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MORPHOLOGY OF PYRITE AND ITS SIGNIFICANCES FROM BAWLONELAY AREA, MOGOK

Wai Yan Lai Aung[1], Thet Tin Nyunt[2], Htay Lwin[3] and Day Wa Aung[4]

Abstract

In the marble of the Mogok Metamorphic Belt from Bawlonelay area, Mogok Township, pyrites crystals exhibit a wide range of different morphologies during regional metamorphism. The pyrite crystals are commonly found as cube, octahedra and cubo-octahedra, pyritohedra and cubo-pyritohedra habits in the research area. On the basis of pyrite crystal habits, they could form under the different temperature condition which controls the speed at which the crystal grew. Moreover, these pyrite crystals are found in association with ruby in the marble from Bawlonelay. Blue corundum (sapphire) is not associated with ruby in the primary gemstone-bearing bands indicates that available Ti may have been used up in forming sphene (titanite) which is a common associated mineral in these bands. There has no more Ti available to form blue sapphire. The present study would like to consider the hypothesis is that ruby in the marble from Bawlonelay together with pyrite indicate that the original limestone contain impurities of aluminous and iron rich materials. Although there has enough alumina from the intruded igneous rocks (i.e syenite), the element, Fe, that would be formed for the formation of sapphire were already used up as the crystallization of pyrite which is found in association with ruby in the marble of Bawlonelay and no more excess Fe for the formation of sapphire.

Keywords: Mogok, Mogok Metamorphic Belt, Bawlonelay, pyrite, ruby, sapphire

Introduction

The research area is situated in the Bawlonelay area, Mogok Township, Mandalay Region. Bawlonelay mine site is situated at the west of Pingu Taung, north of Kyat Pyin. It is about 16 miles west from Mogok and GPS location is 22° 54’ 54.80” N and 96° 23’ 56.50” E. The elevation of the area is 1536 meter above sea level. The Bawlonelay area is one of the noticeable gem mine sites of Mogok (Fig. 1).

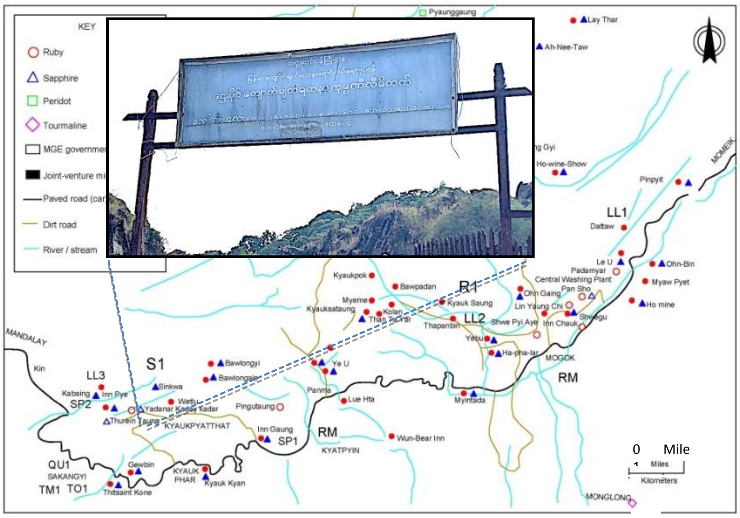

Figure 1 Location of gem mine sites from Mogok and its environs (redrawn after Kammerling *et*. *al*., 1994)

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[1] Dr, Demonstrator, Department of Geology, University of Yangon
[2] Dr, Director General, Department of Geological Survey and Mineral Exploration, Myanmar
[3] Dr, Professor, Department of Geology, University of Yangon
[4] Dr, Professor and Head, Department of Geology, University of Yangon

Pyrite is the most common iron sulphide mineral and the name come from the Greek for fire, as sparks may be struck from it (Liddell & Scott, 1940). Pyrite crystals observed Eighty-five forms (Dana, 1903) and they can exhibit a wide variety of habits; more than one hundred eighty forms (Goldschmidt, 1920). However, only three forms make up the majority of pyrite crystals; these are the cube *a* {100}, the octahedron *o* {111}, and the pentagonal dodecahedron (or pyritohedron) *e* {210} (Sunagawa, 1957), (Fig. 2). Pyrite crystallized in cubic system and forms observed include cubes, pyritohedrons, octahedrons, conglomerates, framboids, and polyframboids (Dana, 1966). However, most of them are combination of cube and octahedron, and cube and pyritohedron habits in the research area.

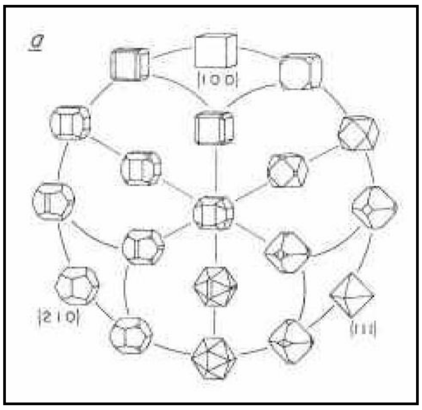


Figure 2 Common pyrite habits with forms *a* {100}, *o* {111} and *e* {211} (Sunagawa, 1957)

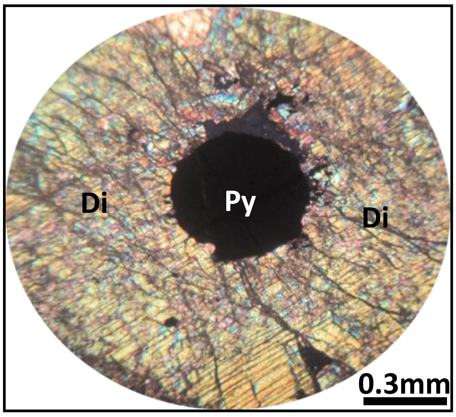


Figure 3 pyrite inclusion in diopside porphyblast in diopside marble at Bawlonelay mine (Photo Courtesy by Soe Ei Ei Myat).

The habit of pyrite varied with grain size (Sunagawa, 1957). In the range of 48 to 8 mesh (0.3 mm to 2.5 mm), the cube was dominant among the smallest grain sizes, the octahedron in the middle sizes, and the pyritohedron in the coarsest fraction. From his work at the Yanago mine, he concluded that pyrite grown with "abundant ore solution" shows a greater variety of habits within one grain-size fraction than crystals grown with a "poor supply of ore solution." Furthermore, highly altered host rock shows the greatest variety of habits and the strongest mineralization whereas the least-altered host rock contains only cubes. Amstutz and Ligasacchi (1958) and Amstutz (1963) noticed conspicuous, systematic changes in pyrite morphology from one ore zone or vein to another at Morococha, Peru. Bush *et al*. (1960) noticed the association of different pyrite habits with each of the stages of mineralization at Tintic, Utah. The lower-sulfide-content middle and late barren stages have cubic pyrite, and the sulfide-rich early productive stage has pyritohedra, implying corresponding degrees of supersaturation of the depositing solution. AmstuIz (1963) showed a simple zoning pattern of pyrite from cubes to pyritohedra with increasing copper values at Cuajone, Peru. Amstutz noted that pyritohedra occurred in mineralized monzonite and limestone whereas barren granite hosted only cubes, suggesting that pyritohedra and cubes were indicative of ore-forming and non-ore-forming conditions, respectively at Antimina, Peru. Bitcher and Bouchard *et. al*., (1968) experimentally studied the pyrite morphology. Large (5 mm) crystals of pyrite were grown by in a temperature gradient from 705 to 665°C over an unspecified distance using Cl_2 gas as the transport agent. Sunagawa (1957) and Endo's (1978) explained that larger temperature gradients produced wavy rather than straight growth fronts and some twinned crystals. Yamada et al. (1979) used Bouchard's method with temperature gradients of 700 to 630°C and 700 to 400°C over an unspecified distance and the crystals were grown by vapor transport and may not accurately reflect growth from hydrothermal solutions. Murowchick and Barnes (1987) studied experimental synthesis of hydrothermal pyrite crystals shows that temperature and degree of supersaturation are important in determining pyrite morphology. But Alonso-Azcárate, J., *et. al*., (1999a, 199b) said that there could not have been important differences in temperature between the pyrite morphologies. And In 2001, they studied the causes of variation in crystal morphology in metamorphogenic pyrite deposits of the Cameros Basin (N Spain). They said that temperature differences between pyrite deposits and As content are possible causes of the different pyrite morphologies in the deposits. They confirmed sulphur isotope data on the pyrites to investigate the degree of supersaturation.

Present work is, on the basis of pyrite crystals' morphologies, we hoped to study the effects of temperature, the degree of supersaturation and other significances of pyrite at Bawlonelay area.

Materials and Methods

To study the relation between pyrite and gem bearing rocks, some days were spent in the Bawlonelay area. Pyrite crystals were collected from the Bawlonelay mine site. Among the collected above 100 pyrite crystals, some are selected to realize the morphologies of pyrite crystals by using Gemmolite and chemical composition measured with the help of EDXRF.

Results

Connection between pyrite and gem bearing rocks

Bawlonelay mine site is one of the primary ruby mines. Ruby is extracted from marble that intruded by syenitic rocks. Pyrites are included into both ruby bearing marble and syenite. Moreover pyrite crystals are widely disseminated and can be seen easily around the outcrops (Fig. 3).

Facing 107° Facing 267° Close-up view

Figure 3 Nature of ruby bearing marble at Bawlonelay mine site (Loc. 182437)

These pyrite crystals are found in association with ruby in the marble from Bawlonelay. Blue corundum (sapphire) is not associated with ruby in the primary gemstone-bearing bands at there. Microscopically, pyrite inclusion is included in diopside porphyblast in the diopside skarn (diopside marble) from Bawlonelay, Htay Paing Mine, (Fig. 4, Photo Courtesy by Soe Ei Ei Myat).

Observed Morphologies of Pyrite

Pyrites crystals exhibit with a wide range of different morphologies during regional metamorphism. In the marble of the Mogok Metamorphic Belt from Bawlonelay area, Mogok Township, we observed 3 different habits of Isometric system and their combination forms in pyrite, generally. These are the cube ({100}), the octahedron ({111}), the pentagonal dodecahedron (or pyritohedron) ({210}) and their combination forms; cubo-octahedron and cubo-pyritohedron among common pyrite habits (Fig. 5). The colour is pale brass-yellow, tarnishes darker and iridescent. Pyrite is opaque and gives metallic lustre (Rutley, 2012).

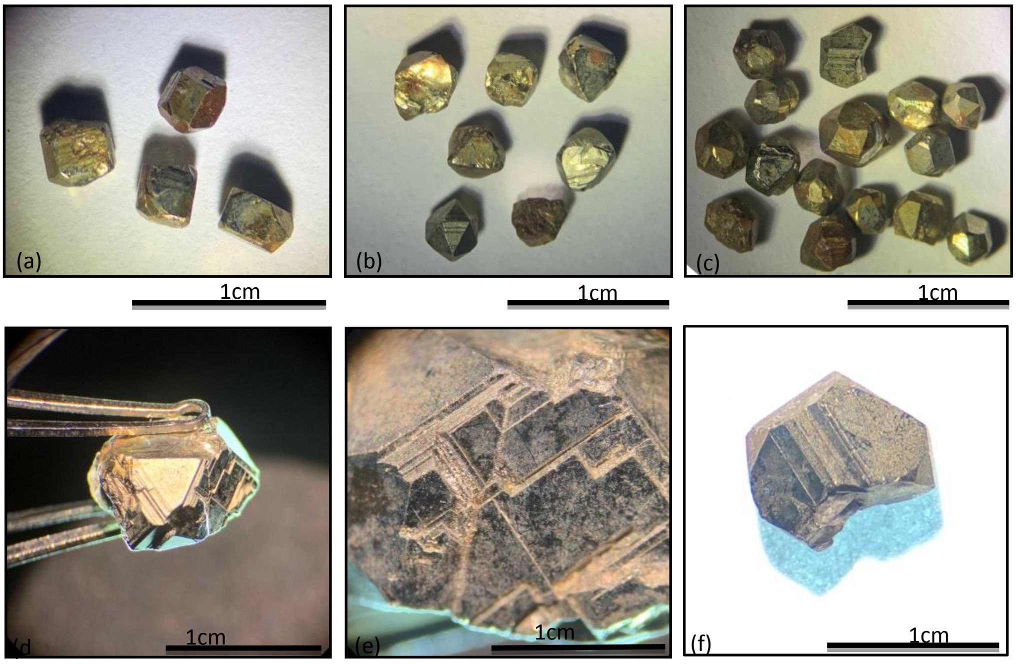


Figure 5 Characteristic pyrite habits in the Bawlonelay area.

a) cube and cubo-octahedral crystals,

b) octahedral crystals,

c) pyritohedra and cubo-pyritohedral crystals,

d) octahedral crystal with triangular facets,

e) step facets on the surface of cubo-pyritohedral crystal and

f) heavily strained twin crystal.

The cubic morphology (Fig. 5a) is frequent in nature but natural minerals are not perfectly cubic forms from the {100} family. Some are equal lengths along the a_1, a_2, a_3 directions but some crystals are elongated along one axis. The average dimension of cubic crystal is 0.3 cm × 0.2 cm and the rectangular face is 0.2 cm × 0.5 cm. Some cube has striations along the edge of the faces.

In the octahedral morphology (Fig. 5b) there are 8 facets from the {111} family. There are striations on plane triangles {111} (Fig. 5d), such as in the cubic case. Average size of octahedral crystal is 0.5 cm and some are distorted.

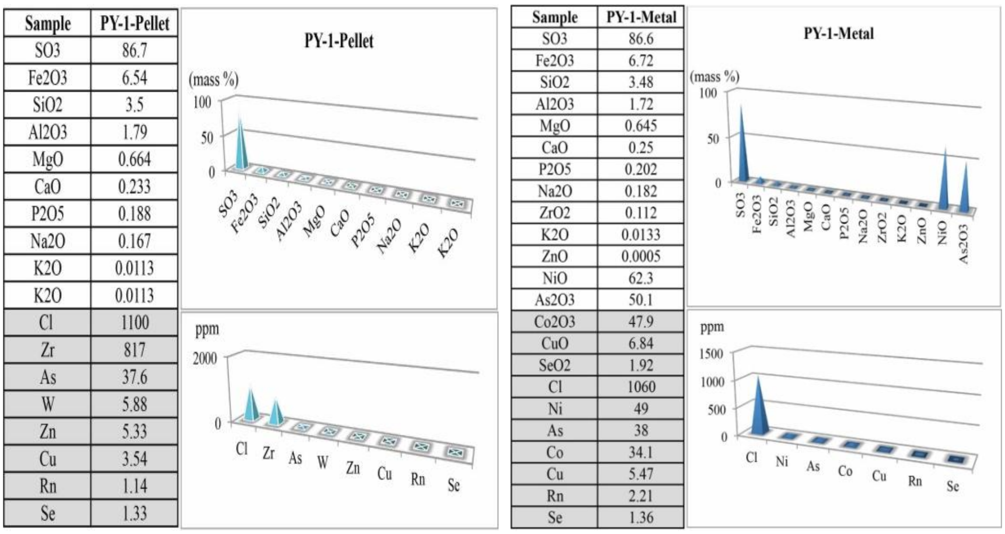
In the pyritohedral pyrite crystals (Fig. 5c) from the {210} family, some have striations on surface (Fig. 5d, 5e) and the crystals' sizes are around 0.5 cm.

Other forms of pyrite can be observed as combination forms of these facets with truncated corners (such as truncated cube, truncated octahedron, truncated dodecahedron) and twin crystals (Fig. 5f).

Analytical Data

The collected pyrite crystals were analysed to determine their composition by EDXRF and the results indicate that some are pyrite and other are arsenopyrite.

Table 1 Compositional variation of pyrite crystal from the study area



Sample	PY-1-Pellet
SO3	86.7
Fe2O3	6.54
SiO2	3.5
Al2O3	1.79
MgO	0.664
CaO	0.233
P2O5	0.188
Na2O	0.167
K2O	0.0113
K2O	0.0113
Cl	1100
Zr	817
As	37.6
W	5.88
Zn	5.33
Cu	3.54
Rn	1.14
Se	1.33

Sample	PY-1-Metal
SO3	86.6
Fe2O3	6.72
SiO2	3.48
Al2O3	1.72
MgO	0.645
CaO	0.25
P2O5	0.202
Na2O	0.182
ZrO2	0.112
K2O	0.0133
ZnO	0.0005
NiO	62.3
As2O3	50.1
Co2O3	47.9
CuO	6.84
SeO2	1.92
Cl	1060
Ni	49
As	38
Co	34.1
Cu	5.47
Rn	2.21
Se	1.36

Discussion

Pyrite morphology and growth mechanism

Possible controls of the habit of pyrite include mechanisms of its crystal growth (Sunagawa, 1957). According to Murowchick and Barnes (1987), morphological differences in pyrites are related to the differences in physiochemical conditions (mainly, supersaturation and/or temperature). They grew pyrite crystals under controlled conditions in the laboratory, in the temperature range between 250 and 500°C. Increasing growth temperature or supersaturation would lead to a change from surface-controlled growth to diffusion-controlled growth (Fig. 6). This change in the growth mechanism would be caused by different crystals morphologies. They found that temperatures around 250°C and low degrees of supersaturation produce needle-like pyrite crystals. An increase in the degree of supersaturation leads to the development of cubes with perfectly smooths *a* {100} and small *o* {111} faces. Higher temperatures (around 450°) and low degrees of supersaturation produce large striated cubes with small octahedral faces. The combination of high temperature and high supersaturation levels leads to the formation of heavily striated cubes with or without octahedral faces. Finally, crystals grown under the very high supersaturation levels achieved in quenching exhibit morphologies ranging from pyritohedral to blocky crystals to skeletal octahedral and dendrites. Murowchick and Barnes (1987) considered that all the morphologies, except those relating to crystals formed during quenching, are the result of surface-controlled growth. Crystals formed during quenching show a sequence of morphologies (octahedral, skeletal octahedral, dendrites and fine-grained pyrite) that indicated the gradual transition from two-dimensional nucleation-controlled growth (surface-controlled growth) to continuous growth (diffusion-controlled growth).

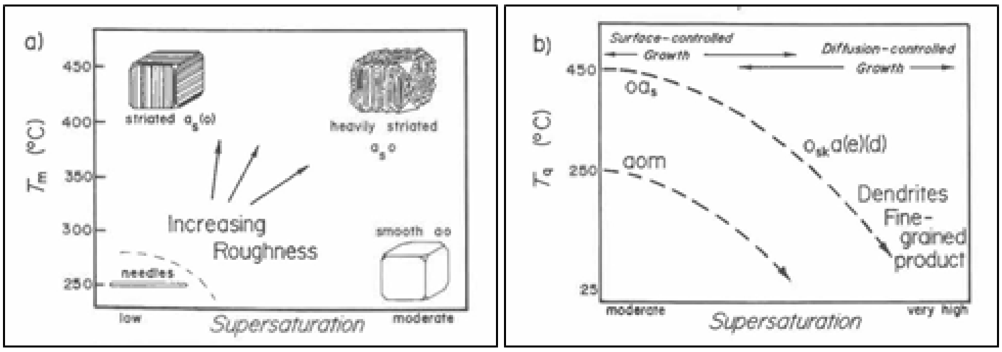


Figure 6 Morphologies of hydrothermally grown pyrite (after Murowchick and Barnes, 1987).

a) Habits produced during steady-state conditions. T_m is the mean run temperature. The degree of supersaturation is known only approximately for this system.

b) Typical temperature vs. supersaturation paths (heavy dashed lines) and habits produced during quenching. T_q is the temperature at the beginning of the quench. Crystal forms are given in decreasing order of development using the letters a = {100}, o = {111}, e = {210}, m = {311}, and d = {110}. Subscripts s and sk indicate the associated forms are striated or skeletal, respectively, and parentheses indicate minor development of the form or fearute.

On the other hand, Alonso-Azcárate, J., *et. al*., 2001 also showed the different pyrite habits and their possible relationship with crystal growth mechanism and degree of supersaturation (Fig. 7). They assumed that pyrite deposits originated during anchizone-epizone hydrothermal metamorphism. There is little variation in metamorphic conditions prevalent at the different deposits. Thus they concluded that temperature has not been an important factor in directly controlling the growth mechanism.

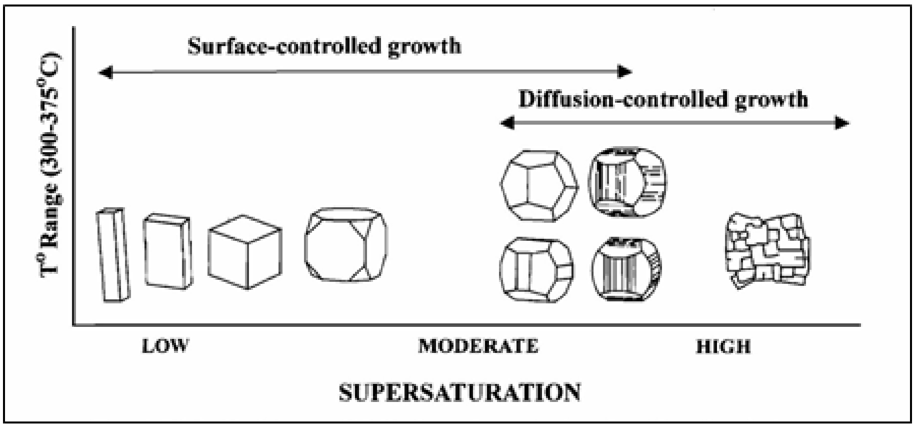


Figure 7 Relationships between pyrite habits, degree of supersaturation and crystal growth mechanism (Alonso-Azcárate, J., *et. al*., 2001)

From the authors' point of view, the existence of a certain mineral is related to their environment. In the Bawlonelay area, Pyrite is associated with gem minerals, ruby. Ruby-bearing marbles formed in the amphibolite facies (T=610 to 790 °C and P~6 kbar) (Winkler, 2013). Thus we considered the following conceptual model (Fig. 8) by using Murowchick and Barnes, 1987's experimental method with temperature gradients. These factors control the speed at which the crystals grew. At low temperature and slow growth rate, pyrite crystals are formed as the rod shaped and needle-like crystals. When the temperature is upper and/or supersaturation is increased, pyrite is formed as smooth cubes. The more cube striated, the greater supersaturation. If the temperature and/or supersaturation are higher, octahedrons and then pyritohedrons are formed. Larger temperature gradients produced wavy rather than straight growth fronts and some twinned crystals (Yamada *et al*. 1979). At the highest degrees of superstauration, crystal growth is very fast and odd dendritic clumps of pyrite.

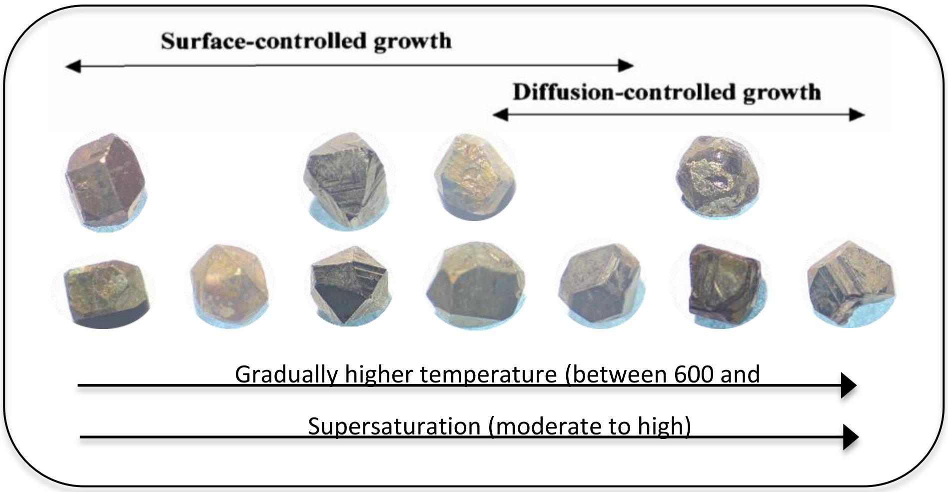


Figure 8 Relationships between pyrite habits and temperature variation at Bawlonelay area.

Possible conceptual factors on pyrite chemistry

Pyrite (FeS_2) is associated with corundum, especially ruby in Bawlonelay mine. Corundum is a crystalline form of aluminium oxide (Al_2O_3) typically containing traces of iron (Fe), titanium (Ti), vanadium (V) and chromium (Cr). The red (Cr-bearing) gem variety is called Ruby and the blue (Fe- and Ti-bearing) gem variety is called Sapphire (Anthony, 1997). These elements are special conditions and controlling factors of gemstones formation. Excess alumina from the syenitic intrusions may have formed ruby and sapphire in the skarns. Blue corundum (sapphire) is not associated with ruby in the primary gemstone-bearing marble bands indicates that available Ti may have been used up in forming sphene (titanite) which is a common associated mineral in these bands. There has no more Ti available to form blue sapphire (Maung Thein, 2008). In the Bawlonelay area, Pyrite is associated with gem minerals, ruby. This fact also indicates that the original limestone contain impurities of aluminous and iron rich materials. The element, Fe, is already used up in pyrite crystallization, so there is no more Fe and Ti to form sapphire in the research area.

Summary

Pyrite commonly forms cubes, octahedrons, pyritohedrons and some combinations of these forms in Bawlonelay area. All pyrite is FeS_2 with the same internal arrangement of iron and sulphur atoms. On the basis of pyrite crystal habits, they could form under the different temperature condition that controls the speed at which the crystal grew. The existence of a certain mineral is related to their environment. The present study would like to consider the hypothesis is that ruby in the marble from Bawlonelay together with pyrite indicate that the original limestone contain impurities of aluminous and iron rich materials. In addition, there has enough alumina from the intruded igneous rocks (i.e syenite), the element, Fe, that would be formed for the formation of sapphire were already used up as the crystallization of pyrite which is found in association with ruby in the marble of Bawlonelay. Further studies will focus on chemical analysis and hope to find detailed petrogenesis on individual different pyrite shapes.

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