Constraints on the formation type of the Kure (Kastamonu, Turkey) massive sulfide deposits

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ABSTRACT


Kure and its vicinity features a number of known massive sulfide deposits. The sulfide mineralization in the Kure Formation (Kastamonu) occurred in brecciform basalts in the upper levels of the basaltic rocks and/or at the contacts of the black shales covering the basalts. The main ore minerals in the deposits are pyrite and chalcopyrite. The Kure basalts have a tholeitic character and originated in an island arc environment. It is suggested that the Kure massive sulfide deposits do not represent a Cyprus-type mineralization as generally accepted in the literature, but in fact resemble a Kieslager-type deposit.

INTRODUCTION

The Kure area is located in the western part (NW Turkey) of the Pontide belt (Fig. 1). Many studies have been made on the copper mineralization in Kure and its surroundings. A number of studies on the genesis of the deposits (Kovenko, 1944; Fieniazek, 1945; Pollak, 1964; Bailey et al., 1966; Güner, 1980) suggested that the mineralization has a hydrothermal-metasomatic origin.

There are a number of recognized settings for the formation of massive sulfide deposits. Cyprus-type massive sulfide deposits are found in mid-ocean ridges and back-arc basins, Kieslager-type massive sulfide deposits form in fore-arc basins, Kuroko-type massive sulfide deposits in island arcs, clastic-hosted massive sulfide deposits in rift systems, and finally carbonate-hosted massive sulfide deposits in shallow shelves and shield margins. Several studies considered that the Kure deposits were formed by Cyprus-type massive sulfide mineralization (Toktaş, 1969; Kamitani and Çamaşırcağlı, 1976; Küçüksüz et al., 1977; Gülç and Erler, 1983; Pehlivanoğlu, 1985; Ediger and Erler, 1990) and noted that the mineralization occurred in the basaltic volcanic rocks and sedimentary rocks. Mizumoto et al. (1993) described the Kure deposits as Cyprus-type, and the Taşköprü deposits near Kure as Besshi-type. Ustaömer and Robertson (1994), who proposed that the Kure complex was opened as a marginal basin on the subduction zone of (northerly subducting) Paleoethys in the late Paleozoic, suggested that Kure ophiolites were developed in this subduction zone and the mineralization is a Cyprus-type massive sulfide deposit.

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sulfide deposit. The genesis of the Küre deposits, however, is still under dispute. In a previous study, Koç et al. (1995) noted that this mineralization could be a Kieslager-type deposit. In this study, it is shown that the Küre ore deposits are not a Cyprus-type, but a Kieslager-type massive sulfide deposit.
METHODS

The present investigation used field and laboratory studies. Field studies comprised geological mapping of the area in a 1:5,000 scale and determination of the relation between regional geology and ore deposits (Fig. 1). Country and ore-bearing rocks were also sampled for petrography, ore microscopy, and whole-rock chemical analyses. Chemical analyses were performed at the laboratories of Chemex (Canada), ICP and XRF at MTA (Turkey), and part of ICP at NED (Nikko Exp. and Development Co., Japan).

GEOLOGY OF THE KÜRE AREA

The geology of the Küre area is shown in Fig. 1 and a stratigraphic column presented in Fig. 2. Rock units in the area from the oldest to youngest age are ultramafic rocks, Küre Formation, Karadana Formation, and Çağlayan Formation. There are also a few intrusions of gabbro-dioritic and dacitic rocks and basaltic dikes (Fig. 2).

Ultramafic rocks

Ultramafic rocks are widely exposed on the Elmakâtiğü and Karamanyayla hills and around the town of Ömeryılmaz, and they are observed as small outcrops at the east of Karacakaya hill and at the north of Bakibaba hill (Fig. 1). They generally consist of serpentinitized peridotites and lesser amounts of pyroxenite and dunite. Kovenko (1944) and Blumenthal (1945) gave a Liassic age for the North Anatolian ophiolites. Aydın et al. (1986), however, gave upper Triassic-Liassic ages. Based on these previous works, the age of the ophiolites is accepted to be pre-Liassic in this study.

Küre Formation

The unit, which is the most abundant rock sequence in the area, has a thickness of between 2000 m and 2500 m. It is best observed in the Zemberekler Creek. The section commences with basaltic volcanic rocks at the bottom and passes into a thick sedimentary sequence at the top (Fig. 2).

The widely exposed basaltic rocks have a special importance for hosting the mineralization. They occur as massive basalts and pillow lava in the lower levels and as breccia-form basalts in the upper levels. Koç et al. (1995) and Ünsal (1996) give detailed petrographic descriptions of these rocks.

The sedimentary rocks consist of black shale, siltstone, and sandstone with rare limestone and dolomitic limestone successions in the upper levels. The typical black shales are found in the Ağıköy, Bakibaba, and Kızılca deposits as cover to the ore. Coaly material with some detritic minerals such as rutile and anatase observed in this unit indicate that sedimentation occurred in a shallow environment. Sandstones with fine to medium grain size are poorly sorted and contain bands and lenses of black shale. The flyschoid character of these sediments is outlined in previous studies (Geiss, 1954; Keten, 1962; Yılmaz, 1979, 1980). Metamorphism of muscovite-chlorite subfacies is observed throughout the sedimentary sequence (Boztuğ and Yılmaz, 1995).

The age of the Küre Formation has been given as middle Liassic (Kovenko, 1944), middle Triassic-Liassic (Blumenthal, 1948), Liassic (Keten, 1962), lower Jurassic (Yılmaz, 1979, 1980), and Jurassic (Ediger and Erler, 1990). In the present study, the age of the Küre Formation is accepted to be Liassic based on the observation that it is older than the granites that in-
Intruded the area in late Liassic–early Dogger times (Yilmaz, 1979).

**Karadana Formation**

The Karadana Formation, which unconformably overlies the Kûre Formation (Fig. 2), is composed of massive, medium- to thick-bedded, fossiliferous limestones with a reef character in places. The unit, which was given a Kimmeridgian–Neocomian age by Ketin (1962), has a thickness of more than 100 m.

**Çağlayan Formation**

Its typical exposures are found around the Çağlayan village at the east of Kûre (outside the study area). The unit is composed of yellowish-gray colored turbiditic sandstone, conglomerate, sandy limestone, marl, and dark gray shale interlayers, and unconformably overlies the Karadana Formation. According to Ketin (1962), its age is lower Cretaceous.

**Intrusive rocks and dikes**

Intrusive rocks, mostly exposed in road cuts between the town of Kûre and Kastamonu, are generally diorite and gabbro. They were given a Dogger age by Mizumoto et al. (1993). Typical basaltic dikes are observed in the Aşk pérd deposit. The exposures found at the western side of the Aşk pérd deposit and northeastern part of Kûre are dacite dikes. Both types of dikes cut through the basalts, black shales, and sandstones and contain their fragments. These units are cogenetic with the gabbro-diorites (Yilmaz, 1979; Pehlivanoglu, 1985).

**MINERALIZATION**

The presently known deposits in the Kûre area consist of the Aşk pérd, Bakibabu, Kızılsu, and Toykondu massive sulfide deposits and the Zembereklı Creek, Erzilerdere and İpsinler mineralization. All the massive sulfide mineralizations have a similar geologic structure and are found in the brecciform basalts and/or at the contacts with black shales. The high-grade massive ore is generally found just below the black shale and changes to the stockwork-disseminated-type ore at lower levels.

The paragenesis of these ore deposits and their structure-texture relations have been described in detail by Ünsal (1996). The main ore minerals are pyrite and chalcopyrite. Also found are minor amounts of sphalerite, marcasite, galena, tetraedrite, covellite, neodigenite, bravoite, carrollite, bornite, and limonite, and trace amounts of hematite, chromite, leucoxene, rutile, anatase, chalcocite, tenorite, magnetite, and native gold.

Ore microscopy studies show that chromite, magnetite, and ilmenite coexist in the country rocks. Hematite was formed from magnetite, while rutile and anatase were transformed from ilmenite. Rutile, anatase, leucoxene, chromite, hematite, quartz, and pyrrhotine are observed as minute inclusions in the euhedral pyrites. These euhedral pyrites are older than the colloform pyrite and all other sulfide minerals. They form a zonal structure together with bravoite and quartz. They are replaced by other sulfide minerals along cataclastic fissures and cleavages. The euhedral, older pyrites have a cataclastic structure and their fractures and fissures have been filled by chalcopyrite, colloform pyrite, sphalerite, marcasite, galena, bornite, native gold, and gange. The colloform pyrite is cogenetic with chalcopyrite and forms concentric, crusted, botryoidal, kidney-shaped, and radial textures mostly together with chalcopyrite, sphalerite, and quartz and rarely with bornite, marcasite, and tetraedrite. Chalcopyrite and sphalerite sometimes also show zoning. Linnaeite is found as euhedral crystals in chalcopyrite and bornite. Bravoite is an alteration product of limonite-pyrite.

The mineral boundaries of chalcopyrite and bornite are transformed to chalcocine, neodigenite, and covellite in places. Neodigenite exists as thin veinlets in the fractures of chalcopyrite and sphalerite. In some cases, it surrounds bornite as a thin rim. Covellite is formed as a secondary mineral in the oxidation and sedimentation zones of surficial alteration of copper minerals, such as chalcopyrite, bornite, neodigenite, and fahlerz. It is also formed by the replacement of these minerals. Goethite, tenorite, marcasite, and azurite, however, are formed as oxidation zone minerals from transformation of copper-bearing minerals.

**ORIGIN OF THE KÛRE BASALTS AND THEIR TECTONIC SETTING**

Detailed descriptions and geochemical characteristics of the basalts are given in previous studies (Koç et al., 1995; Ünsal, 1996) Here, the origin of these rocks and their tectonic setting regarding the type and formation of the mineralization are explained. The tectonic setting of basalts is determined from their minor and trace element abundances. The data of Güner (1980) are also shown in the variation diagrams.

On the Zr/Y–Ti/Y discriminant diagram of Pearce
and Gale (1977), the Kûre volcanic rocks plot in the continental margin field (Fig. 3). No samples plot in the within-plate field. This indicates that the Kûre tholeiites are not produced in a within-plate tectonic setting, such as the ocean island and continental flood provinces. In the Ti–Cr diagram of Pearce (1975), which is used to discriminate volcanic arc from mid-ocean ridge basalts, most Kûre tholeiitic basalts plot in the volcanic island arc field (Fig. 4). Similarly, most of the samples plot in the island arc field in the Cr–Y diagram (Fig. 5). On the Zr–Zr/Y variation diagram proposed by Pearce and Norry (1979), the Kûre samples plot in the island arc basalt field (Fig. 6).

Based on these diagrams, the Kûre basalts are clearly characterized as island arc tholeiites.

Figure 7 shows the environments in which different massive sulfide deposits are formed (Hutchinson, 1980). Cyprus-type massive sulfide deposits are found in mid-ocean ridges and back-arc basins, Kieslagertype massive sulfide deposits form in fore-arc basins, Kuroko-type massive sulfide deposits in island arcs, clastic-hosted massive sulfide deposits in rift systems, and finally carbonate-hosted massive sulfide deposits in shallow shelves and shield margins. There is an age progression from the subduction zone. First, the ores of the trench and island arc are developed, followed by intra-arc and back-arc ores. A decrease in Au and Cu and an increase in Pb and Ag are observed in the paragenesis towards the continent across the subduction zones. An increase in K content is also shown in the same paragenesis (Hutchinson, 1980).

The facts that the Kûre basalts have a tholeiitic character and are a product of island arc volcanism, their close spatial association with the ophiolites, the presence of a thick sedimentary sequence, and the fact that they contain Cu-bearing pyrite deposits support the view that these volcanic rocks were developed in a fore-arc basin or in a trench. Tholeiites are the nearest rocks to the trench in an arc system and generally sedimentary rock units containing lesser amounts of
volcanic material arc formed between the trench and arc (Dickinson, 1971).

The idea that Pontide belt, including the Küre region, was an island arc during the Liassic time is accepted by many workers (Adamia et al., 1977; Saner, 1980; Bingöl, 1983; Ercaen and Gedik, 1983; Tokel, 1983; Boztuğ et al., 1985; Robertson and Dixon, 1985; Yılmaz and Boztuğ, 1986; Dercourt et al., 1986; Şengün et al., 1987, 1990; Tokel, 1991). However, there are two different ideas on the direction of the subduction.

The first school considers that, since the Rhodope-Pontide fragment belongs to the Gondwana, the Paleotethys was subducting to the south (Dewey et al., 1973; Şengör et al., 1980; Şengör and Yılmaz, 1981; Bektas, 1983; Bektas et al., 1984; Bektas and Van, 1986). However, if the Küre volcanic rocks that are assumed to be formed from an island arc (Yılmaz and Tüysüz, 1984) and Kastamonu granodiorites (Dogger in age) are also considered (Boztuğ et al., 1986), they indicate a northerly subduction towards the Pontides (Şengün et al., 1990). The present study supports the idea of Şengün et al. (1990) in respect to data indicating the tholeiitic character of the Küre volcanic rocks, their island arc origin, the close association with the ophiolitic rocks, and the presence of the Kieslager-type massive sulfide deposits in the fore-arc trench. A plate tectonics model illustrating the position of the

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**Exhalative of Volcano genetic Group**

- **Ex V genetic**
  - Cyprus Type
  - Kieslager Type
- **Ex V genetic**
  - Primitive Type
  - Zn-Cu: Ag-Au
- **Ex V genetic**
  - Cu-Py Type

Oceanic ridge Trench Arc

EXTENSION COMPRESSION

**Exhalative of Sedimentary Group**

- **Ex SED.**
  - Polymetallic Type
  - Zn-Pb-Cu:Ag-Au
- **Ex SED.**
  - Clastics related Type
  - Pb-Zn-Ag

Back Arc Basin

EXTENSION

**Massif Sulfide Deposits**

Ophiolite

**Volcanic Arc**

Continental Crust

**Back Arc Argillic Turbidites**

**Shallow Carbonates, Clastics**

**Fig. 7. Schematic diagram showing formation of massive sulfide deposits in various environments (from Hutchinson, 1980).**
Küre Formation is shown in Fig. 8. The consumption of the oceanic crust in a northerly subduction is accepted by a number of workers (Boztuğ et al., 1985; Yılmaz and Boztuğ, 1986; Ustaömer et al., 1991; Boztuğ, 1992; Ustaömer and Robertson, 1993; Boztuğ and Yılmaz, 1995).

Another alternative considers that the Paleoetethys was located in the southern part of the Pontides and was progressively consumed by northerly subduction (Adamia et al., 1977; Letouzey et al., 1977) from Liassic time (Norman 1985; Decourt et al., 1986). However, Şengün et al. (1990) suggest that the Rhodope-Pontide fragment belongs to Eurasia and therefore must have been a northerly subduction starting in Permo-Carboniferous time (Bingöl, 1983). This alternative is based on the idea that ophiolites can be placed on active oceanic margins without any continent-continent collision. It is suggested that Paleoetethys was consumed by the late Tertiary (Norman, 1985).

**DISCUSSION**

The finding that ophiolitic rocks in the study area are not autochthonous and that ore-bearing basalts do not owe their presence to these ophiolites, but to volcanics in the subduction zone, has led to the conclusion that Küre deposits are a Kieslager-type massive sulfide deposit rather than Cyprus-type.

The most important reason why the Küre deposits were thought to be a Cyprus-type sulfide deposit is misinterpretation of the coexistence of ophiolites together with the basalts. Güner (1980) suggested that the source of volcanic rocks was mid-ocean ridge basalts. However, the data of Güner (1980) and this study plot in the same fields in the variation diagrams of this study and clearly discriminate against a mid-ocean ridge origin. Pehlivanoglu (1988) considered the ophiolites to be shallow, rootless, and an incomplete series. The presence of this incomplete series, which is also observed in the Kieslager-type deposits (Franklin et al., 1981), can be explained by the subducting slab pushing the ophiolites onto the other plate margin.

Ustaömer and Robertson (1994) interpreted the deposits as Cyprus-type, and placed them in a back-arc basin. In their Ti–V and Y–La/Nb diagrams, some of the Küre samples plotted in the mid-ocean ridge field, while others plotted in the back-arc basin basalts field. They also thought that black shales were deposited in a semi-pelagic environment. In addition, they placed the Çangaldag complex in an island-arc and fore-arc basin, but the Küre complex in a back-arc basin. However, based on the whole rock analyses of the Küre and Çangal rocks, Kırkıoğlu (1987) showed that the ophiolite assemblages in Küre and Çangal are derived from a similar magma source. Yılmaz and Tüysüz (1984) and Tüysüz (1985) also point out that the units exposed in Küre and Çangal resemble a complete sequence.

There are also some additional geological features which have a primary importance in interpreting the origin of the Küre deposits. The presence of a thick black shale-sandstone sequence above the deposits is an important criterion. A thick marine sedimentation is observed in Kieslager-type deposits, and the clastic sedimentary rocks and volcanics have nearly equal
volumes. In contrast, small amounts of pelagic sediments are observed in the Cyprus-type deposits. The presence of a small amount of coaly material and graphite in the black shales of Kure (Çağatay et al., 1980) suggests a shallow environment of less than 200 m for the formation of volcanie rocks. This feature is also consistent with the Kieslager-type deposits. Iron-rich and magnesium-poor chemical precipitates (so-called “oke”), which are found above the massive ores and their transition to “ambre” occurrences are frequently observed in Cyprus-type deposits. However, these zones are not found in the Kure deposits. The main ore minerals in the Cyprus-type deposits are pyrite, chalcopyrite, sphalerite, pyrrhotite, magnetite, and in trace amounts, limnaeite and valerinite (Constantinou and Govett, 1972). However, only small amounts of magnetite and pyrrhotine are detected in the Kure deposits. The deficiency of magnetite is typical of Kieslager-type deposits. The metamorphic character of part of the Kure Formation and high cobalt-allow chromium contents in the deposits (Güner, 1980) also indicate a Kieslager-type deposit.

In conclusion, it is shown in this work that Kure basalt with a tholeiitic character are formed in an island arc environment (Fig. 8). Since they resemble Kieslager-type deposits, the Kure massive sulfide deposits should not be considered to represent Cyprus-type mineralization.

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