Microstructure of pyrite related to gold deposit, Huai Yuak area, Sukhothai Province, Northern Thailand

L Tangwattananukul
Department of Earth Sciences, Faculty of Science, Kasetsart University, Bangkok, Thailand 10900, Thailand
E-mail: fscildt@ku.ac.th

Abstract. Huai Yuak area is located at Ban Kaeng Subdistrict, Sisatchanalai District, Sukhothai Province, Northern Thailand. The occurrences of gold are distributed along the Sukhothai Fold Belt from Phrae to Lampang though Sukhothai provinces. The Huai Yuak area is a one of the primary gold deposits in the Sukhothai Fold Belt. The geology of the Huai Yuak area is comprised of siltstone, sandstone, shale and tuff from the Permian to Triassic age. Quartz veins of the deposit were formed in siltstone, sandstone and shale. Based on the cross-cutting relationship and mineral assemblages, the quartz veins can be divided into three stages. Quartz veins of stage I are composed of a large amount of microcrystalline quartz with a minor amount of arsenopyrite and a trace amount of calcite, illite, pyrite, chalcopyrite, galena and electrum. Quartz veins of stage II consist of mainly quartz. Quartz veins of stage III are comprised of a large amount of dolomite and a small amount of quartz with a trace amount of illite and arsenopyrite. Electrum is associated with arsenopyrite, galena, pyrite, chalcopyrite and sphalerite. The electrum was formed as inclusion and filled in fractures of arsenopyrite and pyrite. Based on structure, texture and occurrence, pyrite and arsenopyrite can be classified into four types. Type 1 pyrite and arsenopyrite were disseminated in sandstone, siltstone and shale. Type 1 is characterized by euhedral to subhedral shape with size ranging from 0.1 to 3.0 mm. Type 2 pyrite and arsenopyrite were formed in a fracture as veins in shale and metashale. Type 3 pyrite and arsenopyrite occur in quartz veins. Type 3 is associated with galena, chalcopyrite, sphalerite and electrum. The electrum in Type 3 at Huai Yuak deposit was formed as inclusions and native gold associated with pyrite, arsenopyrite, chalcopyrite, galena, sphalerite and quartz of stage III. The concentration of electrum is related to arsenic content in pyrite. Type 4 of pyrite and arsenopyrite was formed in shale rock. Pyrite and arsenopyrite gains at the Huai Yuak gold deposit have had developed under a different structure and physical condition from uplift during volcanic arc setting.
1. Introduction

Several types of gold deposits occur and distribute along the volcanic belts in Thailand such as the epithermal gold deposit in Chatree mining area, Puthep copper-gold skarn deposit in Loei area, Phu Thap Fah gold skarn deposit in Nong Khai area which was formed in Loei-Phetchabun Fold Belt [1-4]. On the other hand, the gold deposits were distributed in the Sukhothai volcanic belt such as Huai Kham On gold deposit and Huai Yuak gold deposit [5,6] (figure 1A). The Huai Yuak deposit is one of gold deposits which are located in Sukhothai Province in the Southern part of the Sukhothai Fold belt, which is extended from Lincang (South of China) through Lamprang and Sukhothai in Thailand (figure 1A). The area is located among Ban Pa Kha, Ban Huai Yuak and Ban Kaeng Subdistricts in Sisatchanai District, Sukhothai Province and covered approximately 16 square kilometers. The aim of the study to understand the occurrence of gold related to sulfide minerals in veins and rocks.

2. Geology

The Huai Yuak area is located in the Sukhothai volcanic belt in the metallogenic mineral from Lamprang to Phrae though Sukhothai provinces (figure 1A) [3,7-9]. Geology of the Huai Yuak area is comprised of shale from the Permian to Triassic age (figure 1B) [8]. The Permian sedimentary rocks are unconformably overlain by Permian-Triassic volcanic rock. The sedimentary rocks were metamorphosed to phyllitic shale. The major structures of fault and fracture are NNE-SSW direction. Various sizes of veins occur along with the major structure in a NE-SW direction with steeply dipping to the west direction (figure 1B). The length of veins ranges from 25 to 150 meters and width ranging from 1 to 3 meters. The veins were formed in siltstone, sandstone and shale of Permo-Triassic age.

![Figure 1](image-url)  
**Figure 1.** (A) Distribution of gold deposits in Thailand such as Loei-Phetchabun and Sukhothai volcanic belts [7,8]. (B) The geology of the Huai Yuak area consists of shale and veins [8].

3. Methodology

Thirty samples of veins and rocks were collected from drilling holes in Ban Kaeng Subdistrict, Sisatchanai District, Sukhothai Province (figure 1B). All the samples were polished and conducted using a scanning electron microscopy analysis (SEM: FEI Quanta 450) at Faculty of Science, Kasetsart University and electron microprobe analyse (EPMA: JEOL JXA-810) at Department of Geology, Chulalongkorn University, Thailand. Operation condition was an acceleration voltage of 20 kV, a beam current of 20 nA and a beam diameter of 5 µm. The standards used for calibration were Pd/Au alloy for Au, CuFeS2 for Fe, Cu and S, and FeAsS and PbS for As and Pb, respectively.
4. Results

4.1. Mode of gold-bearing quartz vein in the Huai Yuak deposit

Veins in the Huai Yuak deposit are hosted in shale, sandstone and phyllite which are formed northeast-southwest direction (figure 1B). These veins are characterized of veins and brecciated veins. On the basis of the cross-cutting relationship, structure, texture and mineral assemblage, it can be divided veins into three stages such as the veins of Stage I are composed of a large amount of microcrystalline quartz with a minor amount of arsenopyrite and a trace amount of calcite, illite, pyrite, chalcopyrite, galena and electrum (table 1). Veins of Stage II consist of main quartz with a trace amount of calcite and pyrite. Veins of Stage III are comprised of a large amount of dolomite and a small amount of quartz with a trace amount of illite and arsenopyrite and electrum. The electrum was formed as inclusion in arsenopyrite and pyrite and associated with galena and sphalerite (figures 2 and 3). The electrum in the Huai Yuak gold deposit is a naturally occurring alloy of gold (80-90%) and silver (10-20%) without copper and other metals.

![Figure 2](image)

**Figure 2.** (A) Shale consists of Type 1 pyrite. (B) Microphotograph of Type 2 pyrite in shale. (C) The gold bearing-quartz veins of Stage I consists of pyrite and arsenopyrite of Type 3. (D) Microphotograph of arsenopyrite, pyrite and electrum of Type 3 formed in Stage 1 vein.

4.2. Occurrence of electrum related to pyrite and arsenopyrite

Pyrite and arsenopyrite minerals were formed in host rocks and veins of the three stages (figure 2). The pyrite and arsenopyrite can be classified into four types based on the structure, texture, shape and occurrence. Types 1, 2 and 4 of pyrite and arsenopyrite were formed in shale and sandstone rocks, while Type 3 of pyrite and arsenopyrite was formed in the veins. Type 1 of pyrite and arsenopyrite were formed in shale and sandstone which are characterized by subhedral to euhedral of cubic shape with size ranging from 0.10 to 3.00 mm in diameter (figure 3A). Type 2 of pyrite and arsenopyrite were formed in a fracture of shale and metashale which are characterized by anhedral to subhedral with size ranging from 200µm to 1.0 mm in diameter and forming accumulated with fine-grained galena and chalcopyrite (figures 3B and C). Type 3 of pyrite and arsenopyrite were formed in quartz veins that are associated with quartz, calcite, galena, chalcopyrite and sphalerite (table 1). The electrum in Type 3 was formed...
in a fracture (figure 3D) and inclusion of arsenopyrite (figure 3E). The characteristics of arsenopyrite display dark lines within the grain represented small mineral inclusion trapped at a different stage of pyrite and arsenopyrite growth (figure 3E). The grain has grown with broadly concentric zones with the final outer crystal shape somewhat different from the earlier stages (figure 3E). Type 4 of pyrite and arsenopyrite occur only in shale rocks that are very fine-grained (size average 10 µm), accumulated with sphalerite and chalcopryite (figure 3F). The pyrite mainly forms spherical clusters of grains called framboids with each cluster made up of hundreds of micro-size crystals (figure 3F).

**Table 1.** Minerals assemblage in the gold-bearing quartz veins of Huai Yuak gold deposit.

| Minerals      | Stage I | Stage II | Stage III |
|---------------|---------|----------|-----------|
| Quartz        |         |          |           |
| Calcite       |         |          |           |
| Iillite       |         |          |           |
| Dolomite      |         |          |           |
| Pyrite        |         |          |           |
| Arsenopyrite  |         |          |           |
| Chalcopryite  |         |          |           |
| Galena        |         |          |           |
| Electrum      |         |          |           |

---

**5. Discussion**

Gold accompanied several stages of pyrite growth in various occurrences as separated gold grains (figure 3D), invisible gold in the crystal structure of the pyrite and arsenopyrite and visible gold as inclusion in pyrite and arsenopyrite (figure 3E). The gold was formed in evidence of multiple growth generation of pyrite with different concentrations of arsenic. The concentration of arsenic is related to the concentration of gold in pyrite grain (figures 4 and 5). The amount of sulphur, iron, copper, lead, arsenic and gold can be determined by electron microprobe analysis (figures 4 and 5). On the other hand, Type 4 of pyrite and arsenopyrite (figure 3F) display framboids in micro-size crystals that are enriched of arsenic in the framboids and also copper, lead and zinc.

**6. Conclusion**

The vein in the Huai Yuak deposit can be separated into three stages. Stage III vein is high gold content and consists of quartz-dolomite-arsenopyrite-pyrite. Pyrite and arsenopyrite formed in shale, sandstone rocks are Types 1, 2 and 4, while Type 3 was formed in the vein. Type 3 of pyrite and arsenopyrite is the high content of gold. On the other hand, Types 1, 2 and 4 of pyrite and arsenopyrite are low of gold contents.
Figure 3. Scanning electron microprobe images of pyrite and arsenopyrite grains from four types. (A) Pyrite grain from Type 1 in shale. (B) and (C) Type 2 of pyrite and arsenopyrite coexist with galena in shale. (D) Type 3 of pyrite and arsenopyrite in the vein related to electrum. (E) The electrum occurs as inclusion in arsenopyrite of Type 3. (F) Type 4 of fine-grained pyrite and arsenopyrite are shown accumulation and flamboyant textures in shale rock. (el: electrum; asp: arsenopyrite; py: pyrite; ccp: chalcopyrite; gl: galena).

Figure 4. Electron microprobe analyses image from Type 1 pyrite. The pyrite shows high concentrations (pink color) of iron and sulphur with a small amount of copper (blue color) and poor of gold, arsenic and lead.
Figure 5. EPMA image of Type 3 pyrite. Arsenopyrite shows high concentration (pink color) of iron and sulphur (green color) with a large amount of arsenic (orange color) and a small amount of gold (blue color) with poor of copper and lead.

Acknowledgements
The authors are grateful for the financial support provided by Thailand Research Fund (TRF). The authors also wish to thank the Faculty of Sciences at the Kasetsart University for financial support. The authors are also grateful to the Department of Mineral Resources in Thailand for support in the collection of drill-core samples. Special thanks are due to Chadayu Kerdsuwan and Aprisara Semapongpan for helping by collecting samples and data analysis.

References
[1] Tangwattananukul L, Ishiyama D, Matsubaya O, Mizuta T, Charusiri P, Sato H and Sera K 2014 Res. Geo. 64 167–81
[2] Salam A, Khin Zaw, Meffre S, McPhie J and Chun-Kit L 2014 Gond. Res. 26 198–217
[3] Khin Zaw, Meffre S, Lai C, Burrett C, Santosh M, Graham I, Manaka T, Salam A, Kamvong T and Cromie P 2014 Gond. Res. 26 5–30
[4] Tangwattananukul L and Ishiyama D 2018 Res. Geo. 68 83–92
[5] Khositanont S, Khin Zaw and Ounchanum P 2007 Adv. Geosci. 13 1–12
[6] Arunsrisanchai W and Potisat S 1992 Conf. on Geologic Resources of Thailand. Potential for Future Development (Bangkok: Department of Mineral Resources) 107–10
[7] Michael J C and Khin Zaw 2011 The Geology of Thailand ed M F Ridd, A J Barber and M J Crow (London: The Geology Society) chapter 17 459–92
[8] Jenrungroj P 1995 Proc. Int. Conf. on Geology, Geotechnology and Mineral Resources of Indochina (Khon Kaen: Department of Geotechnology, Khon Kaen University) 179–86
[9] Potisat S 1992 Proc. National Conf. on Geologic Resources of Thailand: Potential for Future Development (Bangkok: Department of Mineral Resources) 420–33