# Hydrothermal metamorphism process and copper minerals related in the area of Nam Tia, Sin Ho, Lai Chau

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***Abstract**: Mafic volcanic rocks of the Vien Nam Formation ($T_1$vn), in the Nam Tia, Sin Ho, Lai Chau area are regarded as highly prospective for copper ore deposits there. Research results from regional geological and mineral investigations have shown that the mafic rocks in the Nam Tia area mainly belong to the lower part of the geological section of the Viên Nam Formation and include komatiite basalt, olivine basalt, amygdaloidal basalt, hyalobasalt and tuff. The mafic volcanic rocks are strongly altered by sub-alkaline hydro-metamorphic processes (propilitization). The hydrothermal grade is predominantly–epidote – chlorite propilitization, which is characteristic of low to medium temperature hydro-metamorphism related to shallow, near-surface copper mineralisation. The research results on the characteristics of hydrothermal processes and related mineralization in the area have identified two phases:*

*1. Early hydro-metamorphic propilitization affects all mafic volcanic rocks of the Formation, and is characterized by a chlorite + epidote metamorphic assemblage. The metalliferous mineral association consists mainly of the copper sulfide minerals bornite, chalcopyrite and chalcocite.*

*2. Late hydro-metamorphic propilitization mainly affects amygdaloidal basalt with the metamorphic assemblage of prehnite + chlorite + epidote, closely related to native copper.*

*The research results on the hydro-metamorphic process completely conform to research on mineralization in the area and show that the origin of copper mineralization within these mafic volcanic units of the Viên Nam Formation ($T_1$vn) is low – medium temperature volcanic hydro-metamorphism. The level of hydro-metamorphism is only at the level of epidote – chlorite propilitization, characterized as a shallow zone near the surface, and shows the potential for deeper mineralization in the research area.*

## Introduction

Recent studies on the geology of mineral deposits show that most of the endogenous deposits are magmatic deposits and hydrothermal deposits, which are closely related to metasomatic and hydrothermal alteration. At present, research into the affects of metasomatic and hydrothermal alteration is one of the main methods for prospecting and evaluating endogenous minerals, especially for deeply buried ore. This is explained not only by the close relationship between the origin of hydrothermal solutions and associated mineralization, but also by the much wider distribution of the altered rocks compared to the mineralized zone and ore deposits at the earth's surface.

Mafic volcanic rocks form a NW-SE striking belt within the Viên Nam Formation ($T_1vn$) and discontinuously extend along the Sông Đà Structural Zone from the Vietnam-China border to Hòa Bình Province. These mafics are regarded as a promising target for copper mineralisation, and for mineral resource planning and local industrial development. At Nậm Tia, Sìn Hồ, Lai Châu, this volcanic belt has long been recognized as having potential for hosting copper deposits, through many geological research works. The presence of copper minerals in the Nậm Tia area ranges from native copper to copper sulfide minerals, which include chalcocite, chalcopyrite, bornite, covellite and secondary copper mineral such as cuprite, malachite and azurite. The latter reflect their original relationship to hydrothermal and metasomatic processes and alteration by weathering in the epigenetic zone.

The potential for copper deposits in northwestern Vietnam in general and especially within the Viên Nam Formation of the Đà River Structural Zone has also been researched and assessed for mineral deposits for local industrial development. However, research has not focused on the relationship between the origin of and geology of the copper ore. This study highlights some characteristics of metasomatic alteration on the surrounding country rock in the copper mineralization zone at Nậm Tia and has partly determined the metallogenesis as well as highlighting the mineral prospectivity of the region.

## I. Geological setting and hydrothermal alteration characteristics in Nậm Tia, Sìn Hồ, Lai Châu

### *I.1. Geological setting*

Mafic extrusive rocks of Viên Nam Formation ($T_1vn$) in the Nậm Tia area continuously extend in a northwest - southeast direction from the Nậm Ngập hamlet through Nậm Cha to the area of Nậm Ngã – Nậm Kinh villages (Figure 1). In the regional tectonic setting of Vietnam, the volcanic belt of the Viên Nam Formation in general and the study area in particular is located in the Sông Đà Structural Zone, which is an active intracontinental rift zone adjacent to the Sông Mã uplift structural zone in the west and the Phan Si Pan zone in the east (Bùi Phú Mỹ và nnk., 1978).

In the research area, mafic extrusive rocks of the Viên Nam formation mainly consist of komatiite basalt[1] in the lower part of the geological section and amygdaloidal basalt interspersed with olivine basalt in the middle, then hyalobasalt, aphyric basalt, plagioclase basalt and associated tuff in the upper part (

[1] Professor? Hoàng Minh Huệ described this as a dark-coloured basalt.

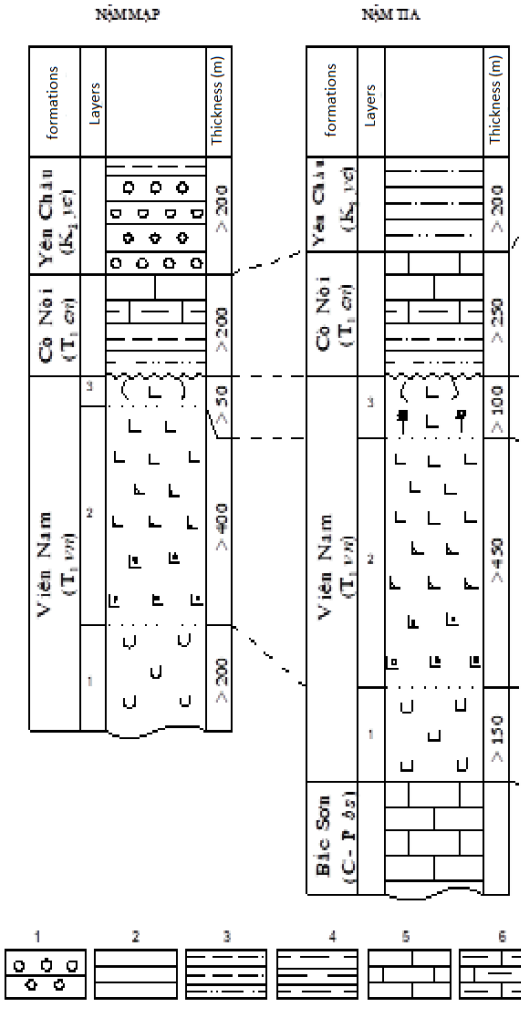



Figure 2). Carbonaceous sediments and limestones of the Bắc Sơn Formation (C-$P_2$*bs*) are restricted in distribution to the western part of this area. Sedimentary rocks of Tân Lạc formation ($T_1$*tl*) are exposed in a narrow northwest to southeast trending belt in the center of the study area. The rocks of Tân Lạc formation mainly consist of fine-grained, yellow-gray medium-bedded sandstone intercalated with gray, light-green foliated siltstone, the upper part being light gray medium to thickly bedded carbonaceous sediments. Red sedimentary rocks of Yên Châu formation ($K_2$*yc*) are distributed on the eastern edge of the Viên Nam volcanic belt and consist mainly of pebble conglomerate, gravel, and red-gray gravels in the lower part and yellow-gray quartzose sandstone and yellow-gray to red-gray siltstone in the upper part.

Intruding the volcanic rocks of the Viên Nam Formation are minor small intrusives or dykes of ultramafic composition, mainly wehrlite, which are classified as part of the Ba Vì Complex ($G^{bp}/T_1$*bv*). The Viên Nam Formation unconformably overlays carbonate sediments of the Bắc Son Formation and is in turn unconformably overlain by sedimentary rocks of the Tân Lạc Formation or Cò Nòi Formation (Bùi Phú Mỹ và nnk., 1978).

Volcanic rocks of the Viên Nam Formation have been studied by many geologists including Phan Cự Tiến (1977), Đào Đình Thục (1985), Đỗ Đình Toát (1986), Poliakov and Trần Trọng Hòa (1991, 1996, 1998). According to these geologists, the volcanics of the Viên Nam Formation have contrasting features with rocks of mafic composition located in the lower part of the geological profile i.e. komatiite basalt, porphyrytic basalt and amygdaloidal basalt and more acidic eruptive components such as dacite and rhyolite in the upper part. In the Nậm Tia area, only mafic rocks are present i.e. they belong to the lower part of the Formation.

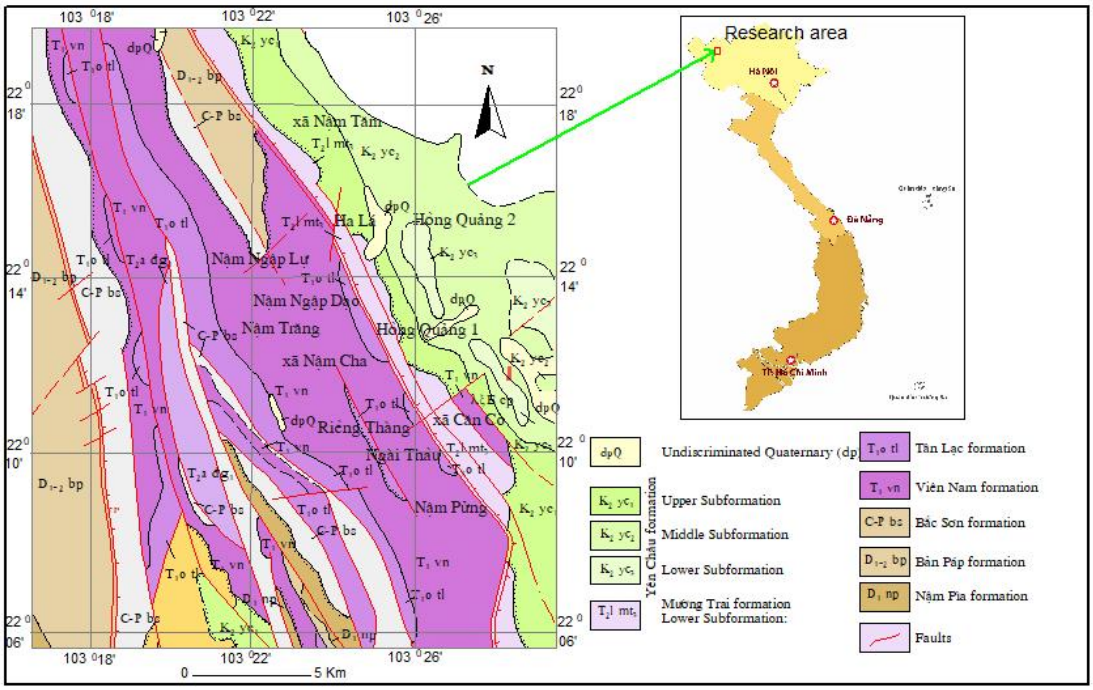



*Figure 1: Geological map of the research area (from the Kim Bình - Lào Cai Geological Sheet, scale 1:200.000 by Thành Vạn Nguyễn at al. (2005))*

### *I.2. Hydrothermal metasomatic alteration in the research area*

Results of hydrothermal metasomatic alteration studies in the Nam Tia area show that the mafic rocks of the Viên Nam Formation as well as small ultramafic dykes (wehrlite) belonging to the Ba Vì Complex are all altered by epidotization and chloritization due to the impact of hydrothermal fluids causing metasomatism (Hoàng Minh Huệ và nnk., 2005; Nguyễn Tâm và nnk., 2015). These are characteristics of the propilitization process (subalkaline metasomatism). In the study area, the process of propylitization on the volcanic-intrusive complex of mafic and ultramafic rocks is as follows:

- Komatiite basalt: dark colored, amygdaloidal with clear relict spinifex texture, strongly altered by propilitization with microflakes of epidote completely replacing plagioclase and chlorite pseudomorphing olivine microcrystals (Photo 1).

- Picrite: Dark green color, medium to fine-grained, with porphyritic texture comprising phenocrysts of olivine and euhedral pyroxene in the groundmass, pre-crystallized plagioclase inlaid in euhedral pyroxene grains creating a poikilitic texture. Euhedral olivines up to 2mm in size are partially replaced by brown idingsite; clinopyroxenes are yellowish-green, automorphic granular, 3-4 mm in size and the groundmass consists of 1-2mm acicular plagioclase and pyroxene. The rocks are altered by the process of propilitization with olivine, pyroxene and plagioclase partially to completely altered by chlorite and epidote (Photo 1).

- Olivine basalt: dark green to gray-green colour, amygdaloidal texture. Phenocrysts mainly consist of 3-10% sub-idiomorphic crystallized olivine in a hyaline groundmass or inlaid in a hyalopilit-groundmass. These rocks are altered by propilitization. Prehnitization mainly occurs in amygdaloidal basalt. The amygdales are replaced by a combination of prehnite, chlorite, epidote and quartz. Copper minerals can be observed in these rocks including chalcocite, bornite, chalcopyrite and native copper. Native copper often occurs within propilitized amygdales forming the mineral association of chlorite – epidote – native copper.

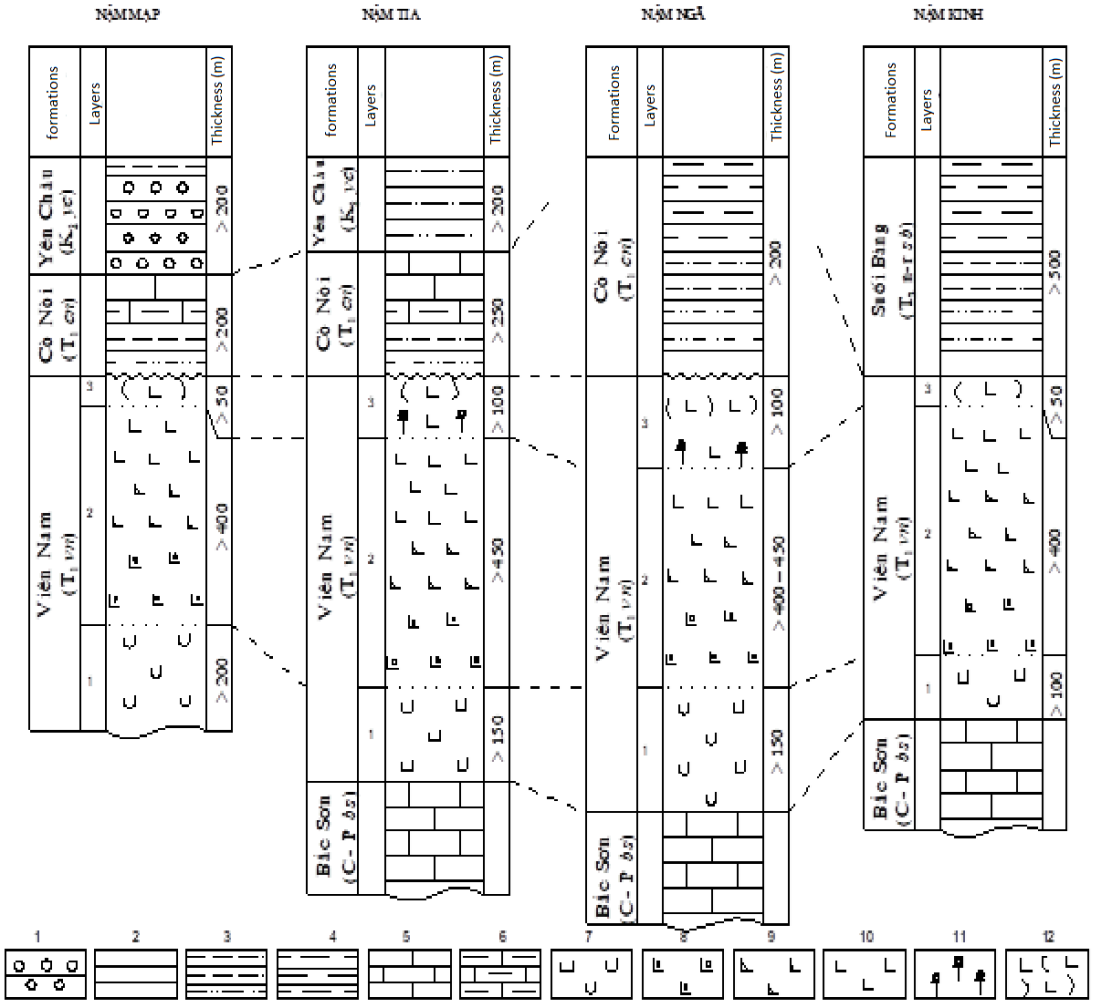


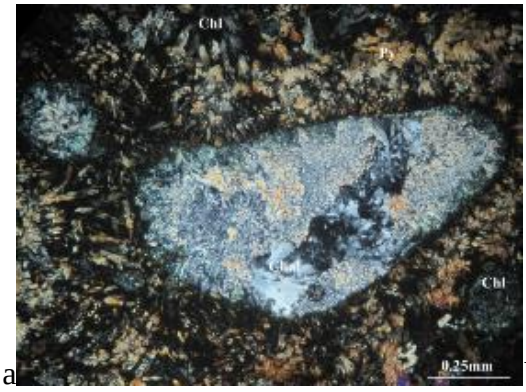

*Figure 2. Stratigraphic column of the Viên Nam Formation in the study area (Hoàng Minh Huệ, 2005).*

- Amygdaloidal basalt, pyroxene-rich amygdaloidal basalt is dark gray to white mottled in color. Amygdales account for a large proportion (50-60%) of the rock and consist mainly of prehnite, calcite, chlorite and quartz. The rocks are amygdaloidal-textured but no phenocryst textured, or microphenocryst, radiating, replacement textured with propilitization rim.

Aphyric basalt and hyalobasalt form the main volume of the Viên Nam Formation in the area studied. Rocks are gray, blue-gray, fine-grained, rarely greenish-gray and are cut by hydrothermal veins which cause the propylitic alteration (Photo 2, Photo 3).

In association with this propylitic mafic volcanic rock, small bodies or dykes of ultramafic composition belonging to the Ba Vì Complex are also weakly to strongly propilitized (Photo 5).

In the study area, small intrusive gabbro - diabase bodies belong to the Ba Vì Complex ($G^{bp}/T_1bv$). They are dark coloured, blocky, and have a clear gabbroic igneous texture. In outcrop, olivine is strongly altered and replaced by the mineral association of chlorite – serpentine – amphibole.

a 

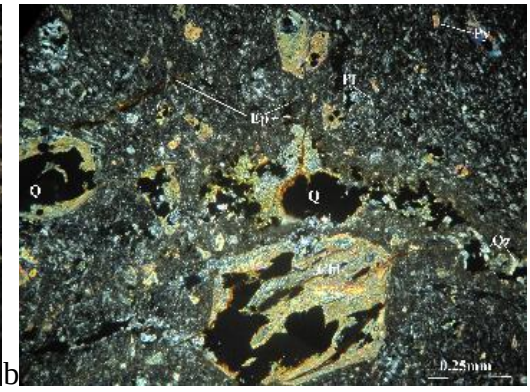
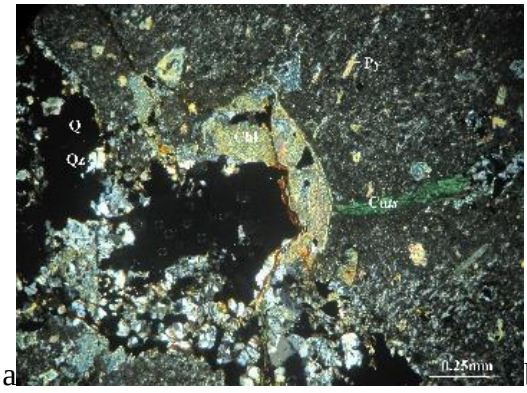
b 


*Photo 1. Dark basalt altered by proplitization. a. Komatiite basalt (NT 1009) strongly altered by propilitization; b. Olivine basalt (NT.1005) with phenocrysts of idiomorphic, weakly propilitized olivine and pyroxene. Legend - Ca: calcite; Pl: plagioclase; Ep: epidote; Chl: chlorite; Qz: quartz; Q: opaque ore minerals. Cross-polarized light.*

a 

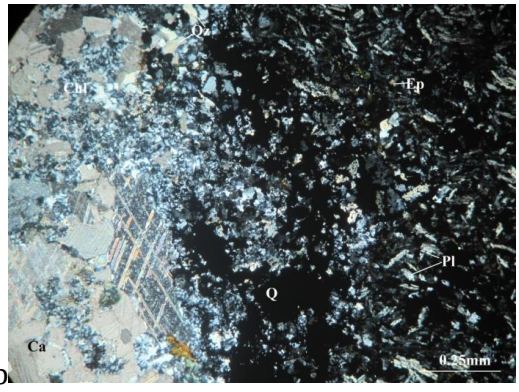
b 


*Photo 2. Mafic volcanic rocks, weakly to strongly propilitized. a. completely propilitized amygdaloidal basalt (NT.2001); b. Aphyric basalt (NT1003/1) completely altered chlorite – propilitization process due to cross-cutting hydrothermal vein of epidote – chlorite – carbonate – ore. Legend - Ca: calcite; Pl: plagioclase; Ep: epidote; Chl: chlorite; Qz: quartz; Q: opaque ore minerals. Cross- polarized light.*

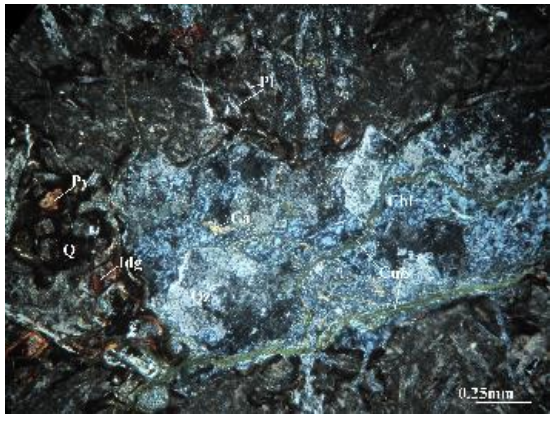



*Photo 3. Completely propilitized amygdaloidal basalt containing native copper (NT 2003/3b). Legend - Ca: calcite; Pl: plagioclase; Ep: epidote; Ch: chlorite; Qz: quartz; Q: native copper. Cross- polarized light.*

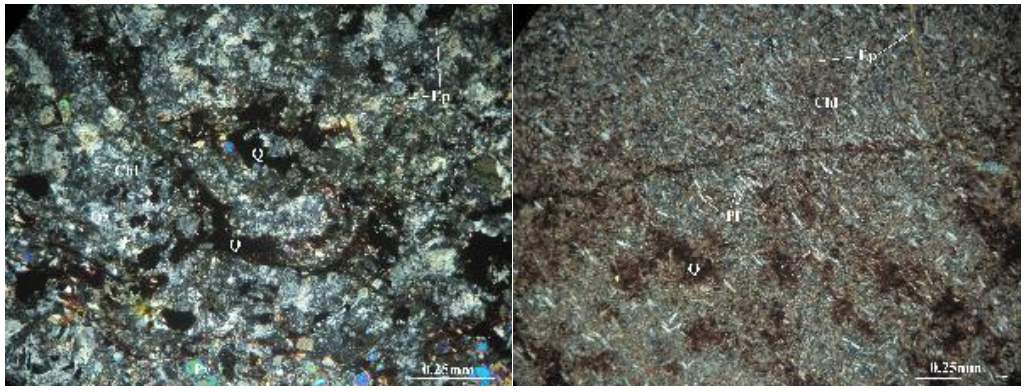



*Photo 4. Propilitized aphyric basalt containing copper minerals (N+) a. aphyric basalt (NT 2003/1) is completely chloritic propilitized by cross-cutting quartz veins; b. strongly fractured chloritic propilitized aphyric basalt contains copper ore (NT 2006). Legend - Pl: plagioclase; Ep: epidote; Chl: chlorite; QZ: quartz; Q: opaque minerals. Cross- polarized light.*

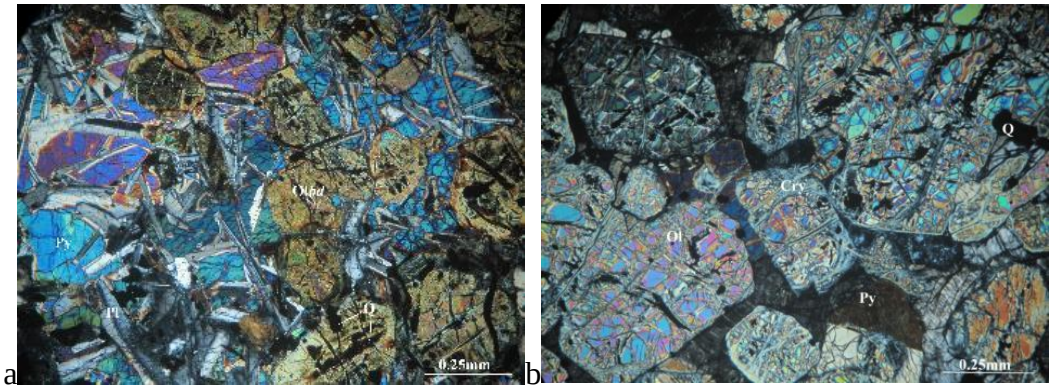



*Photo 5. Ore-bearing intrusive rocks of the Ba Vì complex are weakly propilitized (N+) a. Gabbro-diabase (NT 1016); b. Serpentinized and chloritized wehrlite (NT 2002). Legend - Py: pyroxene; Ol: olivine Olbd: altered olivine; Pl: plagioclase; Cry: chrysotile; Ch: chlorite; Q: opaque ore minerals. Cross-polarized light.*

*Table 1. Oxide chemical analysis of basalt in the study area.*

| Oxide | NT 1003/1 | NT 1009 | NT 2001/1 | NT 2013.Q1/1 | NT 2013.Q2/1 | NT 2013.Q3/1 | NT 2013.Q4/1 | NT 2014.Q1/1 | NT 3001/1 | NT 3026/1 |
|---|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 38,64 | 21,78 | 44,18 | 41,08 | 41,46 | 53,36 | 48,34 | 47,58 | 43,8 | 50,3 |
| $Al_2O_3$ | 8,63 | 3,52 | 11,59 | 8,77 | 12,43 | 12,68 | 13,78 | 11,89 | 11,91 | 10,13 |
| $TiO_2$ | 1,84 | 0,62 | 0,75 | 1,62 | 2,00 | 2,2 | 2,43 | 1,86 | 0,65 | 0,49 |
| $Fe_2O_3$ | 0,54 | 5,18 | 3,5 | 18,54 | 8,96 | 10,2 | 6,54 | 7,54 | 7,68 | 5,69 |
| FeO | 8,5 | 8,95 | 7,55 | 2,18 | 2,6 | 2,4 | 4,35 | 2,67 | 3,1 | 3,35 |
| CaO | 13,17 | 27,2 | 4,15 | 2 | 2,86 | 2,72 | 4,01 | 2,72 | 9,45 | 15,03 |
| MgO | 3,86 | 1,14 | 5,58 | 3,53 | 4,58 | 3,46 | 4,99 | 4,11 | 10,96 | 8,38 |
| $K_2O$ | 0,8 | 0,38 | 0,15 | 0,87 | 1,01 | 1,69 | 1,7 | 1,55 | 0,06 | 0,13 |
| $Na_2O$ | 1,99 | 0,98 | 4,46 | 2,08 | 2,13 | 4,27 | 3,04 | 3,11 | 1,95 | 0,18 |
| MnO | 0,17 | 0,06 | 0,17 | 0,2 | 0,17 | 0,17 | 0,15 | 0,2 | 0,2 | 0,22 |
| MKN* | 8,5 | 17,89 | 5,76 | 6,93 | 8,68 | 3,34 | 4,08 | 6,1 | 5,75 | 3,91 |

The intrusive ultramafic rocks are often observed to be dark coloured, blocky, fine to medium grained wehrlite, mainly composed of pyroxene, altered olivine and minor

plagioclase. These rocks are serpentinized and chloritized. Native copper is observed in xenomorphic-granular, nests or elongate wirey forms (Photo 5).

Based on the research results of these altered rocks, and on the silicate chemical analysis (Table 1) from the Viên Nam Formation in the study area, and collected from the data of geological mapping at 1:50,000 scale by Nguyễn Văn Nguyên (2005), Hoàng Minh Huệ (2005) and Nguyễn Tâm (2015), these mafic volcanic rocks belong to a basalt-komatiite complex characterized by low K, high Na, very low Ti, and variable Al with high Al komatiite to low Al basalt. These volcanic rocks belong to the high Fe and high Mg tholeiite magma series with characteristic high concentrations of Mg, Ni, Co, Cu, and Cr (Figure 3). The eruptive rocks of the Viên Nam Formation are altered mainly by a subalkaline alteration process, the type being propilitization with the processes of epidotization, chloritization and phrenitization.

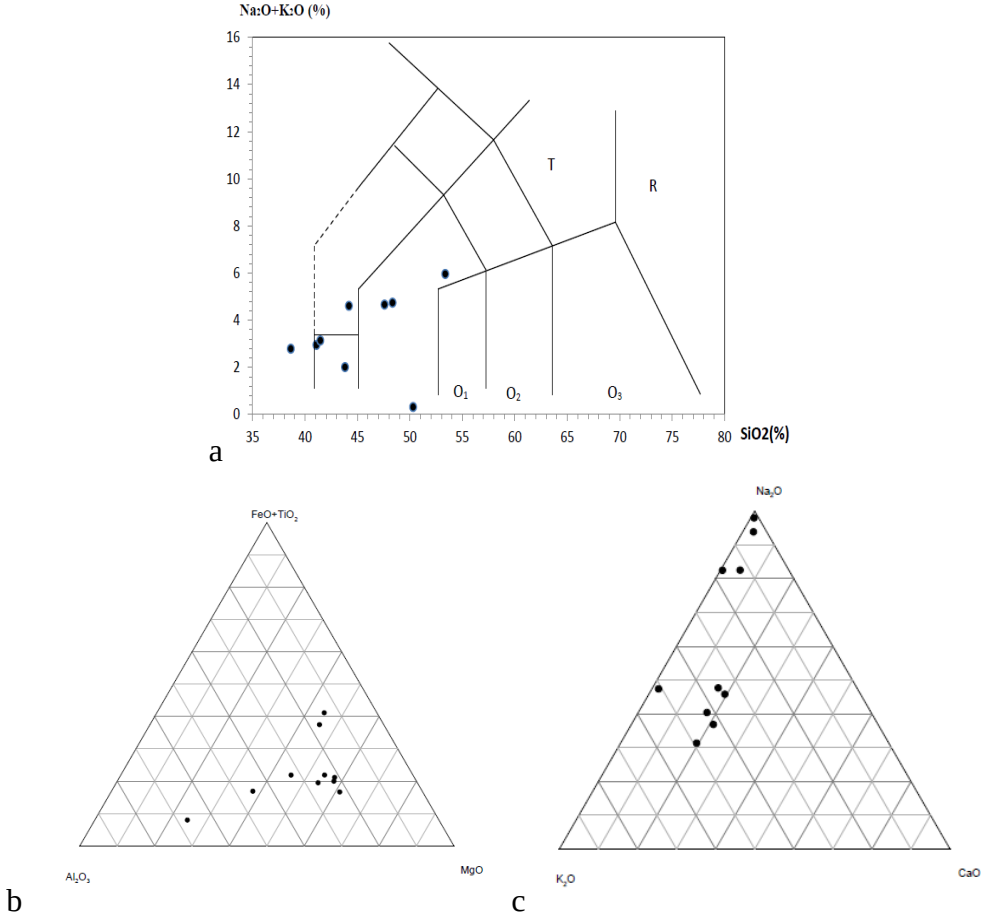



*Figure 3. Classification diagrams of mafic extrusive rocks of the Viên Nam Formation in the Nậm Tia area; a. $Na_2O+K_2O$ diagram by Le Maitre; b. Jensen diagram (1976) corrected for subalkaline komatiite basalt rocks; c. $Na_2O$-$K_2O$-CaO diagram for komatiite basaltic rocks.*

**II. The relation between alteration and copper mineralisation at Nậm Tia, Sìn Hồ, Lai Châu**

According to the research on the magmatic source of endogenous ore deposits as well as the statistical data on metal concentrations in magmatic rocks (Hubert L. B., 1967), it can be seen that mafic rocks have high background copper metal concentrations that are 2-5 times higher than ultramafic, intermediate and acidic rocks (**Error! Not a valid bookmark self-reference.**).

Research results on copper mineralization characteristics at Nậm Tia show that copper

minerals in mafic volcanic rocks range from native copper to copper sulfide minerals and carbonate minerals such as bornite, chalcopyrite, chalcocite, covellite, malachite, azurite and some copper oxide minerals such as cuprite.

The native copper minerals are concentrated in the native copper mineralized bodies distributed along northeast - southwest fracture/alteration zones with host rocks being amygdaloidal basalt and olivine basalt. The native copper minerals are isometric to xenomorphic (anhedral), or concentrated in small, scattered nests in the propilitized amygdales of basalt, with the main mineral association being prehnite – chlorite – epidote – quartz and native copper (Hoàng Minh Huệ và nnk., 2005; Nguyễn Tâm và nnk., 2015).

*Table 2. The concentration of selected major metals from magmatic sources (Hubert L. B., 1967)*

| | Ultramafic | | Mafic | | Intermediate | | Granite | | Syenite |
|---|---|---|---|---|---|---|---|---|---|
| | TW | V | TW | V | TW | V | TW | V | TW |
| Li | 0.X | 0.5 | 17 | 15 | 24 | 20 | 40 | 40 | 28 |
| e | 0.X | 0.2 | 1 | 0.4 | 2 | 1.8 | 3 | 5.5 | 1 |
| Ti | 300 | 300 | 13800 | 9000 | 3400 | 8000 | 1200 | 2300 | 3500 |
| V | 40 | 40 | 250 | 200 | 88 | 100 | 44 | 40 | 30 |
| Cr | 1600 | 2000 | 170 | 200 | 22 | 50 | 4.1 | 25 | 2 |
| Mn | 1620 | 1500 | 1500 | 2000 | 540 | 1200 | 390 | 600 | 850 |
| Co | 150 | 200 | 48 | 45 | 7 | 10 | 1 | 5 | 1 |
| Ni | 2000 | 2000 | 130 | 160 | 15 | 55 | 4.5 | 8 | 4 |
| Cu | 10 | 20 | 87 | 100 | 30 | 35 | 10 | 20 | 5 |
| Zn | 50 | 30 | 105 | 130 | 60 | 72 | 39 | 60 | 130 |
| As | 1 | 0.5 | 2 | 2 | 1.9 | 2.4 | 1.5 | 1.5 | 1.4 |
| Se | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 |
| Zr | 45 | 30 | 140 | 100 | 140 | 260 | 175 | 200 | 500 |
| Nb | 16 | 1 | 19 | 20 | 20 | 20 | 21 | 20 | 35 |
| Mo | 0.3 | 0.2 | 1.5 | 1.4 | 1.0 | 0.9 | 1.3 | 1 | 0.6 |
| Ag | 0.06 | 0.05 | 0.11 | 0.1 | 0.05 | 0.07 | 0.04 | 0.05 | o.ox |
| Cd | 0.X | 0.05 | 0 22 | 019 | 0.13 | | 0.13 | 0.1 | 0.13 |
| Sn | 0.5 | 0.5 | 15 | 15 | 1.5 | | 3 | 3 | X |
| Sb | 0.1 | 0.1 | 0.2 | 1 | 0.2 | 0.2 | 0.2 | 0.26 | o.x |
| Ce | 0.X | | 48 | 4.5 | 81 | | 92 | 100 | 161 |
| Ta | 10 | 0.02 | 1.1 | 0.5 | 3.6 | 0.7 | 4.2 | 3.5 | 2.1 |
| W | 0.77 | 0.1 | 0.7 | 1 | 1.3 | 1 | 2.2 | 1.5 | 13 |
| Au | 0.006 | 0.005 | 0.004 | 0.004 | 0.004 | | 0.004 | 0.005 | o.oox |
| Hg | 0.0X | 0.01 | 0.09 | 0.09 | 0.08 | | 0.08 | 0.08 | o.ox |
| Ti | 0 06 | 0.01 | 0.21 | 0.2 | 0.72 | 0.5 | 2.3 | 15 | 1.4 |
| Pb | 1 | 0.1 | 6 | 8 | 15 | 15 | 19 | 20 | 12 |
| Bi- | | 0.001 | 0.007 | 0.007 | | 0.01 | 0.01 | 0.01 | |
| Th | 0.04 | 0.005 | 4 | 3 | 8.5 | 7 | 17 | 18 | 13 |
| U | 0.01 | 0 003 | 1 | 0.5 | 3.0 | 1.8 | 3.0 | 3.5 | 3.0 |
| S | 300 | 100 | 300 | 300 | 300 | 200 | 300 | 400 | 300 |

*Legend - TW: the data of Turekian – Wedepohl (1961) and V: data from Vinogradov (1962).*

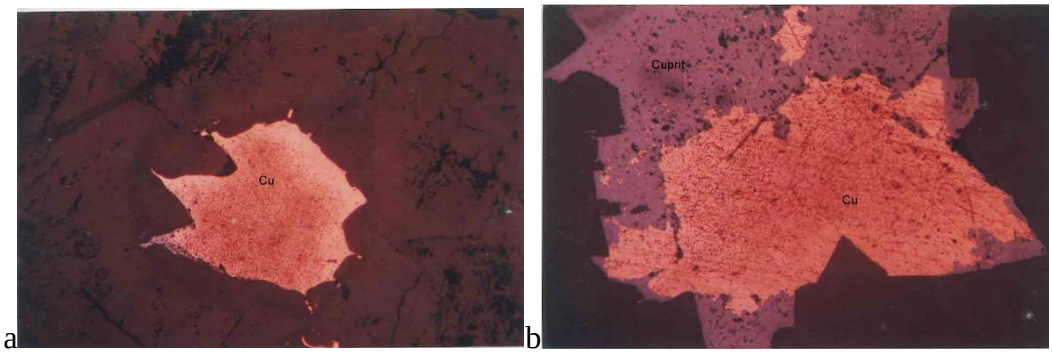
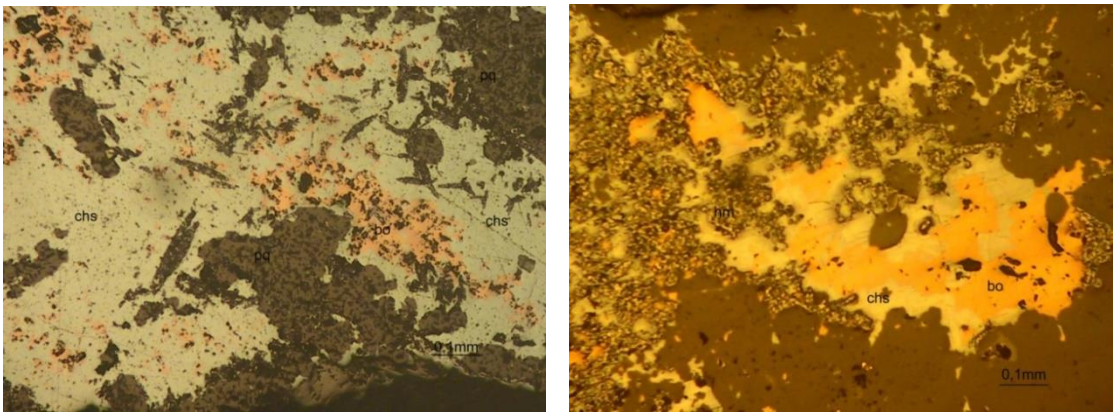



*Photo 6. Xenomorphic native copper: a. Native copper in an amygdale within basalt; b. Native copper replaced by cuprite in an amygdale within basalt.*

The native copper is usually in the form of scattered or elongated isometric to xenomorphic forms on the ground of rocks. In many places, it is possible to observe the syngenetic relationships between chalcocite and bornite or an exsolution texture between bornite and chalcopyrite. This reflects the relation and association of the minerals chalcocite – bornite – chalcopyrite (Nguyễn Tâm và nnk., 2015).

Copper sulfide minerals in the basaltic volcanic rocks in the area are accompanied by copper oxide minerals and carbonate copper minerals including bornite, chalcopyrite, chalcocite, covellite, malachite, azurite and the iron sulfide minerals pyrite and hematite. The copper sulfide minerals are observed in most of the mafic extrusive rocks from komatiite basalt, amygdaloidal basalt, aphyric basalt to hyalobasalt and are often concentrated in hydrothermal alteration and fracture zones with propilitization of the surrounding basalt.

In the studied samples, the chalcocite observed in the rock can be classified into two endogenic generations formed directly by the action of the hydrothermal solution. The first generation of chalcocite is located on ground of rocks in the form of plates, small particles or elongate scattered veinlets or microveins. The syngenetic relation between this type of chalcocite and bornite are sometimes observed (NT.1011/1, Photo 7, Photo 8). The other generation of chalcocite is associated with alteration minerals and rimmed partially to completely replaced by other sulfide minerals such as bornite and chalcopyrite. This alteration chalcocite is often found in hydrothermal veins which are colloidal, allomorphic and are always accompanied by other secondary copper minerals such as colloidal malachite or azurite.




a b

*Photo 7. Two generations of chalcocite in samples a: intergrowth of chalcocite - bornite (NT 1011/1); b: combination of chalcocite and covellite replacing bornite around the rim (NT 1003/1) (Nguyễn Tâm và nnk., 2015). Polished section.*

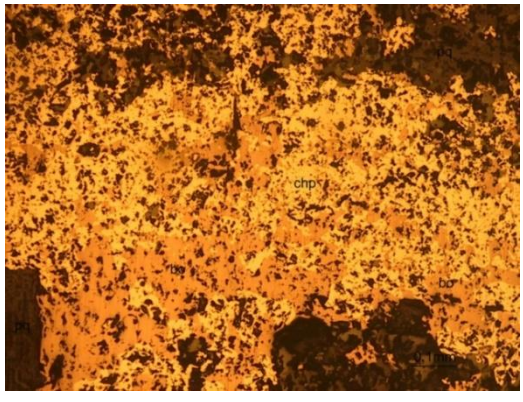



*Photo 8. Exsolution texture between bornite – chalcopyrite. Polished section.*

Chalcopyrite is often observed in allomorphic to idiomorphic grains, as prolonged and intergrown forms with bornite in the exsolution texture. The balanced relationship between chalcopyrite and bornite has determined their syngenetic relationship (Photo 8).

Thus, it can be seen that sulfide copper minerals are directly formed from hydrothermal solutions in the deformation and alteration zones. The analysis of mineral characteristics under the petrographic microscope shows that these are the quartz-calcite hydrothermal veins that form at low to average temperatures. These hydrothermal veins are associated with chloritization, epidotization, prehnitzation, and weak silicification. Those are characteristic of subalkaline hydrothermal process and propilitization.

These studies on metasomatic characteristics of hydrothermal process show that the extrusive – instrusive complex of mafic – ultramafic rocks are mainly altered by the propilitization process. This type is Fe – Mg – Ca metasomatism occurs at shallow depths (0,5-2 km) (Poliakov G.V. et al., 1991) under a wide range of temperature fluctuations (optimally 200-300$^0$C) under the influence of intermediate to weakly alkaline solutions. According to Piusev E. V et al. (1981), the hydrothermal alteration mineral association of chlorite - epidote on dark rocks (mafic, ultramafic) is characterized by homogeneous chlorite – propilitization. Smirnov V. I. (1976) studied and identified that propilitization is a common phenomenon in hydrothermal ore forming processes in the medium – low temperature environment, at shallow zones near the surface, closely related to volcanic activity (Poliakov G.V. et al., 1991). It can be divided into two thermo-dynamic levels of propylitisation (Piusev E. V et al., 1981): (1) at low temperatures (25-150°C) forming an epidote-chlorite mineral assemblage near to the surface which often leads to the sericite mixed carbonatization; (2) at higher temperatures (35-250°C) forming an epidote-actinolite mineral assemblage. In the study area, actinolite has not yet been observed in the collected samples, hence, the metasomatism level here stops at the shallow zone near to the Earth's surface.

Table 3: The order of formation of copper minerals in the study area.

| N | Mineralization phase / Stage / Mineral | Hydrothermal I Q-He-Bor-Chal | Hydrothermal II Bor-Chal- Cu$_{ts}$ | Weathering III |
|---|---|---|---|---|
| 1 | Quartz | ——— | | |
| 2 | Hematite | ——— | | |
| 3 | Pyrite | ---------- | | |
| 4 | Bornite | ——— | | |
| 5 | Chalcopyrite | ---- | ---------- | |
| 6 | Native copper | | ——— | |
| 7 | Chalcocite | ——— | ——— | ——— |
| 8 | Calcite | | ---------- | |
| 9 | Cuprite | | | ---------- |
| 10 | Covellite | | | ---------- |
| 11 | Malachite | | | ——— |
| 12 | Azurite | | | ---------- |
| 13 | Limonite | | | ---------- |
| | Alteration | Chloritization, epidotization | Chloritization, prehnitization | |

Note: ——— idiomorph to Allomorph particle --------- Colloidal, micro particle;

Research results of hydrothermal alteration studies show that the level of chlorite propilitization is consistent with the results of chemical analysis of chalcocite, which is digenite ($Cu_{1.765-1.79}S$), an endogenetic variant of chalcocite formed under low temperature conditions. This level also corresponds to the homogenization temperature of gas-liquid inclusions in quartz – calcite hydrothermal veins. This homogenization temperature fluctuates in two ranges: 178-250$^0$C and 301-445$^0$C, and the formation temperature of

copper ore ranges between 182-237$^0$C (Hoàng Minh Huệ và nnk., 2005). These are all evidence for a low – medium temperature origin that is post-extrusion and hydrothermal. Based on the metasomatic process research, the hydrothermal processes in the area can be divided into two stages. In the early stage, the subalkaline hydrothermal solution widely alters the mafic rocks of the study area and is characterized by epidote and chlorite Table *3*). Based on the metasomatic hydrothermal alteration and metallization research results, it is possible to identify and divide the hydrothermal alteration process into two main stages with the following sequence: basalt is altered by chloritization + epidotization, then prehnitization with a mineral association: prehnite + chlorite + epidote:

- Early stage: Basalt undergoes alteration to varying degrees on a wide scale. Glass commonly devitrifies to chlorite and epidote, olivine is replaced by brown idingsite, and vesicles are filled with chlorite - epidote amygdales. The typical alteration mineral association for this episode is: chlorite + epidote + copper mineralisation. At strong alteration levels, epidote replaces (allomorphs) the entire groundmass. During this period, metal deposition consists mainly of copper sulfide minerals such as bornite, chalcocite and chalcopyrite.

- Late stage: Prehnitization. During this stage, prehnite usually fills vesicles and fractures in epidotized basalt. Under the microscope, chlorite or epidote remnants are occasionally observed in these prehnitized amygdales. The metallic mineral accompanying this late stage is mainly native copper.

## Conclusions

The mafic volcanic belt extending from the northwest to the southeast in the Nam Tia area is a part of the mafic volcanic belt of the Viên Nam Formation which extends from the Vietnam – China boder to Hòa Bình Province and is regarded as a prospective area for copper ore deposits.

Results of the current geological and alteration study of the Nậm Tia, Sìn Hồ, Lai propilitization. The later stage consists mainly of epidotization, chloritization and prehnitization and is more isolated and at lower temperatures than the early stage.

The research results of mineralization in the study area have shown that both native copper and copper sulfides are typical of post-extrusive hydrothermal copper deposits (

Châu area show that:

- Mafic volcanic rocks of the Viên Nam Formation in the study area are mainly komatiite basalt in the lower part and olivine basalt, amygdaloidal basalt and hyalobasalt in upper part. The rocks are strongly altered by hydrothermal solutions causing propilitization, mainly of the chloritized propilitization type, which is typical of medium-low temperature hydrothermal alteration.

- The hydrothermal solution is of post-eruption origin. During the hydrothermal activity, the surrounding rocks are altered by two stages of hydrothermal activity. In the early stage, the alteration consists mainly of epidotization and chloritization with a typical mineral association of chlorite + epidote + copper sulfides. In the late stage, the alteration type is mainly prehnitization with amygdales forming in basalt vesicles and fractures being filled by prehnite - epidote - chlorite – native copper.

- Medium to low temperature hydrothermal metasomatism of the epidote – chlorite propilitization process shows a close primary relationship between hydrothermal processes and mineralization, and their relation to mafic – ultramafic rocks of the volcanic – intrusive complex in the research area. In fact, these results illustrate the potential for additional copper mineralisation in the study area.

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