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IOCG Sin-Quyen deposit, LaoCai, N-Vietnam

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Abstract. The geology, mineralogy and geochemistry of the IOCG Sin-Quyen deposit are described in the paper. The combined mineralogical and geochemical studies constrain the stages of ore mineral crystallization, and establish the timing of uraninites. A special attention is paid to the allanite group of minerals which contain the bulk of the REE.

1 Introduction

The studied copper deposit is located in the Sin-Quyen district, province of Lao-Cai in North Vietnam. Exploitation, enrichment and smelting of the copper metal are active since 2006. During field work in 2014, 45 samples from the operating open pit and waste disposal were collected.

2 Geological setting

The IOCG Sin Quyen deposit is hosted by altered amphibolite and biotite gneiss located in the metamorphosed sedimentary rocks of the Proterozoic Sin Quyen Formation, which fills the wide Red River regional fault zone (Fig. 1). The deposit consists of dozen ore bodies forming lens of several tens of meters in width and a few hundred meters in length trending in the NW-SE direction (Fig. 2) (Ishihara et al. 2011). The deposit can be divided into two zones, the first consists of least-altered rocks and ores, the second of weathered rocks.

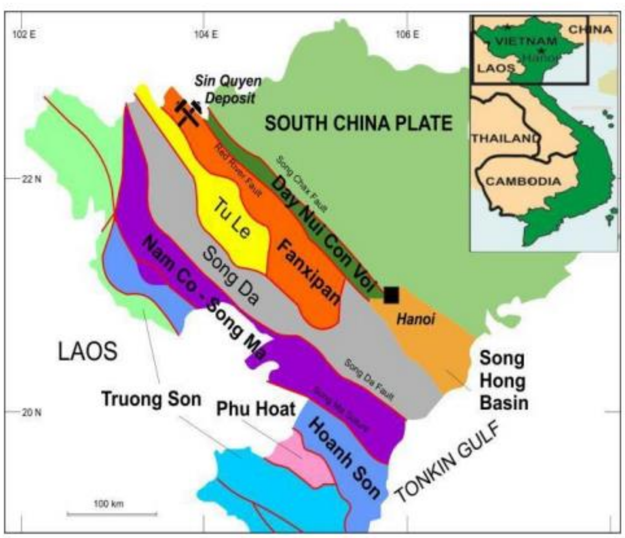

Figure 1. Main tectonic structures connected with the Sin Quyen deposit.

Figure 2. The copper ore body (black lenses) of the Sin-Quyen deposit (photo taken in 2014).

In the deposit massive skarn ores, disseminated and vein types of ore have been described. Based on local geology and ore mineralization and recognized processes, the deposit is classified as an IOCG type. The deposit was passed through a complicated multistage mineralogical composition. The mineralized zone is several meters up to 30 meters of wide, NW-SE trending and is dipping almost vertically. Verticality facilitated penetration of oxidizing surface waters in the ore body leading to an oxidation zone that reaches over 100 m in depth. Macroscopically visible oxidized minerals include malachite, azurite and Fe-hydroxides. Mineralogical and geochemical description of the deposit is based on 42 samples collected through the deposit section crossing the ore body and from the concentrates and wastes.

3 Mineralogy of the IOCG deposit

The bulk chemical analyses show a high concentration of copper (above 1 wt%), iron (above 40 wt%) and gold (2.36 ppm) in massive sulphide ore and elevated uranium (56 ppm). Concentration of copper in the waste ranges between 0.03 wt.% and 0.05 wt.%. The concentration of sulfur is also relatively high - 0.60-0.77 wt.%. The major minerals are chalcopyrite and magnetite, clinopyroxene, allanite, epidote, biotite, titanite and some quartz in hydrothermally altered sequence of the Sin Quyen Formation. Other ore minerals consist of pyrite, pyrrhotite, sphalerite, ilmenite, marcasite, tennantite, cubanite, arsenopyrite, galena, Bi-native, bismuthinite, electrum, native gold, and tellurides (Tab. 1).
Microscopic studies of ore led to the identification of magnetite, ilmenite, pyrite, pyrrhotite, chalcopyrite, sphalerite, marcasite, tennantite, cubanite, arsenopyrite, galena, native bismuth, bismuthinite, and electrum and native gold. Small inclusions of gold (up to a few microns

in size) occur in massive chalcopyrite. Thiosulphate replacing pyrrhotite and Fe-oxides have also been found in the dry waste samples. Thiosulphates are a result of pyrrhotite oxidation.

4 Measurements and results

Generally all collected samples are rich in rare earth elements (REE) and their concentration ranges from dozen of ppm to more than 5400 ppm, the average concentration of uranium and thorium amounts to 20.2 ppm (250 Bq/kg) and 17.9 ppm (72.6 Bq/kg) respectively (Nguyen et al. 2016). Uraninite crystals occur in the copper-massive iron ore samples. Uraninites are inhomogeneous in both optical properties and chemical composition (Fig.3). Inhomogenity of uraninites is also confirmed by two different ages determined, using Jeol 8230 Super Probe.

The uraninites with high REE content are older, and those with low REE content are much younger. Based on uraninites dating two stages of mineralization are proposed for this deposit. The major stage is related to the skarn-metasomatic alteration of the Cambrian age, the younger stage was associated with late Cretaceous-Paleocene (82-42 Ma) tectonic activity. Weathering was recognized as the final stage in evolution of the deposit. The absolute age of these uraninites was calculated as 458-522 Ma (500 Ma average, for n= 36 and σ = 33 Ma) and as 82-78 Ma.

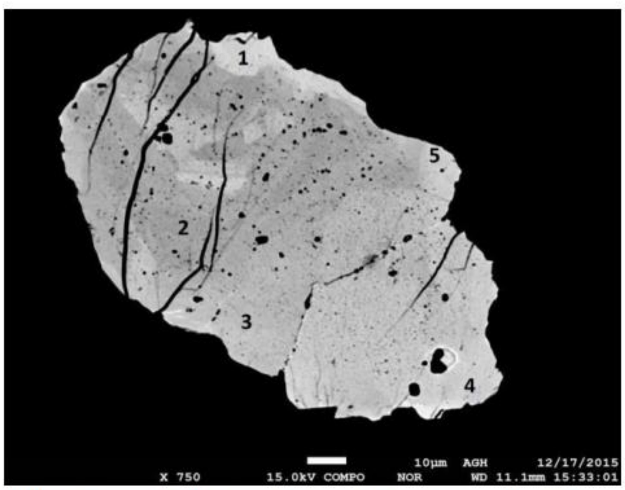

Figure 3. WDS-BSE image of uraninite, 1-5 are the analysis number (sample AP-455, photo 9), black spots are silicates and sulfides.

Microscopic observation let to distinguish two different minerals from the allanite group (Fig. 4). Chemical composition of both varieties was described Nguyen et al. (2016). The bands at 1041, 1033, 958, 920, 907 and 876 are attributed to SiO_2 stretching vibrations. The other bands are found over 750-350 cm^{-1} spectral range. These bands occur at 685, 650, 631, 610, 601, 586, 559, 509, 449, 425, 413, 382, and 375, cm^{-1} (Fig. 5), and are connected with siloxane bending modes. The Raman active bands appearing below 350 cm^{-1} regions, i.e. 310, 268, 219, 192, 126 cm^{-1} are described as lattice vibrations (López and Frost 2015).

The position of Raman active bands at the region 1100-300 cm^{-1} recorded for Viet-5-002 (Fig. 6) and Viet 5-001 (Fig. 5) crystals differ from each other (Fig. 7), the most probable cause is a difference in the composition of these two phases (compare Fig 8a, b, c and d). The presence of weak and broad bands at the wavenumber region of 3300-3100 cm^{-1} suggest the occurrence of some amounts of water in the allanite structure (Fig.7).

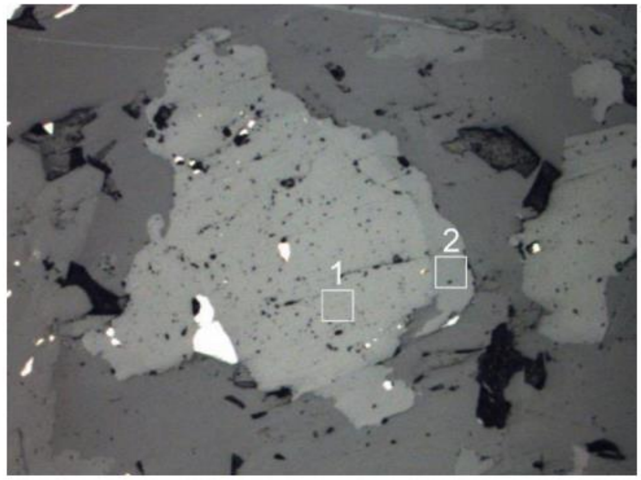

Figure 4. Two different types of allanite (grey). Reflected light, 1-, 2- location of Raman analysis, 10μm in size.

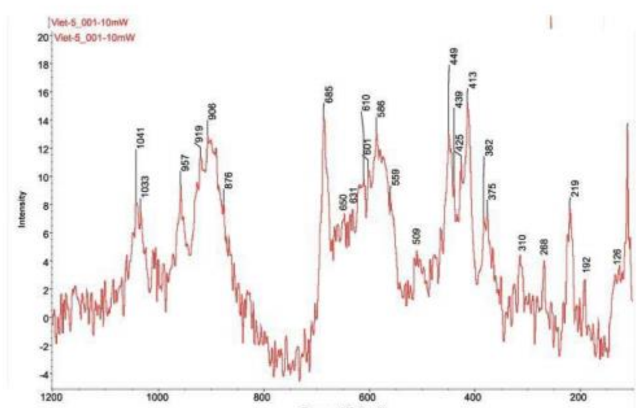

Figure 5. Raman spectra of point 1 from Figure 4.

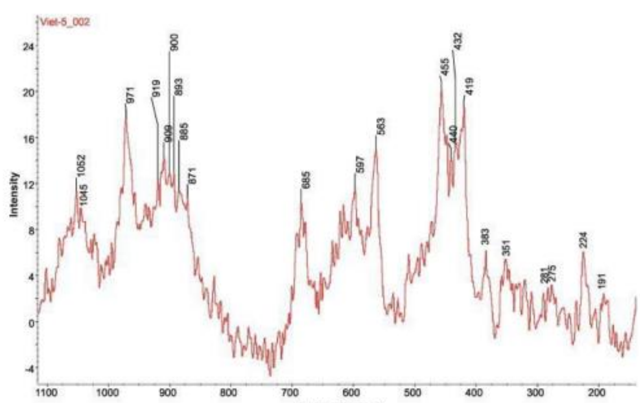

Figure 6. Raman spectra of point 2 from Figure 4.

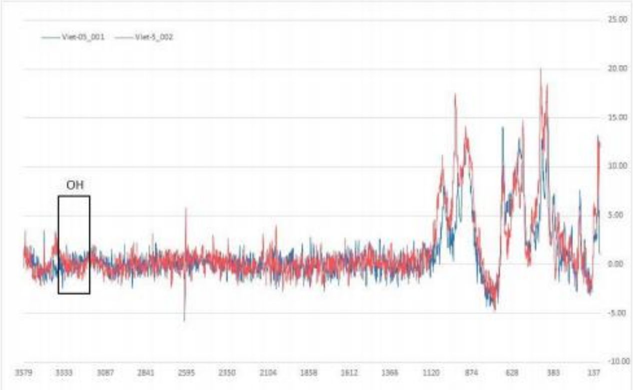

Figure 7. Raman spectra of two different types of allanite.

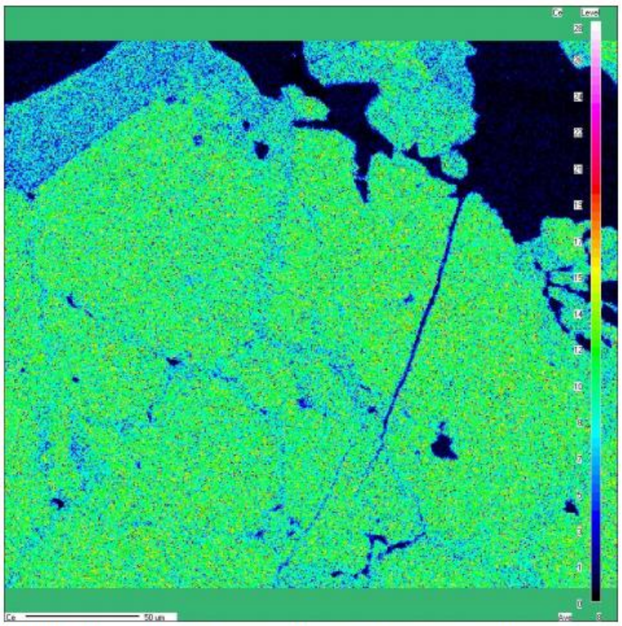

Figure 8a. Ce distribution in allanite, WDS quantitative.

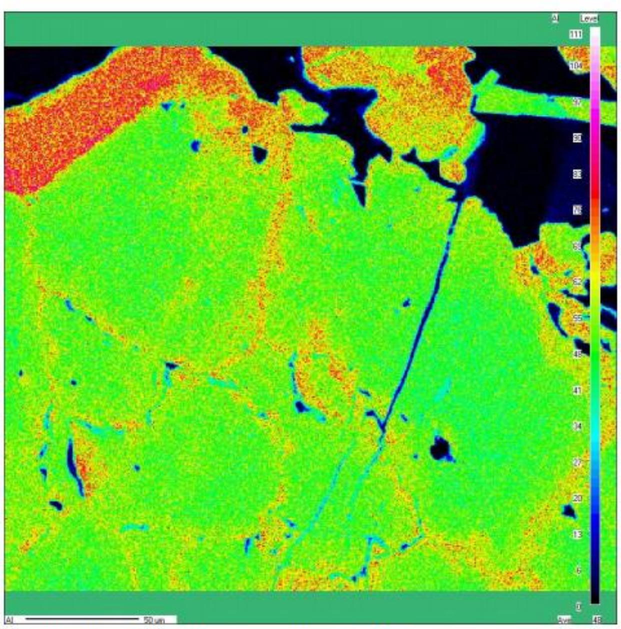

Figure 8b. Al distribution in allanite, WDS quantitative.

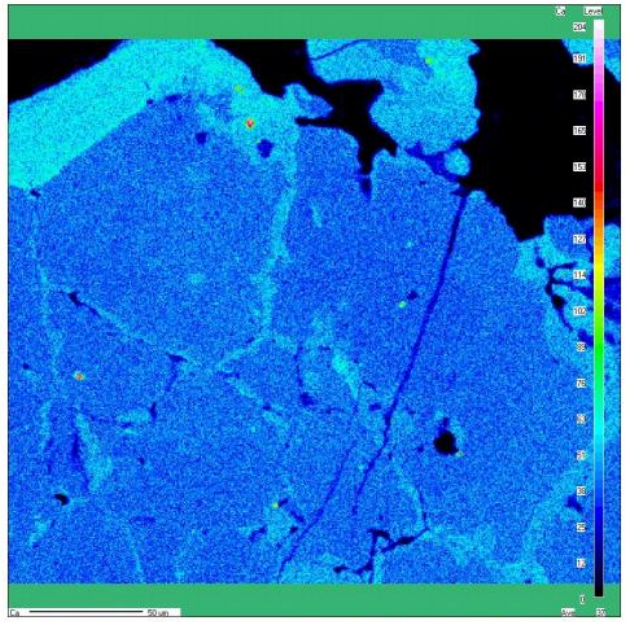

Figure 8c. Ca distribution in allanite, WDS quantitative.

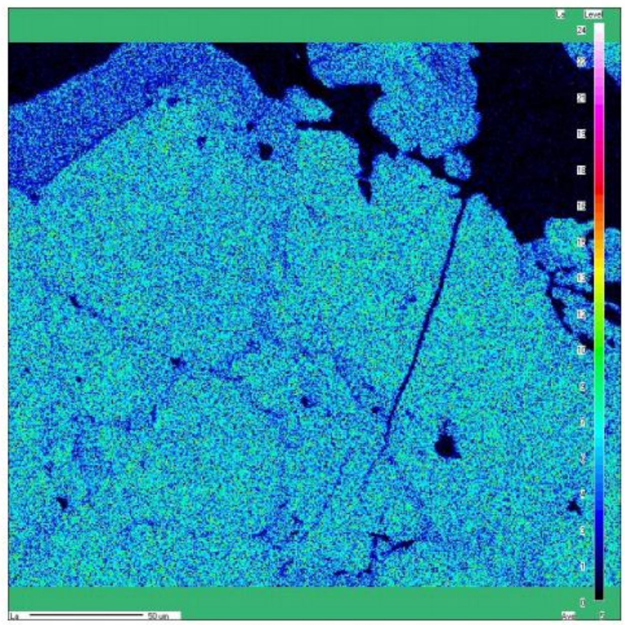

Figure 8d. La distribution in allanite, WDS quantitative.

The localization of bands attributed to SiO_2 stretching vibrations is shifted towards higher wave numbers for crystal point Viet-5-002. The main bands at this region occur at 1052, 1045, 971, 909, and 871 (Fig. 6). The bands coming from siloxane bending modes for Viet 5-002 crystal occur at 685, 597, 563, 455, 440, 432, 419, 383 and 351 cm^{-1} (Fig. 6) and are also sifted towards higher wavenumbers than for Viet-5- 001 crystal (Fig. 5). The position of these bands appears to vary depending of the type of cations in allanite-Ce structure. Distribution of major cations confirms position of both allanite faces (Fig. 8a, b, c, d). Based on mineralogical observations and absolute age dating, three mineral stages have been documented.

Two major are presented in Table 1. The third, last stage is composed of malachite, azurite, Fe-hydroxides and thiosulphates, and is developed in the oxidation zone. These minerals have been also recognized in the telling pond.

Table 1. Stages of mineral assemblage (partly after Ta Viet Dung et al. 1975 and McLean 2001).

Mineral	Skarn-Metasomatic stage	Hydrothermal stage **82-42 Ma**
Albite	——	
Biotite	——	
Hedenbergite	——	
Hessonite	——	
Hastingsite	——	
Hematite	------	
Quartz I	——	
Titanite	----	
Epidote	-------	
Rutile	----	
Ilmenite	----	
Allanite I	——	
Allanite II		——
Chlorite	--------	
Calcite	----------	----
Basnäsite [1]	-?	
Monazite [1]	--?	
Apatite	--	
Magnetite	——	
Uraninite I	——	
Uraninite II		—
Quartz II		--------
Pyrite	——	
Arsenopyrite	—	
Chalcopyrite I	——	
Chalcopyrite II		——
Cubanite	----	
Pyrrhotite	——	
Sphalerite	---	
Tennantite	--	
Molybdenite		--
Galena		--
Native gold		--
Bi-native		--
Bismuthinite		--
Tellurobismuthi		--

1) after Gaskov 2011; mineral in bold are described by the authors.

5 Conclusions

Three stages of ore mineralization have been documented in the deposit. Timing of two major stages was confirmed by absolute age determination using U–Pb–Th quantitative measurement. The skarn-metasomatic stage was developed in age range of 575-430 Ma, and the younger in the age range of 82-42 Ma. In the deposit two different minerals from the allanite group have been documented and contain different amounts of major ions like Ca, Al, Ce and La.

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