Epithermal Pb-Zn-Cu (Ag-Au) Mineralization at İnler Yaylası Deposits (Şebinkarahisar, Giresun)

Fatih Kamburoğlu[1], Ayşe Orhan[2], Ahmet Orhan[2]

[1] Graduate School of Science and Engineering, Nevsehir Haci Bektas Veli University, Nevsehir, TÜRKİYE

[2]Department of Geological Engineering, Nevsehir Haci Bektas Veli University, Nevsehir, TÜRKİYE

Corresponding author: Ayşe Orhan (e-mail: ayse.orhan@nevsehir.edu.tr).

Submitted on 28.02.2023, Revised on 28.03.2023, Accepted on 04.04.2023, Published online on 14.07.2023

ABSTRACT İnler Yaylası Pb-Zn-Cu (Ag-Au) deposits are located approximately 23 km northwest of Şebinkarahisar (Giresun). Mineralization is developed as veins and disseminated types along of the NE-SW trending fractures in the Late Cretaceous volcanic rocks. Propylitization, sericitization and silicification are developed in the wall rock. Three main stages of mineralization have been defined as pre-ore, main sulfide and supergene. In the first stage, hematite, chlorite and epidote developed. Sericitization and silicification are associated with the sulfide phase. Quartz is in the form of mosaic-textured and filling open-space vein with a crustiform and comb-textured. The textural features show that the main sulfide phase develops in two sub-phases. First sub-phase composed of sphalerite, galena, pyrite and less abundant chalcopyrite, Ag-sulfosalts and Pb-sulfosalts. The second sub-phase consist of pyrite, chalcopyrite, sphalerite, galena, and less abundant Ag-sulfosalts and gold. Supergene stages are characterized by bornite, covellite, malachite, azurite, smithsonite, limonite, calcite, and chalcedony. In the İnler Yaylası, base and precious metal element contents are between 631 and >150.000 ppm for Zn, 637 and 48.875 ppm for Pb, 132 and >150.000 ppm for Cu, 3 and 2564 ppm for As, 20 and 344 ppm for Ag, 0.1 and 1.6 ppm for Au, 0.5 and 413 ppm for Sb. The Ag:Au ratio ranges from 39:1 to 1721:1. Strong positive and negative correlation confidents between Pb–Zn (R^2=0.70), Au–Cu (R^2=0.83) and Pb–Cu (R^2=-0.91), Zn–Cu (R^2=-0.60) manifest that Pb–Zn and Cu–Au mineralization in the region is related to the different sub-phase. The strong correlation confidence between Ag–Sb are (R^2=0.78) associated with Ag-rich sulfosalt. Mineral assemblage and geochemical properties indicate that İnler Yaylası deposit typically characterize an intermediate-sulfidation epithermal type deposit.

KEYWORDS Epithermal, İnler Yaylası, Giresun, geochemistry, mineralogy, Pb-Zn-Cu (Ag-Au) mineralization

1. INTRODUCTION

Following the subduction of the Neo-Tethys Ocean under the Eurasian continent, several magmatic episodes developed in the Pontides between Late Cretaceous and Middle Eocene [1, 2, 3, 4, 5, 6]. In the eastern Pontides, many different types of ore deposits such as volcanogenic massive sulfide (VMS), porphyry, skarn and epithermal type mineralizations developed depending on the changing magma character and the geodynamic evolution of the region [5, 7, 8, 9] (Fig. 1). İnler Yaylası (Şebinkarahisar) Pb-Zn-Cu (Ag-Au) mineralization, which is the subject of this study, is in the eastern Pontides (Fig. 1).

Şebinkarahisar region is an important mining area where Pb and Zn have been produced. Some of the ore veins in the region were mined in the past and still have important ore zones that are still being exploited. In this region, only Pb-Zn mining was operated in many localities and galleries at different levels. The genetic characteristics of the mineralization were investigated in many studies [10, 11, 12, 13, 14, 15, 16]. In these studies, primary ore minerals such as sphalerite, galena, pyrite, chalcopyrite, fahlerz, enargite and hematite; gang minerals such as quartz, calcite and barite were determined. Silicification, chloritization, sericitization, carbonation, argillization and epidote identified as the wall rock alteration products. In the İnler Pb-Zn-Cu (Ag-Au) deposit, the average grade at 1725 m and 1803 m levels was 8% for Pb, 10.2% for Zn and 2.4% for Cu [13]. Ag grade varies between 40 and 90 ppm. According to the homogenization temperature values (Th=150–290°C and Th=138–313°C), the deposit was classified as epithermal and hydrothermal type mineralization [10, 15]. As a result of fluid inclusions and stable isotope studies carried out at 1725 m and 1803 m levels, it was determined that the mineralization developed with magmatic fluids mixed with meteoric fluids [15]. In the light of these data, it had been suggested that hydrothermal fluids from Paleocene granitoids probably caused host rock alteration and ore deposition [10, 15]. These studies did not perform geochemical analysis for the other precious metal content from ore samples. In the İnler Yaylası, Pb-Zn extraction has been in progress between 1665 m and 1725 m levels by the Nesko Mining Incorporated Company (NMIC). It has been determined that the grade of the ore varies between 1–16% Pb and 2–20% Zn (explanation of NMIC). There has been no detailed mineralogic, petrographic, and geochemical study at these levels. The aim of this study is to provide insights on the type of hydrothermal deposit and the exploration for other precious metals in the region. To achieve this aim, detailed mineralogical-petrological descriptions of ore and alteration mineral assemblages and ore geochemistry analysis results are presented.

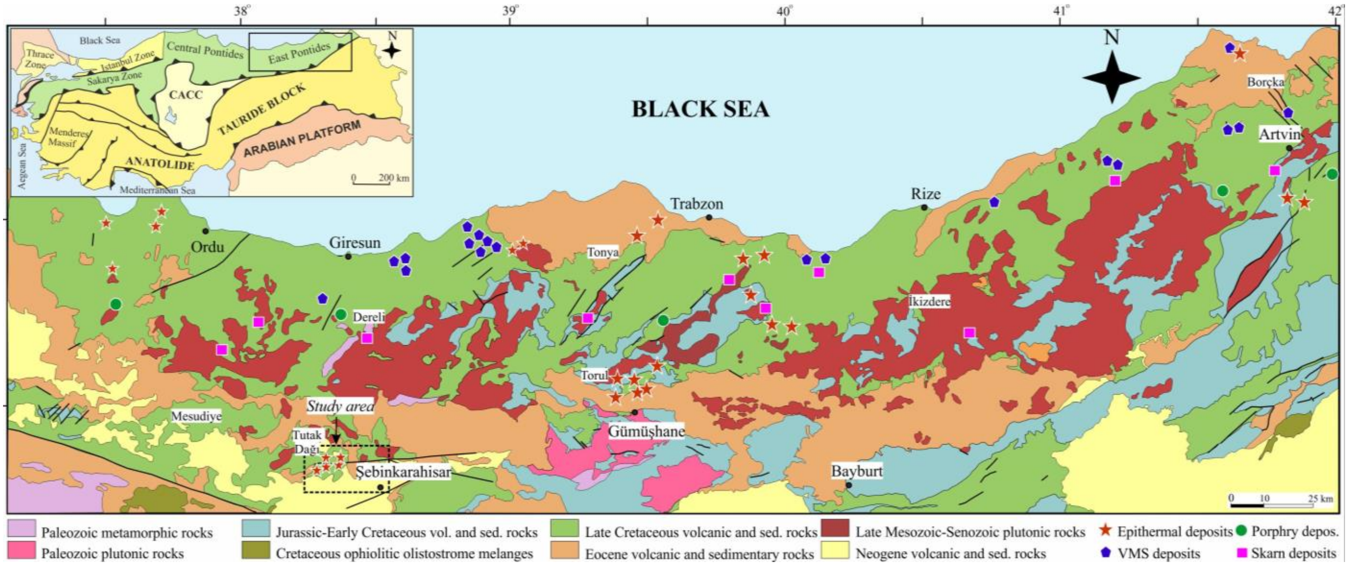

Figure 1. Simplified geological map of the eastern Pontides and distributions various ore deposits associated with Cretaceous–Eocene magmatism (geology map after 1/500.000-scale prepared by the MTA [17]; deposits are taken from [8]; tectonic map of Türkiye is taken from [18])

2. REGIONAL GEOLOGY

In Türkiye, six tectonic units were defined as Thrace Zone, Istanbul Zone, Sakarya Zone, Central Anatolia Crystallen Complex, Anatolide-Tauride Blok and Arabian Platform [18] (Fig. 1). The eastern Pontides, in which the study area is located, are tectono-stratigraphically located to the eastern of the Sakarya Zone [19]. In the region, Paleozoic metamorphic and granitic rocks, Mesozoic-Cenozoic plutonic, volcanic, volcano-sedimentary and sedimentary rocks crop out (Fig. 1).

Paleozoic metamorphic and granitic rocks form the basement of the eastern Pontides [20]. These rocks started to rift under the extensional tectonic regime in the early Liassic after the erosion process [21]. Volcano-sedimentary units were formed from sedimentary rocks accompanied by volcanic products due to rifting in the Liassic period [22]. Shallow marine limestones were deposited on these units conformably [23]. As a result of the active magmatism that developed in the region during the Late Cretaceous and Eocene period, a thick volcano-sedimentary sequence formed by the bimodal volcanic rocks. The volcanic rocks in the region are arc volcanics developed due to the northward subduction of the Neo-Tethys Oceanic crust [1]. The Late Cretaceous volcanism is completely submarine and hosts many VMS, Pb-Zn-Cu, porphyry Mo-Cu, Fe-(Cu) skarn and epithermal Pb-Zn±Au type mineralizations [5, 7, 8, 9]. Eocene volcanism is related to regional extension and hosts epithermal Pb-Zn±Au and Fe-skarn mineralizations [8, 24]. Volcanic units are cut by the younger granitic masses [5]. According to the petrogenesis studies, the age of this granitoid is Late Cretaceous [3, 4] and Middle Eocene [3, 6]. These granitoids composition change from a medium potassium calc-alkaline to a high potassium calc-alkaline character [2, 3].

3. GEOLOGY OF THE İNLER YAYLASI Pb-Zn-Cu (Au-Ag) DEPOSITS

İnler Yaylası Pb-Zn-Cu (Ag-Au) deposits are located approximately 23 km northwest of Şebinkarahisar (Giresun) (Fig. 1). In the study area, the Late Cretaceous felsic volcanic and marine carbonate rocks, Paleocene granitic rocks, Eocene bimodal volcanic rocks and Plio-Quaternary basaltic volcanic rocks are exposed from the oldest to the youngest (Fig. 2). The field and mineralogical features of the Late Cretaceous volcanic rocks, hosting the mineralization, are presented in detail below.

The Late Cretaceous volcanic rocks, which forms the basement of the study area, is widely distributed in Sübak, Dereköy, Kuzuluk, Maden Tepe and İnler Yaylası (Fig. 2). Volcanic rocks are represented by dacite and trachyandesite composition and their tuff, pyroclastic rocks [16]. NE–SW and E–W trending fractures well developed in the volcanic rocks (Figs. 2 and 3).

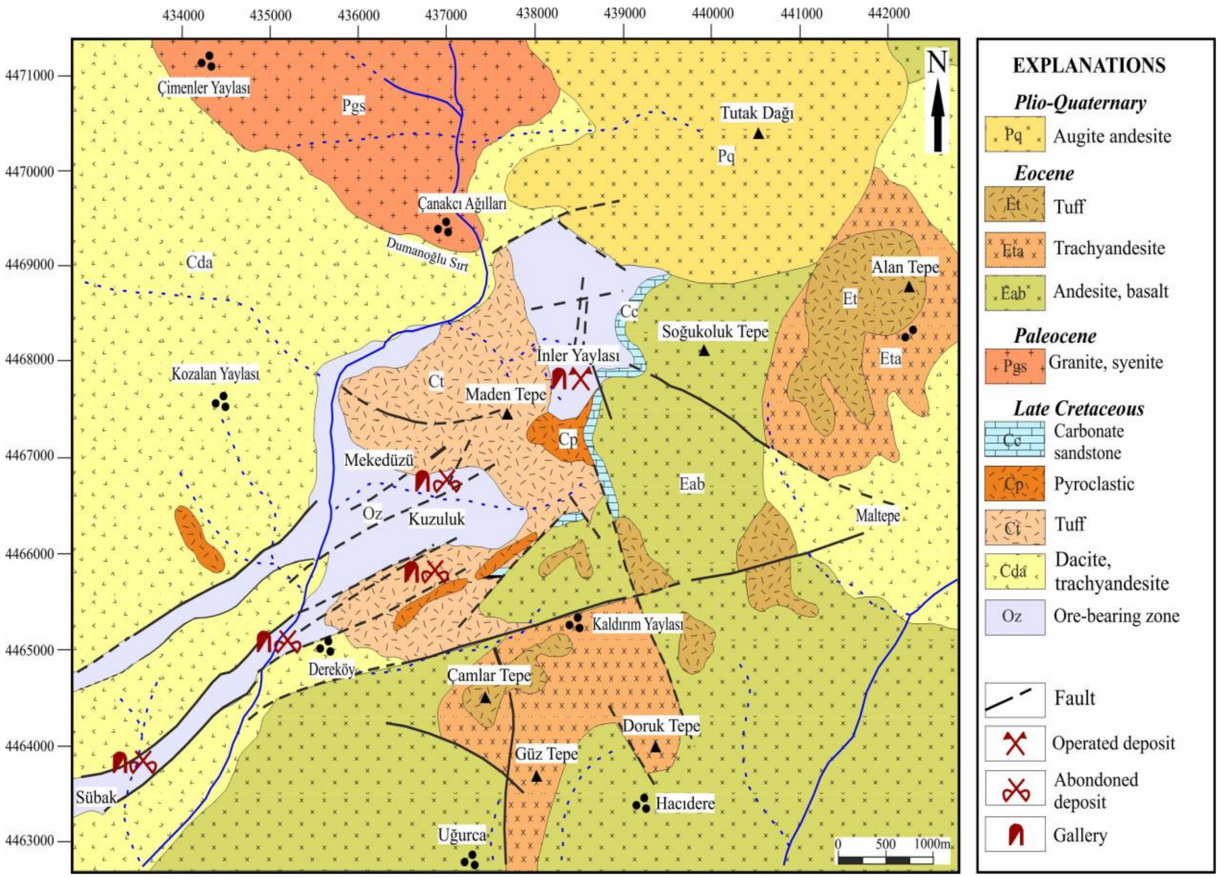

Figure 2. Geological map of the study area [13]

The Late Cretaceous volcanic rocks are observed in yellow, pink, green, gray and white colors (Fig. 3a, c). They have been commonly altered. Microscopically, the rock has a porphyritic hypocrystalline texture (Fig. 3b). It contains quartz, plagioclase, feldspar, biotite, amphibole and opaque minerals as phenocrysts. The groundmass consists of quartz and feldspar microliths. Mostly silicification and sericitization and less chlorite, epidote and hematite alterations were developed. Plagioclases are in oligoclase composition. The rock is frequently cut by quartz veins. Tuffs are commonly composed of vitric grains (pumice) and less crystal (quartz, feldspar, biotite, amphibole, opaque) and lithic fragments (< 5%) (Fig. 3d). Silicification, sericitization and chloritization developed as secondary products.

In the study area, Pb-Zn-Cu (Au-Ag) mineralization in represents NE–SW trending. The inclinations of the ore veins are 45°–85°. The veins were cut and deferred by NW-SE trending faults.

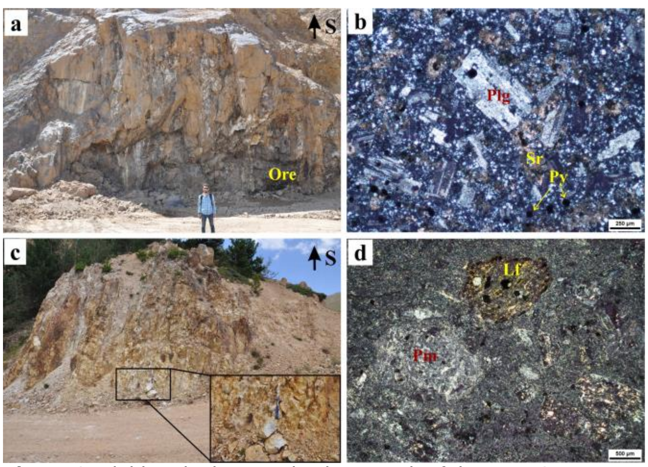

Figure 3. Field and microscopic photograph of the Late Cretaceous (a–b) dacite, and (c–d) tuff (a, c; + Nicol) (Lf; lithic fragment; Plg; plagioclase, Pm; pumice, Sr; sericite)

4. MATERIAL and METHODS

Sampling was made from the NMIC operating area for textural and mineralogical determinations and geochemical analysis of the İnler Yaylası Pb-Zn-Cu

(Ag-Au) deposits. A total of 78 samples were taken from the surface, galleries and drilling core samples in order to determine the ore minerals and host rock. The Pb-Zn-Cu (Ag-Au) mineralization in the study area consists of six ore-bearing zones from north to south as Mortaş, Northern, 1, Copper, 2 and 4. Mineral paragenesis and textural properties of wall rock alteration and mineralization were determined by mineralogical-petrographic analysis carried out on samples taken from these zones. The samplings were made the base and roof rocks from the east, middle and west sections of 6 different zones in these galleries at 1665 m and 1725 m levels. Geochemistry analyses for the base and precious metals were conducted on 9 samples.

Thin and polish sections were made at the Earth Science Applications and Research Center, Ankara University. The mineral content and textural characteristics of the mineralization, host rock and wall rock alteration were determined using Nikon 50iPOL polarize and reflect at microscopy at the Geological Engineering Laboratories, Nevşehir Hacı Bektaş Veli University. Microphotographs were taken with a 5 Megapixel Nikon digital camera system connected to the same microscope. Geochemistry analysis were carried out using an Thermo X SERIES II ICP-MS device at the General Directorate of Mineral Research and Exploration Laboratories.

5. ANALYTICAL RESULTS

5.1. Wall Rock Alteration

According to mineral paragenesis and abundance, three alteration types were determined as propylitic, sericitization and silicification alteration.

Propylitic alteration is the pre-ore alteration phase in the İnler Yaylası Pb-Zn-Cu (Ag-Au) mineralization (Fig. 4). The alteration consists of chlorite, epidote and hematite (Fig. 5a–b). Chlorite and epidote developed as a replacement product of ferromagnesian minerals such as amphibole and biotite. Hematite is observed in specular texture. Silica alteration in the İnler Yaylası is associated with mineralization (Fig. 4). Silicification in ore body is in the form of diffuse replacement and veins/veinlets (Fig. 5c–h). The alteration is mainly characterized by sericite, quartz and sulfide minerals (Fig. 5c–h). Illite and barite are less abundant. Sericite had developed as alteration products of plagioclase. Quartz is in the form of fine-grained with a mosaic-textured (Q-I) and filling open-space vein with a crustiform and comb-textured (Q-II). Barite is accompanied with coarse-grained quartz (Q-II) at the surface.

Limonite commonly and less chalcedony and calcite have been formed as a supergene product in the İnler Yaylası deposit (Fig. 4). Chalcedony filled fractures and vugs among the illite. (Fig. 5i). Calcite cut the alteration zone and it is present in roof rocks. (Fig. 5e).

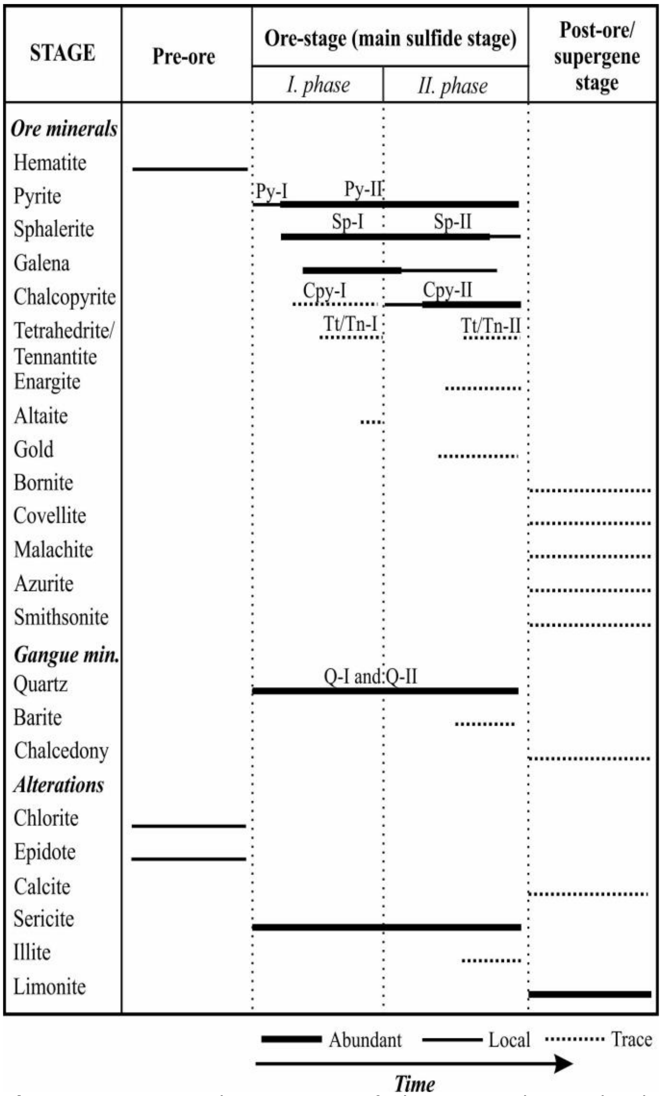

Figure 4. Paragenetic sequence of the ore and associated alteration minerals in the İnler Yaylası Pb-Zn-Cu (Ag-Au) deposit

5.2. Paragenesis of Mineralization

In the İnler Yaylası deposit, the mineralization was developed as disseminated and open-space filling veins (Figs. 5c, f–h and 6a–c). The predominant sulfide minerals in the region are sphalerite, galena, pyrite, chalcopyrite and with smaller amounts of gold, Pb- and Ag-sulfates (e.g., altaite, tetrahedrite-tennantite and enargite) (Fig. 4). Cataclastic, exsolution and substitution textures were developed in ore minerals (Figs. 7 and 8). Three main stages of mineralization have been defined as pre-ore, main sulfide and supergene (Fig. 4). According to the textural properties of the ore minerals, two sub-phases were defined for the main sulfide phase (Fig.

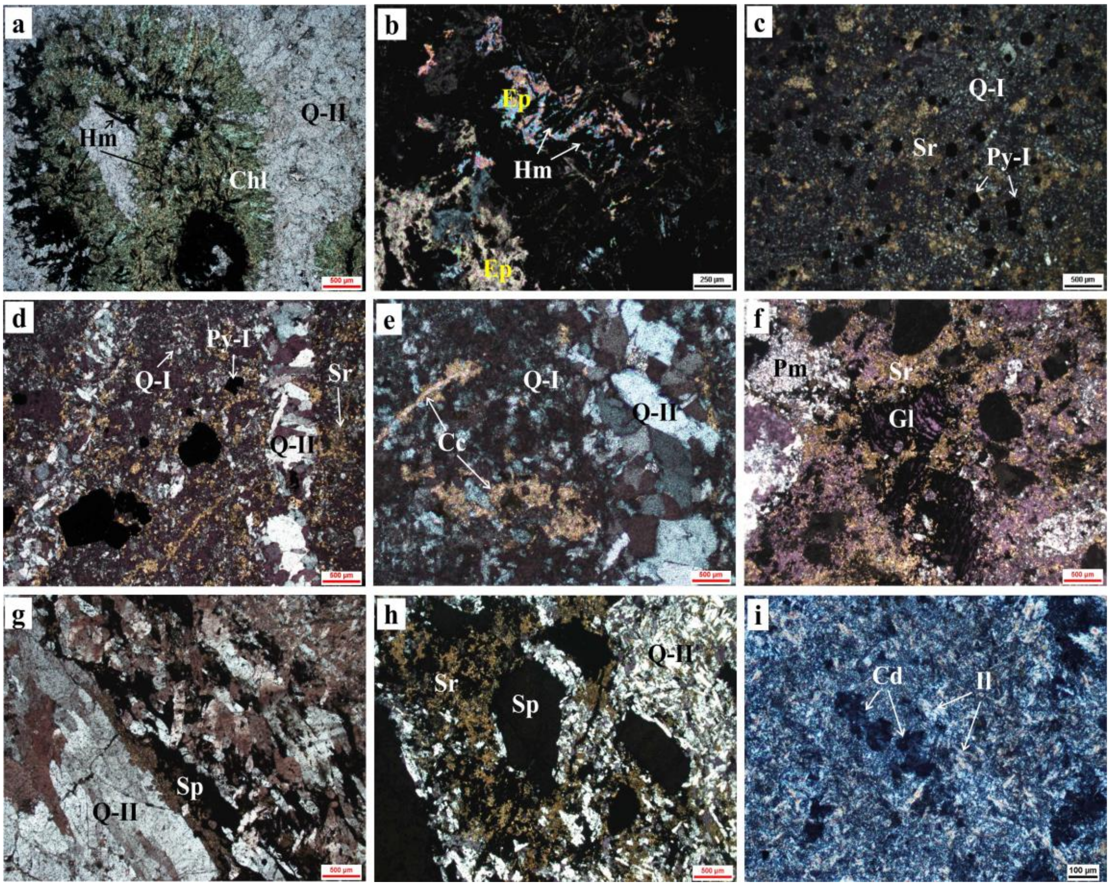

Figure 5. Photomicrographs of the mineral assemblages and their textural properties in the **(a–b)** propylitic alteration, **(c–i)** silisic alteration (Chl; cholorite, Ep; epidote, Cc; calcite, Cd; chalcedony, Gl; galena, Hm; hematite, Il; Illite, Q-I; sugar-textured quartz, Q-II; coarse-grained and comb-textured quartz, Pm; pumice, Py; pyrite, Sp; sphalerite, Sr; sericite) (a–i; +N)

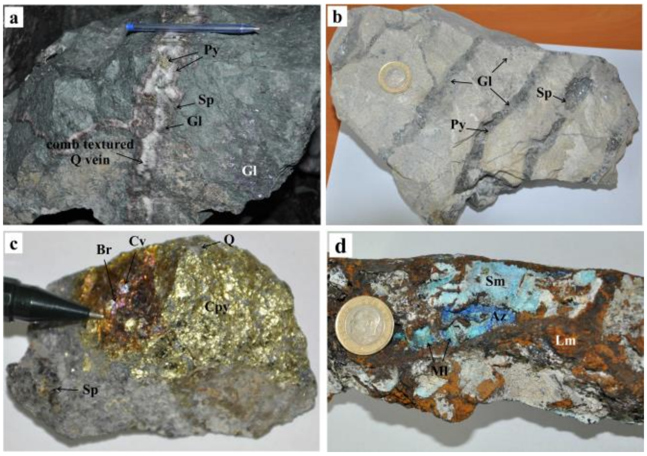

Figure 6. Field view of **(a–c)** disseminated and vein type mineralization, and **(d)** supergene minerals in the İnler Yaylası deposit (Az; azurite, Br; bornite, Cpy; chalcopyrite, Cv; covellite, Gl; galena, Lm; limonite, Ml; malachite, Py: pyrite, Sm; smithsonite, Sp; sphalerite, Q; quartz)

4). While cataclastic and exsolution textures are dominant in the first sub-phase, replacement texture developed in the second sub-phase (Figs. 7 and 8).

Two types of sphalerites are observed in the İnler Yaylası deposit. In the first phase, sphalerite (Sp-I) is mostly observed in coarse-grained with cataclastic textured (Fig. 7b–c). Chalcopyrite (Cpy-I) blebs were commonly formed in the Sp-I. In the second phase, sphalerite (Sp-II) is mostly in the form of inclusions in pyrite together with chalcopyrite (Fig. 8b–c).

Pyrite developed in two forms. Fine-grained euhedral pyrites (Py-I) are observed as disseminated in silica alteration (Fig. 5c–d). Py-II is subhedral-anhedral and coarse-grained cataclastic textured and inclusion-rich pitted pyrite (Figs. 7c–d and 8a–c). It is observed that hematite replaced by anhedral pyrite (Py-II) (Fig. 7a). It can be said that Py-II formed after hematite. Py-II presents colloform texture in some samples from the copper zone (Fig. 8c).

Galena is anhedral coarse-grained. It mostly filled fractures of Sp-I and Py-II. It is probably formed after these minerals. In the first-phase, galena contains Cpy-II, tetraedrite and altaite inclusions. Cpy-II is anhedral and formed by substitute the minerals before

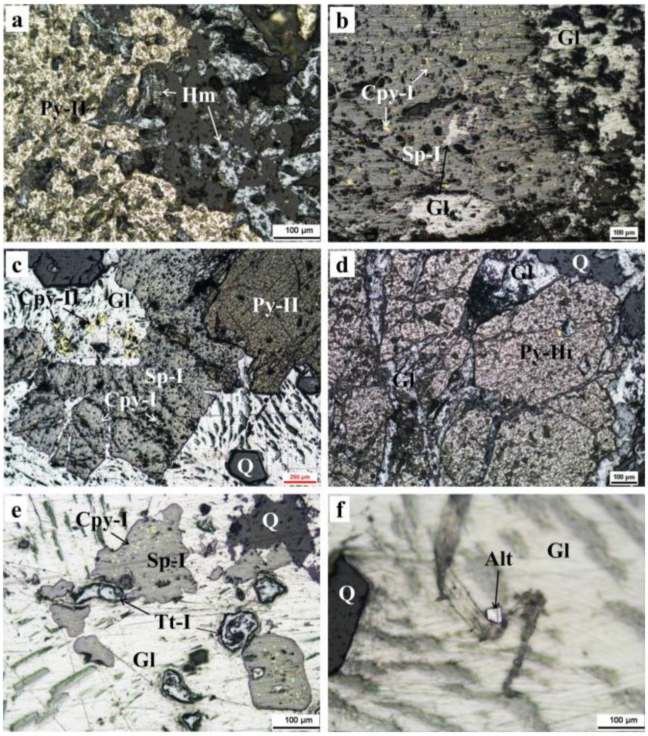

Figure 7. Photomicrographs of the ore mineral assemblages and their textural properties for the first-substage in the İnler Yaylası mineralization (Alt; altaite, Cpy; chalcopyrite, Gl; galena, Py; pyrite, Sp; sphalerite, Q; quartz; Tt; tetrahedrite)

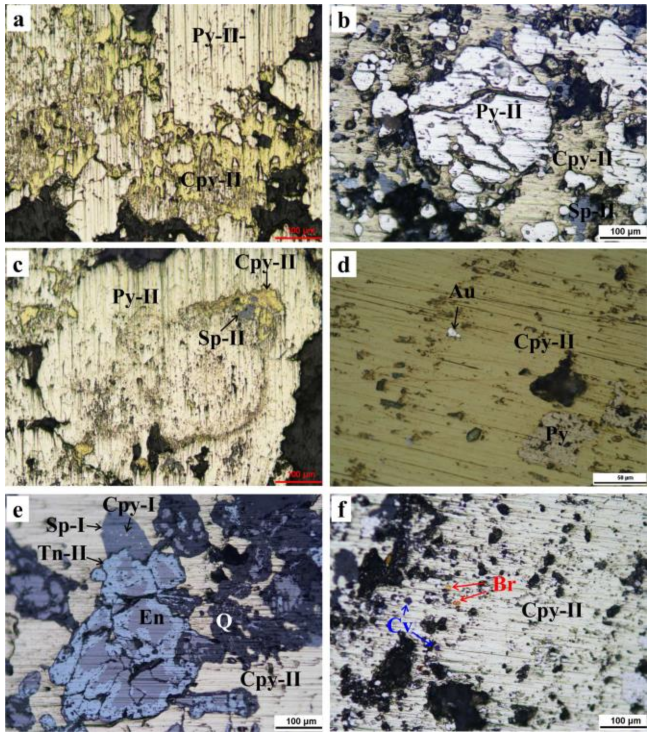

Figure 8. Photomicrographs of the ore mineral assemblages and their textural properties for the second-substage in the İnler Yaylası mineralization (Au; gold, Br; bornite, Cpy; chalcopyrite, Cv; covellite, En; enargite, Py; pyrite, Sp; sphalerite, Q; quartz; Tt; tetrahedrite)

it. Pyrite-II was commonly replaced by Cpy-II along its fractures and pores (Fig. 8a–c). It can be said that Cpy-II formed after sphalerite, galena and Py-II. In the second sub-phase, Cpy-II contains enargite, tennantite and gold inclusions (Fig. 8d–e).

Post-ore stage is characterized by supergene products derived from the oxidation of primary ore minerals. This mineral assemblage in this stage was hematite, limonite, bornite, covellite, malachite, azurite and smithsonite (Figs. 6d and 8f).

5.3 Ore Geochemistry

The results of geochemistry analysis of base and precious elements of 9 ore samples are presented in Table 1. Base and precious element contes are between 631 and >150.000 ppm for Zn, 637 and 48.875 ppm for Pb, 132 and >150.000 ppm for Cu, 3 and 2564 ppm for As, 20 and 344 ppm for Ag, 0.1 and 1.6 ppm for Au, 5 and 138 ppm for Bi, 0.5 and 413 ppm for Sb. The highest Pb and Zn values were found mostly in the samples taken from the northern zones. The highest Cu and Au values are in Mortaş, Copper and Zone 4 in the regions taken from the north and south. Ag exhibits enrichment in all zones. Ag:Au ratio ranges from 39:1 to 1721:1 (Table 1).

In the İnler Yaylası deposit, there is a positive correlation between Pb and Zn (R^2=0.70) (Table 2; Fig. 9a), Sb and Ag (R^2=0.78) (Table 2; Fig. 9f), Cu and Au (R^2=0.83) (Table 2; Fig. 9g), Au and Bi (R^2=0.83) (Table 2; Fig. 9h) and Cu and Bi (R^2=0.76) (Table 2; Fig. 9i). There is a negative correlation between Pb and Cu (R^2=-0.91) (Table 2; Figs. 9b) and Zn and Cu (R^2=-0.60) (Table 2; Fig. 9c). There is no correlation between Ag and Pb and between Ag and Zn (Table 2; Fig. 9d–e).

6. DISCUSSION and CONCLUSION

İnler Yaylası Pb-Zn-Cu (Ag-Au) mineralization is a typical epithermal deposit as described [25, 26, 27]. Typical features showing the epithermal deposit; (1) advanced wall-rock alteration such as propylitization, sericitization and silification (Fig. 5), (2) mineralization in the form of disseminated, and replacement ore texture with open-space-filling veins (Figs. 5d, g–h and 6a–c), (3) open-space-filling crustform and comb-textured quartz (Figs. 5g–h and 6a), (4) the ore minerals are predominantly pyrite, sphalerite, galena, chalcopyrite and less abundant gold and Pb- and Ag-sulfates (altaite, tennantite-tetrahedrite) (Figs. 4; 7; and 8).

Table 1
Geochemical analysis results of base and precious metal elements in the ore samples

Zone	*Samp. no*	*Ag (ppm)*	*As (ppm)*	*Bi (ppm)*	*Co (ppm)*	*Cu (ppm)*	*Mo (ppm)*	*Ni (ppm)*	*Pb (ppm)*	*Sb (ppm)*	*V (ppm)*	*Zn (ppm)*	*Au (ppm)*	*Ag:Au*
Mortaş	S4	63.5	660	62	4.9	145468	28	0.49	22584	355	0.49	>150000	1.6	40:1
North.	22	344.1	5.0	4.99	4.99	132	0.49	0.49	48875	413	0.49	51055	0.2	1721:1
1	11	26.2	59	7.0	7.0	2304	0.49	0.49	44439	0.49	24	>150000	0.1	262:1
1	5	20.2	3.0	16	6.0	1297	0.49	0.49	30578	0.49	5	>150000	0.1	202:1
Copper	5	26.6	100	41	11	144847	0.49	0.49	637	5.0	17	631	0.4	67:1
Copper	10	18.6	2.99	4.99	9.0	989	0.49	0.49	47501	6.0	0.49	>150000	0.1	186:1
2	25-2	41.7	29	19	7.0	3077	0.49	0.49	45325	0.49	10	>150000	0.3	139:1
2	27	62	2564	49	30	8203	8.0	7.0	43119	93	41	>150000	0.2	310:1
4	19	58.9	481	138	15	>150000	97	0.49	2566	39	42	7492	1.5	39:1

Table 2
Correlation coefficients between measured variable for the İnler Yaylası mineralization (n=9)

	Ag	*As*	*Bi*	*Co*	*Cu*	*Mo*	*Ni*	*Pb*	*Sb*	*V*	*Zn*	*Au*
Ag	1.00											
As	-0.07	1.00										
Bi	-0.17	0.31	1.00									
Co	-0.17	0.90	0.38	1.00								
Cu	-0.18	0.01	***0.76***	0.01	1.00							
Mo	-0.07	0.13	0.95	0.21	0.64	1.00						
Ni	-0.04	0.96	0.10	0.91	-0.22	-0.08	1.00					
Pb	0.29	0.06	-0.74	-0.07	***-0.91***	-0.61	0.22	1.00				
Sb	***0.78***	0.09	-0.01	-0.22	0.14	0.02	-0.02	0.15	1.00			
V	-0.25	0.61	0.63	0.79	0.22	0.54	0.57	-0.33	-0.38	1.00		
Zn	-0.32	0.19	-0.50	-0.04	***-0.60***	-0.47	0.24	***0.70***	-0.09	-0.28	1.00	
Au	-0.06	0.10	***0.83***	-0.03	***0.83***	0.80	-0.19	-0.63	0.35	0.18	-0.30	1.00

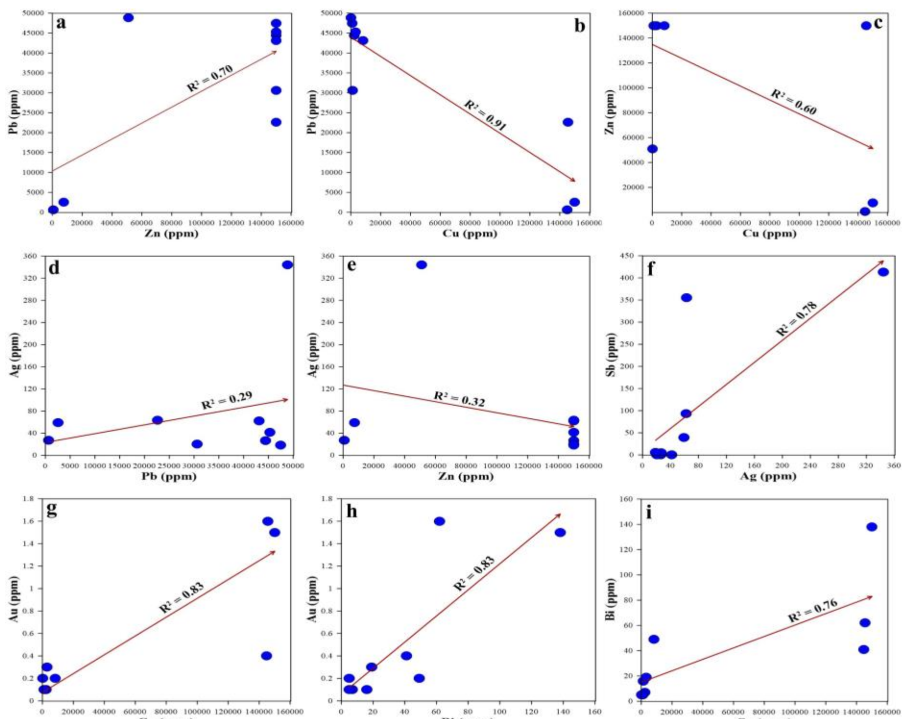

Figure 9. Base and precious metal element from the İnler Yaylası as plotted on the (a) Pb–Zn, (b) Pb–Cu, (c) Zn–Cu, (d) Ag–Pb, (e) Ag–Zn, (f) Sb–Ag, (g) Au–Cu, (h) Au–Bi, (i) Bi–Cu diagrams and correlation coefficients

In the İnler Yaylası, the temperature stability of the mineral assemblage of alteration and mineralization demonstrate epithermal ore deposit (approximately 180 to 300°C) (Fig. 10). However, the mineral paragenesis in the region feature an epithermal deposit with both low- (neutral pH) and high-sulfidation (acid) [26]. Intermediate-sulfidation epithermal deposits are defined as containing mineral assemblage of high-sulfidation deposits, excluding the early enargite-containing assemblage, and with having the higher Ag:Au (at least 10:1, and typically >100:1) [27]. The base-metal + silver is characterized by vein-type mineralization. The veins have a halo of illite+adularia. The alteration gradually changes from sericitic to propylitic mineral assemblages at outward. The main sulfide assemblage is sphalerite, galena, pyrite, chalcopyrite and tetrahedrite. Silver exists as Ag sulfosalts*.*

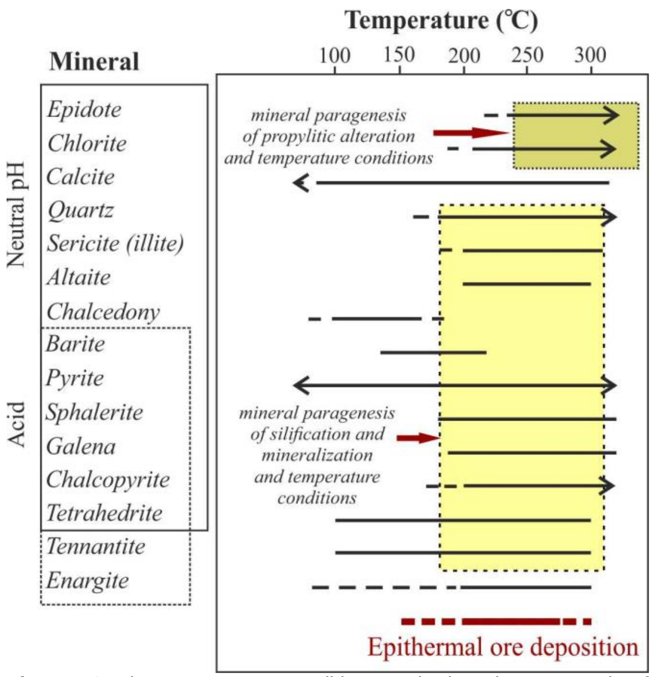

Figure 10. The temperature conditions and mineral paragenesis of silification and mineralization of the İnler Yaylası Pb-Zn-Cu (Ag-Au) mineralization (modified from [26]) (temperatures are taken from [28, 29, 30, 31, 32, 33])

Epithermal base metal veins at İnler Yaylası contain predominantly quartz with pyrite, galena, sphalerite, chalcopyrite and lesser tennantite–tetrahedrite (Figs. 4; 7 and 8). The less abundance enargite developed in as a substitution product of chalcopyrite in the late sulfide phase (Fig. 8e). The less abundant calcite and chalcedony is a supergene formation that cuts through the alteration zones (Fig. 5e, i). Barite is less abundant at the surface. The proximal alteration assemblage contains sericite (illite), but adularia is not observed (Fig. 5c–d, g, h–i) Propylitic alteration was developed in the outer zone (Fig. 5a–b). Ag:Au ratio is greater than 39:1 (39:1 to 1721:1) (Table 2). These features show that İnler Yaylası deposits typically characterize an intermediate-sulfidation epithermal type deposit.

Strong positive and negative correlation confidents between Pb–Zn (R^2=0.70) and Pb–Cu (R^2=-0.91), Zn–Cu (R^2=-0.60) show that Pb-Zn and Cu mineralization in the region are related to the different sub-phase (Table 2 and Fig. 9a–c). The strong correlation confidence between Au–Cu (R^2=0.83) indicates that gold mineralization increased in the second sub-phase. These data support the mineralogical-petrographic results. There is no correlation between Ag–Pb, Zn and Cu. On the other hand, the strong correlation confidents between Ag–Sb is (R^2=0.78) associated with Ag-rich sulfosalt such as tennantite – tetrahedrite [(Cu,Ag)(Pb,Zn)(As,Sb)S] and enargite [(Cu,Ag,Fe,Zn)(As,Sb)S].

ACKNOWLEDGMENT

This research was produced from the first author's master's thesis. We would like to thank Nesko Mining Incorporated Company management and employees for their assistance and hospitality during the fieldwork. Two anonymous reviewers are kindly appreciated for their valuable comments.

REFERENCES

[1] Şengör, A.M.C., Yılmaz, Y., Ketin, İ., "Remnants of a pre-Late Jurassic Ocean in Northern Turkey: fragments of a Permian-Triassic Paleo-Tethys". *Geol Soc Am Bull*, 91, 599–609, 1980.

[2] Yılmaz, S., "Dereli-Şebinkarahisar (Giresun Güneyi) Arası Granitoyid Plütonlarının Karşılaştırılmalı İncelenmesi", *Cumhuriyet Üniversitesi Fen Bilimleri Enstitüsü*, Doktora Tezi, s. 310, Sivas, 1995 (in Turkish).

[3] Boztuğ, D., Jonkheere, R., Wagner, G.A., Yegingil, Z, "Slow Senonian and fast Paleocene-Early Eocene Uplift of the Granitoids in the Central Eastern Pontides, Turkey: Apatite Fission-Track Results", *Tectonophysics*, 382, 213–228, 2004.

[4] Topuz, G., Altherr, R., Schwarz, W.H., Siebel, Satır, M., Dokuz, A., "Post-collisional plutonism with adakite-like signatures: the Eocene Saraycık granodiorite (Eastern Pontides, Turkey)", *Contrib Mineral Petrol*, 150: 441–455, 2005.

[5] Eyüboğlu, Y., Santosh, M., Yi, K., Tüysüz, N., Korkmaz, S., Akaryalı, E., Dudas, F. O., Bektas, O., "The Eastern Black Sea-type volcanogenic massive sulfide deposits: Geochemistry, zircon U–Pb geochronology and an overview of the geodynamics of ore genesis", *Ore Geology Reviews*, 59, 29–54, 2014.

[6] Kaygusuz, A., Öztürk, M., "Geochronology, geochemistry, and petrogenesis of the Eocene Bayburt intrusions, Eastern Pontides, NE Turkey: Evidence for lithospheric mantle and lower crustal sources in the high-K calc-alkaline magmatism", *Journal of Asian Earth Sciences*, 108, 97–116, 2015.

[7] Güven, I.H., "Doğu Pontiler'in Jeolojisi ve 1/25.000 Ölçekli Kompilasyonu", *MTA*, Ankara, 1993 (in Turkish).

[8] Yiğit, Ö., "Gold in Turkey – a missing link in Tethyan metallogeny", *Ore Geology Reviews*, 28, 147–179, 2006.

[9] Revan, M.K., Maslennikov, V.V., Genç, V., Delibaş, O., Maslennikova, S.P., Sadykov, S.A., "Sulfur isotope study of vent chimneys from Upper Cretaceous volcanogenic massive sulfide

deposits of the eastern Pontide metallogenic belt, NE Turkey", *Turkish J. Earth Sci.*, 25, 227–241, 2016.
[10] Çapakulu, F., "Asarcık (Şebinkarahisar) Uranyumlu Pb-Zn-Cu Cevherleşmelerinin İncelenmesi", *E.Ü Yer Bilimleri Fakültesi*, Doçentlik Tezi, s. 1065, 1982 (in Turkish).
[11] Karaoğlu, N., "İnler Yaylası (Şebinkarahisar-Giresun) Kurşun-Çinko-Bakır Cevherleşmesinin ve Çevre Jeolojisinin İncelenmesi", *Dokuz Eylül Üniversitesi Fen Bilimleri Enstitüsü*, Yüksek Lisans Tezi, s. 120, İzmir, 1985 (in Turkish).
[12] Aktan, A., "Balkovan Dere (Şebinkarahisar-Giresun) Çevresinin Jeolojisi ve Pb-Zn-Cu Cevherleşmeleri", *D.E.Ü.M.M.F. Jeoloji Mühendisliği Diplomasi Çalışması*, s. 54, İzmir, 1992 (in Turkish).
[13] Şaşmaz, A., Sağıroğlu, A., "Geology of the Inler Yaylasi (Sebinkarahisar-Giresun) Pb-Zn deposits", *Geological Bulletin of Turkey*, 37, 13–28, 1994 (in Turkish).
[14] Demirkıran, Z., "Mining Geology and Mineralization of İnler Yaylası (Şebinkarahisar-Giresun) Pb-Zn Mine", *Dokuz Eylül Üniversitesi Fen Bilimleri Enstitüsü*, Yüksek Lisans Tezi, s. 234, İzmir, 1994 (in Turkish).
[15] Gökçe, A., Bozkaya, G., "Fluid Inclusion and Stable-Isotope Characteristics of the Inler Yaylası Lead-Zinc Deposits, Northern, Turkey", *International Geology Review*, 45, 1044–1054, 2003.
[16] Kamburoğlu, F., "İnler Yaylası Pb-Zn-(Cu) Yatağının Mineralojik ve Jeokimyasal Özellikleri (Şebinkarahisar/Giresun)", *T.C. Nevşehir Hacı Bektaş Veli Üniversitesi Fen Bilimleri Enstitüsü*, Yüksek Lisans Tezi, s. 73, Nevşehir, 2019 (in Turkish).
[17] "Geological map of Turkey. 1/500.000 scaled Samsun and Trabzon sheets", *MTA*, 2002.
[18] Okay, A.I., Tüysüz, O., "Tethyan sutures of northern Turkey. In: Durand, B., Jolivet, L., Horvath, F., S´eranne, M. (Eds.), The Mediterranean Basins: Tertiary extension within the Alpine orogen", *Geological Society of London, Special Publication*, 475–515. 1999.
[19] Ketin, İ., "Anadolu'nun Tektonik Birlikleri", *MTA Dergisi*, 66, 20–34, 1966 (in Turkish).
[20] Çoğulu, E., "Gümüşhane ve Rize Bölgelerinde Petrolojik ve Jeokronolojik Araştırmalar", *İTÜ Yayını*, No: 1034, s. 112, 1975 (in Turkish).
[21] Bektaş, O., Yılmaz, C., Taslı, K., Akdağ, K., Özgür, S., "Cretaceous rifting of the eastern Pontide carbonate platform (NE Turkey): The formation of carbonate breccias and turbidites as evidence of a drowned platform", *Geologia*, 57, 233–244, 1995.
[22] Okay, A., Şahintürk, Ö., Yakar, H., "Stratigraphy and Tectonics of the Plulur (Bayburt) Region in the Eastern Pontides", *Bulletin of the Mineral Research and Exploration*, 119, 1–22, 1997 (in Turkish).
[23] Yılmaz, C., "Tectono-Sedimentary Records and Controlling Factors of the Mesozoic Sedimentary Basin in the Gümüşhane-Bayburt Region", *Geological Bulletin of Turkey*, 45 (1), 141–164, 2002 (in Turkish).
[24] Akaryalı, E., "Arzular (Gümüşhane KD-Türkiye) Altın Yatağının Jeolojik, Mineralojik, Jeokimyasal ve Kökensel İncelenmesi", *Karadeniz Teknik Üniversitesi Fen Bilimleri Enstitüsü*, Doktora Tezi, s. 223, Trabzon, 2010 (in Turkish).
[25] Hedenquist, J.W., Lowenstern, J.B., "The role of magmas in the formation of hydrothermal ore deposits", *Nature*, 370, 519–527.1994.
[26] White, N., Hedenquist, J.W., "Epitermal gold deposits; styles, characteristics and exploration", *Published in SEG Newsletter*, 23, 9–13, 1995.
[27] Einauidi, M.T., Hedenquist, J.W., Inan, E.E., "Sulfidation State of Fluids in Active and Extinct Hydrothermal Systems: Transitions from Porphyry to Epithermal Environments" *Soc. Econ. Geol. Spec. Publ.*, 10, 285–313, 2003.
[28] Fournier, R.O., "Silica minerals as indicators of conditions during gold deposition", *US Geol Surv Bull,* 1646,15–26, 1985.
[29] Samson, I.M., Russell, M.J., "Genesis of the Silver mines zinc-lead-barite deposit, Ireland; fluid inclusion and stable isotope evidence", *Economic Geology*, 82(2), 371–394, 1987
[30] Seal, R.R., Essene, E.J., Kelly, W.C., "Tetrahedrite and Tennantite: Evaluation of Thermodynamic Data and Phase Equilibria", *Canadian Mineralogist*, 28, 725–738, 1990.
[31] Lüders, V., Ziemann, M., "Possibilities and limits of infrared light microthermometry applied to studies of pyrite-hosted fluid inclusions", *Chemical Geology*, 154, 169–178, 1999.
[32] Plotinskaya, O.Y., Damian, F., Prokofiev, V.Y., Kovalenker, V.A., Damian, G., "Tellurides Occurrences in the Baia Mare Region, Romania", *Carpathian Journal of Earth and Environmental Sciences*, 4(2), 89–100, 2009.
[33] Zhang, J., Shao, Y., Liu, Z., Chen, K., "Sphalerite as a record of metallogenic information using multivariate statistical analysis: Constraints from trace element geochemistry" *Journal of Geochemical Exploration*, 232, 106883.