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LE THI THU

CHARACTERISTICS OF SEDIMENT-HOSTED COPPER IN BIEN DONG-QUY SON

MAJOR**: GEOLOGICAL ENGINEERING**
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PUBLICATION

The PhD student has 04 prestigious works published in journals and specialized scientific seminars. Chaired 02 scientific research projects at ministerial level. The content of the works is related to the research field of the thesis.

1. Le Thi Thu, Do Van Nhuan, Hoang Thi Thoa, Characteristics of mineral composition, structure and architecture of copper ore in Quy Son Dong Dong strip, Mining Industry Magazine, No. 5, 2018.

2. Le Thi Thu, Do Van Nhuan, Hoang Thi Thoa (December 7, 2018), Characteristics of material composition and physical and chemical conditions to form copper ore in Bien Dong - Quy Son in An Chau basin, General Conference National Earth Science and Resources with Sustainable Development.

3. Le Thi Thu, Do Van Nhuan, Nguyen Kim Long, (2018) Structural feature of some copper mines in Bien Dong-Quy Son strip of An Chau structural zone, Vol.59, Issue 3.

4. Tran Anh Ngoan, Le Thi Thu, Hoang Thi Thoa, Multi-metallic mineralization related to surrounding rocks and hydrothermal change in Northeast Vietnam, Journal of Mining and Geology Science, No. 21, page 44- 48 January 2008.

5. Chair of ministry-level science and technology topic, code B2006-02-06. Research on Mineral composition, structure of ore architecture to establish standard atlate set of multi-metal ore facies in the Northeast of Vietnam, which was tested and accepted in 2008.

6. Leading ministry-level science and technology project, code B2016-MDA-05ĐT, Study on conditions for forming copper ore in An Chau basin, Northeast of Vietnam, and accepted in 2018.

INTRODUCTION

1. Overview

Copper is a typical metal using in many fields such as the production of electrical wires, electrical equipment, tools in human life ... Copper ore is present in many places in the world, but the most important place is the Americas, the annual copper mined on this continent (in 2009 it was 8,960,000 tons) using about 50% of the worldwide copper mining (15,757,800 tons).

According to the results of previous research, copper ore is often concentrated in the types of mines originating such as porphyritic copper, magmatic magma, carbonatite, skarn, erupting hydrothermal, stratigraphic mines ... Among mine types above, Porphyr copper mines often have large scale and reserves, typical mine of this type is the Kounrat mine in Kazacstan ...

In Vietnam, during the geological mapping process, scientists have discovered a number of copper mines with high industrial value, which have been exploited, such as Sin Quyen copper mine, Ban Phuc copper nickel mine, Suoi Chat copper mine, copper mines in An Chau basin ... Among copper mines above, in particular copper formations were distributed in the sediments of An Chau basin in general and Bien Dong - Quy Son region has been discovered for a long time and currently these copper mines are being exploited. However, research on origin, forming conditions, distribution rules, and factors control orezation that are not conducted and invested fully.

Nowadays, more and more technology applies on research and focus on the nature, the above-mentioned problems will be proved by the PhD student with their latest research results. That is the main reason to choose the thesis topic titled "Characteristics of copper orezation in Bien Dong – Quy Son area".

2. Objective

To elucidate geological characteristics, ore material composition, surrounding rock changes and physical and chemical conditions of the ore forming solution. From these, determine origin and forming conditions of copper ore in sedimentary formations in Bien Dong - Quy Son region.

3. Research subject : The object of the study is copper ore and related geological formations in the Dong Dong - Quy Son region.

4. Research scope: The study area was located in the East - Southeast of An Chau basin, in two districts of Luc Ngan and Son Dong, Bac Giang province

5. Research accountability

- Research on geological structure of Dong Dong - Quy Son region.
- Research on characteristics of material components: mineral composition, lower secondary school, structure and architecture of ore; chemical composition of copper ore and associated useful component combinations.
- Research on formation conditions: studying geological and chemical-physical conditions to form copper ores.
- Research on factors that control copper ore: study on stratigraphic factors that control copper ore; research on structural tectonic factors that control copper ore; study of hydrothermal change rocks surrounding copper ores.
- To establish type of origin and the copper ore creation process in the study area.
- To establish premise and search-forecast signs.

6. Research methodology

* Methods of collecting, analyzing, comparing and synthesizing documents

* Combination of field research methods:

- Surveying and determining the positions of ore bodies in the main geological cross sections passing through the mines;
- Determination of the composition of rocks surrounding the ore;
- Determine tectonic conditions that control the position of the ore body;
- Determine the morphology, size and composition of ore bodies, etc.
- Collect samples at the site, exposed as well as core samples.

* Combination of research methods in the room:

- General mineral analysis method;
- Laminate analysis method;
- Analytical methods of plasma spectroscopy (ICP, ICP-MS);
- Analysis methods of scanning electron microscopy (SEM);
- S, O, C isotopic analysis methods;
- Analyzing methods of the temperature of homogenization;

- Cold test method to determine the level of salt in the bag;

-Raman spectroscopic method to determine the body composition;

Methods of data synthesis, processing, comparison and interpretation;

7. Scientific and industrial significance

Scientific significance: The study results have clarified the origins and forming conditions for the copper mineralisation in the Bien Dong - Quy Son area that is the hydrothermal mineralisation style formed at medium-low T. This is an important study result contributing to the geological science data set and the geological training at the University of Mining and Geology.

Industrial significance: The study results have generated important contributions to the investigation and exploration strategies for similar copper mineralisation styles in Dong Dong - Quy Son area as well as in surrounding areas.

8. Proposes

1. The copper mineralisation in Dong Dong - Quy Son area is hydrothermal mineralisation hosted in sedimentary rocks, with the ore mineral assemblage of tetrahedrite - tennantite - chalcocite - bornite - chalcopyrite formed at medium-low temperature (T).

2. The copper mineralisation mainly occurred in the NE-SW deformational structures, and is constrained by (1) the arc-shaped sub-north trending and NE-SW faults that is the fluid pathways and traps to the copper mineralization and (2) the continental carbonate-bearing sediments of the middle-upper Mau Son Formation

9. Findings

- The medium-low T copper mineralization was formed from a mixture of fluids sourced from magma, marine carbonate-bearing sediments and groundwater.

- The hydrothermal mineralisation was divided into three stages, in which the copper mineral assemblage (i.e. tetrahedrite - tennantite - chalcocite - bornite -chalcopyrite) is formed in the middle stage (stage 2).

- Better understanding of geological and structural settings and sedimentary facies in the study area.

- The hydrothermal alteration associated with the copper mineralisation includes dolomitization, silicification and chloritization.

- The data sets of P-T conditions, fluid inclusion composition from quartz and stable isotopic composition of S, O and C.

10. Data

The thesis is built on the basis of references in the work of measuring and drawing geological maps at scale 1: 200,000, Lang Son by Doan Ky Thuy and the authors of geological mission number 20G in 1976. The Geological map of Thanh Moi, scale 1: 50,000, made by the authors of the Institute of Geosciences and Minerals in 1997. The documents searching and exploring copper ore in the study area since 1960.

The documents surveyed by PhD student and colleagues to implement science and technology project, code B2016MDA-05ĐT, entitled "Research on the formation conditions of copper ore in An Chau basin, northeast of Vietnam", is chaired by PhD student, implemented in 2016 - 2017. In addition, the thesis also references other domestic and foreign research works.

11. The structure

In addition to the introduction, conclusion and references, the thesis includes 5 chapters with 132 pages, 18 tables and 57 figures, images.

12. Place of thesis implementation

The thesis was completed at the Department of Search and Exploration, Faculty of Geosciences and Engineering, University of Mining and Geology under the scientific guidance of Dr. Do Van Nhuan and Dr. Tran Ngoc Thai. The author would like to express his deep gratitude to the instructors who have been enthusiastic and closely instructed during the time of studying and constructing the thesis.

During the implementation of the thesis, the author has received favorable attention from teachers in the Department of Exploration Search and Exploration and many comments from other scientists and colleagues. The author would like to thank deeply.

The author sincerely thanks the support and assistance of the Board of Directors of University of Mining and Geology, Department of Postgraduate Training, Department of Geology Science and Engineering Department; Former Department of Minerals and Department of Search and Exploration during the author's dissertation.

The author would like to thank family and relatives who have always encouraged, helped, and motivated the author to complete the thesis.

Chapter 1: GEOLOGICAL STRUCTURAL CHARACTERISTICS IN BIEN DONG-QUY SON

1.1. Location of the study area

Bien Dong - Quy Son has main area to belong to An Chau basin and dominated by tectonic activities that related to the formation and development of this basin. Currently, most geologists in Vietnam believe that the An Chau basin is a continental rift basin.

1.2. Studying history of geology and minerals

Copper mineralization in study area is known before the August Revolution in 1945. In 1955 - 1956 Soviet experts carried out surveys and measurements at the scale of 1: 2.000; 1: 1.000 Bien Dong, Lan, Giao Liem mines. In 1959, Vietnamese geologists and Chinese experts conducted, investigated and assessed of the South China Sea area. In 1960-1961, the 105 delegation combined with Czechoslovak experts conducted exploration and detailed search for a number of mines and ore points. Geological mapping and mineral searching and searching work of Thanh Moi group in 1997 conducted a detailed investigation of ore points in the area ...

Regarding the origin, the studies show different perspectives and research levels:

- In the 60s of the last century, researchers from the Soviet Union, China and Vietnam believed that the Dong Dong copper ore originated from sediments called "copper sandstone";

- In 1976, in the geological mapping project at the scale of 1 / 200,000 sheets of Lang Son, Doan Ky Thuy said that the copper ore here has medium - low temperature hydrothermal origin;

- In 2013, Tran Binh Chu indicated copper ore in Bien Dong - Quy Son region belonged to type of layer mine or copper in sandstone (Textbook Geology of industrial metal mines).

In summary, the history of regional geological research showed that: The geological structure of the area has been studied in relatively detailed and reliable enough to build the thesis. However, the structural factors that control the mineralization as well as the characteristics of sedimentary formations containing copper ore in the region have not been clarified. Research results on the origin and forming conditions of copper ore lacked data, so there are still different perspectives. There is also an opinion that copper ore in the study area is from medium - low temperature hydrothermal (Doan Ky Thuy et al, 1976), but has not given the

documents and data to support the claim. These are important issues that the thesis needs to focus on to clarify.

1.3. Bien Đong-Quy Son geological structure

1.3.1. Stratigraphic overview

In the study area, the stratigraphy consists of: Tan Mai (O_3 - S_2*tm*), Mia Le (D_1*ml*), Ho Tam Hoa ($D_{2\text{-}3}$*th*), Bac Son (C_{1V}-P_2*bs*), Dong Dang (P_{3c} *đđ*), Lang Son (T_{1i} *ls*), Binh Lieu (T_2a*bl*$_2$), Khon Lang (T_{2a} *kl*), Na Khuat (T_2*nk*), Mau Son (T_3c*ms*), Van Lang (T_3n-r*vl*), Ha Coi ($J_{1\text{-}2}$*hc*), Ban Hang (K_1*bh*).

1.3.2. Intrusive magma overview

In the study area, no intrusive magma appearance was observed, however intrusive magma manifestations around the study area were recorded including Triassic Infiltration between Nui Dieng Complex γT2nđ (Nguyen Kinh Quoc, 1969) and Pia Oắc Complex (γK2 po). However, the research results showed that these intrusive magma complexes do not have copper mineralization specialization.

1.3.3. Structural and tectonic characteristics

1.3.3.1 Structural and tectonic units

Bien Dong – Quy Son region is located in the eastern and northeastern of the An Chau rift and bordering with early North East Paleozoic continental mountain belt and Quang Ninh moat. Therefore, the process of formation and geological development of the region is associated with the formation and development of the An Chau interior rift and influenced by tectonic activities in the early Paleozoic continental mountain belt Northeastern North and Quang Ninh moat.

The boundary between An Chau rift and northeastern inland mountain-forming belt in Bien Dong - Quy Son region is the Song Thuong fault zone (F1) in the northwest; the boundary between An Chau rift and Quang Ninh moat in Yen Tu - Tan Mai fault zone (F7) in the south.

structure - tectonic map (drawing No. 2) shows that 03 areas are separated by 02 fault zones F1, F7 into different geological structures. Therefore, the study area is possible to divide into 03 structural blocks; they are Chi Lang structural block, Bien Dong - Quy Son structural block and Luc Son - Tan Dan structural block.

1.3.3.2 The jelly-tectonic combinations

According to Tran Van Tri et al (2009, 2015), formations in the Dong Dong - Quy Son region are classified into the following fossil-tectonic complexes:

- TH - Children with disabilities like aulacogen Cambri - Silur

- TH - Children with disabilities in the passive subcontinent Devon - Permi

- TH-TKT rift Inner Permian Late-Triassic

- TH - TKT molas of Late Triassic-Early Kreta continent

1.3.3.3. Tectonic deformation characteristics

Folding: In the study area, the developmental folds are quite plentiful, they play an important role in the control and habitat of the orezation.

Faults: Based on the researched results, it is possible to divide the fault systems in the region into three main systems such as arc fracture system; Northwest - Southeast fault system; The system of meridional rupture. Three fault systems above, the arc fault system is the largest fault system. It was the longest history of development, controled process of formation and developed structural blocks as well as copper orezation chemical process in the study area

1.3.4. Minerals

In general results of geological - mineral investigation and mineral searche up to now shows that the research area has relatively rich and diverse mineral resources such as iron, copper, lead – zinc, gold, mercury, barite, oil…

Chapter 2: RATIONALE AND METHODOLOGIES

2.1. Geochemistry and mineralogy characteristics of copper

Copper has number 29 in Mendeleev's Periodic table, atomic weight 63.54. Copper has 2 isotopes 63 and 65. Clark's value for copper is 4.7x10-3. Copper content in ultramafic rock is 2.10-3%, in mafic rock is 1.10-2%, in neutral rock is 3.5.10-2%, in acid rock is 2.10-3%.

Mineralogy characteristics of copper: Currently over 240 copper minerals have been identified. Among them, copper minerals are suitable for industry such as native copper; Chalcopyrite; Bornit; Cubanit; Chalcozin; Covellit; Tennantit; Tetrahedrit; Enacgit; Cuprit; Domeykit; Tenorit; Malachit; Azurit; Chrysocolla.

2.2. Classification of copper mine the world and in Vietnam

The copper mines in the world are very diverse, they belong to different groups of origin. Among the industrial mines of copper are divided into: magma mine, carbonatite mine, skarn mine, plutonite (porphyritic copper), konchedan mine, stratiform mine (copper shale and sandstone). These types of mines have very unequal economic values.

Specifically, porphyr copper deposits account for 65-70% of the world's confirmed reserves, copper shale and sandstone accounts for 15-20%; konchedan mines account for 5-8%, Cu-Ni sulfide mines account for 2-2.5%, skarn mines account for 2-4%, carbonatite mines account for 0.5-0.75.

- Copper mine types in Vietnam: So far, the research results have been found some copper mine in the territory of Vietnam such as Cu - Ni mines of magma origin; type of hydrothermal copper mine; copper Konchedan mine type; copper - quartz mine type; the type of sandstone deposit and copper shale

2.3. Methodologies

In order to carry out this research, PhD student used the methods such as methods of collecting, analyzing, comparing and synthesizing documents; Method of ore survey and analysis; General mineral method; Thin-slice lithology method; Method of scanning electron microscopy (SEM); ICP-MS method; S, C-O isotopic geochemical method; Method of determining the temperature of homogenization of fluid inclusion; Cold test method to determine the salt in the bag; Raman spectroscopy method determines the fluid inclusion.

2.4. Academic terms and concepts in thesis

Mine type, ore type, ore body, ore, mineral combination, mineral symbiotic combination, ore region, ore strip, ore point, mineralization point, mineral formation period, mineral formation period.

Chapter 3
GEOLOGICAL CHARACTERISTICS OF COPPER OREZATION IN BIEN ĐONG-QUY SON

3.1. Characteristics of geological formations surrounding copper ore

Rock contained copper ore (rock surrounding copper ore) in the region, which are platinum sedimentary rocks such as arkos sandstone, siltstone (belonging to the middle Mau Son formation) and cove-grained fine-grained carbonate platinum. shallow bay (belonging to the upper Mau Son formation). Particularly in the Dong Dong - Quy Son area near the middle of An Chau basin, the full cross-section consists of three strata as follows:

- Subsystem of lower layer includes sandstone, red brown siltstone sand and mixed sandstone under quaczite form, conglomerate lense and gravel;

- Subsystem of middle layer includes sandstone, red brown siltstone, mix with fine grained limestone, gray lime clay;

- Subsystem of upper layer includes siltstone clay, siltstone, lime clay, lime clay, micro limestone, gray dolomite limestone, coal clay, dark gray coal lime clay. The top layer is sandstone, siltstone and a little mix with brown gravel.

3.2. Distribution, morphology and structure characteristics of copper ore bodies

The research results showed that copper ore bodies in the study area were distributed mainly in the complexes of continental sedimentary rocks such as arkos sandstone, siltstone (belonging to the subsystem of Mau Son middle layer) and continental fine-grained carbonate in shallow sea (belonging to the upper Mau Son). Ore body was usually lenses form, cross through or distributed in the stratum surface of the formation (Figure 3.1). These mines and ore points were limited by northwest-southeast fault systems (F10, F12) and sub-latitude fault systems to northeast-southwest (F2, F6) in the structural block of Bien Dong - Quy Son. Based on the structure and distribution of the mines and copper ore points in the study area, it showed that copper mineralization separated into two ore bands.

Ore range 1: Consisting of copper ore mines and points distributed along the two sides of the fault near the surface of the sub-latitude axis to the northeast-southwest. This was an ore strip with rich distribution of homogeneous ore and mineralization points. Representative of this ore strip were mines and ore points such as Cau Nhac, Lang Dinh, Deo Vang, Cai village ....

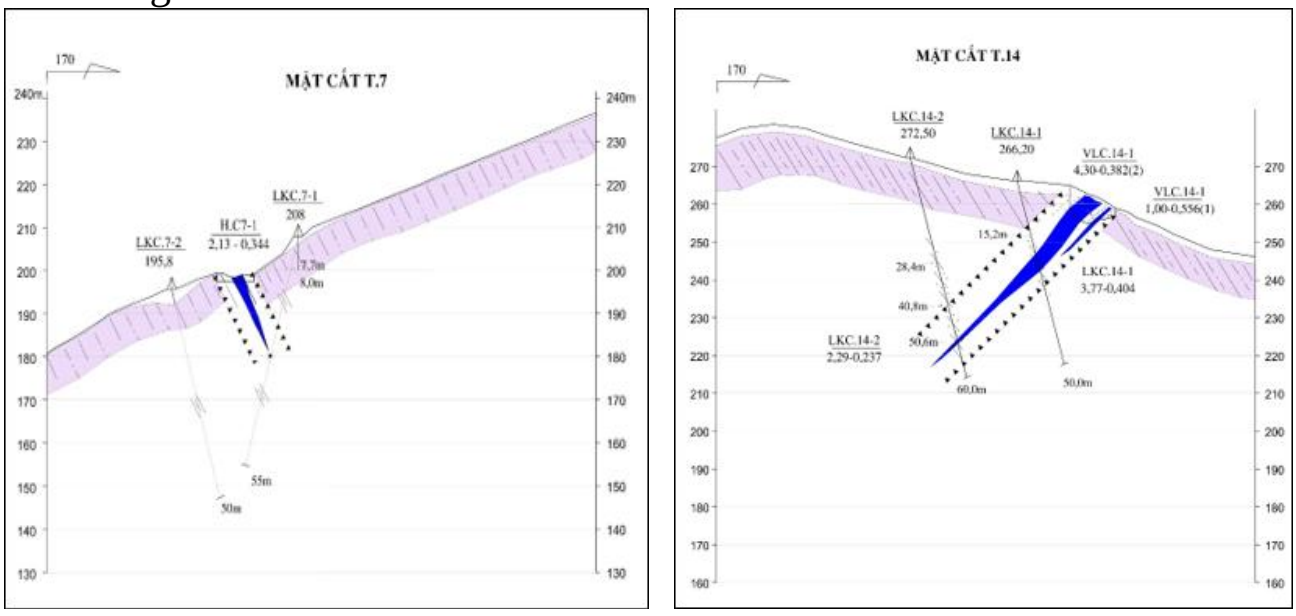

Figure 3.1. Geological section T7 and T14 at Cau Nhac ore point

Ore range 2: Consisting of mines and ore points distributed at the center of the study area, along the fault that cut through the north-northwest wing of the Tan Hoa concave and a few mines distributed along two wings of the small convex of Giao Liem. These included ore points, mineralization points such as Dong Bua mine, Khuoi Muoi mine, Giao Liem mine, Goc Sau mine, Lan mine, Suoi Than ore point, ... (details of the ore points in the ore strip 1 and 2 described by the PhD student in the thesis)

Photo 3.1. The crumpled area was broken, the steep lying position contains the Gac Sau mine copper ore

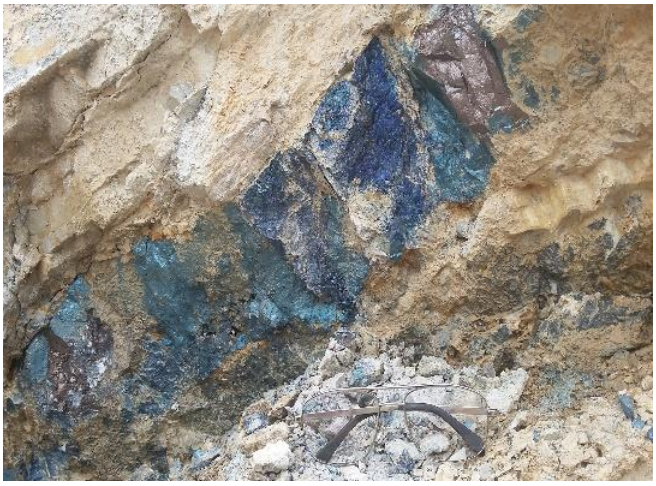

Photo 3.2. A dense chalcosin circuit cross-cuts the layers of shale - lime

3.3. Characteristic of hydrothermal altered rock surrounding ore

Phenomenon of hydrothermal changes in the study area included quartz, chloritization, dolomitization, sericite. In addition to the above phenomena, in the study area occurred calciteized hydrothermal changes and sericit at a weak level.

Chapter 4
THE MATERIAL COMPOSITION CHARATERISTICS OF COPPER ORE IN BIEN ĐONG-QUY SON REGION

4.1. Mineral composition characteristics

Analysis results of mineral facies samples, lithological thin slices, combined with SEM analysis at the University of Mining and Geology and synthesis of previous research. Ore mineral composition Bien Dong - Quy Son areas were listed in Table 4.1

Table 4.1: Mineral composition of copper ore in Bien Dong- Quy Son

Ore mineral		**Non-ore mineral**	
Primary mineral	**Secondary mineral**	**Mineral creating changed rock**	**Vascular mineral**
Tetrahedrite	Azurit	Clorit	Quartz
Bornite	Malachit	Dolomit	Calcit
Chalcocite	Covelin	Sericit	
Chalcopyrite	Limonit		
Tennantite			
Autogenous copper			
Electrum			
Pyrite			
Galenite			
Sphalerite			
Autogenous gold			

4.2. Composition and structure characteristics of ore

4.2.1. Ore composition characteristic

Ore minerals in the study area were mainly formed by the mode of filling fissure systems, faults, crushing zones, slab separations, leaching and alternative exchange modes (corrosion, dissolving) with pre-forming minerals.

Due to the uneven distribution of the minerals in the ore bodies, the ore has a diverse structure. The microstructures encountered under the glass are circuits, lattice networks, diffusion, drives, beads, corrode, rim, ...

4.2.2. Ore structure characteristic

In the study area, there existed 2 groups of primary and secondary structures. The primary structure group was formed concurrently with the ore-forming process due to the exchange of replacing pre-formed minerals with the hydrothermal solution. Secondary structure group of primary ore was formed after the ore creation process, was related to the tectonic destruction after the ore, the ore was crushed, crushed, recrystallized, oriented, ... Mineral analysis of ore samples in the study area has the following structure: Self-shaped, semi-self-shaped particle architecture; Constructive grain architecture; Alternative corrosive architecture;

Radiating intercrystalline architecture; Architectural glue, sophisticated, hypocrisy; Architecture interspersed.

4.3. Chemical composition characteristic of ore

Synthesis of chemical analytical results of 1339 ore samples showed that copper content in the study area ranged from 0.01% to 29.01%, average 1.44%.

In addition to the above copper ore chemical analysis results, author has further analyzed some primary geochemical samples in the study area for copper-lead - zinc at the experimental analysis center of Geological Federation. Rare Radioactive substances using RS-ICPMS machine. The results showed that the copper content ranged from 0.02 to 0.05%, the average was 0.03%; Zinc was from 0.06% to 0.1%, average 0.08%; Lead was from 0.01% to 0.02%, average 0.012%.

4.4. Origin of copper orezation

4.4.1. Relationship with magma activity

In the study area mentioned above, no intrusive bodies of magma have been observed. Therefore, determining the relationship between the mineralization with magma in the study area according to the above signs was not found. However, the analysis of the material composition showed that the ore forming solution was of magma origin or in other words, the mineralization in the region has a relationship with the magma in terms of origin. It was possible that orezation in the study area was related to some hidden magma that has not been discovered.

4.4.2. The water and the material sources of the hydrothermal solution

The results of analysis of the bulk material composition in the study area showed that the mineral forming solution was a hydrothermal solution, formed at a rather large depth, with an initial temperature of about 410^{o}C, the pressure of more than 1300atm. The presence of N_2 in the fluid composition in the primary mitochondria showed that the solution was of magma origin with an initial solution temperature of about 300-410^{o}C. When the temperature of the solution droped below 300^{o}C, the binder could be no longer or very little N_2, the CO_2 and NaCl. The water content increased to the time of 170^{o}C, then showed the increasing participation of meteorological water when the temperature decreases.

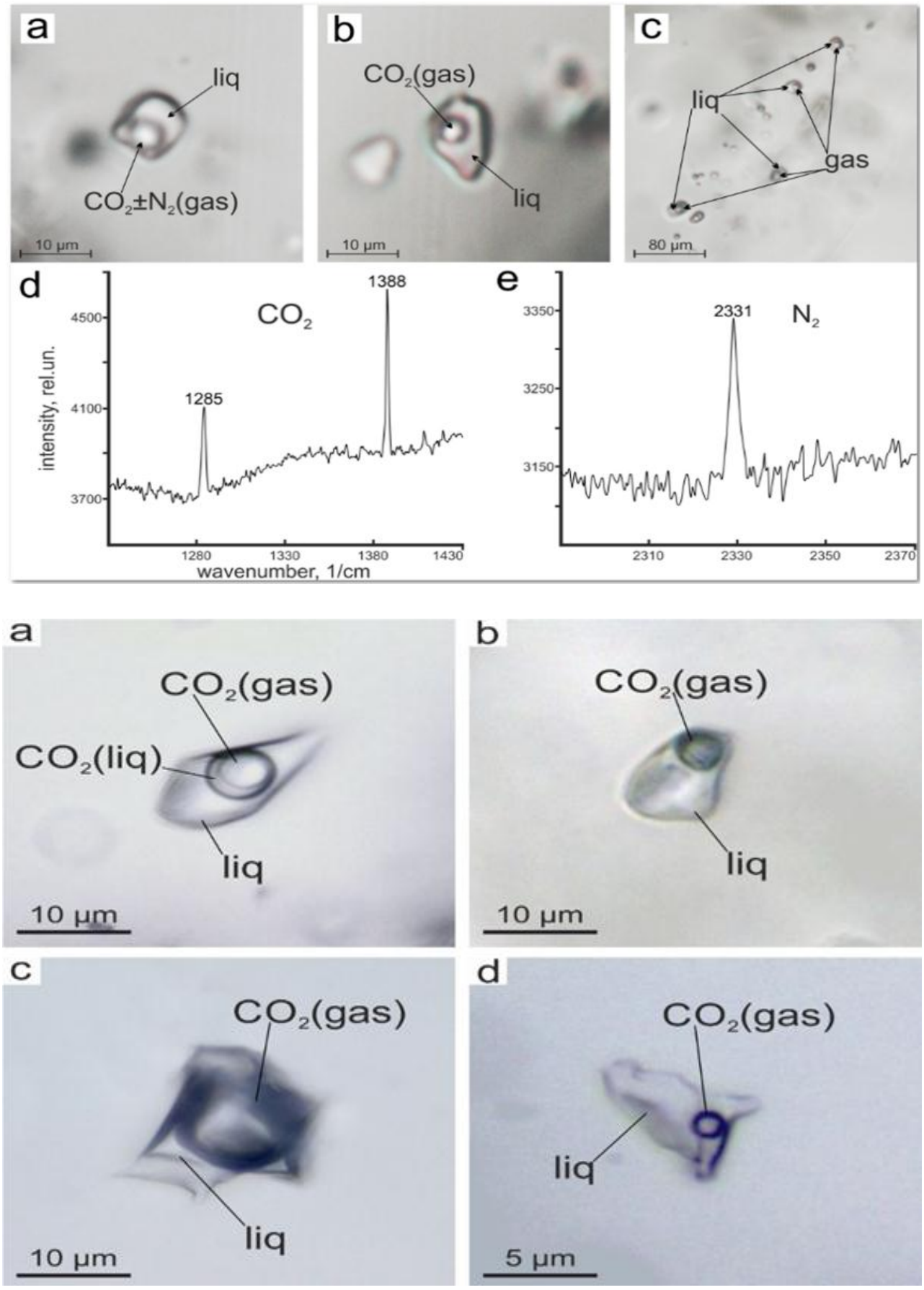

Photo 4.1. Composition analysis of fluid inclusion

Table 4.2 Composition analysis results of fluid inclusion

(Source: Analysis at Sobolev Institute of Geophysics and Geophysics, Russian Federation, 2019)

Sample sign	Main minerals	Fluid inclusion type	Temperature Otecti ($-^0$C)	Freezing temperature ($-^0$C)	Salt concentration (wt.%NaCl-eq)	Temperature assimilation (^{0}C)	Gas phase
AP-02	Quartz	Liquid gas	-11 to -15	-3,1 to -3,5	5,11-5,71	360-410	CO_2+-N_2
	Quartz	Liquid gas		-1,5 to -2	2,57-3,39	250-290	CO_2
DD-02	Quartz	Liquid gas, liquid		-0,2 to -0,4	0,35-0,71	170-195	CO_2
	Quartz	Liquid gas, liquid	-24 to -18	-6,5 to -0,8	1,4-9,68	230-320	CO_2
ĐB-13	Quartz	Liquid gas	-21,5 to -21	-3 to -0,5	4,96	210-225	CO_2

4.4.3. Temperature and pressure of ore formation

Analysis results of assimilative temperature in the quartz veins in the study area showed that mainly primitive bodies such as liquid - gas, gas-liquid, and less gas body (table 4.3).

Table 4.3 Analysis result of fluid inclusion in quartz

STT	Sample sign	Assimilative temperature of fluid inclusion as type of quartz-copper-sulfur (^oC)
1	ĐB 02	200 - 254
2	GS 01	220 - 245
3	ĐĐ 03	205 - 280
4	KM 01	220 - 253
5	GS 1b	207 - 248
6	GS 05	200 - 240
7	DD 02	170 - 320
8	ĐB 13	210 - 225
9	AP 02a	250 - 290
10	AP 02b	360 - 410

(Source: Analysis at Vietnam Institute of Geosciences & Biology and Sobolev Institute of Geology and Mineralology - Russian Federation, 2019)

The above analysis results show that the temperature of forming copper ore in the study area fluctuates in the range of 200 - 4100C (mainly 200-2530C), the pressure of 1050 - 1300 atm.

4.4.4. Origin type and the ore forming process

*4.4.4.1. **Origin type***

The initial research results on ^{34}S, ^{13}C and ^{18}O isotopes in the study area were shown in (table 4.4). Data were compared on the correlation diagram between $\delta\ ^{13}C$ and $\delta\ ^{18}O$ carbonate classification by origin (Rollinson, 1993). Results showed that protozoa symbiotic complex was formed under the hydrothermal conditions that belonged to the Mississpi Valley hydrothermal type and the Mid-Ocean ridge hydrothermal type, (figure 4.1).

Analytical results of isotope ^{34}S were compared on the chart of ^{34}S values of sulfur-containing minerals in hydrothermal mineral deposits (Rollinson, 1995) showed that S in ore in the study area was from multiple

sources, including sulfur in the magma and S formed in modern marine sediments (figure 4.2). From the analysis results of ^{13}C, ^{18}O in calcite and ^{34}S isotope in sulful minerals, combined with the analysis results of anabolic temperature and composition of the material. Copper ore in the study area has origin from medium to low temperature that formed an original hydrothermal solution of magma origin in temperature range from 200^{o}C to 410^{o}C, pressure from 1050 to 1300 atm.

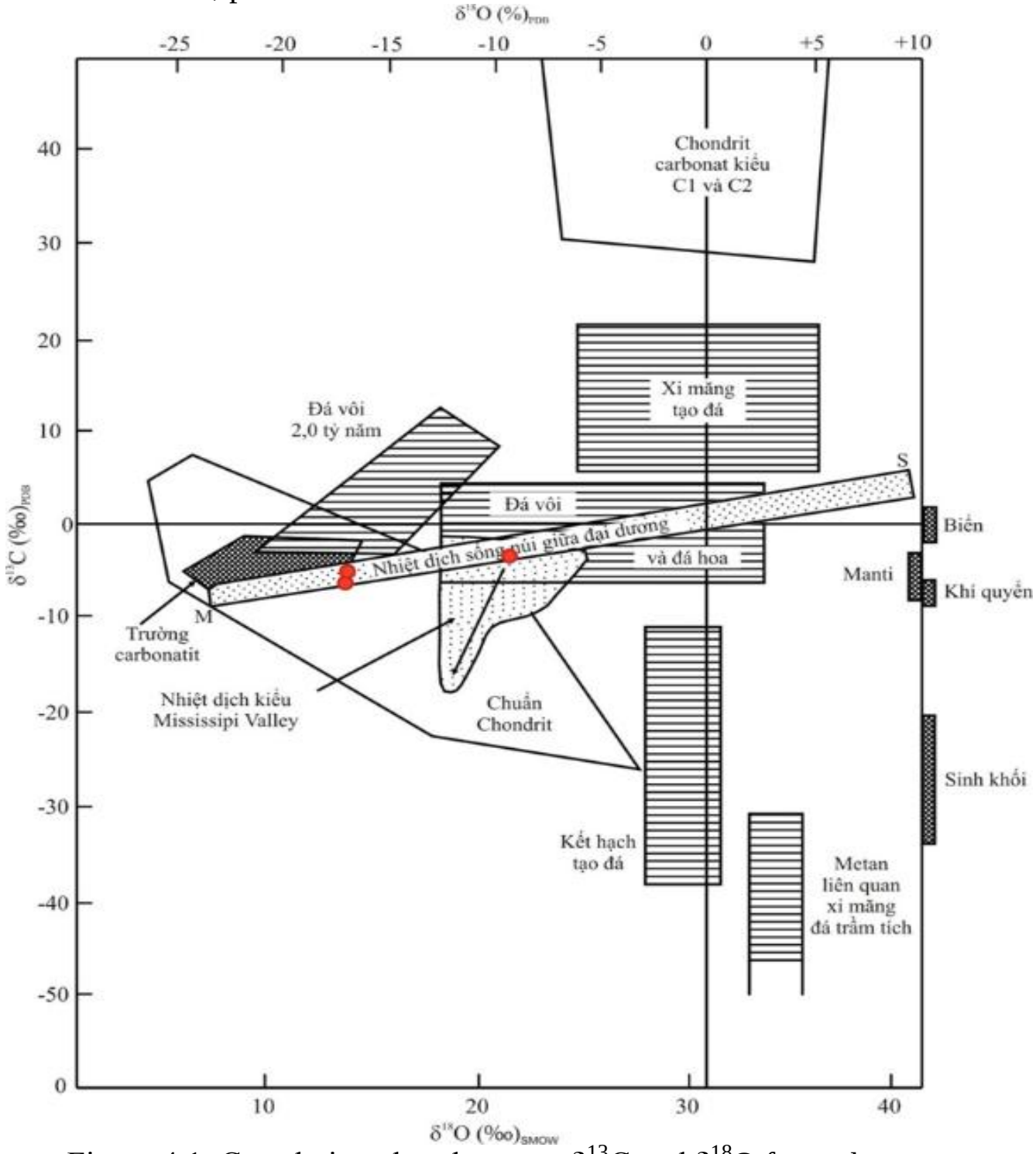

Figure 4.1. Correlation chart between $\delta^{13}C$ and $\delta^{18}O$ for carbonate classification by origin (Rollinson, 1993)

Table 4.4. Results of isotope analysis for ^{34}S, ^{13}C and ^{18}O

No	Sample sign	Mineral	Isotope	Result
1	ĐB 04	Pyrit	$\delta^{34}S$, ‰ CDT	+6,6
2	ĐB 03	Galenit	$\delta^{34}S$, ‰ CDT	-22,2
3	ĐB 04	Pyrit	$\delta^{34}S$, ‰ CDT	5,7
4	KM 26	Galenit	$\delta^{34}S$, ‰ CDT	-20,7
5	KM 2.6-2.9	Galenit	$\delta^{34}S$, ‰ CDT	-16,4
6	KM 1.2	Galenit	$\delta^{34}S$, ‰ CDT	-22,0
7	GS 23/3	Chalcopyrit	$\delta^{34}S$, ‰ CDT	6,8
8	GS 04	Sulfide'mix	$\delta^{34}S$, ‰ CDT	-13,6
9	GS 05	Sulfide'mix	$\delta^{34}S$, ‰ CDT	-8,5
10	ĐB 12	Calcit	$\delta\,^{13}C_{VPDB}$, ‰	-3,5
11	ĐB 34	Calcit	$\delta\,^{13}C_{VPDB}$, ‰	-5,4
12	TB 3/4	Calcit	$\delta\,^{13}C_{VPDB}$, ‰	-6,6
13	ĐB 12	Calcit	$\delta\,^{18}O_{VSMOW}$, ‰	21,4
14	ĐB 34	Calcit	$\delta\,^{18}O_{VSMOW}$, ‰	13,9
15	TB 3/4	Calcit	$\delta\,^{18}O_{VSMOW}$, ‰	13,8

(Source: Analysis at Sobolev Institute of Geophysics and Geophysics, Russian Federation, 2019)

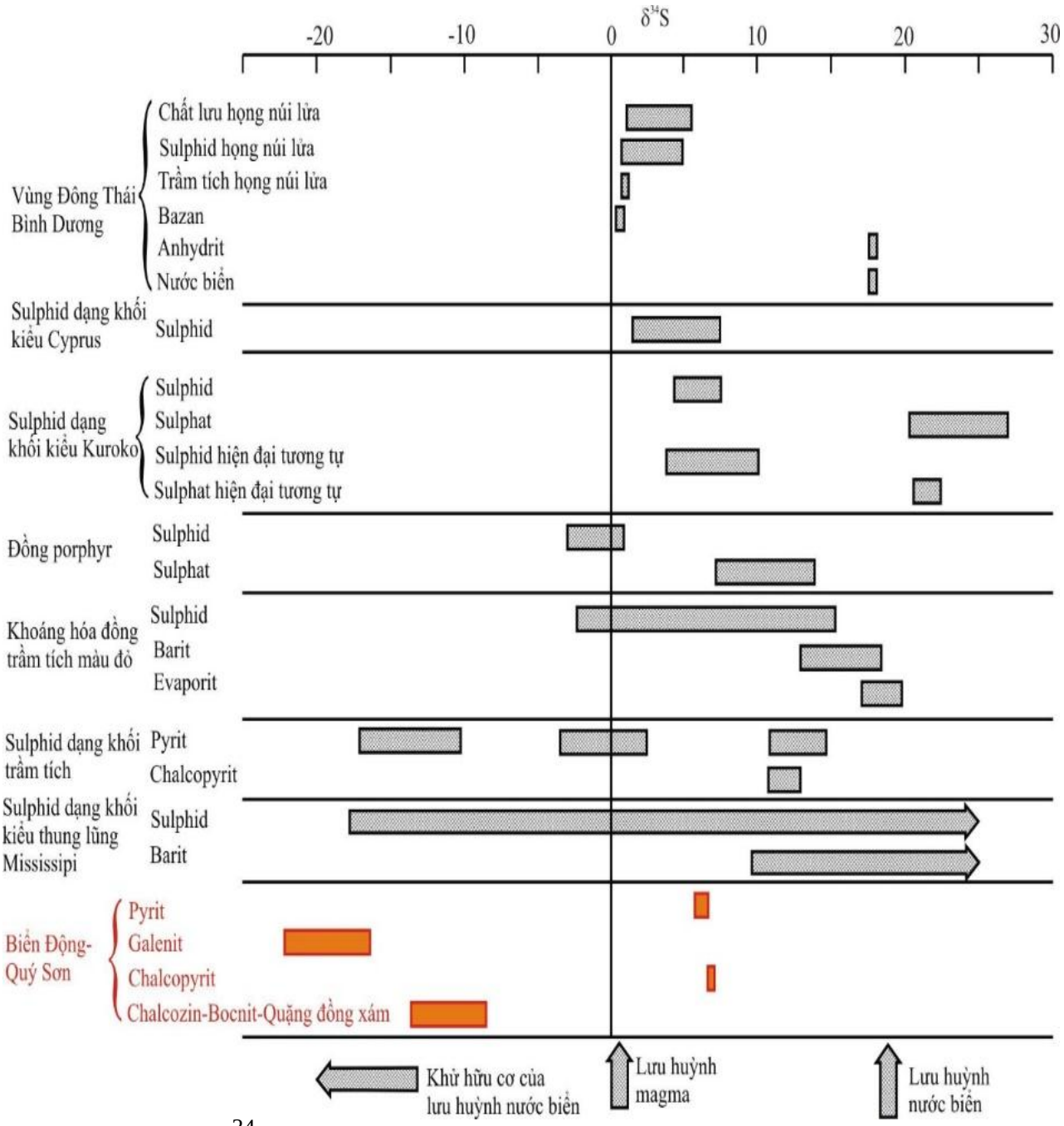

Figure 4.1. δ ^{34}S value of sulfur-containing minerals in hydrothermal mineral deposits (Rollinson, 1993)

4.4.4.2. Ore creation process

Analysis results of facies, slices, inclusions, isotopes and other types of samples, it can be divided into periods and stages of mineral formation in Bien Dong - Quy Son as follows (Table 4.5).

Hydrothermal mineral formation period

The hydrothermal mineralization period occured in three phases:

- Early hydrothermal phase: The hydrothermal solution causes changes in the hydrothermal of quartz in the rock surrounding ore veins with the characteristic mineral-biotic complex of quartz I - pyrite.

Table 4.5: The forming order and the lithium mineralogy paragenesis assemblages in Bien Dong-Quy Son

Period	Hydrothermal			Weathered
Phase	I	II	III	IV
MPAS / Mineral name	Qu -pyrit	Tetrahedrite-tennantite-chalcosine-bornite-chalcopyrite	Qu-calcite	Malachite, azurite, coveline, limonite
Quartz	———	———	———	
Calcite		———	———	
Dolomite		———		
Clorite		———	- - - - - - - - -	
Pyrite	- - - - - - - - - -	- - - - - - - - - -		
Tetrahedrite		———		
Tennantite		———		
Bornite		———		
Chalcocite		———		
Chalcopyrite		———		
Autogenous copper		- - - - - - - - - -		
Galenite		- - - - - - - - - -		
Sphalerite		- - - - - - - - - -		
Electrum		- - - - - - - - - -		
Autogenous gold	- - - - - - - - - -			
Malachite				———
Azurite				———
Coveline				———
Limonite				- - - - - - - - -
Structural features	Diseminated	Pocket, veins	Veins, diseminated	Traces, remnants, rim
Typical structure	Xenomorphic idiomorphic-granular, instead corrosion	Idiomorphic-granular, instead corrosion	Hypautomorphic allotriomorphic granular	Glue, hypocrisy, instead corrosion, micro veins
Typical altered phenomenon	Quartzization	Quartzization, dolomitization, chloritization	Calcitization, quartzization	Oxidize, hydrolysis, carbonatization

Note ——— Major area; ——— Secondary area; ——— little area

- Middle hydrothermal phase: The hydrothermal solution changing the hydrothermal dolomite, quartz the surrounding rocks, forming finished ore with the characteristic mineral symbiotic complex were quartz II- dolomite - copper ore gray-chalcosin - bornite - chalcopyrite - sphalerite - galenite. Orezation in this period usually has characteristic ore structure to be dense, diffuse dense, vein, lattice, and pyramid-shaped, eroded grain architecture ... This is the main ore-forming stage in the study area.

- Late hydrothermal phase: This phase was considered to be the end of the ore-forming process in the study area with the formation of symbiotic complex of quartz minerals III + calcite (Table 4.5).

Weathering period

Under effects of oxidation, hydrolysis, carbonation of the weathering process in the study area, sulfur minerals such as gray copper ore, chalcopyrite, bornite, chalcosin, pyrite, ... in the upper part of the ore body were changed into secondary minerals malachite, azurite, covelin, limonite, ... (table 4.5). These exogenous minerals could remain in the upper part of the ore body and also moved with surface water or groundwater deposited in rocks with high permeability such as sandstone, siltstone, rocks in the crushing zone. tectonic, ... to create the ore bodies in weathered-absorbent type.

Chapter 5: OREZATION CONTROL FACTORS AND PREMISES, SEARCH SIGNS OF COPPER ORE IN BIEN ĐONG-QUY SON

5.1. Factors controlling copper ore

Copper orezation in Bien Dong - Quy Son region were mainly distributed in the sub-latitude tectonic fracture zones to the northeast - southwest and were controlled by two factors:

- The tectonic structure was a ring-shaped fault system from sub-latitude mode to the Northeast – Southwest that played a role of distribution and storage.

- The stratigraphic agar factor was the limestone-containing intact sedimentary rocks of the middle and upper sub-formation of the Mau Son formation.

5.2. Premise and search sign

5.3.1. Search premise

From the presented problems of Dong Dong - Quy Son copper characterization, the following problems can be drawn to find them.

- The research results show that copper ore was mainly distributed in the second and third episodes of the Mau Son formation. They mainly concentrated in the formations of siltstone, claystone, limestone, and limestone clay, micro limestone, gray dolomiticized limestone, coal clay, black gray coal lime clay.

- Structural-tectonic premise: Copper ore bodies, usually thrive in places where rocks were crushed, cracked, crumpled, and fissure systems were developed. The more level of fracturing, crushing was the more mineralizing ability. The discovered copper ore points and bodies was mainly distributed along the crushed rock zones of the sub-latitude fault systems to the northeast - southwest; Northwest - Southeast and arches of convex folds.

5.2.2. Search sign

Search sign in the study area:

- The traces of primary copper ore including tetraedrite, tennantite, bornite, chalcopyrite, chalcosin were often weathered to produce secondary minerals such as malachite, azurite, cuprite ... related to silty clay, siltstone, limestone, clay limestone, micro-granular limestone, gray dolomite limestone, coal clay, dark gray coal lime clay and ore-bearing quartz veins.

- The secondary geochemistry anomalies of the Cu monomer and characteristic accompanying elements were good signal for searching: Cu and other minerals such as Pb, Zn, Au, Ag ... in research area.

- The rocky zones of hydrothermal change such as dolomite, quartz, chlorite, sericite.

5.3. Potential zoning of copper ore in the Bien Dong - Quy Son region

Base on synthesis and analysis of relevant geological factors and control of copper ore, the signs of direct and indirect searches (ore points, mineralization points were detected, geolocation rings). PhD student has identified 8 prospective copper ore areas in the Bien Dong - Quy Son (details are presented in the thesis).

CONCLUSION

From the research results of the thesis, the following conclusions are as follows.

1. The copper ore in Bien Dong - Quy Son region distributed mainly in the sub-latitude tectonic fracture zones to the northeast - southwest and was controlled by two factors:

- The tectonic structure was the sub-latitude arcs condition fault system to the Northeast - Southwest playing the role of distributing and storing ore.

- The agar-stratigraphic factor was the limestone-containing intact sedimentary rocks of the middle and upper formation of the Mau Son formation.

2. The copper ore bodies in the study area were often in the form of veins, lattices, lenses, drives ... that mainly distributed in the complex of continental sedimentary rocks such as arkos sandstone, pre-delta siltstone middle Mau Son formation) and fine-grained carbonate platinum (belonging to the upper Mau Son sub-formation). The weathered ore bodies usually took the form of lenses, layers (layers), drives, circuits, ...

3. Material composition, structure and architecture of ore:

The main beneficial elements in the ore were copper. The combined symbiotic element were Pb, Zn, S, Ag, Au;

Ore mineral composition was relatively complex, primary ore minerals include tetraedrite, tennantite, bornite, chalcosin, chalcopyrite, native copper, pyrite, galena, sphalerite, electrum, native gold. The secondary ore minerals included malachite, azurite, covelin; cuprit, limonit.

Hydrothermal ores have diffuse structure, veins, lattices,… tha particle architecture, semi-self shaped particles,…; Weathered ores have traces, remnants, rims, shells, ... colloidal architecture, hypocrisy, corrosion, microparticles ...

Phenomenon of hydrothermal changed encountered in the study area include quartz, chloritization, dolomitization, sericite.

4. The temperature of copper ore formation in the study area fluctuated in the range from 200^{o}C – 410^{o}C, pressure from 1050 atm to 1300 atm. The ore forming solution has a mixture of magma sources, marine carbonate sediments and meteorological water.

5. The research results of the dissertation interpreted scientific explanations about the origin and forming conditions of copper ore in Bien Dong - Quy Son region which was medium - low temperature hydrothermal with solid mineral symbiotic complex (Tetraedrit - chalcosin - bornite - tenantite - chalcopyrite). This is an important new research result, contributing to geological sciences in general and the training work of University of Mining and Geology in particular. In addition, the research results of the thesis also helped to orient, search, explore and exploit copper ore in Bien Dong - Quy Son region and in surrounding areas with similar geological conditions.

REQUEST

Need to invest in further research on the source of primitive materials for the formation of copper ore in particular and the associated ores in general, magma or sediment?

During the time to carried out the thesis, the PhD student has completed basic tasks. However, due to incomplete and inconsistent geological, geophysical and geochemical documents, the thesis cannot avoid shortcomings. PhD student is looking forward to receiving suggestions from geologists and friends and colleagues. Hopefully, after defending the thesis, the shortcomings and shortcomings will be further researched and resolved to serve the search, exploration and efficient use of copper ore in Bien Dong – Quy Son.