Bull. Min. Res. Exp. (2015) 150: 51-64

Bulletin of the
Mineral Research and Exploration

http://bulletin.mta.gov.tr

THE SECRETS OF MASSIVE SULFIDE DEPOSITS ON MID-OCEAN RIDGES AND KÜRE-MAĞARADORUK COPPER DEPOSIT

Yılmaz ALTUN[a]*, Hüseyin YILMAZ[a], İlyas ŞİNER[a] and Fatih YAZAR[a]

[a] *Eti Bakır A. Ş. Maden Arama Grubu, Samsun.*

Keywords:
Cyprus Type, Massive Sulfide Deposits, Küre Mağaradoruk, Hydrothermal Vent, Lineiite.

ABSTRACT

Küre region is located in western part of the Pontide tectonic belt. The oldest rocks around Küre are Paleozoic metamorphic rocks constituting "Rhodope-Pontide" continent. Liassic-pre Liassic ophiolites and basaltic volcanics, which form Paleotethys Ocean Floor are situated on "Rhodope-Pontide" continent as Paleotethys Ocean Floor residuals. Massive sulfide deposits in Küre Region are closely associated with pre Liassic – Liassic basaltic volcanics and intercalating black shale. These deposits are considered to have formed during hydrothermal mineralization processes when basaltic volcanism had stopped and defined as "Black Smoker" today. Massive sulfide bodies in Mağaradoruk copper deposits are lens shaped. Although ore lenses take place sometimes in basalts and black shales, they are generally located on basalts and are covered by black shales. In Küre region, fold structures are intensely observed, and Mağaradoruk deposit is located on western flank of an overturned anticline. Mağaradoruk deposit is formed by several small and a big ore body and by less developed, underlying stockwork disseminated ore. The big ore body is 600 m long, 250 m wide and nearly 40 m thick. As main ore minerals; pyrite and chalcopyrite are observed. In few amounts; marcasite, magnetite, hematite, sphalerite, covelline, neo-digenite, malachite, azurite, fahlers are seen. In fewer amounts; bravoite, lineiite (karolite), limonite, and in trace amounts; chromite, rutile anatase, chalcosine, cuprite, tenorite, pyrrhotite, valleriite, bornite, galenite, native copper and native gold are observed. Main gangue minerals are; quartz, siderite-ankerite calcite, dolomite and chlorite. Mağaradoruk massive sulfide deposit rocks resembles to Siirt Madenköy, Ergani massive sulfide deposits, to "Cyprus" type massive sulfide deposits and modern Cyprus type massive sulfide deposits in terms of mineral contents; and to Ergani Mihrapdağı, Papuke, Pakotai and Parakoa deposits in terms of cover rocks, which are Cyprus type massive sulfide deposits, in New Zealand.

1. Introduction

The purpose of this study is to investigate geological environments, wall rock relationships and ore minerals of the Mağaradoruk deposit, and to compare these deposits with other "Cyprus" type massive sulfide deposits considering their like and unlike characteristics. This deposit was revealed by studies carried out around Aşıköy, Kızılsu, Toykondu and Bakibaba deposits which are located within the boundaries of Küre Town, Kastamonu. Within this scope, the geological research of deposits was performed, structural relationships were asserted, and the ore and gangue minerals were detected analyzing drill cores. The obtained data were then compared with "Cyprus type massive sulfide deposits" and the newly forming "modern Cyprus massive sulfide deposits".

Küre copper deposits have been the subject of Mining Sector for many years. However; mineral exploration and development studies in scientific manner began with the foundation of Republic of Turkey.

Nikitin (1926) studied the geology of Küre vicinity, the ore mineralogy of Bakibaba and cinders.

* *Corresponding author: Yılmaz Altun, yilmazaltun@etibakir.com.tr*

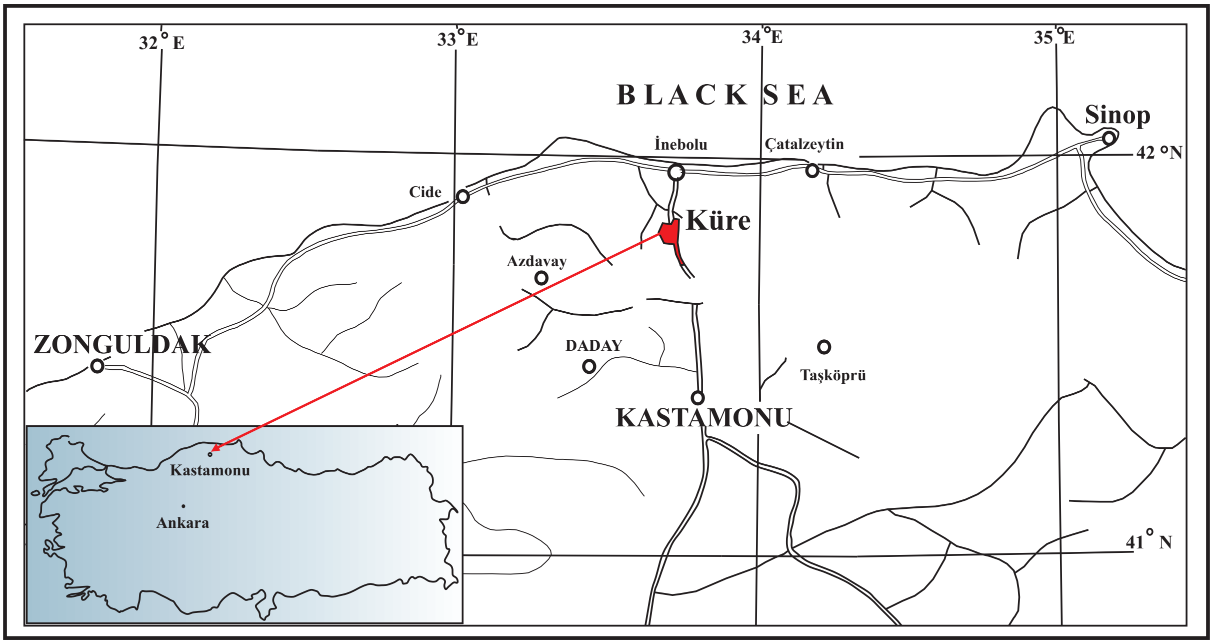

Figure 1- Location map of the study area.

Kovenko (1944) studied the geology of close vicinity of Küre deposits in 1938 for MTA Institute.

Pieniazek (1945) asserted that Küre deposits were derived from hydrothermal metasomatic origin.

Pollack (1964), in his short study, mentioned about the relationship of mineralization with tectonics. He also pointed out that, faults determined the geometry of ore bodies and ore boundaries occurred passing through faults.

Sarıcan (1968) performed a reserve estimation based on data obtained by MTA and Etibank between 1963 and 1965.

Çağatay et al. (1980) carried out a detailed mineralogical study in Küre surround and mentioned about the importance of cobalt and gold in these deposits in terms of economics in addition to copper.

Pehlivanoğlu (1985) carried out a geological investigation in Küre copper deposits and its vicinity. He also pointed that, copper deposits were in stockwork disseminated within upper layers of volcanic sequence, and these deposits were formed in the form of massive ore between the overlying sedimentary sequence and those volcanic sequence.

The Metal Mining Agency of Japan (MMAJ), (1985) studied the geology and geophysics of the region among Taşköprü-Devrekani-Küre-Ağlı towns for Etibank Co. The agency has also performed drilled investigations around Küre, but there have not been detected any mineral reserves.

Kuşçu and Erler (2002), based on data obtained by studies carried out on the mineral deposits of Küre region, stated that pyrites in this region had been subjected to deformational effects and accordingly; the series of deformation and late deformation texture had been formed.

Altun et al. (2009) have obtained results in studies performed between 2005 and 2008 in Küre copper deposits, and suggested that northern and western continuity of the new ore body detected in Mağaradoruk should have been investigated.

2. Geology

2.1. Regional Geology

The study area is located on the western part of “Pontide” tectonic belt. Investigators such as; Şengör and Yılmaz (1983) and Yılmaz (1980) claimed that metamorphic massifs in “Western Pontides” belongs to “Rhodope-Pontide” continent, “Paleotethys” ocean crust in North in Permo-Triassic had become an active continental margin by southward subduction. They also stated that thick flyschoidal deposit had been formed on “Paleotethys” ocean crust in Early Jurassic, and Küre ophiolites, which represents “Paleotethys” ocean curst, had been placed on “Rhodope-Pontide” continental margin due to the closure of “Paleotethys” in Dogger. Şengün (2006) said that, associating Küre basin with the beginning of detachment of Eastern and Western

Pontides in Early Mesozoic would be more acceptable, rather than being a European marginal basin. He also claimed that Küre ophiolite should have been emplaced within rotational processes as it had been in Antalya basin or in Western Pontides, and as a reason to this, he showed the Küre ophiolite to be cut off by granites.

The oldest units, in this part of Western Pontides, are gneiss, schist, marble, quartzite in greenschist facies which form metamorphic massifs like Daday-Ballıdağ and Ilgaz-Kargı, and metaophiolites intercalating with them (Ketin, 1962; Pehlivanoğlu, 1985). Most of the rocks forming these massifs are Paleozoic (Ketin and Gümüş, 1963). The age of ophiolites, which are transitional with metamorphic rocks, is Cretaceous (Ketin and Gümüş, 1963). Fossiliferous Upper Paleozoic rocks are encountered in most the region and represented by Carboniferous coals. It has large and small outcrops as slices of allochthonous thrust on Cretaceous flysch. Permian is represented by clastic rocks such as; conglomerate, sandstone and sandy shales in places where they overlie coaly units, and by greywacke and limestone in other places. Triassic is observed as massive limestone below Liassic flysch between Devrekani and Abana, only in east of Küre. Liassic, which shows a wide distribution between the southern part of Küre and İnebolu, is represented by ophiolitic rocks consisting of oceanic sediments, serpentines, gabbros, diabase dikes and mafic volcanic rocks (Güner, 1980; Pehlivanoğlu, 1985). This unit grades into gray greywacke in upper layers. Minor fossil findings in deposits mainly indicate Liassic-Lower Dogger (Ketin and Gümüş, 1963). Liassic deposits in Küre overlie mafic pillow lavas of the ophiolitic sequence (Bailey et al., 1967), and are overlain by Malm-Lower Cretaceous reefal massive limestones which begin to deposit with red basal conglomerate. In the region between Kastomonu-İnebolu, Liassic-Malm aged intrusives composed of granodiorite-adamellite are observed which cut Liassic flysch (Pehlivanoğlu, 1985). Malm - Lower Cretaceous limestones are transgressively overlain by a Lower Cretaceous flysch in northern parts of the region which starts with Lower Cretaceous conglomerate and continues with the alternation of sandstone–sandy limestone–marl (Pehlivanoğlu, 1985). The Upper Cretaceous flysch is composed of sandstone, clayey limestone and marl alternation. It consists of intercalations of Pontide island arc volcanism, which is composed of calc alkaline andesite and dacites towards south, along the coastline in west (Pehlivanoğlu, 1985). The Upper Cretaceous flysch around Küre has developed more as marl and limestone intercalation and conformably grades into Paleocene limestones. Eocene in flysch facies is composed of marl–shale–sandstone alternation which occasionally consists of intercalations of lava, tuff and agglomerate, but Oligocene is only in flysch facies. Neogene basins consist of terrigenous and lagoonal deposits.

2.2. Geology of the Study Area

Ultrabasic rocks at the bottom, the overlying Küre formation, which is formed by basaltic rocks and black shales, and cross cutting gabbro-diorite and dacites are located around Küre massive sulfide deposits

Ultrabasic rocks, located at the bottom of the study area, are composed of serpentinized peridotite, dunite and pyroxinites, and outcrop in NW of Küre, Elmakütüğü hill, around Ömer Yılmaz locality and in east of Karacakaya hill (Figure 2). The lower boundary of ophiolites in Küre region is not observed, and chromite and chrome spinal are observed in rare amounts (Bailey, et al., 1967). Boundaries of the unit with other units are faulted.

Küre formation, which is abundantly observed in Küre and its vicinity, is mainly composed of basaltic rocks and black shales. Basaltic rocks are widely observed in the form of pillow lavas. The unit was defined by Kovenko (1944) and Ketin (1962) as diabase, by Bailey et al. (1967) as mafic volcanic rocks (pillow lava, breccia, tuff), by Güner (1980) as basaltic sequence, by Çağatay and Arda (1984) as spilite, by Pehlivanoğlu (1985) as basic volcanic sequence and by MMAJ (1995) as Küre volcanics.

Basaltic volcanic rocks are formed by basalt, hyaloclastic and pillow lavas (Figure 2). They mostly consist of plagioclase, clinopyroxene and/or phenocrysts of iron-titanium. Feldspar microliths, calcite veins and amygdales are locally observed. Massive basalt lavas in lower layers grade into pillow lavas and breccias towards upper layers (Güner, 1980; Çağatay and Arda, 1984; Pehlivanoğlu, 1985). Pillow structures are well developed (Figure 3).

Massive basalt flows are green to blackish green, very fine grained, ophitic to sub-ophitic in texture, and they contain albitized, carbonated plagioclases and chloritized, carbonated augites (Çağatay and Arda, 1984; Pehlivanoğlu, 1985). Carbonation and silicification is widespread in mineralized parts. The diameter of pillows in lavas is in between 25-200 cm. The material between pillows is made up of pelagic sediments or chloritized mafic glass. Pillow lavas are ophitic to intersertal in texture. They also consist of albitized plagioclases, chloritized augites, very rare

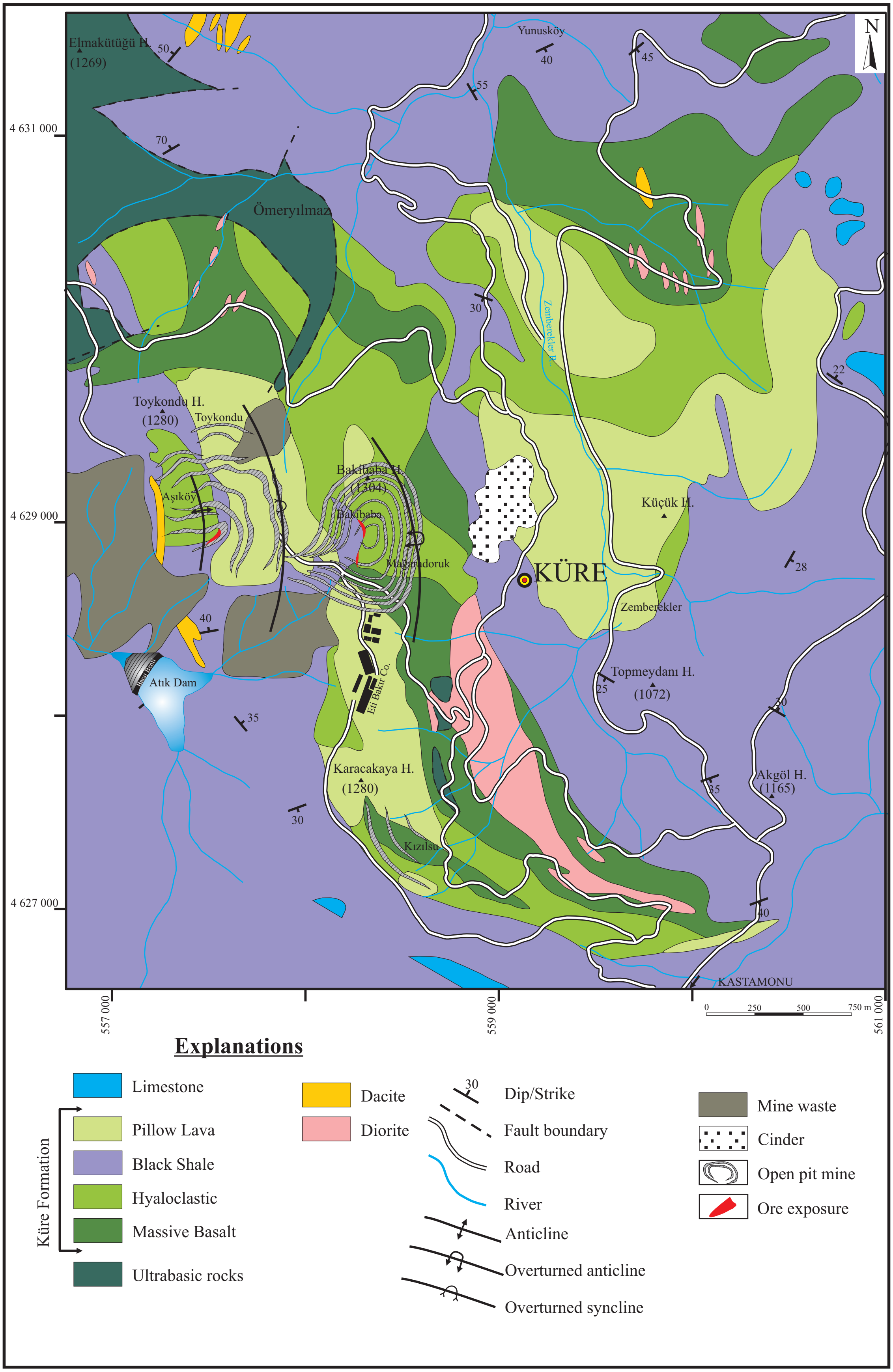

Figure 2- Geological map of the study area (modified from Metal Mining Agency of Japan (MMAJ), 1995).

Figure 3- Basalts in pillow structure.

opaque minerals and secondary quartz (Pehlivanoğlu, 1985). Koç et al (1995) claim that Küre basalts are in tholeiitic character and derived from a SiAl and SiMa type magma (Figure 4). Güner (1980) has studied the geochemical characteristics of these lavas and concluded that these were tholeiitic in character and were the product of oceanic ridge volcanism (Figures 5 and 6).

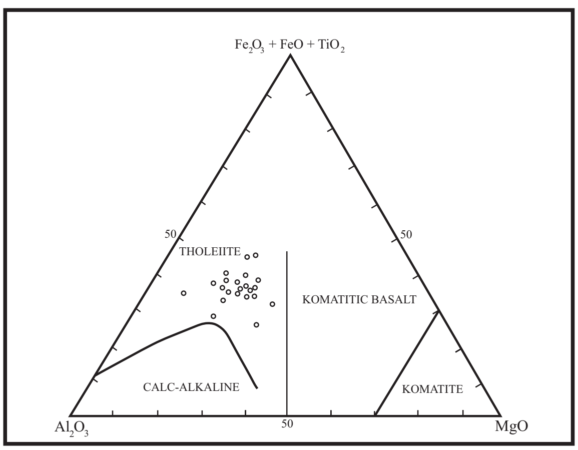

Figure 4- Jensen (1976) diagram of volcanics (from Koç et al., 1995).

Basalts cover very wide areas around Küre, in Kızılsu, Bakibaba, Aşıköy and Mağaradoruk deposits and their vicinities (Figure 2). Total thicknesses of these basalts are more than 2000 meters. Basalts are formed by several lava flows, and their physical characteristics, and mineralogical contents mostly resemble to each other. However; it is understood from black shale and massive sulfide bodies that this body was a lava accumulation heaped on each other which generated at different stages.

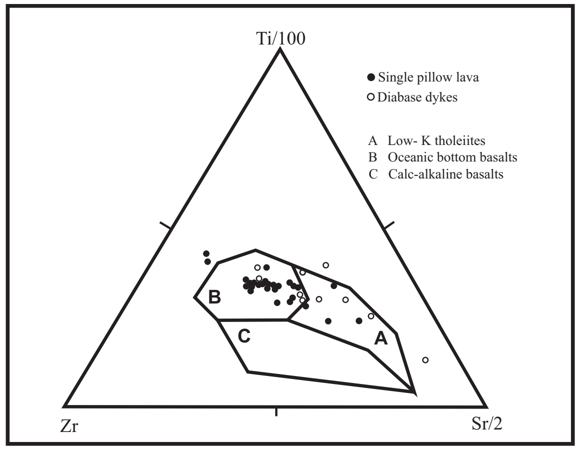

Figure 5- The plot of basaltoids around Küre on Pearce and Can discrimination diagram (1973) (Güner, 1980).

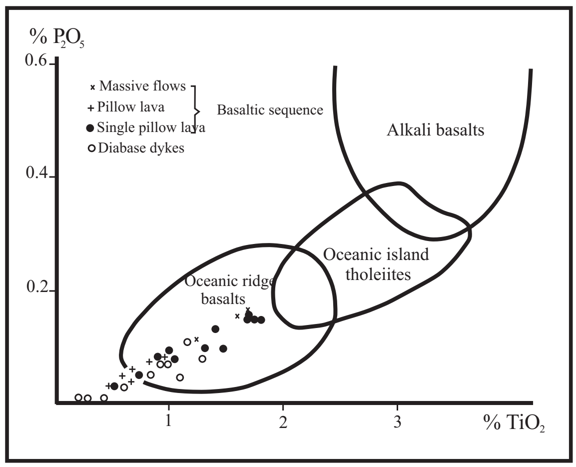

Figure 6- The variation of P_2O_5 among basaltoids around Küre with respect to TiO_2 according to Ridley et al. (1974) (Güner, 1980).

Black shales were named as “argillite” in several previous studies (Bailey et al., 1967; Çağatay and Arda, 1984). The “black shale” definition was first used by Güner (1980). Although it is accepted that black shales overlie basaltic sequence of Küre ophiolite (Pehlivanoğlu, 1985), several black shales are encountered within basalts around Küre deposits. Some of them are closely associated with mineralization, but the others are observed between basalts and/or as lenses in basalts as they were in Mağaradoruk deposit (Figure 7, 8 and 9).

Black shales are cut by Dogger aged granitic intrusions, dacite dyke and sills. Although these shales are considered as roof rock of the massive ore, they are located both as roof and basement rock of the massive ore in Mağaradoruk deposit (Figure 9).

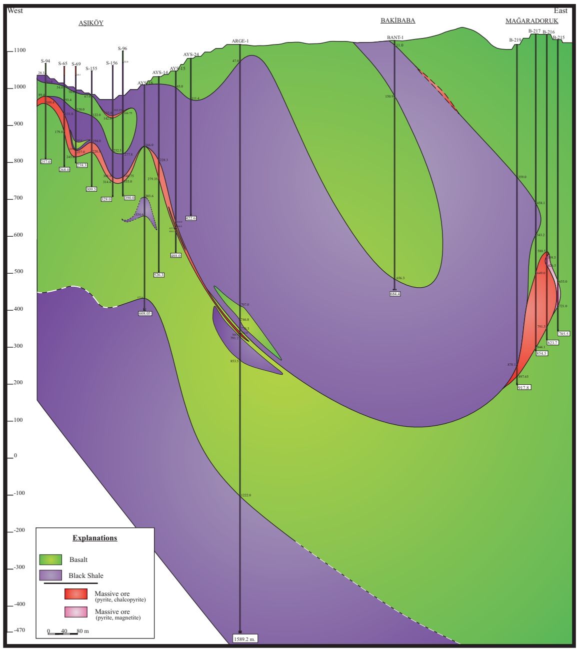

Figure 7- Geological section crossing Aşıköy, Bakibaba and Mağaradoruk deposits.

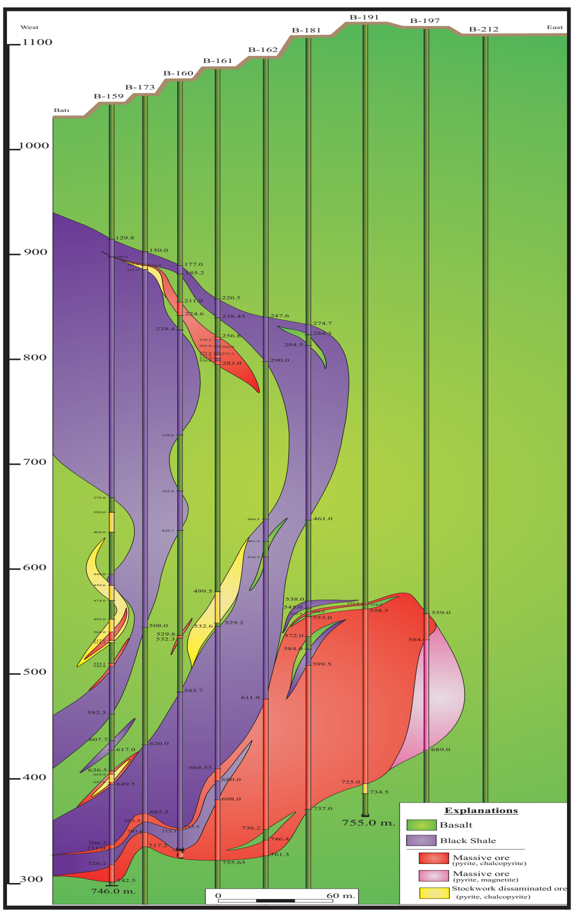

Figure 8- Vertical cross section (to the axis of north-south directing overturned anticline) in Mağaradoruk deposit.

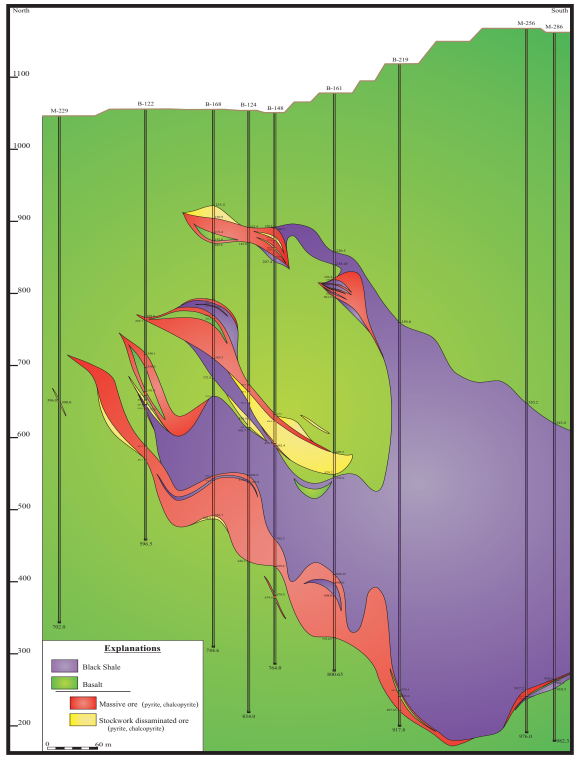

Figure 9- Parallel cross section (to the axis of north-south directing overturned anticline) in Mağaradoruk deposit.

Black shales are nearly 150 m thick in Aşıköy village (Çağatay and Arda, 1984). The true thickness of these shales in Mağaradoruk is more than 200 meters.

It is dark gray to black, very fine grained and thin bedded, and consists of basaltic pebble and blocks on the boundary with basaltic lavas. Upper layers show transition into graded sandstone (Çağatay and Arda, 1984). Petrographic and X-ray diffraction and ore microscopy studies show that this rock is formed by illite, quartz, chlorite, siderite and muscovite, and secondarily consists of coal-like material, graphite, pyrite, chalcopyrite, chrome spinal, ilmenite and hematite (Güner, 1980; Çağatay and Arda, 1984).

Gabbros and diorites are observed around Küre, on Dikmen mountain at west, in the vicinity of İkiçay bridge along İnebolu road at north of Küre, around Dibekköy at east and at south of Küre in the form of big and small intrusions; and as restricted bodies in lower parts of the basaltic sequence (Pehlivanoğlu, 1985). Gabbros are dark green and gray to green colored. Labrodorites consist of augite and olivine; however, diorites consist of amphibole, biotite and albite.

Dacites in the west of Aşıköy and Toykondu open pit mining area contain corroded quartz and phenocrysts of partly seriticized plagioclase (Pehlivanoğlu, 1985). When relationships of dacites with black shales are taken into consideration, it was concluded that these dacites could most probably be sill – dyke (Figure 2).

3. Structural Geology

Liassic volcanic rocks and black shales around Küre have been effectively folded, and their fold axes are roughly in N-S direction (Figure 2). The dome, which its long axis is in N-S direction in Aşıköy, has a quite high inter-limb angle (Bailey et al., 1967; Pehlivanoğlu, 1985). Basalts between Aşıköy and Mağaradoruk, which overlie black shales in east of this anticline, are mostly in the form of pillow lava. There is also observed N-S extending overturned anticline between Aşıköy and Bakibaba-Mağaradoruk, and a nearly N-S extending overturned anticline towards east of Bakibaba-Mağaradoruk deposits (Figure 2). This overturned anticline also plunges towards south in Mağaradoruk deposit.

4. Ore Deposits

Massive and stockwork disseminated sulfide deposits, which are known as Küre copper deposits and mainly composed of pyrite and chalcopyrite, are located at west of Küre town center, and they align in the order of Toykondu, Aşıköy, Bakibaba, Mağaradoruk and as Kızılsu from north to south (Figure 2).

Küre copper deposits have been the subject of mine operations since ancient times. Mining activities in the region dates back to Greek and Roman times and have also continued during Seljuk, Genoa and Ottoman times. The mining activities of Ottomans in Bakibaba deposit ended in 1845. Mineral exploration and development studies in scientific manner began in 1935 with the foundation of the General Directorate of Mineral Research and Exploration (MTA), and Aşıköy deposits was explored in 1944. Exploration studies, which began in 1963 in Bakibaba deposit, were revealed in two ore bodies as north and south sections (Sarıcan, 1968). It is understood that the deposit, which has been known and operated since ancient times, is the southern ore body in Bakibaba copper deposit from historical documents, operational traces and from cinder heaps around Bakibaba. The northern ore body here has been operated by Black Sea Copper Co. (K.B.İ.) for many years since 1968, but the site was abandoned due to pyrite fire in galleries in 1990 (Ildız and Dağcı, 1990).

The whole ore deposits in Toykondu, Kızılsu, Bakibaba and Aşıköy, which were taken over by Cengiz Holding from Etibank Co. in 2004 and produced by open pit mining method, has been depleted until 2009 (Altun et al., 2009). The ore, which was explored by studies carried out in Aşıköy deposit between the years 2005-2008, still continues its production by open pit mining method.

Mağaradoruk massive sulfide deposits were explored as a result of exploration studies, which began in 2008 and intensified around Mağaradoruk hill, on the eastern steps of Bakibaba open pit mining.

4.1. Mineralization

Kovenko (1944), Pollack (1964) and Bailey at al. (1967) claimed that the mineralization in Küre copper deposits were hydrothermal in origin and formed by metasomatic processes. Çağatay (1981) interpreted deposits as being based on basaltic volcanism and sea floor product. Koç et al. (1995) state that these deposits resemble genetically to “Kieslager type” deposits which form in forearc rather than “Cyprus type” deposits. Üşümezsoy (1988) says that these deposits are associated with the opening of Kimmeridgian basins, and they are products of bimodal rift volcanism and oceanic spread volcanism.

The mineralization in Küre deposits is closely associated with basalt-black shale units. As a result of studies, Küre basalts are mid ocean ridge basalts (Güner, 1980). Massive sulfide bodies like black shales, which are located with Küre basalts, are in the position of basement and roof rock. Some of the ore bodies here are located within basalts, of some are in black shales or on basalts, and are overlain by black shales (Figure 7 and 8). The black shale overlying the massive sulfide ore (Figure 10) consists of ore bands, which are mainly composed of occasionally well sorted pyrite and chalcopyrite in places where the mineralization thins out (Figure 11).

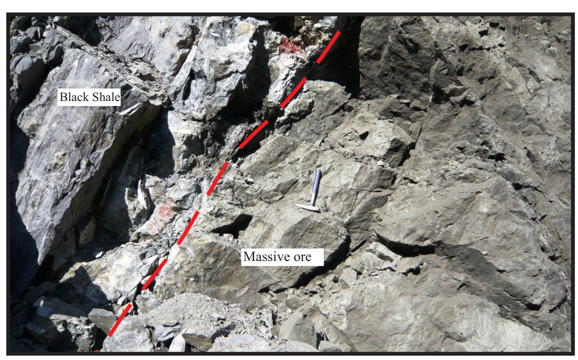

Figure 10- Black shale covering the massive ores.

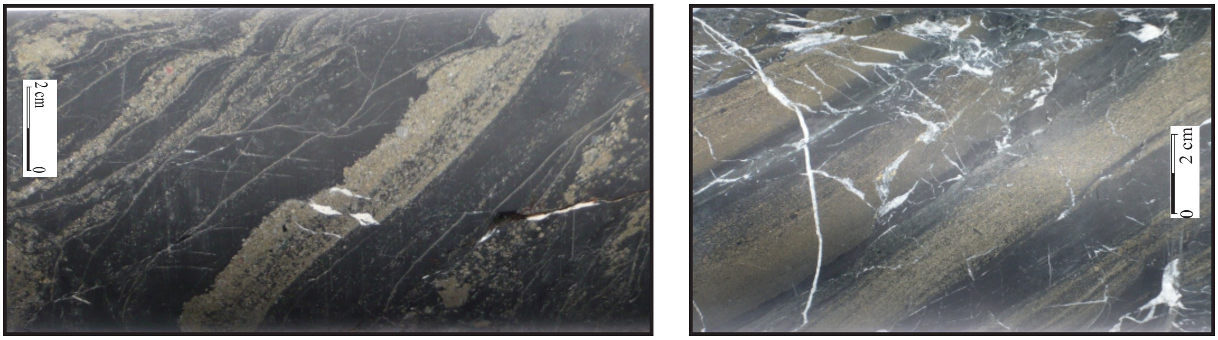

Figure 11- Traces of sorting in massive ore bands which are formed by pyrite and chalcopyrite in black shale.

Total of 30 samples taken from drill cores in main ore body of the Mağaradoruk deposit were analyzed in terms of Cu, Zn, Pb, Au, Ag, Co, Ni, As, Mo, Sb, Se and Ti contents (Table 1). Analyses were performed in ALS Mineral Laboratory. Samples were dissolved by quadruple acid solution method and analyzed by Inductively Coupled Plasma Atomic Emission Spectrometry (ICP-AES) method. Au element was analyzed by Atomic Absorption Spectroscopy (AAS) method. One sample, which has Au concentration higher than 10 ppm, was dissolved by Fire Assay Fusion technique and analyzed by Gravimetric method.

Küre deposits resemble to “Cyprus” type massive sulfide deposits of which have ophiolitic wall rocks, defined by Galley and Koski (1999), because of the environment where Mağaradoruk deposit is located. This resemblance is also supported by Cu, Pb, Zn discrimination diagram (Figure 12), which was prepared by using analyses of samples taken from major sulfide body in Mağaradoruk deposit (Table 1).

On the other hand, Zaccarini and Garuti (2008) emphasize that Co/Ni ratio in massive sulfide deposits, of which their main rock is serpentine, varies between 0.29 and 1.97. However; the ratio of massive sulfide deposits of which the main rock is basalt varies between 1.09 and 8.

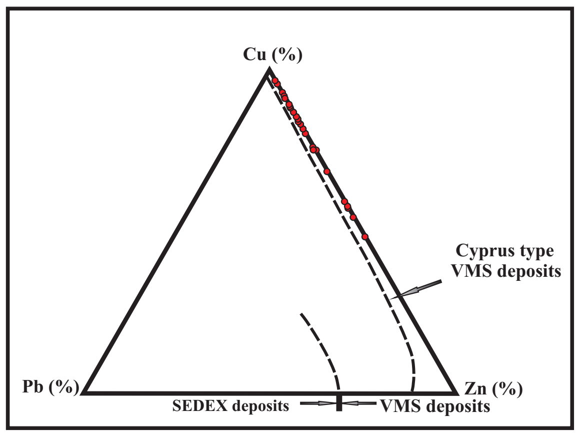

Figure 12- Cu, Pb, Zn discrimination diagram (from Galley and Koski, 1999).

Table 1- Results of analysis of samples taken from drill cores cutting main ore body in Mağaradoruk deposit.

Sample	Cu	Zn	Pb	Au	Ag	Co	Ni	As	Mo	Sb	Se	Ti	Co/Ni
	%	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	%	
M-1	5.86	18700	282	1.58	8.17	5580	31.2	461	39.4	26.7	70	<0.005	178.85
M-2	4.51	20400	209	2.1	11.7	3770	16.4	597	37.6	31.1	37	<0.005	229.88
M-3	5.26	7650	114.5	2.82	7.9	9080	101.5	471	56.6	28	156	0.009	89.46
M-4	4.66	11200	112	1.725	8.34	6710	32.2	356	43.5	21.6	56	<0.005	208.39
M-5	8.01	9660	146.5	1.805	8.61	5960	52.5	431	57.4	26.2	102	<0.005	113.52
M-6	4.8	8980	137	1.615	7.7	4280	62.4	363	58.1	17.85	50	0.052	68.59
M-7	7.35	12900	131	1.8	9.95	6240	47.3	458	59.9	24.9	118	<0.005	131.92
M-8	4.49	7780	83.9	1.685	8.07	6490	43.6	323	47.4	16.1	66	<0.005	148.85
M-9	4.75	1760	179	2.5	12.65	4810	34.3	456	32.1	15.1	73	0.043	140.23
M-10	6.14	2070	206	3.1	14.6	2930	29.5	463	43	16	45	0.042	99.32
M-11	6.05	4680	133	1.39	5.68	5180	13.6	295	50.3	12.9	25	<0.005	380.88

Table 1- (continued)

M-12	6	12050	133	1.29	5.59	6600	19.6	359	49.8	14.1	33	0.007	336.73
M-13	1.575	1440	47.2	0.392	1.23	13000	48.5	199	43.6	6.92	198	<0.005	268.04
M-14	2.36	1790	57.4	0.633	2.25	7940	37.8	193.5	47.8	7.33	114	<0.005	210.05
M-15	4.44	5560	145.5	1.495	5.03	9700	38.3	412	52.8	15.5	69	<0.005	253.26
M-16	4.62	2100	80.2	0.875	1.77	8650	36.1	291	48.5	8.19	89	<0.005	239.61
M-17	7.15	9460	160	1.76	9.13	5490	52.1	278	58.5	14.6	59	<0.005	105.37
M-18	5.09	8510	104	2.09	9.83	4930	22.5	472	46.1	16.05	61	0.031	219.11
M-19	3.15	23000	119.5	2.65	12.9	3850	21.2	390	43.4	17.8	38	0.017	181.60
M-20	1.01	8370	89.3	0.652	9.37	1000	67.6	184	18	9.1	31	0.394	14.79
M-21	11.85	38800	199.5	8.35	38.4	2840	17	375	67.7	23.3	18	<0.005	167.06
M-22	8.27	18350	138	10.7	30	3950	17.2	266	62.7	18.05	20	<0.005	229.65
M-23	3.24	4710	96.6	3.37	5.46	4520	17.1	416	42.5	15.85	35	<0.005	264.33
M-24	6.47	2730	140.5	1.845	5.92	5150	21.2	332	55.1	13.55	27	<0.005	242.92
M-25	5.28	4540	140	1.145	3.93	7810	33.2	332	61.6	11.35	66	<0.005	235.24
M-26	4.07	5300	196	2.43	13.05	3730	18.5	556	42.1	30.8	22	<0.005	201.62
M-27	4.41	13550	302	2.67	18.3	3150	25.3	890	35.8	35.6	26	<0.005	124.51
M-28	3.14	21200	120.5	1.985	9.46	4470	24.5	327	36.9	20.2	29	<0.005	182.45
M-29	3.6	38100	169.5	2.25	13.55	5090	32.9	448	39.8	22.8	44	<0.005	154.71
M-30	3.53	26100	159	2.95	12.85	4950	36.6	618	41.5	26.9	40	0.008	135.25

Co/Ni ratio in Mağaradoruk deposit (Table 1) is; however, much higher than values in massive sulfide deposits of which their wall rock is basalt.

Küre massive sulfide deposits should have formed either by the occurrence of basalts that had occurred by Liassic-pre Liassic submarine volcanism or as a result of hydrothermal processes which occurred when the volcanism had ended. Constantinou (1980) states that Cyprus type deposits have been shaped on Mid Ocean Ridges and formed by hydrothermal circulation when there was a gap in magmatic activity.

Brathwaite and Pirajno (1993) assert that Papuke, Pakotai and Parakoa massive sulfide deposits in New Zealand are "Cyprus" type massive sulfide deposits and were formed due to basaltic volcanism in mid ocean ridges in "Black Smoker" environment. Irregular ore lenses in Papuke deposit are surrounded by claystones and sandstones. Ore lenses in Pakotai deposit are located in mudstones. In Parakoa deposit, small sulfide lenses are in volcanic rocks and shales. (Brathwaite and Pirajno, 1993). Ergani Mihrapdağı mineralization is located between Eocene mudstones and chloritized basalt, and Ergani Anayatak mineralization occurs between bedded diabases (Bamba, 1976; Wijkerlooth, 1944). Siirt Madenköy massive sulfide deposit is, on the other hand, located in porphyritic spilites (Çalgın, 1987; Yıldırım and Alyamaç, 1976; Ulutürk, 1999). Mineralizations observed in Koçali ophiolitic complex in Southeast Anatolian Orogenic Belt are located in highly altered oceanic crust origin spilitized basic volcanics and mudstone-radiolarites (Yıldırım et al., 2012; Yıldırım, 2013; Yıldırım et al., 2014). The occurrence of massive sulfide lenses in Mağaradoruk deposit in basalts and black shales, and being overlain by back shales show big resemblance with formation of environments of deposits mentioned above (Figure 13).

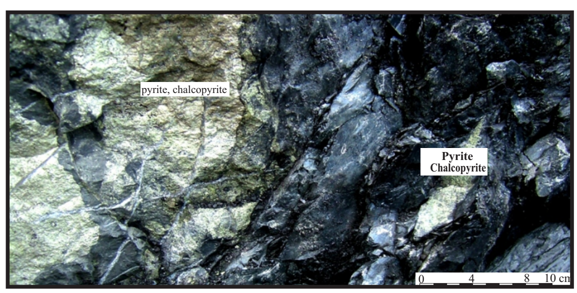

Figure 13- Small massive sulfide lenses observed in black shales.

The occurrence of massive sulfide lenses in Mağaradoruk deposit in more than one level (Figures 7, 8 and 9) supports the opinion of Harper (1999). He suggests that "Cyprus" type massive sulfide deposits could form in several levels starting from the top of magma chamber to sedimentary cover rocks.

There is a very special hydrothermal field on Juan de Fuca ridge in Pacific Ocean, 300 km away from Washington. There is observed a graben there which is 1 km wide and 100-200 m deep. In this graben, there are four sulfide formations, which are formed by several hydrothermal vents (black smoker) that cover wide areas with lengths reaching 400-500 meters. Massive sulfide deposits in Küre occur in a limited area and close to each other (Figure 2). This situation highly resemble to massive sulfide deposits in mid ocean ridges and Troodos today (Stos-Gale et al., 1997), and to locations of Ergani copper deposits (Wijkerlooth, 1944). Stockwork disseminated ore consisting of sulfidic dissemination, veins and veinlets with quartz and carbonate veins in basalts have better developed mostly below massive ore bodies as it is in Ergani copper deposits (Wijkerlooth, 1944).

The maximum thickness of stockwork disseminated ore is 50 meters. In Mağaradoruk deposit towards bottom and margins, silicified, seriticized magnetite, hematite and disseminated pyrite, chalcopyrite bearing basalt show a gradual transition into chloritized basalt. Stockwork disseminated ore, which is observed in Trans-Atlantic Geotraverse (TAG), is formed by quartz-pyrite-chalcopyrite, and continues down to 95 meters below sub sea floor Besides; silicified wall rock breccia gradually grades into chloritized basalt at the bottom of stockwork disseminated ore zone (Hannington et al., 1998).

On the eastern margin of the massive ore body in Mağaradoruk deposit, magnetite and hematite accompany with other sulfides like pyrite and chalcopyrite (Figure 8, 14). Similar characteristics are also observed in Siirt Madenköy (Çalgın, 1978) and Ergani copper deposits (Çağatay, 1978; Bamba, 1976).

Although; the reserve of deposits in some of “Cyprus” type massive sulfide deposits reaches 30 million tones, the approximate size of them are 5 million tones (Galley and Koski, 1999). Mağaradoruk massive sulfide deposit is among the biggest ones with its 29 million tones in reserve.

4.2. Mineralization and Structural Relationships

Basalts in Mağaradoruk and Bakibaba were formed most probably in the same phase with basalts at the bottom of Aşıköy, and they form an overturned anticline which is pushed westward which its long axis is in N-S direction (Figure 2).

Massive ore bodies are observed both inside these basalts and along the contacts with black shales. These bodies, which are above 780 m height of Mağaradoruk deposit, are seen as overturned position. Big ore body in Mağaradoruk deposit is located in non-overturned lower part of the western flank of this overturned anticline (Figure 10).

Ore bodies are in the form of highly tilted lenses (60°-85°) in most parts of Aşıköy, Bakibaba and Mağaradoruk deposits. However; these structures were acquired after the formation of rocks in which ore and ore bodies are kept. It is significant to know in which environment these ore bodies have occurred. When basalts located at the bottom of massive ore bodies especially in Mağaradoruk and Aşıköy deposits and in other deposits were studied, it was seen that these basalts possessed an irregular topography with depressions and hills. Massive ore bodies are thicker in depression zones whereas; they are less or not developed at all on hills (Figures 7, 8 and 9).

This topographical difference has a close relationship with mineralization. However; whether this mineralization had occurred as a result of volcanic activity or due to a pre mineralization movement in post volcanism cannot be understood, because of deformations they had been subjected to after formations. Looking at contemporaneously forming hydrothermal vents (black smokers) in TAG massive sulfide deposits in detail, fractures parallel to axis, faults in east-northeast directions and a couple of graben like depressions (Kleinrock and Humphris, 1996), the presence of four hydrothermal vents (black smokers) in 2-3 km intervals in a 1 km wide, 100-200 m deep graben in Juan de Fuca Ridge and still the occurrence of sulfide deposition in these vents are the answers to this question.

4.3. Ore and Gangue Minerals

In Küre Mağaradoruk massive sulfide deposit, mainly; pyrite, chalcopyrite (Figures 14 and 16), in few amounts; marcasite, sphalerite (Figures 14c, 14d and 14h), covelline, neo-digenite, malachite, azurite, fahlers, in very few amounts; bravoiite (Figure 14g), lineiite, karolite (Figures 14e, 14f), limonite, hematite, magnetite and in trace amount; chalcosine (Figure 17), cuprite, tenorite, pyrrhotine, valleriite, bornite, galenite, native copper, native gold (Figure 14h), chromite, rutile and anatase are observed. Main gangue minerals are quartz, siderite-ankerite, calcite, dolomite and chlorite. Bravoiite, lineiite, magnetite (Figure 15), hematite and native copper (Figure 18) in Mağaradoruk deposit are observed more than they are in Aşıköy and Bakibaba deposits (Çağatay et al., 1980, 1982). Similar mineral assemblages are also observed in Ergani (Wijkerlooth, 1944; Göymen- Aslaner, 1963; Çağatay, 1978) and Siirt Madenköy copper deposits (Çağatay, 1978; Çalgın, 1978; Ulutürk, 1999).

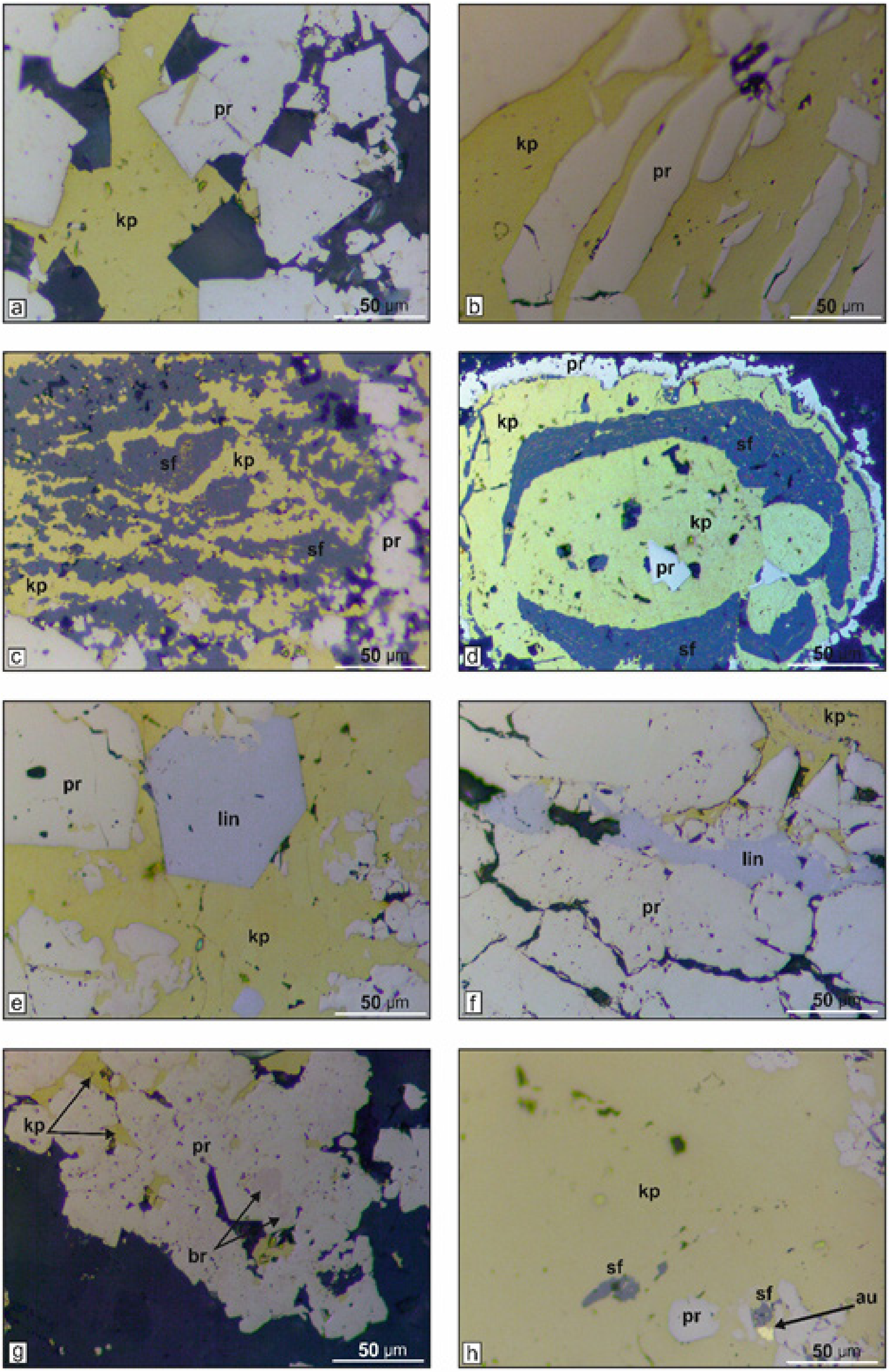

Figure 14- a) Chalcopyrite (Ccp) and gangue minerals (black) infilling grain voids of euhedral pyrites (py), b) chalcopyrite infilling cataclastic fractures of pyrites, c) chalcopyrite and sphalerite (sp) showing intergrowth which surround euhedral, subhedral pyrites, d) sphere with concentric crust which was formed by pyrite, chalcopyrite and sphalerite, e) euhedral lineiite (lin) in chalcopyrite which surrounds pyrite, f) lineiite accumulations and gangue minerals which fulfill cataclastic fractures of pyrite, g) bravoite (br) accumulations (as banded and worm like) which reveal the zoning structure of pyrite in pyrite, h) native gold which is observed among pyrite, chalcopyrite and sphalerite.

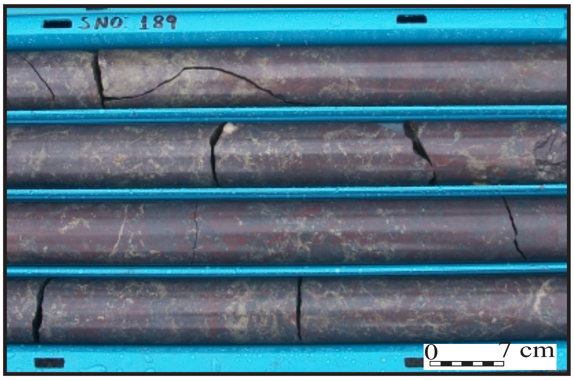

Figure 15- Massive ore which is formed by pyrite, chalcopyrite and magnetite in east of Mağaradoruk deposit.

Figure 16- Chalcopyrite veins within massive pyrite, chalcopyrite in Mağaradoruk deposit.

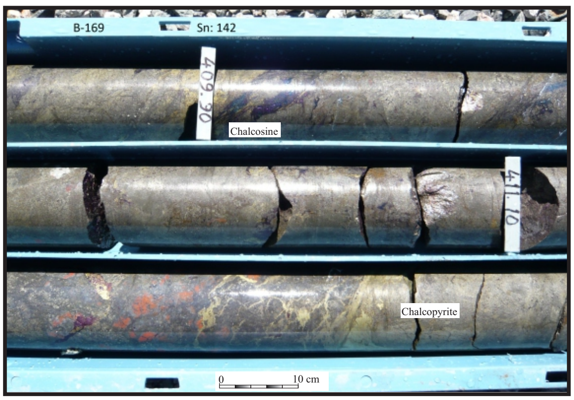

Figure 17- Chalcopyrite and chalcosine veins in massive pyrite and chalcopyrite in Mağaradoruk deposit.

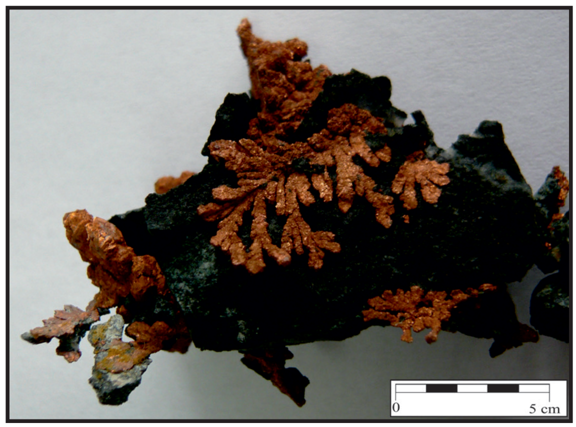

Figure 18- Native copper in basalt.

Main ore minerals in “Cyprus” type deposits are pyrite, chalcopyrite, sphalerite, pyrrhotine and magnetite (Constantinou and Govett, 1972). These are accompanied by lineiite and valeriite in few amounts.

Main ore minerals in TAG massive sulfide deposit are pyrite, chalcopyrite, sphalerite and bornite. Most observed gangue mineral is anhydrite (Thompson et al., 1988; Rona et al., 1993; Brown and Mc Clay, 1998).

4.4. Alteration

Main rocks in Mağaradoruk deposit are basalts, pillow lavas, hyaloclastics and black shales. The ones, which have traces of hydrothermal differentiation, are basaltic rocks. Basaltic rocks are formed by several lava flows which were formed in different times though they have similar mineralogical characters. They are partly more fresh, but mostly chloritized and carbonated away from ore bodies. They do not show any significant change until a distance very close to ore bodies. Epidotization is quite often observed in upper parts of ore bodies. In basalts, which consist of massive ore bodies, the primary textures of the rock have completely disappeared just above the massive ore.

As going away from massive ore bodies, the sericitization gives way to chloritization. Stockwork disseminated ore, which is formed by sulfide vein, veinlet and disseminations below massive sulfide bodies, grade into chloritized basalt with continuously weakening ore as it was in Ergani Anayatak deposit (Wijkerlooth, 1944). This zone becomes narrow towards deeper levels but do never develop under the whole massive ore body. Here; pyrite, chalcopyrite disseminations and veinlets are accompanied by magnetite and hematite dissemination, vein and veinlets.

5. Results

Küre - Mağaradoruk copper deposit should be a massive sulfide deposit, which developed based on hydrothermal processes when volcanism has ended in the environment in which Liassic- pre Liassic mid ocean ridge basalts had been formed.

This deposit is formed by a couple of small and a big massive ore deposit, and consists of less developed, stockwork disseminated ore below massive ore body.

In Mağaradoruk massive sulfide deposit, the abundance of magnetite-hematite-pyrite-bravoite at the bottom, chalcopyrite in middle parts and sphalerite in uppermost layers indicate a mineral zonation.

The presence of several massive sulfide deposits in Troodos massive, which are very close to each other, the observation of massive sulfide deposits within narrow area such as; Şahgeltepe, Mihrapdağ, Arpameydanı and Anayatak in Ergani, several hydrothermal vents that are arranged in short distances in Atlantic and Pacific mid ocean ridges to form contemporaneous sulfide deposits indicate that massive sulfide deposits in Küre (Mağaradoruk, Toykondu, Aşıköy, Bakibaba ve Kızılsu) might have also been formed in similar environments.

Massive sulfide lenses, in Mağaradoruk massive sulfide deposit, are mostly located on basaltic rocks within basaltic rocks and black shales, and are covered by black shales. This deposit resembles to Siirt Madenköy, Ergani massive sulfide deposits, to "Cyprus" type massive sulfide deposits and "modern Cyprus type massive sulfide deposits" in terms of mineral contents; and to Ergani Mihrapdağı, Papuke, Pakotai and Parakoa deposits in terms of cover rocks, which are Cyprus type massive sulfide deposits, in New Zealand.

Received: 14.01.2014
Accepted: 05.01.2015
Published: June 2015

References

Altun, Y., Yılmaz, H., Hatko, C., Yılmaz, B. 2009. Kastamonu- Küre Bakır yatakları ve bu yataklar da 2005- 2008 yılları arasında yapılan arama çalışmaları ile elde edilen sonuçlar. Eti Bakır A.Ş. Genel Müdürlüğü, Kastamonu (unpublished).

Bailey, H., Barnes, J. W., Kupfer, D. H. 1967. Türkiye Kastamonu ile Küre Bölgesi cevher yatakları ve jeolojisi. *Etibank Genel Müdürlüğü raporu* (unpublished).

Bamba, T. 1976. Ophiolite and related copper deposits of the Ergani mining district, Southeastern Turkey. *Bulletin of the Mineral Research and Exploration 86, pp.36-50*

Brathwaite , R.L., and Pirajno, F. 1993. Metallogenic map of New Zealand. *Institue of Geological and Nuclear Sciences Monograph* 3.

Brown, D., McClay, K. R. 1998. Sulfide Textures in the Active TAG massive sulfide deposit 26° N, Mid– Atlantic Ridge. Herzig, P.M., Humphris, S.E., Miller, D.J., and Zierenberg, R.A. (Eds.). Proceeding of the Ocean Drilling Program, Scientific Results, 158p.

Constantinou, G. 1980. Metallogenesis associated with the Troodos ophiolite. A. Panayiotu (Ed.). *Ophiolites Proceeding İnternational Ophiolite Symposiu,* 1980 Nicosia-Cyprus, pp.663-674.

Constantinou, G., Govett, G.J.S. 1972. Genesis of sulphide deposits, ochre and umber of Cyprus. *Institute Mining Metallurgy* 8(b), pp.33-46.

Çağatay, A. 1978. Güneydoğu Anadolu bakır yatak ve zuhurlarının jeolojik-mineralojik etüdü sonunda elde edilen jenetik bulgular. *Maden Tetkik ve Arama Dergisi* 89, pp.46- 69.

Çağatay, N. 1981. Yeni gelişmelerin ışığında Türkiye'nin volkanik kökenli masif sülfid yatakları. *1.Türkiye Jeoloji Mühendisliği Bilim ve Teknoloji Kongresi. Jeoloji Mühendisleri Odası Yayını* 6, pp.35-36.

Çağatay, A., Pehlivanoğlu, H., Altun, Y., 1980. Küre piritli bakır yataklarının kobalt-altın mineralleri ve yatakların bu metaller açısından ekonomik değeri. *Maden Tetkik ve Arama Dergisi,* 93/94 (1979-1980), pp.110-117.

Çağatay, A, Arman, B., Altun, Y., Pehlivanoğlu, H. 1982. Küre (Kastamonu) Yataklarında izlenen ve lineyit grubundan olan kobalt mineralinin elektron mikroprob analizi. *Karadeniz Teknik Üniversitesi Yer Bilimleri Dergisi* 2 (1-2), pp.131-134.

Çağatay, A., Arda, O. 1984. Küre Bölgesindeki kayaçların mineralojik incelenmesi. Kastamonu (unpublished).

Çalgın, R. 1978. Siirt-Madenköy bakır yatağının jeolojisi ve mineralizasyonu. *Maden Tetkik ve Arama Genel Müdürlüğü Rapor No: 5651, Ankara* (unpublished)

Galley, A.G., Koski, R.A. 1999. Setting and Caracteristics of ophiolite hosted volcanogenic massive sulphide deposits. *United States, Society of Economic Geologists* 8, pp.221-246.

Göymen- Aslaner, G. 1963. Doğu Anadolu'da bulunan Ergani maden bakır yatağının ve bilhassa yantaşlarının maden mikroskopik incelenmesi. *Maden Tetkik ve Arama Dergisi* 72, pp.177-187.

Güner, M. 1980. Küre civarının masif sülfid yatakları ve jeolojisi pontidler (Kuzey Türkiye). *Maden Tetkik ve Arama Dergisi* 93/94, pp.65-109.

Hannington, M.D., Galley, A.G., Herzig, P.M., Petersen, S. 1998. A comparison of the TAG Mound and stockwork complex with Cyprus- type massive sulfide deposits: Proceedings Ocean Drilling Program, Scientific Results 158, pp.389- 415.

Harper, G.D. 1999. Structural Styles of hydrotermal discharge in ophiolite/seafloor systems. pp.53-73 (chap.3) in Barrie , C.T., and Hannington, M.D. (eds.). Volcanic Associated massive sulfide deposits. *Reviews in Economic Geology Society of Economic Geologists* 8, Chap- 3, pp.53- 73.

Ildız, T. , Dağcı, Z. 1990. Bakibaba rezerv hesapları raporu. Karadeniz Bakır İşletmesi Genel Müdürlüğü Ankara.

Jensen, L.S. 1976, A new cation plot for classifying subalkalic Volcanic rocks: *Ontorio Dep. Mines., Mise Paper*, 66, pp.1-22.

Ketin, İ. 1962. 1/500 000 ölçekli jeolojik haritası Sinop paftası ve izahnamesi. *Maden Tetkik ve Arama Enstitüsü Yayınları*, Ankara.

Ketin, İ., Gümüş, A. 1963. Sinop-Ayancık arasında 3. bölgeye dahil sahaların jeolojisi. *Türkiye Petrolleri Anonim Ortaklığı Rapor No: 288.*

Kleinrock, M. C., Humphris, S. E. 1996. Structural control on seafloor hydrothermal activity at the TAG active mound. *Nature* 382, pp.149-153.

Koç, Ş., Unsal, A., Kadıoğlu, Y.K. 1995. Küre (Kastamonu) cevherleşmelerini içeren volkanitlerin jeolojisi, jeokimyası ve jeotektonik konumu. *Maden Tetkik ve Arama Dergisi* 117, pp.41-54.

Kovenko, V. 1944. Küre'deki eski bakır yatağı ile yeni keşfedilen Aşıköy yatağının ve Karadeniz orta ve doğu kesimleri sahil bölgesinin metallojenisi. *Maden Tetkik ve Arama Dergisi* 2/3, pp.180-211.

Kuşçu, İ., Erler, A. 2002. Pyrite deformation textures in the deposits of the Küre Mining District (Kastamonu-Turkey). *Turkish Journal of Earth Sciences* 11, pp.205-215.

Metal Mining Agency of Japan 1995. The Republic of Turkey Report on The Mineral Exploration of Küre Area.

Nikitin, V. 1926. Küre bakır madeni. *Maden Tetkik ve Arama Derleme Rapor No: 850,* Ankara (unpublished).

Pearce J.A., Cann, J.R., 1973, Tectonic setting of basic volcanic rocks determined using trace element analysis: *Earth Planet. Sci. Lett.,* 19, pp.290-300.

Pehlivanoğlu, H. 1985. Kastamonu- Küre piritli bakır yatakları (Bakibaba, Aşıköy) ve çevresinin jeoloji raporu. *Maden Tetkik ve Arama Rapor No: 1744*, Ankara (unpublished).

Pieniazek, J. 1945. Küre araştırmaları kati raporu. Etibank Küre Bakırlı Pirit İşletmesi Müessesesi, (unpublished).

Pollak, A. 1964. Küre pirit- bakır yatağı hakkında rapor. *Maden Tetkik ve Arama Genel Müdürlüğü Rapor No: 3693*, Ankara (unpublished).

Ridley, W.L., Rhodes, J.M., Reid, A.M., Jakes, P.; Shih. C., Bass, M. 1974, Basalts from Leg 6 of the Deep-Sea Drilling Project: *Journal of Petrology,* 15.

Rona, P.A., Hannington, M.D., Raman, C.V., Thompson, G., Tivey, M.K., Humphris, S.E., Lalou, C., and Petersen, S. 1993. Active and relict sea floor hydrothermal mineralization at the TAG hydrothermal field, MidAtlantic Ridge. *Economic Geology* 88, pp.1987−2013.

Sarıcan, K. 1968. Bakibaba cevher yatağı arama ve değerlendirme çalışmaları raporu. Küre Etibank, Karadeniz Bakır İşletmeleri Raporu (unpublished).

Stos- Gale, Z.A., Maliotis, G., Gale, N.H., Annetts, N. 1997. Lead isotope characteristics of the Cyprus copper ore deposits applied to provenance studies of Copper axhide in gots Archaeometry 39, pp.107-109.

Şengör, A. M. C., Yılmaz, Y. 1983. Türkiye'de Tetis'in Evrimi: Levha Tektoniği Açısından Bir Yaklaşım. *Türkiye Jeoloji Kurumu Yerbilimleri Özel Dizisi* No. 1, Ankara

Şengün, M. 2006. Anadolu'nun Kenet Kuşakları ve Jeolojik Evrimine İrdelemeli ve Eleştirel Bir Bakış. *Maden Tetkik ve Arama Dergisi* 133, pp.1-26.

Thompson, G., Humphris , S.E., Schroeder, B., Sulanowska, M., and Rona, P.A. 1988. Active vents and massive sulfides at 26°N (Snakepit) on the Mid-Atlantic Ridge. *Canada Mineral* 26, pp.697-711.

Ulutürk, Y. 1999. Siirt Madenköy bakır yatağı. *Maden Tetkik Arama Genel Müdürlüğü Rapor No:* 7562. Ankara (unpublished).

Üşümezsoy, Ş. 1989. Istranca Metamorfik Kuşağı Rift Volkanitlerinin Petrolojisi, Karadeniz Kimmeriyen Çanağının Açılımı ve Masif Sülfidlerin Kökeni. 42. Türkiye Jeoloji Kurultayı Bildiri Kitabı, 20p.

Wijkerslooth, P. 1944. Elazığ ili (Ergani-Maden) bakır yatakları hakkındaki bilgiye yeni bir ilave. *Maden Tetkik ve Arama Dergisi* 33, pp.76-104.

Yildirim, N., Ilhan, S., Yildirim, E., Dönmez, C. 2012.The Geology, Geochemistry and Genetical Features of the Ormanbaşı Hill (Sincik, Adiyaman) Copper Mineralization. Bulletin Mineral Research and Exploration., 144, pp.75-104.

Yıldırım, N. 2013. Havza-Kuşak Madenciliği Kapsaminda Keşfedilen "GD Anadolu Kıbrıs Tipi VMS Metalojenik Kuşağı": Koçali Karmaşığı, Adiyaman Bölgesi, Türkiye. *MTA Doğal Kaynaklar ve Ekonomi Bülteni,* 14, pp.47-55

Yıldırım, N., Dönmez, C., Kang, J., Lee, I., Yıldırım, E., Özkümüş, S., Çiftçi, Y., Günay, K., İlhan, S. 2014. Manyetit'çe zengin Kıbrıs tipi VMS yataklarına GD Türkiye'den bir örnek: Ortaklar (Gaziantep) VMS yatağı. *67.Türkiye Jeoloji Kurultayı 14-18 Nisan/April 2014*

Yıldırım, R., Alyamaç, F. 1976. Siirt ili Madenköy-Hürmüz yöresi jeoloji etüdü. *Maden Tetkik ve Arama Genel Müdürlüğü Rapor No: 5851, Ankara*

Yılmaz, O. 1980. Daday- Devrekani masifi kuzeydoğu kesimi litostratigrafi birimleri ve tektoniği. *Hacettepe Üniversitesi Yerbilimleri Dergisi* 5- 6, pp.101-131.

Zaccarani, F., Garuti, G. 2008. Mineralogy and chemical composition of VMS deposits of northern Apennine ophiolites, İtaly evidence for the influence of country rock type on ore composition. *Mineralogy and Petrology* 94, pp.61-83.