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The Hakkari nonsulfide Zn–Pb deposit in the context of other nonsulfide Zn–Pb deposits in the Tethyan Metallogenic Belt of Turkey

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ABSTRACT

The Hakkari nonsulfide zinc deposit is situated close to the southeastern border of Turkey. Here both sulfide and nonsulfide Zn ≫ Pb ores are hosted in carbonate rocks of the Jurassic Cudi Group with features typical of carbonate-hosted supergene nonsulfide zinc mineralization. The regional strike extent of the mineralized district is at least 60 km. The age of the supergene deposit has not been determined, but it is probable that the main weathering happened during Upper Tertiary, possibly between Upper Miocene and Lower Pliocene. The Hakkari mineralization can be compared to other carbonate-hosted Zn–Pb deposits in Turkey, and an interpretation made of its geological setting. The zinc mineral association at Hakkari typically comprises smithsonite and hemimorphite, which apparently replace both sulfide minerals and carbonate host rock. Two generations of smithsonite are present: the first is relatively massive, the second occurs as concretions in cavities as a final filling of remnant porosity. Some zinc is also hosted within Fe–Mn-(hydr)oxides. Lead is present in cerussite, but also as partially oxidized galena. Lead can also occur in Mn-(hydr)oxides (max 30% PbO). The features of the supergene mineralization suggest that the Hakkari deposit belongs both to the "direct replacement" and the "wall-rock replacement" types of nonsulfide ores. Mineralization varies in style from tabular bodies of variable thickness (<0.5 to 13 m) to cross-cutting breccia zones and disseminated ore minerals in pore spaces and fracture planes. At Hakkari a As–Sb–Tl(≫ Hg) geochemical association has been detected, which may point to primary sulfide mineralization, quite different from typical MVT.
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1. Introduction

Nonsulfide zinc (NSZ) deposits are a relatively uncommon ore type. They formed some of the earliest sources for mined zinc, and recently have enjoyed a resurgence in interest utilizing new processing technologies. Two types of NSZ deposits are indicated: hypogene and supergene types (Hitzman et al., 2003). The supergene ores are derived from the weathering of primary sulfide deposits and a combination of conditions is needed for the development of economically significant NSZ deposits. Key conditions include: (1) a pre-existing zinc deposit, (2) efficient oxidation promoted by tectonic uplift and/or prolonged, seasonal, deep weathering; (3) a permeable wall rock to allow for ground-water movement; (4) effective trap sites; and (5) a hydrogeological environment that does not promote dispersion and loss of Zn-bearing fluids (Large, 2001). Hypogene ores are derived from high temperature fluids in hydrothermal and/or metamorphic environments (e.g. Angouran–Iran, Vazante–Brazil, Beltana–Australia and Franklin–USA deposits, Hitzman et al., 2003). The hypogene NSZ are less abundant and economically less significant than supergene types.

Recent developments in extraction technologies for the treatment of nonsulfide zinc deposits (acid-leaching, AmmLeach®, electrowinning) have led to increased commercial interest for nonsulfides zinc ores with a revival in exploration throughout the world, blossoming at the beginning of the twenty-first century (Hitzman et al., 2003; Large, 2001). The best example of a new mining project is the Skorpion operation in Namibia (Borg et al., 2003), and there are other examples: e.g. Accha in Peru (Boni et al., 2009), Angouran in Iran (Boni et al., 2007), and Vazante in Brazil (Monteiro et al., 2006). Nevertheless, at both Skorpion and Angouran the hydro-metallurgical plants are underperforming relative to initial expectations, which has resulted in delays to the development of NSZ deposit exploitation. Capital and operating costs, acid consumption and metal recoveries have not completely met the feasibility study expectation, and other oxide resources (Mehdiabad in Iran, Sierra Mojada in Mexico, Torlon Hill in Guatemala) are still battling technology issues (Allen, 2010). Some of the problems can be mitigated by better identification of the mineralogical association of the metallic and nonmetallic minerals and this should be a first and fundamental step in the exploration and exploitation of nonsulfide mineral deposits, because the extraction process is highly sensitive to mineralogy. Before the metallurgical

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processing methods are chosen, it is necessary to take into account both the physical and chemical properties of the ores and their association with gangue minerals.

Another problem is the geo-political position of several nonsulfide orebodies (e.g. Yemen, Iran). Hakkari shows evidence of high grade metal content and tonnage (in the order of 10 Mt at +15% Zn equivalents (Zn/Pb/Ag), but the deposit may be potentially affected by its difficult location in eastern Turkey.

The Hakkari NSZ project (Red Crescent Resources Ltd., shortened as RCR) is situated in the Hakkari and Sirnak provinces at the extreme southeastern margin of Turkey, close to the border with Iraq (approximately 20 km to the south) and Iran (almost 80 km to the east). The license area is located from about 25 km west of the small town of Hakkari, to about 65 km to the west, and covers an area of approximately 265 km^2. The Hakkari location is shown on the geological map 1:500,000 of Turkey (Günay and Şenel, 2002). In the Hakkari area both nonsulfide and sulfide $Zn \gg Pb$ ores are hosted in carbonate rocks belonging to the Arabian Platform (Fig. 1). There are several deposits of variable size and tonnage, which show a mixture of supergene zinc (with minor Pb) carbonates, hydrocarbonates, and silicates, all capping the primary sulfide bodies. Preliminary data about the occurrence of nonsulfide zinc ores in the Hakkari region have been reported by Ceyhan (2003), Yigit (2009), Grodner (2010), and Reynolds and Large (2010). However, neither a detailed geological study of the mineralized area, nor a complete definition of the mineral assemblage in the main orebodies has been carried out so far.

The aims of this paper are twofold:

1. to place the Hakkari deposit within the metallogenic context of Tethyan Turkey;
2. to characterize the nonsulfide ore assemblage and mineral composition of the deposit, in order to define the mechanisms leading to the secondary mineral enrichments, and provide information for formulation of an economically viable processing method.

Currently, Red Crescent Resources Ltd. is carrying on a full feasibility study on an optimized process engineering solution utilizing AmmLeach® for primary zinc metal production (MSA Group Ltd., 2011). If successful, this process is quite low cost and does not impact the carbonate host rock, as any acid extraction method would do.

In the mean time, mine production from open pit operations on the Pentagon license from the Hakkari area commenced in mid-September 2012 (Red Crescent Resources, 2012, http://www.rcrholding.com.tr/), and to date has generated approximately 1100 t of "Direct Shippable Ore", which is currently in the process of homogenization and scheduled to be shipped to the processing plants.

2. Zinc–lead deposits in Turkey

Turkey forms part of the Tethyan Belt and hence not only its tectonic setting, but also the numerous mineral deposits are related to the evolution of the Tethys Ocean. Although Turkey is best known for its porphyry and epithermal copper and gold deposits (Lips, 2007), it hosts a range of significant zinc–lead concentrations belonging to the Tethyan Metallogenic Belt, as those in China and Iran (Reynolds and Large, 2010). In Fig. 2 the distribution of the carbonate-hosted Zn–Pb deposits in Turkey is shown, which include both primary sulfide and secondary nonsulfide concentrations. Turkey hosts a diversity of Zn–Pb sulfide deposits:

2.1. VHMS (VMS) deposits

Polymetallic felsic volcanic-associated traditionally classified as 'Kuroko-type' deposits mainly occur in the Pontide belt (north-eastern Turkey), which relate to the subduction of Paleotethys beneath Eurasia (Robertson and Grasso, 1995; Yilmaz et al., 2000). The deposits are associated with Late Cretaceous bimodal volcanics (Yigit, 2009). The largest VHMS deposit of this type is the Murgul deposit, mainly a stockwork containing chalcopyrite and pyrite with minor galena and sphalerite. The Cayeli, Lahnos, Koprubasi and Cerrattepe deposits (northern Turkey) also contain Cu–Zn–Pb, and in places are enriched in gold and barite (Yigit, 2009). Copper-dominated mafic volcanic-hosted 'Cyprus-type' deposits are of lesser economic importance and typically occur in southeastern Turkey, associated with the Anatolian orogenic belt (Late Cretaceous to Middle Miocene) (Yigit,

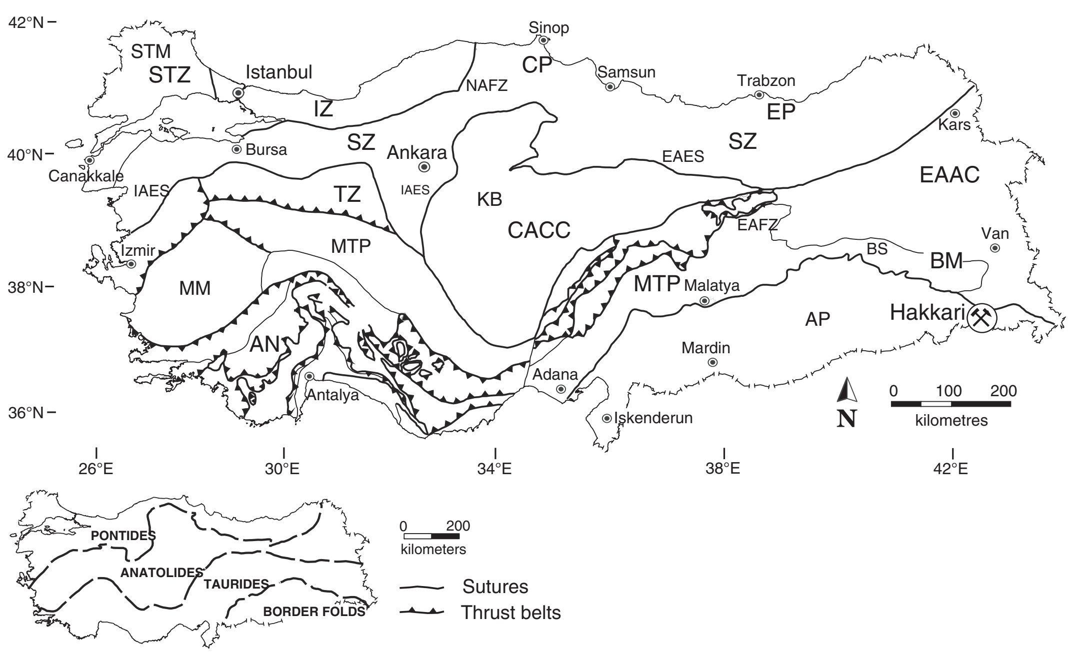

Fig. 1. Geological–structural map of Turkey according to Ketin, 1966 (small, bottom left) and Okay and Tüysüz (1999). AN = Anatolian Nappes, AP = Arabian Platform, BS = Bitlis Suture, CACC = Central Anatolian Crystalline Complex, CP = Central Pontides, EAFZ = East Anatolian Fault, EAAC = East Anatolian Complex, EP = Eastern Pontides, IAES = Izmir–Ankara–Erzincan Suture, IZ = Istanbul zone, KB = Kirsehir Block, MM = Menderes Massif, MTP = Menderes–Tauride Platform, NAFZ = North Anatolian fault zone, STM = Strandaja Massif, STZ = Strandaja zone, SZ = Sakarya zone, TZ = Tansvali zone. In the circle the position of the Hakkari zinc district (modified from Yigit, 2009).

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