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Mineralogy and Petrography of Skarn in Khao Lek Area, Nong Bua District, Nakhon Sawan Province, Northern Thailand

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ABSTRACT

Khao Lek deposit is located at District Nong Bua, Province Nakhon Sawan. The deposit is hosted in Permian limestone of Tak Fa Formation and Late Permian-Early Triassic volcanic rocks. The Permian limestone was metamorphosed to calc-silicate and marble. The volcanic rocks unit ranges in composition from basaltic andesite to basalt. Skarn is better developed in limestone than volcanics protoliths. In limestone skarn zonations represented by garnet skarn, pyroxene skarn, garnet-pyroxene, pyroxene-wollastonite. In contrast, in volcanics protolith, only pyroxene skarn has been identified. Hence, most of pyroxene skarn occurs as veinlets or infilled vugs. In addition, skarn also occurs in few meters wide dioritic dyke hosting in limestone (marble). This endoskarn shows similar zoning to major skarn. Skarns also display mineralogical variation for example garnet skarn in which in the western part of the zone is represented by dark brown, medium- to coarse-grained associated with calcite whereas, at the eastern part garnet is reddish brown to yellowish green closely associated with pyroxene. This is consistence with composition obtained from EPMA analyzes suggesting that garnet at proximal has composition of spessartite-grossularite-andradite series and at the distal become andradite. These reflect source of fluid and type of protolith and proximal and distal from source intrusion. Similar to pyroxene where diopside represent pyroxene hosted in volcanic whereas, pyroxene hosted in or close to limestone protolith is represented by ferroaugite. These are likely reflected the influence of type of protolith. Other prograde skarn minerals identify at Khao Lek include biotite, tremolite, hornblende and quartz. Magnetite orebody is likely replaced the major endoskarn which was emplaced along ENE-WSW major fault as a dyke. This magnetite mineralization could well be formed during retrograde skarn formation as by cross cutting of quartz-chlorite-sulfides and epidote-chlorite ± calcite and calcite vein/veinlets and their associated hydrothermal alteration seem to have closed link to magnetite mineralization. These three veining systems are responsible for retrograde skarn alteration at the Khao Lek. The skarn at Khao Lek can be classified as calcic skarn based on its mineralogy. When consider in terms of ore deposits that are hosted by skarns, this deposit can be classified as skarn deposit. It is classified as iron ± copper skarn deposit which is based on the dominant metal i.e., Cu, Au, Pb-Zn, Fe, Mo, W and Sn.

Keywords: Mineralogy, Petrography, Skarn, Khao Lek, Iron, EPMA, Alteration

1. Introduction

Khao Lek iron skarn deposit is located District Nong Bua, Province Nakhon Sawan, central Thailand (Fig.1). Several skarn deposits/occurrences lie with the Loei Fold Belt (LFB) (Zaw et al., 2009) are reported and among them are Phu Thap Fah, Puthep 1 and Puthep 2 and Phu Lon in Loei-Udon Thani area (northeastern Thailand), Khao Phanom Pha and Singto in Phichit-Phetchabun area and Khao Phra Ngam and Khao Lek in

Nakhon Sawan-Lopburi area (central Thailand). Other economically potential prospect and old mine are Ban Bothong and French Mine respectively.

Khao Lek iron skarn deposit is small deposit which has been operated as open pit mining by local company for the past 10 years. The current operation is shifted to industrial material or construction materials from both volcanic host rocks and marble of the previous iron mine area particularly. The mineral resource (iron ore) at Khao Lek has not been reported. The Khao Lek is of interested skarn deposit as it is hosted in both limestone and volcanic rocks which allow us to have a better understanding in skarn deposit in the region both in academic and mineral exploration especially for similar deposit which could be potential target for bigger deposits. At Khao Lek, there was no proper study has been undertaken in the past. This study will be focusing on documenting characteristics of skarn alteration and iron-copper mineralization.

2. Tectonic setting

Thailand and its adjacent areas of mainland SE Asia comprise two major tectonic terranes: Indochina in the east and Shan-Thai on the west (Fig. 2). These two terranes are delimited by Sukhothai Fold Belt (SFB) in the west and Loei Fold Belt (LFB) in the east. The Shan-Thai terrane is continental block comprising of the west Myanmar, east Myanmar, western Thailand, western Malaysia Peninsular and Sumatra. The Indochina block, enclosed the central and east Thailand, Cambodia, Lao PDR, and Vietnam. Prior the collision with Shan-Thai, Indochina Terrane is believed to have already been amalgamated to the South China along the Song Ma Suture during Devonian or Early Carboniferous (Gatinsky et al., 1984). The Shan-Thai and Indochina Terranes moved north from Australia into Paleo-Tethys Ocean during Phanerozoic and they were subsequently amalgamated into Asia (Hall and Gómez-Torres, 2000; Metcalfe, 2002). SFB and LFB were interpreted to have been formed as a result of subduction of Shan-Thai underneath Indochina in Late Permian. Skarn and epithermal deposits in the LFB are closely associated with subduction related magmatism.

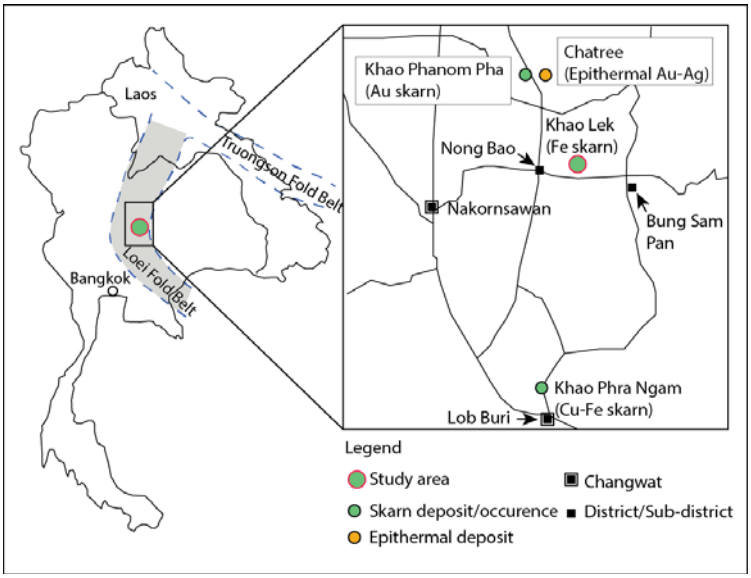

Figure 1. Map of Thailand and Laos showing distribution of major mineral deposits in the LFB.

Permo-Triassic volcanic rocks in SFB are believed to be related to eastward subduction underneath the Indochina Terrane. Subsequently, the subduction was followed by the I-type granitoid emplacement in the area during Late Triassic to Jurassic. However, recently many authors regard Nan-Uttaradit-Sra Kaeo Suture as remnant of back arc basin situating behind Sukhothai Arc and Indochina Terrane. However, they failed to explain predominantly distributed of volcanic and plutonic rocks in LFB. Khin Zaw et al. (2007a) and recently published works by Salam et al. (2014) suggested that the emplacement of volcanic rocks (ranging in composition from basalt to rhyolite) and plutonic rocks (granite to gabbro of I-type affinity) occurred in the LFB is the results of the Late Permian subduction of the oceanic crust underneath Indochina. Similar rocks and ages are also widely identified in both along SFB and are predominantly of I-type affinity.

The collision and accretion of Shan-Thai and Indochina Terranes in Late Triassic are generally accepted (Bunopas, 1981; Bunopas and Vella, 1983; Chaodumrong, 1992; Intasopa, 1993; Khin Zaw et al., 2007b; Metcalfe, 2002; Salam et al., 2014; Srichan et al., 2009). This collision was subsequently followed by post-collision magmatism represented by the occurrence of granitoid rocks in SFB and LFB (Khin Zaw et al., 2007a; Salam et al., 2013).

2. Geology of deposit

The oldest rock in the study area is Permian limestone of Tak Fa Formation which is characterized by massive to well bedded limestone interbedded with sandstone and shale (Listerud and Meineke, 1977). Limestone exposures (including marble and calc-silicate) were observed in the northeastern and southern part of the mine area. It is overlain by Permo-Triassic volcanic rocks consisting of rhyolite, tuff, agglomerate and andesite. Triassic granite to diorite are mainly cropped out in low land area in the east and northeast of study area (Figs. 2).

At Khao Lek, there are few places where Permian limestone are found and it has been metamorphosed to calc-silicate and marble particularly near the contact with diorite intrusion. However, the nearest calc-silicate and marble exposures outside the pit area is a long road cut northwest of the mine area (Fig. 2). Here, marble is light gray to white, well crystalline rock contain abundance chert nodules. Here, skarn alteration was not observed during this field work. At mine area, the limestone (marble) is mainly found at the center of pit floor and pit wall on the eastern part of the mine area. It was metamorphosed to medium- to coarse-grained marble. Under microscope, the marble consists of calcite about 70 to 75 % by volume and 25 to 30% of dolomite. Small amount of quartz and opaque minerals may also present. Calcite and dolomite range in size from 0.2 to 1.5 mm, euhedral to subhedral crystals.

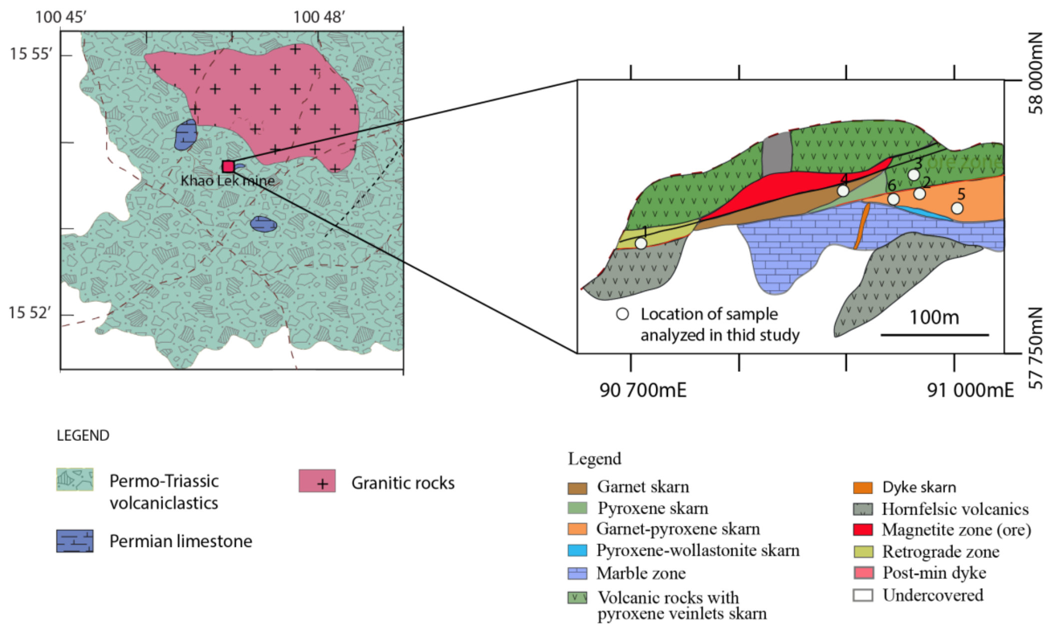

Figure 2 Geological map of Khao Lek and its adjacent area, **(left)** Major rock units in Khao Lek, **(right)** Geology of iron skarn deposit.

Khao Lek volcaniclastic rocks unit is a part of Thung Faeg-Sap Samran volcanics forming as a ring shape enclosing the diorite intrusion at Ban Khao Mae Kae (Figs. 2). These volcanic rocks are similar in composition to the volcaniclastics in Chatree area or “Chatree volcanics” in District Thap Khlo (Province Phichit) and District Chon Daeng (Province Phetchabun) which is about 50 km north of the study area and their ages range from 258 to 250 Ma (Salam et al., 2014; Salam et al., 2013).

At Khao Lek and its adjacent area, the volcanic rocks range in composition from basaltic andesite to basalt, comprising of basaltic and basalt lava, and volcaniclastic are mainly tuff, lapilli tuff and breccia (intermediate volcanic sandstone and breccia). Observation within the pit area reveals that the Late Permian-Early Triassic volcanic rocks are dominated by coherent rocks (basaltic andesite and basalt). The volcanic sequence has strike northwest-southeast with moderate dipping about 20 to 30° to the east. Hornfelsic volcanic rock is mainly identified at southeast and southwest of the pit. The rock is grayish green in hand specimen and resemble to silicified volcanic rocks. They are locally cross cut by green epidote-chlorite ± calcite veinlets. These volcanic rocks are strongly altered in which feldspars are partly to completely altered. Characteristic minerals of this rock include quartz, and chlorite.

3. Skarn alteration

Mapping of skarn alteration mainly focus on the pit floor and lower level of pit wall as the rest of the area is inaccessible during this study. In addition, there is no diamond drill core available for deeper level study. The prograde skarn has been observed both in limestone and volcanics protoliths (Fig. 2). The lack of clarity of the intrusive body limits the study to exoskarn. Skarn is better developed in limestone in comparison to volcanic rocks and produced distinct skarn alteration for different type of protoliths. Details of their characters are described bellows.

3.1 Skarn in limestone protolith

Skarn in limestone has distinct alteration zones which could be mapped into at least four zones namely, 1) Garnet skarn zone, 2) Garnet-pyroxene zone, 3) Pyroxene-wollastonite zone and 4) Pyroxene zone (Fig. 2). Details of each skarn zone are described bellows.

Garnet skarn ± pyroxene

The garnet skarn is best developed in limestone protolith which is parallel to the main magnetite orebody (Fig. 2). This zone occurs as lenticular shape about 4 to 10 meters wide. This zone contains predominantly of medium-grained to coarse-grained garnets in association with medium- to coarse-grained calcite with unevenly distributed of garnets particularly at the western side of the zone. In general, garnet of this zone is euhedral and varying in color from dark brown (Fig. 3A) to reddish brown or yellowish green. Microscopically, garnet is often zoning and is characterized by isotopic core and anisotropic rim (Fig. 3B). EPMA analyzes suggested it is spessartite-grossularite-andradite series. Coarse grained garnet is often fractured and commonly filled with carbonate mineral and/or partially altered to chlorite.

Garnet-pyroxene skarn

This zone occurs in the eastern part of the area (Fig. 2). It is exposed on pit floor and on the pit wall. This zone is about 10 to 20 meters wide and the length could further extend to the east into pit wall. It is bounded by fault with the volcanics containing pyroxene veinlet and patches. This skarn contains abundance of garnet which is varying in color from reddish brown to purple red in association with pyroxene. EPMA results suggested that garnet in this zone is identified as andradite and spessartite-grossularite-andradite series. Pyroxene found in this zone is mainly clinopyroxene and minor orthopyroxene. Small amount of wollastonite may also present particularly close to pyroxene-wollastonite zone. Some quartz present in these samples may have been replaced wollastonite. Small amount of calcite is interstitially associated with garnet.

Pyroxene-wollastonite skarn

Narrow zone of pyroxene-wollastonite has been mapped between the garnet-pyroxene zone and marble (Fig. 2). This zone is estimated about 2 to 3 meters wide. Wollastonite is difficult to recognize due to its fine-grained. Under microscope, wollastonite occurs as fine-grained ranging in size from 0.2 to 0.5 mm and closely associated with pyroxene. Quartz is similar to and also can replace wollastonite.

Pyroxene skarn

At Khao Lek, pyroxene skarn is least developed in limestone protolith. It tends to form better in volcanic rocks as pyroxene veinlets and infilled in vugs. However, narrow zone of pyroxene skarn has been mapped out between the garnet skarn and marble at center of the pit (Fig. 2). This zone is about few meters wide where it forms as small lenses hosted by marble. However, during field visit, part of the area that might be represent pyroxene zone was under covered by mining waste rocks. Therefore, the extension of skarn zone is not well understood.

3.2 Skarn in volcanics protolith

Garnet skarn has not been identified in basaltic andesite-basalt host sequence during this study. In volcanics host, pyroxene skarn is less pervasive but may quite extensive. It is confined to volcanics unit especially on the hangingwall of Khao Lek open pit. However, the extension of skarn alteration beyond the pit wall is not known due no thick vegetation. Here, pyroxene skarn occurs in two styles, 1) very narrow stripe at the contact with magnetite orebody on the footwall side, 2) pyroxene skarn veinlets and/or vugs. The first one occurs at the contact with magnetite orebody which is possible to have replace diorite intrusion.

Pyroxene skarn in volcanic rocks

As mentioned earlier that the pyroxene skarn is less obvious at the Khao Lek mine in comparison to garnet skarn. Pyroxene skarn in volcanic rocks is better observed from those samples collected from the footwall where volcanic rocks are close to the magnetite orebody (Fig. 2B). The identification of pyroxene skarn should focus mainly on petrographic investigation due to skarn veinlets are too small to identify by naked eyes.

Based on petrographic investigation, it shown that pyroxene tends to occur as fine-grained replaces in volcanic rocks and veinlet and/or infilled vugs (Figs. 3C and D). Those volcanics located close to the garnet zone (or orebody) may developed narrow pyroxene zones. In some samples, larger pyroxene crystals (primary pyroxene) may have been replaced by pyroxene skarn.

3.3 Dyke skarn

A distinctive endoskarn is identified as dyke skarn occurs at the center east of pit area (Fig. 2). This skarn is about 2 to 3 meters wide hosted in coarse-grained crystalline marble. Based on texture features of skarn and morphology, this skarn could have been confined to dyke and most likely is dioritic composition. The contact between dyke skarn and marble is shape and there are no skarn minerals identified in coarse-grained marble wallrock. This skarn is considered as endoskarn in which they are displayed distinctive zonation as indicated by garnet zone core (<1 meters wide), followed by garnet-pyroxene zone (<0.5 meter wide) and pyroxene-wollastonite zone (<0.5 meter wide).

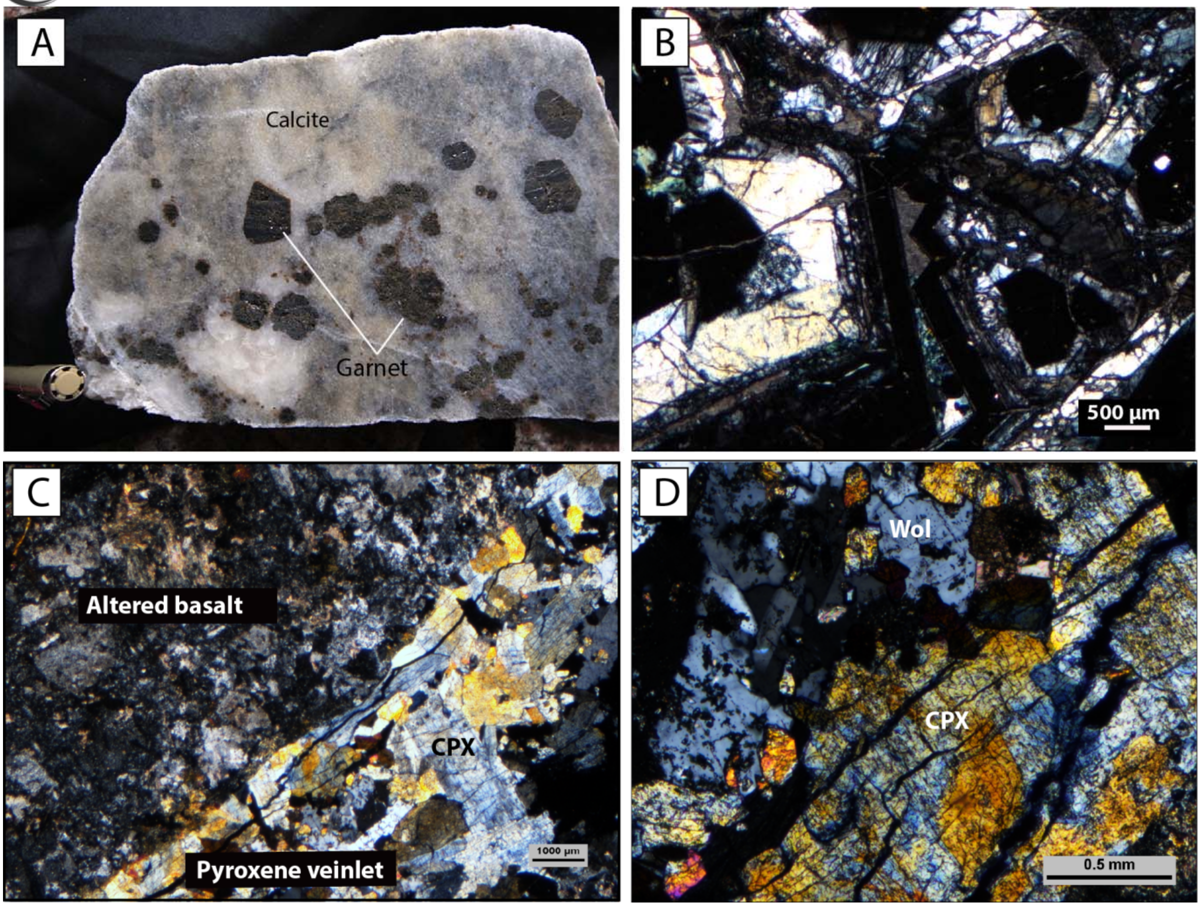

Figure 3. Skarn alteration, **A.** Photograph of hand specimen showing garnet and calcite from garnet zone, **B**. Photomicrograph of garnet zone showing zonation in garnet with isotropic (core) and anisotropic (rim), **C**. Photomicrograph of pyroxene skarn showing pyroxene veinlet, mostly clinopyroxene (CPX), **D**. Photomicrograph of pyroxene zone showing clinopyroxene (CPX) associated with wollastonite (Wol).

It should be noted that this dyke skarn contains lenses of magnetite ore at the center and similar to that of major magnetite orebody. Wollastonite may forms as narrow zone next to pyroxene zone. Pyroxene skarn is well developed in this contaminated skarn.

4. Mineralization

The iron mineralization is represented by massive magnetite orebody occupying a major structure trending northeast-southwest to east-west (Fig. 2). The orebody extends about 60 meters in length and 2 to 5 meters wide. The geometry of the orebody apparently widest at the center of the pit and narrow on both sides of body. The orebody is steeply dipping but the vertical extension of the orebody could not be identified at this stage. In hand specimen, magnetite ore is dark gray to black and massive (Fig. 4A). Small magnetite ore lenses also occur the southeast of the pit where it is formed in dyke skarn. Here, magnetite associated with brown garnet rich band (very narrow zone) followed by dark green to yellowish green zone and narrow zone of wollastonite. Under microscope, magnetite forms aggregate of fine-grained (Fig. 4B). Small veinlets of quartz-pyrite-chalcopyrite often cross cut massive magnetite.

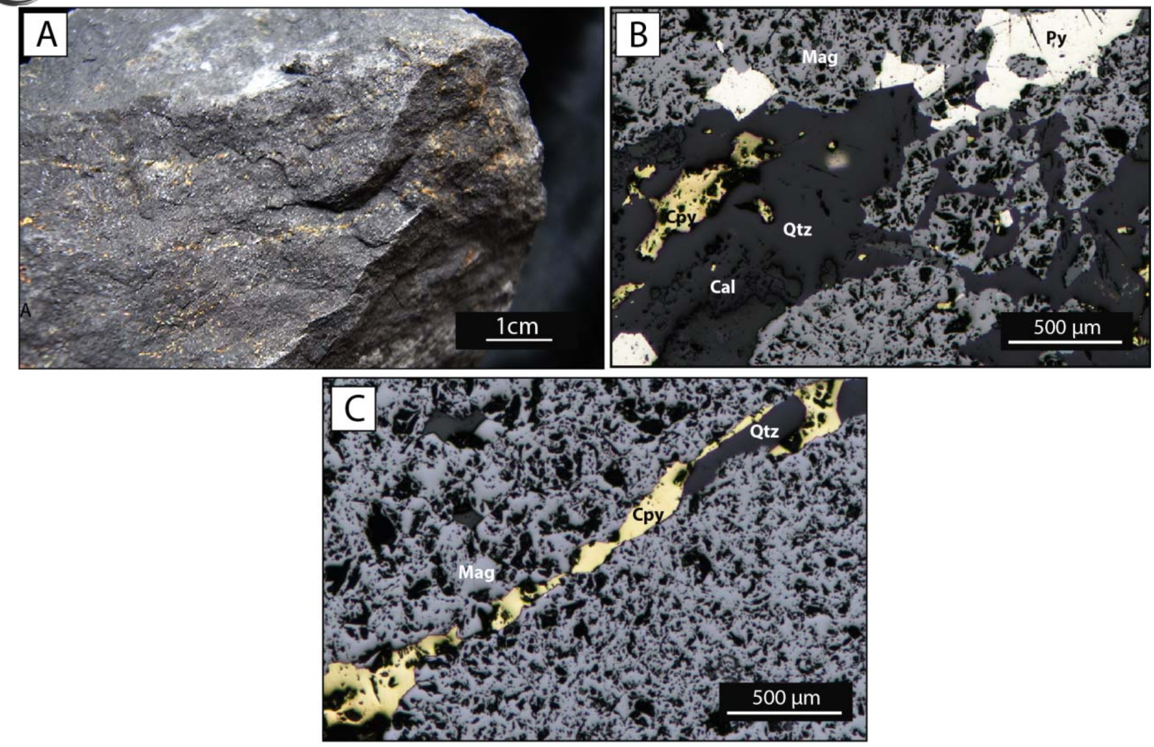

Figure 4. Iron mineralization, **A**. Photograph of hand specimen showing massive magnetite containing small veinlets and patches of quartz-pyrite-chalcopyrite late mineralization. **B**. Photomicrograph of massive magnetite cross cut by quartz ± calcite-pyrite-chalcopyrite veinlet/patch, **C**. Photomicrograph of massive magnetite similar to Fig. 4B showing small veinlet of quartz ± calcite-chalcopyrite-pyrite. Abbreviation: Qtz = quartz, Cal-calcite, Cpy = chalcopyrite, Py = pyrite.

Regrade Skarn

Quartz-amphibole-chlorite-sulfides veinlet (stage 2) associated alteration which is characterized by quartz-tremolite-hornblende ± biotite assemblage may include in retrograde skarn. However, as it is mineralized (or bearing ore minerals) veins/veinlets. Hence, it is preferred to describe in. Retrograde skarn is particularly well developed around major fault especially on the hangingwall side and at the southwestern part of the pit. Elsewhere, retrograde skarn is also identified including in pyroxene skarn veins/veinlets in basaltic andesite and/or basalt along the northern pit wall. However, the later one is less pervasive and unmappable. The retrograde skarn in the area mentioned above is clearly observed as it has a distinctive pinkish orange color in outcrop particularly on surface. Here, volcaniclastic rocks contain pyroxene veinlets skarn were overprinted by epidote- chlorite ± calcite veinlets accompanied by strongly bleaching into light greenish gray to pale pink alteration. Chlorite and epidote are the most common retrograde skarn minerals at Khao Lek. In addition, calcite veinlets were also identified and often have similar orientation to epidote-chlorite ± calcite veinlets.

5. Discussion

Field and petrographic investigations

have provided information about the type and distribution as well as the relationships of igneous and metamorphic rocks in the Khao Lek area. The intrusion of dioritic composition has thermally metamorphosed the rocks of Permian limestone which is composed predominantly of limestone intercalated with chert nodules. At the same time, it also metamorphosed the Permo-Triassic volcanics and volcaniclastic of basaltic andesite to basaltic composition to hornfelsic volcanic rocks.

Metasomatism occurred and series of rocks metamorphic zones were identified and classified based on the mineral assemblage. A systematic zonal arrangement of rock types identified from the host rocks side to the intrusion rocks are; marble, pyroxene-wollastonite skarn, pyroxene skarn, garnet-pyroxene skarn and garnet skarn and contaminated dioritic skarn (?) The occurrences of both marble and skarn near dioritic intrusion and dyke suggest a contact metamorphic origin for the high temperature marble and skarn minerals at Khao Lek. Although, there is no obvious intrusion that directly in contact with the host rocks (garnet zone) at the Khao Lek but geometry, the skarn at Khao Lek can be classified as calcic skarn based on its mineralogy. When consider in terms of ore deposits that are hosted by skarns, this deposit can be classified as skarn deposit. It is classified as iron ± copper skarn deposit according to common classification of (Einaudi and Burt, 1982) which is based on the dominant metal i.e., Cu, Au, Pb-Zn, Fe, Mo, W and Sn.

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