MINISTRY OF EDUCATION AND TRAINING

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TECTONIC CHARACTERISTICS OF HOA AN AREA, CAO BANG PROVINCE AND THIER SIGNIFICANCE WITH NICKEL - COPPER MINERALIZATION

Sector: Geology

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SUMMARY OF PH.D THESIS

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The thesis will be defended in front of the School-level Thesis Evaluation Council at the University of Mining and Geology at …..., date ….. month ….. year ……

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INTRODUCTION

1. The urgency of the research topic

Nickel minerals are the high economic value metal minerals because it is the main raw materials in the development of industries such as: superalloys manufacturing, plating and electric batteries manufacturing etc, in recent years the demand for raw materials has increased steadily by about 2.2%/year. Currently, many industrial-scale nickel ore mines have been discovered in our country, related to ultramafic bodies such as: Bản Sang (Sơn La province), Suối Củn, Phan Thanh, Hà Trì blocks và Đông Chang (Cao Bằng province), ….

In the Northeast Vietnam region, in recent years, there are are some studies on the tectonics, structural geology and lithology of ultramafic ore-bearing magmatic rocks, e.g. Tran Trong Hoa et al., 2004, 2008; Tran Thanh Hai et al., 2007, 2011; Ngo Xuan Thanh et al., 2014; Halpin, et al., 2015 v.v… These works have solved some problems about regional tectonics, ore-coltrolling strudture, and nickel - copper mineralization on some ultramafic blocks in Cao Bang area. These results are important information s for the further research orientation.

Recent research results have shown that the study area has complex geological features, including sedimentary, intrusive and eruptive formations of different ages and origins, most of which are allochthonous tectonics, limited by large-scale shear zones (Tran Thanh Hai et al., 2007). In particular, in the Hoa An - Cao Bang area, there are also ultramafic formations containing significant potential of nickel - copper and other useful minerals (Tran Trong Hoa, 2008), which are currently being explored for exploitation. Hence, the understanding of regional tectonic characteristics, spatial relationships and geological formations origins as well as their role in related mineralization not only provides new insights into the regional geology, tectonic history but also has important significances in forecasting and evaluating geological resources in the area and in the vicinity and likewise other geological formations with similar characteristics. Therefore, the topic ***"Tectonic characteristics of Hoa An and Cao Bang areas and the relationship with nickel-copper mineralization"*** is posed with important significance both in terms of science and practicality for the above problem.

2. Objectives

Clarifying the tectonic characteristics, magmatic tectonic setting, and the relationship between tectonics, structural geology, magmatic elements with nickel - copper mineralization in Hoa An area. These data will provide important inforation for nickel - copper minerals prospecting and evaluation in the Hoa An area.

3. Research object and scope

Object: Geological formations, geological structure and nickel-copper mineralization related to ultramafic intrusion.

Scope: Hoa An area, Cao Bang province.

4. Tasks

Clarifying of the material composition, geological formations age, and the geological background of their formation.

Clarifying igneous tectonic setting and its significances in nickel - copper metallogeny.

Research the tectonic structure characteristics in Hoa An, analyzing the role of tectonic structure factors in the nickel - copper mineralization process related to ultramafic intrusion. Explanation of the relationship between tectonics - magma - nickel copper metallogeny.

5. Scientific and practical significance of the thesis

5.1. Scientific significance

The determination of tectonic stages, tectonic deformation phases and the relationship of ultramafic magma with the nickel - copper mineralization process are the important scientific findings as a basis for interpretation of the geological formations nature and distribution as well as the nickel - copper mineralization distribution in the study area

The lastest and synchronous data of the thesis regarding tectonic structure characteristics,

geodynamic background, magmatic rocks lithogeochimistry characteristics, metallogenic ability, isotopic age and nickel - copper mineralization characteristics in the study area is a significant contribution to the geological document system in Vietnam

5.2. Practical significance

The determination of tectonic deformation phases, especially the tectonic deformation phases closely related to the ultramafic intrusive blocks formation and distribution, has an important meaning in orienting the research work, delineating nickel - copper mineralization promising areas in the study area.

The lastest data regarding the characteristics of ultramafic magmatic rock lithogeochimistry and nickel-copper mineralization of the thesis are valuable in establishing the metallization type and their relationship with the tectonic background as the basis for determining direction for minerals investigation and assessment in Hoa An, Cao Bang.

6. Thesis defense arguments

Argument 1: Hoa An area has undergone at least 05 tectonic events from Early Paleozoic to Cenozoic, in which the Late Paleozoic - Early Mesozoic stage plays as an important role in the formation of mafic, ultramafic rocks and nickel - copper ores. The geological formations in the area have been affected by at least 05 tectonic deformation phases, including the first deformation phase occurring in the Early Paleozoic, the second and third phases occurring in the Early Mesozoic, and the fourth and fifth deformation phases in the Cenozoic.

Argument 2: Ultramafic rocks in Hoa An area were derived from crustal-enriched mantle origin forming in a back-arc tectonic setting, they play the role of nickel - copper metallogeny, in which the disseminated ore type in ultramafic rocks is predominant, nickel metallogeny is more dominant than copper, PGE. The nickel-copper mineral bodies are concentrated in the lower part of the ultramafic blocks, they were re-concentrated by the second deformation phase and also pushed up, redistributed by the second and third thrust phases, and futher moved, dissected by the fourth and fifth deformation phases.

7. Recent findings in the thesis

Five tectonic events have been identified in the tectonic history in Hoa An area. In which, the Late Paleozoic - Early Mezozoic period is related to the formation and distribution of ultramafic intrusive bodies bearing nickel - copper mineralization.

Five tectonic deformation phases have been established in the study area and the role of each deformation phase in the formation, distribution and rearrangement of geological formations and nickel - copper ores in Hoa An area.

Field occurrence, petrogranphy, formation age, whole-rock geochemistry of the Late Paleozoic - Early Mesozoic mafic rocks have been dated, thereby contributing to the active continental margin identification during this period in the Song Hien -An Chau tectonic zone.

The role of deformation phases in the ore-bearing ultramafic rocks has been established.

The discovering of existence of granodiorite magmatic rock aged 441-450 Ma (Ordovic) in Hoa An area, Cao Bang.

8. Thesis's layout: The content of the thesis is presented in 160 pages of A4 paper, in which there are 41drawings, 15 tables, 46 photos and 01 appendices. In addition to the introduction and conclusion, the thesis is structured into 4 chapters.

9. Documentary basis to complete the thesis

The thesis is completed on the basis of collected documents including: 4979 chemical samples, 50 mineralographic sample, 99 petrographic samples belonging to the Ha Tri, Phan Thanh exploration report etc. Especially the results of the analysis carried out by the PhD student from 2016 up to now, including: 50 petrographic samples at the Ha Noi Univesity of Mining and Geology, Analytical and Experimental Center for Geology; 50 samples for rock-forming mineral composition determination, 34 samples for major elements, trace elements geochemical composition analysis, 5 samples for geochemical composition analysis of Sr, Nd and Pb isotopes, in Okayama University, Japan; 15 samples for isotopic pairs analysis $^{87}Sr/^{86}Sr$ and $^{143}Nd/^{144}Nd$ were analyzed at the Korea Basic Science

Institute of (KBSI); 11 samples for analysis of elemental composition of platinum group were analyzed at Actlabs Analytical Laboratory, Canada and 08 samples dated by U-Pb isotope on zircon minerals of gabbrodiabas, gabbro by MC-ICP-MS technology, at Okayama University, Japan.

10. Place to carry out the thesis

The thesis is carried out at the Department of Geology, Faculty of Geosciences and Engineering, Hanoi University of Mining and Geology.

THESIS CONTENTS

Chapter 1. Overview of the study area

1.1. Overview of the study area location and characteristics

The study area is located in Hoa An district, Cao Bang province, about 8.0km northwest of Cao Bang city. The study area has low mountain topography, gentle slopes, with an absolute altitude of 200-500m, the system of rivers and streams in the region mainly flows in the southeast direction, convenient transportation for geological investigation and research

1.2. Brief history of geological research

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

1.2.2. 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. In 2017, Tran Minh Quang et al explored the Ha Tri area. Studies on tectonic structure to explain the history of tectonic evolution in Northeast Vietnam, with typical works such as: Tran Trong Hoa et al., 2004, 2008b; Polyakov et al., 2009; Lepvrier et al., 2011; Tran Thanh Hai et al., 2007; Cai, J.X., Zhang, K.J., 2009, 2009; Qin et al., 2011; 2012; Tran Thanh Hai et al., 2011; Jacqueline A.Halpin, Tran Thanh Hai, Chun-KitLai, Sebastien Meffre, Anthony J.Crawford, KhinZaw, 2015; Ngo Xuan Thanh et al., 2014; ….The research data of these works are very important in interpreting and repeating the tectonic evolutionary history of the region, orienting the investigation and prospecting for endogenous minerals.

1.3. Location of the study area on the regional structural zone

The study area is classified into the Song Hien and Ha Lang structural zones, belonging to the "Eastern Vietnam fold standard region" (Dovjikov A. E. et al., 1965, Tran Van Tri et al., 1977,). In recent years, the Northeast in general and Song Hien in particular have not yet agreed on its tectonic positions. Among them, it is worth noting that the tectonic viewpoints all believe that the Northeastern part of Vietnam is part of the South China's block tectonic map (Tran Trong Hoa et al., 2008; Tran Van Tri et al., 2015).), or tectonic melange zone (ophiolite, volcanic arc..., Tran Thanh Hai et al., 20011; Halpin et al., 2015).

1.4. Geological features overview of the study area and its vicinity

Sedimentary formations: including the Than Sa Formation shales; terrigenous sediments, carbonate sediments, Mia Le, Na Quan, Bac Son, Toc Tat, Dong Dang shales, Bang Giang Formation extrusive basalt and pillow basalt; rhyolite, ryodacite, dacite and their tuf interbeds of layers of sandstone, shale, siltstone, limestone lens, dark gray marl of Song Hien Formation and Cenozoic sediments.

Intrusive magmatic formations: Intrusive bodies with Cao Bang Complex mafic and ultramafic compositions and intrusive rocks of Early - Middle Triassic age Nui Dien Complex granite to granodiorite.

Tectonic features overview: In the Early Paleozoic period, the Song Hien - An Chau zone belongs to the East Việt Bắc subzone in the North-Eastern zone, which has divided 4 petrotectonic assemblages and 6 tectonic deformation phases (Tran Van Tri and Vu Khuc (2009) and Tran Van Tri (2015).

1.5. Some limitations before

1.5.1. Stratigraphy: Some relationships between formations in the study area are still unclear, typically the relationship between Devonian formations, the relationship between the Song Hien and the Bang Giang formation, the relationship between the Bac Son, Bang Giang formations with older formations.

1.5.2. Magma: The age of formation is mainly based on a few results of age studies U-Pb, Rb-Sr of the works in the area and the vicinity. In which, mafic and ultramafic rocks are classified in age P_3-T_1, rhyolite formations are classified in T_2 and intrusive rocks are of age T_1. The magmatic geochemistry and lithology is quite sparse in Hoa An area, especially there is no synchronous research on geochemistry, isotopic age (U-Pb zircon), source isotope to assess the magmatic formation source, background and magmatic processes, as well as the nickel - copper metallogenic ability of magmatic rocks intruding Cao Bang Complex.

1.5.3. Structure tectonic: In Hoa An area, studies on tectonic structure have not been conducted in detail or quantitative data on tectonics is lacking to re-establish the tectonic evolution history as well as evaluate the tectonic structure role, tectonic influence on the geological formations distribution, especially mafic and ultramafic rocks bearing nickel - copper mineralization.

1.5.4. Ni-Cu mineralization in ultramafic: There are not been intensive and quantitative research to determine the nickel - copper mineralization origin and characteristic as well as using the studies on PGE group geochemical specialization, S isotope and so on have not been conducted. Intensive research on geochemical characteristics, magmatic isotopes combined with ultramafic magmatic lithology characteristics to elucidate the nickel-copper mineralization characteristics and the existence form of nickel-copper mineral bodies in the study area also sparse.

Chapter 2. Theoretical foundations and methodology

2.1. Theoretical foundations

2.1.1. Regional tectonic

Tectonics (from Latin tectonicus; derived from Ancient Greek (τεκτονικός (tektonikos)) are processes controlling the structure and properties of the Earth's crust and its evolution through time. These include the processes of continental and ocean formation, orogen uplift, subsidence creating sedimentary basin, volcanic activity, metamorphism, deformation, etc., and how the Earth's tectonic plates interact with each other. Tectonic activities in an area could take place in many stages creating a diversity of material compositions in the area. In plate tectonics, the lithosphere could be divided into many different plates and the relationship between the plates includes convergence boundary, spreading boundary, transform boundary (Philip et al., 2009).

2.1.2. Deformation and deformation relation

Tectonic deformation is the one of rocks under the tectonic movements influence. In the geological history of an area, the Earth's crust could experience through many different deformation stages, each stage is characterized by a deformation mode and leaves a assemblage of characteristic structures in the rocks of a certain area. A deformation development stage is called a 'deformation phase', and a combination of geological structures characteristic of that phase is called a structural generation (Tran Thanh Hai, 2017). In order to recover the regional deformation history, it is necessary to identify and divide the specific structural generations for each deformation phase, determine their relative age and interpret the essence of the deformation regimes acting on rocks (Tran Thanh Hai, 2017). Therefore, in order to systematically interpret and distinguish the types of structures, determine their distribution rules as well as the relative ages between geological structures in the field, this study applies a combination of principles and techniques of

scientific observation and interpretation. The following principles are implemented such as: Interpretation of geologic structure: Law of initial horizontality, Law of continuity in space, Law of superposition, Law of cross-sectional relationship, Pumpelly's Law; identification of primitive structures and deformation-induced structures; deformation events dating and division of the petrotectonic assemblage.

2.1.3. Overview of liquation-magmatic Ni-Cu sulfide deposits

Liquation sulfide magma deposits are a type of actual magma deposits formed by magmatic divergence occurring in mafic and ultramafic magma chambers. The essence of the liquation is the differentiation and separation of a metal sulfide-rich magma part from the silicate solution even in the liquid state. The silicate liquid separates as a drop of liquid sulfide, heavier than the silicate solution, settling to occupy the bottom of the chamber or block.

* **Liquation-magmatic Ni-Cu sulfide mineral deposits**

Currently, liquation-magmatic Ni-Cu sulfide deposits are the main source of nickel in the world. Ni-Cu sulfide ore type is related to ultramafic magmatic rock formed by the differentiation of sulfide-rich magma, typically: Petsenga-Russia, Norilsk-Russia, Sudbury-Canada, Jinchuan-China mines and some mines other in Australia, USA, South Africa.... In Vietnam, Ni-Cu sulfide ore mineralization has been found in Ta Khoa area, Son La province, in Cao Bang and in Thanh Hoa.

* **Ni-Cu tectonic and metallogeny background**

In the mantle environment on subduction zones, magma is more alkaline and oxidized than tholeitic or komatic magma, which increases the solubility of S, which is an important parameter in the formation of sulfide liquids to form into nickel-copper mineral deposits. Currently, a number of nickel-copper mines have been found related to the back-arc environment connected to subduction activities such as: Ni-Cu Ferguson Lake, Nunavut, Canada; Yueyawan, Huangshangdong, Kalatongkte or Xiangshan mines in China.

*** S saturation efficiency and Cu-Ni-PGE ore concentration**

The degree of mantle source melting is an important factor of the amount of siderophile and S elements entering the magmatic liquid phase, where the S saturation process in the liquid phase occurs when the source melting level is sufficiently large (typically above 15-25%) to form Cu-Ni-PGE sulfide ore deposits. The S saturation process occurs, in addition to the high-source melting, there may be factors such as mixing of magma with S-rich shell matter, fractional crystallization, the changes in magmatic crystallization temperature and pressure or the sedimentary material impacting process into the mantle (Sproule et al., 2002).

2.1.4. Geological processes controling magmatic chemical composition

*** Mantle source melting process**

Research on the formation of magmatic rocks includes two basic processes, one is the Mantle or Earth's crust partial melting to form primordial magmatic chamber and the other is the crystallization cooling process of liquid formming hard rock. In particular, the partial melting process is divided into two types: batch melting and fractional melting, also known as Rayleigh melting. The differential crystallization process, depending on the original liquid, during the crystallization process, could result in different products.

*** Mantle source melting degree and relationship with the potential Cu-Ni-PGE**

The formed magmatic composition depends on the one of the rock source and the degree of mantle source melting. The melting degree depends on temperature, pressure and the change in the mantle composition due to the mixing of matter (hydrothermal, molten material from the subduction zone). The greater the temperature and mixed matter into the mantle, the higher the degree of melting, while the reduced pressure is the condition for the mantle to melt (rift), the high pressure makes it difficult for the material in the mantle to melt (deep mantle is harder to melt than shallow mantle). Magma tholeite olivine and picrite are related to the 15-30% degree of mantle melting. Magma komatite is formed by very high melting mantle, up to >35%. Thus, the degree of melting is related to the potential to

generate different types of minerals, for example: The source of mantle is primitive, the melting level must reach 17 - 25% will let most of the PPGE, Cu matter in the mantle could escape upward along the magmatic flow (Rehkämper et al., 1999).

2.1.5. The relationship between magmatic activity and tectonic processes

Magmatic activity is always associated with certain tectonic backgrounds. According to theories of plate tectonics, on the basis of tectonic backgrounds, three environments could be identified in which magma would be formed: Mid-ocean spreading magma; convergent plate magrin magma and intraplate magma.

2.2. Methodology

2.2.1. Identification of structures due to tectonic deformation

Deformed structures are formed by deformation processes and have different characteristics from the original structures. In order to distinguish between the structure created by deformation and the original structure, it is necessary to identify and distinguish identification criteria such as: folds, faults, surface structure, line structure.

2.2.2. Deformation phases division

In order to divide the deformed phases, it is known that each deformed phase produces a generation of formed structures with specific characteristics, a formed generation is a collection of formed structures at the same time, under the same stress field.

2.2.3. Deformation events dating

The age of deformation events includes relative age and absolute age. Relative age: is the age determining the formations formed before or after. Absolute age: is the age that determines the specific time that the deformation phase occurs. To determine the absolute age, radioisotope dating is usually used.

2.2.4. Petrotectonic assemblage division

A set of closely related rocks, formed in contiguous periods of time, in environments characterized by a certain tectonic background and representing a certain period of geologic evolution (Kondie, 1989).

2.3. Approach

To elucidate the characteristics of tectonic structure, geological history and their relationship with the mineralization process of nickel - copper in ultramafic rocks in Hoa An and Cao Bang areas as the goal of the thesis, the PhD student applied using the approaches and research methods that are both inherited, traditional and modern that have been applied in the world and Vietnam.

2.4. Research methods

In this report, the PhD student has been using a combination of key research methods as Survey, field study and sample collection; Laboratory Research and Modeling Methods.

The following types of samples have been collected and analyzed: 50 petrographic samples; 50 samples for rock-forming mineral composition determination, 34 samples for analysis of geochemical composition of major elements, trace elements, 5 samples for analysis of geochemical composition of Sr, Nd and Pb isotopes; 15 samples analyzed isotopic pairs $^{87}Sr/^{86}Sr$ and $^{143}Nd/^{144}Nd$; 11 samples were analyzed for the elemental composition of Platinum group and 08 samples were dated by U-Pb isotope by MC-ICP-MS technology, most of the samples analyzed in Korea, Japan and Canada.

Chapter 3. Geological characteristics and nickel - copper minerals in Hoa An area

3.1. Stratigraphy

3.1.1. Thần Sa formation ($\varepsilon_3 ts$): The petrographic composition is mainly fine- to medium-grained sandstone, irregular grains interspersed with a little siltstone and claystone. The rock is deformed and moderate altered with the appearance of chlorite and mica belonging to the regional greenschist metamorphic facies.

3.1.2. Mia Lé formation (D_1 ml): The main petrographic composition: sand, siltstone

interbeds of thin layers of marl, lime lenses, the top is shale mixed with interbed marl.

3.1.3. Nà Quản formation ($D_{1-2}nq$): The formation petrographic composition is mainly limestone, clayish limestone, siliceous lime, sometimes dolomitized and marbleized.

3.1.4. Tốc tát formation (D_3-C_1tt): The main composition is stripped limestone interbeds of thin to medium or thick limestone, the high part of the formation contains a manganese seam.

3.1.5. Bắc Sơn formation (C-P_2bs): The formation petrographic composition is mainly block limestone, thick layered limestone, fine grain, gray, light gray, white gray in the upper part and the lower part is clay containing limestone, siliceous lime.

3.1.6. Đồng Đăng formation ($P_3đđ$): The formation petrographic composition is len-formed cornstone, fine grained green bauxite, pisolitic structure, moving upwards to medium to thick layered oolithic limestone, microgranular limestone, little clayish limestone sometimes dolomitized, medium to thick layered structure.

3.1.7. Bằng Giang formation (P_3-T_1bg): The formation petrographic composition is mainly amygdale basalt, basaltdolerite, andesitobasalt and their tuf, interbeds of layers or lenses of shale, siltstone, sandstone, limestone, and marl. In particular, in these basalt extrusive layers, there are many layers or sets composed of spherical pillow forms, having tectonic relationships with host rocks.

Major elements: SiO_2 content ranges from 47.0-53.72%, MgO from 6.22-12.34%, total (K_2O + Na_2O) varies from 3.01-4.42% and belonging to the field of basalt magma to basalt andesite. The graphs show that the mafic rocks range from calc-alkali rhyolite basalt to high-K calc-alkali, low TiO_2 (0.89-1.25%), Al_2O_3 (12.75-16.45%), the content of FeO^T varies from 8.29 to 11.97% and the Mg#index (Mg/(Mg+Fe2+) is relative high, varying from 54.36 to 69.44%.

Trace elements characteristics: Mafic rocks are characterized by the light rare earth elements group (LREE) enriched with the ratio $(La/Sm)_N$ = 2.09-2.71, the heavy rare earth element group (HREE) almost horizontal, indicating that the rock comes from mantle source of spinel to plagioclase - spinel. All samples have Eu depletion, with the ratio Eu/Eu* = $Eu_N/\sqrt{(Sm_N \times Gd_N)}$ varying from 0.75-0.90, the Eu depletion phenomenon may be related to mineral fragmentation of plagioclase material. On the sample matching chart with the original Mantle value, the basalt rocks in Hoa An area are characterized by enriched large-ion lithophile elements (LILE) such as Rb, Ba, K, Cs. High field strength elements (HFSEs) such as Nb, Ta, Zr, Hf, P and Ti are quite strongly depleted, typically Nb, Ta elements are very strongly depleted while Th, U are quite strongly enriched.

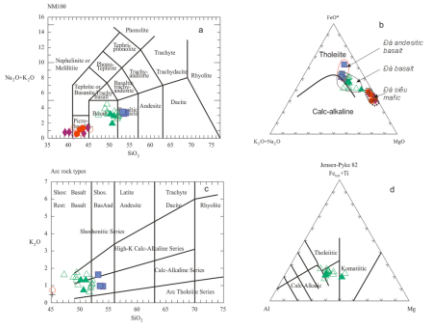

Figure 1. *Mafic and ultramafic rock classification chart*

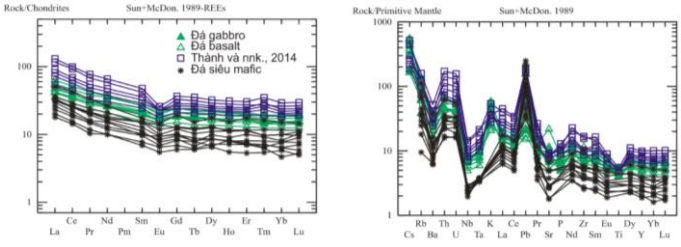

Figure 2. *Chondrite normalization chart of rare earth element group and primordial mantle normalization for trace element group for mafic and basalt andesite rocks in Cao Bang area*

$^{87}Sr/^{86}Sr$ và $^{143}Nd/^{144}Nd$, Pb isotopes

The mafic rocks are characterized by a high isotope ratio (initial isotope calculated for 250 Ma) of $^{87}Sr/^{86}Sr$, varying from 0.7064 to 0.7097, and a low isotope ratio and $^{143}Nd/^{144}Nd$ (0,512018-0.512122); εNd(t) value in mafic rocks varies from -5.99205 to -3.9652, similar to EMII rich mantle source. The original Pb isotope (calculated for 250 Ma) has the characteristics $(^{206}Pb/^{204}Pb)o$ from 18.1814 to 19,47645, $(^{207}Pb/^{204}Pb)o$ from 15,75966 to 15.83329 and the isotope ratio $(^{208}Pb/^{204}Pb)o$ varied from 37.91505 to 39.90097. The isotopic

values shown on the correlation chart, over lying the mixing line between the depleted mantle (DM) with the crust source (HIMU), are quite similar to the type II-enriched mantle (EMII). The isotopic value similarity between basalt and gabbro rocks, indicating that they are derived from the same mantle source in the same tectonic background.

3.1.8. Sông Hiến formation (T_1sh): In the study area, the Sông Hiến Formation is present in all three member, with a large distribution area and concentrated in the center of Hoa An area: Member 1: rhyolite, ryodacite, dacite and their tuf interbeds of sandstone, shale, siltstone, limestone lens, dark gray marl layers; Member 2 (T_1sh_2): Tuf sandstone, silty sandstone, siltstone, gray, yellow-gray shale, interbeds of thin layer or lens of acid extrusive rock, small lens of limestone, dark gray marl; Volume 3 (T_1sh_3): silty sandstone, dark gray shale, interbeds of sandstone, tuf sandstone thin layer.

Timing of formation: Two samples SC1, SC2 were taken along National Highway 3 in Suoi Cu area to determine the age of U-Pb isotope on zircon minerals. The SC1 sample identified 9 suitable analytical points for the mean age of 246.6±4.4 Ma and the SC2 sample identified 11 suitable points for the age of 247.2±1.9 Ma.

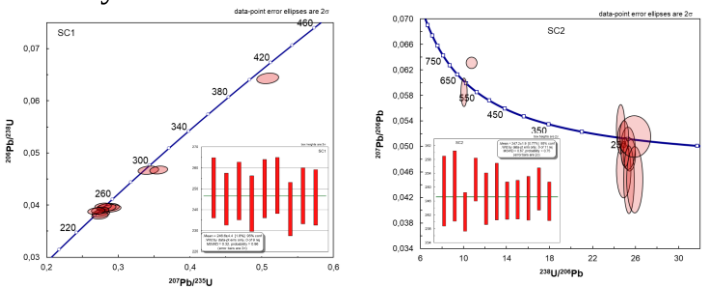

Figure 3. *U-Pb analysis results of rhyolite samples (SC1, SC2)*

3.1.9. Cao Bằng formation (N_1^3cb): The formation petrographic composition is mainly conglomerate, gritstone, interbeds of thin layerd standstone lens, interbeds of siltstone, coaly shale and thin layered lignite

3.1.10. Quaternary (Q): Composition of loose pebbles, gravel, sand, clay, silt.

3.2. Magma

3.2.1. Late Ordovician intrusive magma

This is a newly discovered magmatic formation in Hoa An area, granodiorite magmatic formation was collected at the bottom of borehole HT115.1 (65.4m depth) in Ha Tri area and the bottom of borehole K7.07 (105m depth) in Phan Thanh area, they have an upper boundary with ultramafic magmatic rocks. The rock has a block structure, bright color, coarse grain, strongly slate, strongly ruptured and weathered.

Formation age: The dating results of U-Pb isotopes on zircon minerals by MC-ICP-MS technology in Japan give an average age of 441 to 450 Ma. This new dating result has confirmed the existence of early Paleozoic magmatic formations in the study area.

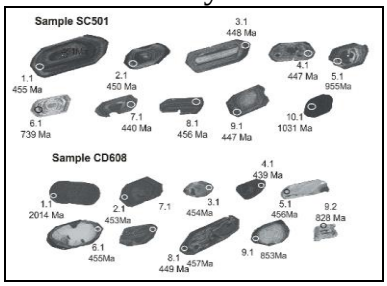

Figure 4. *CL photo of zircon grains of SC501 and DC608 samples*

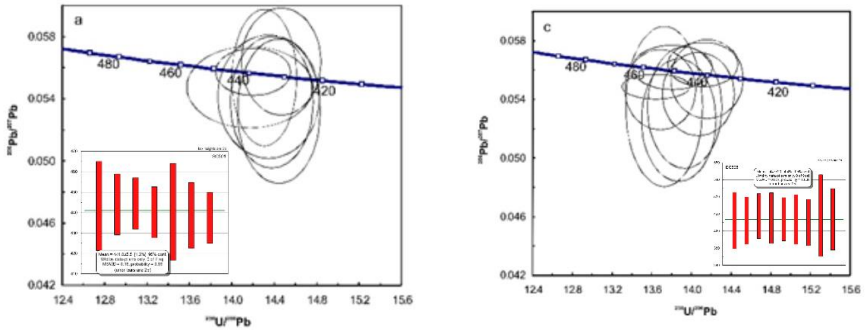

Figure 5. *Results of granodiorite samples dating in Hoa An area*

3.2.2. Cao Bằng complex

*** Ultramafic**

Ultramafic formations are distributed along the Cao Bang – Tien Yen fault, with small-sized blocks appearing mainly in the central part of the study area. In the study area, more than 6 main supermafic blocks have been discovered and delineated, namely: Suoi Cu, Khuoi Khoang, Khuoi Bac, Na Can,

Phan Thanh and Ha Tri; Rocks with petrographic composition of ultramafic blocks are mainly lherzolite, wehlit containing interbeds of plagioclase and little gabbro. The rock has a full automorphic-granular texture, sometimes with mosaic texture (small olivine crystals encrust on the surface of pyroxene plates), average grain size, usually 0.5-1.0mm. Main element composition: SiO_2 content mainly concentrates in the range of 37.02-45.19%, MgO from 18.63-30.64%, Al_2O_3 from 5.22-9.7%, FeOT from 5, 67-13.23%, CaO from 3.32-7.32%, low content of TiO_2 (from 0.2-1.3%), Na_2O (from 0.1231 to 2.96%), K_2O (from 0.0635-1.746%). From the similarity in mineral composition, texture, and petrographic characteristics between the ultramafic masses in the study area, it proves that they are the same original magmatic source. Trace element geochemical characteristics: Light rare-earth elements are relatively enriched with a ratio of up $(La/Sm)_N$ about 1.2-2.4, while the heavy rare-earth element group is slightly depleted to almost unchanged from Gd to Yb with (Gd/Yb)N about 1.1 to 1.3. All samples had a weak negative Eu anomaly that could be reflected by the weak differential crystallization of the mineral plagioclase. The correlation chart between samples and primitive mantle shows that they have quite similar characteristics to the Bang Giang Formation mafic rocks with strongly enriched lithophile elements (Ba, Rb, Cs), the high field strength elements as Nb, Ta is strongly depleted while Th, U and Pb are enriched. All samples without Zr-depletion expression suggest that the rock may have crustal impact during mantle molten or during intrusive crustal mixing (Figure 2).

The analysis results of 11 isotopic samples of ultramafic rocks in boreholes in Ha Tri, Phan Thanh, Dong Sang areas show that ultramafic rocks have the initial isotope ratio ($^{86}Sr/^{87}Sr$)i varied from 7,082-7,093; εNd(t) value varies from -3.97 to -5.65, similar to EMII-type enrich mantle source.

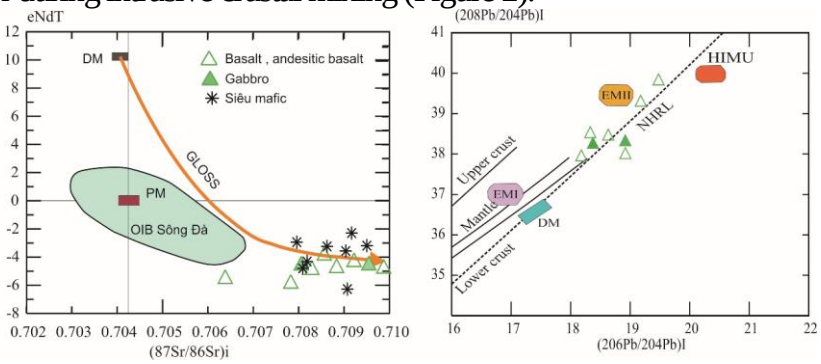

Figure 6. *Correlation diagram to determine the source of ultramafic and mafic magmatic rocks in Hoa An area*

*** Mafic**

The gabbrodolerite intrusive formations appear quite commonly in the study area such as Phan Thanh, Ha Tri, Suoi Cu, Khuoi Khoang, Khuoi Bac, Na Can... Mafic intrusive rocks could be small in size, lenticular in shape, cutting through terrigenous sediments, sometimes in the member of ultramafic rocks of the Cao Bang Complex. The rock is crushed, broken, and cut through by the calcite and quartz veins in the later penetration stages. The boundary of the mafic intrusive formations has a tectonic relationship with the surrounding formations by mainly reverse, overthrust fault. The gabrodiabas are gray, greenish-gray sometimes, block structure, fine-grained, medium ophite, ophite mosaic. Mineral composition (%): Plagioclase 55-59, pyroxene oblique 40-43, common minor minerals are apatite; minerals containing ore are mainly scatter-formed chalcopyrite, pyrite. The plagioclase minerals are zoizited, sericized, sometimes the plagioclase is completely transformed. Characteristics of U-Pb isotopic age on zircon minerals: Gabbrodiabas, gabro formations are dated by U-Pb isotopes on zircon minerals by MC-ICP-MS technology in Korea. The analysis results of 03 gabbrodiabas rock samples showed age values from 250 to 251 M.a. The zircon grains have automorphic growth fringes, Th/U ratio (>0.1), reflecting the crystallization age of the rocks, they are considered similar to the magma formation age due to zircon minerals crystallizing in the magma at high temperature (>700^oC) corresponds to the early stage of magma.

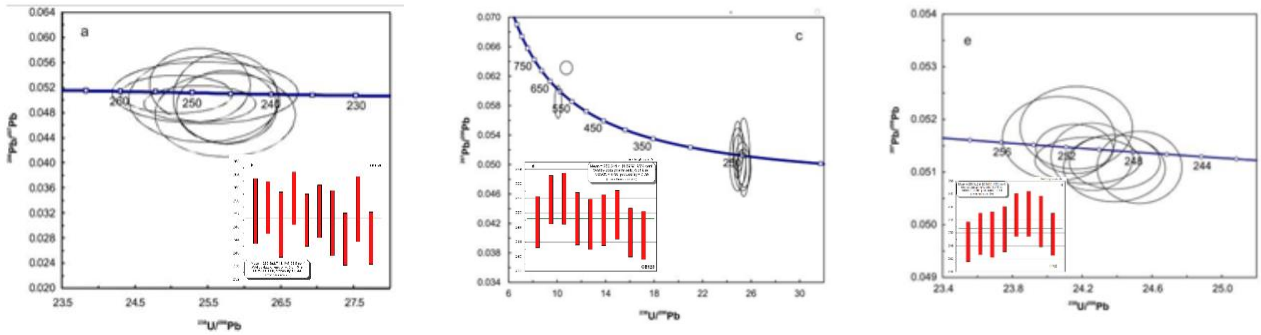

Figure 7. *Average age of gabrodiabas samples CB168, CB123, HT02 in Hoa An area*

Major elements geochemical characteristics: SiO2 content ranges from 50.15-53.17%, MgO from 5.66-9.23%, total (K_2O+Na_2O) varies from 2.89-4.30 and belongs to the gabbro-diorite magmatic field. The gabbrodiabas are from calc-alkali tholeite to high-K calc-alkali, low TiO_2 (0.85-1.06%), Al_2O_3 (13.44-16.71%), FeOT content varies 7.43 -12.08% and Mg# index (Mg/(Mg+Fe2+) is quite high, varying from 51.68 to 71.77%; Features of rare, traces element: Geochemical gabbrodiabas of rare, traces element are similar to the basalt rocks of the Bang Giang Formation, the ratio $(La/Sm)_N$ = 2.20-2.79. The samples all have Eu depletion, with the ratio Eu/Eu* = from 0.55 - 0.89. On the sample matching chart with primitive mantle values, basalt and gabbrodiabas in Hoa An area have similar distribution, large-ion lithophile elements (LILE) are enriched such as Rb, Ba, K, Cs. High field strength elements (HFSEs) such as Nb, Ta, Zr, Hf, P and Ti are quite strongly depleted, typically Nb, Ta elements are very strongly depleted while Th, U are fairly strong enriched; Geochemical and isotopes of $^{87}Sr/^{86}Sr$ and $^{143}Nd/^{144}Nd$, Pb characteristics: Analysis results of isotopic ratios (original isotope calculated for 250 ma.) show that gabbrodiabas rocks have a high $^{87}Sr/^{86}Sr$ ratio, varying from 0.708072 to 0.70957 and a low isotope and $^{143}Nd/^{144}Nd$ ratio (0.512085-0.512086); εNd(t) value in mafic rocks varies from -4.68222 to -4.6669, similar to EMII rich mantle source. The initial Pb isotope (calculated for 250 ma.) has characteristics $(^{206}Pb/^{204}Pb)o$ from 18.1814 to 19.4764, $(^{207}Pb/^{204}Pb)o$ from 15.7596 to 15,8332 and isotope ratio $(^{208}Pb/^{204}Pb)o$ varies from 37.9150 to 39.9009. The isotopic values shown on the correlation chart, over lying the mixing line between the depleted mantle (DM) and the crust source (HIMU), are quite similar to the type II-enriched mantle (EMII). The similarity of isotope values between the basalt and gabbro rocks proves that they are derived from the same mantle source in the same tectonic background.

3.2.3. Núi Điệng complex ($\gamma T_{1\text{-}2nđ}$)

The formations of the Núi Điệng Complex ($\gamma T_{1\text{-}2nđ}$) have a small outcrop in the southwest of the study area, stretching in the NW-SE direction and are located on the southwest wing of the Cao Bang - Tien Yen fault , the north of the block is in penetrated contact with the Bac Son formation limestone (C-P), causing skarnization and dolomitization. In the south and southwest, the granite has a transitional relationship to Song Hien Formation ryodacite and rhyolite, the north of the block is covered by Cao Bang formation Neogene sediments. The petrographic composition is mainly granite amphibolite, sometimes with granite amphibolite - biotite with different types of microarchitecture: semi-automorphic (granite texture) and granophyr. Mineral composition: quartz 25-28%, potassium feldspar 30-35%, plagioclase 20-25%, biotite 5%, amphibol 5%. Secondary minerals of apatite, zircon, sfen; The geochemical characteristics are as follows: SiO_2= 68.11-71.3%, total (Na_2O+K_2O)=6.66-8.36%), quite high K_2O content 3.09-4.86%, TiO_2 content is low 0.41-0.73%. On the correlation chart, all the studied samples fall into the granite field, the type of high K alkaline-limestone. On the sample comparison chart with Chondrite and primitive mantle, it shows that Nui Dieng granite in the study area is characterized by relatively enriched light rare-earth elements, the ratio of $(La/Sm)_N$ from 1.5-1.8, the group of heavy rare-earth elements being depleted and weak from Gd to Yb with $(Gd/Yb)_N$ about 1.0-1.1, the weak negative anomaly Eu is reflected by the weak differential crystallization of the mineral plagioclase. On the correlation chart between the sample and the primitive mantle, it shows that they have quite similar characteristics with the Mafic rocks of the Bang Giang Formation, the lithophile

elements are quite strongly enriched (Ba, Rb, Cs) while high field strength elements such as Nb, Ta is strongly depleted, Th, U and Pb are enriched.

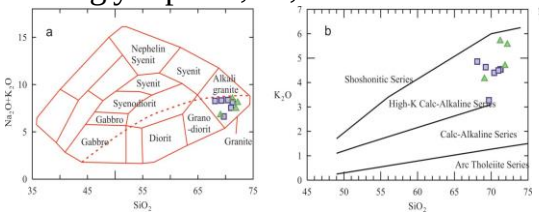

Figure 8. *(a) Classification chart of SiO2 and (K2O+Na2O) intrusive igneous rocks (Middlemost, 1994); (b) Rock classification chart by K2O content (Peccerillo and Taylor, 1976)*

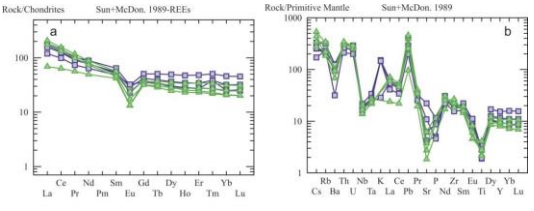

Figure 9*. a. Pattern Matching Chart with Chondrite; b- Sample comparison chart with Nui Dieng granite primitive mantle (According to Sun and McDought, 1989)*

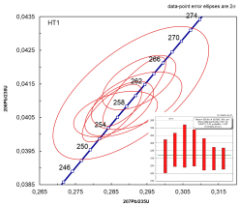

Figure 10. *U-Pb age results of granodiorite samples (256 Ma)*

3.2.4. Geodynamic conditions for the formation of the Late Paleozoic - Early Mesozoic magmatic rocks in Hoa An area

*** The tectonic background of magmatic complexes:** Research results on the formation age and tectonic nature of ultramafic, gabbro, basalt, granite and rhyolite magmatic rocks show that in the Late Paleozoic – Early Mesozoic the study area was in the active continental margin. In which the rhyolite and granodiorite rocks belong to the magmtatic type of subduction zone magmatic arc while the mafic and ultramafic rocks correspond to the magmatic type of back-arc basin (Figures 12, 13).

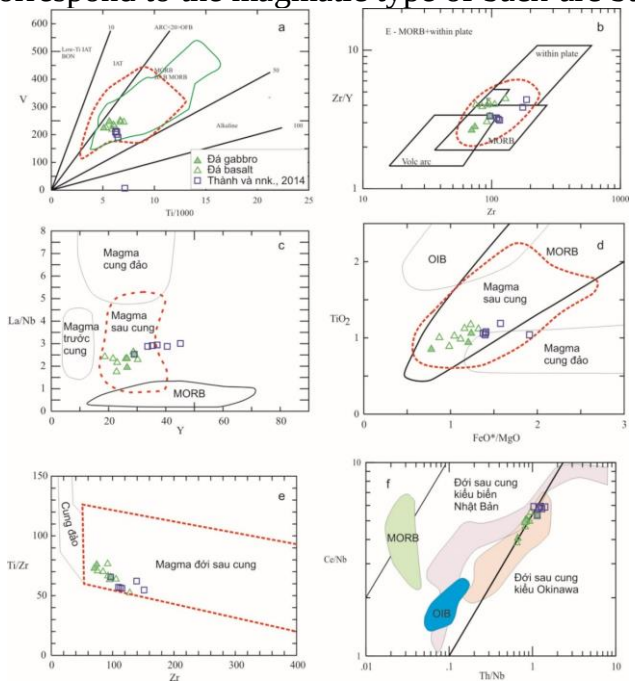

Figure 12. *Correlation of geochemical ratios (a) Ti to V, (b) Zr to Zr/Y, (c) Y to La/Nb, (d) FeO*/MgO to TiO2, (e) Zr to Ti /Zr, and (f) Th/Nb with Ce/Nb show study patterns that are similar to the mafic magmatic type formed related to the back-arc basin spreading zone.*

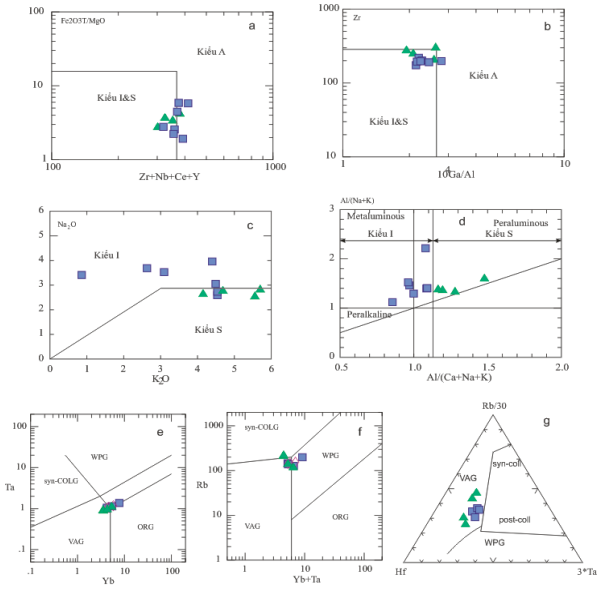

Figure 13. *Geochemical composition correlation chart of granite in Hoa An area. (a, b, c, d) Classification chart of granite type; (e, f, g) Granite background delimitation charts (according to Whalen et al. 1987; Shand, 1943; Pearce et al., 1984; Harris et al., 1986; Maniar et al. 1989)*

*** Geodynamic context of Late Paleozoic - Early Mesozoic magmatic formations:**

The dating reseach results of intrusive magma formations in the region show that the study area has a varying age and origin magmatic rocks complex, ultramafic intrusive rocks have the oldest age (270 ma) and then mafic rocks (263 ma) and acid rocks with very different ages (440 ma) and (256 ma). Other studies on the extrusive rocks also show the divergence, in which the ocean floor eruption rocks could be up to 330 Ma and the continental acid eruptions have an average age of about 250 Ma. A

special feature is that all the magmatic formations of different ages are concentrated in a small area along the Song Hien structural zone boundary with surrounding formations, in a multi-phase overthrust deformation zone. The boundaries between them are all large-scale overthrust shear zone systems and all of the above formations are allochthonous tectonic wedges. This structure couble be commonly seen and be characteristic of a tectonic suture zone formed by the destruction of an active continental margin taking place in the Early Mesozoic as suggested by Tran Thanh Hai et al., (2011), Tran and Halpin (2011) and Halpin et al. (2015). Therefore, the study area might be part of the Dian Qiong - Song Hien suture zone (Cai and Jiang, 2011; Halpin et al., 2015) and may be an extension of the Song Ma suture zone if taking into account of the slip displacement and deformation in the Cenozoic of regional faults such as the Chay River and to a lesser extent Cao Bang - Tien Yen passing through this area.

3.3. Metallization characteristics of nickel - copper sulfide

3.3.1. Mineral composition of ore: Disseminated sulfide ore has the main ore mineral composition: pyrotine from 0.5-20%, chalcopyrite from 0.1-2%, pentlandite from 0.01-2%, magnetite accounts for 0.1-2%, covelline only found in some samples <0.1%. Compact sulfide ores have the main composition: pyrotine up to 80%, chalcopyrite up to 10%, pentlandite up to 10%, less than sphalerite with content from 0.01 to 0.1%, magnetite <0.1%, pyrite 1-10% and covelline <0.1%.

3.3.2. Ore geochemical characteristics: The PGE group compositions analysis results of 11 ultramafic rock samples with the nickel-copper sulfide dissemination degree from sparse to dense in Canada by HR-ICP-MS analysis method are as follows: The sulfide ore contains 1.6-7.8% Ni content, 0.8-1.0% Cu, and 1.3-4.2 ppm total Pt + Pd content value in sulfide ore is about 1.1% Ni content, 0.35% Cu, and 0.7 ppm total Pt + Pd. The ratio of Cu/Pd is 7086, Pd/Ir > 100, and (Pt + Pd)/Ir > 140, Cu/Pd, Pd/Ir and (Pt + Pd)/Ir in sulfide ore respectively 3367- 10571 (average 7400).

The δ34S isotope of sulfide minerals ranges from -1.5 to +3.4 ‰ (T. V. Svelitskaya et al., 2015 and 2017). On the element distribution diagram of PGE, Cu, Ni, the Cao Bang area ultramafic rocks show that they have similar distribution lines of PGE, Cu and Ni elements and show quite similar elemental fragmentation, with the characteristics that Pd and Pt elements are enriched relative to other elements, and depleted in Os, the total amount of PGE is not high.

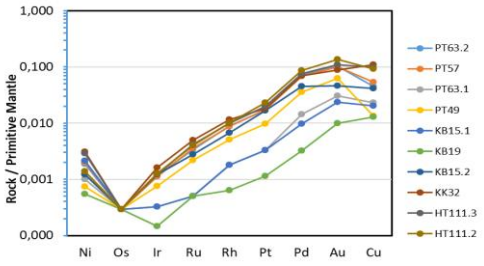

Figure 14. *Normalization of sulfide ore PGE groups in ultramafic rocks with Chondrite*

3.3.2. Ni-Cu ore origin in Hoa An area

To assess sulfide ore origin, the PhD student has been using the analysis results of platinum group (PGE), combined with the sulfur index. The results on the chart show that the mafic and ultramafic rocks in Hoa An area show that they belong to the type of high-magnesium intrusive magma. With the S isotope value here being -3.4 to +1.0, the sulfides in the studied rocks are derived from the same primordial mantle source that is enriched impacting by sulfur from the crustal material (negative value lower than -1.5). Thus, the nickel-copper ore-bearing formations in the study area related to actual magmatic type ore formations derived directly from enriched crust material mantle.

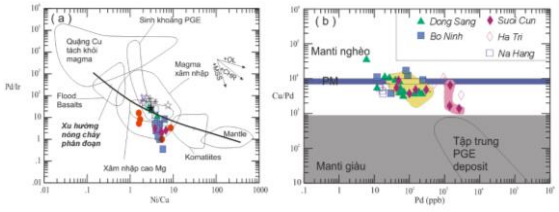

Figure 15. *Distribution of Cu/Pd and Pd (according to Barnes et al., 1993), showing formation fields of Ni-Cu sulfur ore and PGE group (a) and comparison chart of Ni/Cu and Pd/Ir ratios with magma fields under different tectonic conditions (b)*

3.3.3. Melting of the mantle source and the ability to concentrate Cu-Ni ores:

Mafic, ultramafic magma formed during the Late Paleozoic - Early Mesozoic due to the direct melting from deep mantle sources. The analysis results of isotope and geochemistry of rare, trace

elements show that these rocks are formed related to type II enriched mantle (EMII) sources. This enrichment of crustal material in this mantle leads to the melting of the mantle source, creating magmatic formations containing Ni-Cu mineralization in Hoa An area. In order to calculate the melting degree of mantle source, the PhD student has been using the correlation model between La/Sm with Gd/Yb (Becker and Le Roex, 2006) and La/Yb with Dy/Yb (Thirlwall et al., 1994). The results show that the ultramafic rocks are molten products from spinel mantle sources with a melting level of about 3%-10% (Fig. 17 a, b). With this source melting level is low and corresponds to the conditions of formation of magmatic type Ni predominate, while Cu mineralization, low PGE (O'Neill et al., 1995; Lesher and Stone, 1996).

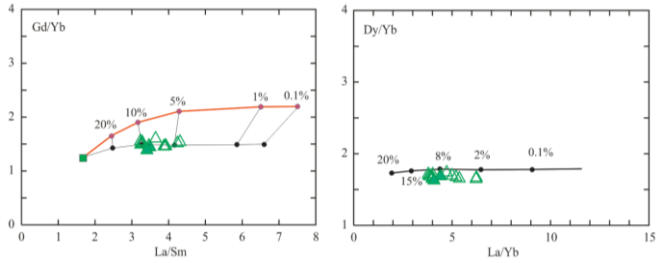

Figure 17. *Estimation of mantle source melting using ultramafic rocks rare earth elements in Phan Thanh and Suoi Cu areas. (a) La/Sm with Gd/Yb (Becker and Le Roex, 2006), (b) La/Yb with Dy/Yb (Thirlwall et al., 1994)*

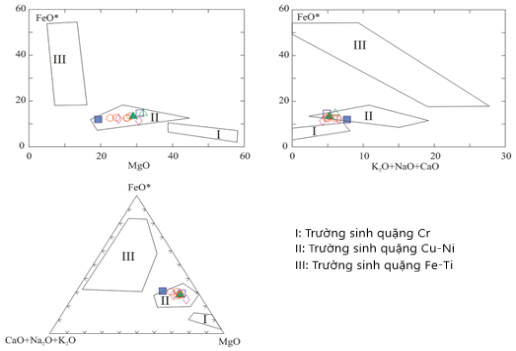

Figure 18. *Diagram of ultramafic rocks metallogenic field determination*

3.3.4. Ni-Cu metallogenic mineralization ability of ultramafic magma:

Ultramafic magma might be related to non-ferrous metal mineralization such as Cu, Ni, Fe, Co, Cr… Chemical analysis results of Cao Bang complex ultramafic rocks in Hoa An area was calculated and put on the chart to forecast the ultramafic rocks ore-generating potential, it was found that the ultramafic rocks in Hoa An area are located in the Cu-Ni metallogenic field and are typical ultramafic rock metallogenic field. Thus, the geochemical characteristics of ultramafic magmatic rocks in Hoa An area show that they are completely capable of Cu and Ni metallogeny. This result is completely consistent with the distribution characteristics of Cu, Ni sulfide minerals in ultramafic formations in the study area.

3.3.5. The process of Ni-Cu ores differentiation and concentration in ultramafic magmatic rocks

Evaluation of magmatic rocks fractional crystallization:

The fractional crystallization process was evaluated on the basis of Bowen crystallization on the basis of elemental geochemical data. In order to evaluate the fractional crystallization process, the PhD student has been using the correlation chart of the MgO element with other major elements of the magmatic rock.

The Harker diagram (Figure 19) shows the negative correlations between MgO and the major elements SiO_2 with Al_2O_3, TiO_2, CaO, and P_2O5. The negative correlation with SiO2 shows that there is fractional crystallization between the highly mafic minerals (olivine, orthopyroxene) and the lower mafic group (clinopyroxene, plagioclase).

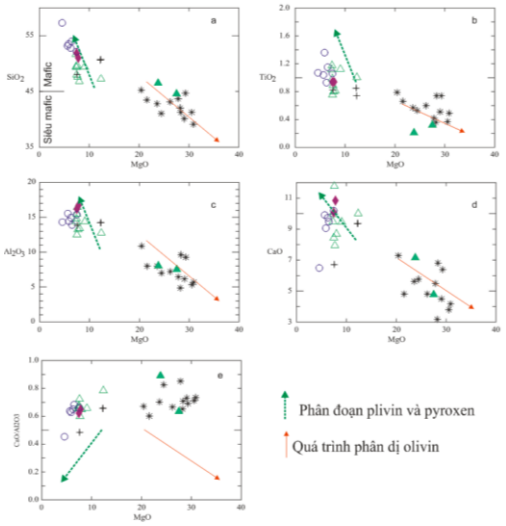

Figure 19. *Harker diagram showing the correlation between the composition of MgO and other major elements in Hoa An mafic and ultramafic rocks*

The negative correlation with the Al_2O_3, CaO element (typical element in clinopyroxene and plagioclase minerals) shows that the rocks have olivine simultaneous fractional crystallization with clinopyroxene and plagioclase in the studied samples. The negative relationship between Al_2O_3 and MgO content and Eu anomaly on the Chondrite comparison chart shows that the plagioclase fraction crystallization process has occurred in the studied rocks.

Evaluation of the Ni-Cu ores concentration ability in the magma process: In order to evaluate the fractional crystallization process involving Cu, Ni, PGE ores with rock-forming minerals (olivine, pyroxene...), the PhD student used the correlation chart between MgO and Ni, Cu and between Ir and Pd, Pd and PGE group Cu/Pd with rare, trace element group. The positive correlation between the olivine typical element group (MgO) with Ni, Cu (ore elements) shows that the fractional crystallization of olivine is concurrent with the one of Ni, Cu sulfide ore minerals. The correlation diagrams between Ir and Pd/Ir and between Pd and Cu/Pd show that sulfide ores in the study area are mainly distributed according to the fractional crystallization field and the differentiation process with olivine (olivine cumulated), demonstrating that the Cu-Ni-PGE ore concentration in the rocks is accompanied by fractional crystallization and ore concentration in the early magmatic phase, related to the olivine fragmentaton and differentiation in the rocks. The analysis results of ultramafic rocks sample tend to have little change in the Pd/Ir ratio, typical for fractional crystallization with olivine and with S depletion during ore formation (Figure 20a). The relationship diagram between Pd and Cu/Pd (Figure 20b) shows that the research data is mainly distributed related to depleted mantle with the average to low degree of sulfide minerals fractional crystallization (R=1000, figure 20b).

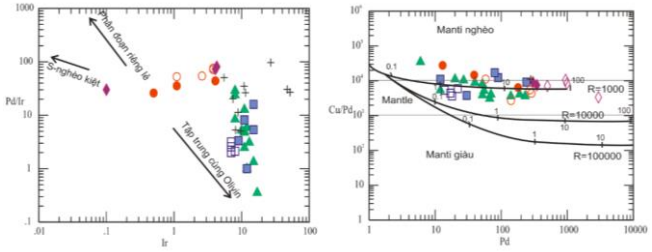

***Figure 20. a**. Pd/Ir ratio, typical for fractional crystallization with olivine and with S depletion during ore formation; **b**. Relationship diagram between Pd and Cu/Pd*

Figure 21 shows the correlation between the PGE group element with the ratios Zr/Nb and Th/Nb (geochemical ratio showing the mixed crust in magma) to assess the possibility of magmatic fractional crystallization, the separating sulfide ore process in magma with the influence of crustal material composition in magma. The research data of ultramafic mass in the study area shows that the tendency of Pd and Pt elements to be depleted in magmatic rocks is similar to the increased level of crustal matter (increasing Zr/Nb and Th/Nb).

This is due to the fact that the sulfide group minerals have been separated from the magma, leading to the PGE element release in the samples strongly impacted by the crustal material. The ore separation degree from magma due to the impact of crustal material could be clearly seen in samples of Phan Thanh area.

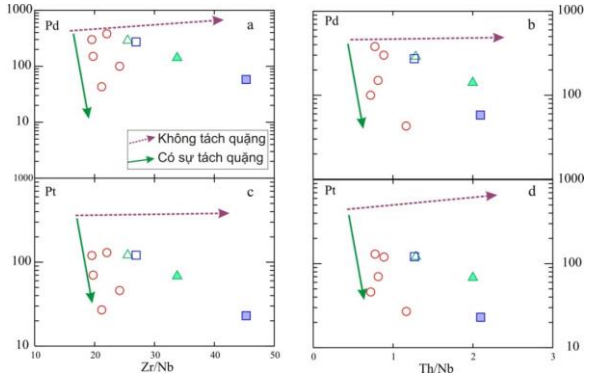

***Figure 21.** Shows the correlation between the PGE group element with the ratios Zr/Nb and Th/Nb (Song a al.., 2009)*

In summary, the Ni-Cu sulfide ore minerals in Hoa An area are related to low-melting mantle sources formed in ultramafic magmatic rocks. The ultramafic rocks geochemical characteristics show that they have the main ability to Ni metallogeny, and the levels of Cu and PGE mineralization are quite low. The main concentrated sulfide ore is related to the

fractional crystallization process in the early stage with olivine rock-forming minerals, the ore separation process creates not very dense ores.

Chapter 4. Tectonic characteristics of Hoa An area and the relationship of Ni-Cu ore mineralization

4.1. Overview

Hoa An area (Cao Bang) in the northeastern region of Vietnam, is a geological structure with complex geological history and origin, undergoing many overlapping deformation stages (Nguyen Cong Thuan, 2005; Vu Quang Lan, 2009, Pham Dinh Truong, 2004; Tran Thanh Hai et al., 2006; 2011; Halpin et al., 2015). Tran Thanh Hai et al. (2006, 2011), Halpin et al. (2015) suggested that the study area is a remnant of a tectonic suture zone, possibly related to, and part of, the Dian Qiong - Western Guangxi (Cai and Zhang, 2009) and Ailao Shan - The Ma River suture zone formed in the Late Permian, destroyed and displaced by regional fault systems such as Dien Bien Phu, Red River and Hepu–Hetai. Tran Trong Hoa et al. (2008) suggested that the Late Paleozoic-Early Mesozoic magmatic formations in the area may be part of the Emeishan Large Igneous Province (ELIP). Tran Van Tri and Vu Khuc (2009) and Tran Van Tri et al., 2015 suggested that the study area is part of the Song Hien - An Chau zone, in which the Permian - Mesozoic period is classified as an intracontinental rift system overlapped developing on the East Bắc Bộ Neoproterozoic - Early Paleozoic polyepisodic orogenic belt.

4.2. Petrotectonic assemblage

4.2.1. Early Paleozoic passive continental margin petrotectonic assemblage: consists of Than Sa Formation sedimentary rocks, exposed to a small area in the northeast of the study area. The homogeneity of the petrographic composition and sedimentary structure of the Than Sa Formation proves that the formations of this complex were deposited in a sedimentary basin with a stable sedimentary regime as part of a passive continental shelf. These formations are strongly deformed, completely foliated, accompanied by isolateral folds and possibly antiquated zones parallel to the fold structure, represented by mylonitization zones (Nguyen Cong Thuan, 2005). Accompanying the deformation is the metamorphism to the greenschist facies, which erases almost the entire original sedimentary structure. These formations lie under a large regional unconformability and are covered by the early Devonian sedimentary complexes, representing a long period of uplift, deformation and erosion of this complex before being deeply buried and covered unconformably with younger formations.

4.2.2. Later - Middle Paleozoic passive continental margin petrotectonic assemblage: In the study area, the middle Paleozoic passive continental margin petrotectonic assemblage consists of sedimentary members with composition ranging from coarse terracotta to carbonate, carbonate - silicon and Early Devonian to Early Carboniferous silicon deep-sea facies of the Mia Le, Na Quan and Toc Tat formations rocks. In the study area, the assemblage includes 3 petrographic ones: a. Peripheral facies terrigenous petrographic assemblage, consisting of thin-layered fine-grained terrigenous sediments of early Devonian age of the Mia Lé Formation. In the surrounding area, coarse terrigenous sediments ranging from cobblestone to red sandstone, early Devonian continental facies (Tran Van Tri and Vu Khuc, 2009) are unconformably covered on a deformed rock bed (Than Sa Formation) and moved upwards are shallow marine facies terrigenous sediments (Mia Lé Formation) showing that this petrographic assemblage was formed in the early stages of subsidence and formed a sedimentary basin after a long period of sedimentary discontinuity from late Cambrian to early Devonian; b. The continental shelf facies carbonate terrigenous sedimentary petrographic assemblage consists of thinly layered carbonate terrigenous formations and thick layered carbonates or the Na Quan Formation (D1-2nq), which is typical for the passive shelf environment; c.

The terrigenous-carbonate-silicone petrographic assemblage contains thin layers of late Devonian to Early Carboniferous manganese (Toc Tat Formation), Early Carboniferous to Middle Permian thickly layered limestone containing siliceous of the Bac Son Formation, typicaly for deep-water, sediment-depleted facies of the continental foothills, belonging to a passive margin. This member of sediments is not only in the Northeast region but the entire southern part of the South China Plate and the northern part of the Indochina Plate, represented by the appearance of thick carbonate deposits or the form of the Bac Son Formation widespread distributed. In general, the early Devonian-Permian petrotectonic assemblage in the study area characterizes the evolution of a sedimentary basin from the spreading phase to the formation of a passive continental margin. In particular, during the period of the typical oceanic crustal magma formations appearance by the discovery of pillow basalt at the age of Rb-Sr about 334 Ma (Tran Thanh Hai et al., 2007), this is an evidence for the existence of the great ocean during this period.

4.2.3. Late Paleozoic passive continental margin petrotectonic assemblage: In the Late Permian period, the study area is characterized by a series of carbonate - terrigenous sediments interbeds of late Permian bauxite members and clusters. Thus, during this period there is a transition from deep-sea facies sediments to shallow-sea facies, representing a period of regression around the late Permian. Some geologists (Carter and Clift, 2008: Metcalfe, 2013) suggested that at this stage Paleotethys was closing due to the plates integration and transformed into a shallow sea regime before being destroyed by the orogenic collision activity during the Late Paleozoic period and transition to an active continental margin regime. In particular, Vu Quang Lan (2009) described the existence of late Permian carbonate sediments interbeds of basalt in Hoa An area. In addition, the appearance of intrusions and eruptions aged from 270 Ma (Middle Permian) to 250 Ma in the area proved that in the middle Permian period in the study area, it changed from passive to an active continental margin mode that forms a magma arc and with the continental crust rupture and the formation of a spreading basin.

4.2.4. Late Paleozoic to Early Mesozoic active continental margin petrotetonic assemblage: During the Middle Permian to Early Triassic period, the study area was in an active tectonic mode, marked by a petrotetonic assemblage of Middle Permian to Early Triassic intrusive and extrusive magmatic rocks, including ultramafic, mafic, neutral and acidic intrusions. In Hoa An area in particular and Song Hien zone in general, formations of ryolite, dacitryo, litporphyr, tufryolite, sand, tuf siltstone, tuf siltstone, ash-gray tuf siltstone, gradually changed to siltstone, silty claystone, silty sandstone, banding silty claystone, limestone lens of Song Hien Formation mainly distributed to the southwest. Partially distributed in the study area center are the Nui Dieng Complex rocks (granite, hornblende granodiorite). The research results on the lithological-geochemical characteristics and age of these magma formations have identified the Nui Dieng Complex granodiorite magmatic formations and the Song Hien Formation rhyolite formations belonging to the subduction zone magma arc style. Mafic and ultramafic formations are distributed in discontinuous bands extending in the NW-SE in the study area center. They are composed of mafic eruption rocks, mainly porphyr basalt, plagiobasalt, green to light green amygdale basalt, belonging to the Late Permian Bang Giang Formation surrounding the ultramafic blocks. This Cao Bang Complex intrusive rocks assemblage has a mixed composition and has discontinuous bodies attitude, surrounded by overthrust faults. The ages of these formations are considered to be from 270-260 Ma (Tran Trong Hoa et al., 2008; Halpin et al., 2015). The research results show that they are formed during intracontinental spreading and back-arc basin formation. They may also be part of an back-arc style ophioit assemblage (Tran Thanh Hai et al., 2011, Tran and Halpin, 2011; Halpin et al., 2015). These research results have made an important contribution to confirm the Late Paleozoic - Early Mesozoic

(Middle Permian - Early Triassic) petrotectonic assemblage of the study area belonging to the active continental margin petrotectonic assemblage.

4.2.5. Cenozoic intracontinental rift petrotectonic assemblage: The typical rock assemblage is Neogene continental facies sedimentary rocks of the Cao Bang Formation, which fills the Cao Bang pull-apart basin in the west of the study area. These formations were formed in a controlled pull-apart basin and as a result of lateral activity along the Cao Bang - Tien Yen fault system and mainly as lateral faults in the Cenozoic.

4.2.6. Quaternary friable formations: Due to the strongly dissected topography, the study area has many intermontane basins or modern river valleys, which are filled with Quaternary young sediments with different sediment compositions.

4.3. Deformation characteristic

4.3.1. First deformation phase (D1):

The first deformation phase (D1) is only observed in the formations of the Than Sa Formation in the northeast of Hoa An area. This deformation phase characteristic is the formation of S1 lamellar structures (Figure 1) develops in the entire Than Sa Formation. In some places, the lamellar structures are often formed into mylonitized zones, accompanied by isocline with axial planes parallels the lamellar structure. These structures are strongly folded and shifted by later structural generations. This feature erases almost the entire original structure of the rock and makes the lamellar position extremely complicated.

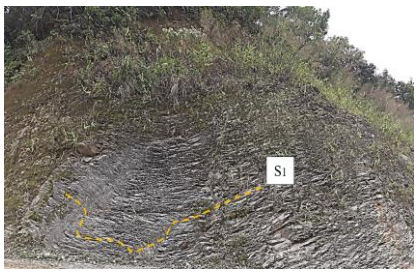

Photo 1. *This deformation phase characteristic is the formation of S1 lamellar structures develops in the entire Than Sa Formation*

The D1 deformation phase is also accompanied by regional greenschist facies metamorphism activities in the Than Sa formations (Nguyen Cong Thuan, 2005; Tran Van Tri and Vu Khuc, 2009). The common isocline phenomenon with many different sizes folds have an axial plane almost paralleling the lamellar structure, accompanied by mylonite zones, indicating that an overthrust fold style deformation event that took place after the late Cambrian. The absence of Ordovician - Silurian sedimentary formations in Hoa An and Cao Bang areas proves that the study area is in the deformation mode and tectonic uplift from the late Cambrian to the end of Silurian and may be similar to the first deformation phase.

4.3.2. The second deformation phase (D2): The second deformation phase (D2) is widespread and affects all pre-Middle Triassic rocks. The second deformation phase takes place in the ductile deformation condition, characterized by the overthrust shear zone systems development, accompanied by folds with parallel axial planes in the entire study area. The deformation phase 2 basic structures are large-scale overthrust shear zones, accompanied by a system of inclined, over folds and isocline of different scales. On the structural plan, the 2nd generation overthrust shear zones act as the boundary of most mafic intrusive and eruptive magma formations. These zones link together to form a large zone extending from the northwest to the southeast and are cut through and displaced by the later deformed phase structures. The overthrust shear zones second generation (F2) are often easily observed in the field (Photos 2, 3). In many places, these zones transport older geological formations that overlap younger ones. On the outcrop, the 2nd generation shear zones are often tens of centimeters to tens of meters in thickness, characterized by the lamination phenomenon from pre-mylonite to super-mynonite developed in many different rocks (Photo 2).

Photo 2. *S1 laminar structure in the Bang Giang Formation basalt and the high deformation zone in the Bac Son Formation limestone due to the impact of D2*

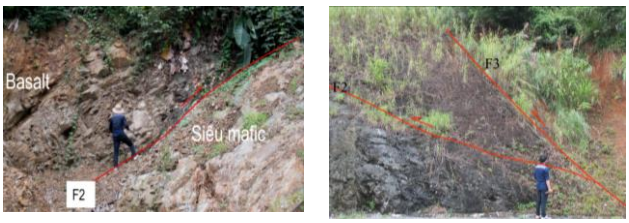

Photo 3. *The plastic shear zone of the second deformation phase creates tectonic boundaries between geological formations*

The second deformed phase lamellar structure is also widely detected in the ore-bearing ultramafic formations in the Suoi Cu, Phan Thanh, and Ha Tri blocks, especially along the contact boundary between the ultramafic bodies and the host rocks. In these zones, the disseminated nickel sulfide ore ultramafic rocks were flattened, stretched, created laminated zones and some places created mylonite. In these zones, sulfide ores in dense form are often concentrated and filled in cracks, while pre-existing ore minerals are often flattened and stretched to form lamellar bands (Photo 5). This relationship shows that the F2 shear zones are the agents that re-concentrated metallization to form dense sulfide bodies in this area.

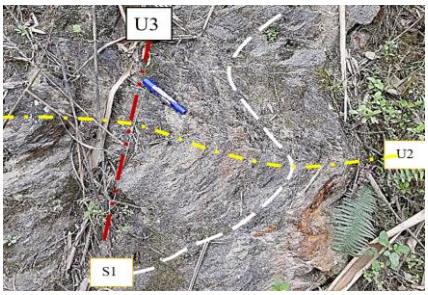

Photo 4*. S1 lamellar structure in Than Sa Formation is affected by D2 creating a U2 fold with an almost horizontal axial plane and then slightly folded by the D3 deformed phase fold*

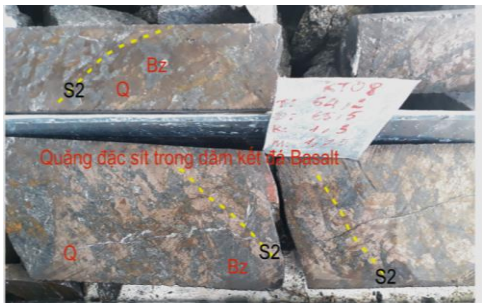

Photo 5. *The densely developed nickel sulfide ore zone overlaps with the lamellar structure formed in ultramafic rocks in the Phan Thanh reservoir (LK08)*

Therefore, in the study area, the deformation phase 2 (F2) overthrust shear zone systems most widely develop playing an important role in the regional structural plan. This overthrust deformation type is typical for a Early Triassic geoplate collision. These deformations are the cause of the geological formations destruction at the edge of the basin, transportation, and superposition of different origin and age formations, which causes the overlay of older rocks on top of the younger formations along their distribution to form allochthonous bodies in tectonic chaos zone, a typical suture zone. This is the reason that different origins and ages geological formations are concentrated in this zone as described in the previous sections. F2 faults also act as agents to break up mafic and ultramafic intrusive formations into tectonic wedges and push them upward along the faults and create zones that control the formation dense nickel-copper mineralization in the area.

4.3.3. The third deformation phase (D3): The deformation phase is widespread and affects all pre-Middle Triassic rocks and pre-existing structures. This deformation phase takes place in the ductile to brittle ductile regime, they are characterized by reverse/overthrust fault zones with the NW-SE dominant direction. Accompanying them are axial plane folds parallel to the D3 shear system throughout the study area. This deformation phase creates large-scale overthrust shear structural zones and regional-scale systems of inclined folds, narrow overfolds, and laciniate dome. On the structural plan, the 3rd generation overthrust shear zones act as the boundary of many geological formations in the area, cutting through to shift, deform and fold the structures belonging to the pre-existing secondary deformation phase. In the field, the deformation system of the 3rd lamellar phase is often quite commonly observed. The 3rd deformation phase structures form large complex folds and often interfere with older folds and are affected

by young structures to create a very complex structure. In many places, the deformation interference between the third and second deformation phases represented by clearly observed shear zones and folding systems (Photos 4, 5, 6).

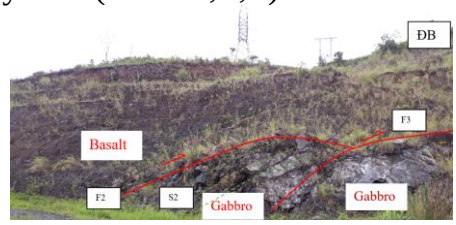

Photo 4. *S2 lamellar structure, F2 shear zone creating tectonic boundary*

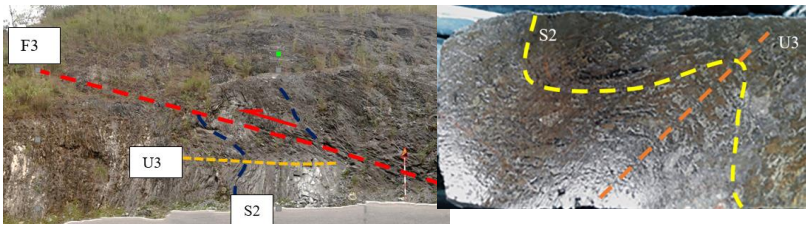

Photo 5. *S2 lamellar structure, folded due to the impact (U3) of D3, accompanied by the F3 fault system.*

The ores-containing ultramafic rocks with the 3rd deformed phase split the block, creating tectonic boundaries (Photo 4), the laminated deformed ore in the 2nd deformed phase is deformed and folded, creating a inclined axis fold structure (Photo 5). These evidences show that the third deformation phase is the agent that separates the dense ore-bearing ultramafic bodies in the area and pushes the block-shaped uplift to move to different locations through the overthrust shear zones, at the same time, cause deformation, creating a complex ore distribution in the study area. In the Song Hien - An Chau tectonic zone, studying late Triassic to Jurassic sedimentary formations represents the orogenic stage due to continental collision (Tran Van Tri and Vu Khuc, 2009, 2015). The 3rd strain phase structures are probably formed equivalent to this phase (about after T_3 to Jura). This basin closure event formed the Dian - Qiong - Song Hien suture zone (Tran Thanh Hai et al., 2011; Halpin et al., 2015).

4.3.4. The fourth deformation phase (D4):

The fourth deformation phase (D4) coincides with the Cao Bang - Tien Yen fault activity, the characteristic of this deformation phase is the reverse, the left-lateral reverse fault system formation, accompanied by a brittle to brittle ductile deformation system and abundantly presenting in the study area. The structural direction of the faults of this phase is NW-SE. Accompanying them is the formation of a number of folds observed in Neogen sediments, wide diapiric folds, axial plane parallel to the fault system of the D4 deformed phase in the entire study area. This deformation phase affects Miocene and older formations and is covered by Quaternary sediments. On that basis, the author believes that the 4th deformation phase takes place at the end of Neogen. The structural characteristics as well as the active period of this deformation phase are quite similar to the left and reverse left sliding phase of the Cao Bang - Tien Yen fault (Wysocka et al., 2020).

Photo 6. *The characteristic of this deformation phase is the reverse,the left-lateral reverse fault system formation*

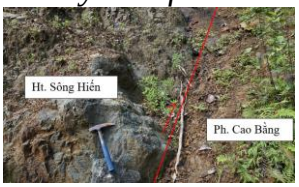

Photo 7. *The 4th tectonic counter-slip zone creates the boundary between the ultramafic block*

Photo 8. *Sliding track construction related to right side sliding (Phase D5))*

4.3.5. The fifth deformation phase (D5): The fifth deformation phase is the deformation phase that occurs in brittle, small-scale conditions. This deformed phase fault system affects locally the rock formations and deformed structures belonging to the earlier deformed phases in the region, they take place in a completely

brittle regime characterized by left-lateral and right-lateral faults, the main direction is NE-SW. The geological outcrops study shows that the fault manifestations of this deformation phase are mainly large slopes fault systems and cracks, principally right-lateral normal fault with the NE-SW predominant direction accompanied by deformation zones of gravel, tectonic humus and fault slip surfaces (Photo 8).

4.4. The history of regional tectonic evolution

4.4.1. Late Cambrian period: During the early Paleozoic period, Hoa An area was located in a passive continental margin characterized by thin-layered terrigenous - carbonate - siliceous formations belonging to continental shelf or margin facies, which were deposited in a the sedimentary basin has a stable sedimentary regime. These formations are located on an older basement complex, but the basement occurrence within the study area and the northeastern region could not be determined.

4.4.2. Ocdovician - Silurian period: In the study area, there are no Ocdovician - Silurian sediments, but the oldest formations covering Late Cambrian rocks are Early Devonian sediments, creating a large scale regional unconformability and shows that in this period the study area experienced inverse tectonic, deformation and erosion. All the late Cambrian sedimentary formations were strongly deformed in the first deformation phase (D1) in the greenschist facies metamorphism condition, creating regional lamellar systems, accompanied by folds and overthrust fault relating to the orogenic process and is considered to be similar to the Caledonian orogenic phase.

4.4.3. Middle Paleozoic period: In this period, the entire Northeast region as well as in Hoa An area is characterized by the subsidence regime creating sedimentary basins. Subsidence activities to create basins began in the early Devonian period and formed margin facies sedimentary. The sedimentary basin developed into marine and oceanic regimes from the late early Devonian to early middle Devonian, represented by a series of shallow marine and marginal marine sediments. In the late Devonian to early Carboniferous - Permian period, the subsidence process in this period was probably at its peak, belonging to the deep sea, ocean basin regime.

The discovery of pillow basalt bodies in the area of Bong Lau and Khau Khoang passes with similar composition to oceanic crust, age Rb-Sr is 334 Ma (Tran Thanh Hai et al., 2007) is evidence of the oceanic crust existence during this period (SH1). Research results in Hoa An area in this period are similar to the model proposed by Halpin et al (2015) for the Northeast region. The spreading process during this period formed an ancient ocean dividing the South China and Indochina Plateau, in which the Northeast area is part of the Indochina Plateau (Figure 22).

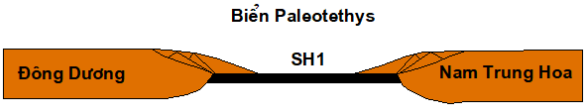

Figure 22. *Model describing the spreading phase that formed the Paleotethys ocean basin and the geologic distribution of South China and Indochina, in which the Northeast is part of the Indochinese block (According to Halpin et al. ., 2015)*

4.4.4. Late Paleozoic: In the Early Permian to early Late Permian, the study area continued to develop sediments inheriting the passive continental margin basins of the previous period and the tectonic activity was relatively stable until the beginning of Late Permian. At the beginning of the Late Permian, the study area in particular and the Song Hien - An Chau tectonic zone in general was marked by the formation of carbonate deposits, carbonate terrigenous and aluminum-rich sediments of the Dong Dang formation, typical for neritic facices. This sedimentary feature shows that in the late Permian period, the entire area began to have an uplift (Tran Van Tri et al., 2009; Tran Van Tri et al., 2015).

4.4.5. Late Paleozoic – Early Mesozoic: During the Middle Permian to the beginning of Early Triassic (about 274-250 Ma), magmatic activity took place strongly in the entire study area as well as the Song Hien – An Chau zone. The magmatic activity in this period formed granite, granodiorite and rhyolite magma assemblage (256-247 Ma) and intrusive magma, mafic eruptions, and ultramafic assemblage

(274-250 Ma). The results of this study allow to confirm that the 274-247 Ma magmatic assemblage in the area belongs to the active continental margin magmatic type, related to a subduction activity in the area. At the same time, this period also marked the active continental margin subsidence related to the back-arc basin (Okinawa type). This spreading event created a assemblage of mafic, ultramafic, neutral, pillow basalt rocks interbeds of sedimentary member of sandstone, shale, siltstone, limestone lens, and marl discovered in the area. The back-arc basin spreading has also facilitated the melting mantle process from a relatively deep source upward to form ultramafic bodies containing Ni-Cu ores in Hoa An area. These new findings combine with the research results of Tran Thanh Hai et al., (2011), Tran and Halpin (2011), Halpin et al (2015), Ngo Xuan Thanh et al., (2014) in In the Song Hien area, the author has built a tectonic model related to subduction activities in the period 274-247 Ma (Figure 23). Subduction activity of the ancient oceanic plate under the Indochinese continent during Permian – Triassic formed the Truong Son volcanic arc (Halpin et al (2015). Magmatic distribution from subduction arc to back-arc (from the southwest to northeast) in the study area as well as the location of the area located to the southwest of the Dian – Qiong – Song Hien suture zone, the author suggests that the magmatic assemblage in the study area was formed related to subduction activity of the ancient oceanic plate under the South China block. According to this study, the back-arc spreading might have occurred from 270 Ma, related to the continental magmatic arc formation. Following this model, it is required a subduction zone that plunge towards the South China plate, contrary to the model of Halpin et al (2015) and some other studies that suggest a subduction zone towards the Indochinese plate.

This study proposes that during Paleotethys development, the the Indochinese and South China plates compression before the basin was destroyed led to the formation of a subduction zone towards the South China plate and create a magmatic arc along the edge of the plate as well as a create a back-arc basin.

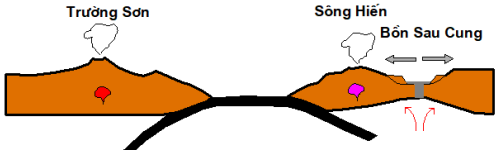

Figure 23. *The tectonic configuration of the study area in the period 270-250 Ma*

4.4.5. The late Early Mesozoic - Middle Mesozoic: The orogenic event, sedimentary basin closure in the area took place about 245 million years ago (Tran Thanh Hai et al., 2011) and the continental regime existed until the end of the Cenozoic, represented by deformed phases series. During the period from 245 Ma, the integration of South China into Indochina led to the destruction of Paleotethys, and these two oceanic continental margins led to the destruction of the back-arc basin before the maximum collision event occurs (Hawkins, J.W., 1995). The basin destruction led to a second deformation phase, creating a fold-overthrust deformation belt, causing the ocean floor formations and magmatic arcs to be pushed up, deformed, and shifted over each other in the Dian Qiong - Song Hien tectonic stitch zone. Thus, the collision period recorded in the study area is quite similar to the collision event between the Indochina block and South China (Halpin et al., 2015). This orogenic collision event has formed the Dian - Qiong - Song Hien suture zones and formed an oceanic crust-type ophiolite assemblage (SH1, Tran Thanh Hai et al., 2011; Halpin et al., 2015), arc and subduction back-arc magmatic assemblage (SH2) (Figure 24).

Continuously, the tectonic collision continued along the edge of the newly formed Indochina - South China with the closing of Mesotethys and the integration of the Sibumasu plate into Indochina (Metcalfe 2013) leading to the next event of the 3rd deformation phase. This is the reverse, overthrust faulting system, taking place in the brittle ductile to brittle environment, which continues to deform the geological formations and the older formations, forming large-scale fold overthrust

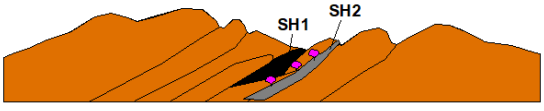

Figure 24. *The collision between the South China and Indochina blocks (including the Northeast) occurred around 245-240 Ma forming ophiolite*

zones and shaping the regional structural framework. Thus, two deformation events related to deformation phase 2 and 3 play an important role in the movement and uplift of deep geological formations and create complex tectonic boundaries in the study area.

(SH1) assemblage along the Dian - Qiong - Song Hien suture zone (Halpin et al., 2015) and arc and back-arc magmatic formations in the Song Hien - An Chau area.

4.4.6. Cenozoic phase: During this period, the study area continued to exist in a continental regime. In the Oligocene period, the study area was affected by the activities of the Cao Bang - Tien Yen fault zone. The Cao Bang - Tien Yen fault system is recorded to be active in the Cenozoic with the characteristic feature of a left-lateral and reverse fault system. Some recent studies and the its results also show that the Cao Bang - Tien Yen fault (deformed phase 4) in this phase has cut through and significantly shifted the geological formations on the flank traveling tens of kilometers simultaneously causes deformation and re-deformation of rocks and pre-existing deformation phases. In the Northeast region, this left- and reverse-slip phase is considered to have played a major role in forming a pull-apart basin series recorded at Cao Bang, Lang Son. During the Pliocene - Quaternary period, the Cao Bang - Tien Yen fault zone changed to the right -lateral, normal operation mode, the right-lateral slip phase is confirmed to be weak, with a small displacement distance (the fifth deformation phase).

4.5. The role of regional tectonics with nickel – copper metallogeny - Hoa An area

4.5.1. The role of the Early Triassic tectonic deformation (D2): The second deformation phase acts to the ore-bearing ultramafic formations lamination accompanied by the seperating and obduction of the ore-bearing ultramafic bodies. This deformation phase impact when the ultramafic bodies are in a thermoplastic state creates ore concentrations along the laminated zones in the ultramafic rock and in the host rock tectonic breccia zones. The result of this process is to create high ore concentration zones in ultramafic rock and in tectonic breccia zones of host rock found in Hoa An area. In favorable structures, this ore concentration could form significant-scale deposits as found in the northwestern part of the Ha Tri block (Photo 8, 9).

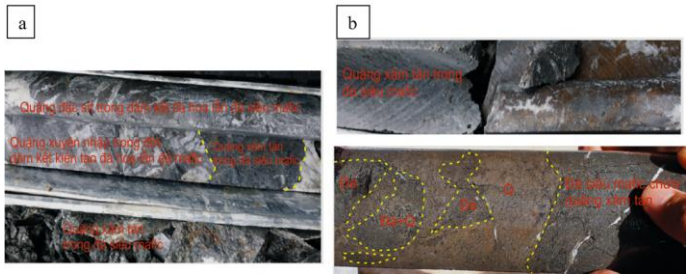

Photo 8. *The boundary of ultramafic rock with brecciation carbonate rock containing Ni-Cu sulfide ore of penetrating form observed in borehole LK111.1 (31.5m) in Ha Tri area (a) and dense ore in the ultramafic composition tetonic breccia zone observed at borehole LK64.2 (17.5m) in Phan Thanh area (b)*

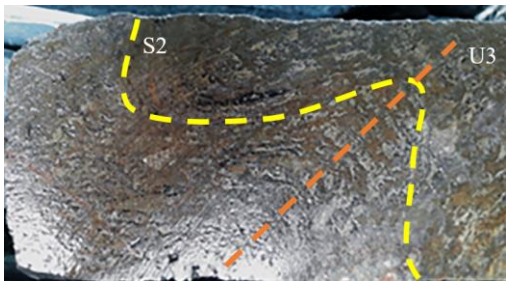

Photo 9. *The ore is subjected to prolonged lamellar deformation due to the impact of the second deformation phase (S2) and folded deformation (U3)*

The regional overthrust tectonic activity during this period also displaced and pushed ultramafic and ore blocks with great intensity. Their result is to create overthrust relationships of ultramafic blocks with host rocks in Hoa An area, and at the same time, they also divide and shift the ultramafic bodies into different blocks that slide and change their primordial order (Picture 10).

Photo 10. The reverse/overthrust fault (F2) of the second deformation phase (D2) divides the Phan Thanh internal mass.

4.5.2. The role of the Mesozoic - Jurassic (D3) tectonic deformation activities: The third deformed phase overthrust activity continues to affect the ore-

bearing ultramafic formations, causing them to be re-deformed and displaced, in which the ores are deformed and laminated in the second deformation phase has been complicatedly impacted and folded the ore structure.

The third deformation phase continued to push out the ultramafic bodies, increasing the ultramafic masses and ores displacement to the east and southeast. This process created tectonic boundaries between the ultramafic rocks with other rocks in Hoa An area. These relationships are represented by the overthrust slip zones recorded in the ultramafic interior, creating a more complex division and displacement, and the original relationship of the rock (Picture 10, Figure 25).

4.5.3. The role of Cenozoic tectonic activities (D4, D5):

The fourth deformation phase (D4): The D4 deformation phase is characterized by brittle and brittle ductile deformation along the left-lateral, reverse left fault zones. This deformation phase with a large horizontal displacement scale is the cause of the rearrangement and redistribution of ultramafic formations in the area parallelling the Cao Bang - Tien Yen fault system. The fault system reverse deformation activity in this tectonic deformation phase has once again divided and pushed up the tectonic boundary between ultramafic rocks and other rocks in Hoa An area as observed in the field and on the regional structural plan (Figures 26, 27).

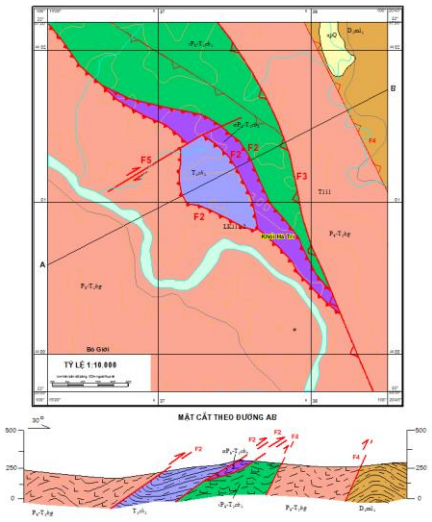

Figure 25. *Second tectonic deformation phase fault (F2); The 3rd deformation phase (F3) acts to create tectonic boundaries and uplifts supermafic bodies*

The fifth deformation phase (D5): The fifth deformation phase activity is quite weak, characterized by shear surfaces, tectonic breccia and fault humus zones which are detected only in Hoa An ultramafic formations. Studying the shear surfaces, deformation zones in Hoa An area related to these shear zones cause negligible slippage of ore-bearing geological formations in the study area, typically structural zones observed in the ultramafic blocks of Suoi Cu, Phan Thanh…

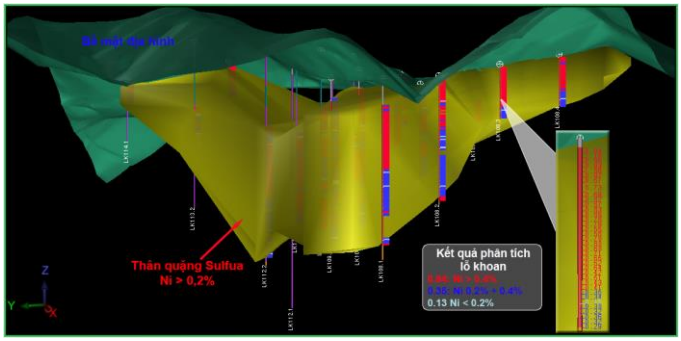

Figure 26. *The ultramafic mass modeling in Ha Tri area, the nickel content distribution is not according to the liquation rules due to the impact of the D2, D3 deformation phase tectonic activities*

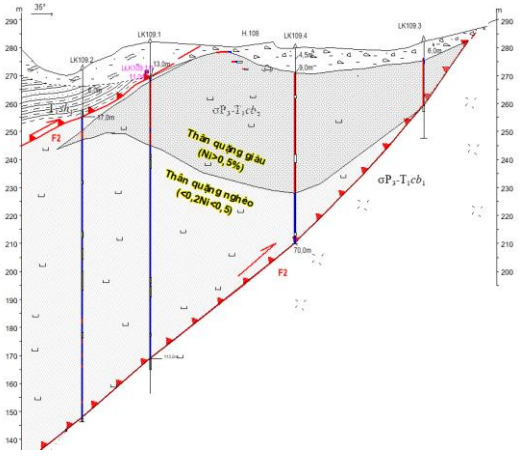

Figure 27. *The T109 section of Phan Thanh ultramafic block is affected by the D2 and D3 deformation phase, which changes the Ni-Cu ore content distribution*

On that basis, the author believes that the deformed phase D5 has little role in shifting, rearranging and restructuring ore formations in particular and geological formations in general in Hoa An area. Thus, the deformed phase D5 has little role in shifting, rearranging and restructuring ore formations in particular and geological formations in general in Hoa An area.

CONCLUSIONS AND RECOMMENDATIONS

Conclusion

Based on the synthesis, processing and analysis results of the study area's research documents combined with the filed survey of the PhD student on the material composition, formation environment, tectonic background, deformation characteristics, geologic bodies spatial relationships, origin of formations, the PhD student has the following conclusions:

1. Hoa An area has a complicated geological development history, has gone through at least 05 tectonic stages, in which, the Late Paleozoic - Early Mesozoic in the study area belongs to the active continental margin type, with plays an important role in the formation of mafic, ultramafic magmatic rocks and nickel - copper sulfide ores.

2. The geological formations in the area have been affected by at least 05 major tectonic deformation phases, including the first deformation phase (D1) taking place in the ductile regime, formed in the Early Paleozoic; The second deformation phase (D2) took place in the ductile regime with overthrust sliding activity formed around the end of the Early Triassic; The third deformation phase (D3) takes place in the ductile, brittle ductile regime related to reverse and overthrust faults developed in the Late Triassic to Pre-Jurassic period; The fourth deformation phase (D4) took place in the Pliocene - Miocene period, typically by NW-SE left and reverse left sliding zones; The fifth deformation phase (D5) in the Miocene - Quaternary period, is characterized by right lateral and normal right fault systems.

3. Nickel - copper ore in Hoa An area belongs to the actual magma origin ore type, the ore mainly exists in disseminated form in ultramafic intrusive bodies. The ultramafic intrusive magmatic rocks in Hoa An area play a role in nickel-copper metallogeny, in which nickel metallogeny is more dominant than copper, PGE.

4. The early Mesozoic to Cenozoic deformation activities have the role of re-concentrating ore, controlling the ore-bearing formations boundaries in the study area. In which, the second deformation phase plays the ore concentration role forming ore zones, pocket of ore with high density in ultramafic blocks and in surrounding tectonic breccia zones. The second and third deformation phases play the controlling role of the ore formations outshifting through the overthrust shifting in the opposite direction from the SW to the NE. The fourth tectonic phase has the role of dividing and re-shifting ore-bearing rocks both horizontally and vertically. These tectonic deformation phases have rearranged and reshaped the current regional structural framework.

Recommendations

1. Continue to study in detail about Ordovician magmatic formations presenting in the region (distribution area, petrographic composition, mineralogy, geochemical characteristics etc.) to supplement geological data for correct interpretation regarding the geological development history of the area.

2. Expanding the magmatic rocks research in the Viet Trung zone, prospecting, identification of mafic and ultramafic blocks along the Cao Bang-Tien Yen fault to clarify the their formation tectonic features as well as related mineralization serving the investigation planning, and exploration of minerals in general and nickel - copper minerals in particular.

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