Volcanogenic Massive Sulfide Deposits in the East Pontic Metallotect, NE Turkey

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Abstract: The East Pontic metallotect represents a Jurassic to Miocene island arc system, hosting a great number of stratabound base metal deposits (i.e. Murgul, Madenköy, and Lahanos). These deposits occur in a 150 to 300 m thick strongly altered Upper Cretaceous pyroclastic host rocks. The mineralization is related to the first stage phyllic and argilllic alteration and the second stage silicic alteration. The first stage alteration is associated with poor mineralization of disseminated pyrite and chalcopyrite(type i). By comparison, the second stage hydrothermal activity is characterized by silicic alteration which contains the commercial ore (types ii and iii). Genetically, the mineralization at Murgul in the eastern part of the East Pontic metallotect is assigned to subvolcanic-hydrothermal origin whereas the deposits at Madenköy and Lahanos in the western part of the East Pontic metallotect are genetically associated with a submarine hydrothermal activity in a volcano-sedimentary sequence related to island arc volcanism. The Murgul deposit might be interpreted as a transitional type tending to porphyry copper deposits (Murgul type). By comparison the deposits at Lahanos and Madenköy are Kuroko-type deposits.

INTRODUCTION

The East Pontic metallotect in NE Turkey extends over an area of more than 350 km E-W and 60 km N-S. This area is dominated by volcanic rocks representing a Jurassic to Miocene island arc system which host many base metal deposits. The base metal ratios of important deposits in the altered pyroclastic series of Senonian age changes along the general strike of the metallotect from east (Cu>Pb+Zn) to west (Pb+Zn>Cu) progressively. Among these deposits, Murgul, Madenköy, and Lahanos (Fig. 1) have been investigated and different genetical interpretations have been presented by SCHNEIDERHÖHN (1955), TUGAL(1969), and CAGATAY and BOYLE (1980). The aim of this paper is the give an overview and to elucidate the genesis of these economically very important deposits.

GEOLOGIC SETTING

The metallotect consists of about 3,000 m thick volcanic sequence with relatively thin intercalations and lenses of marine sediments. The volcanic events can be divided in to three cycles (MAUCHER et al., 1962; AKIN, 1979; SCHNEIDER et al., 1988) as follows (Fig. 2):

(i) The first cycle (lower basic series, LBS) comprises a volcanic pile deposited in Jurassic to Upper Cretaceous ages.The volcanics are represented by initial basaltic activity (spilites) and changes progressively to felsic lava flows in the top level.

(ii) The second cycle (lower dacitic series, LDS) starts transgressively with volcanic breccias, tuffs, and marine sediments of minor thickness overlain by andesitic and rhyolitic flows and followed by limestone of Maastrichtian age.

(iii) The last cycle (upper basic series, UBS) is introduced by Paleocene marine sediments which are overlain by andesitic and minor basaltic lava flows.

In the entire East Pontic metallotect, the economically important deposits are linked to 150 to 300 m thick altered dacitic pyroclastic host rocks of the upper part of the first volcanic cycle revealing very turbulent and repeated volcanic activity.
The Upper Cretaceous (Senonian) host rocks of the metallotect reveal dacitic and rhyolitic in origin (ÖZGÜR et al., 1991).

THE ORE DEPOSITS

The common ore mineral paragenesis of the deposits of Murgul, Madenköy, and Lahanos consists of pyrite, chalcopyrite, sphalerite, galena, fahlore, arsenopyrite, covellite, and bornite (TUGAL, 1969; CAGATAY and BOYLE, 1980; ÖZGÜR, 1985). The enrichment of gold has been detected in pyrite and in boundary between pyrite and chalcopyrite (Fig. 3). Moreover, aikinite, hessite, tetradymite, and clausthalite occur in the orebodies at Murgul (two open pits: Anayatak and Cakmakkaya; WILLGALLIS et al., 1990).

Three well mined ore deposits at Murgul, Madenköy, and Lahanos consist of (1) disseminated ore, (2) stockwork (-like) ore, and (3) small ore lodes (Figs. 4, 5, 6). The disseminated ore occurs generally over the entire deposits and shows varying Cu contents ranging from 0.2 to 0.8%. The disseminated ore is considered to be product of the initial stage mineralization. The stockwork ore is a product of the hydrothermal remobilization of metals during an interval of volcanotectonic fracturing of the pyroclastic pile. The Cu contents of the stockwork ore range from 1.0 to 3.0%. Cu contents of the small ore lodes are up to 10.0% and are concentrated mainly in relatively short veins. The deposits at Lahanos and Madenköy in the western part of the metallotect possess massive ores and are comparable with the Kuroko-type deposits (type 4).

The recoverable ore reserves are estimated to be about 40 million metric tons with an average grade of 1.25% Cu, 0.1% Zn, 0.05% Pb, 25 ppm Ag, and 0.2 ppm Au (Murgul), 30 million metric tons with an average ore grade of 2.9% Cu and 4.3% Zn (Madenköy), and 8 million metric tons with an average ore grade of 1.6% Cu and 2.3% Zn (Lahanos).
Fig. 2 Simplified lithostratigraphic column of the East Pontic metallotect. LBS: Lower Basic Series, LDS: Lower Dasitic Series, UBS: Upper Basic Series, Cu: Base metal deposits.

Fig. 3 Native gold (Au) in pyrite (FeS₂) with contact of chalcopyrite, Akarsen deposit near Murgul. Polished section, plane light, oil immersion.

Fig. 4 Fine-grained disseminated ore minerals (type i) (black) with intergrowths of quartz (white), sericite, and clay minerals (gray), locally depicting the layered structure of the pyroclastic rock. Anayatak open pit (Murgul).
Hydrothermal alteration and mineralization

The mineable base metal occurrences are confined to a distinct phase of altered dacitic and rhyolitic eruptives of the Upper Cretaceous sequence. The pyroclastic host rocks are identified everywhere by their extreme alteration and their primarily petrological character is difficult to define. The pyroclastic host rocks have been classified by the microscopic investigations and by the mobile elements geochemistry (ÖZGÜR et al., 1991).

The intense host rock alteration can be divided into (i) an initial stage phyllic and argillic alteration and (ii) a late stage silicic alteration (CAGATAY and BOYLE, 1980; DIETERLE, 1986; SCHNEIDER et al., 1988). The initial stage alteration is characterized by the destruction of the primary paragenesis of the pyroclastic series and the replacement of the rock by quartz and sericite. An extensive mineralization of pyrite and chalcopyrite took place during the first alteration stage. The late stage silicic alteration is intimately related to economic mineralization of the stockwork and small ore lodes in the metallocotect. The rare earth element (REE) patterns of the pyroclastic host rocks indicate a progressive REE depletion with increasing intensity of phyllic, argillic, and silicic alteration (ÖZGÜR, 1985; DIETERLE, 1986; SCHNEIDER et al., 1988).

GEOCHEMICAL FEATURES

Due to ascending hydrothermal fluids, the dacitic and rhyolitic host rocks of three deposits (Murgul, Madenköy, and Lahanos) are strongly altered and exhibit a depletion of Na, Ca, K, Mn, Ti, Rb, Cs, and REE, and an enrichment of Cu, Zn, Pb, As, Ba, F, Ag, and Au (TUGAL, 1969; CAGATAY and BOYLE, 1980; ÖZGÜR, 1985; DIETERLE, 1986). In connection with the hydrothermal alteration, Cu is enriched within phyllic and silicic alteration zones. ÖZGÜR and PALACIOS (1990) proposed the use of F, Ti, and Mn as the exploration indicators of blind ore deposits in the East Pontic metallocotect.

Comparison of Co/Ni ratios of pyrites from the deposits at Murgul, Madenköy, and Lahanos indicates that the Murgul pyrites are volcanogenic in origin and differ from the Lahanos and Madenköy pyrites (ÖZGÜR et al., 1991). The Lahanos pyrites are mixtures of...
volcanogenic and sedimentary pyrites, while Madenköy pyrites are transition between Murgul and Lahanos pyrites in origin. In terms of Cu/As and Ag/As ratios of pyrites and chalcopyrites, the deposits at Murgul, Madenköy, and Lahanos possess geochemical similarities with the Fiji deposits (COLLEY and RICE, 1975; ÖZGÜR et al., 1991; Fig. 7).

**DISCUSSION AND CONCLUSIONS**

The base metal deposits at Murgul, Madenköy, and Lahanos occur in the strongly altered (dacitic-rhyolitic pyroclastic host rocks which belong to the Upper Cretaceous volcanics of the first volcanic cycle. The host rocks in the western part of the metallotect exhibit immense intercalations with marine sediments, whereas the host rocks in the eastern part are sparsely and locally intercalated with marine sediments. This indicates a shallow water depositional environment at least for the upper part of the first volcanic cycle. Geochemical and isotopic data indicate that the pyroclastic host rocks have been derived from magmas generated by partial melting of distinct sources in the upper mantle (AKINCI et al., 1991). The deposits at Lahanos and Madenköy are predominated by stratiform ores, whereas the Murgul deposit consists of strata-bound stockworks, short veins, and disseminations.

The hydrothermal mineralization in the entire East Pontic metallotect is accompanied by the first stage phyllic and argillic alteration and the second stage silicic alteration. The first phase of mineralization (disseminated ore) occurs with the first stage alteration. The second and third phases of mineralization (stockwork ore and small ore lodes) correspond with the second stage hydrothermal alteration. Although the features of the concentric alteration-mineralization patterns show similarities to porphyry copper deposits, there are some remarkable differences: (i) the high-grade ore is mainly concentrated in the center, (ii) there is no potassic zone, and (iii) the mineralization must have taken place relatively close to the surface. The features of the base metal deposits at Lahanos and Madenköy might be compared with the Kuroko ore deposits in Japan (CATHLES et al., 1983; MARUMO, 1989; URABE and MARUMO, 1991) and Undu deposit in Fiji (COLLEY and RICE, 1975). The $\delta^{34}$S values of sulfides in Murgul and Lahanos range from 2.33 to 4.83 per mil (Fig. 8) and are comparable with the values of the Kuroko-type deposits (OHMOTO et al., 1983).

As reported by LEITCH (1981), ÖZGÜR (1985), and ÖZGÜR and SCHNEIDER (1988), the predominance of pyrite framboïdes (15 µm) and concentric
pyrite spherulites (150 µm) in the deposits at Lahanos and Madenköy suggest their exhalative-sedimentary origin. Similar origin can not be accepted for the Murgul deposits, because the concentric pyrite spherulites contain small inclusions of chalcopyrite and sphalerite and rock fragments. Occasionally recrystallized pyrites exhibit these relicts, indicating an early colloidal origin. However, the colloidal origin is still debatable due to the absence of any organic matter in the volcanogenic sequence and its relatively high formation temperatures.

Based on the geological, microscopical, geochemical, and isotopic data, the copper deposit at Murgul can be assigned to a subvolcanic-hydrothermal deposit genetically associated with an Upper Cretaceous island arc volcanism under subaerial conditions (Fig. 9). The host rock of the Murgul deposits shows features similar to the “ore related breccias” (SILLITOE, 1985), suggesting a subsurface brecciation generated by volcanoplutonic activity contemporaneous with tuff sedimentation. On the other hand, the copper ore deposits of Lahanos and Madenköy are related to a submarine-hydrothermal activity in a volcanosedimentary sequence under temporally subaquatic conditions. Subsequently, the Murgul copper ore deposit might be interpreted as a transitional type tending to copper porphyries (Murgul type) whereas the deposits of Lahanos and Madenköy represent Kuroko-type deposits.

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