MINISTRY OF EDUCATION AND TRAINING
HA NOI UNIVERSITY OF MINING AND GEOLOGY

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CHARACTERISTICS OF GOLDEN MINERALIZATION IN THE ERUPTION FORMATION OF THE SOUTHWEST EDGE OF BU KHANG STRUCTURE

Speciality: Geotechnical Engineering
Code: 9520501

PhD thesis summary

Ha Noi - 2022

The thesis was completed at **the Department of prospecting and exploration, Faculty of Geological Sciences and Engineering, University of Mining and Geology**.

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INTRODUCTION

1. The urgency of the topic

The study area is located at the southwest edge of the Bu Khang uplift, a small part of the Late Paleozoic - Early Mesozoic in the Truong Son fold belts (Tran Van Tri et al., 2008) and is controlled by the Muong Lam - Quy Hop large faults in the northeast, Song Ca in the southwest. This is an area with the complex geological structures and abundanc**e** gold mineralization. According to the results of Geological mapping and mineral prospecting at the scale of 1:50,000, in the Kim Son sheet group, in Nghe An province, the geologists of the Intergeo Devision had discovered 13 sulfur mineralized zones containing gold and had circled 15 ore bodies. The mineralized zones and the ore bodies are distributed in the acid to neutral eruption rocks. The rock are broken, crushed and modified, extending discontinuously about 20 km, along the sub-latitude direction from Huoi Co village in Huu Khuong commune, Tuong Duong district through Huoi May village to Tang village in Cam Muon commune, Que Phong district, Nghe An province.

Although many sulfur mineralization zones containing gold and gold ore bodies had been discovered, due to the limitations of investment level in geological mapping and mineral prospecting, the research level on the material composition and the formation conditions of gold ore in the region is still very sketchy, not clarifying the nature of origin, type of deposit, type of gold ore distributed in the eruption formations, as well as geological controlling factors, in order to determine the distribution characteristics and the prospective assessment as a scientific basis for the search, exploration and exploitation of gold ores in the region, contributing to promote the country's economy.

Therefore, the topic of the doctoral thesis: "Characteristics of gold mineralization in the eruption formations at the southwestern edge of Bu Khang structure" was posed entirely from the needs of objective reality, in order to solve the remaining problems of science and practice mentioned above.

2. Objectives

Clarifing the characteristics of the material composition, origin and controlling factors of gold mineralization in the eruptive formations at the southwestern edge of the Bu Khang structure, creating a scientific basis for orienting the forecasting, propspecting and exploration of gold minerals in the region.

3. Tasks

- Collect, systematize and evaluate the available documents on geology and gold minerals in the study area.
- Study the material composition, ore-forming processes and determine the type of deposit, the type of gold mineralization. Determine the geological and chemical - physical conditions forming the origin of gold deposit.
- Research and determine the controlling factors on the gold mineralization and the prerequisites and signs for prospecting gold in the study area.
- Research to clarify the distribution characteristics and assess the prospect of gold ore in the eruptive formations at the southwestern edge of the Bu Khang structure.

4. Research object and scope: is gold ore and geological objects related to the gold mineralization at the gold occurences, the gold mineralization occurences in the southwestern edge of the Bu Khang structure

5. New points of the thesis

* By modern quantitative analysis methods (Cold test method, Raman spectroscopy method, Stable isotope analysis method O ($\delta^{18}O$) & H (δD), etc.) have clarified the chemical - physical conditions of gold ore formation in the study area (temperature, pressure, depth of ore formation, density of solution) and determining the source of the ore forming solution related to the intrusive magma.

* The role of the neutral and acidic extrusive formations (Country rocks) of T_2a age has been clearly identified in the Dong Trau Formation and the role of the granitoid formation of the Song Ma Complex, aged T_2 in the Au ore-forming process in the study area;

* The process of Au ore-forming and gold mineralization in the study area have been clarified, the type of hydrothermal gold deposit relates to the intrusive rock and is characterized by two types of ore mineral assemblages: quartz-arsenopyritee-gold and quartz-sulfide polymetallic - Au;

* The factors controlling the Au mineralization in the extrusive formations in the southwestern edge of the Bu Khang structure have been identified, including: The magma factor (the granitoid of Song Ma Complex); factors of tectonic-structure (northwest-southeast fault system and accompanying structures); The petrographic-stratigraphic factors (the combination of neutral and acidic extrusive rocks of the Dong Trau Formation).

* The author's additional new research results on the age of the U-Pb zircon isotope of the Song Ma Complex (247±2.5 Ma) contributed to clarify the process of magma activity in the study area in particular and the regional geological structure in general.

6. *Scientific and practical significance of the thesis*

** Scientific significance:*

Determination of the hydrothermal deposits associated with the intrusive magma with 2 types of typical ore-mineral assemblages: quartz-arsenopyritee-gold and quartz-sulfide polymetallic - Au, as well as clarifying the role of country rock the neutral, acidic extrusive rock formations, T_2a age of the Dong Trau Formation and the ore-forming role of the granitoid formation (I type granite) of the Song Ma Complex of T_2 age in the process of ore-formation is a scientific-practical basis that contributes to the theory of formation of ore deposits.

** Practical significance:*

The research results of the thesis will contribute to the orientation of forecasting, prospecting and discovering gold mineralization on surface and depth in areas with similar geological characteristics, serving the basic investigation planning, gold mineral prospecting-exploration in Vietnam.

7. Thesis defense arguments

Argument 1: Gold mineralization in the extrusive rock formations at the southwestern edge of the Bu Khang structure belongs to the type of hydrothermal deposits related to the intrusive rock. Hydrothermal mineralization activities take place in 4 stages, in which stages II & III are 2 stages of producing gold ore products corresponding to 2 types of mineral assemblage: quartz-arsenopyritee-gold and quartz-sulfide polymetallic - Au.

Argument 2: The process of gold ore formation in the study area is controlled by the following factors: The granitoid formations of the Song Ma Complex (G^p/T_2sm); the northwest-southeast fault system and accompanying faults; extrusive rocks: ryolite, ryodacite, andesite and their tuf belong to the set 1 of Dong Trau Formation ($T_2a\text{đ}t_1$) which plays the role of country rock.

8. *Documentary basis to complete the thesis*

The thesis is built on the main documentary source collected by the author and colleagues during the performance of the task "Geological mapping and mineral investigation, the scale of 1: 50,000, Kim Son sheet group", combined with additional analysis results during the author's doctoral thesis. Quantitative analysis data include: 134 samples of thin section for detailed analysis, 356 samples of fire assay, 60 samples of silicate, 144 samples of atomic absorption, 120 samples of pan-concentrate, 207 samples of plasma (ICP), 100 samples of polish section, 43 samples of ICP-MS, 16 samples for determination of inclusion temperature, 15 samples of Microseconds , 2 samples for analysis of U-Pb zircon isotope, 2 samples for analysis of stable isotope Oxygen ($\delta^{18}O$) and Hydrogen (δD)), 2 samples of Raman spectroscopy to determine inclusion composition. In addition, the researcher also consulted the published research papers on geological and mineral characteristics in the study area.

9. Thesis's layout

The content of the thesis is presented in 150 pages of A4 paper, in which there are 53 drawings, 13 tables, 96 photos and 02 appendices. In addition to the introduction and conclusion, the thesis is structured into 5 chapters.

10. The place to carry out the thesis topic

The thesis was conducted and completed at the Department of Minerals (now the Department of Prospecting and Exploration), Faculty of Science and Technology of Geology, University of Mining and Geology under the scientific guidance of Assoc. Prof. Dr. Nguyen Quang Luat and Dr. Nguyen Van Nguyen.

In the process of completing the thesis, the Ph.D student has received the favorable attention of the Rector Board of the University of Mining and Geology, the Postgraduate Training Department, the Department of Minerals, the Department of prospecting and Exploration - Faculty of Science and Technology of Geology; Leaders of the General Department of Geology and Minerals of Vietnam and especially the facilitation and support of all aspects of the Leaders of the International Geological Division (Intergeo Division). PhD also received encouragement, support, and enthusiastic suggestions from teachers and scientists in the fields of mineral geology and prospecting-exploration. PhD would like to thank very much.

THESIS CONTENTS

Chapter 1: Geological structure characteristics of the southwest edge of the Bu Khang structure

1.1. Location of the study area on the regional structural plan

The study area is located at the southwest edge of the Bu Khang uplift, a small part of the Late Paleozoic - Early Mesozoic of Truong Son fold belts (Tran Van Tri et al., 2008) and belongs to the southern part of the geological map of Kim Son sheet group, the scale of 1:50,000, has an area of about 580 km^2 bounded by the geographical coordinates: 19°21'12" - 19°30'58" north latitude; 104°35'59"- 104°54'17" east longitude. On the regional structural plan, the study area is composed of a part of 3 structural blocks: Bu Khang, Song Ca, Sam Nua-Hoanh Son, corresponding to 3 tectonic lithological complexes: ancient continental crust Neoproterozoic (NP), passive continental margin Paleozoic (PZ), post-collision intracontinental rift Mesozoic (MZ).

1.2. Brief history of geological and Au-mineral research

1.2.1. Brief history of geological research

**** The period before 1954:*** geological research was mainly conducted by French geologists at a small scale with a preliminary level of research.

**** The period after 1954:*** the study area was mapped the geology and minerals at the scale 1:500,000, 1:200,000 and 1:50,000 for some neighboring areas. From 2006-2019, the new study area is mapped the geology and minerals at the scale of 1:50,000 by the Intergeo Division.

1.2.2. History of research, prospecting – exploration of gold minerals

In 1992, Tran Quang Hoa et al. discovered placer gold existing in the study area with reserves and resources (level C_2+P_1+P_2) of 2,095kg Au.

From 2006 to 2019, during mapping the map of geology and investigating minerals at the scale of 1:50,000, geologists of the Intergeo Division discovered in the study area a number of promising areas of original gold ore: Huoi. Palm - Ban San, Ban Tang - Na Quya, Dong Ban Tang, Huoi May. Initially, 13 mineralized zones and 15 ore bodies have been identified with the level of resources 334a of 4,119 kg of gold.

1.2.3. Evaluating the previous research results and existing problems that need to be further studied

* The results of geological and gold mineral research have been achieved: clarifying the structural-tectonic context of the area, Scientifically-based division of the tectonic-lithological complexes, deformation phases, and stratigraphic units, magma formations in the study area; have determined the basic ore material composition in a preliminary way. It has initially clarified the potential of gold mineral resources in the study area.

**** Existing problems that need to be further studied:*** characteristics of material composition, ore – forming process; type of deposit, type of gold ore in the study area; Geological conditions for ore-forming, the relationship between the gold-mineralization with the extrusive and intrusive formations; chemical - physical conditions of formation, origin of gold ore; Factors controlling ore mineralization; Distribution characteristics and prospective assessment of gold ore in the study area.

1.3. Overview of the region's geological features

1.3.1. Stratigraphy

The stratigraphy of the study area is made up of: Neoproterozoic metamorphic terrigenous formations of the Bu Khang Formation (NP_{bk1}), terrigenous formations intercalated with the carbonaceous rocks that belonging to the deep sea facies of late Ordovician-Silurian age of the Song Ca Formation (O_3-S_{sc}), terrigenous-carbonate formations belong to the shallow marine facies of Late Silurian-Early Devonian age of the Huoi Nhi Formation (S_3-D_{1hn}), terrigenous-carbonate formations belong to the shallow marine facies of Early-Middle Devonian age of the Huoi Loi Formation ($D_{1\text{-}2\ hl}$), terrigen-carbonate formations belong to the shallow sea facies of Middle Devonian age off the Nam Can Formation (D_2nc), terrigenous formations intercalate the neutral, acid extrusive rocks of Middle Triassic age of the Dong Trau Formation (T_2a_{DT}), loose sediments of the Quaternary (Q). In which, the Dong Trau formation contains the mineralized zones and the gold ore bodies, which is the main research object of the thesis.

Dong Trau Formation ($T_2a_{đt}$): distributed in a strip in the northwest-southeast direction in the center of the study area and divided into two members: Member 1 ***($T_2ađt_1$)*** is characterized by the predominance of coarse terrigenous sedimentary rocks interlayer the lenses of acidic, neutral extrusive rocks with facies: extrusive facies include: andesite, porphyr ryolite, quartz porphyr, dacite; Explosive facies include: andesite tuf, dacite tuf, ryolite tuf; sub-volcanic facies: sub-volcanic diabas. Member 2 (T_2a*dt₂*) is composed of the fine-grained terrigenous sedimentary rocks such as siltstone, shale. The thickness of the formation is about 1800m, of which the total thickness of the extrusive rock layers is 1000m.

Geochemical characteristics of the extrusive rocks of Dong Trau Formation: the main element group research results are posted on the petrological research charts showing that the extrusive rocks of Dong Trau formation fall into the ryolite and basalt-andesite fields; belonging to the alkaline lime series; potassium series (potasic); medium alkali-lime series to high potassium; aluminum medium range, to oversaturated aluminum (peraluminous). The results studying the rare-trace element group are shown on the normalized charts, showing that: the extrusive rocks of the Dong Trau Formation are typical for magma formations that were formed in the geodynamic environment "the edge of the convergent plate" in the spreading tectonic regime, close to the tectonic context of "intracontinental rift after orogeny".

Age of the formation: in the study area, the sedimentary and extrusive formations of the Dong Trau Formation (T_2a*dt*) are penetrated by the granitoid of the Song Ma Complex (γT_2*sm*). On the other hand, in the sedimentary formations intercalates in the extrusive formations discovered many fossils of Ammonoidea and Pelecypod, dating to Anisi (T_2a). Therefore, the age of the Dong Trau Formation is recorded in the Middle Triassic (T_2a), Anisi level as the previously published documents.

Characteristics of alteration zone and related minerals: the terrigenous sedimentary rocks and the extrusive rocks: ryolite, ryodacite, andesite of the Dong Trau Formation and their tufs have been crushed, broken according to the faults and often altered hydrothermal strongly, forming the altered rocks including: quartz, chlorite, sericite, sometimes with calcite, actinolite, epidote, and intercalted by the gold-sulphide-bearing quartz veins. With the above characteristics, the Dong Trau Formation plays the role of country rock of the gold ore.

1.3.2. Magma

Song Ma Complex (G^p/T_2*sm*): The granitoid rocks of the Song Ma Complex are distributed in the small blocks that cut through the rocks of the Dong Trau Formation (T_2a*đt*) in the southwest of Tang village and along the tectonic boundary between the rocks of the Dong Trau Formation (T_2a*đt*) and Nam Can Formation (D_2*nc*), Huoi Loi Formation ($D_{1\text{-}2}$*hl*). The largest block (Suoi Rong block), with an area of 25km^2, is located in the southwest of Tang village about 3.5km, the other blocks are smaller the occurrence areas. The petrographic composition of the block is mainly: granodiorite and granite.

Geochemical characteristics: the results of research on the main element groups are posted on the lithological research charts showing that: The granitoid rocks of the Song Ma Complex dominate more sodium than potassium - corresponding to the Sodic magma series, or the calc alkaline magma series with medium - low potassium; high aluminum content is characterized by the aluminum saturation index ASI always greater than 1 (ASI>>1), belongs to the oversaturated aluminum magma series, corresponding to the typical calc alkaline magma series (I- type granite). The intrusive rocks of the Song Ma Complex are mainly granite and granodiorite, with medium to low alkalinity belonging to the sodic magma series, or the calc alkaline magma series. The results of the study of rare-trace element groups are shown on the normalized charts, showing that: The granitoid formations of the Song Ma Complex correspond to the magma formations of the calc-alkaline magma series formed in the geodynamic environment. " the edge of convergent plate". However, the high content of Ta-Nb shows that the Song Ma granitoid here is related to the "intracontinental rift" spreading tectonic regime. Therefore, it is more reasonable than the geodynamic environment “intercontinental rift after orogeny” (Post-CoLL) for the granitoid formation of the Song Ma Complex.

Origin & geodynamic context: According to the characteristics of material composition (lithology, mineralogy, geochemistry) mentioned above, the granitoid assemblage of the Song Ma Complex belongs to the calc-alkaline magma series and medium - low in potassium, rich in large ion lithophile elements (LILE), light rare earths (LREE) and Ta-Nb, and poor in heavy rare earths (HREE) and high-field-strength elements (HFSEs), corresponds to the magma formations arising in the geodynamic environment of "converging plate edge" under the "spreading" tectonic regime after orogeny! Therefore, the Song Ma granitoid complex is similar to the post-orogenic granite type (post-CoLG).

Formation age: Song Ma granitoid complex is closely related in space, time and origin with the extrusive formations of Dong Trau formation with the fossils of Anisi dating (T_2a*đt*). During the thesis work, Author analyzed 01 absolute age sample of granite of the Song Ma Complex by the U-Pb zircon isotope method in Korea, giving the age range from 246 ±1.5 Ma to 284.5±0, 56 Ma, average 247±2.5 Ma. From the above results, it shows that the granitoid formations of the Song Ma Complex have an average age of 244-247 Ma, corresponding to the Middle Triassic, Anisi order (T_2a).

Related Minerals

According to the above data, it shows that the rocks of the Song Ma Complex are closely related in space, time and origin with the extrusive formations of the Dong Trau Formation (T_2a*đt*), in the distribution area of this formation has many manifestations of mineralization and gold deposits. Au minerals are spatially related to the Song Ma Complex and the Dong Trau Formation.

Vein rocks of unknown age: include diabas and gabrro, they are distributed mainly in the central area of the study area. They cut through terrigenous sedimentary rocks and intercalated the acid extrusive rock of the Dong Trau formation (T_2a*đt*). These vein rocks have a thickness of 1-3m, sometimes they have a hump form with size of 10-15m. The relationship between the gold ore and the diabas and gabbro veins has not been studied.

1.3.3. Structural - tectonic characteristics

1.3.3.1. Deformation phases

- *The first deformation phase:* the recorded signs are inverted and horizontal fold structures, mainly in the NW-SE direction and the NW-SE thrust faults or sub-latitudes in the distribution area of the formations from Proterozoic to Middle Permian. This deformation phase occurred during the Permian - Triassic period, related to the Indosinian orogenic movement in the East and Southeast Asia.

- ***The second deformation phase:*** the recorded signs are the NW-SE thrust faults with the direction of the fault surface to the northeast together with the broken and folded zones develop along the fault zones. The age of this deformation phase is assumed to occur at the end of the Late Triassic.

- ***The third deformation phase:*** this deformation phase is related to the uplift activity of the Bu Khang block that occurs in the early Kainozoic. The recorded signs include the gentle normal faults surrounding the Bu Khang block, recorded in the granite of the Ye Yen Sun complex, and the rhyolite of the Muong Hinh complex.

- The fourth deformation phase: temporarily classified into this deformation phase are the brittle strains occurring in the late Kainozoic. The signs of this deformation phase are the normal faults, reverse faults, strike slip faults that develop in the different directions, cutting through all the geological formations and structures in the region.

1.3.3.2. Fault characteristics

In the study area, many major faults with the different dynamic properties have been recorded. However, the major and large-scale faults that play a main role in creating the structure of the region and play a main role in forming minerals are the faults with the northwest - southeast or sub-latitudes. The northeast - southwest faults are usually small-scale faults, active in the Kainozoic.

Based on their scale (length, depth) and their role in the area, faults are divided into 2 levels: level I, level II and undivided faults.

1.3.3.4. Characteristics of the fold structure

The main folding structures formed in the study area are the NW-SE oriented fold structures. The fold structure of the NW-SE direction is clearly recorded and most characteristic is in the Song Ca structural zone. These are linear structures with the prominent features of island folds, horizontal folds with rather gentle axial surfaces, mainly oriented to the North and Northeast. This folding system is associated with the squamous structure, which is a consequence of the thrust fault activities of the early deformation phase, related to the Indosinian orogenic movements, during the Late Permian - Triassic period.

Chapter 2: Theoretical background and research methods

2.1. Gold overview

2.1.1. Geochemical characteristics of gold

Gold has the chemical symbol Au and is located at 79th position in the Mendeleev periodic table. Gold lies between platinum (78th) and mercury (80th). Gold belongs to group IB, in order, including: copper, silver and gold; in which, copper and silver are symbiotic elements accompanying gold. Gold has an atomic mass of 79 and a density of 19.5. Gold melts at 1065^{o}C and boils at 2960 ÷ 2970^{o}C. Up to now, gold is known to have 14 isotopes with masses from 192 to 206, but only one stable isotope in its natural state is ^{197}Au. In contrast, the unstable isotopes of gold are short-lived, as known ^{196}Au - ^{198}Au - ^{199}Au. Gold has valence 1+ and 3+, trivalent gold compounds are more stable, in which gold forms complex anions.

Gold is a very inactive metal, less active than silver, belonging to the group of siderophil and chalcophil elements; in which, gold prefers iron over copper. Gold is a less common element, unevenly dispersed in the Earth's crust with a Clark value of 4.3x10^{-7}%. The average gold content in magmatic rocks also varies (RW Boyle,1979): ultramafic - 4.0x10^{-7}%, mafic - 7.0x10^{-7}%, neutral - 5.0x10^{-7}%, acidic - 3.0x10^{-7}%.

2.1.2. Characteristics of mineralogy of gold

- *Minerals of gold:* In primary ore, more than 20 minerals of gold have been identified, they manifest in the form of natural gold, the natural alloy form of gold and the form of gold telluride. Native gold in endogenous ores is the main industrial mineral; secondary significance is the minerals: Muthmannite, electrum and tellurides - calaverite, krennerite, sylvanit, Petzite.

- Chemical composition of native gold :

Currently, more than 40 impurity elements have been detected in native gold such as: Ag, Fe, Cu, Pb, Sb, As, Hg, Zn, Bi, Se, Te, Mn, Ti, Cr, Sn, W, Mo; very rarely: Co, Ni, V, Pt, Pd, Ir, Y, Nb, Rh, Cd, In, Os, Th, Be, B, C, Mg, Al, Si, Ca, Zr, O, S, Cl.

2.2. Types of industrial deposits of Gold

Based on the formation conditions and economic value, gold mines are divided into the following types of industrial deposits: skarn deposit, hydrothermal deposits related to intrusive magma, and hydrothermal deposit related extrusive magma, gold depoisit related to metamorphic origin (including hydrothermal-metamorphic deposits and sedimentary-metamorphic deposits), weathering deposits, and placer deposits.

2.3. *Research situation of Au mineralization in Vietnam*

The study and classification of gold deposits in Vietnam has been conducted since the 80s of the last century. Typically, the research works of the authors: Yu.A. Epstein (1987); Nguyen Van De (1987); Nguyen Nghiem Minh et al (1990); Nguyen Nghiem Minh, Vu Ngoc Hai et al (1991); Nguyen Nghiem Minh, Nguyen Van Chu (co-authors), Nguyen Van Pho, Nguyen Ngoc Truong (1993-1995) and some other researchers.

2.4. Terms used in the thesis

The terms used by the author in the thesis include: type of deposit, type of ore, mineral symbiotic assemblage, mineral assemblage, period of mineral formation, mineral forming stage, ore region, ore field, magmatic ore system.

2.5. Research Methods

2.5.1. Field research methods

Research on the structural-tectonic characteristics; Determine the location of mineral deposits, gold ore bodies in the geological cross-section; Determine the spatial relationship (or non-relationship) of the gold ore to the intrusive rocks; Study the characteristics of country rocks; Study the characteristics of distribution, morphology and structure of ore bodies. Take the sample types serving the research contents.

2.5.2. Research methods in the room

a. Methods of synthesizing, analyzing and systematizing the relevant documents: synthesizing the overview research documents on gold in the world and in Vietnam. Synthesizing the research documents on geology - gold minerals in the study area. Analyze, process and interpret the data and documents related to the research subjects.

b. Analytical methods: In order to serve the study of material composition, physico-chemical conditions for gold ore formation, isotope research, thin section analysis; mineral analysis; silicate chemistry analysis; atomic absorption spectroscopy analysis; analysis of plasma spectroscopy (ICP, ICP-MS); scanning electron microscopy (SEM); analysis of inclusion homogenization temperature; Raman spectroscopy analysis; freezing point determination (cryoscopic method); isotope analysis $\delta^{18}O$ and δD; U-Pb zircon isotope age analysis.

c. Expert method: carried out through seminars and discussions with experts in the field of in-depth research, related to the research field of the thesis.

Chapter 3: Geological characteristics of gold mineralization in the southwestern edge of the Bu Khang structure

3.1. Characteristics of distribution, morphology and structure of mineral bodies

3.1.1. Distribution characteristics of mineralization zones and gold ore bodies

In the study area, eight gold-bearing sulfur mineralization zones have been discovered. The mineralization zones extend discontinuously about 20km, along the sub-latitude direction from Huoi Co village in Huu Khuong commune, Tuong Duong district through Huoi May village to Tang village in Cam Muon commune, Que Phong district, Nghe An province. In which, 15 ore bodies and 3 mineralization zones have been circled. General characteristics of the mineralization zones and the gold ore bodies are distributed in the fractured, crushed and alteration zones of propritization, bezeritization, quartzization, sericitization, chloritization, calcification, epydotization according to the northwest - southeast faults that cut through rhyolite, ryolite intercalated siltstone, silstone-ryolite tuf, sandstone-silstone-ryodacite tuf, ryodacite tuf intercalated with small-grained quartz sandstone, andesite and andesite tuf..... belong to member 1 of the Dong Trau formation ($T_2a\textit{đ}t_1$).

3.1.2. Characteristics of morphology and structure of gold ore bodies

3.1.2.1. Huoi Co - Ban San Area

- *Mineralization zone No. I:* extends in the direction of east - west about 2300m, width from 60 - 270m, dip-direction to the south, south-southwest. In the mineralization zone No. I, 02 gold ore bodies (TQ.1, TQ.2) have been identified: TQ.1 extends from the northwest to the southeast about 210m, the average thickness is 1.35m, dip-direction to the Southwest with dip angle from 80^0-85^0; TQ.2 extends 300m in the general direction of Northwest - Southeast, the average thickness is >1m, dip direction to the South, South - Southwest with the dip angles of 30^0 - 65^0.

- *Mineralization zone No. II:* extends in the direction of east - west about 3600m, wide 120 - 340m, dip-direction to the south, southwest with dip angle from 30^0 - 80^0. In the zone, 03 ore bodies have been circled (TQ.3; TQ.4; TQ.5) and 02 mineralized zones (TK.1, TK.2): TQ.3 extends about 120m in the direction of northwest - southeast, the thickness is from 0.80 to 1.90m, dip-direction to the south, southwest with the dip angle from 65^0 - 80^0; TQ.4 extends from the northwest to the southeast about 60m, the body thickness reaches ~2.0m, dip-direction to the southwest with the dip angle of ~65^0; TQ.5 extends along the sub-latitude about 100m, the thickness reaches ~1.9m, dip-direction to the north with the dip angle of ~65^0; TK.1 extends from the northwest to the southeast about 100m, the thickness reaches ~0.8m, dip-direction to the northeast with a dip angle of ~300; TK.2 extends from the northeast to the southwest about 400m, the average thickness is 1.25m, dip-direction to the northwest with the dip angles of 60^0 - 75^0.

The ore-bearing rock is andesite which is pressed, propylitized, sericitized, chloritized, quartzized, calcitized, concentrated with many stockwork veins of quartz – sulfur with thickness from a few mm to >1cm, penetrating mainly along the pressed surface, secondary to the fractures. The average gold content in the ore bodies ranges from 0.6 - 12.3 g/T.

3.1.2.2. Huổi Mây area

- *Mineralization zone No. I:* extends from the northwest to the southeast about 2,500m, the width is from 40 to 130m, dip-direction to the southwest, sometimes reverses to the northeast with the dip angles of 50° - 85°.

- *Mineralization zone No. II*: extends from the northwest to southeast about 290m, dip-direction to the north - northeast with the dip angle of 50^0 - 80^0. In the zone, the ore body TQ1 has been circled, extending 120m from the Northeast to the Southwest, average thickness: 1.67m, dip-direction to North - Northeast with the dip from 50^0 to 80^0.

- *Mineralization zone III:* extends along the sub-latitude of about 860m, width is from 10 - 70m, dip – direction to the South - Southwest at the dip angle of 40^0 - 50^0. In the zone, the ore body TQ.2 has been circled, extending about 280m, average thickness: 1.15m, dip – direction to the south, southwest with the dip angle from 50^0 to 55^0.

Ore-bearing rocks are ryolite, ryodacite, ryodacite tuf intercalated with the black shale. The ryodacite tuf intercalated with the strongly pressed fine-grain quartz sandstone with quartz-sulphide veins and network veins that cut mainly along the pressure surface, secondary along the fractures. The rocks were compacted and altered (bezeritization, sericitization, quartzization, and chloritization). The average gold content in the ore bodies is 2.01 - 2.50g/t.

3.1.2.3. Bản Tang - Na Quya area

- *Mineralization zone No. I*: extends about 3800m in the east-west direction, 50-280m wide. The rocks in the zone usually have the dip direction to the north and northeast with a dip angle of 30^0 - 70^0. In this zone, 02 ore bodies (TQ.1; TQ.2) have been identified: TQ.1 extends about 300m in the east - west direction, with the thickness of 2.0 - 2.1m, dip – direction to the north with the dip angle of 45 - 50^0; TQ.2 extends about 900m in the east-west direction, the average thickness: 2.0m, dip-diėction to the north with the dip angle of $45\text{-}60^0$.

- Mineralization zone No. II: extends about 2,200m in the sub-latitude direction, 50-80m wide, dip – direction to the north and northeast with the dip angle of 30-700. In this zone, the ore body TQ.3 has been identified about 300m in the east – west direction, average thickness: 1.4m, dip diretion to the north with the dip angle of 75^0.

In mineralization zones No. I, II and ore bodies TQ.1, TQ.2, TQ.3, ore-bearing rocks are ryolite, sandy siltstone, ryolite tuf, rhyolite intercalated the broke and altered (Quartzization, sericitization) siltstone containing the quartz – sulphide veins. The average gold content in the ore bodies is 1.19 - 1.3g/t, silver is from 0 - 30g/t.

- *Mineralization zone III:* extends about 1000m in the sub-latitude direction, from 30 - 120m wide. The general dip direction of the zone is the northeast, sometimes to the northeast, with the dip angle of 40^0 - 70^0. In the mineralization zone, 03 ore bodies have been identified (TQ.4, TQ.5, TQ.6): TQ. 4 extends about 200m in the direction of east-west, with the thickness of 1.6 - 2.2m, dip direction to the north with a dip angle of 45 - 60^0; TQ.5 extends about 300m in the sub-latitude direction, with the thickness of 1.5 - 2m, dip direction to the north - northeast with the dip angle of 65 - 70^0; TQ.6 extends about 100m in the sub-latitude direction, with the thickness of 1.8 - 2m, dip direction to the north with the dip angle of 50 - 70^0.

- *Mineralization zone No. IV:* extends about 1150m in the northwest-southeast, 40-150m in width, dip directio to the north-northeast, in some places to the northeast, with the dip angle of $55\text{-}75^0$. In this mineralization zone has circled two ore bodies (TQ.7 and TQ.8): TQ.7 extends about 100m in the sub-latitude direction, thickness is from 1.0 - 13.8m, dip-direction to the north with the dip angle 65 - 70^0; TQ.8 extends about 300m in the east-west direction, the average thickness is 2.93m, dip-direction to the north and northeast with the dip angle of $55\text{-}75^0$.

In mineralization zones III, IV and TQ.4 - TQ.8 ore-bodies, the ore-bearing rocks are andesite, andesite tuf which are crushed, broken and altered as propytization, sericitization, chloritization, calcitization, there are the quartz – sulphide veins. The country rocks are strongly compacted blue-gray andesite, andesite tuf. The average gold content in the ore bodies is 1.27 - 4.69g/t, silver is from 0 - 30g/t.

3.1.2.4. Đông Bản Tang area

- *Mineralization zone No. I:* extends to the sub-latitude ~500m, width ~5m, dip direction to the North - Northeast with the dip angle from 70 - 900; *Mineralization Zone No. II:* extends to the sub-latitude ~400m, width from 5 to 10m, dip-direction to the North - Northeast with the dip angle of 50^0; *Mineralization zone III:* extends along the sub-latitude ~900m, width is from 2m - 50m, dip direction to the North with the dip angle of 45^0 - 50^0. In mineralization zone III, the ore body TQ.01 has been circled, extended along the sub-latitude about 450m, the average thickness of 0.87m, dip direction to the north with the dip angle of ~45^0; The ore-bearing rock is ryolite intercalated with thin layers of sericite-chlorite-quartz schist. Rhyolite intercalated with the sericite schist which was crushed, cracked, broken and altered weekly as quartzitization, sericitization, choritzation. In the rock, there are the quartz-sulphide veins cutting. The average gold content in the mineralized zone is >= 0.4g/t to 1.5g/t. The average gold content in the ore body TQ.1 is 1.32g/t; copper from 0.091 to 0.22%; lead from 0.025 - 3.3%; zinc from 0.093 to 2.82%.

- *Mineralization zone No. IV:* extends to the sub-latitude of about 400m, width is ~10m, dip-direction to the North - Northeast with a dip angle of 60 - 70^0. The ore-bearing rock is andesite that was greenitized, crushed strongly and propylitization, sericitization, chloritization, calcification. There are the quartz – sulphide stockwwork veins cutting. The gold content in the zone ranges from >0.4g/t to 0.6g /t.

3.2. *Features of hydrothermal alteration of country rocks*

In the study area, the hydrothermal alterations are encountered as:

* Propylization: the process of propylitization develops in the intermediate extrusive rocks as andesite, andesite tuf. This process develops almost over the distribution areas of the above-mentioned rocks with the characteristics of alteration in the area-form, especially where these rocks are compressed, crushed, broken forming the propylite as greenshist in form. This is a favorable environment both in terms of geochemistry, both in terms of physical and mechanical aspects, creating conditions for later ateration processes such as epidotization, quartzization, ... forming the propilitization zones closely associated with the sulfur mineralization zones bearing gold, such as the gold ore bodies in Huoi Co - Ban San and Ban Tang areas. The process of propylitization almost erases the mineral composition, texture, and structure of the original rock, sometimes shows faintly phenocryst or tuf fragments, while the background is completely replaced. The research results have recorded 3 types of Propylization (V.L. Ruxinov, 1968) as follows: + Propylite actinolite - epidote belongs to the high-temperature Propylization; + Propylite albite - epidote - chlorite belongs to the medium-temperature Propylization; + Propylite calcite - albit - chlorite belongs to the low-temperature Propylization.

* Beresitization: the beresitization process develops in the acid extrusive rocks such as dacite, ryodacite, ryolite and their tuf. This process develops locally, especially where these rocks are compressed, crushed, broken, cracked, forming the beresitized rocks closely associated with the gold-bearing sulfur mineralization zones, such as the gold ore bodies in the Ban Tang, Na Quya areas. The beresitization process almost erases the mineral

composition, texture, and structure of the original rock, sometimes show faintly phenocryst or tuf fragments, while the background is completely replaced. The research results have recorded 2 types of beresitization: quartz beresite + sericite + pyrite and quartz beresite + sericite + alkerite + pyrite.

* Ankeritization: in addition to the alkeritization process associated with the quartz + sericite assemblage in the beresitization. The alkeritization process develops independently and not commonly, develops locally, replace in the scattered form, clusters, small clusters, sometimes replacing along fissures creating microveins, stockwork veinlets in the Ban Tang, Na Quya areas.

* Chloritization: in addition to the chloritization process associated with the mineral assemblages of actinolite + epidote + chlorite + albite + pyrite, albite + epidote + chlorite + quartz + pyrite, calcite + albite + chlorite + pyrite, ... The chloritization process grows independently, not commonly, grows locally, replaces overlap in the form of dispersion, scatters, small clusters, sometimes replacing along the fissure, creating microveins, stockwork veinlets in the Ban Tang and Na Quya areas.

* Sericization: in addition to the sericitization process associated with the asemblages of quartz + sericite + pyrite, quartz + sericite + alkerite + pyrite, ... in beresitization, propitization, the sericitization process develops independently and less commonly, it is often closely related to the process of quartzitization, grows locally, replaces in the form of dispersion, scatters, clusters, small clusters, sometimes replacing along the fissure forming microveins, stockwork veinlets in the Huoi May area.

* Quartzization: in addition to the quartzization process associated with the mineral assemblages of quartz + sericite + pyrite, quartz + sericite + alkerite + pyrite, ... in beresitization, the process of quartzization (quartz II) develops quite commonly in the extrusive rocks and their tufs, terrigenous sedimentary rocks, terrigenous carbonaceous rock, etc.. The extrusive rocks and their tufs have been propylitized, beresited. The process of quartzization (quartz II) occurs after propitization, beresitization, ankeritization, chloritization, grows locally, replaces in the form of dispersion, scattered, clusters, small clusters, sometimes replaces along the cracks forming veinlets, stockwork veinlets, often accompanied by the sulfur mineralization containing gold, such as the gold ore bodies in Huoi May, Na Quya, etc.

* Calcitification: in addition to the calcination process associated with the mineral assemblages of calcite + albite + chlorite + pyrite, calcite + albite + chlorite + sericite + quartz + pyrite, ... in propitization, the calcitization process develops independently, separately, quite commonly. It occurs at the latest after the above alteration processes. Calcification develops locally, replaces in the forms as dispersion, scatters, clusters, small clusters, sometimes replaces along fissures creating vugs, microveins, stockwork veins and usually occurs after sulfur mineralization.

Chapter 4: Characteristics of Material composition and origin of gold ore in the southwest edge of Bu Khang structure

4.1. Characteristics of of ore mineral composition

Based on summarizing results from the polish section method and the thin section method showed that the mineral composition of ore includes: ore minerals (from primary to secondary), non-metallic ore minerals (materials of the hydrothermal alteration rocks and vein rocks) as follows:

Group of primary ore-forming minerals

- Native gold (Au): Research results under the microscope show that gold exists in the native form, commonly in the anhedral with the diverse morphology and very different sizes and consists of 2 generations: formed in two distinct mineralization stages, corresponding to stages II & III of the hydrothermal ore formation.

+ Gold generation I (Au I): in the polish section samples, Au I is encountered in the form of microparticles, distortion, euhedral, isometric, globular or elongated particles that fill up the micro-fissures, the size of Au I particles from 0 .01 - 0.05mm, bright yellow. Gold generation I is distributed dispersedly in the quartz or dispersion in the alteration rocks, especially Au I has a close symbiotic relationship with arsenopyritee I. Au I is also closely associated with pyrite II and pyrrhotite; sometimes meet Au I and pyrite II diffused in quartz, in which Au I and pyrite II have a flat contact relationship, showing a symbiotic relationship. The analysis results of Au I minerals under the scanning electron microscope (SEM) showed that Au I had an average Au content of 97.39%, an average Ag content of 2.61%, corresponding to the purity of natural Au. born is 974 in the high category.

+ Gold generation II (Au II): in the polish section samples, Au II is encountered in the form of distortion, in bright yellow. Gold generation II is dispered in quartz, often accompanied with sphalerite, galena, arsenopyritee II, pyrite III and chalcopyrite. Under the microscope and the scanning electron microscope (SEM), it was clearly observed that Au II has a plat contact (co-symbiotic) relationship with the sphalerite that fills the micro-fissures in pyrite II. The size of Au II particles is always fine, mostly less than 0.05 mm. The analysis results of Au II minerals under the scanning electron microscope (SEM) showed that Au II has a Au content of 87.42%, Ag content of 12.58%, corresponding to the purity of native Au of 874 belonging to Au II from medium to high.

+ Pyrite (FeS_2): It is a common mineral in the gold ores of the study area, in the set of the polish section samples, the average pyrite content is ≈5%. Pyrite is distributed dispersedly, concentrated in the small clusters, sometimes fills up in the micro-fissures creating the short veinlets in the alteration rocks or in the quartz. Under the microscope, three generations of pyrite were distinguished:

- *Pyrite generation I (Pyrite I):* accupy about 10% of the total pyrite in the sample set, typical for the first stage of hydrothermal ore formation in the study area.

- *Pyrite generation II (Pyrite II)*: accupy about 80% of the total pyrite in the sample set, formed during the mineralization phase II of the hydrothermal ore formation in the study area.

+ *Pyrite generation III (Pyrite III):* accupy about 10% of the total pyrite in the sample set, formed during the mineralization phase III of the hydrothermal ore formation in the study area.

+ Arsenopyritee (FeAsS): is quite the common mineral in the polish section set. Arsenopyritee exists mainly in the form of semi-automorphic, automorphic and anhedral particles with the common grain sizes ranging from 0.1-0.5mm, sometimes >1mm. The arsenopyritee content in the polish section samples is often uneven, some samples are up to ≈70%. Under the microscope, two generations of arsenopyritee can be distinguished:

- *Arsenopyritee generation I*: accupy about 80% of total arsenopyritee. Asenopyrite I together with Au I, pyrite II and pyrrhotite forms the mineral symbiotic complex typical for the ore type: Quartz-arsenopyritee-gold.

- *Arsenopyritee generation II:* accupy about 20% of total arsenopyritee. Asenopyrite II together with Au II, pyrite III, sphalerite, galena and chalcopyrite form the mineral symbiotic complex typical for the ore type: Quartz-sulphide polymetallic-gold.

+ Pyrrhotite (FeS): is a less common mineral in the gold ore samples in the study area. The pyrrhotite content in the polish section samples ranged from 1 ÷ 3%. Pyrrhotite exists in the form of anhedral particles with sizes varying in a wide range from 0.02 to 2mm. Pyrrhotite creates the mineral symbiotic assemblage with pyrite II, arsenopyritee I, Au I, formed in the secondary mineralization stage, which is typical for the ore type: Quartz-arsenopyritee-gold.

+ Chalcopyrite ($CuFeS_2$): is quite a common mineral with a frequency of 60% in the sample set, but chalcopyrite has a very low content in the polish section samples ≤0.2%. Chalcopyrite exists in the form of plates, anhedral with the grain size of 0.01 ÷ 0.5mm, especially ≈2mm. Chalcopyrite often accompanies arsenopyritee II, galena and sphalerite to form a secondary mineral.

+ Galena (PbS): is a less common mineral with a frequency of about 30%. In the polish section samples, galena was encountered with the content ranging from 0.5 ÷ 2 %, especially 5%. Galena exists in the form of anhedral particles with the size of 0.02-1mm, sometimes ≥2mm. Galena is usually accompanied by sphalerite or with chalcopyrite and arsenopyritee II.

+ Sphalerite (ZnS): is a less common mineral with a frequency about 30%. In the polish section samples, sphalerite was encountered with the content ranging from 1 ÷ 5%, especially 10%. Sphalerite exists in the form of anhedral particles with the size of 0.1-1mm, sometimes ≥2mm Sphalerite is often accompanied by galena or with chalcopyrite and arsenopyritee II. Sphalerite together with galena, chalcopyrite, arsenopyritee II, pyrite III and Au II formed the symbiotic mineral assemblage typical for the quartz-sulphide polymetallic-gold ore in the study area.

Secondary ore minerals

In addition to primary minerals, in the ore, there are also secondary minerals that are the product of the alteration process of primary minerals in the oxidizing environment. Common secondary ore minerals in the ores of the study area include: Goethitee, Scoroditee, Covelinee, Bornitee, anglesite, limonite.

Group of vein minerals and altered rock minerals: includes quartz, calcite, sericite, chlorite, epidote, ankerite.

4.2. Characteristics of structure and texture of ore

4.2.1. Ore structure features

The ores in the study area have the main structures as:

- *Vuggy structure:* characteristic for sulfur minerals such as pyrrhotite, pyrite and partly the combination of these two minerals with chalcopyrite or the combination of galena and sphalerite.

- *Dispered structure:* The dispered structure at different levels is the most common type of structure in the ores of the study area. This type of structure is typical for ore minerals such as pyrite, arsenopyritee, pyrrhotite, chalcopyrite, galena, chalcopyrite.

- *Vein and stockwork structure:* This type of structure is typical for the method of filling cracks of the hydrothermal solution, encountered the minerals: pyrite, arsenopyritee, chalcopyrite, galena, sphalerite, but most commonly for minerals minerals: chalcopyrite, galena, sphalerite.

4.2.2. Ore texture characteristics

The ores in the study area have the main textures following:

- *Euhedral particle, semi-euhedral particle:* common in arsenopyritee and pyrite mineral particles, they have clear crystal morphology with size 0.1-0.4mm.

- *Ạnhedral texture*: is the most common structure and is found in most minerals in the ores of the study area such as: pyrite, arsenopyritee, pyrrhotite, chalcopyrite, galena, sphalerite, native Au with variable sizes in the range from 0.02 ÷ 2mm, sometimes >2mm.

- *Filled texture:* common with minerals: chalcopyrite, galena, sphalerite and sometimes native Au, they intercalated, filled into the joints of alteration rocks or quartz and sometimes filled into other veins containing minerals such as pyrite, pyrrhotite.

- *Hard solution decomposed texture:* is an uncommon texture in ores, but is typical for two minerals sphalerite and chalcopyrite.

- *Alternative corrosive texture:* this type of texture is common in the ores of the study area. Under the polish section samples, minerals such as pyrite, pyrrhotite, chalcopyrite, galena, and sphalerite can be observed very clearly, replacing, corrosion, sometimes bonded with the rock-forming minerals or ore minerals as well as the previous vein minerals.

In addition to the textures described above, in the ores of the study area, there are also some typical textures for the oxidized ores such as the colloidal textures, zonal colloidal texture, cell-blocking hole texture, microcrystal particles, relict particles, allomorphic particles,... shown in minerals such as Goethitee, Scorodite, Covelinee, Bornitee, anglesite, Melnicovitee.

4.3. Chemical characteristics of Au ore

The chemical composition of the Au ore bodies in the study area includes the main elements Au, Ag, the minor elements include: Fe, Ti, Cu, Co, Ni, Pb, Zn, Sn, As...

4.4. Periods and stages of mineralization forming

On the basis of synthesis of analysis results of the polish section, thin section and other types of samples in the Southwest region of Bu Khang structure, it shows that the Au ore in the study area was formed in 2 periods: The hydrothermal period consists of 4 stages of mineralization forming and the weathering period includes one stage of mineralization forming. Each mineralization stage has a typical mineral symbiotic assemblage (Table 4.4).

+ Hydrothermal period:

Mineralization stage I: this is the first stage of the hydrothermal period marked by the linear alteration in the extrusive rocks from neutral to acidic in the Dong Trau Formation. The main alterations are quartzization, chloritization, and pyritization that develop along the folliated zone, broken and crushed zones along the faults after faulting that cut through the Dong Trau Formation. The typical mineral symbiotic assemblage of this period is: Quartz I - Pyrite I.

Mineralization stage II: The typical mineral symbiotic assemblage: Quartz II-Arsenopyritee I - Au I, accompanied by pyrite II, pyrrhotite, forming the bodies in the vein - form of Quartz - Arsenopyritee - Au, distributed in the extrusive rocks from neutral to acidic of Dong Trau formation ($T_2 a\text{đ}t_1$). Native gold is in close symbiosis with Arsenopyritee I. The less common hydrothermal alteration are propylitization, sericitization, beresitization, quartzization, and chloritization. Mineralization stage II is considered as the first producing stage, which plays an important role in both quantity and quality of Au ore in the study area.

<u>*Mỉnalization stage III:*</u> characterized by the mineral assemblage: Quartz III - galena-sphalerite-Au II, accompanied by arsenopyritee II, pyrite III, chalcopyrite. Gold in the native form, size from 0.05 to 0.15mm has a flat contact relationship (co-symbiotic) with sphalerite very clearly. This stage is the second producing stage, creating the product ore type: Quartz - sulphide - polymetallic Au.

This stage formed the stockwork ore bodies, including the collection of veinlets and quartz veins containing the sulfur minerals and the altered rocks containing gold, distributed in the strong crushed, broken and cracked zones. The composition is andesite, andesite tuf, rhyolite intercalated with the sericite-shist, set 1 of the Dong Trau formation (T_2a*đ*t_1). The hydrothermal alteration of wall rock is characterized by propitization, sericitization, chloritization, and calcitization.

Mineralization stage IV: this is the late alkaline stage ending the hydrothermal period, characterized by the symbiotic mineral assemblage: Quartz IV - Calcite. They often form small vugs or veinlets that cut through the altered rocks as well as ore minerals that have been formed from the earlier periods.

+ Weathering period:

<u>*Mineralization stage V:*</u> due to the effect of weathering agent on the surface, sulfur minerals were oxidized into the stable minerals in the oxidation zone and released the gold in the mineral veins to provide for placer. The typical mineral symbiotic assemblage at this stage is: Goethitee-Scoroditee, accompanied by Covelinee, Bornitee, anglesite, and Melnicovitee. In the Scoroditee ground, there is the native gold, demonstrating the symbiosis of native Au with arsenopyritee.

Table 4.5: Mineral formation sequence and the mineral symbiotic assemblage in the gold ore in the southwest edge of Bu Khang structure

Ore forming periods	Hydrothermal				Weathering
Stages	I	II	III	IV	V
Typical mineral symbiotic assemblage / minerals	Quartz-pyrite	Quartz - arsenopyrite-Au	Quartz-sulfide polymetallic -Au	Quartz-calcite	Goethitee-Scoroditee
Quartz	———	———	———	———	
Calcite				———	
Pyrite	———	———	———		
Chalcopyrite			———		
Sphalerite			———		
Galena			———		
Pyrrhotite		———			
Arsenopyrite		———	·······		
Native Au		·······	·······		
Magnetite	·······				
Goethite					———
Scorodite					———
Anglezite					·······

Coveline					....
Bornite					....
Melnicovite					....
Typical structure	Melnicovit, *veinlets, microstrip*	*Dispersion, stockwork, spots, breccias, microstrip*	*Dispersion, stockwork, vug, filled veinlets, mount*	*Veins*	*Inheritance, hole, fringe*
Typical texture	*Automorphic - semi-automorphic microparticles*	*Semi euhedral, anhedral, Corrosed and replaced particles.*	*Semi euhedral, euhedral, anhedral*	*Semi euhedral-anhedral*	*Pseudomorphic, glue zone, anphanitic, micro particles.*
Hydrothermal alteration	*Quartzitization, pyritization*	*Propylitization, sericitization, berezitization,quartzitization, cloritization*	*Berezitization, sericitization, chloritization, ankeritization.*	*Calcitization*	
Au purity		*974*	*874*		
Inclusion temperature in quartz		*290 ÷ 350°C*	*197 ÷ 270°C*		
Forming pressure (bar)		*950 ÷1883*	*940 ÷1052*		
Crystallization depth (km)		*3,90 ÷ 5,34*	*3,30 ÷ 3,90*		
Salt concentration NaCl (w%)		*3,39 ÷ 5,86*	*3,06 ÷ 4,18*		
The density of CO_2 in the solution (g/cm^3)		*0,733 ÷ 0,905*	*0,693 ÷ 0,857*		
Oxygen isotope ($\delta\ ^{18}O$ ‰)		*+5,4 ÷ +5,6*	*+5,1 ÷ +5,3*		
Hydrogen isotope (δD ‰)		*-68 ÷ -73*	*-75 ÷ -79*		

Note: ——— Mineral >10% ——— Mineral 1 - 10 % .... Mineral <1%

4.5. Origin and model of gold ore formation in the southwest edge of Bu Khang structure:

4.5.1. Relationship with magma activity:

4.5.1.1. The relation of spatial distribution and the role of magma activity in the ore-forming process

In the study area, the mineralization zones, the gold ore bodies and the extrusive formations belonging to the first set of the Dong Trau Formation (T_2a *đt*$_1$) are located in the same structure and have a close spatial distribution relationship with the granitoid of the Song Ma Complex that plays the role of the material source in the gold ore formation process. The potential producing gold ore of Song Ma granitoid is studied and evaluated in detail below.

4.5.1.2. Potential of gold ore generation of granitoid of the Song Ma Complex

**The mineralogy of the granitoid of the Song Ma Complex from the research results of the origin type and the geodynamic environment:* according to the geological - structure characteristics and material composition, the granitoid assemblage of the Song Ma Complex belongs to series of supersaturated aluminum magma (ASI >>1), dominant sodium over potassium - corresponding to Sodic magma series, corresponding to typical calc - alkaline magma series (I-granite type). Applying the method of M.Takahashi et al., 1980 to determine the origin type of Song Ma granitoid according to the iron oxidation rate and the basic parameters in the magmatic rock also gave results the Song Ma granitoid of type I-granite. Based on the characteristics of the granitoid origin and related mineralogy, combined with the analysis of the lithology and the geodynamic environment (Kent C.Condie, 2003 and Walter L. Pohl, 2011), the Song Ma granitoid complex is characterized by hydrothermal mineralization Pb-Zn, Au & Ag.

** Mineralogenicity of the granitoid of the Song Ma Complex from the research results of the secondary mineralization and oxidation-reduction properties of magma:* according to the method of Baker, T., Pollard, PJ, Mustard, R., Mark , G. & Graham, JI,2005, on the Fe_2O_3/FeO - Rb/Sr chart, the Song Ma granitoid formations have the speciality of minor-mineral Magnetite and are classified into the Magnetite series, while the Song Ma granitoid magma has special characteristics of strong - medium oxidizing properties. On the chart, it is clear that the Song Ma granitoid belongs to the field capable of generating Au-Bi ore.

According to the method of Blevin, 2003, on the FeO* - log(Fe_2O_3/FeO) graph, it shows that the Song Ma granitoid has strong-moderate oxidizing properties, from which it can be assumed that the Song Ma granitoid is capable of producing Au

** Mineralogenicity of the granitoid of the Song Ma Complex from the results of the study of fossil modules*: according to the method of B.N. Permiacov (1983), calculation results of fossil modules of silicon (q: 0.49-0.60), calcium (c: 0.12-0.31), alkalinity (α: 0.65-) 0.80), iron degree (f: 0.31-0.53) and alkaline type (n: 0.59-0.76) compared with the fossil modulus quantities of granitoids belonging to the magmatic assemblage having potential ores in the Zabaican region (Russian Federation), show that the intrusive formations of the Song Ma Complex are located in a rock complex related to gold and polymetallic gold mineralization.

** Mineralogenicity of the granitoid of the Song Ma Complex from the research results on the correlation between atoms Na^+, K^+, Mg^{2+} and the correlation between oxides Na_2O, K_2O, CaO:* according to the method of Sattran (1977), on The correlation charts K^+-Na^+, Mg^{2+} - K^+ and Mg^{2+}-Na^+ classifying the mineralization speciality of the the granite magmatic rocks, the samples of the Song Ma Complex tend to be highly concentrated in the golden field (Au).

4.5.2. Physico-chemical conditions for ore formation and origin of ore forming solution

4.*5.2.1.* Physico-chemical conditions of ore formation

The study results on the inclusions of quartz in both types of ores show that: the temperature of complete assimilation of the inclusions into liquid for quartz-arsenopyrite-Au ore is 290 ÷350^oC, for the type of quartz -sulphide pollymetallic-Au is 197 ÷ 270^oC; The salt content for the quartz-arsenopyrite-Au ore type is 3.39 ÷ 5.86 wt % NaCl, for the quartz-sulphide polymetallic-Au ore type is 3.06 ÷ 4.18 wt % NaCl. Based on the received data, it can be concluded that the deposition of product ore (product stage I) is initiated at the relatively high temperature and pressure (950-1883 bar, ~290-350^oC) from the chloride solution containing CO_2, the average salt content (3.39-5.86 wt% NaCl). Then, due to a decrease in pressure (940-1052 bar) - the solution is out of phase, accompanied by a decrease in the temperature and concentration of the solution and the deposition of the ore of the product phase II occurs from the chloride solution that having a temperature of medium (197-270^oC) and low salinity (3.06-4.18 wt% NaCl).

4.5.2.2. Origin of ore-forming solution

The presence of nitrogen gas in the gas phase composition of the inclusions of quartz of both ore types demonstrates that the solution is of magma origin. The gradual decrease in temperature and salinity during ore formation due to fluid dilution by atmospheric water is observed.

The results of stable isotope analysis have determined the ratio of isotopes ^{18}O‰ (+5.1 to +5.6) and D‰ (-79 to -68) of water in inclusions of both ore types in the study area, shows that the water source of the ore-forming hydrothermal solution of magma origin is diluted by atmospheric water (Meteoric water).

4.5.3. Origin model of Song Ma Magma - ore system

The model of Song Ma magma - ore system was built by author based on the original model for the quartz-sulphide-gold deposit (Figure 4.21).

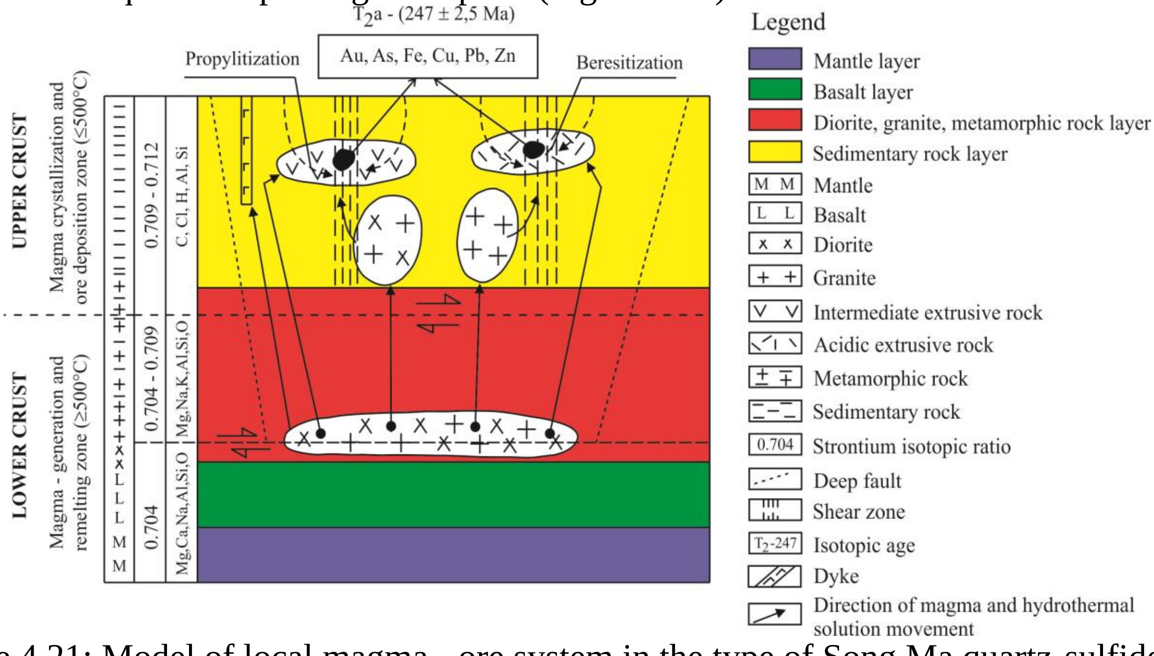

Figure 4.21: Model of local magma - ore system in the type of Song Ma quartz-sulfide-gold deposit

4.6. Determining the type of deposit and dividing the types of gold ore in the southwest edge of the Bu Khang structure

On the basis of the research results of the material composition, geological and physico-chemical conditions, the origin of the ore-forming solution and the relationship with the granitoid magma in the region, compared with the types of industrial deposits presented in Chapter 2, the author classifies the gold deposits and the ore occurences at the southwestern edge of the Bu Khang structure into the type of deposit: hydrothermal deposit related the intrusive source with the following characteristics:

- Distribution in the extrusive formations and their tufs have composition from neutral to acidic and Middle Triassic age of Dong Trau formation ($T_2ađt_1$). In which, the neutral extrusive rock was altered Propylitization after eruption.

- Quartz is formed at all mineralization stages of the hydrothermal period. Quartz contains few sulfur minerals in dispersion form: pyrite, arsenopyrite, pyrrhotite, galena, sphalerite, chalcopyrite...

- Native Au grains are often closely symbiotic with quartz and sulfur minerals such as arsenopyrite, sphalerite. In addition to vein minerals like quartz, calcite also have little barite, sometimes with siderite.

- Hyddrothermal alteration of wall rocks is usually sericitization, beresitization, quartzitization, chloritization, and calcitization. In the mineralization area often has the porphyr diabas dike, gabrodiaba of unknown age and acid rocks of the Song Ma Complex.

- The structure of the ore field shows that the ore veins develop mainly along the crushed, broken zone, direction from NW-SE to sub-latitudes and from Ban Tang to Suoi Lo.

Based on the characteristics of gold minerals and the industrial value of gold in the ore bodies as well as the mineral symbiotic assemblage, two types of gold ores in the study area can be divided: quartz - asenopyrite - gold ore type and type of gold ore quartz - sulfide polymetallic - gold.

Chapter 5: Factors controlling ore and preconditions, signs finding gold ore in the southwest edge of Bu Khang structure

5.1. Geological factors controlling the gold mineralization

5.1.1. Geological location of the gold ore bodies

The study area belongs to the Song Ca mineralization zone, located to the southwest of the Bu Khang uplift, where the contiguous place is between the Song Ca and Phu Hoat mineralization zones. This is an area with a quite complex geological structure that has gone through the geological periods from Paleozoic to Cenozoic, many minerals were formed in the different tectonic contexts, have different ages, and are diverse in types and origin.

The mineralized zones containing gold in the study area are distributed in the member 1 of the Dong Trau formation ($T_2ađt_1$), belonging to the Song Ca mineralization zone. Therefore, the mineralization elements have the characteristics of this mineralization zone.

5.1.2. Geological factors controlling the gold mineralization

5.1.2.1. magmatic factor

a. The spatial relationship and distribution characteristics: the gold ore bodies, the Song Ma granitoid complex and the volcanic formations of the Dong Trau formation are all distributed in the same structure and are controlled by the Ban Chieng - Ban Cuon fault.

b. Geochemical specialization of magma: on AFM charts, standard geochemical distribution of rare earth elements with Chondrite, normalized histogram with normal midocean ridge basalt (N-MORB), shows that the porphyr granites of the Song Ma Complex in the study area belong to the calc – alkaline series (type I-granite) with high concentrations of Cu, Pb, Sn, and Zn, with specialized Au, Ag geochemical properties.

c. Evaluation of the ability to produce gold ore of magma formations: the ability to generate gold ore of the granitoid formations of the Song Ma Complex was evaluated in chapter 4 on the basis of the study results of origin and geodynamic environment; the research results on the secondary mineralization and oxidation - reduction characteristics of magma. In addition, based on the fossil composition, the method of evaluating the gold-forming ability of magmatic rocks according to some authors: Correlation K^+ - Na^+, Mg^{2+} - K^+ and Mg^{2+}-Na^+ (according to Sattran, 1977); correlation of Na_2O - K_2O - CaO (M.M. Konstantinov, 1984); Fossil modules of silicon (q), calcium (c), alkalinity (α), iron (f) and alkaline type (n) (BN Permiacov, 1983), showing the intrusive formations of the Song Ma Complex is located in a rock complex related to gold mineralization and polymetallic gold.

The ratio between the stable trace elements in geological processes such as Ti, Zr, Y, Nb in gold ore and the magmatic rock of the Song Ma Complex, Dong Trau Formation, showed that there may be a source relationship between them.

The variation of the trace element content between the magmatic rock and the gold ore is quite similar, reflecting the close relationship of origin between rock and ore.

From the above data, it shows that the magma formations in the southwestern region of the Bu Khang structure have the role of controlling gold ore, including the Song Ma complex and the extrusion of the Dong Trau formation.

5.1.2.2. Factors of lithology and stratigraphy

Research results show that the extrusive rocks have acidic to neutral composition such as ryolite, ryodacite, dacite, andesite and their tuf belong to the member 1, Dong Trau formation (T_2a *đt_1*), when they were crushed, compressed, altered propitization, quartzization, sericitization... is a favorable environment for the process of accumulation and mineralization of gold.

The layers of greenshist, shale, and siltstone interlayered into the Dong Trau Formation and acts as screens, more favorable for the concentration of gold mineralization.

In addition, the distribution is interlayered between the terrigenous sedimentary rocks and the extrusive rocks with different physical and mechanical properties, during the tectonic and metamorphic activities, creating favorable voids for ore concentration.

The petrographic - stratigraphic factors play a very important role in the formation of gold-bearing sulfur mineralization zones in the study area. The mineralization zones show quite obvious selection, they only develop in rhyolite, andesite and their tuf that are compressed, crushed, broken, and strongly altered. In terrigenous sedimentary rocks, it almost does not appear.

5.1.2.3. Structural - tectonic factors

a. Faults

- *Zone margin fault:* Ban Chieng - Ban Cuon fault [Dovijicov, 1965] is the boundary between Song Ca structural zone and Phu Hoat structural zone. This is the fault that plays the role of ore conduction. Accompanying this main fault are radiating, feather faults, joints, which play the role of containing and controlling ore mineralization in the region.

- *Internal zone fault:* includes two main fault systems controlling the structure of the whole study area:

+ The northwest-southeast fault system is the major fault, playing the main role in the formation of crushed, broken and altered zones with the sulfur mineralization containing gold.

+ *Northeast-southwest fault system:* formed later, on the smaller scale, they are almost no significance for ore formation, but only complicate the previous formations, shifting and somewhat break the structural plan that was formed by the previous periods.

In summary, tectonic fault factors play a very important role in the mineral formation and accumulation, but this factor is also the biggest ore-destroying factor, where major faults pass through, the ore - bodies were cut and displaced, broken, thereby greatly affecting the morphology and quality of ore.

b. Fratures: The area with high density of fractures is concentrated mainly on the margin of the zone fault and the internal fault system in the northwest - southeast direction, which is favorable for the concentration of hydrothermal gold ore in the study area.

c. Folds: the study area is the southern limb of Ban Chieng - Kim Son large anticline. The anticline has a large elliptical shape with the main axis in the northwest-southeast strike. The limbs are composed by the metamorphic formations of the Bu Khang Formation with the core being penetrated by granitoid blocks. In the southern part, the folding activity usually occurs strongly in a certain stratigraphy, often creating folds in the stratum with the main winding axis in the northwest - southeast direction with two disproportionate limbs.

5.2. The premises and signs for propspection

5.2.1. Structural – texture premise

In the study area, the northwest-southeast fault system and its accompanying structures such as the intersections between faults and the favorable rock sets, intersections between faults and faults, the fracture zones are favorable structure for ore accumulation.

5.2.2. Magmatic Premise

The intrusive magmatic rocks of the Song Ma Complex are of type I-granite with potential for gold ore generation that scattered in the study area, which is a favorable premise for forming gold minerals.

5.2.3. The premise of petrology - stratigraphy

The acidic to neutral extrusive rock sets: ryolite, ryodacite, andesite and their tufs were crushed, compressed, broken and altered propilitization, quartzization, sericitization, chloritization, and calcitization in the member 1 of Dong Trau Formation that is the lithological - stratigraphic premise for the prospect of gold mineralization in the study area.

5.2.4. Prospective signs

Signs of ore occurences, manual gold mining works (adit, wells); signs of hydrothermal alteration of wall rock surrounding the ore (Propylitization, beresitization, quartzitization, sericitization, chloritization, calcitization); dispersion rings of pan concentrate.

5.3. Gold ore prospect zoning

5.3.1. Prospective zoning standards

- Prospective area of level A (level A): is the most promising area for gold ore, has favorable premise for mineral-forming, appears many signs of direct and indirect prospect, and has a high concentration level of the ore occurences, ore bodies. Th mineralization points and mineralization zones were discovered and studied by a combination of many methods, of which a number of ore bodies of industrial significance were basically identified. This is an area with favorable conditions for further research as well as future mineral processing.

- Prospective area of level B: is an area that also has favorable premises and signs for prospecting, in which a number of ore occurences, ore bodies, mineralization points and mineralization zones have been identified but are less concentrated, more limited in the study degree, geographical location, economy, traffic is more difficult.

- Prospective area level C: is the least promising area, the research level is still limited. In this area, ore occurences, ore veins, and mineralization points are scattered, not concentrated or have not been detected. However, there are also geological structures and favorable premises for mineral formation.

5.3.2. Results of zoning the potential area and assessing the original gold resources in the study area

In the study area, the promising areas of original gold minerals with levels A, B and C have been delineated as follows:

- Prospective area level A includes 2 zones: Ban Tang - Na Quya area has an area of about 4.5km^2, has identified 04 mineralized zones (mineralization zones I, II, III, IV) containing 08 original gold ore bodies (TQ.1 - TQ.7). The result of calculating resource level 334a+334b is 11060 kg; Huoi Co - Ban San area has an area of 3.5km^2, has identified 02 mineralization zones (mineralization zones I, II) containing 05 original gold ore bodies (TQ.1 - TQ.5). The result of calculating resource level 334a+334b is 3880 kg.

- Prospective area of level B includes 2 zones: the Huoi May area is 2.3 km^2, has identified 03 mineralized zones (I, II, III) and 02 ore bodies TQ.1 with level 334a+334b natural resources is 858 kg; Dong Ban Tang area has an area of 10.5 km^2, has identified 04 mineralization zones (I, II, III, IV) and 01 ore body (TQ.1). The result of calculating resource level 334a+334b is 742 kg.

- Prospective area of level C: 40.9km2 wide, distributed in the periphery of the above-mentioned A and B prospective areas, including a number of discrete ore occurrences and mineralization points, not enough basis to delineate the ore bodies or . mineralized zones. In this area, sampling the pan concentrate samples was also carried out and the dispersion rings of placer gold have been identified. In the area of level C, it is necessary to investigate and detect alteration of wall rocks and mineralization, especially pay attention to signs of favorable propspecting, so that a more objective and overall assessment of the area can be made.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions:

1. In the study area, the extrusive rock members of the neutral composition of the first member of the Dong Trau Formation (T_2a*đt*$_1$) were altered propylitization over surface of the block after the eruption, then they were pressed, folliated linearization along the faults, fractures, and hydrothermal altered over such as: chloritization, sericitization, quartzitization accompanied by Au ore. The acid extrusive formations undergo typical beresitization, which is a reliable sign of the presence of gold ore bodies in the study area.

2. The results of modern quantitative analytical methods (Cold method, Raman Spectroscopy method, O(δ ^{18}O) & H (δD) stable isotope analysis method, etc.) have clarified the physico-chemical conditions for gold ore formation in the study area (temperature, pressure, depth of ore formation, density of solution) and determining the

source of the ore-forming solution is from the magmatic intrusive granitoid of the Song Ma Complex

3. Gold ore in the extrusive formations in the southwestern edge of the Bu Khang structure belongs to the type of hydrothermal deposits related to the intrusive sources. Hydrothermal mineralization takes place in 4 stages, in which stages II & III are two stages of producing gold ore products corresponding to 2 types of ores: quartz - arsenopyrite - gold & quartz - sulfur - polymetallic - gold. In the ore, gold exists in the form of native Au and closely symbiotically with quartz, arsenopyrite, pyrite, pyrrhotite, chancopyrite, sphalerite, galena.

4. The process of gold ore formation in the study area is controlled by the following factors: The granitoid formations of the Song Ma Complex (Gp/T_2*sm*); the northwest-southeast fault system and the associated structures; extrusive rocks ryolite, ryodacite, andesite and their tufs belong to member 1 of the Dong Trau Formation (T_2a*đt₁*) which plays the role of wall rock surrounding the ore.

5. Origin Model of the magma-ore system of gold-mineralization in the extrusive formations in the southwest edge of the Bu Khang structure is the scientific basis for forecasting the gold-mineralization on the surface and in the depths.

6. Research results have divided into 05 areas with the different prospects, of which 02 most promising areas (level A) - 8.5 km^2, 02 promising areas (level B) - 12.8 km^2, the rest is the least promising area (level C) - 40.90km^2. These areas have also indicated the tasks that need further research in the next stage of investigation, evaluation, prospect and exploration.

Recommendations:

1. In promising areas of levels A, B, and C, it is necessary to conduct research, investigation and evaluation tasks, and use the necessary and reasonable technical measures to each area to clarify the prospect levels of these areas.

2. It is necessary to conduct a thematic study on the characteristics of the diabas porphyrite and gabbro-diabas of unknown age and their relationship to gold mineralization in the study area.

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