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Mineralogy of the Lahanos Deposit a Kuroko-Type Volcanogenic Massive Sulfide Deposit from the Eastern Pontides (Giresun-NE Turkey)

Lahanos Maden Yatağının Mineralojisi Doğu Pontidlerde Kuroko-Tipi Bir Volkanojenik Masif Sülfit Yatak

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Abstract

The Lahanos volcanogenic massive sulfide (VMS) deposit is situated in the westernpart of the eastern Pontide tectonic belt. The deposit is hosted predominantly by a late Cretaceous felsic volcanic complex and is mined mainly for copper and zinc. The deposit is essentially stratabound, with characteristics of both Cu-Zn- and Cu-Zn-Pb-type stratiform VMS deposits. The deposit consists mainly of yellov ore (oko) and a zone that can be considered as semi-blackore.

Ore mineralization occurs mainly as massive ore, and to lesser extent as disseminated andstochvork ore. Major ore minerals include pyrite, chalcopyrite, sphalerite, galena, tetrahedrite/tennantite, bornite, and minor to trace covellite, marcasite, chalcocite, and digenite. Gangue minerals are chiefly auartz and barite with minor calcite and dolomite. The deposit has aparagenetic seguence of pyrite (I, II) - chalcopyrite (I) sphalerite - galena tetrahedrite/tennantite digenite chalcosite pyrite (III) - chalcopyrite (II) bornite - covellite. A great variety of intimate intergrowth ore textures including replacement, colloform, disseminated, and fragmental textures prevail throughout the deposit.

The fine-grained nature of the Lahanos ore presents difficulties in beneficiation. Sphalerite, as in other VMS deposits of the region, is notably Fe-poor (< 0.7 wt. %).

Keywords: *Lahanos, VMS, eastern Pontides, texture, ore mineral*

Öz

Lahanos volkanojenik masif sülfit (VMS) yatağı, doğu Pontid tektonik kuşağının batı bölümünde yer almaktadır. Yatak esas olarak Geç Kretase yaşlı felsik volkanik bir kompleks içerisinde bulunmakta ve kurşun ile çinko için işletilmektedir. Yatak esasen stratabound nitelikte ve hem Cu-Zn- ve hem de Cu-Zn-Pb-tipi stratiform VMS yatakların özelliklerini taşımaktadır. Yatak çoğunlukla masif, daha az olarak da sacınımlı ve ağsal olarak *bulunmaktadır.*

Ana cevher mineralleri pirit, kalkopirit, sfalerit, galen, tetraedrit/tenantit, bornit ve azdan esere değişen oranlarda kovelit, markazit, kalkosit ve dijenitten oluşmaktadır. Gang mineralleri çoğunlukla kuvars ve barit ile az miktarda kalsit ve dolomitten ibarettir. Yatak, pirit (I, II) - kalkopirit (I) sfalerit - galen-tetraedrit/tenantit dijenit kalkosit - pirit (III) - kalkopirit (II) bornit - kovelitten oluşan bir parajenetik sekansa sahiptir. Ornatım, koloform, disemine ve kırıntılı dokular gibi beraber büyüme dokularının bir çok türü yatakta yaygın olarak bulunur.

Lahanos madeninin ince-daneli tabiyatı, cevher kazanımında problemler sunmaktadır. Sfalerit, bölgenin diğer VMS yataklarında olduğu gibi, demir içeriği bakımından oldukça fakirdir (< ağ. %0,7).

Anahtar sözcükler: Lahanos, VMS, doğu Pontidler, doku, cevher minerali

Introduction

The Lahanos VMS deposit is located in the western part of the eastern Pontides, where about a dozen similar VMS deposits occur in the vicinity. (Fig. 1). This deposit consists mainly of yellow ore and semi-black ore within a single ore body. As is the case for other VMS deposits of the region, it is hosted by a felsic volcanic complex and is overlain by a thin layer of a volcano-sedimentary sequence. A barren dacite, regionally known as the "purple dacite", overlies both the deposit and the overlying sedimentary rocks (Ciftci, 2000).

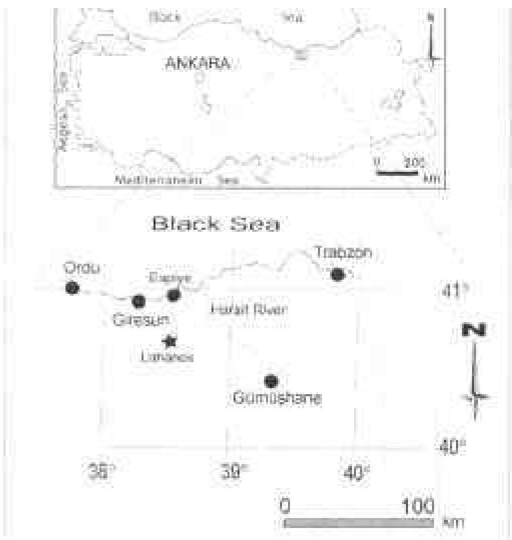

Figure 1. Location map of the study area.
Şekil 1. Çalışma alanının yer bulduru haritası.

The Lahanos VMS deposit has long been considered to be a Kuroko-type VMS deposit (Vujanovic, 1974; Leitch, 1981 and 1990; Akıncı, 1985; Tüysüz and Er, 1995; Tüysüz, 1995; Ciftci, 2000; Çiftçi et al., 2001). it has been reported that the deposit contains about 2.3 mt of high-grade ore consisting 3.6% copper and 2.4% zinc, with an additional 0.3 mt of low-grade ore containing 0.5% copper and 0.3% zinc (Tuğal, 1969;Aslaner, 1977). The deposit has been mined mainly for copper and zinc by a national mining company. Ore and gangue minerals and their textural intergrowths are highly variable in comparison to other VMS deposits of the region (Ciftci, 2000). Table 1 lists all of the phases identified in the present investigation.

Although a semi-black ore zone is present, the deposit lacks a typical black ore zone (the Kuroko ore). The deposit also exhibits vertical textural zoning in addition to mineralogical zoning. Disseminated and stockwork ores predominate at the bottom, whereas massive ore makes up the top of the deposit.

This paper deals with mineralogy, ore-mineral-textures and mineral chemistry of the Lahanos deposit to explain depositional conditions.

Regional Geology

Devonian-early Carboniferous metamorphic rocks and the Permian Gümüşhane granite together constitute the basement rocks of the region. These rocks largely crop out in the southern part of the region. Despite the prevalent occurrence of magmatic rocks in the region, sedimentary rocks are also present, and vary from late Carboniferous-early Permian to Oligocene-Miocene in age.

Igneous rocks intruded the volcanic and sedimentary formations during at least three major pulses in the region (Moore et al., 1980). The Jurassic-Early Cretaceous volcanic complex, which is known as the "lower basic volcanic complex" (LBVC), discordantly overlies the basement rocks. The LBVC consists mainly of basalt, basaltic agglomerates, locally spilitized basalts, andesite, andesitic agglomerates, and basic tuffs. Locally, intercalated marble lenses occur within the complex, and they frequently have skarn-type mineralization at their contacts with younger acidic intrusives.

The LBVC is overlain by late Dogger-Malm-early Cretaceous carbonate rocks. These carbonate rocks are thought to be neritic and are widespread in their occurrence, and are considered to be a marker formation by many investigators. Pelin (1977) first characterized the unit and named it the "Berdiga Formation".

One of the major phases of granitoid emplacement occurred between the Early and Late Cretaceous; this phase is represented by the Artvin granitoid in the easternmost corner of the region (Van, 1990), and by the Harsit granitoid in the central to western part of the eastern Pontides (Gedikoglu, 1978).

Upper Cretaceous-lower Eocene units, comprising basic and felsic rocks, occur most widely in the region. These units are exposed along the Black Sea coast, known as the northern zone of the eastern Pontides. The felsic volcanic rocks, known as "mineralized dacites", are of particular interest due to their close association with VMS deposits of the region and some of the vein-type mineralization. This volcanic complex is overlain by barren dacite, regionally known as the purple dacite- and a marl-limestone (locally mudstone) sequence of Maastrichtian-Paleocene age. However, Akıncı (1980) observed that mineralized dacites could occur at different stratigraphic levels in the region.

A significant number of the major granitoid intrusions occurred during the Paleocene. These intrusions are dominantly hornblende-biotite granodiorite and quartz diorite with respect to normative composition and are generally calc-alkaline in character (Moore et a1, 1980;Yalçınalp, 1992; Ciftci, 2000).

The middle-upper Eocene interval in the region comprises basaltic-andesitic rocks and intercalated sedimentary rocks; these rocks are known as the "upper basic volcanic complex" (UBVC). The Oligocene-Miocene interval has a very limited distribution in the region. In addition to a few narrow windows, the largest exposure occurs in the southern zone of the eastern Pontides. The sequence comprises mainly marl, siltstone, mudstone, sandstone, and locally gypsum interbeds.

Tablel. *Minerals recognized in samples from the Lahanos VMS deposit (XRD: X-ray diffractometry; RLM: Reflected light microscopy; EPMA/SEM: Electron probe microanalysis/Scanning electron microscopy).*

Tablo 1. Lahanos VMS yatağından orneklerde tamımlanan mineraller (XRD: X-isim kirmimi; RLM: Cevher mikroskobisi; EPMA/SEM: Elektron prob mikroanaliz / Taramah elektron mikroskobisi).

Analytical Method Minerals	XRD	RLM	EPMA/SEM
chalcopyrite ($CuFeS_2$)	X		
pyrite (FeS_2)	X		
marcasite (FeS_2)		X	
bornite (Cu_sFeS_2)	X		
digenite (Cu_9S_5)		X	
enargite (Cu_3AsS_4)			X
chalcocite (Cu_2S)		X	
sphalerite (ZnS)	X		
gersdorffite (NiAsS)		X	
tetrahedrite-tennantitc ($Cui_2(As, Sb)S_{13}$)	X		
galena (PbS)	X		
covellite (CuS)		X	
acanthite (Ag_2S)			X
electrum (Au.Ag)			X
quartz ($Si0_2$)	X		
barite ($BaS0_4$)	X		
calcite ($CaCO_3$)			X
dolomite ($CaMg(C0_3)_2$)	X		
ankerite ($Ca(Mg,Fe,Mn)(C0_3)_2$)	X		
anhydrite ($CaSO_4$)			X
gypsum ($CaS0_4.2H_20$)			X
apatite ($Ca_5(P0_4)_3(OH, F, CI)$)			X
anatase ($Ti0_2$)			X
muscovite ($K(SiAl)4O_{,0}(OH)_2$			X
kaolinite ($Al_2Si_20_5$)	X		

Local Geology

Despite its very limited exposure, the LBVC of Jurassic-Early Cretaceous age is the oldest unit in the area, and was produced by a phase of basic volcanism which commenced in the early Liassic and continued until the Early Cretaceous. The LBVC comprises diabase, basalt, andesite lava, and pyroclastic rocks with intercalated marble lenses. Spilitization is present throughout the region within the LBVC. It is suggested that rocks of this complex range from low-K calc-alkaline to shoshonitic in character, and are mainly calc-alkaline to tholeiitic, signifying rather primitive arc environments (Koprübaşı, 1993; Ciftci, 2000). The LBVC is discordantly overlain by a felsic volcanic complex (FVC) of Late Cretaceous age. The felsic volcanic complex is made up mainly of highly altered dacitic tuffs, breccia, and locally lava, and interbeds of sedimentary rocks which were deposited between volcanic pulses. Kaolinitic alteration is somewhat widespread, but silicification also is quite common within the FVC. Disseminated pyrite occurs in upper Cretaceous felsic volcanic rocks throughout the region; thus, these rocks are called "mineralized dacites". The Lahanos ore body is hosted by the FVC. Barren dacite, known as purple dacite or hematitic dacite due to its high iron-oxide content immediately overlies the FVC. The upper basic volcanic complex (UB VC), comprising basic volcanic rocks (e.g., olivine augite basalts with spectacular columnar joints along Murtad Creek about 15 km from the Black Sea coast) and a volcano-sedimentary sequence of marl-lirnestone-tuffite, discordantly overlies the pre-Late Cretaceous lithologies (Fig. 2).

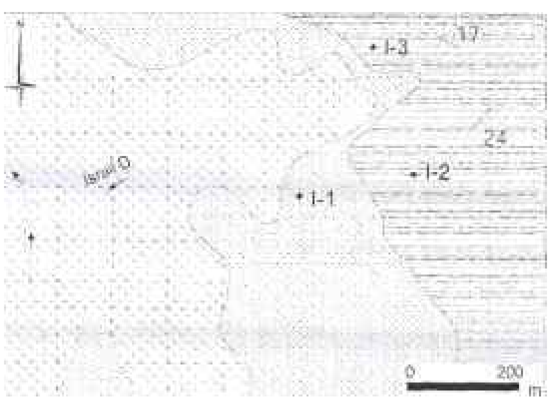

Figure 2. Geologic map of the Lahanos mining site (modified from Tüysüz, 1995).

Şekil 2. Lahanos maden alanının jeolojik haritasi (Tuysüz, 1995'ten degistirilerek).

Samples and Analytical Methods

Representative samples of the major ore types in the deposit were collected from open pits and cores. Polished sections were prepared for Reflected Light Microscopy (RLM) and Electron Probe Microanalysis (EPMAYScanning Electron Microscopy with Energy Dispersive Spectrometry (SEM-EDS). Representative splits from each ore type are also analyzed by employing Inductively Coupled Plasma (ICP) and Fire Assay for selected elements, and X-Ray Diffractometry (XRD) was used for semi-quantitative phase analysis.

The SEM-EDS and RLM investigations were carried in the laboratories of the University of Missouri - Rolla (U.S.A.), the EPMA investigations at Purdue University and Indiana University (U.S.A.), the XRD analyses in the Barrick Gold Inc. Mineral Processing Labs and the University of Missouri-Rolla Labs (U.S.A.), and the ICP and Fire Assay Analyses at Acme Labs (Canada).

Ore Mineralogy and Mineral Chemistry

The Orebody

The Lahanos VMS deposit is a typical example of an ancient mound-chimney sulfide accumulation on or very close to the sea floor. Massive ore formed along the flanks of the chimney, whereas stockwork and disseminated ores formed within the chimney and toward the base of the mineralizing system, resulting in an overall form that is roughly funnel shaped (Fig. 3).

The host rocks of the deposit are the felsic volcanic complex (FVC), which are strongly altered and zoned outward from the ore body. Sericitic alteration is dominant at the centre followed by chlorite, montmorillonite, andkaolinite in the outermost zone.

The deposit consists of two massive ore lenses separated from each other by a stockwork/ disseminated ore zone. It is quite possible that massive-ore formation was a result of the paleotopography of the depositional site, in that the sulfide pods could have formed in depressions in the depositional area to yield the massive-ore zones. The total length of the deposit is about 600 m; the deposit consists of relatively thin massive-ore zones, averaging about 30 m in thickness. The disseminated pyrite ore continues downward for about 120 m but have no economic value.

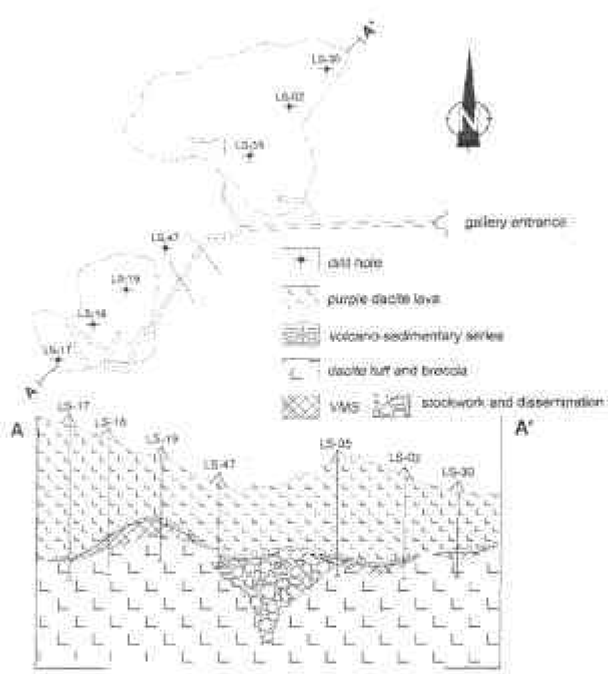

Figure 3. *Cross-section through the Lahanos deposit together with a plan view (not to scale; modified from Tüysüz, 1995).*

Sekil 3. Lahanos yatagını kateden düşey kesit ve üstten görünümü (ölçeksiz; Tüysüz, 1995'ten degistirilerek).

Ore Mineralogy and Textures

This deposit consists of apyritic ore zone at the base followed upward by chalcopyrite- dominated ore, and together these zones make up the yellow ore. Variety and abundance of the ore minerals changes significantly upward. Sphalerite becomes dominant upward together with significant tetrahedrite-tennantite-series minerals, pyrite and less abundant galena. Thus, this portion is not typical black ore, but rather resembles a semi-black ore. The presence of chalcopyrite also is significant in this zone. Bornite occurs in the latest stage of deposition where it replaces all of the earlier major phases, including barite gangue. XRD patterns for the various ore zones indicating their major phases are given in Figure 4. Table 1 list all of the minerals observed using various techniques in samples collected from the Lahanos VMS deposit.

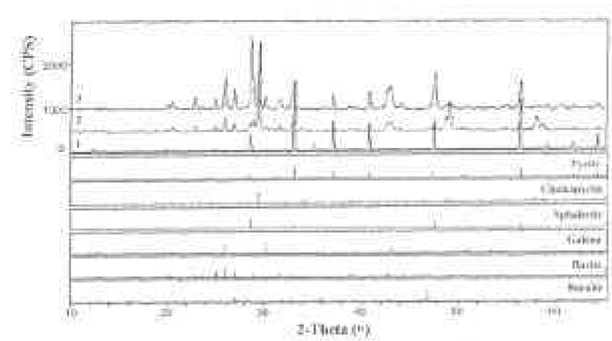

Figure 4. *X-Ray Diffraction patterns for the major ore zones in the Lahanos VMS deposit (1 represents the pyritic ore; 2 the yellow ore; 3 the semi-blackore).*

Şekil 4. *VMS Lahanos yatağindaki ana cevher zonlarına ait X-Işını Kırınımları (1 piritik cevheri, 2 sarı cevheri, 3 yarı-siyah cevheri temsil etmektedir).*

Pyrite (FeS2)

Three generations of pyrite were identified. Early pyrite occurs in subhedral to euhedral crystals that are the most common form in the disseminated sulfide ore. A second generation of pyrite occurs in colloform and framboidal forms, showing sequential intergrowth with early sphalerite and chalcopyrite. The framboids may reach 150 urn in diameter and locally may form clusters. The last generation of pyrite forms relatively large subhedral to euhedral crystals with rare overgrowths on earlier generations of pyrite (Fig. 5). EPMA revealed that the early pyrite is Co poor; however, the late pyrite contains cobalt up to 0.5 wt. %. Some pyrite crystals contained as much as 0.1 wt. % silver (Table 2). Pyrite is present in all of the zones, except for in the chalcopyrite zone where it is completely replaced by chalcopyrite. Figures 6 A through 6E illustrate the general intergrowth textures of the pyrite.

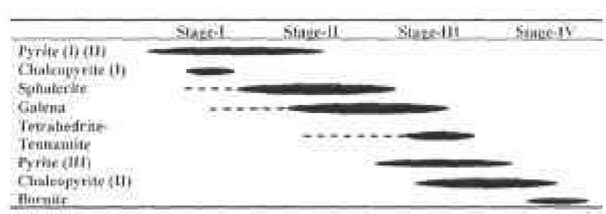

Figure 5. *Ore-mineral paragenetic sequence for the Lahanos VMS deposit.*

Şekil 5. Lahanos VMS yatagı için belirlenen cevher mineral parajenetik sekansı.

***Table** 2. EPMA resulls far selected elements of the major ore minerals in theLahanos VMS deposit (in wt. %).*

Tablo 2. Lahanos VMS yatağındaki ana cevher minerallerinin seçilen elementleri için EPMA sonuçlan.

Element	pyrite	chaleopyritc	tetrahedrite	tennanlıte	bornite	sphalerite	galena
Co	0.63	na*	na	na	0.22	na	nd*
As	1.03	nd	5.80	20.00	nd	0.02	nd
Se	nd	na	na	na	nd	na	na
in	na	na	na	na	na	na	na
Fe	46.47	30.14	0.29	0.40	10.71	0.05	nd
Ni	nd	na	na	na	nd	na	nd
Cu	1.03	34.66	38.71	44,23	60.41	0.31	0.08
S	48.51	34.61	21.47	28.05	25.91	31.09	11.87
Pd	nd	na	na	na	na	na	na
Au	0.05	nd	nd	nd	nd	nd	nd
As	0.04	nd	nd	nd	0.21	0.02	nd
Zn	0.09	nd	7.78	8.23	0.01	67.88	0.12
Ge	na	na	nd	nd	na	na	na
Bi	2.62	nd	1.06	nd	2.19	1.41	2.39
Hg	nd	na	0.10	0.07	na	na	0.03
Pb	nd	nd	nd	nd	nd	nd	85.80
Sn	na	na	0.10	nd	na	na	na
Sb	nd	0.06	22.80	0.27	nd	nd	nd
Te	na	na	nd	0.12	na	na	na
Ga	nd	nd	na	na	na	0.23	nd
Cd	nd	nd	na	na	na	0.46	nd
Mn	na	na	na	na	na	na	na
Mo	na	na	na	na	0,54	na	na
V	0.03	N/a	na	na	na	na	0.06
TOTAL	100.50	99.47	101.01	101.37	100.20	100.48	100.35

xtures

of voids (pseudo wurtzite). Sphalerite crystallization began with a colloform mode accompanying pyrite, and then ehanged character during the following ore stage, probably due to an inerease in temperature that produced the larger crystals. Sphalerite replaced early chalcopyrite and was replaced by pyrite (III), chalcopyrite (II), galena, tetrahedrite-tennantite, and bomite. The sphalerite is extremely Fe-poor containing less than 0.6 wt. %, but it contains significant amounts of gallium and cadmium, averaging 0.25 wt. % and 0.4 wt. %, respectively (Table 2). Figures 6A through 6D show the general intergrowth textures that sphal erite has with the maj or phases.

Galena (PbS)

Galena is mainly associated with the semi-black ore, especially with sphalerite. Galena has irregular crystal outlines and grain sizes, and oecurs in crystals up to 1 mm in size that can be seen with the naked eye. Micron-sized galena inelusions are common in all of the earlier phases. Galena may replace sphalerite and early pyrite and is replaced by chalcopyrite (II), tetrahedrite-tennantite, and bornite. The most significant trace element content is that of bismuth, averaging 0.35 wt. % (Table 2).

Tetrahedrite-Tennantite $(Cu,Fe)_{12}Sb_4S_{13})$ - $(Cu,Fe)_{12}As_4S_{13})$

Tetrahedrite-tennantite series minerals are present mainly in the semi-black ore. Tetrahedrite appears to be more abundant than the other phases. However, tennantite also is present in significant amounts. These two minerals are always present together and they replace all of the earlier phases, particularly sphalerite. Tennantite locally replaces tetrahedrite, indicating its possible late precipitation from As-enriched solutions. Both minerals contain significant bismuth (up to 2 wt. %), and tetrahedrite always contains silver (as high as 0.1 wt. %) as is the case for the other VMS deposits of theregion (Çiftçi et al., 2001) (Table 2). The general intergrowth textures of tetrahedrite and tennantite with the other phases are shown in Figures 7A and 7B.

Bornite $(Cu_5FeS_4$ Textural evidence suggests that bornite crystallized the last stage of the paragenetic sequence (Fig. 5). Bornite locally replaces nearly all of the early phases including barite gangue; however, itpreferentially replaces pyrite framboids giving rise to a variety of ring textures. Bornite generally occurs as irregular masses.

The abundant presence of prismatic barite crystals within the bornite ore suggests that either the depositional site experienced a partial reduction, which enabled later copper-enriched solutions to precipitate bornite at the final stage, or that possible slumping (due to unstable sulfıde mound-chımney formatıon) took place immediately after or during bornite deposition which brought barite into contact with bornite. However, the presence of fragmental ore textures particularly associated with the bornite ore suggests that the latter is much more probable. The most significant trace-element contents include silver up to 0.2 wt. %, which is the case for the other bornite-bearing VMS deposits of the region (Çiftçi et al., 2001), bismuth up to 2 wt. %, molybdenum up to 0.6 wt. %, and cobalt 0.15 wt. % (Table 2). Typical intergrowth textures of bornite with the other sulfides are shown in Figures 6E, 6F and 7A through 7E.

Rare Mineral Occurrences

Rare minerals observed by the writers include acanthite (AgS), where present, it is associated with chalcopyrite (II). Electrum (Au,Ag), which is the only goldphase, is also closely associated with chalcopyrite (I, II). Enargite (Cu_3AsS_4) also is present locally in minör quantities, and occurs mainly with tetrahedrite-tennantite-series minerals. Scarce marcasite (FeS_2) crystals were observed, mainly occurring with pyrite (II) as colloform or band-like intergrowths. The abundance of covellite is locally significant, particularly in association with late-stage ore phases chalcopyrite and bornite, and it preferentially replaced bornite. Chalcocite (Cu_2S) and digenite (Cu_9S_5) also are present, occurring with enargite. It appears that local enrichments of arsenic induced precipitation of As-bearing minerals, such as gersdorffite ((Ni,Co,Fe)AsS) and tennantite. These minerals are closely associated with tetrahedrite, having formed during the last stage of ore deposition.

Discussion and Conclusions

The Lahanos VMS deposit contains well-developed mineralogical upward zoning as indicated by distinct ore zones (Fig. 4). This situation is mainly due to decreasing temperature and changing chemistry of the hydrothermal fluids during ore-mineral deposition. As is the case in the other yellow-ore-dominated VMS deposits of the region, bornite is of particular significance due to its being formed in the final stage of the ore- paragenetic sequence, as indicated by pervasive bornite replacement of all earlier phases including even the barite gangue. This deposit is one of the few deposits in the region that contains both yellow ore and a semi-black ore zone; however, it lacks the typical black ore zone.

Textural zoning is also present and began with colloform textures and fine-grained sulfide crystallization, indicating low temperature and relatively rapid formation follwing the earliest sulfide phases (that occur mainly as large, disseminated euhedral crystals at the bottom of the massive ore zones). These textures are followed upward by relatively coarse-grained massive-ore formation as a result of hotter fluids and chimney build-up, and these sulfides replaced earlier minerals. in this respect, chalcopyrite replacement modified the original textures of earlier-crystallized minerals. During the final stage of sulfide deposition, bornite was crystallized as a result of Cu enrichment, due either to Fe depletion because of intense pyrite deposition or to remobilization of Cu from earlier chalcopyrite. Thus, extensive replacement by bornite of all earlier phases and complex ore-mineral textures in parts of the semi-black ore zone resulted.

The abundant presence of colloform ore textures mainly in facies I sulfides (Eldridge et al., 1983) and fragmental ore make this deposit highly significant. Although brecciation of massive ore in the Japanese Kuroko deposits has been related to minör phreatomagmatic explosions (Clark, 1983) and slumping, the latter explanation (or process) is more widely accepted (Eldridge et al., 1983). in the Lahanos VMS deposit, fragmental ore becomes much more abundant toward the top of the deposit, particularly bornite-rich ore. Mesoscopic fragments of bornite occur embedded in fine-grained pyrite in the semi-black ore zone. Thus, slumping most probably occurred in the final stage of mineralization due to abnormal growth of the sulfide mound. However, the Lahanos deposit does not have layers of ore containing fragmental ore as is quite typical of the Japanese VMS deposits.

The major differences berwen Cu-rich and Cu-poor (as chalcopyrite) deposits of the region are that the former do not contain the stage-II mineral association, whereas the latter lack the stage-IV mineral assemblage (Fig. 3). Some of the Cu-rich deposits exhibit slight indications of stage II, as in the case of the Lahanos VMS deposit. This situation could be attributed to the availability of certain metal ions within the ore-forming system. All of the VMS deposits of the region have common host rocks. Nevertheless, striking differences between ore deposits of the same district with respect to ore-mineral contents can be explained by localized convection cells that were enriched in certain metal ions and gave rise to a variety of VMS deposits within a single district.

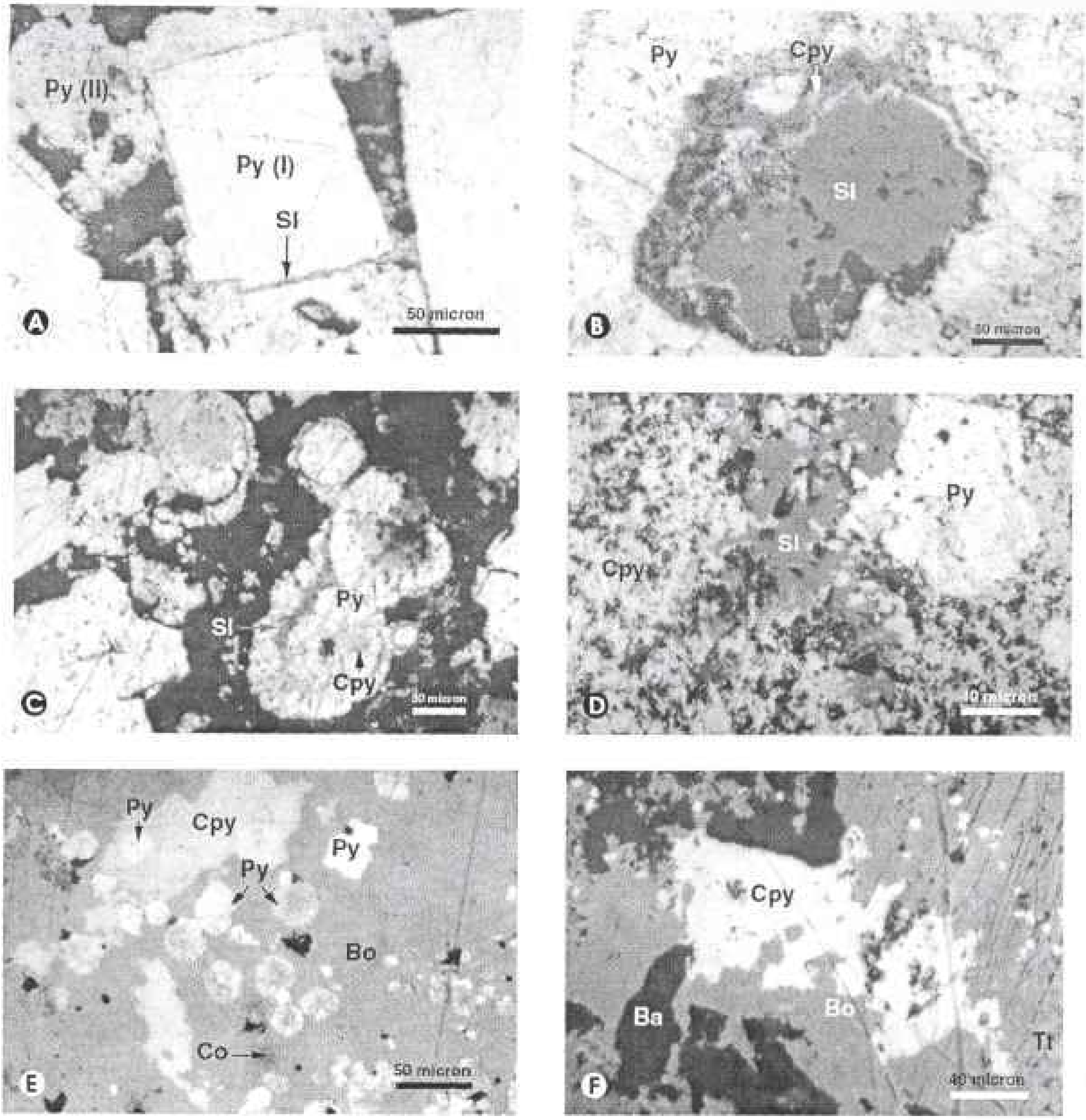

Figure 6. a. Overgrowth offine-grained pyrite (py) (II) with sphalerite (SI) on early euhedralpyrite (I) crystal, b. Colloform ormation of coeval sphalerite, chalcopyrite (Cpy) and pyrite (II), c. Colloform formation of coeval sphalerite, pyrite (II), and chalcopyrite, d. Chalcopyrite replacement of pyrite (I) and sphalerite, e. Chalcopyrite replacement of pyrite and bornite of chalcopyrite andframboidalpyrite, f Bornite (Bo) replacement of chalcopyrite.

Şekil 6. a. İnce-kristalli piritin (II) sfaleritle erken oluşmuş öhedral pirit (I) kristali üzerine büyümesi, b. Aynı evreye ait falerit, kalkopirit ve pirit (II)'in koloform oluşumu, e. Aynı evreye ait sfalerit, pirit (II) ve kalkopiritin koloform oluşumu, d.] lalkopiritin pirit (I) ve sfaleriti ornatması, e. Kalkopiritin piriti, bomitin kalkopirit ve framboyidal piriti ornatması, f. Bomitin 1 alkopiriti ornatması.

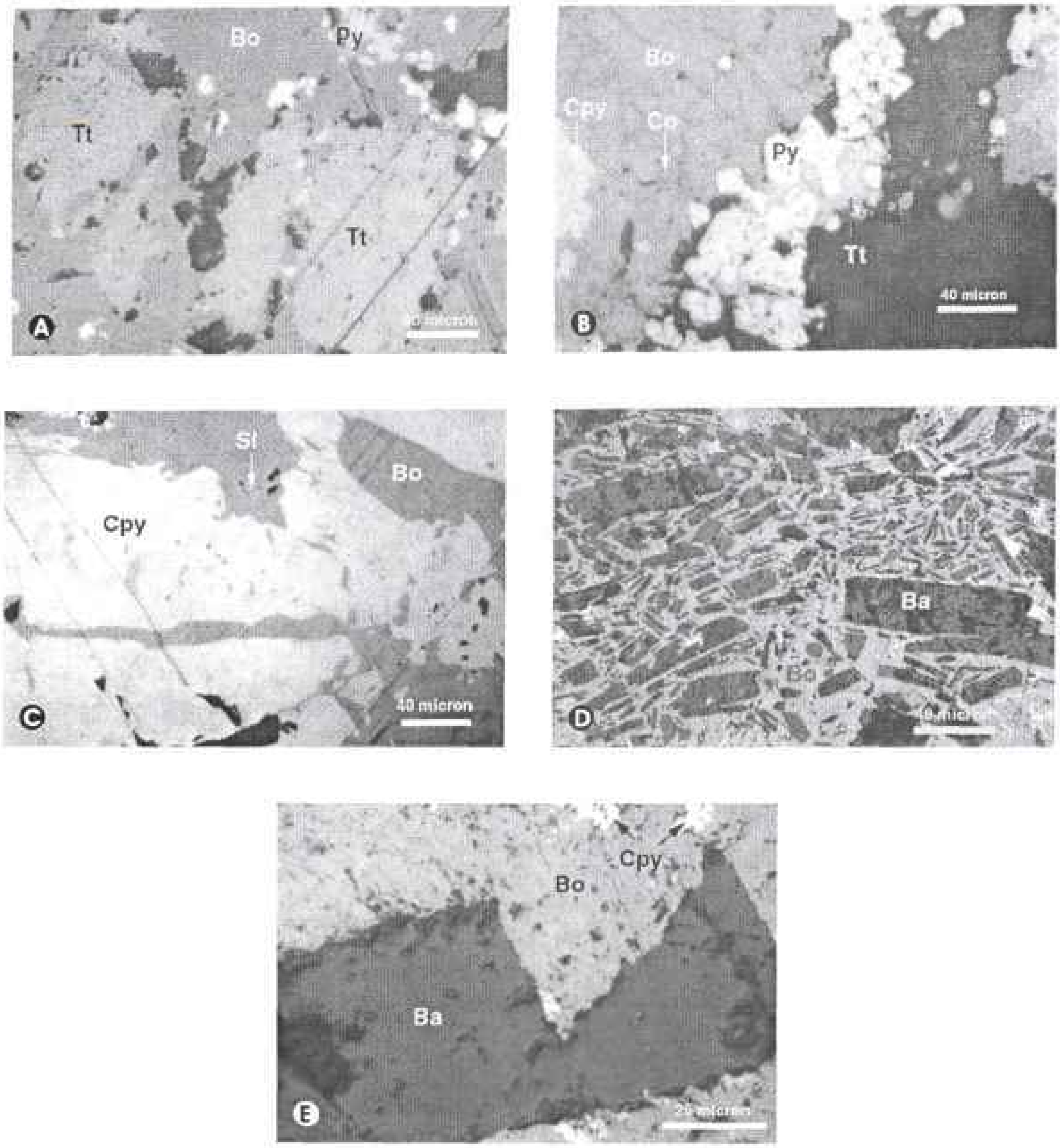

Figure 7. a. *Bornite replacement* ***of*** *tetrahedrite-tennantite, b.* ***Bornite*** *replacement of* ***chalcopyrite and*** *tetrahedrite of pyrite, c. Chalcopyrite replacement* ***of sphalerite,*** *d.* ***Prismatic*** *barite* ***crystals*** *(Ba)* ***in*** *bornite groundmass, e. Bornite replacement* ***of*** *barite.*

Şekil 7. a. Bornitin tetrahedrite-tennantiti ornatması, b. Bornitin kalkopiriti, tetrahedritin piriti ornatması, c. Kalkopiritin sfaleriti ornatması, d. Bornit matriksi içinde barit kristalleri (Ba), e. Bornitin barite ornatması.

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