19. КОНГРЕС **ГЕОЛОГА СРБИЈЕ**

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Борско језеро 3 – 6. јун 2026.

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Напомена: Аутори су одговорни за садржај и квалитет својих саопштења, за припрему рада према дефинисаном упутству, као и за сва мишљења, тврдње и резултате објављене у њима. Издавач не преузима одговорност за ставове и мишљења изнета у радовима, нити их нужно дели. Превод на енглески језик извршили су сами аутори. Сви радови су рецензирани од стране чланова научног одбора или рецензената. Појединачни радови су објављени на језицима и писмима на којима су их аутори доставили приликом пријављивања.

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COMPOSITION OF SOME MAJOR MINERAL PHASES FROM THE IBERLI SCARN DEPOSIT, VARDAR ZONE, REPUBLIC OF NORTH MACEDONIA

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Keywords: Iberli; mineral phases; composition; scarn deposit.

ABSTARCT

The skarn deposit of Fe–Zn–Cu Iberli is located in the southern part of the Vardar Zone within the territory of the Republic of North Macedonia. The main development of hydrothermal ascending alterations and the skarn zone is related to the contact between granite and the marble mass.
The leading and most significant ore minerals are magnetite, hematite, maghemite, chalcopyrite, sphalerite, bismuthinite, and martite. As constant accompanying minerals, pyrite, hematite–martite, hematite–specularite, limonite, goethite, malachite, chalcocite, and others also occur. Most of these ore mineral phases were identified using a modern polarized optical microscope and a scanning electron microscope. The results of which are presented in detail within this study.
According to their quantitative representation and occurrence, among the ore components only the concentrations of magnetite, hematite, sphalerite, and chalcopyrite are considered significant.
For illustration, it should be emphasized that within magnetite increased contents of Al, Si, Mg, and Ti were determined (Al – 1.04–3.02%, Si – 2.64–4.29%, Mg – 4.00%, Ti – 0.52%). In hematite, increased contents of the following elements were identified: Al, Si, Mg, Ca, and Ti (Al – 1.04–3.02%, Si – 0.82–4.29%, Mg – 4.00%, Ti – 0.52%, Ca – 0.42%). In sphalerite, Fe contents of 1.35–1.96% were determined.

INTRODUCTION

The Iberli ore deposit is located 10 km northeast of Demir Kapija, measured as an air distance from this settlement. The Fe–Zn–Cu deposit Iberli, in geotectonic terms, belongs to the southern part of the Vardar Zone within the territory of the Republic of North Macedonia (*Figure 1*).

It is situated in the southwestern part of Gradeshka Mountain, east of the village Iberli, which is also the nearest settlement to the deposit. The altitude at which this deposit occurs ranges between 800 and 900 m, and the mineral occurrences extend in a NW–SE direction.

The length of the identified mineralization is about 1 km, while the hydrothermal alterations that follow the contact between granite and marble extend over a much greater distance, exceeding 4 km.

All research and investigations conducted so far have contributed to the creation of a professional and scientific database. Among these, we would like to highlight the work of Stojanov, R., (1960), Strachkov, M., and Hristov, S.,(1961), Ivanov, T., and Chulev, Gj., (1962, 1963, 1964), Ivanov, T., Ivanova, V., Denkovski, Gj., and Chulev Gj., (1965), Chulev Gj., and Hadji Petrushev, B., (1974), Bandilov, L., (1985), Bogoevski, K., Denkovski, Gj., and Bandilov, L., (1988, 1990), Gligorov., (1988), Cifliganec, V ., (1995), Shpritova, K., (2016), as well as Shpritova, K., and Spasovski, O.,(2016).

GEOLOGY

In the geological structure of the Iberli Deposit and its wider surroundings, three main rock complexes are present:

- Complex of metamorphic rocks
- Magmatic rocks
- Ascendant (hydrothermally) altered rocks

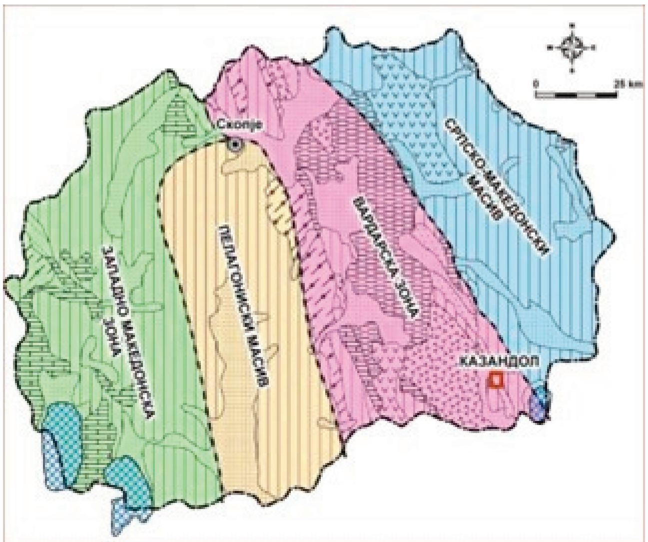

Figure 1. *Schematic representation of the geotectonic units in Republic of Macedonia*

Complex of metamorphic rocks – Within the metamorphic rock complex of the Iberli deposit the following rocks are represented: marbles, schists, sandstones, quartzites, mica schists, and gneisses. A large part of the immediate surroundings of the deposit is composed of magmatic rocks, among which the most common are granites and effusive rocks that occur as small vein-type bodies with limited extension and small thickness, usually appearing as intrusions within the granite itself. Among the effusive rocks, the following can be distinguished: granodiorite porphyries, keratophyres, and diabases.

Ascendant altered rocks – At the contact between granites and marbles, ascendant alterations are developed. These are characterized by the formation of skarns and skarnoids, as well as zones of silicification, chloritization, and opalization around the skarn zones. In the deeper parts of the skarns, ore mineralization is present, accompanied by magnetite, sphalerite, chalcopyrite, pyrite, and others.

Skarns – Among the skarns, endoskarns and exoskarns are distinguished. Endoskarns are relatively poorly developed, whereas exoskarns associated with marbles are much more developed. Endoskarns originate through the transformation of the magmatic rock and, besides minerals typical for skarns such as garnet and pyroxene, they also contain relics of the magmatic rock that are resistant to metasomatic processes, primarily zircon. Exoskarns are formed by the replacement of marble, where calcite has locally been replaced by pyroxenes, garnets, or a combination of pyroxenes and garnets, and in some cases vesuvianite is also preserved.

Skarnoids – Hydrothermal activity is superimposed on the skarns, during which the temperature decreases and minerals of lower temperature are formed at the expense of the original skarn minerals. These new minerals are formed as a result of the decomposition of the skarn minerals.

Rocks surrounding the skarns – By their origin, these rocks represent metasomatic rocks that accompany the skarns. Their composition includes calcite, quartz, feldspar, ore minerals, chlorite, epidote, apatite, and opalite, and in addition some skarn minerals such as vesuvianite may also occur.

METHODOLOGY

The complete ore-microscopic examination was carried out using a polarization microscope ZEISS Axiolab Pol equipped with a ZEISS MC 80 DX camera (Databack D4), as well as a LEICA DMP 4500 microscope equipped with a digital camera and the corresponding LEICA LAS software.

During the detailed microscopic observations, combinations of objectives with magnifications of 10×, 20×, 40×, 50×, and 63× were used, in combination with 10× eyepieces.

Chemical analyses for determining the composition of the mineral phases were performed using a scanning electron microscope (SEM – Scanning Electron Microscope) manufactured by TESCAN (Czech Republic), model VEGA 3 LMU, equipped with SE and EDS detectors, operating at an accelerating voltage of 20 kV and a high vacuum of 10^{-2}.

MORPHOLOGY OF ORE BODIES

According to its morphological characteristics, the Iberli Deposit is quite complex and occurs within an exposed contact zone characterized by an uneven footwall and hanging wall, as well as irregular thickness along the strike of the deposit (*Figure* 2).

The ore body extends over a length of approximately 200–250 m, while its thickness varies from a few meters up to 30 m. Toward the northwest (NW) and southeast (SE), the ore body gradually becomes poorer, so that overall it forms a larger lens-shaped body or stockwork.

The ore in the richer parts is compact and is composed mainly of magnetite with admixtures of pyrite, sphalerite, and chalcopyrite. In some places, rich sulfide ore bodies occur that are composed of pyrite, chalcopyrite, and sphalerite, with a smaller proportion of magnetite. In certain cases, the mineralized zone within the granite is represented only by pyritization.

The Iberli deposit belongs to ore bodies characterized by a gentle dip along the contact between two lithological environments, with dip angles ranging from 35°–46° and 48°–54° (*Figure 3*). The ore body represents a type of interlayered deposit with variable thickness, whose extension can be traced up to 1000 m and whose thickness ranges from 10–60 m. At the surface, the skarn zone has been traced over a length of approximately 900 m with a thickness of about 20 m.

The skarns exposed at the surface are characterized by oxidation processes, in which iron minerals are transformed into limonite, while Cu minerals are converted into copper hydrocarbonates—azurite and malachite.

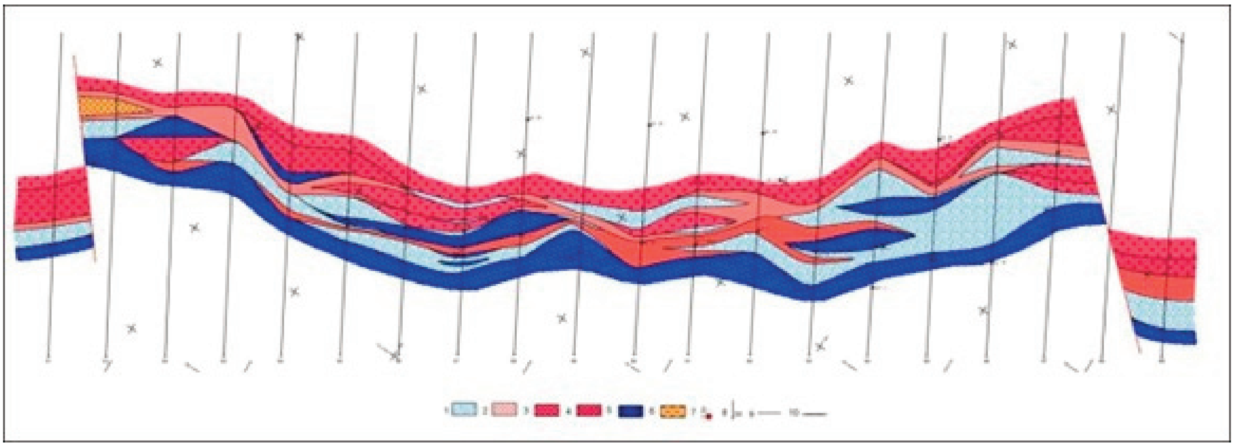

Figure 2. *Map of the level 700, Iberli deposit. 1.Skarnization zone, 2.Ore body, 3. Granite, 4.Hydrothermally altered granite, 5.Marbles, 6.Clayey material, 7.Exploration borehole, 8.Profile line, 9.Assumed contour of the ore body, 10.Probable contour of the ore body.*

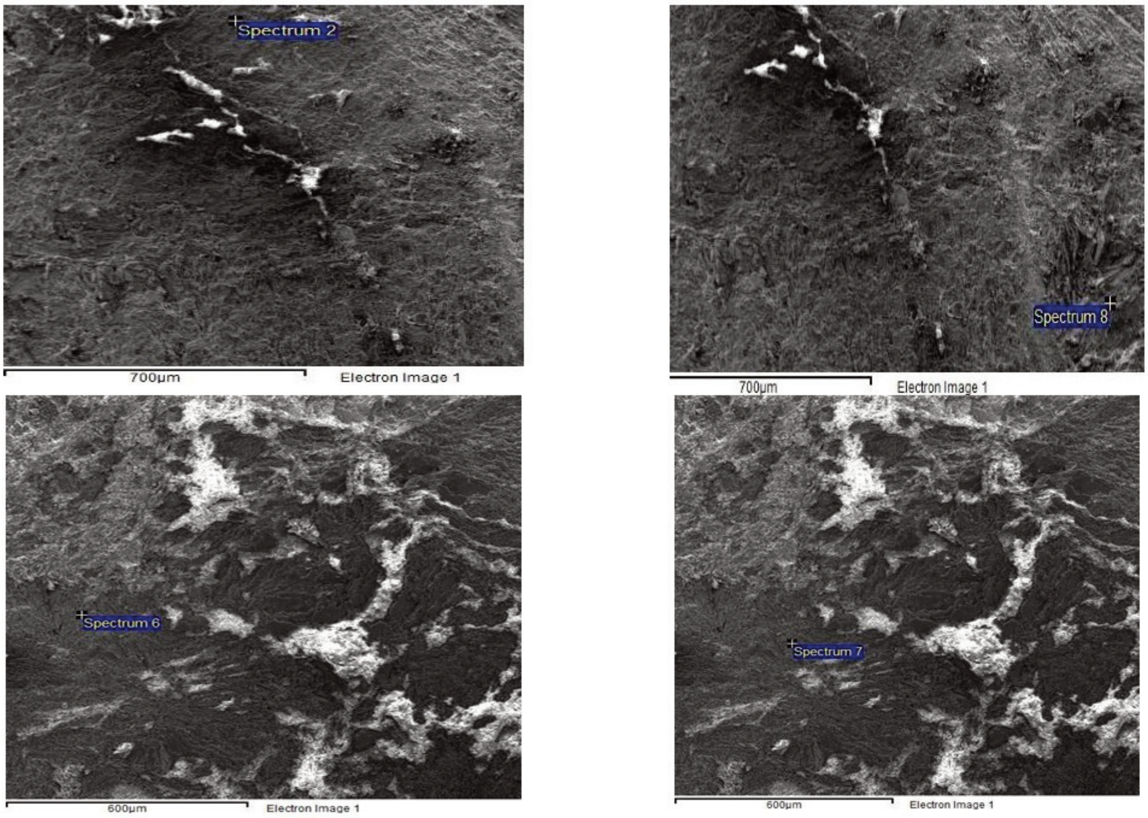

Figure 3. *SEM microphotograph of magnetite (a-analysis 1, b-analysis 2, c-analysis 3, d- analysis 4).*

COMPOSITION OF SOME MAJOR MINERAL PHASES

Also, we made efforts to confirm analytically some of the minerals present within the ore mineral association in the Iberli deposit. Our preliminary results have confirmed magnetite, hematite, sphalerite, chalcopyrite and pyrite compositions under the SEM-Scanning Electron microscopy at the Faculty of Natural and Technical Sciences, Goce Delčev University,

Some of the magnetite mineral grains, deter mined under the polarized optical microscope LEICA DMP 4500 equipped with digital still camera and complementary software LEICA LAS, have been analyzed under the SEM-Scanning Electron microscopy (*Figure 3*, (a-analysis 1, b-analysis 2, c- analysis 3, d- analysis 4)

The chemical composition of magnetite, as it is shown in Table 1, have shown slight discrepancies from the stoichiometric magnetite composition (Fe_3O_4) in standards.

Table 1. *Chemical composition of magnetite and hematite from the Iberli deposit*

Element	*Chemical analysis (%)*							
	magnetite				*hematite*			
	1	2	3	4	1	2	3	4
O	29.49	26.79	29.53	32.08	30.27	32.08	30.57	38.68
Fe	70.51	70.58	58.63	66.88	68.91	66.88	59.33	58.37
Mg	-	-	4.00	-	-	-	3.00	-
Al	-	-	3.02	1.04	-	1.04	2.15	2.53
Si	-	2.64	4.29	-	0.82	-	4.29	-
Ti	-	-	0.52	-	-	-	0.66	-
Ca	-	-	-	-	-	-	-	0.42
Σ	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

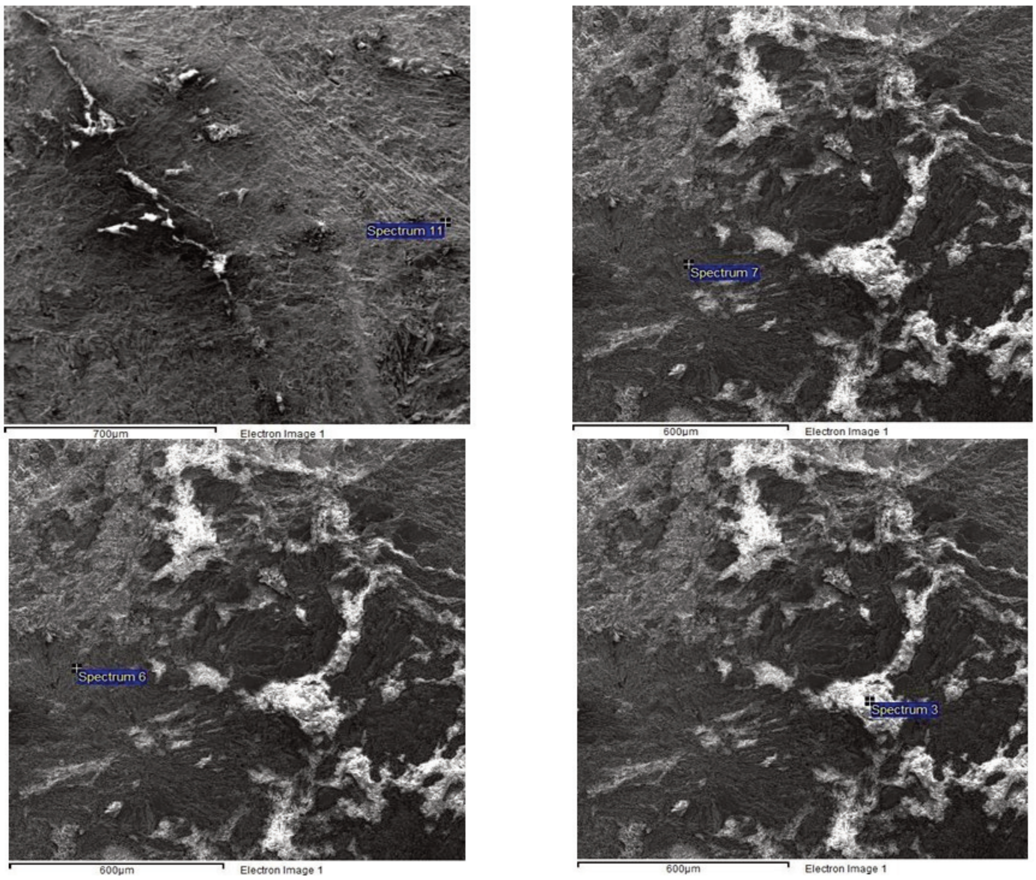

Figure 4. *SEM microphotograph of hematite (a-analysis 1, b-analysis 2, c-analysis 3, d- analysis 4)*

In contrast to samples 1, 2, and 3, sample 3 shows enrichment in impurity elements, specifically Mg (4.00%), Al (3.02%), Si (4.29%), and Ti (0.52%). The presence of impurity elements in some magnetite grains indicates phased formation of magnetite, that is, the isomorphic substitution of Fe by the impurity elements.

Although relatively scarce, hematite was de termined in several samples during the optical microscope study and SEM-Scanning Electron microscopy (*Figure 3*). Microscopic observa tions in regards to occurrence of hematite in samples from the Iberli deposit in the best manner were confirmed by electron microprobe analyses (Table 1).

Based on the data presented in Table 1, it can be observed that hematite has a relatively uniform chemical composition, reflected in Fe contents ranging from 66.88% to 68.91% (analyses 1 and 2). As impurities, it contains very small amounts of Si (0.82%) and Al (1.04%).

The data presented in the same table (analyses 3 and 4) indicate that the impurity elements are not present in significant concentrations, with values of Al ranging from 2.15% to 2.53%, Mg around 3.00%, Si up to 4.29%, Ti about 0.66%, and Ca about 0.42%.

Also, our study included the most common ore mineral within the Iberli deposit, pyrite (*Figure 5*). The analysis of the most common within the Iberli deposit, pyrite, in general have shown close to the standard values (Table 2).

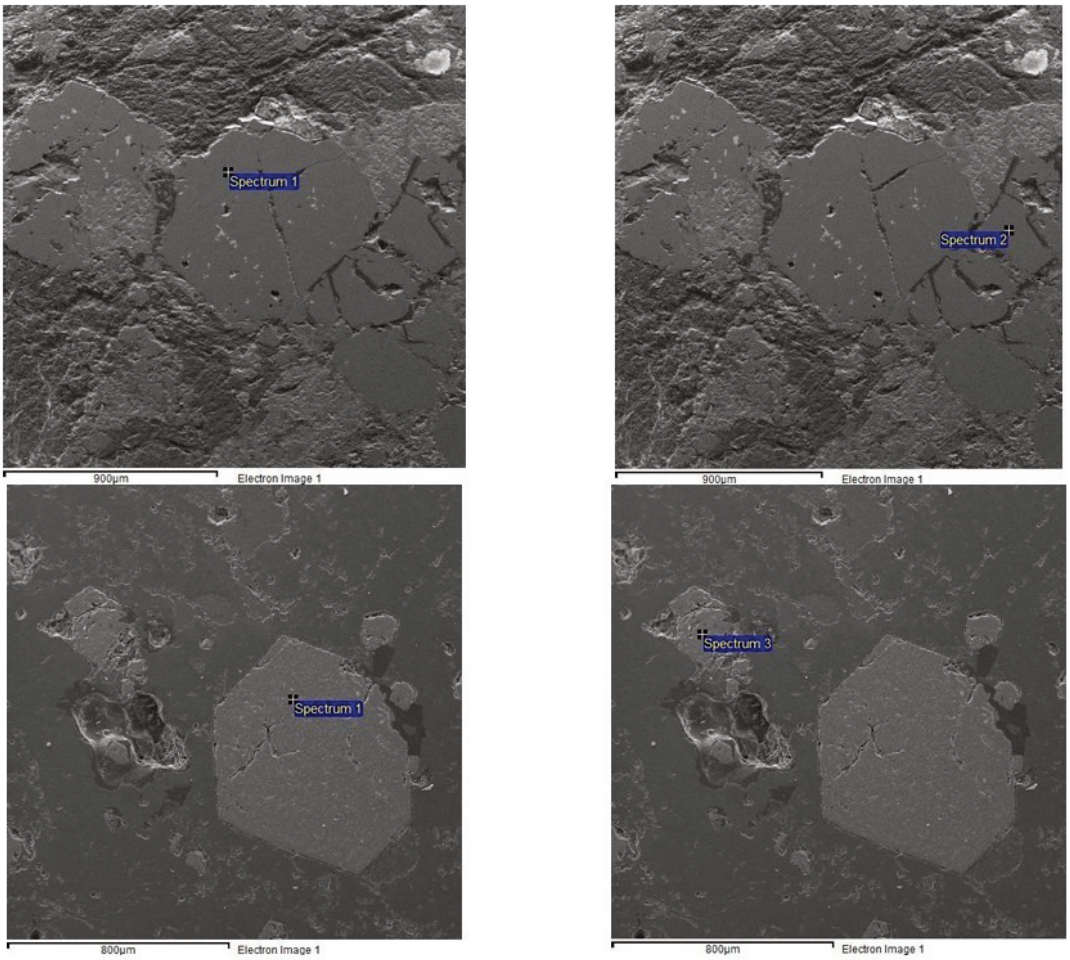

Figure 5. *SEM microphotograph of pyrite (a-analysis 1, b-analysis 2, c-analysis 3, d- analysis 4)*

Based on the data presented in Table 2, it is evident that the mineral is sphalerite with a relatively uniform chemical composition (67.62% to 68.04% Zn), with values very close to the theoretical ones (Chvileva et al., 1988). As an impurity element, Fe is present in concentrations ranging from 1.35% to 1.96%.

The provided data for chalcopyrite (Table 2) indicate values that are also very close to the theoretical ones (Chvileva et al., 1988).

Table 2. *Chemical composition of pyrite, sphalerite and chalcopyrite from the Iberli deposit.*

Element	Chemical analysis (%)							
	pyrite				sphalerite		chalcopyrite	
	1	2	3	3	1	2	1	2
S	61.87	64.66	53.56	52.88	29.53	30.00	32.89	35.94
Fe	38.13	35.34	46.44	47.12	1.35	1.96	31.11	29.08
Zn	-	-	-	-	69.12	68.04	-	-
Cu	-	-	-	-	-	-	36.00	34.98
Σ	Σ	100.00	100.00	100.00	100.00	100.00	100.00	100.00

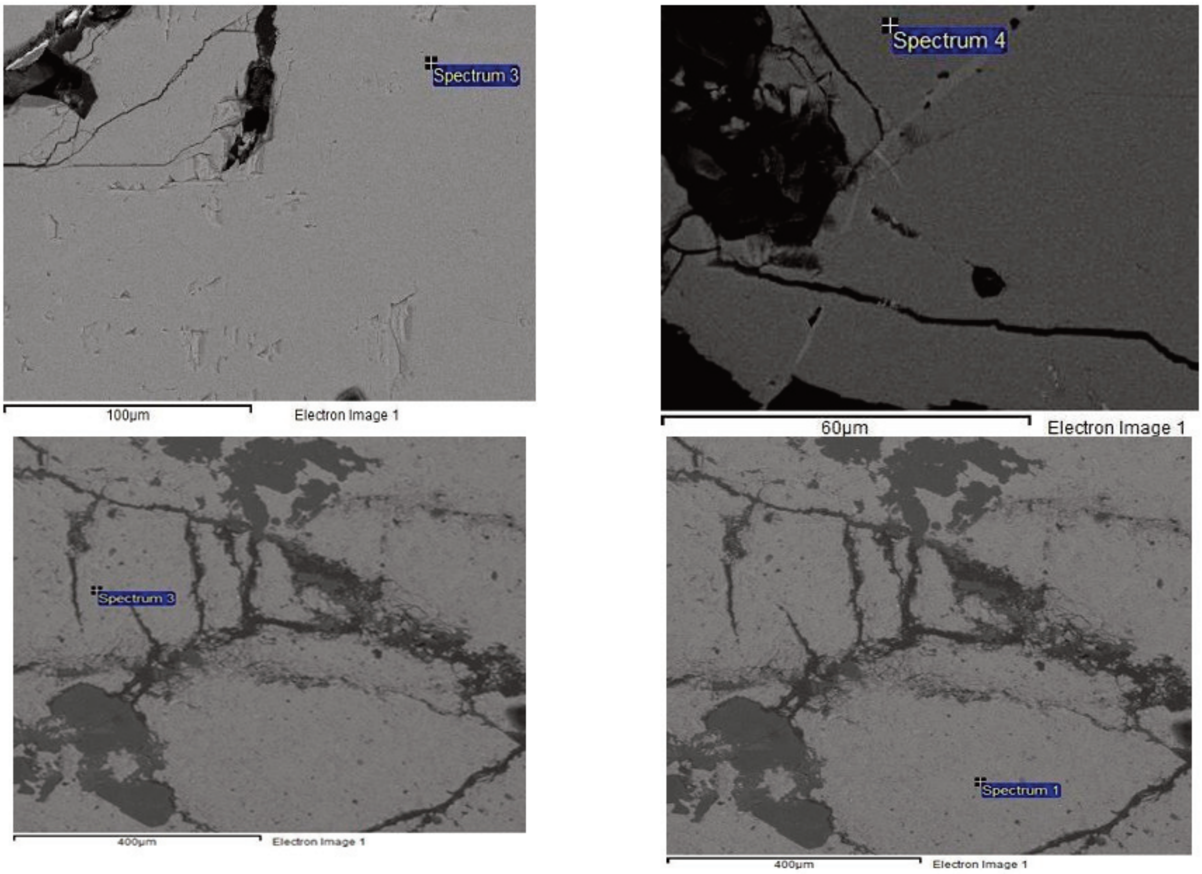

Figure 6. *SEM microphotograph of sphalerite and chalcopyrite (a-analysis 1 sphalerite, b-analysis 2 sphalerite, c-analysis 1 chalcopyrite, d- analysis 2 chalcopyrite)*

CONCLUSION

The Fe, Zn, and Cu ores from the Iberli Deposit are complex in terms of their mineral composition, but the main minerals in the association are magnetite, hematite, sphalerite, and chalcopyrite, regularly accompanied by martite, pyrite, bismuthinite, malachite, chalcocite, epidote, and garnet.

The deposit was formed under tectonically highly unstable conditions, which is reflected in the deposition of each successive mineral, corresponding to previous reactivations of the fault on which the deposit is located.

During the hydrothermal stage, a sequence of minerals is formed, initially at very high temperatures, leading to the formation of magnetite and the segregation of chalcopyrite within sphalerite. This stage concludes with the formation of low-temperature minerals such as antimonite.

Overall, the deposit appears to have been formed under high-temperature conditions, likely corresponding to hydrothermal environments associated with the formation of skarn minerals.

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