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Metallization characteristics and gold ore controlling factors in the south region of Tra Nu - Phuoc Thanh, Quang Nam Province

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ABSTRACT

The gold mineralization in the southern region of Tra Nu-Phuoc Thanh was initially discovered and assessed by the Central Geological Division. However, mineralization characteristics and ore-controlling factors in the Tra Nu-Phuoc Thanh area remain inadequately understood. To assess the gold mineralization potential in this research area, this study conducts a comprehensive synthesis of prior research findings, complemented by the analysis of an additional 50 thin sections, 100 thick sections, SEM scanning electron microscopy, and 10 ICP-MS samples. The research results reveal the presence of gold deposits within the study area, including native gold and electrum. The identified gold-bearing minerals in the deposits encompass quartz, pyrite, galena, sphalerite, pyrrhotite, and goethite. The ore formations predominantly exhibit disseminated, vein, and breccia structures, along with granular, semi-granular, spherical, and solid inclusions. It has been ascertained that the gold ore in the study area belongs to the gold-quartz-sulfur formation and can be categorized into two types: gold-quartz-pyrite ore and polymetallic gold-quartz-sulfur ore. The ore is primarily situated within ancient metamorphic sedimentary rocks of the Kham Duc formation and young granitoid rocks of the Ba Na complex. Typically, the gold ore body occurs in a single-vessel form, with less common branched, vascular zone, and infiltrative vascular forms. All gold ore bodies are aligned along the fault systems, primarily oriented in the northeast-southwest direction. These sub-meridian fault systems serve as conduits for hydrothermal solutions carrying gold ore in the study area.

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1. Introduction

The southern region of Tra Nu-Phuoc Thanh lay neatly in the southern part of the Kham Duc architectural block, which was a part of the northern edge of the Kon Tum block. This was an area with a complex geological structure, and diverse and rich minerals, the most prominent of which is primary gold. Many gold mines and spots have been discovered, researched and evaluated, some of which have been put into operation (Binh, 2016). However, so far, the systematic research on gold ore in this area has been very limited. The most important issue at present is to determine the formation properties and classification of gold ore, and identify favourable geological factors to establish a scientific basis for prospecting, exploration and exploitation of gold ore in the study area, contributing to the development of the country's economy (Figure 1).

2. Research contents

2.1. Overview of ore geology features

2.1.1. Distribution characteristic

Gold ore bodies are distributed in the rock formations of Kham Duc (PR_3*kđ*), A Vuong (e-O_1*av*), and in the magmatic complexes of Chu Lai (g$PR_{2\text{-}3}$*cl*) and Ba Na (gK-E*bn*). Metallization primarily occurs in the inner and outer zones where young granitic massifs of the Ba Na complex contact with ancient metamorphic rock formations (Luat, 1995). This metallization also intersects fault systems, appearing in split cracks, faults, and sliding fractures. Research results have shown that gold ore in the southern Tra Nu - Phuoc Thanh area is distributed across geological formations with diverse compositions, origins, and geological ages. Notably, it is found in light-coloured granite associated with the Ba Na complex of Cretaceous-Paleogene age. This relationship suggests that gold mineralization in the study area is relatively recent, being younger than the Cretaceous-Paleogene period (Khai et al., 1994)

2.1.2. Morphological characteristic of the ore body

In the study area, gold ore bodies primarily manifested as single, lenticular, chain or parallel veins. Occasionally, these veins appeared staggered diagonally. In some cases, vascular infiltrations were observed, though foci formations were rare. These ore bodies typically have a thickness ranging from 0.20÷3.00 m and stretch between 50÷800 m. They often have a steep incline greater than 30^0, with a few ore bodies exhibiting a more horizontal orientation. In the metamorphic formations, the ore bodies frequently fill inter-stratum fissures. They also split and crack, forming lenticular chains both in the direction of the slope and perpendicular to it. Their primary development direction is NE-SW, with

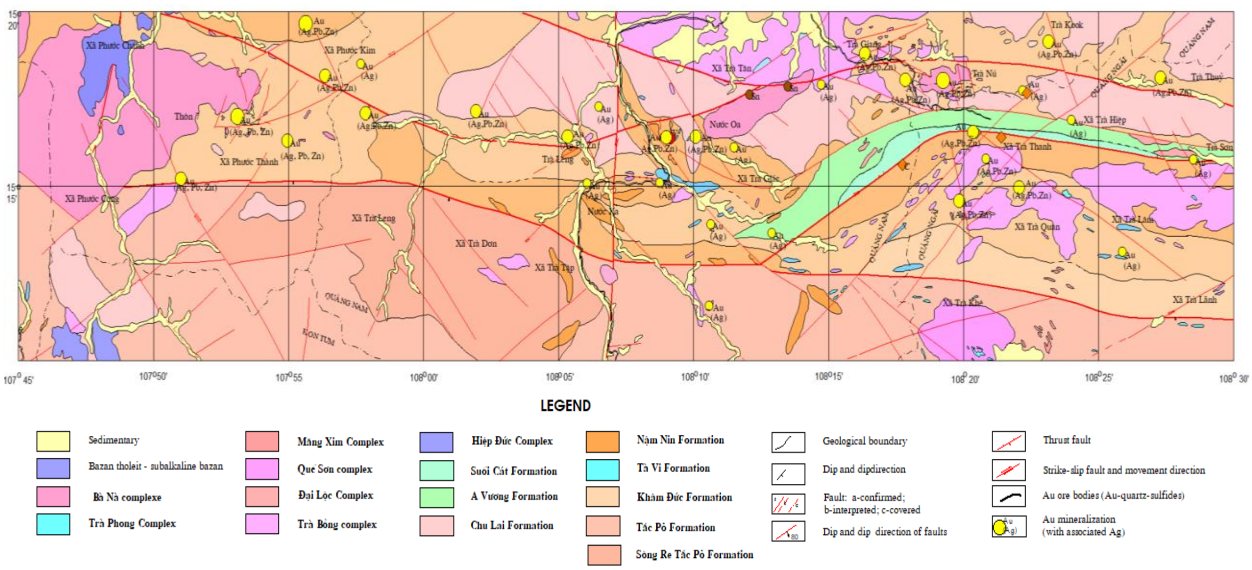

Figure 1. Simplified geological map of the Tra Phu - Phuoc Thanh area (modified from Binh, 2016).

a few ore bodies taking a sub-meridian alignment. In contrast, within the magmatic formations, gold metallization fills fissures and appears at open, sliding fault points. Here, the development tends to be in the sub-latitude direction, leaning towards the southeast.

Furthermore, in the study area, ore bodies frequently appeared as vascular networks or infiltration zones. Such veins typically exhibited a consistent thickness, often taking the form of a seam, characterized by a microvessel and nest structure. Sulphide ore infiltration penetrated the surrounding rock, creating distinct zones. Hydrothermal alterations in the surrounding rock were pronounced, with beresitization being predominant. Notably, the boundary between these ore bodies and the adjacent rock was often indistinct.

2.1.3. Characteristic of hydrothermal alteration of country rock

The hydrothermal transformation process of the ore-bearing rocks in the southern Tra Nu - Phuoc Thanh region exhibited significant and diverse development. The extent of change and hydrothermal transformation closely depended on the composition and structure of the surrounding rock, often resulting in overlapping phases during the hydrothermal mineralization process. The primary transformation processes included sericitization, chloritization, epidotization, beresitization, and argilitization. Among these, sericitization was the most prominent and typical process observed in all vein rocks with modified ore, while beresitization ranked as the second most significant process (Li et al., 2013).

The hydrothermally altered minerals formed at the periphery of the ore vein by replacing and corroding the primary rock-forming minerals. They occupied the spaces formerly occupied by these minerals, including micro-fissures, and in

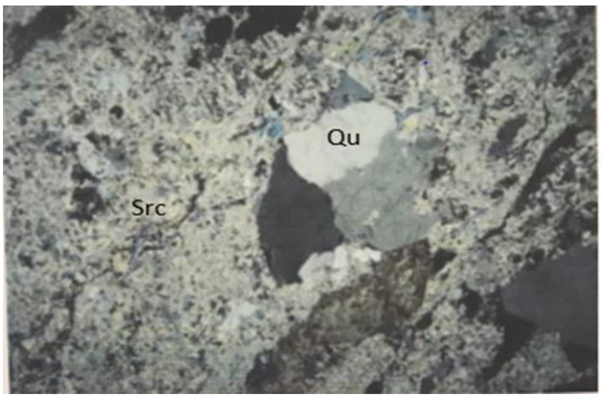

Figure 2. Gneis biotite is beresited, Nicon (+), 35^x.

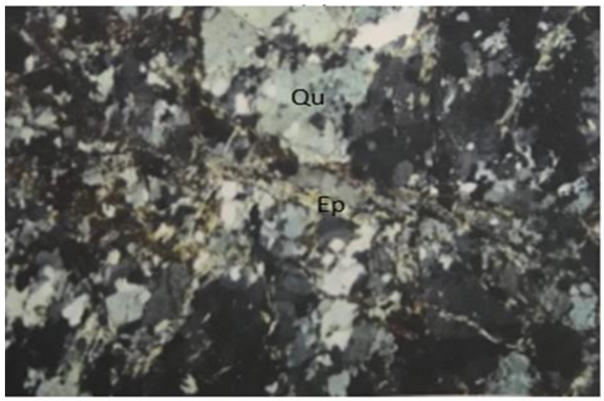

Figure 3. Plagiogneis-biotite is chloritized, slightly epidotized; Nicon (+), 35^x.

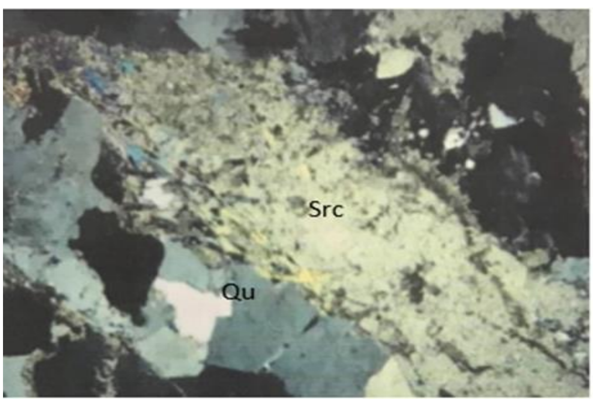

Figure 4. Quartz modified stone -sericite-ankerite Nicon (+), 35^x.

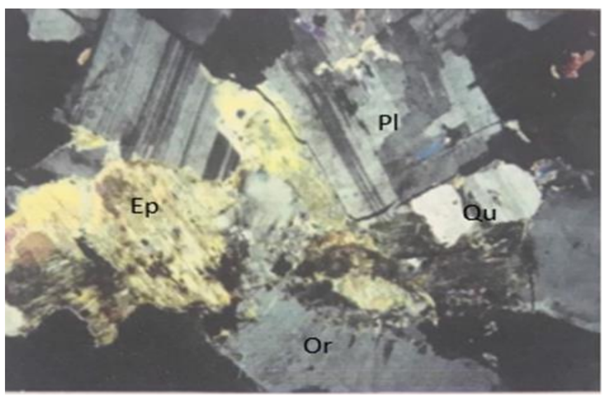

Figure 5. Chlorite, epidote, biotite granite Nicon (+), 35^x.

some cases, completely replaced the original minerals in the surrounding rock. These hydrothermal-modified minerals were distributed in various forms, such as clusters, veins, bands, scales, and grains within the host rock, and they extended throughout the vicinity of the ore deposit (Figures 2÷5).

2.2. Characteristics of gold ore

2.2.1. Features of ore mineral composition

The mineral composition of the ore has been determined through a comprehensive analysis, which includes the examination of facie mineral samples, lithological thin slices, as well as microsond and SEM analysis conducted at the University of Mining and Geology. Additionally, these findings have been synthesized with previous research results. The key minerals identified in the ore include.

The main primary ore minerals, the most common, are pyrite, galenite, sphalerite, chalcopyrite, native gold, and electrum, the less common secondary minerals are arsenopyrite, pyrrhotine (Figures 6÷9). There are also some other minerals but very few and rare such as galenobismutite, and autogenous bismuth;

Among the primary minerals mentioned above, gold is the most valuable mineral in the study area. Research results show that they are common in the form of polymorphic grains with diverse morphology, not meeting complete crystals.

Secondary ore minerals in the deposit are typically represented by common species such as limonite, hydrogoethite, goethite, and anglesite. Less frequently encountered minerals in the deposit include cerussite, smithsonite, covellite, scorodite, and melnikovite, among others. The occurrence and abundance of these secondary minerals can vary within the samples, with their presence influenced by factors like the composition and quantity of sulphur minerals within the ore vein, as well as the degree of oxidation of these sulphur minerals under near-surface conditions.

Belonging to the group of vascular minerals and modified rock minerals related to ore formation in the study area, there are quartz, sericite, chlorite, epidote, ankerite, and a few other minerals.

Vein minerals in hydrothermal ores are mainly quartz for generations, which are the main components that create gold ore veins in the region, in addition, calcite also often occurs in ore bodies in the form of holes, piercing veins in limited quantities

Based on the research results, gold in the study area exists in the form of two minerals, which are natural gold and electrum gold. Minerals containing gold include quartz, galenite, pyrite, sphalerite, and goethite. Gold usually comes in the form of granules, sheets, fibbers and inclusions.

Among the primary minerals mentioned above, gold is the most valuable mineral in the study area. Based on detailed research results using scanning electron microscopy on the composition of gold mineral, morphological characteristics, particle size, especially the relationship expressed between gold and other ore-generating minerals. It can be seen that the

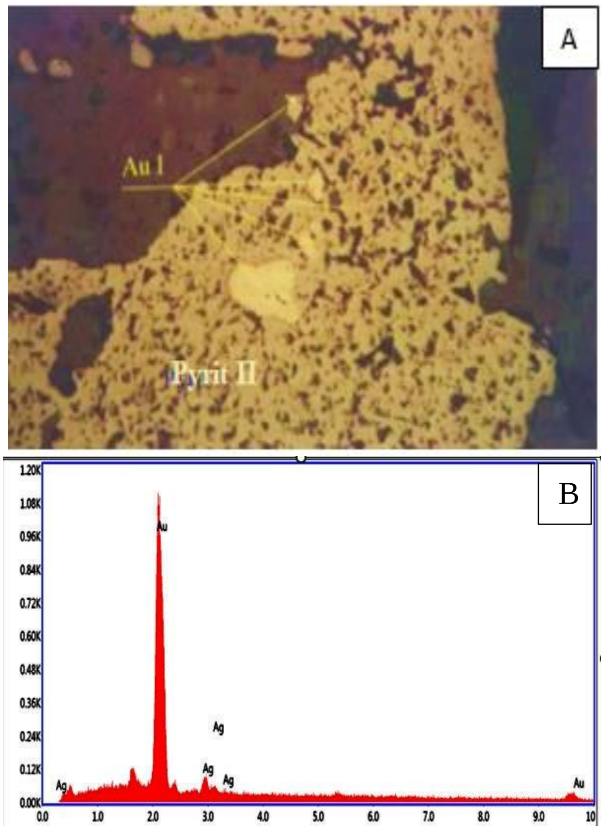

Figure 6. Gold particles (Au I) in the form of emulsion inclusions of chalcopyrite in the pyrite II background; 100x(A) and SEM scanning electron microscopy(B).

gold in the study area was formed in two mineralization phases.

In the early product stage, 1st generation gold (Au I) often existed in close symbiosis with pyrite II, quartz, and arsenopyrite. Under scanning electron microscopy, Au I is found in the form of a single inclusion or a cluster of inclusions in pyrite II (Figure 6) or in the diffuse form in quartz having an equal relationship with pyrite II and being pyrite III pierced penetration. The results of microzone analysis of some Au I particles in the mineral samples showed that their purity ranged from 629÷751, with an average of 705, the number of analysed gold particles belonging to the autogenous type accounted for 60%. The number of particles belonging to electrum accounted for 40% of the total number of particles analysed (Binh, 2016).

During the late product stage, the presence of gold generation II (Au II) became more prominent in terms of both quantity and morphological diversity. It exhibited a close association with minerals like galenite, pyrite III, sphalerite, chalcopyrite, and pyrrhotite. Under scanning electron microscopy, Au II displayed a more diverse appearance compared to Au I. Au II appeared as polymorphic distorted particles, short microchips, filaments, drops, spheres, plates, and ribbed forms. These Au II particles filled the micro-fissures and boundaries of pyrite II and quartz grains from the previous geological period. Microzone analysis of some Au II particles within the mineral samples revealed a purity range of 401 to 799, with an average of 686 (Binh, 2016). Notably, a majority of the gold particles, 54%, belonged to electrum, while the remaining 46% were self-generated gold in the analysed samples.

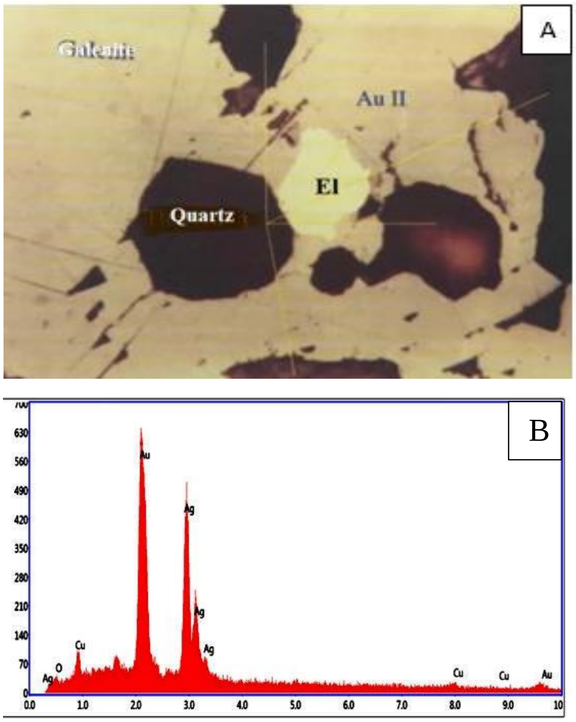

Figure 7. Electrum inclusion in galenite - bound quartz grains, 200x (A) and SEM scanning electron microscopy(B).

2.2.2. Characteristics of ore chemical composition

Based on distribution characteristics, form of existence, and correlation with current research, the South Tra Nu-Phuoc Thanh gold ore can be categorized into 5 groups, each containing various chemical elements.

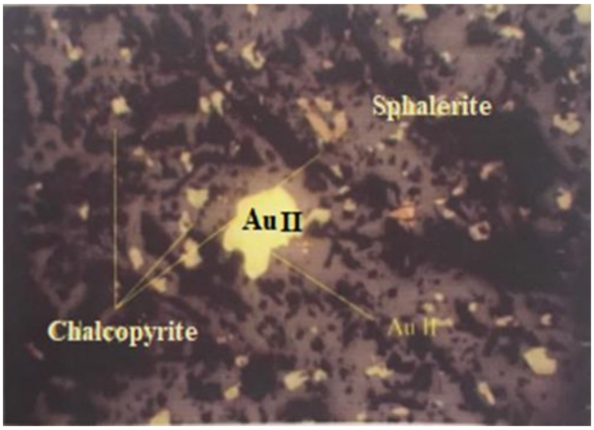

Figure 8. Gold particles (Au II) in the form of emulsion inclusions of chalcopyrite in sphalerite background; 100^{x}.

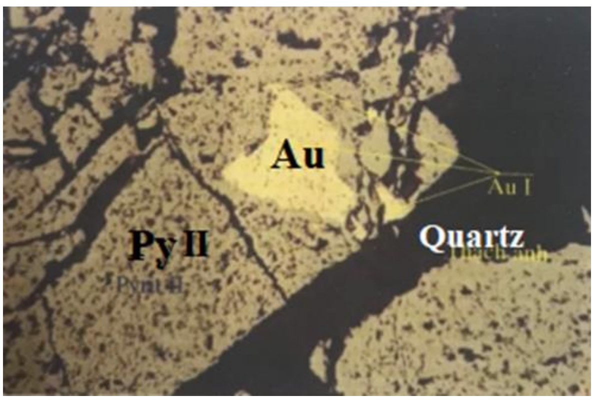

Figure 9. Gold particles (Au I) are scattered in quartz and pyrite (Py II); 200^{x}.

- Group 1: Elements that create gold minerals and in the form of impurities in gold minerals: Au, Ag, Fe, Cu (Table 2).

- Group 2: Elements that form minerals closely symbiotic with gold: Fe, S, Zn, Pb, Cu, As are the most common group of elements, they often link together to form gold-containing minerals (Table 3).

- Group 3: Group of elements in mineral combination with gold or impurities in sulphur minerals along with Bi, Sb, Co, Ni, Mn.

- Group 4: Characteristic elements for the combination of vein minerals in the original gold ore: Si, Al, Ca, Mg, K, Ti, O, H, C.- Group 5: Rare and trace elements in gold ores: Sm, Ce, Hf, Th, Yb, Ba, Sr, Zr. Rb, Ta, Nb, and Y contribute to the explanation of the origin of gold ore formation.

Comparing the content of trace elements of the gold ore groups in the study area (the gold ore group distributed in the rocks of the Ba Na complex, the gold ore group distributed in the rocks of the Kham Duc formation, group of gold-quartz-pyrite and polymetallic quartz-sulphur gold ores) shows that they are identical or in other words they share the same supply of gold-containing hydrothermal solution (Table 1; Figure 10).

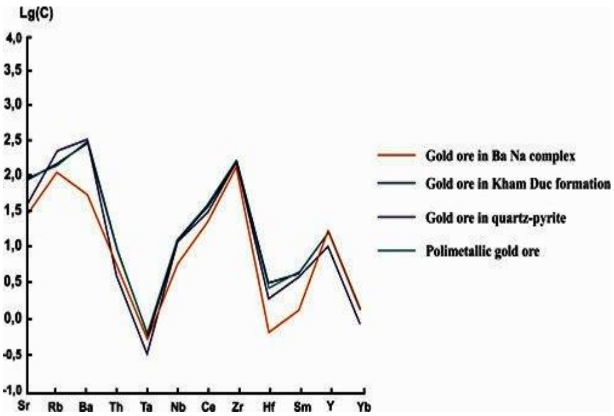

Figure 10. Logarithmic graph of trace elements of gold ore groups the south of Tra Nu-Phuoc Thanh.

Table 1. Trace elements of gold ore groups the south of Tra Nu-Phuoc Thanh.

No	Gold ore groups	Logarithmic trace element content (LgC)											
		Sr	Rb	Ba	Th	Ta	Nb	Ce	Zr	Hf	Sm	Y	Yb
1	Gold ore in Ba Na	1.44	2.05	1.730	0.72	-0.30	0.76	1.31	2.14	-0.22	0.10	1.20	0.11
2	Gold ore in Kham Duc	1.92	2.16	2.43	0.89	-0.28	1.07	1.52	2.16	0.45	0.57	1.16	0.10
3	Gold ore in quartz-pyrite	1.51	2.31	2.51	0.65	-0.51	0.88	1.43	2.18	0.74	0.51	0.94	-0.04
4	Polymetallic gold ore	1.94	2.13	2.39	0.91	-0.26	1.08	1.53	2.16	0.40	0.57	1.19	0.12

Table 2. Results of chemical composition determination by microsond method of gold particles in facies and monomeralic samples.

No	Minerals	Area	Sample	Content (%)				Total	Purity of gold
				Au	Ag	Fe	Cu		
1	Monomeralic gold	Tra Nu	GD.NC.5017	69.14	30.30	0.45		99.89	695
2		Tra Nu	H.104	76.42	23.50			99.92	765
3		Tra Nu	H.104	76.86	23.03	0.06		100	769
4		Tra Nu	H.104	77.80	22.02	0.03	0.07	99.92	
5		Tra Nu	H.26	81.38	18.11	9.41		99.90	818
6		Tra Nu	H.27	82.02	17.46	0.23		99.71	824
7	Thick sections	Phuoc Thanh	KTNC50139	73.61	26.05	0.13		99.79	739
8		Phuoc Thanh	KTNC50143	76.46	23.36	0.07		99.89	766
9		Phuoc Thanh	BTNC50139	74.69	24.79	0.43		99.91	751
10		Phuoc Thanh	KTNC50147	79.52	19.95	0.34		99.81	799
11		Phuoc Thanh	KTNC50149	69.01	30.15	0.67		99.83	696
12		Phuoc Thanh	H201/1	78.65	20.66	0.61		99.92	792
13		Phuoc Thanh	G38/1	87.33	12.41	0.09		99.83	876
14		Phuoc Thanh	GHK	77.10	22.46	0.26		99.82	774
15		Phuoc Thanh	L.6291/1	89.55	10.34			99.89	896

Table 3. The results of determining the chemical composition of ore minerals by microsond method on facies mineral samples in the south of Tra Nu-Phuoc Thanh area.

No	Samples	Minerals	Content (%)					Total
			Fe	S	Zn	Pb	Bi	
1	GĐ.NC 5017	Monomeralic pyrite	46.66	53.17				99.78
2	BT.NC 5018/3	Pyrite	46.04	53.81				99.85
3	BT.NC 50112/12	Pyrite I	46.23	53.77				99.80
4	GD.NC 50115	Monomeralic pyrite	46.47	53.36				99.83
5	BT.NC 50137/8	Pyrite II	46.51	53.35				99.86
6	BT.NC 50143/10	Pyrite II	46.69	53.28				99.97
7	BT.NC 50150/11	Pyrite	46.22	53.67				99.89
8	KT.NC 50139/7	Pyrite	46.37	53.39				99.76
9	KT.NC 50149/6	Pyrite	46.64	53.21				99.85
10	BT.NC 50139/10	Galenite		13.85		86.03		99.88
11	BT.NC 50150/11	Galenite		13.37		86.44		99.81
12	BT.NC 50137/8	Galenite		13.47		86.37		99.84
13	BT.NC 50110/9	Sphalerite	0.36	35.89	63.53			99.78
14	H.209/1	Lillianite		14.91		50.69	39.14	104.7
15	H.209/1	Abiogenesis bismuth in lillianite				2.46	97.37	99.83

2.2.3. Structural characteristic, ore texture

The gold ore in the study area was formed mainly by the modality of material deposition, crystallizing from the hydrothermal solution, filling of the fissure systems, fracturing, crush zones, slab separation face and delamination, etc. In addition, the exchange modality (Corroding, dissolution, backfill) with pre-formed minerals was also important in the ore formation process. Due to the uneven distribution of minerals in the ore body, the ore has a rather diverse structure. The common and specific structures were infiltrative, foci, penetrating vessels, lens circuits, chained vessels, and vascular networks. The microstructures encountered under the glass were vascular, diffuse, foveal, granular, erosive, vascular network, block, inheritance, and rim, etc. The most common was diffuse structure. Ore minerals such as pyrite, native gold, galenite, sphalerite, and chalcopyrite, etc. dispersed unevenly on non-ores. The mass structure was less common, only characteristic of pyrite forming dense clusters with substitution of other sulphur bindings. The results of the mineralogy analysis of ore samples in the study area show the following structures:

Panautomorphic-granular, typical subhedral texture for pyrite, arsenopyrite. Particles often developed into squares, cubic crystals that diffused in quartz or non-ore substrates.

The polymorphic partial texture was the most common texture, typical for pyrite, galenite, sphalerite, chalcopyrite, abiogenesis gold and electrum with varying sizes in a wide range and with many different shapes.

The overlapping texture was also quite common with minerals such as galenite, sphalerite, chalcopyrite, abiogenesis gold, and electrum interspersed in the cracks of pyrite grains. The shape and size of the intercalated minerals depended on the shape and size of the cracks in the pyrite grains.

The replaceable corrosive texture was also common. In some samples, clear minerals such as sphalerite, galenite, chalcopyrite, abiogenesis gold, and corrosive electrum can be observed, replacing a part of the pyrite grains.

Typical hard solution decomposition texture of sphalerite and chalcopyrite.

Cataclasis texture was sometimes observed in some samples: Pyrite particle, and arsenopyrite. The early formation was cataclastic, ruptured, galenite, sphalerite, chalcopyrite or goethite, hydro-goethite.

The texture of colloidal zone, microcrystalline, remnant grain, and hypomorphic grain, typical for oxidized ores showed in minerals such as covellite, melnikovite, goethite, hydro-goethite, etc.

2.3. Gold metallization controlling factor

2.3.1. Lithostratigraphy

The detailed and systematic research results showed that factors of favourable geological formation for gold mineralization in the study area were quite extensive. The gold ore bodies located in the geologic formations: Song Re (PR_1*sr*), Tac Po (PR_1*tp*), Kham Duc (PR_{2-3}*kd*). A Vuong (□-O_1*av*), Suoi Cat (O-S?*sc*) and in the formation of the Chu Lai complex. Thus, it can be seen that the gold ore in the study area is distributed in geological formations without selection properties, they are distributed in rocks with very different composition and structure, proving the factors stratigraphic lithology does not play a dominant role in spatial positioning of ore formation. However, in fact, it can be seen that the Kham Duc formation is an important object, they play the role of a favourable residence for gold ore bodies of industrial value, especially the weakness zone, tectonic nodes, adjacent ring structures to the granitoid blocks of the Ba Na Complex (Bao et al., 2001). The phenomena of hydrothermal change such as sericitization, beresitization, quantization, and chloritization were signs of gold ore in the rocks of the Kham Duc formation.

2.3.2. Magma

In the study area, a total of 10 intrusive magma complexes have been identified. These complexes are named as follows: Ta Vi, Nam Nin, Chu Lai, Hiep Duc, Tra Bong, Dai Loc, Que Son, Mang Xim, Tra Phong, and Ba Na. Additionally, there is one undivided vascular complex. Geological and mineralogical aspects of these magmatic complexes have been the subject of numerous studies conducted by lithologists and mineralogists. However, many of these studies have provided generalized information and lack a reliable database, particularly when it comes to understanding gold metallogeny. The most recent research findings indicate that the gold ore bodies in the study area share the following common characteristics.

In terms of spatial distribution, the research findings reveal a close spatial association between the gold ore bodies and the formations within the Ba Na complex in the general structural plan of the Tra Nu-Phuoc Thanh texture zone. These gold ore bodies tend to concentrate at both the inner and outer contacts of the granite blocks within the Ba Na complex, as well as neighbouring arch structures. Specifically, they are often found along the eastern and western edges of these blocks, aligning with the general structural orientation of the study area. This spatial relationship is notably observable in locations such as Bong Mieu, Phuoc Hiep, and Kham Duc. Consequently, it can be concluded that the formation of gold ore in the southern Tra Nu-Phuoc Thanh area is closely linked to the granitoid formations within the Ba Na complex in terms of their spatial development.

Regarding the chronological aspect, the gold ore bodies are observed to cut across the rocks of the Ba Na Complex, indicating that they are younger in geological age. This observation is supported by the exposure in Khe Ma, where tungsten ore veins intersect with the granite vein belt containing tourmaline from the Ba Na Complex. Conversely, these gold ore bodies are cut and displaced by polymetallic gold-quartz-sulphur ore veins. This evidence suggests that tungsten mineralization is unquestionably associated with the magmatic formations of the Ba Na Complex, while gold mineralization can only be related to geological processes that occurred after the formation of tungsten minerals.

Based on both inherited and independent research findings, it is possible to formulate a hypothesis regarding the gold mineralization process. It is hypothesized that hydrothermal solutions carrying gold ascended from the depths subsequent to the intrusion of the Ba Na granite magma. During their ascent, these solutions closely followed the favourable geological structures and textures established by the earlier formations within the Ba Na complex. These structures and textures shaped a particular structural zone. Consequently, it can be inferred that the granite formations within the Ba Na complex play a pivotal role in determining the spatial distribution and orientation of gold mineralization within the study area. In essence, the Ba Na complex serves as a crucial factor influencing the formation and orientation of gold deposits in the region.

2.3.3. Tectonic structures

Research findings related to the structure, tectonics, and controlling factors of mineralization reveal that the southern Tra Nu-Phuoc Thanh region can be divided into three distinct structural zones. These zones are characterized as follows:

Tra Trung-Tac Po structural zone: This zone is separated from the Tra Nu-Phuoc Thanh structural zone by the Ta Vi-Hung Nhuong fault (F1).

Tra Bong-Tra My fault zone: This fault zone serves as the boundary between the Tra Nu-Phuoc Thanh structural zone and the Bong Mieu-Phuoc Hiep structural zone.

Tra Nu-Phuoc Thanh structural zone: The Tra Nu-Phuoc Thanh structural zone is oriented in a sub-latitude direction and is considered a dynamic structural zone with high mineralization potential for elements such as gold (Au), lead (Pb), zinc (Zn), and others.

The mineral potential of the Tra Nu-Phuoc Thanh zone is particularly promising to the west and north, as indicated by research and development recommendations (Takayuki, 2014). This suggests that further exploration and study in these directions could yield valuable insights and opportunities for mineral resource development.

The presence of fault systems such as F_{III}, F_{IV}, F_{VI}, and F_{VII} cutting through the Tra Nu-Phuoc Thanh structural zone is a fundamental factor for gold prospecting in the area. These fault systems are closely associated with the granite formations of the Ba Na Complex, particularly the veined rock phase. This spatial relationship suggests that these fault systems played a significant role in the formation and localization of gold mineralization within the Tra Nu-Phuoc Thanh structural zone. Consequently, understanding the geological features and dynamics of these fault systems is crucial for effective gold exploration and prospecting efforts in the region.

3. Conclusion

Gold ore in the southern region of Tra Nu - Phuoc Thanh is found in rocks of varying compositions and ages, but it is most commonly associated with the rocks of the Kham Duc Formation and the granitoid formations of the Ba Na complex.

The ore mineral composition consists of several key minerals, including pyrite, chalcopyrite, galenite, sphalerite, arsenopyrite, pyrrhotite, primary gold, and electrum. These minerals fall under the classification of the gold-quartz-sulphur system, and they give rise to two typical ore types: gold-quartz-pyrite ore and gold-quartz-polymetallic sulphur ore.

The distribution of all gold ore bodies in the area is closely related to the fault and fissure systems, primarily oriented in a northeast-southwest direction. There is also some association with directions trending northwest-southeast and sub-meridian. Notably, the sub-meridian fault system serves as a conduit and distribution pathway for hydrothermal solutions containing gold ore within the study area.

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The paper was written to commemorate the 45th anniversary of the Prospecting and Exploration Geology Department, which has served as a cradle for training numerous geologists who have made significant contributions to the nation's construction and development.

Contribution of author

Thu Thi Le - conception, design of the study and drafting of the manuscript, acquisition of data, analysis or interpretation of data.

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