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GOLD ORES MINERALIZATION CHARACTERISTICS AND ORIENTATION FOR NATIVE GOLD INVESTIGATION, EXPLORATION IN ATTAPEU, LAOS PDR

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Code: 9520501

SUMMARY OF Ph.D THESIS

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This thesis was completed at the Department of Mineral Exploration, Faculty of Geosciences and Geology Engineering.

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The Thesis will be defended in front of the Thesis Judging Committee at the Hanoi University of Mining and Geology at … hour … date … month, 2022.

This Thesis can be found at the library: Hanoi University of Mining and Geology.

INTRODUCTION

1. The necessity of the Thesis

Gold ore is very important in the economic development of each country; Laos PDR is no exception. Therefore, the research, investigation, assessment, exploration and exploitation of gold ore is an urgent requirement and a very important issue for each country; especially for countries with developing mining industry like Vietnam, as well as Laos PDR.

According to recent geological research results, the Attapeu region is considered to have great potential for native gold. However, the in-depth researchs are still limited, most of the research results are isolated and mainly focus on investigation, assessment and exploration in some promising gold ore mines, directly serving mining projects of enterprises

The thesis "Gold ores mineralization characteristics and orientation for native gold investigation, exploration in Attapeu, Laos PDR" was selected by Ph.D student which aim to solve the above task and reality demandent.

2. Purposes of Thesis

The research aim to clarify the ore characteristics, establish relevant factors and controlling the native gold ores in the Attapeu region; thereby assessing the potential of resources, zoning the potential area and orienting the investigation and exploration works.

3. Research object of Thesis

Native gold ores and related geological settings distributed in the Attapeu region.

4. Study area

Attapeu province, south of Laos, total area more than 9.500km^2.

5. Tasks of Thesis

- Collecting, synthesize and systematize existing documents on geology and minerals in the study area; scientific papers related to the native gold ores have been published in Laos, Vietnam and the world.

- Research to clarify the ores mineralization characteristics, classify ore types, distribution characteristics, morphology - structure

of ore bodies and native gold mineralization zone in the area.

- To determine gold ores material composition (mineralogical, chemical), alternative characteristics of rock surround native gold ores.

- Determining related geological factors and controlling native gold ores mineralization; identify premises, investigation indicators and zoning prospect areas.

- Evaluate the potential of native gold ores resources in each identified prospective area and propose orientations for investigation and exploration for the primitive type of gold ores in Attapeu region.

6. Scientific and practical significances of the thesis

1. Scientific significances:

The establishment of related geological factors and controlling gold ore mineralization, morphological - structure characteristics of gold ore bodies and mineralization zone as well as the results of establishing the group of mine types and the native gold exploration grid in the study area are the scientific basis that complement scientific theories in the field of geology for minerals investigating, prospecting and exploration; creating a premise for further studies.

2. Practical significance:

- Provide governmental bodies and businesses with a reliable geological and minerals database of gold in Attapeu region; Those will be a reference document to orient the work of prospecting, exploration and mining investment.

- Provide enterprises a system of methods to improve the reliability of resource and reserve assessment; selecting a suitable exploration grid that matches the native gold mine type in Attapeu region and other regions with similar geological settings.

7. Theoretical basis of thesis

Basis 1:

The native gold ores in the Attapeu region has hydrothermal origin with medium temperature (200^{o}C - 300^{o}C), including 02 phases of gold ores forming which characterized by 02 mineral symbiotic combinations: quartz - pyrite - gold and quartz - pyrite - chalcopyrite - galenite - sphalerite - gold; those has great potential and is distributed

mainly in the Southern Truongson - Sekong structural zone.

Basis 2:

The native gold ore bodies have a complex morphology - structure, thickness variation is not stable, gold contents is very unevenly distributed; Gold mines in the study area are mainly in exploration group III. The most reasonable exploration works are using grid networks, with distances of exploration lines from 40 to 60m, and exploration works on each line from 20 to 30m.

8. Research methodologies

- Approaching methods.
- Documents synthesis and analysis.
- Field surveying works.
- Ore material composition research methods.
- Indoor data and documents processing.

9. New scientific contributions of the thesis

1. By using modern quantitative analysis methods, the thesis determined that origin of the native gold ores in the study area has an medium temperature hydrothermal (200^0C-300^0C), which has 2 phases of product ore forming and characterized by 2 mineral paragenetic combination are quartz - pyrite - gold and quartz - pyrite - chalcopyrite - galenite - sphalerite - gold.

2. The thesis established 3 groups of geological factors and native gold ore mineralization controlling, clarified morphological – structural characteristics of ore bodies; Estlablished premises and investigate indicators of gold ore; Delineated 14 potential areas of native gold ore with a total area of 411.2km2 (02 promising areas of grade A, 08 areas of potential grade B and 04 areas of unknown prospect of grade C).

3. By using quantitative resource prospecting method, the thesis prospected that the native gold ore resources of Attapeu region are quite large (reaching over 200 tons), distributed in the Southern Truong Son - Sekong structural zone in the eastern part of the study area (close to border of Vietnam and Cambodia).

4. By applying geo-mathematical methods, the thesis has

established the group of native gold mines in the study area mainly belonging to the group III of exploration mines, also, established an exploration grid and proposed a suitable combination of investigation and exploration methods.

10. Structure of the thesis

The thesis is presented in 137 pages, in A4 size; 08 figures; 27 tables; 70 illustrations; 63 references. In addition to the introduction and conclusion, the content of the thesis is structured into 4 chapters:

Chapter 1. Geological and minerals settings of Attapeu region, Laos PDR.

Chapter 2. Methodology and research methodology.

Chapter 3. Characteristics of the native gold ores mineralization in Attapeu region, Laos PDR.

Chapter 4. Evaluation of resources and orientation of gold ores prospecting, exploration in the Attapeu region.

11. References

This thesis is completed based on reference documents from previous studies and additional research results of the Ph.D student from 2014 to 2021 as follow:

- Geological map in Attapeu region, at scale 1:500.000; 1:200.000; 1:25.000; 1:10.000; 1:2.000.

- Report on Geological mapping and mineral resources investigations for bauxite and other minerals in the southern Lao PDR, scale 1:500.000.

- JICA, Report on Geological and minerals survey in Attapeu region, scale 1:200.000.

- Report: Gold ores investigation, exploration in Vangtat, Sanxay, Attapeu, scale 1:25.000.

- Report: Gold ores investigation, exploration in Huaydai-Namxuan, Phuvong, Attapeu, scale 1:25.000.

- Longthanh Mining Company, Report on Copper, gold ores and accompanying minerals investigation, scale 1:25.000.

12. Deployment

This thesis was completed at the Department of Mineral

Exploration, Faculty of Geosciences and Engineering, Hanoi University of Mining and Geology under the scientific guidance of Assoc. Prof. Dr. Meritorious Teacher Nguyen Phuong and Dr. Nguyen Tien Dung. I, a Ph.D student, would like to express deep gratitude to the supervisors who have guided wholeheartedly during the implementation of the thesis.

I would like to thank scientists, geologists and colleagues for allowed me to refer and inheritance of scientific documents to complete this thesis.

CHAPTER 1
GEOLOGICAL AND MINERALS SETTINGS OF ATTAPEU REGION, LAO PDR

1.1. Location of the study area in the regional structure

Southern of Laos is the part in the central region of the Indochina peninsula, in Southeast Asia, where made up of geological formations from Pre-Cambrian and Phanerozoic.

The Attapeu region located in the Indochinese complex including the Indosini Craton, the Early Paleozoic Hue - Sekong, the Indosini Mekong, the Late Mesozoic terrarium and other Cenozoic intracontinental structures of different origins.

1.2. Brief history of geological and mineral researchs

+ Before 1975 period: mainly carried out by French geologist on a small scale with a preliminary level of research.

+ After 1975:

- From 2005 to 2008: Intergeo Division and Department of Geology and Minerals of Laos finished the Project: Investigate and evaluating bauxite and other minerals in Southern region of Laos, scale 1:500.000.

- In 2008, JICA carried out Geological and minerals survey in Dakyoy-Vangtat area, Attapeu province, scale 1:200.000

- From 2008 to 2014, Vietnam - Laos Joint Stock Company and the Mining Division of the Laos Ministry of Defense conducted an investigation and geological, minerals mapping at the scale of 1:25,000 in the Sanxay area.

- In 2019, Intergeo Division carried out a project of gold ore investigation and assessment in the Namxuan region

- In 2021, KN Minerals Company completed the investigation and evaluation of gold ore in Kongyong area.

1.3. Overview of geological settings of Attapeu region

1.3.1. Overview of stratigraphy

PROTEROZOIC FORMATIONS

Distributed in the east and southeast of the study area, including biotite gneiss, quartz-biotite schist, crystalline schist.

PALEOZOIC FORMATIONS

- *Mid Cambrian - Early (Lower) Ordovician (ε_2-O_1):* Distributed in the eastern center of the study area, consist of sericite schists, quartz - sericite schists, quartz - muscovite schists, quartz schists. Thickness: 1,400-1,800m.

- *Late (Upper) Ordovician - Silurian (O_3-S):* Including sericite shale, quartz - sericite shale, sandstone; partially distributed in the northeast and southeast of the study area. Thickness: 1,580-1,730m.

- *Lower Carboniferous (C_1):* Including sandstone, siltstone, shale, coal shale and coal seams; contain plant fossils; distributed in the northeast of the study area. Thickness: 280-700m

- *Upper Carboniferous - Lower Permian (C_2-P_1):* Distributed in the northeast center, contains microgranular limestone, clay limestone with few layers of siltstone and shale. Thickness: 500-800m.

MEZOZOIC FORMATIONS

- *Lower – Mid Triassic (T_{1-2}):* Widely distributed in the central part of the study area, extending from the north to the south. Consists of conglomerate, gravel, sandstone, claystone, shale interspersed with rhyolite and tuf eruption layers. Thickness: 550 - 1,500m.

- *Lower - Mid Jurassic, (J_{1-2}):* Distributed from the center to the southwest of the study area, including grey sandstone, red brown, red-brown, purple siltstone mixed with little clay. brown, lime sandstone, lime siltstone and copper mineralization. Thickness: 600m.

- *Upper Jurassic - Cretaceous (J_3-K):* Exposed at the northwest boundary and a part in the west center of the area, including gravel,

grit, small to medium grained sandstone. Thickness: 160-340m.

- *Upper Cretaceous (K_2):* Distributed in the northwest and a part in the western center of the region, including alluvium, gravelstone, sandstone, sandstone. Thickness: 500-600m.

CENOZOIC FORMATIONS

- *Neogen System, Pliocene Epoch (N_2):* Distributed with small area in the center and east of the study area, including cobblestone, grit, sandstone, weakly cohesive powder. Thickness: 50 - 150m.

- *Neogen System, Pliocene Epoch - Quaternary, Pleistocene Epoch (βN_2-Q_1):* Partially distributed in the west and northeast of the study area, composed of olivine basalt, porphyr basalt and their tuf. Thickness: 260m to 300m.

- *Quaternary System, Holocene Epoch (apQ_2):* contains Aluvi - proluvi: river sediments, consist of pebbles and sand, rarely found in the northeast. Thickness: 1-6m.

- *Quaternary System, Pleistocene Epoch (βQ_1):* Contains olivine basalts, pyroxene basalts, porous rocks, porphyritic architecture. Thickness: 260-300m.

1.3.2. Overview of intrusive magma characteristics

**** Early Paleozoic (PZ1) magmatic formations (PZ_1)***

- Ultramafic intrusive formations (σPZ_1): Distributed above Sexu; The petrographic composition includes peridotite, pyroxenite.

- Mafic intrusive formations ($\nu\mu PZ_1$): Distributed above Sexu; main rocks are gabro-amphibole and gabro.

**** Middle Paleozoic magmatic formation (PZ_2)***

- Early Silurian-Devonian granitoid intrusive formations ($\delta.\gamma\delta.\gamma S$-$D_1$): Distributed near the southeast of Huaykeo area and partly in Vangtat. The composition includes quartz diorite, tonalite, granodiorite, biotite - hornblende granite and biotite granite.

**** Paleozoic-Mesozoic magmatic formation (PZ_3-MZ_1)***

- Early Permian-Triassic granitoid intrusive formations ($\delta.\gamma\delta.\gamma P$-$T_1$): Composed of gabrodiorite, diorite, granodiorite to granite, including 3 intrusive phases: phase 1: biotite granite, bi-mica granite; phase 2: quartz diorite, tonalite, granodiorite, horblend granite

- biotite; phase 3: biotite granite with hornblende, biotite granite, granite and vascular rock phase; distributed in the Southern Truongson - Sekong structural zone.

**** Early Mesozoic magmatic formation (MZ_1)***

Early Triassic granitoid intrusive formations (γT_1): Mainly biotite granite, bi-mica granite, granite and aplitic granite which are composed in two intrusive phases.

**** Intrusive magma formations of unknown age (Da.ml.l)***

Consists of diabase and lamprophyre dyke. Scattered distribution and penetrated Paleozoic - Early Mesozoic formations.

1.3.3. Overview of tectonic structure features

- *Folding activities*: The system of folds in the study area are divided into 03 main fold complexes: the Southwest Laos trough complex; Kaleum trough complex; Nong Viat - Bang Ha Noy trough commune.

- *Fault activity*: There are 03 fault systems developing in the northwest - southeast, sub-meridian, northeast - southwest directions. In which, the northwest - southeast and sub-meridian fault systems develop strongly, which control the native gold ore body in the region.

1.3.4. Overview of minerals characteristics

The study area recorded metallic and non-metallic mineral deposits belonging to the group of industrial minerals distributed mainly in the eastern region bordering Vietnam and Cambodia, including: gold, copper, lead-zinc, bauxite, iron, peat, molybdenum, sapphire, kaolin.

CHAPTER 2
METHODOLOGY AND RESEARCH METHODOLOGY

2.1. Theoretical basis

2.1.1. Overview of gold ore mineralization

a. Geochemical characteristics of gold

Gold (Au) belongs to the group of precious metals, yellowish color, density 19,30g/cm^3, hardness in Mohr scale from 2.5-3, melting point 1.064,18^oC, boiling point 2.856^oC

The average content of gold in the Earth's crust is $4{,}3^{-3}$ppm

(Vinogradov, 1962), one of the rarest elements. Gold is closely related to granitoids (especially sodium-rich granite), sometimes including alkaline, mafic and ultramafic igneous rocks. The Clark value of gold is $4,3.10^{-7}$. In metamorphic rocks from 0,7 to $4,2.10^{-7}$%.

b. The mineralogy of gold

Naturally, gold is often found in its spontaneous form, chemically this is not pure and usually contains Ag (up to 5%-15%), Cu (1.5%), Fe (2%), sometimes contains Bi, Pt, Pd. Native gold oftens symbiotic with pyrite and chalcopyrite. Native gold always contains some metal in the form of a homomorphic mixture. Therefore, people introduced the concept of gold purity.

2.1.2. Classification of industrial gold mines in the world and in Laos PDR

a. Gold mines types classification in the world

Căn cứ vào điều kiện thành tạo và giá trị kinh tế, các mỏ vàng được phân chia thành 05 kiểu mỏ công nghiệp sau: kiểu mỏ skarnơ vàng; kiểu mỏ nhiệt dịch nguồn gốc magma sâu; kiểu mỏ nhiệt dịch nguồn gốc núi lửa; kiểu mỏ biến chất; mỏ sa khoáng.

Based on the forming conditions and economic value, gold mines are divided into 05 types of industrial mines as follows: gold skarn type; hydrothermal deposits type of deep magma; hydrothermal mine of volcanic origin; metamorphic mine type; placer mine.

b. Gold mines types classification in Vietnam

According to the State-level research Project KT-01-08 (1993-1995) on "Evaluating Vietnam's gold prospects and developing appropriate technological processes", Nguyen Nghiem Minh, Nguyen Van Chu, Nguyen Van Pho and Nguyen Ngoc Truong has classified Vietnamese gold ore mineralization types are: true native gold; placer gold; symbiotic gold; epigenetic gold

c. Gold mines types classification in Laos PDR

There are types of gold ores as follow: true native gold ore, symbiotic gold ore, epigenetic gold and placer gold

2.2. Basic definitions and terms used in the thesis

2.2.1. Definitions of studying ore characteristics and ore deposits

Includes: mine type; mineral complex; mineral symbiotic complex; ore manifestation; mineralization point; minerals point; ore deposit; mines; ore body; morphology - ore body structure.

2.2.2. Concepts of mineralization space and time

Includes: Ore zone; mineralization period; mineralization phase.

2.2.3. Some terms used in mining type classification

Includes: Dyke zone; Dyke type (Vein type).

2.3. Research approaches and methods

2.3.1. Approach methods

Systems approach; multi-dimensional approach; integrated and interdisciplinary approach

2.3.2. Research methods

Documents synthesis and analysis method; Field surveying works method; studying the ore material composition method; Indoor data and documents processing methods include: geo-mathematical methods and geo-informatics methods; Resources assessment methods include: identified resource assessment method and unidentified resource forecasting method

CHAPTER 3
CHARACTERISTICS OF THE NATIVE GOLD ORES MINERALIZATION IN ATTAPEU REGION, LAOS PDR

3.1. Distribution characteristics of gold mines and deposits in the study area

In the study area has identified 02 native gold mines Vangtat and Namxuan which have been explored in detail and are being exploited; 04 promising areas, with native gold ore manifestations and deposits, including: Vangtat area; Huaypeak - Antoum area; Namxuan - Namlay - Sexu area; Dakkanat area. These 04 areas have been investigated and evaluated for geology - minerals at the scale of 1:50,000; 1:25,000; 1:10,000.

Gold mineralization zones are distributed mainly in the sedimentary zones of Middle Cambrian age - Early Ocdovician ((ε_2-O_1), Late Ocdovician - Silurian (O_3-S), intrusive rocks of Permian - Early Triassic (P - T_1).

3.2. Distribution characteristics of the native gold ore zones and bodies

3.2.1. Characteristics of mines and mineralization zones

a. Vangtat mine

Vangtat is located in the northeast of the study area, with an area of 03km^2. The gold ore bodies distributed in the Middle Cambrian - Early Ocdovician sedimentary rock zone (ε_2-O_1) include quartz - sericite schist, quartz - muscovite schist, which are quartzized, sericitized, chloritized. The mineralization zone is 80-180m wide; extending from north to south about 1.500m; Estimated depth is about 100-200m. There are 04 native gold ore bodies with industrial significance. The ore body is 100 - 400m long, 0,4 - 14,5m thick; dip to the east-northeast with slope angle from 45^0-80^0.

b. Namxuan mine

The mine is located in the southeast of the study area, the ore body is mainly located in the fracture zone of diorite rock and metamorphic sedimentary rock altered by quartzization, sericitization, and chloritization. The ore body develops discontinuously according to the rupture zone of the northwest-southeast fault. There are 11 industrial native gold ore bodies distributed in diorite intrusive rocks of Permian - Early Triassic age (P-T_1) and in sedimentary rocks of Late Ocdovician - Silurian (O_3-S).

c. Namxuan - Namlay - Sexu area

- *Namlay mineralization zone*: The zone has a thickness of 25 - 30m, extending from the northwest to the southeast about 350m, the expected depth is about 75-150m. The ore bodies are distributed in the O_3-S and Early Permian - Triassic diorite intrusive rocks (P-T_1)

- *Sexu mineralization zone:* Located in the southeast of the study area, this area has discovered many exposed rocks of the altered rock zone containing quartz - sulfur - gold microveins located in the distribution of sedimentary rocks of the ε_2-O_1. The mineralization zone is 2-15m wide, extending in different directions from 100 to 250m.

d. Huaypeak - Antoum area

- *Huaypeak mineralization zone*: The zone is 1.000-2.500m

wide, 4.000-5.000m long; in this zone, altered rock zones contain veins, microveins of quartz - sulfur - gold in sedimentary rocks of the ε_2-O_1 is a quartz-sericite schist, a quartz-muscovite shale

- *Antoum mineralization zone:* The zone is 500-800m wide, 1.000-2.000m long, 10-15m thick. In this zone, many altered rock zones containing veins and microveins of quartz - sulfur - gold distributed in sedimentary rocks of Late Ocdovician-Silurian (O_3-S) and intrusive in Early Permian-Triassic (P-T_1).

e. Dakkanat mineralization zone

This zone located in the north of the study area, the zone is 200-500m wide, 800-1.000m long, 0.2-10m thick; At the contact edge between the Middle Permian acid eruptioned rock (P_2) and the Early Permian - Triassic intrusive formations (P-T_1), some gold-containing quartz-sulfur veins were detected, the fractured zones were quartzization, chloritization altered with diffusion of sulfur mineralization.

3.2.2. Characteristics of the native gold ore bodies in the study area

a. Distribution characteristics of ore bodies

The native gold ore bodies in the study area are mainly made up of quartz - sulfur veins with different sizes or a collection of gold-containing quartz - sulfur microveins.

b. Morphological - structural characteristics of ore body

The native gold ore bodies in the study area has 2 main types: Vein (dyke) type ore body and Vein (Dyke) zone type ore body.

3.2.3. Characteristics of hydrothermal alteration surrounding the ore

The typical hydrothermal alteration surrounding the ore in the area are: quartzization, sericitization and chloritization, which are reliable signs to detect the native gold ore bodies in the region.

3.3. Characteristics of ore material composition

3.3.1. Mineral composition characteristics

Base on synthesizing results of analysis of facies mineral samples, thin slices, mineral composition include: primary minerals with pyrite, chalcopyrite, native gold, rutile, ilmenite, pyrotin,

galenite, sphalerite; secondary mineral: goetite, coveline, limonite; hydrothermally altered minerals: microgranular quartz, chlorite, sericite; vein mineral with quartz.

3.3.2. Chemical composition characteristics

a. Gold (Au) và silver (Ag)

Applying statistical methods to determine the statistical characteristics of Au, Ag content in the study area. The results as following:

- Au: contents from 0,02 g/T to 58,3 g/T; average from 0,4 g/T-0,9g/T. Coefficient of variation of gold content from unequal (Vc=78%) to very unequal (Vc=118-148%) and specially unequal (Vc= 163 - 386%).

- Ag: contents from 0,1 to 442 g/T; average from 1,8 to 35,8g/T. Coefficient of variation of silver content from unequal (Vc=103-144%) to specially unequal (Vc=152-263%).

b. Accompanying elements

According to the average atomic absorption results, Cu content: 86 - 1363 ppm; Pb: 8 - 1322 ppm; Zn 10 - 708 ppm; Cr: 33 - 124 ppm; Co: 17-55; Ni: 28 - 91 ppm.

3.3.3. Structural and architecture characteristics of the ore

a. Ore structure features

The native gold ore in the study area mainly has vein structure, nest structure, and diffuse structure.

b. Ore architectural features

- Primary structure: idiomorphic granular, hypidioblast, and anhedral grains.

- Secondary structure: Corrosive grain architecture

3.3.4. Summary of technological characteristics of the native gold ore in Attapeu region

The results of the native gold extraction at Vangtat mine by gravity extraction showed that the cyanide extraction process had high gold recovery efficiency, condensed gold is more than 65% of the ore. Recovery coefficient reached 67.5%.

3.3.5. Mineral symbiosis and ore-forming period

Figure 3.9: Order of formation and mineral symbiosis in the study area

Period	Hydrothermal		Exodiagenesis
Phase	I	II	III
Symbiosis / Mineral name	Quartz, Pyrite, gold	Pyrite, galenite, sphalerite chalcopyrite, pyrotine, gold	Limonite, goetit, covelline
Quartz	━━━━━━	──────	
Gold	- - - - - -	──────	
Pyrite	━━━━━━	━━━━━━	
Rutile	- - - - - -		
Ilmenite	- - - - - -		
Pyrotine		- - - - - -	
Galenite		▬ ▬ ▬ ▬ ▬ ▬	
Sphalerite		▬ ▬ ▬ ▬ ▬ ▬	
Chalcopyrite			
Limonite			━━━━━━
Goetite			━━━━━━
Covelline			- - - - - -
Typical ore architecture	idiomorphic granular, hypidioblast, and anhedral grains	Extend shape, blade shape, radiolitic shape	Colloid, pseudomorph, corrasion
Typical ore structure	Nest, disseminated, vein	Nest, vein, disseminated, oriented dissemination	Colloid, nest, vein
Surrounding hydrothermal alteration	Sericization, quartzization, chloritization	Chloritization, quartzization	Oxidation

━━━━━━ Major Minerals.

────── Minor Minerals.

- - - - - - Rare minerals.

3.4. Origin of native gold ore formation in the study area

Summary of research results shows that the native gold ore in Attapeu has the following characteristics:

- The native gold ore deposits and points are mainly distributed in the South Truongson - Sekong structural zone.

- The geological factors controlling the ore body are the northwest - southeast and submeridian faults; Middle Cambrian - Early Ocdovician sediments (ε_2-O_1); (O_3-S) has the role of containing ore. Intrusive formations of Permian - Early Triassic (P-T_1) are the material source for the native gold ore forming process in the region.

- The native gold ore bodies of Attapeu region are vein type and vein zones. The main ore-forming mineral complex: pyrite, chalcopyrite, galenite, sphalerite, pyrotil and native gold.

- Results of analysis of K-Ar isotope age for white mica (analyzed in Japan): 2 samples in the ore body (Vangtat) with a value from 235±4 to 206±4 million years. The results of K-Ar (biotite) analysis in the Early Permian-Triassic magmatic rock (P-T_1) of the JICA project: value from 269.3 to 248.6 million years

- The results of analysis of 2 samples of primary inclusions of liquid-gaseous elements for quartz minerals (analyzed in Vietnam) show a forming temperature is about 202^{o}C-268^{o}C. The results of analysis of 2 samples of inclusions of liquid-gaseous protozoa (analyzed in Japan) showed a forming temperature is about 240-260^{o}C. The analysis results of the JICA project show that the original gold ore forming temperature in the Attapeu region ranges from 200^{o}C-300^{o}C.

From the above results, we have the following conclusions:

- The nativre gold ore-forming solution in the area is a medium-temperature hydrothermal solution (200^{0}C - 300^{0}C).

- The study area includes 02 phases of ore forming, which is characterized by 02 mineral symbiotic combinations, which are quartz -pyrite-gold and quartz-pyrite-chalcopyrite-galenite-sphalerite-gold.

CHAPTER 4
EVALUATION OF RESOURCES AND ORIENTATION OF GOLD ORES PROSPECTING, EXPLORATION IN THE ATTAPEU REGION

4.1. Evaluation of the potential of native gold ore resources in Attapeu region

4.1.1. Premises and investigation indicators

a. Investigation premises

- *Stratigraphic premise:* The metamorphic sediments of the Middle Cambrian - Early Ocdovician (ε_2-O_1) are: sericite quartz schists, sericite schists, biotite quartz, muscovite quartz. The terrigenous sedimentary formations are: sericite schist, quartz - sericite schist, gritty sandstone, sandstone, siltstone, siliceous limestone, late Ocdovician-Silurian quartz - calcite schist (O_3-S).

- *Magmatic premise:* Research results show that intrusive formations of Permian - Early Triassic age (P-T_1) are related to the process of forming native gold ore and some other metallic minerals. Thus, the Permian - Early Triassic (P-T_1) formations are important premises for native gold investigation in the study area..

- *Tectonic premise:* Along the northwest-southeast and the submeridian direction faults, mineralization points of hydrothermal origin have been recorded, this is the premise to find for endogenous deposits in the region, especially native gold ore.

b. Investigation indicators

* *Direct indicators:* Exposed ore on the surface containing sulfur minerals, excavation works done by local people. The rolling rocks contain sulfur minerals. Heavy dispersion haloes.

* *Indirect indicators:* hydrothermal alteration of the rocks surrounding the ore body such as sericitization, quartzization, and chloritization. Magnetic, natural electric fields anomalies.

4.1.2. Prospect zoning

Based on the principles of reasonable prospects zoning, Ph.D students classified and ranked prospects according to the following 03 grades:

- *Very promising area (grade A)*: Total area 13,4km^2, has 2 zones: Vangtat, area 03km^2 (A1); Namxuan, area 10.4km^2 (A2).

- *Promising area (grade B):* Total area 216,1km^2, with 03 zones: Vangtat, (B1=44,2km^2; B2=6,8km^2; B3=2,9km^2; B4=14,7km^2);

Huaypeak - Antoum, (B5=27,5km^2; B6=11km^2); Namxuan - Namlay - Sexu, 33km^2 (B7=38,6km^2; B8=70,4km^2).

- *Unknown prospect areas (grade C):* Total area: 181,7km^2, with 04 zones: Huaypeak - Antoum, (C1 =142,5km^2); Namxuan - Namlay - Sexu, (C2=8,9km^2; C3=11,3km^2); Dakkanat, (C4=19km^2).

4.1.3. Evaluation the native gold resources of the Attapeu region

a. Determined resources

The total determined resource is 60.347 kg (Au); in which Vangtat mine has a reserve of 122 grade is 23.412 kg (Au), a resource of 333 grade is 30.092 kg (Au); Namxuan mine has a reserve of 122 grade is 2.871kg (Au), grade 333 is 3.972kg (Au)

b. Prediction resources

Table 4.1: The results of gold resource assessment for the Attapeu region according to the method of straight calculation according to the ore parameters

No	Area	Prospect grade	Resource Au (Kg)
1	Vangtat	A1	3.735
2	Namxuan	A2	10.551
3	Vangtat	B1	27.512
		B2	4.233
		B3	1.805
		B4	9.150
4	Huaypeak - Antoum	B5	16.710
		B6	3.928
5	Namxuan - Namlay - Sexu	B7	11.768
		B8	15.692
6	Huaypeak - Antoum	C1	86.590
7	Namxuan - Namlay - Sexu	C2	2.713
		C3	3.445
8	Dakkanat	C4	3.465
	Total		201.298

Table 4.2: Result of assessment of prediction gold resources for Attapeu region according to similar geological method

No	Area	Prospect grade	Resource Au (Kg)
1	Vangtat	A1	3.548
2	Namxuan	A2	10.119
3	Vangtat	B1	28.062
		B2	4.317
		B3	1.841
		B4	9.333
4	Huaypeak - Antoum	B5	16.486
		B6	4.216
5	Namxuan - Namlay -Sexu	B7	11.788
		B8	15.717
6	Huaypeak - Antoum	C1	86.854
7	Namxuan - Namlay - Sexu	C2	2.718
		C3	3.451
8	Dakkanat	C4	3.641
	Tổng		202.092

4.2. Orientation for the investigation and exploration of native gold ore in the Attapeu region

4.2.1. Overview of the investigation and assessment of native gold in the region

The research results show that the Attapeu area is very promising for gold minerals, so further research is needed in order to effectively orientate mining and mineral processing in the near future.

The methods used in the investigation and assessment of native gold in the study area include: geological and mineral mapping at the scale of 1:25,000; 1:10,000; geological route methods, geochemical, heavy sediments, geophysical methods; excavation and drilling works; Collect and analyze geological samples. Research results have

identified promising areas for native gold and some other minerals such as copper, lead-zinc, bauxite,... in the Attapeu region.

4.2.2. Orientation of investigation and evaluation

a. Select the area for investigation and evaluating

PhD student selected promising areas (grade B) and areas of unknown prospects (grade C) with a total area of 216,1km^2 to orient theinvestigation and assessment of native gold ores.

b. Basis for selecting the system of investigation and evaluation methods

There are 5 main factors affecting the selection of objects and combinations of investigation methods, including:

- Physic-chemical properties of minerals.
- Shape, size, position of mineralized body.
- The geological structure and complexity of the ore.
- Geographical circumstances, hydro-engineering geological conditions.
- Economic conditions.

c. Requirements to be achieved in the investigation and evaluation phase

According to Circular 42/2016/TT-BTNMT, Ministry of Natural Resources and Environment of Vietnam. The requirements to be achieved in the process of mineral prospecting, investigation and assessment include:

- Processing and synthesizing documents of all types of work in the mineral assessment phase;
- Prepare documents, drawings, maps etc. fully and consistently to ensure the correct of the geological and mineral settings of the area;
- Calculating mineral resources in accordance with regulations;
- Determine the rules of ore distribution;
- Identify potential areas for exploration proposals

d. Selecting a investigation methods

The Ph.D student proposes a combination of methods for investigating and evaluating the native gold of the Attapeu as follows:

- Synthesize, analyze and determine the premises for gold ore

from the results of geological, minerals mapping at scale 1:200.000, 1:50.000; 1:25.000 to identify potential native gold ore;

- The method of analyzing remote sensing images to delineate favorable structures as a basis for zoning the prospective area;

- Analysis of aviation gamma spectrum measurement documents;

- Method of geological and structural survey at scale 1:25,000 - 1:10,000 or 1:5,000 to clarify the geological structure features of the ore zones, mineralization zones, and identify relevant geological factors and control gold ore;

- Excavation work of trenches, wells, outcrop clearance combined with drilling (vertical, oblique), possible to use a combination of several tunnel works;

- System of methods to study material composition.

4.2.3. Orientation of exploration work

a. Basis for selection of mine exploration area

Select a very promising area (grade A) including 2 areas Vangtat and Namxuan mine, total area of 13,4 km^2 to orient exploration work.

b. Set up exploration mine group

*** Basis for establishing group of exploration mines**

According to Decision No. 03/2015/TT-BTNMT of the Ministry of Natural Resources and Environment of Vietnam dated February 13, 2015 has divided the group of exploration mines into groups: a) Simple mines (I); b) Relatively complex group of mines (II); c) Complex mine group (III); d) Very complex group of mines (IV). At the same time, there are specific regulations on the conditions for grouping exploration mines

*** Characteristics of geological structure, morphological - structural of ore body and distribution of gold content in ore bodies**

Thickness variation and gold content are two basic parameters contributing to the division of exploration mines. To evaluate the variation of these two parameters, Ph.D student carried out statistical processing of thickness and gold content for typical ore bodies at

Vangtat and Namxuan mines. Statistical processing results of two mines' characteristic parameters are as follows:

+ Vangtat mine: The degree of variation of gold content belongs to the group of very uneven variation (V_C = 106,8% - 134.1%); Variable thickness from stable to unstable type (V_m= 8,9% - 64,6%).

+ Namxuan mine: The variation of gold content in the group varies from unequal to particularly unequal (V_C=90% - 385%); Variable thickness ranges from unstable to very unstable (V_m= 46,7% - 116,8%).

*** Result of establishing group of exploration mines**

Based on the main criteria used to classify the native gold ore exploration mines in the Attapeu region, the mines have a complex geological structure; the ore bodies are small to medium in size and the bedding position changes sharply; the thickness variable from stable to very unstable; Gold content varies from very uneven to particularly uneven. Based on the mentioned characteristics, compared with regulations, the Vangtat and Namxuan native gold mines in particular; identified deposits and gold mines in the study area in general, are classified in group III of exploration mines.

For mines group III, the reserve requirement to be achieved in exploration to serve the formulation of investment projects for mining works is 122 grade. In which, the reserve at 122 grade must satisfy the minimum requirements for the first 5-7 years of mining project

c. Establishing the native gold ore exploration grid

*** Similarity method or comparision method**

With the results of grouping exploration mines, based on Circular No. 03/2015/TT-BTNMT, the exploration grid to calculate 122 grade reserves for group III is as follows:

- Trenches and wells works follow strike line from 20 to 30m.

- Drilling works, tunnel or a combination of drilling and tunnel follow strike line from 40 - 60m. These works are arranged on the route in the direction of slopes at a distance from 20 to 40m.

*** Geo-mathematical method**

- The results of the analysis of the exploration grid by statistical

methods show that the distance of the exploration line ranges from 53 to 60m, the works on the line from 32-40m; This result is quite consistent with the orientation of exploration grid according to Circular No. 03/2015/BTNMT of the Ministry of Natural Resources and Environment of Vietnam for group of exploration mines III.

- The results of the density analysis of the exploration grid based on the stable random function theory show that: The size of the influence zone of the thickness and the gold content along the slope direction are similar; but follow the direction of the strike line there is a difference, but not much. In general, the zone size affects the thickness more than the content. In this case, the best exploration grid is interpreted according to the variation of Au content in the ore bodies. Average anisotropy index from 1.8-2 for content; 1.9-2.1 for thickness.

With the above results, the gold ore exploration grid of Vangtat and Namxuan mine type to calculate the 122 grade reserves follow the strike line is from 30 to 50m, with an average of 40m; follow the direction of slope is from 15 to 28m, average 20-25m.

**** Selection of exploration grid***

- The most reasonable exploration grid to evaluate ore body volume is to use parallel line or rectangular grid.

- Propose a grid to orientate the arrangement of native gold ore exploration works for Vangtat and Namxuan as shown in Table 4.3.

Table 4.3: Orientation grid of native gold ore exploration works in Attapeu region.

Group of exploration mines	Works	Reserve 122 grade		Resource 333 grade	
		Strike line (m)	Slove (m)	Strike line (m)	Slope (m)
III	Drilling	40 - 60	20 - 30	80-120	40 - 60
	Excavation	20 - 30		40 - 60	

d. Selecting a system of exploration works

Based on the characteristics of geological structure, morphological - structural characteristics, the distribution characteristics of the ore bodies, according to the PhD student, the suitable system of exploration works for the Vangtat and Namxuan

native gold mines should use a combination of excavation works (trenches, wells, outcrop clearance, combining several flat tunnel), combined with the system of drilling works (vertical, oblique) and ground geophysical methods, borehole geophysics; In some cases, primary geochemical methods can be used.

e. Requirements to be achieved during the exploration and development phase of the mine

During the exploration and development phase of the mine, The company needs to comply with and ensure the requirements under Regulation No. 1419/NL&M of the Ministry of Energy and Mines of Laos. Pay special attention, the exploration grid must meet the reliability requirements to calculate the 122 grade reserves as proposed in the thesis.

CONCLUSIONS AND RECOMMENDATIONS

1. Conclusions

1.1. The native gold ore in the Attapeu region is distributed mainly in the Southern Truongson - Sekong structural zone in the eastern part of the study area. The geological structural factors controlling the native gold ore mineralization are the northwest - southeast and sub-meridian faults; The lithological - stratigraphic factors are metamorphic sediments aged Middle Cambrian - Early Ocdovician (ε_2-O_1) and the Late Ocdovician - Silurian (O_3-S).

1.2. The origin of native gold ore in the Attapeu region is hydrothermal, formed under medium temperature conditions (200^0C - 300^0C), including 02 stages of ore-forming, the product is characterized by 02 symbiotic combinations of minerals: quartz - pyrite - gold and quartz - pyrite - chalcopyrite - galenite - sphalerite - gold. The Permian - Early Triassic (P-T_1) intrusive formations are the sources of material for the native gold ore forming in the region.

1.3. The native gold ore bodies in the Attapeu region are mainly vein type or vein zone, quartz - sulfur - gold microveins, the ore body is often steep to very steep (45^0 - 85^0), the ore body has a complicated morphology - structure. The typical hydrothermal alteration are quartzization, sericitization, and chloritization.

1.4. The research results have established the premises and indicators for native gold investigation in the region; from scientific basis and documents, the thesis identified 02 very promising areas of grade A, 08 areas of potential grade B and 04 areas of unknown prospects of grade C. Combining geo-mathematical methods with traditional geological methods and applying quantitative mineralogy evaluating methods, the Attapeu region has a large potential for native gold resources. The total identified resource is about 60,3 tons of gold; total estimated resources (334 grade) will reach over 200 tons of gold.

1.5. The native gold mines and deposits in the study area belong to group exploration mines III. For mine exploration and development, it is necessary to comply with the requirements mentioned in the thesis; mine exploration and development objectives must be fully assessed in terms of quality, technological properties, exploitation conditions and grade 122 reserves; grade 333. Of which, 122 grade must satisfy the minimum requirements for the first 5-7 years of the mining project.

The most appropriate exploration grid works for calculating reserves of grade 122 should use the line, distance between excavation works is 20 - 30m; the distance between drilling line is 40 - 60m; works on the route are 20-30m.

2. Recommendations

- It is necessary to study in more detail about the ore-bearing geological structure of promising areas for native gold ore.

- Studying the vertical zoning, the grade of ore body erosion, the depth of existence, building up a model of ore forming and should pay attention in research, investigate native gold ore that deep hidden in the region.

- In addition to the native gold, in the region there are also manifestations of placer gold and other minerals that need attention such as: copper, silver, lead - zinc... Therefore, in the process of geological research, investigation and assessment of mineral resources in the region, it is necessary to conduct comprehensively and it is necessary to simultaneously evaluate the scale and quality of all minerals in the study area.

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