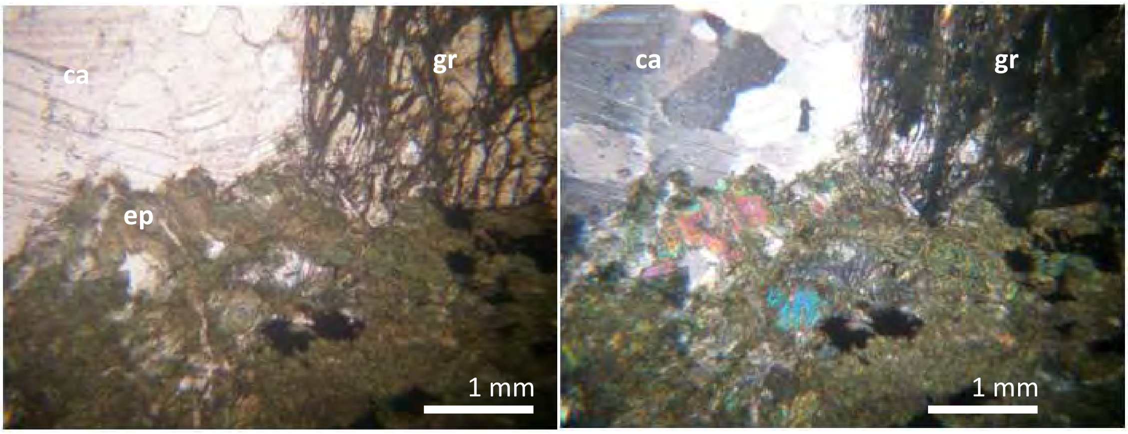


Figure 3-10: A slabbed core sample of light grey marble crosscut by garnet skarn vein (left).



A B

Figure 3-11 Photomicrograph of garnet skarn-marble contact showing garnet partly alterated to epidote and pyroxene? altered to actinolite –chlorite. (A: plane-polarized light. B: crossed-nicol, 5X).

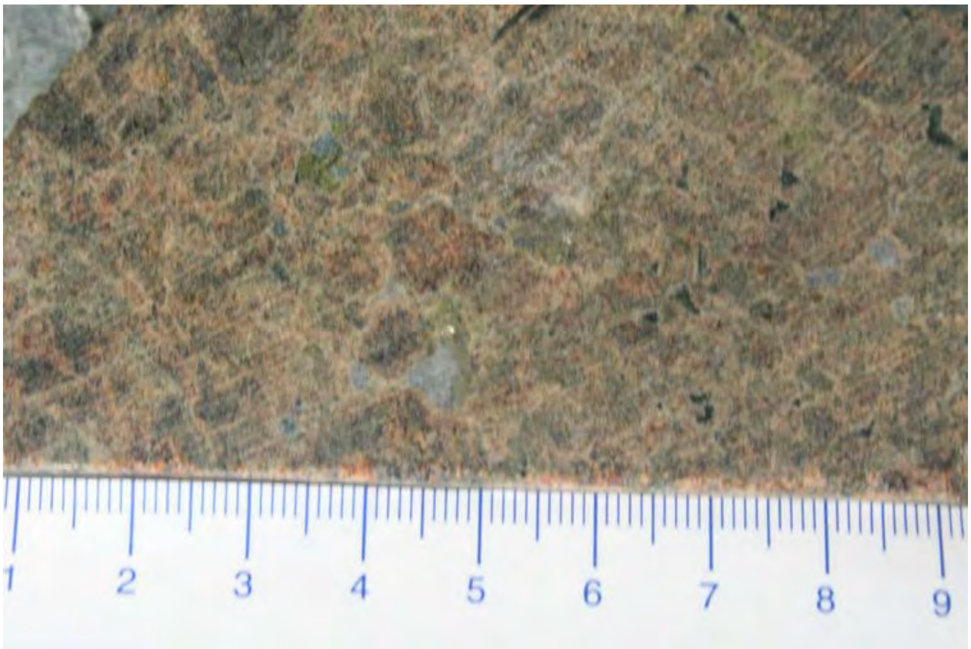
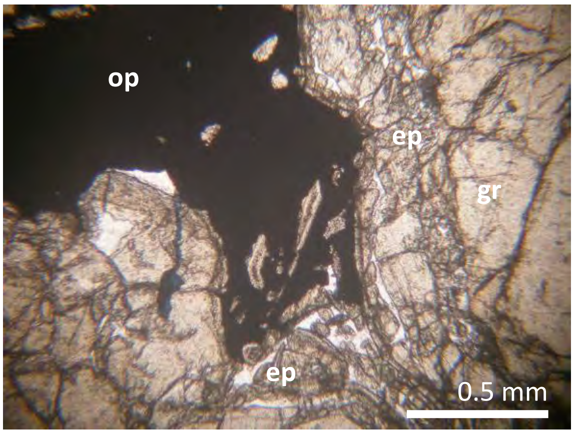
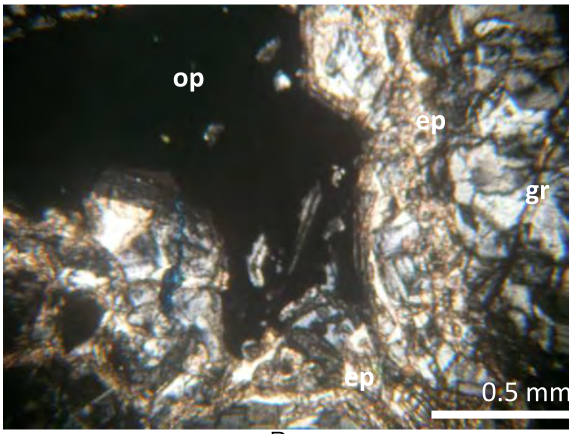


Figure 3-12: A slabbed core sample of garnet skarn showing greenish brown, medium to coarse-grained garnet with pale green epidote and quartz.



A



B

Figure 3-13: Photomicrograph of garnet skarn showing anisotropic garnet (gr) replaced by epidote (ep) with related opaque minerals. (A: plane-polarized light. B: crossed-nicol, 5X).

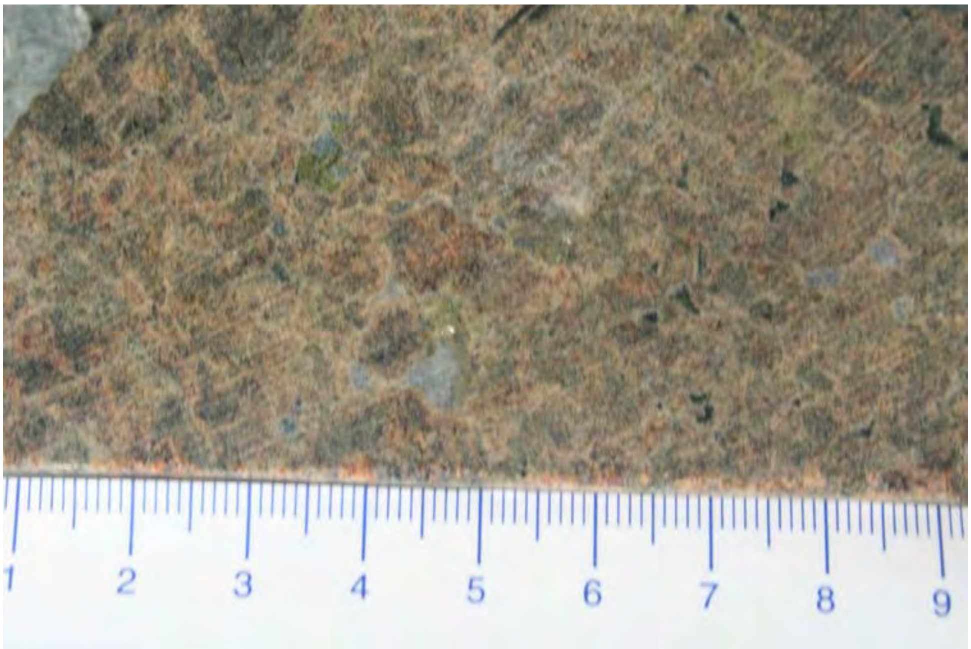
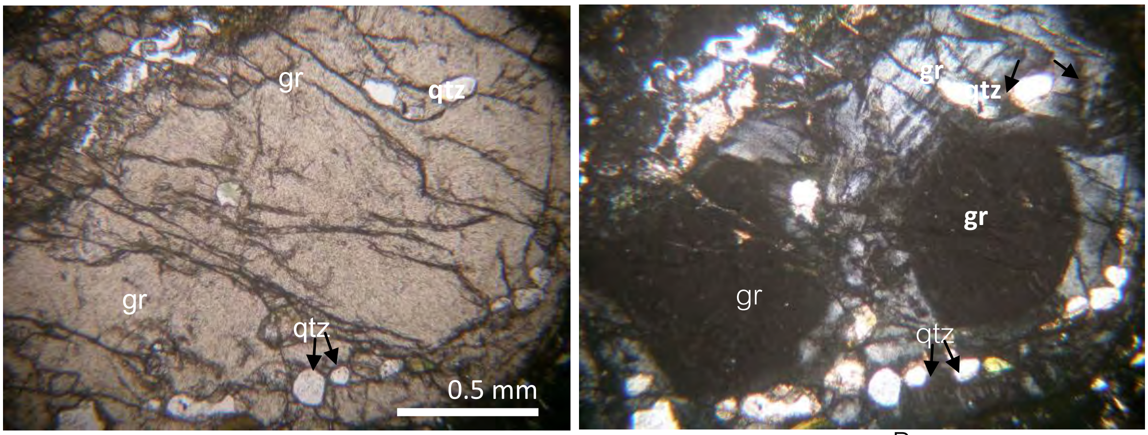


Figure 3-14: A slabbed core sample of garnet skarn showing greenish brown, medium to coarse-grain garnet with pale green epidote and quartz.



A

B

Figure 3-15: Photomicrograph of garnet skarn in figure 3.14 showing two generations of garnet formation; early isotropic garnet core and late anisotropic zoned garnet intergrowth with poikilitic quartz. (A: plane-polarized light. B: crossed-nicol, 5X).

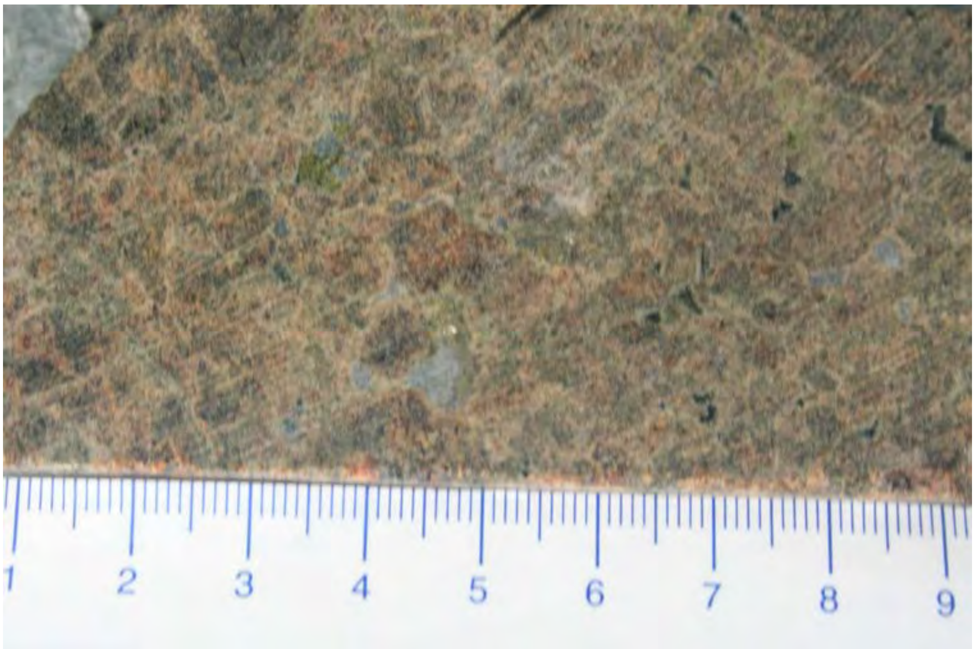


Figure 3-16: A slabbed core sample of garnet skarn showing greenish brown, medium to coarse-grained garnet and pale green epidote.

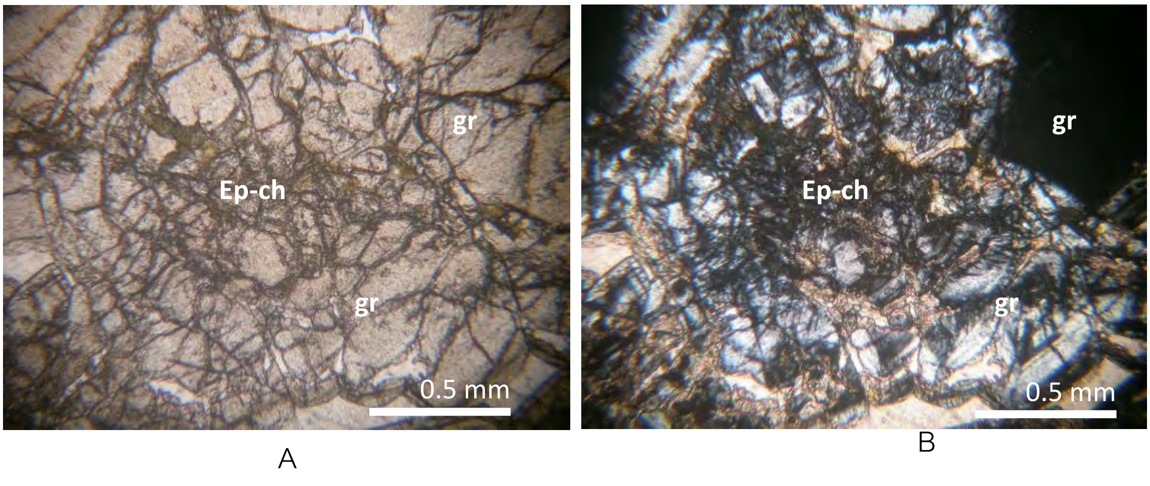
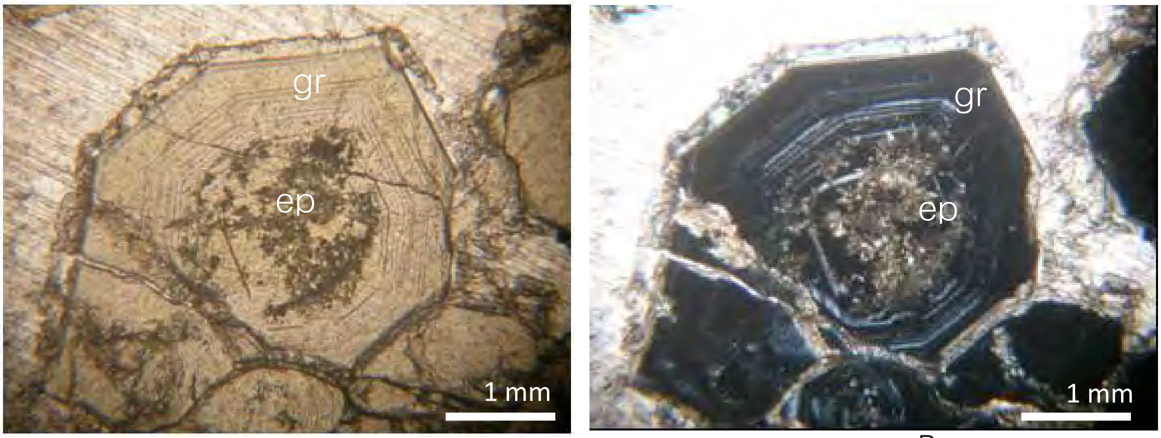


Figure 3-17: Photomicrograph of garnet skarn in figure 3-16 showing anisotropic zoned garnet (gr) partly replaced by epidote (ep). Note the isotropic garnet to the right. (A: plane-polarized light., B: crossed-nicol, 5X)

Figure 3-18: A slabbed core sample of reddish brown garnet skarn crosscut by epidote vein?



A

B

Figure 3-19: Photomicrograph of garnet skarn showing finely zoned anisotropic garnet (gr) partly replaced and crosscut by epidote veinlets?(ep) and reaction rim of garnet. (A: plane-polarized Light. B: crossed-nicol, 5X).

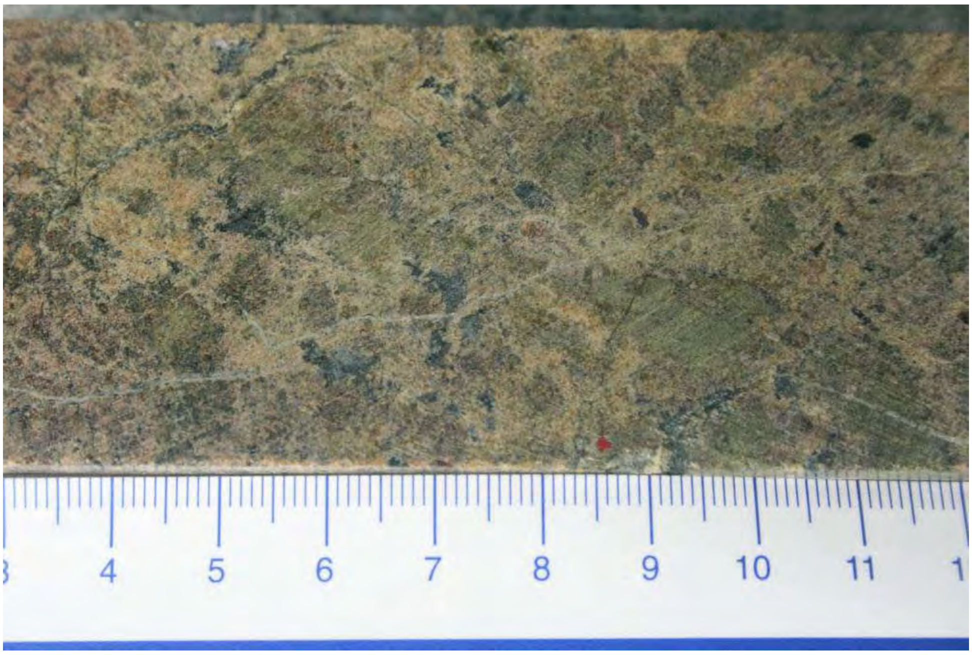


Figure 3-20: A slabbed core sample of garnet skarn showing coarse-grained garnet and pyroxene? altered to chlorite – actinolite.

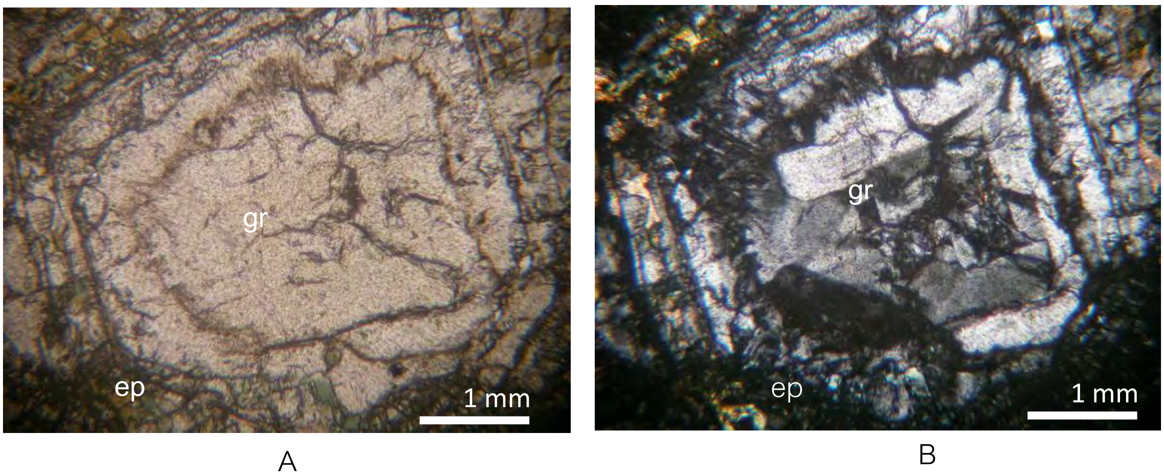
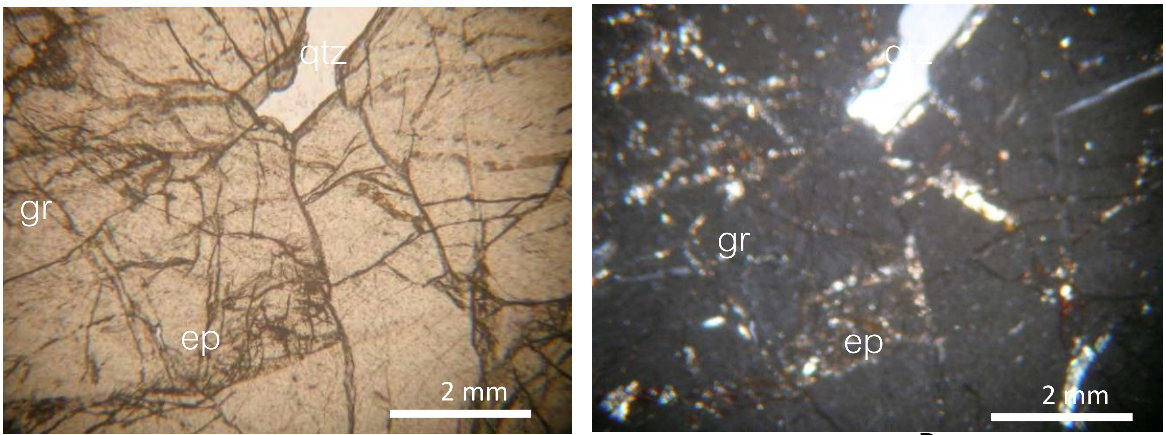


Figure 3-21: Photomicrograph of garnet skarn showing zoned anisotropic garnet (gr) partly replaced by epidote (A: plane-polarized light. B: crossed-nicol, 5X).

Figure 3-22: A slab core sample of garnet skarn showing coarse-grained garnet.



A B

Figure 3-23: Photomicrograph of garnet skarn showing coarse-grained garnet (partly replaced by epidote) with interstitial quartz. (A: plane-polarized light. B: crossed-nicol, 5X).

3.2.3 Epidote skarn

At 27-42 m depth, epidote skarn is pale green, fine-grained, contains 75-85% epidote, 5-10% chlorite, minor opaque minerals and calcite vein (2 mm) (Figure 3-28). epidote skarn with associated chlorite and tremolite- actinolite forms as alteration products or crosscutting veins in garnet skarn(Figures 3-24 to 3-31).

3.2.4 Andesitic lappilli tuff

At 2-22 m. depth, andesitic lappilli tuff (Figures 3-32 to 3-37) is generally dark green to black , fine-grained and contain rock fragements varying in sizes from 0.1-5 cm with calcite and quartz veins/veinlets (0.3 cm to1 cm in sizes).

Microscopically the rock contains rock fragments of andesite, rhyolite silicified shale in groundmass of plagioclase, amphibole. Some parts were affected by hydrothermal alteration (Figure 3-35).

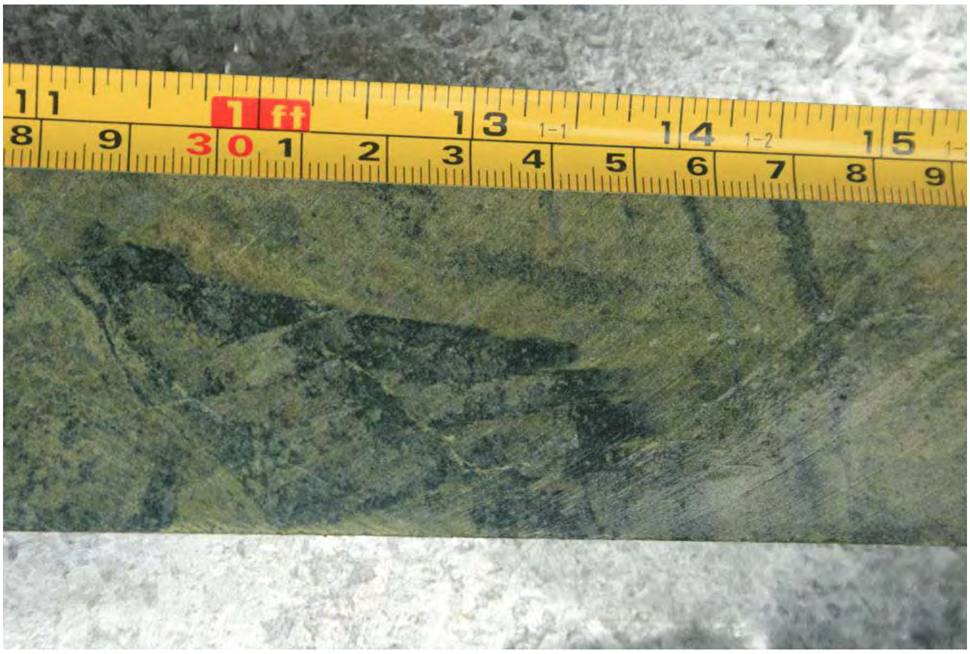
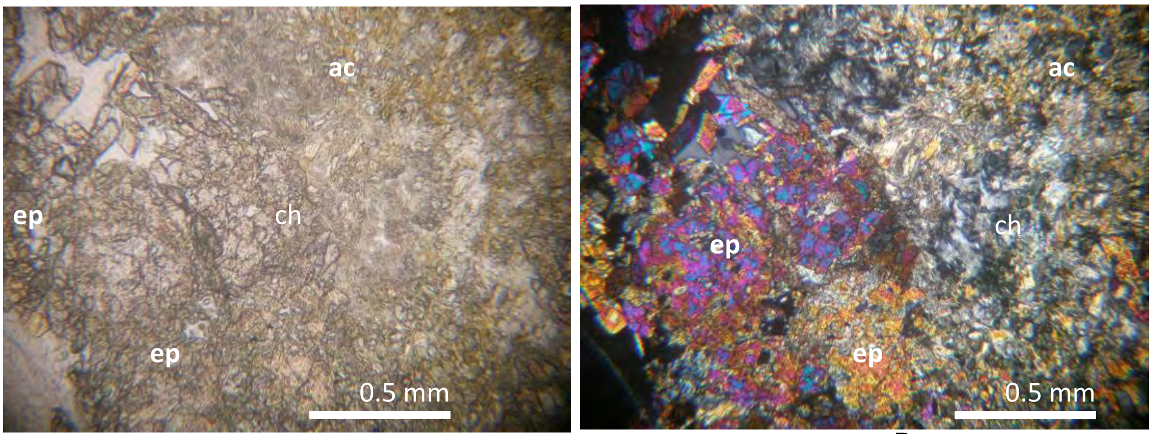


Figure 3-24: A slabbed core sample of yellowish green epidote skarn and dark green chlorite.



A B

Figure 3-25: Photomicrograph showing epidote (ep), actinolite (an) and chlorite (ch). (A: plane-polarized light. B: crossed-nicol, 10X).

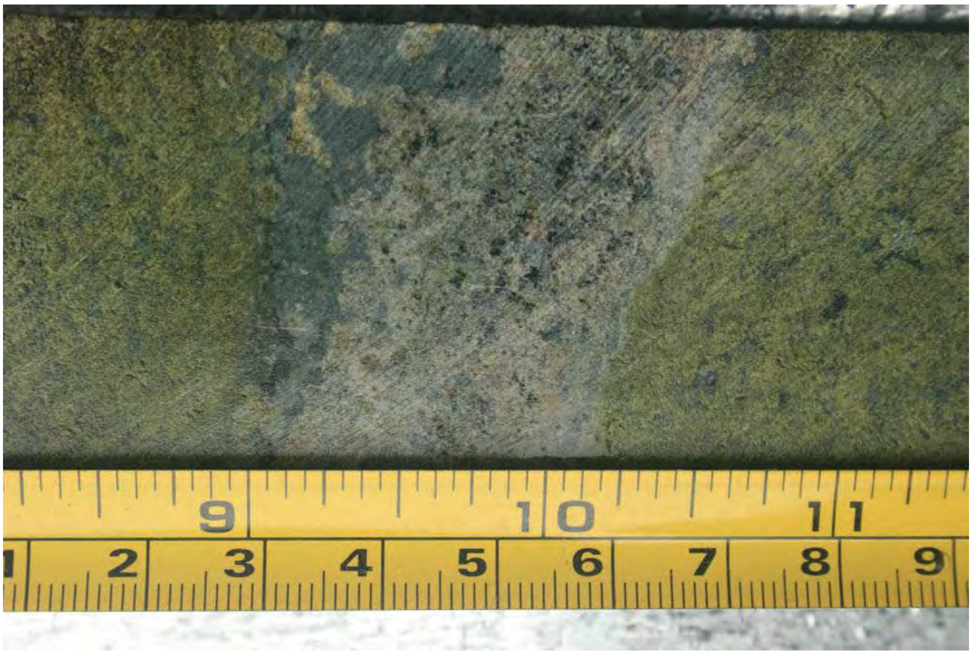
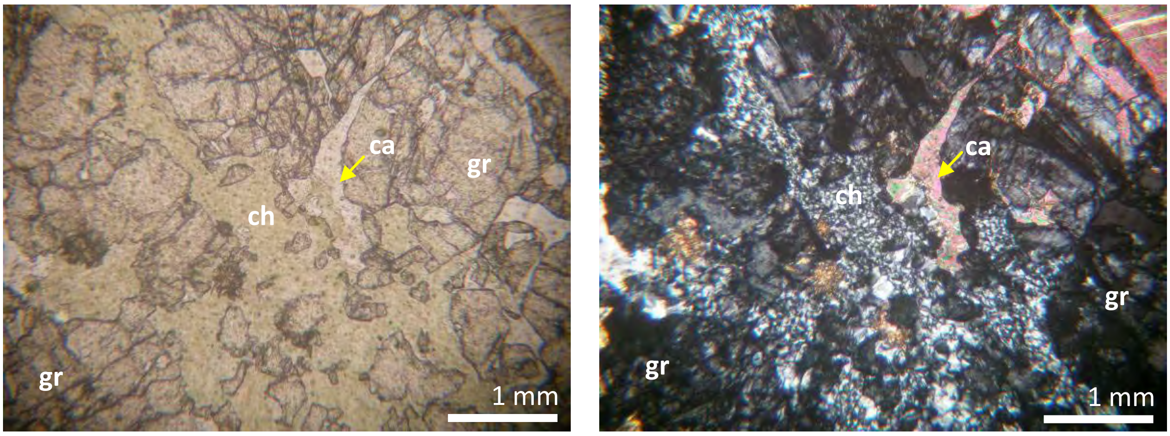


Figure 3-26: A slabbed core sample of epidote skarn crosscutting fine-grained garnet skarn.



A

B

Figure 3-27: Photomicrograph showing coarse-grained garnet (gr) replaced by chlorite (ch) and actinolite (A: plane-polarized light. B: crossed-nicol, 5X).

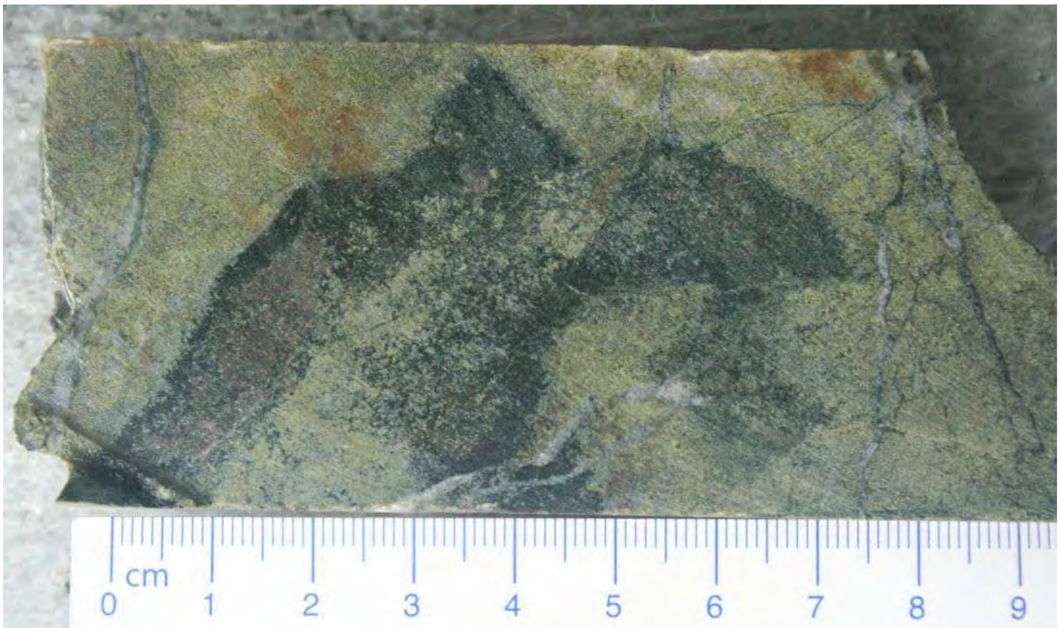
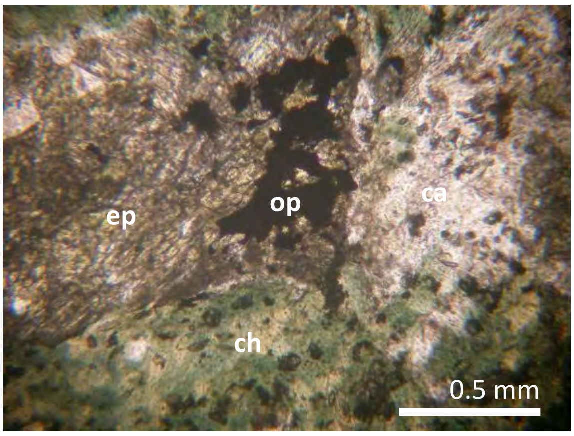
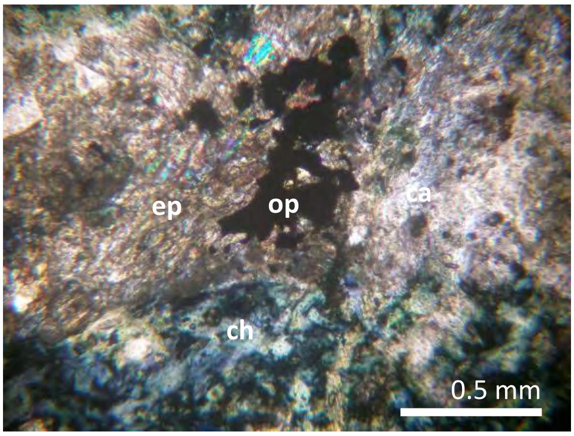


Figure 3-28: A slabbed core sample of epidote skarn containing of pale green, fine-grained epidote and dark green, fine-grained chlorite and calcite vein.



A



B

Figure 3-29: Photomicrograph showing epidote-chlorite replacing garnet with associated opaque minerals. (A: plane-polarized light. B: crossed-nicol, 5X).

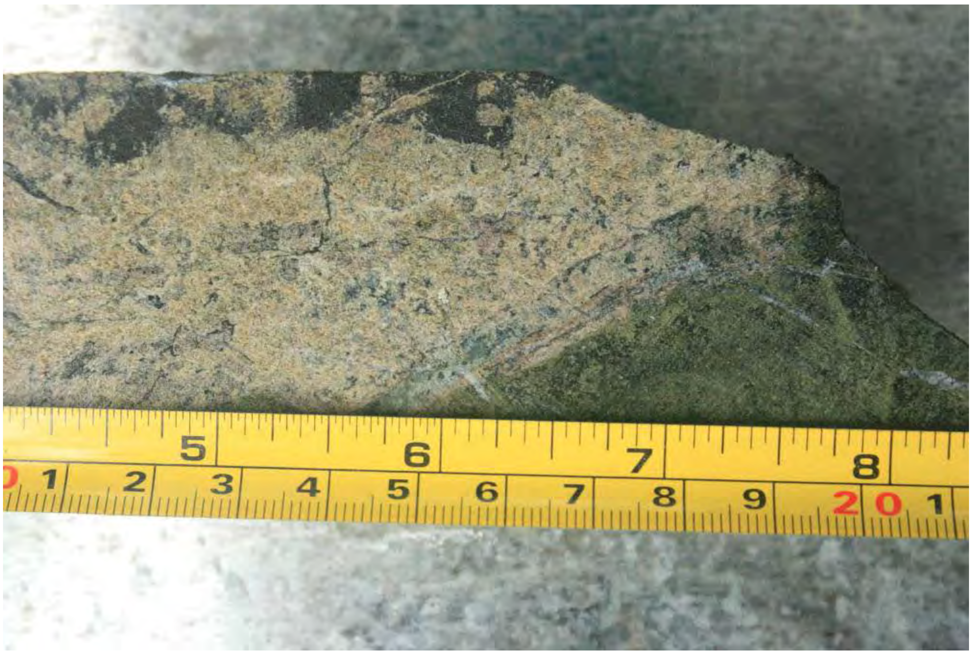
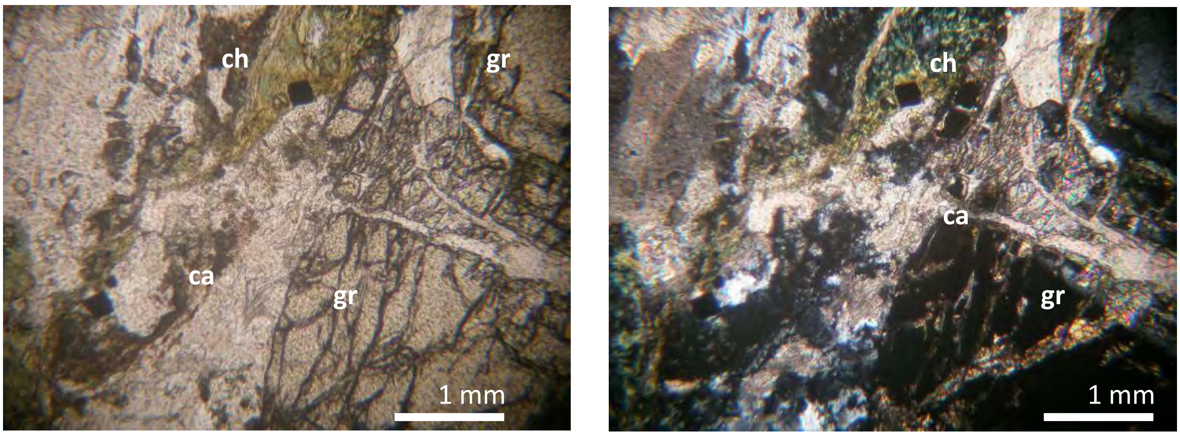


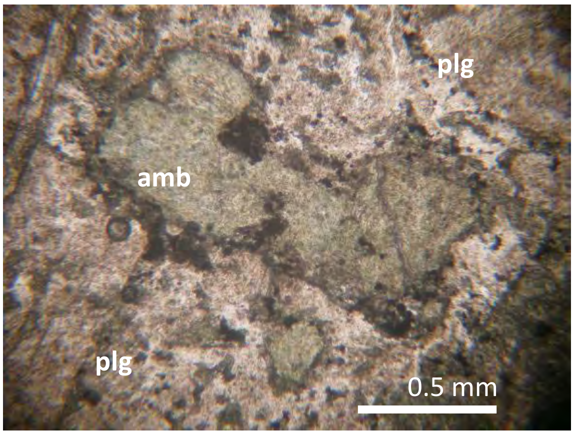
Figure 3-30: A slabbed core sample of green epidote skarn replacing and crosscuting fine-grained garnet with associated opaque minerals.



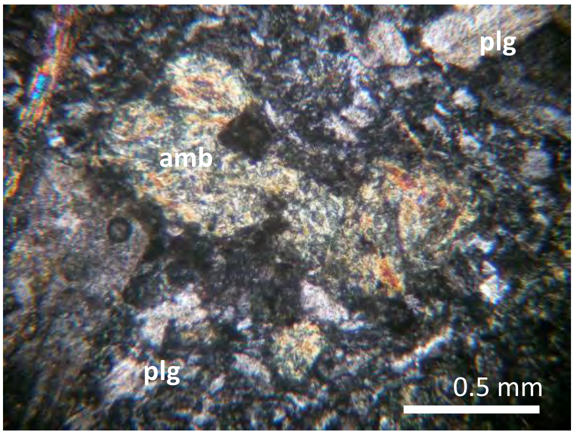
A B

Figure 3-31: Photomicrograph showing coarse-grained garnet (gr) replaced and crosscut by chlorite (ch)–epidote (ep) and calcite vein. (A: plane-polarized light, B: crossed-nicol, 5X).

Figure 3-32: A slabbed core sample of andesitic lapilli tuff showing dark green to black, fine-grained rock and containing fragments varying from 0.1-3 cm.



A



B

Figure 3-33: Photomicrograph of andesitic lapilli tuff showing amphibole (amb) altered to epidote (ep) and actinolite (ac). (A: plane-polarized light. B: crossed-nicol, 5X).

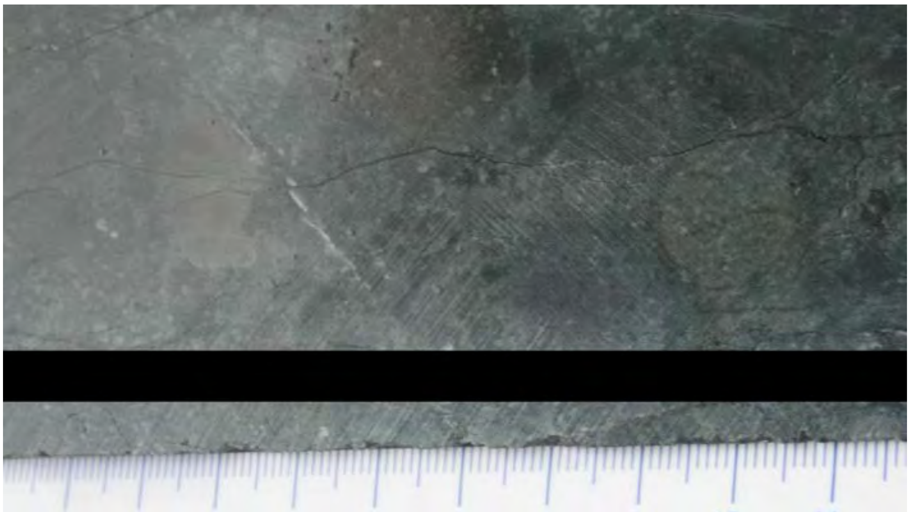
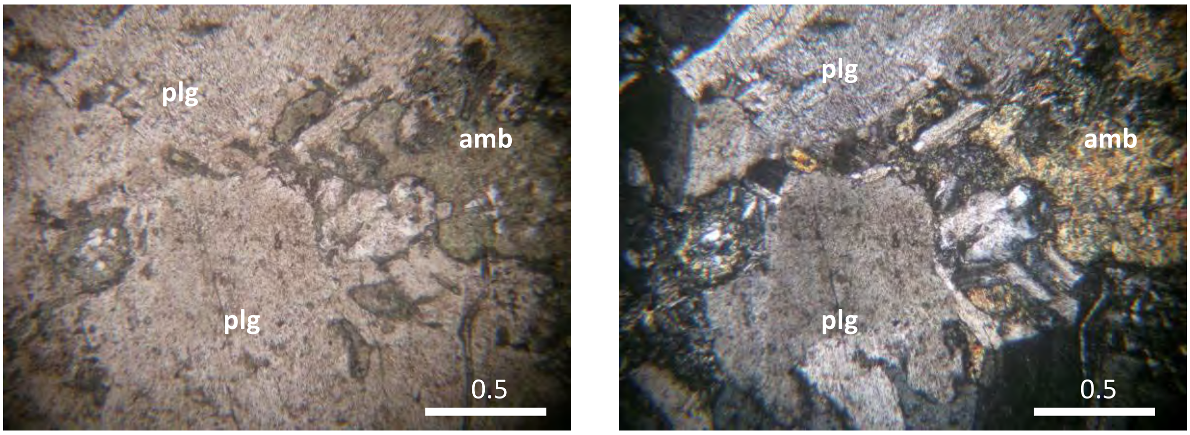


Figure 3-34: A slabbed core sample of andesitic lapilli tuff containing angular rock fragments.



A B

Figure 3-35: Photomicrograph of andesitic lapilli tuff showing coarse plagioclase containing rock fragments (plg, 0.01-0.05 mm) in microcrystalline plagioclase groundmass (A: plane-polarized light. B: crossed-nicol, 5X).

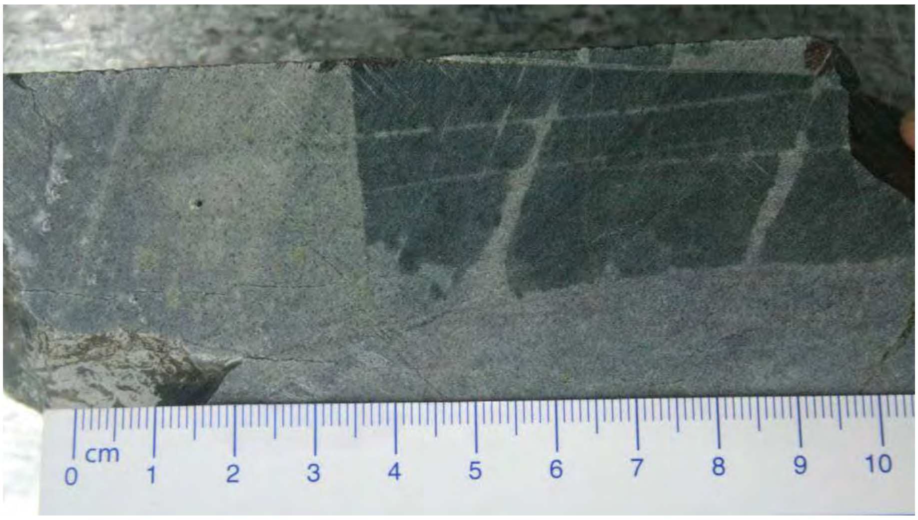
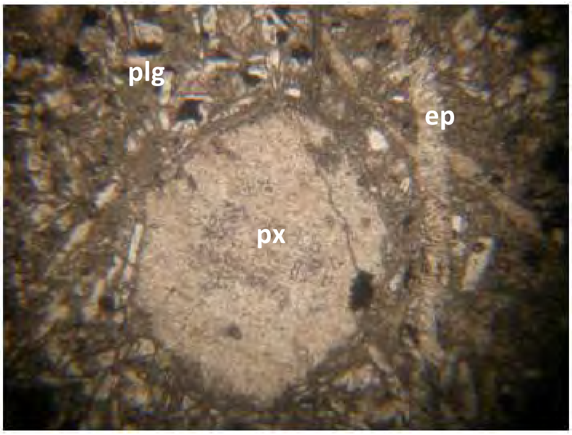
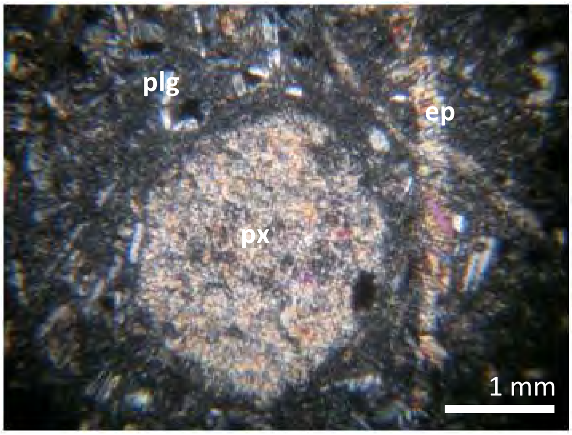


Figure 3-36: A slabbed core sample of andesitic tuff containing fine-grained rock fragments.



A



B

Figure 3-37: Photomicrograph of altered andesitic tuff showing a volcanic rock fragment containing large altered phenocryst in fine-grained groundmass. (A: plane-polarized light, B: crossed-nicol, 5X).

3.2.5 Iron ore deposit

Minor copper occurrence was partly open-cut at the foot at Khao Lek area in form of secondary malachite and azurite (Figure 3-38). Major iron ores related with epidote-garnet skarn at 31.30-33.90 m. depth.

Under polished section, magnetite occurs as subhdral to euhedral crystal aggregate (varying in size from 0.1 to 1 mm) closely associated with garnet (Figure 3-40).

Figure 3-38: An exposure of secondary copper minerals (malachite and azurite) at the foot at Khao Lek area.

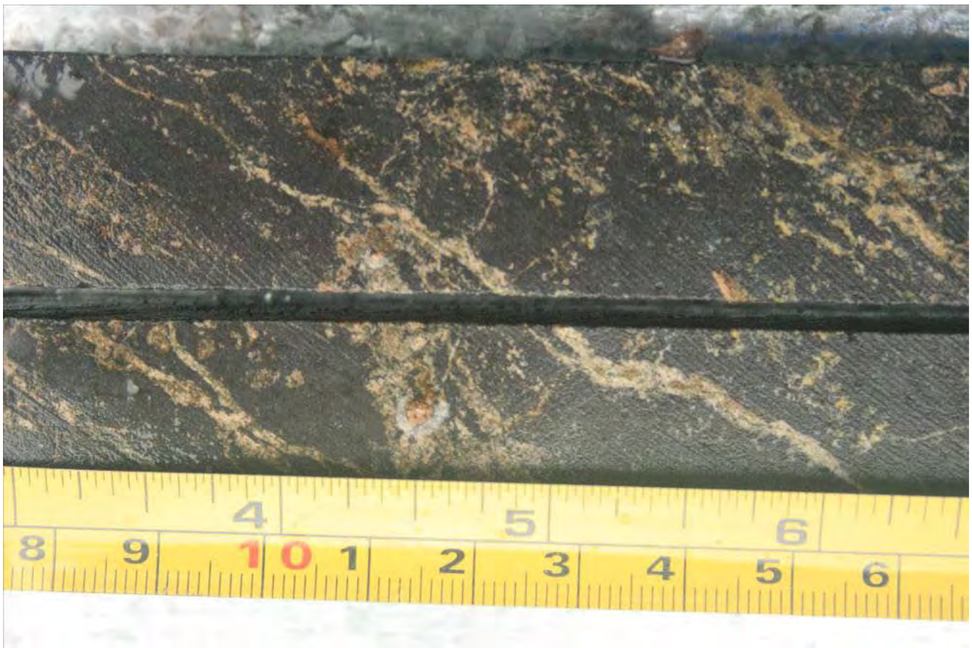


Figure 3-39: A slabbed core sample of massive magnetite in garnet skarn.

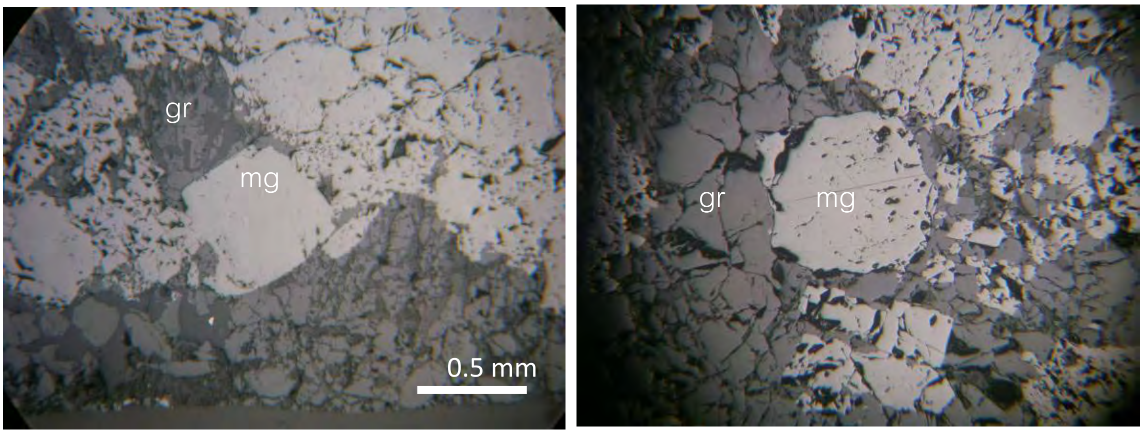


Figure 3-40: Photomicrograph of Garnet skarn showing euhdral to subhedral magnetite crystal aggregate closely associated with garnet. Reflected light 10X

CHAPTER IV

DISCUSSION AND CONCLUSION

4.1 Discussion

From core logging and petrographic study given in previous chapter, it is possible to decipher two evolutionary stages of ore mineralization as summarized in Table 4-1. The first stage of mineralization is prograde stage which is characterized by garnet, clinopyroxene. Garnet skarn was formed in close association of major magnetite mineralization. The secend stage is reteograde stage, which is shown by hydrous minerals such as epidote, chlorite and tremolite-actinolite with quartz and calcite in the forms of replacement and crosscutting veins/veinlets. The skarn at Khao Lek is therefore the calcic magnetite exoskarn.

minerals	Prograde		Retrograde	
	Early	Late	Early	Late
Garnet	—	—		
Pyroxene	—			
Epidote ± Chlorite ± Tremolite-Actinolite			—	—
Calcite			—	—
Quartz			—	—
Magnetite		—		

Table 4-1: Ore-gangue paragenetic sequence of the Khao Lek mineralization.

4.2 Conclusions

1. From core logging it can identified four types of rock: marble, epidote skarn, garnet skarn and andesitic lapilli tuff.
2. The skarn at Khao Lek area can be classified as calcic iron exoskarn deposit.
3. Iron (magnetite) related with garnet skarn at 31.30-33.90 m. depth and occurred during late prograde.

REFERENCES

Intayot, S., 2000. Mineralogy and petrography of skarn at Khao Phra Ngam area, Amphoe Muang , Changwat Lopburi. M.Sc. Thesis, Department of Geology, Chulalongkorn University. 96 p.

Meinert, L. D.,2004. Skarns and Skarn Deposites. Ore Deposit Models Volume II. Geological Association of Canada. pp. 117-134.

Pisutha-Arnond, V., Sunmanee, S., Yaemniyom, S., 1992. Copper-Iron-Gold-Silver Skarn Prospect at Phu Lon, Changwat Nong Khai, Northeastern Thailand: A Porphyry-Style Mineralization. Resource Geology Special Issue, No. 15, pp. 265-274.

Premgamone, C., 2005. Drilling Report on ore estimation Khao Lek Iron Deposit: area of Mining leases No. 16820/14857 and 16821/14856 Tambol Thung Thong, Amphoe Nong Bua, Nakronsawan Province, Central Thailand. 37 p.

Yamned, S., Ore Mineragraphy of Thung Kham Deposits, Amphore Muang, Changwat Loei. B.Sc. Senior Project, Department of Gelogy, Chulalongkorn Univercity. 71 p.