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Sulfur and lead isotopes of Guern Halfaya and Bou Grine deposits (Domes zone, northern Tunisia): Implications for sources of metals and timing of mineralization

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A B S T R A C T

The Pb–Zn ore deposits in the Guern Halfaya and Bou Grine areas (northern Tunisia) are hosted mainly by dolostones in the contact zone between Triassic and Upper Cretaceous strata and by Upper Cretaceous limestones. The deposits occur as lenticular, stratiform, vein, disseminations and stockwork ore bodies consisting of sphalerite, galena, pyrite, chalcopyrite and sulfosalt (gray copper). Barite and celestite dominate the gangue, with lesser calcite. The $\delta^{34}S$ values of barite and celestite (12.7–15.0‰) at the Oum Edeboua mine are consistent with the reduction of sulfates in Triassic evaporites within the study area ($12.8 < \delta^{34}S < 14.0$‰). The $\delta^{34}S$ values in base-metal sulfides from both study areas (2.6–9.5‰) and the presence of bacterial relics suggest involvement of bacterially-mediated sulfate reduction in the mineralization. The present Pb isotope data are homogeneous with $^{206}Pb/^{204}Pb$, $^{207}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$ ratios of 18.723–18.783, 15.667–15.685 and 38.806–38.889, respectively, which suggest a single source reservoir of Pb at depth in the upper crust. The syn-diagenetic mineralization in the Bahloul Formation and the calculated age from the Pb isotopic data suggest an Upper Cretaceous age for the Pb–Zn deposits in the Guern Halfaya and Bou Grine areas. During this period, NE–SW to ENE–WSW trending regional extensional tectonic structures likely favored migration of mineralizing fluids and eventual deposition at Guern Halfaya and Bou Grine.

1. Introduction

The present structural pattern of northern Tunisia resulted from a complex tectonic evolution that began with the break-up of Pangaea in the Upper Permian and ended with the Alpine orogeny of the Maghrebides fold–thrust belt in the Cenozoic (Bouaziz et al., 2002; Frizon De Lamotte et al., 2006; Rouvier, 1977; Tricart et al., 1994). The eastern part of the Maghrebides fold–thrust belt is the Nappe zone (Fig. 1 inset), which was formed by the stacking of Numidian flysch along south-verging Tellian thrust sheets (Ould Bagga et al., 2006; Rouvier, 1977). To the east and at the front of the Nappe zone is the Domes zone. This NE–SW trending, roughly 50-km-wide and 300-km-long zone, which has been referred to as the Domes area, the Mejerda valley or the Triassic dome belt, is characterized by surface exposures of Triassic evaporitic lithologies related to the emergence of major thrusts and anticlines (Perthuisot et al., 1999). The Numidian flysch and the Triassic evaporitic lithologies overlie tectonically the Tunisian Atlas substrata (Khomsi et al., 2009), which crop out in the area east of the Domes zone. The Tunisian Atlas consists of NE–SW trending Middle Miocene folded strata as in the Algerian Saharan Atlas (Boccaletti et al., 1990; Burollet and Rouvier, 1971). Further to the east, the Tunisian Atlas is separated by the North–South Axis belt from the Sahel–Pelagian Platform (Anderson, 1996). The North–South Axis belt, which is made up of N–S to NE–SW trending 'jebels' or ridges that abruptly rise to heights of roughly 700–800 m from adjacent lowlands, forms the deformation front of the Atlas domain (Boccaletti et al., 1988, 1990). Thus, the Nappe zone is an orogen, whereas the Domes zone (Orgeval, 1979), the Tunisian Atlas and the North–South Axis belt form the foreland of that orogen (Bouaziz et al., 2002; Khomsi et al., 2009).

Metals that have been mined in northern Tunisia were derived from Pb–Zn deposits in the Domes zone (e.g., 1.5 Mt of 17% Zn + Pb in Fedj-el-Adoum, 1 Mt of Zn in Bou Grine) (Charef and Sheppard, 1987, 1991; Orgeval, 1994; Perthuisot and Rouvier, 1996; Rouvier et al., 1985; Sheppard et al., 1996). The formation of Pb–Zn deposits in the Domes zone is akin to the classical process of formation of the Mississippi Valley-type (MVT) deposits in the forelands of orogens (cf. Appold and Garven, 1999; Bradley and Leach, 2003). The Pb–Zn deposits in the Domes zone (Fig. 1; Table 1) are distributed around NE–SW trending and evaporite-bearing Triassic outcrops (Rouvier et al., 1985). The Pb–Zn deposits in the Domes zones display generally three main mineralization types (cf. Orgeval et al., 1986):

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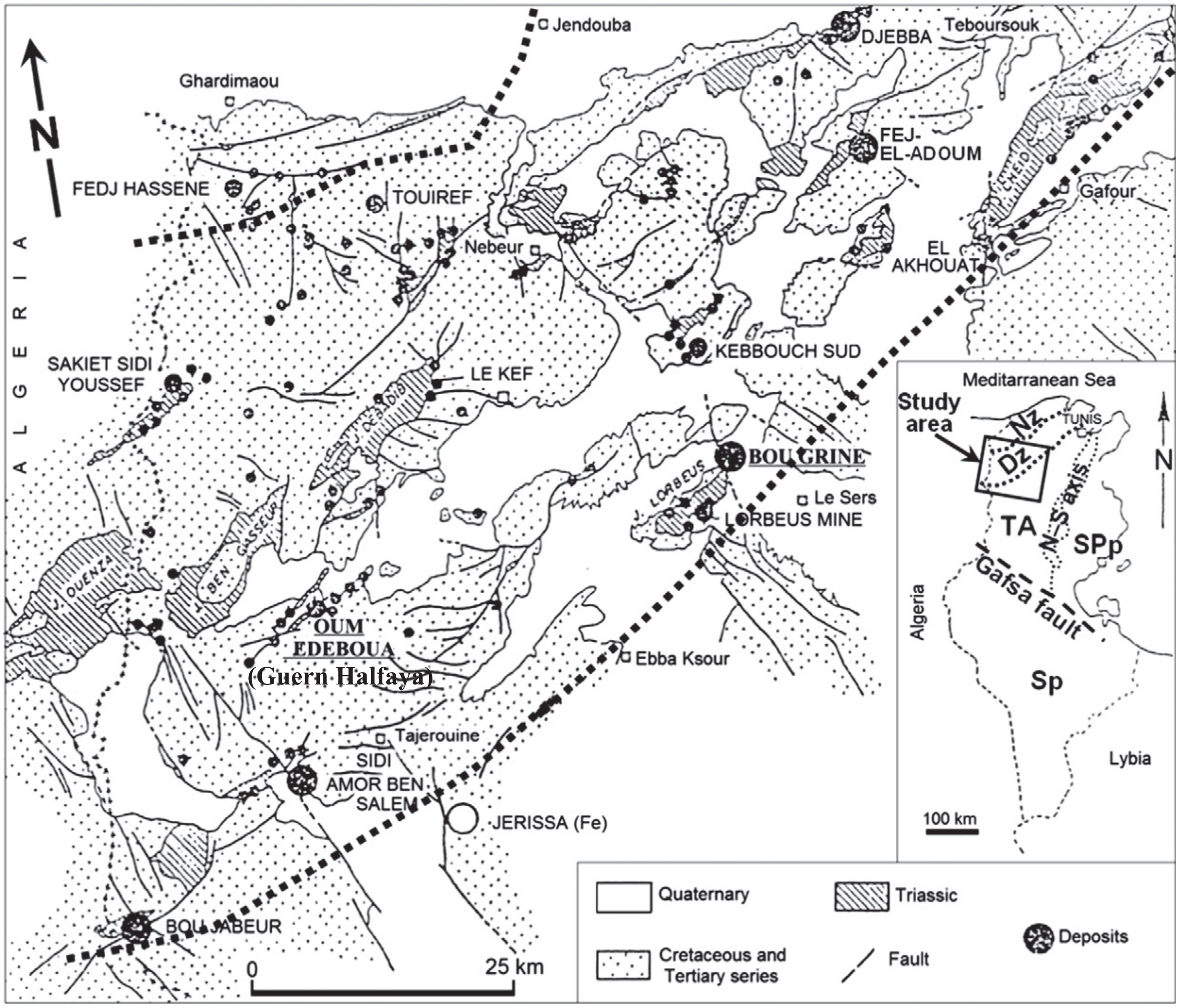

Fig. 1. Map of Pb–Zn deposits and Triassic evaporite outcrops in the Domes zone, northern Tunisia (modified from Monthel et al., 1986) indicating the locations of the Oum Edeboua (Guern Halfaya) and Bou Grine mines, on which this study is focused. Nz = Nappe zone. Dz = Domes zone. TA = Tunisian Atlas. N–S = North–South. SPp = Sahel–Pelagian platform. Sp = Saharan platform.

(i) stratabound lenticular orebodies in the contact zone (or transition zone) between Triassic and Cretaceous strata; (ii) stratabound orebodies associated to Cenomanian–Turonian strata; and (iii) veins, stockworks and open-space fillings developed in the peridiapiric cover.

Several publications have proposed various genetic models for base-metal mineralization linked to evaporite diapirs (Charef and Sheppard, 1987; Kyle and Agee, 1988; Kyle and Posey, 1991; Kyle and Price, 1986; Machel, 1989; Montacer et al., 1986, 1988; Orgeval, 1994; Orgeval et al., 1986; Perthuisot and Rouvier, 1996; Rouvier et al., 1985). In Tunisia, the principal models proposed for the genesis of the Pb–Zn deposits in the Domes zone are based mainly on the studies of the deposits at Bou Grine and Fedj-el-Adoum. Perthuisot (1978) and Rouvier et al. (1985) proposed that Pb–Zn deposits in the Domes zone are diapir-related. Slim-Shimi and Tlig (1993) argued that the role of the Triassic evaporite diapirs in ore genesis at Fedj-el-Adoum is that they have been inserted during halokinesis in deep-seated fractures in the basement, through which admixtures of endogenic and other deep-seated fluids ascended. Montacer et al. (1986, 1988) suggested that the Bahloul Formation was the likely source of metals as well as the hydrocarbons in the Bou Grine deposit. Charef and Sheppard (1987, 1991), Sheppard and Charef (1990) and Sheppard et al. (1996) suggested that hot springs on the sea floor, guided by diapir tectonics, were the sources of metals in the Bou Grine and Fedj-el-Adoum deposits and that the metals were leached from sedimentary rocks at depth by saline brines. Orgeval et al. (1986), Orgeval (1994, 1995) and Bechtel et al. (1996, 1998, 1999) demonstrated evidence that oil accumulation, biogeochemical alteration of hydrocarbons and microbial sulfate reduction played major roles in the formation of the Bou Grine Zn–Pb deposit. They also proposed that the metals were likely leached from sedimentary rocks at depth by hypersaline basinal brines during density-driven fluid convection. Considering celestite in the Jebel Doghra deposit, Souissi et al. (2007) propose that mineralization was due to the mixing of deeply-sourced hot fluids (enriched in Sr due to the leaching of feldspar-rich series) with sulfate-bearing waters associated with the Triassic facies.

The present study focuses on two old mining camps in the Domes zone of northern Tunisia, one where the Bou Grine Zn–Pb deposit is located and the other where the Guern Halfaya (Oum Edeboua mine) Pb–Zn (Fe–Ba–Sr) deposit is located (Fig. 1). In both of these two old mining camps, base-metal mineralization is hosted mainly in the contact zone between Triassic and Upper Cretaceous rocks and in Cenomanian–Turonian limestones (Bahloul Formation). The Pb–Zn deposits at the Oum Edeboua mine situated near the Guern Halfaya evaporite diapir occur beneath the Triassic series. The evaporite diapir comprises a cap rock sequence of halite, anhydrite and gypsum, which has been intersected by drilling (Hatira and Zouari, 1997). According to Orgeval et al. (1986), the Zn–Pb mineralization at Bou Grine was deposited on top of an evaporite diapiric structure.