

Abstract

Source of ore-forming fluids in El Cobre VHMS deposit (Cuba): evidence from fluid inclusions and sulfur isotopes

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Abstract

The El Cobre deposit, east of Cuba, lies in the intermediate volcanosedimentary sequence of the Sierra Maestra intraoceanic island arc. The structure of the deposit corresponds to that of a volcanogenic-hosted massive sulfide (VHMS) model. It comprises (a) thick stratiform bodies (baryte and anhydrite), (b) three stratabound bodies (formed by silicification and sulfidation of limestones or sulfate strata), (c) stockwork zones, an older anhydrite stockwork and a younger quartz–pyrite stockwork grading downwards to (d) simple veins (quartz with sulfide ores). Pyrite, chalcopyrite and sphalerite are the most abundant sulfides. Fluid inclusions from this deposit have a salinity between 2.3 and 5.7 wt.% NaCl eq., homogenization temperatures range between 177 and 300 °C. Sulfur exhibits a range of $\delta^{34}\text{S}$ values from -1.4‰ to $+7.3\text{‰}$ for sulfides and from $+16\text{‰}$ to $+21\text{‰}$ for sulfates. Fluid inclusions and sulfur isotope data at El Cobre deposit indicate that the hydrothermal fluid from which the sulfide precipitated was seawater, modified by reaction with volcanic host rocks during hydrothermal circulation.

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Keywords: VHMS deposit; Fluid inclusions; Sulfur isotopes; El Cobre deposit; Sierra Maestra; Cuba

1. Introduction

The “El Cobre” deposit is located in eastern Cuba, 13 km NW of Santiago de Cuba city, in the Sierra Maestra range. The deposit, found in 1530, is one of the oldest mines in America.

In spite of the economic interest of this deposit, more than 1 million tons of $\text{Cu}>14\%$ ore and more than 2 million tons $\text{Cu}>3\%$ ore have been extracted, little work has been reported. Different authors, based on regional studies, proposed a mesothermal origin of the El Cobre deposit (Cabrera et al., 1983) or an epithermal origin (Kesler et al., 1990). However, the structural patterns of the deposit, traced in detail in the 1990s decade by means of a dense drilling network, indicate that it is a volcanogenic-hosted massive sulfide (VHMS) deposit (Cazañas et al., 1998a).

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This paper presents a fluid inclusion and sulfur isotope study of the El Cobre deposit with the aim of characterizing the ore-forming fluids.

2. Geological setting

The El Cobre deposit lies in the middle sequence of the El Cobre Group in the Sierra Maestra volcanic island arc (Danian–Middle Eocene) (Fig. 1). This volcanic activity was limited to the eastern part of the Island of Cuba and is represented by a sequence of volcanic rocks, the “El Cobre Group”, thicker than 4000 m (Iturralde-Vinent, 1994; Cazañas et al., 1998b; Kysar, 2001).

The El Cobre Group consists of a sequence of volcanic and volcanoclastic rocks with intercalations of epiclastic material and fossiliferous limestones. The volcanic sequence is composed of lava, pyroclastic flows, synvolcanic mass flows and subvolcanic sills and their feeder dikes (Kysar, 2001). This

group includes a large number of hypabyssal bodies of diorite to granite composition and small plutons, up to 150 km², that outcrop in the southern flank of the Sierra Maestra (Kysar, 2001).

The El Cobre deposit is related spatially to the so-called El Cobre fault zone. This fault zone consists of a system of fractures of approximate E–W trend that generated joint systems pointing SW and NW. This fault has been traced over more than 40 km. Rocks in the fault zone are extremely cataclasized. Dykes, quartz veins, hydrothermal alteration minerals and a copper mineralization are associated with the fault zone (Cazañas et al., 1998a).

3. Mineralization

Three main styles of mineralization can be distinguished: (a) stratiform, (b) stratabound and (c) vein mineralization.

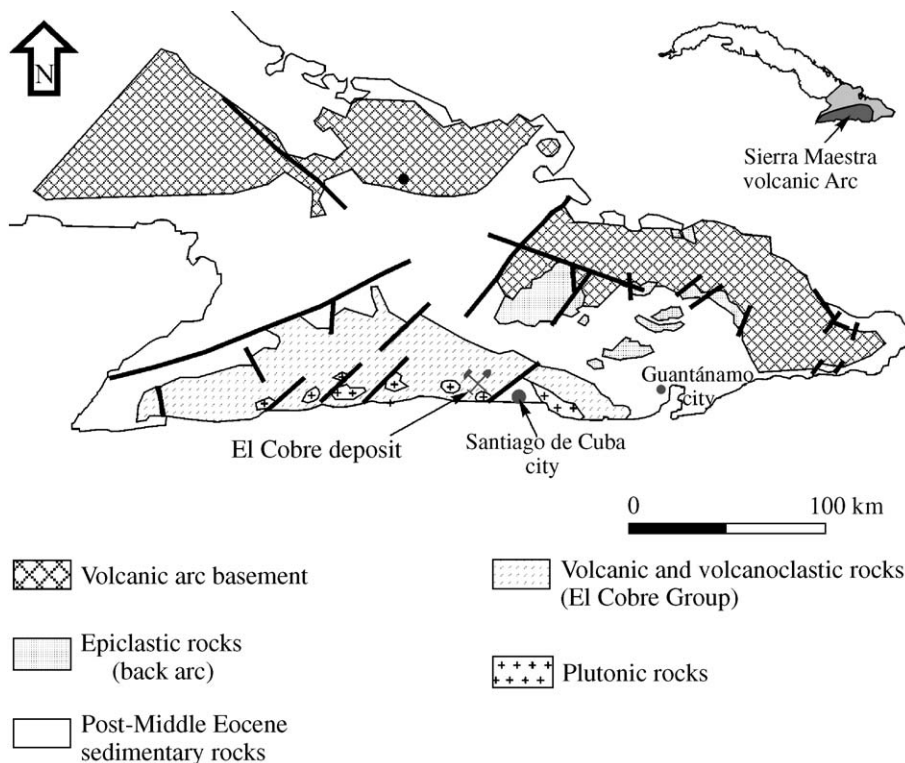


Fig. 1. Schematic geological map of the Sierra Maestra range with the location of the El Cobre deposit.

3.1. Stratiform mineralizations

The mineralizations are located in the north of the El Cobre fault, within a belt trending E–W. They are about 1.7 km long and 100 m wide and consist of several essentially monomineral baryte, anhydrite and manganese oxide lenses.

3.2. Stratabound mineralizations

Three types of stratabound mineralization can be distinguished according to depth: upper, intermediate and lower.

The upper stratabound mineralization consists of polymetallic ores (Zn–Cu–Pb), with low Cu/Zn ratio, developed directly below the anhydrite stratiform mineralization. Pyrite is the most abundant sulfide. It is replaced by chalcopyrite and sphalerite (sphalerite I), which are in turn replaced by chalcopyrite and by a late sphalerite generation (sphalerite II). There are remains of very corroded anhydrite crystals. At the bottom of the upper stratabound mineralization, a zone of kaolinite alteration, up to several tens of meters thick, is found. Mineral composition in the zone is pure nodular kaolinite.

The intermediate stratabound mineralization is made up of a partially silicified, discontinuous carbonate level of tens of meters in thickness. A polymetallic mineralization occurs in this structure.

The lower stratabound mineralization is characterized by a horizontal zoning related to the El Cobre fault. In distal zones, highly recrystallized carbonate horizons occur. In proximal zones, anhydrite and quartz replace calcite. Hessite, tetradimite and tellurobismuthite associated with chalcopyrite, as well as late tetrahedrite veins associated with pyrite, occur in minor quantities.

3.3. Vein mineralizations

Vein mineralizations consist of stockwork at surficial sectors and subparallel veins in depth. The stockwork, up to several hectometers thick, can be siliceous at intermediate depth and anhydritic in the uppermost parts. In depth, the stockwork grades to subparallel veins with chalcopyrite and pyrite. In the siliceous stockwork, two types of veins occur: one is composed by quartz with sulfides (pyrite and

chalcopyrite) and the others are late, barren quartz veins.

4. Sampling and analytical methods

Fluid inclusions have been studied in 16 samples, representative of the main types of mineralization. Microthermometric measurements were performed on a Linkam THMSG 600 heating and freezing stage in the University of Barcelona. The accuracy was ± 0.2 °C for the final ice melting temperature and ± 2.0 °C for the high temperature measurements.

Sulfur isotopes were analyzed in 60 samples of sulfides (chalcopyrite, pyrite, sphalerite and galena) and 24 samples of sulfates (gypsum, anhydrite and baryte). Analyses were performed at the SUERC. Sulfates were treated by the conventional methods. For sulfides, in situ laser combustions were carried out with a Nd-YAG laser system. Gas samples were analyzed on a VG SIRA II mass spectrometer. The analytical precision is within ± 0.2 ‰; data are reported as $\delta^{34}\text{S}$ ‰ relative to CDT.

5. Results

5.1. Fluid inclusions

Fluid inclusions were measured in quartz (stockwork and upper stratabound mineralization), sphalerite (upper stratabound mineralization and siliceous subparallel veins), anhydrite (upper, middle and lower stratabound mineralization and anhydrite-epidote veins) and calcite (middle and lower stratabound mineralization). They occur isolated, following the crystal growth, or in clusters located in the center of the crystal. Only primary fluid inclusions, according to the criteria of Roedder (1984), have been measured.

Fluid inclusions are two-phase, liquid + vapor. They are 5–20 μm in size and the degree of filling is 0.7–0.8. The temperature of first melting (T_c) obtained is between -22 and -21 °C, indicating that the dissolved salts are mainly NaCl. The final temperature of ice melting ($T_{m_{ice}}$) ranges between -3.7 and -1.1 °C. The salinity is between 1.9 and 6.0 wt.% of NaCl eq. (Fig. 2a). Clathrates have not been observed. In addi-

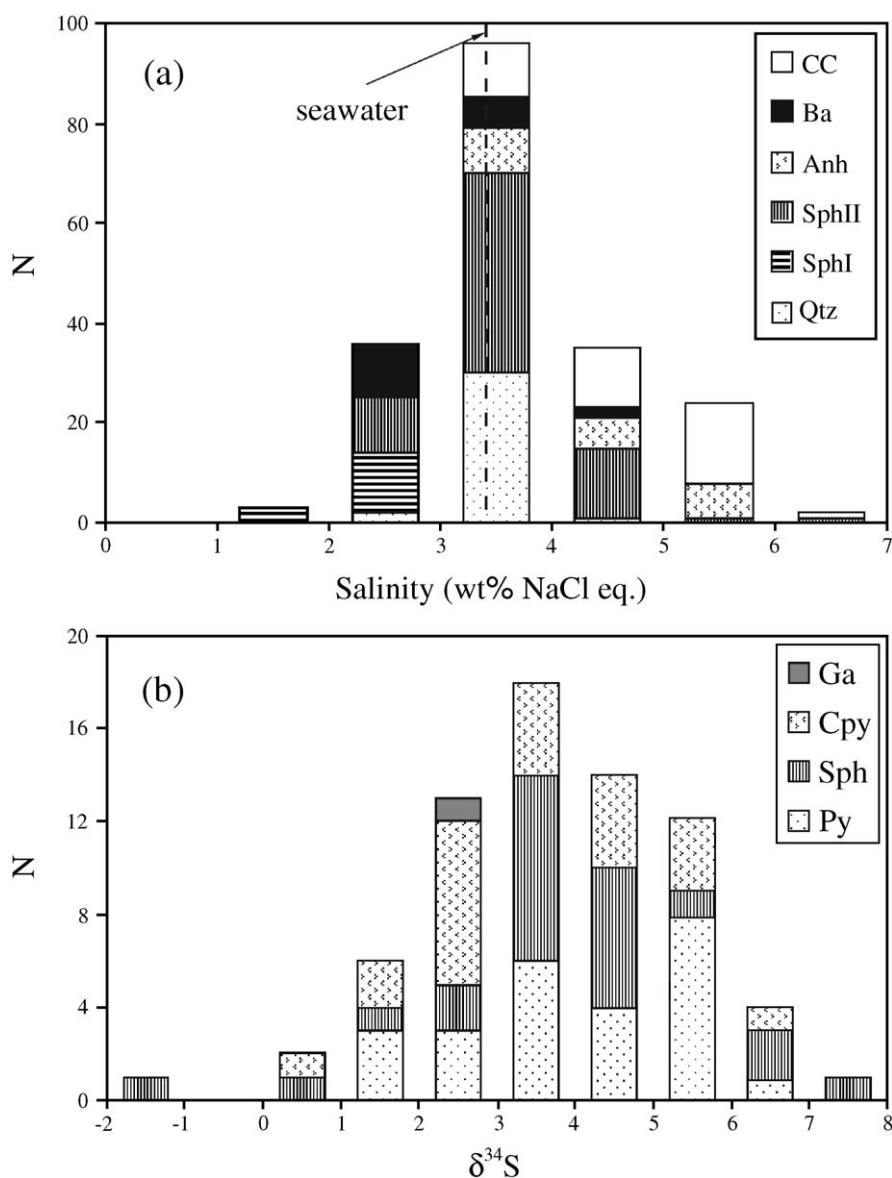


Fig. 2. (a) Frequency distribution of salinities calculated from final ice-melting temperatures of fluid inclusions from El Cobre deposit; (b) frequency distribution of $\delta^{34}\text{S}$ values in the studied sulfides.

tion, Raman spectroscopy did not detect dissolved gases in the fluid inclusions.

The homogenization is always to liquid. Homogenization temperature ($T_{h(L-V)}$) ranges between 150 and 300 °C. The highest values of homogenization temperatures are those of the siliceous stockwork (258–300 °C), while calcite and anhydrite from the

intermediate stratabound mineralization exhibit the lowest homogenization temperatures (150–242 °C).

5.2. Sulfur isotopes

Sulfides from El Cobre deposit exhibit a range of $\delta^{34}\text{S}$ values from -1.4‰ to $+7.3\text{‰}$, with an aver-

age value of +3 ‰ (Fig. 2b). $\delta^{34}\text{S}$ values between -1.4 ‰ and +4 ‰ are found in the stockwork and from +0.8 ‰ to +7.3 ‰ in the stratiform sulfides. The distribution of the isotopic composition of sulfur from the sulfides is not closely related with their distribution in the deposit, but the highest values occur at the top of the deposit.

The $\delta^{34}\text{S}$ values for sulfates range between 16.3 ‰ and 20.9 ‰, except two samples with values as low as +5.9 ‰ and +7.7 ‰.

6. Discussion and conclusions

Most of the fluid inclusions from El Cobre deposit exhibit similar or slightly higher salinity than that of seawater (Fig. 2a). Therefore, seawater was the main fluid in the formation of the deposit. Nevertheless, fluid inclusions from sphalerite I have lower salinity, mean of 2.3 wt.% NaCl eq. Possible explanations for those values are boiling and phase separation (Rona, 1988; Cathles, 1993). However, in the El Cobre case, primary fluid inclusions do not display variable liquid-vapor phase ratios that would provide evidence for boiling or phase separation.

The $\delta^{34}\text{S}$ values of sulfides from El Cobre deposit are similar to $\delta^{34}\text{S}$ values of sulfides formed at modern mid-ocean ridges. The inorganic reduction of seawater is the most common source of sulfur in VHMS deposits. This process takes place readily when the temperatures are above 250 °C and when more organic matter or ferrous iron is present (Shanks et al., 1981). Sulfates from El Cobre deposit have slightly higher $\delta^{34}\text{S}$ values (+16.3 ‰ to +20.9 ‰) than the Paleocene-Eocene sulfate Caribbean seawater (16–18 ‰) (Claypool et al., 1980). These data indicates that some reduction of seawater sulfate took place. Sulfates with very low $\delta^{34}\text{S}$ could be formed from the oxidation of hydrothermal sulfide (Sherlock et al., 1999). Therefore, the range of the $\delta^{34}\text{S}$ values of sulfur from the sulfides of El Cobre deposit can be explained by a mixing model where the main source of sulfur is thermochemically reduced seawater sulfate and a minor sulfur contribution from the host volcanic rocks.

Fluid inclusions and sulfur isotopes at El Cobre deposit indicate that seawater was the main ore-forming fluid, partially modified by interaction with the host rock during deep hydrothermal circulation.

Finally, an influx of primary magmatic fluids in the ore-forming processes cannot be ruled out in El Cobre deposit, as it takes place in other VHMS deposits (Yang and Scott, 1996; Herzig et al., 1998). The occurrence of kaolinitic alteration and the presence of hessite, tetradimite and tellurobismuthite associated with chalcopyrite in the stratabound mineralization could be explained by the participation of such fluids.

Acknowledgements

This research was sponsored by a PhD fellowship of the Agencia Española de Cooperación Iberoamericana (AECI) to X. Cazañas, and by a postdoctoral grant of the Spanish Ministerio de Educación y Cultura to P. Alfonso. These results are contributions to the Spanish DGES project, BTE2001-3308, an AECI grant (Programa de Cooperación Científica con Iberoamérica 2000). SUERC is funded by NERC and a consortium of Scottish Universities. A. Tait helped in the sulfur isotope analyses. We thank J.L.R. Touret and C.J. Peach for reviews of the manuscript

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