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Detailed characterisation of antimony mineralogy in a geometallurgical context at the Rockliden ore deposit, North-Central Sweden

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ABSTRACT

The antimony (Sb) content of the Rockliden complex Zn–Cu massive sulphide ore lowers the quality of the Cu–Pb concentrate. The purpose of this study is to characterise the Sb mineralogy of the deposit. The Sb-bearing minerals include tetrahedrite $(Cu,Fe,Ag,Zn)_{12}Sb_4S_{13}$, bournonite $PbCuSbS_3$, gudmundite FeSbS and other sulphosalts. On a microscopic scale these minerals are complexly intergrown with base-metal sulphides in the ore. Based on these observations mineralogical controls on the distribution of Sb-bearing minerals in a standard flotation test are illustrated. Deposit-scale and rock-related variation in the Sb-content and distribution of Sb-bearing minerals were found. This underlines the importance in understanding the geological background as a basis of a 3D geometallurgical model for Rockliden. Such a model is expected to predict the Sb content of the Cu–Pb concentrate, among other process-relevant factors, and helps to forecast when the Cu–Pb concentrate has to be treated by alternative processes, such as alkaline sulphide leaching, before it is sold to the smelter.

1. Introduction

Antimony (Sb) has no commercial use as metal itself, but it finds application in form of metallo-organic and inorganic compounds as flame retardants, pigments, heat and radiation stabilizers for plastics and clarification of specialty glasses, as well as Sb-based catalysts and Sb alloys, to increase strength and hardness of Pb (Butterman and Carlin, 2004; Masters, 2005; Anderson, 2012). Given its usage, it was defined as critical raw material for the modern society (Anderson, 2012; European Commission, 2010). The world market of Sb is dominated by China although the closure of mines in the Hunan Province has caused a decrease in surplus (Anderson, 2012; Masters, 2005).

The world's largest natural resources of Sb, such as those in China, primarily contain stibnite associated with pyrite, arsenopyrite, jamesonite, and various oxides if the deposits are affected by oxidation (Butterman and Carlin, 2004; Tian-Cong, 1988; Table 1). Other Sb deposits are more complex in terms of their metal content, i.e. they are polymetallic and are primarily mined for commodities such as Cu, Pb, and Ag. Sulphosalts form the dominant Sb-bearing minerals (e.g. tetrahedrite, Table 1) in these deposits, accompanied by sulphide minerals such as galena and pyrite (Anderson, 2012; Butterman and Carlin, 2004). An example is the Sunshine Mine, Coeur d'Alene mining district, Idaho (Anderson et al., 1991) with Pb–Ag–Zn–Cu–Sb sulphides bearing tetrahedrite-rich quartz–siderite veins (Wavra et al., 1994).

Mineral processing techniques traditionally applied to the primary, stibnite dominated, Sb ore material are hand-sorting, heavy medium separation, and flotation (Anderson, 2012; Tian-Cong, 1988). The processing of the more complex and polymetallic ore material requires, in addition to mineral processing, the involvement of alternative pyrometallurgical and hydrometallurgical process solutions to extract Sb from the ore material (Anderson, 2012).

The zinc–copper (Zn–Cu) volcanic-hosted massive sulphide (VHMS) deposits of the Skellefte district (northern Sweden, Fig. 1) contain Sb as impurity element with grades commonly above 200 ppm (e.g. Rakkejaur), but generally below 2.5 wt% (Allen et al., 1996). The Sb grades at the Rockliden massive sulphide mineralisation also fall into this range (Raat and Årebäck, 2009). For this range in the Sb content pyrometallurgical methods, such as oxide volatilisation or roasting, which are normally used for production of Sb from low grade Sb-ores (5–25 wt%) (Anderson, 2012 and references therein), are not considered further. However, attempts have been made to remove Sb from As–Sb–Bi-rich sulphide concentrates by partial roasting before the material was to be sent to the smelter in Rönnskär, Skellefteå, Sweden (Björnberg et al., 1986).

Studies by Lager (1989) on massive sulphides from the Rakkejaur deposit (Skellefte district, Sweden) showed that certain

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Table 1
Common Sb bearing minerals (cf. Anderson, 2012; Butterman and Carlin, 2004).

Name	Composition
Stibnite	Sb_2S_3
Jamesonite	$Pb_4FeSb_6S_{14}$
Senarmontite, Valentinite	Sb_2O_3
Kermesite	Sb_2S_2O
Tetrahedrite	$Cu_{12}Sb_4S_{13}$
Bournonite	$PbCuSbS_3$

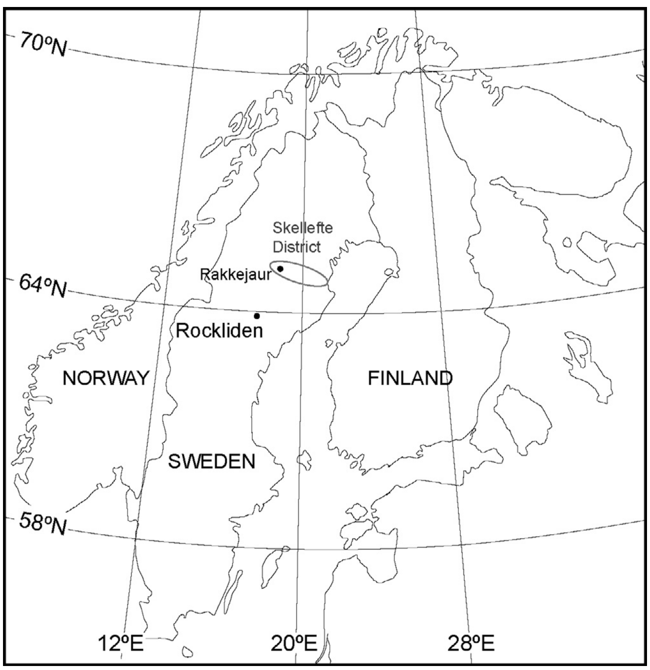

Fig. 1. Location of the Rockliden project south of the Skellefte district.

(liberated) Sb-bearing minerals (e.g. gudmundite) can be depressed during Cu–Pb and Zn flotation, whereas other minerals (e.g. bournonite and tetrahedrite) show flotation properties similar to chalcopyrite and will report to the Cu–Pb concentrate. Due to complex mineralogy, poor liberation and selectivity in flotation, Sb-bearing minerals end up in Cu–Pb and Zn concentrates. When Sb is transferred to the Cu–Pb concentrate, it lowers the quality of this product and causes penalties at the smelter. Thus, solutions to remove Sb from the Rockliden Cu–Pb concentrate by hydrometallurgical processes have been considered (Bolin, 2010). Generally, hydrometallurgical methods can be employed to extract Sb from polymetallic ore, for example by alkaline sulphide leaching as used at the Sunshine Mine plant, Coeur d'Alene mining district, Idaho (Anderson et al., 1991). Sulphide leaching was tested successfully for Cu–Pb concentrates from the Rakkejaur massive sulphide deposit and Rockliden (Awe et al., 2012; Lager, 1985). During further processing steps Sb could be recovered via electrowinning (Anderson, 2012; Anderson et al., 1991; Awe, 2010; Awe and Sandström, 2012; Filippou et al., 2007).

The Rockliden Zn–Cu massive sulphide deposit is located in North-Central Sweden, approximately 150 km south of the Skellefte ore district (Fig. 1). The deposit was discovered by Boliden in the 1980s but development was put on hold when flotation tests showed that the quality of the Cu–Pb concentrate is lowered by the Sb content (Raat and Årebäck, 2009). However, currently the deposit is again under consideration. The inferred mineral resource of Rockliden is 3.53 Mt with 4.2 wt% Zn, 1.9 wt% Cu, 0.7 wt% Pb and 71 g/t Ag (New Boliden, 2013). The Cu and Zn contents are fairly constant throughout the steeply dipping mineralisation. However, the Sb content varies. For example, the average Sb-content of all analysed intersections drilled below ca. 400 m depth is about half of that from the upper part of the deposit (Raat and Årebäck, 2009), ranging on average from ca. 750 to 1500 ppm.

Most of the mineralisation at Rockliden is found at the altered stratigraphic top of rhyolitic–dacitic volcanic rocks (Depauw, 2009; Mattsson and Heeroma, 1985). The volcanic rocks are thought to form an inlier, isolated within the metamorphosed sedimentary rocks of the Bothnian Basin (Depauw, 2009; Kousa and Lundqvist, 2000). Silicification and sericitation, and locally carbonate- and chlorite-alteration, have affected the volcanic host rocks (Depauw, 2009; Raat and Årebäck, 2009). The metamorphic grade of the volcanic and sedimentary host rocks reaches greenschist facies (Depauw, 2009), which is low compared to the regional, amphibolite facies, metamorphic grade (Kousa and Lundqvist, 2000). Folding and faulting resulted in steeply dipping mineralised zones (Fig. 2) with complex geometry (Evins, 2011; Raat and Årebäck, 2009). Additionally, NE–SW to ENE–WSW trending faults and parallel mafic dykes cross-cut the Rockliden mineralisation (Depauw, 2009). Remobilisation of Sb during the intrusion of the dykes has been suggested and some of the dykes contain about 1 wt% Sb (Depauw, 2009).

The work presented here is part of the Rockliden geometallurgical case study. Generally, geometallurgy combines all steps involved in finding and extracting metals from the earth under current economic conditions (e.g. Dunham et al., 2011; Jackson et al., 2011; Lamberg, 2011). This general description, however, implies that a broad range of aspects are considered from all involved disciplines. The Rockliden geometallurgical project focuses on understanding and gaining knowledge of the response to processes involved in extracting minerals from this deposit (cf. Jackson et al., 2011). Process-relevant, i.e. metallurgical-driver, rock-intrinsic parameters need to be identified (Walters and Kojovic, 2006; Williams, 2011). Further, the variability of these parameters should be captured over the spatial extent of the Rockliden deposit to outline domains representing homogeneous populations in terms of the parameters under consideration (cf. Jackson et al., 2011). These domains form a geometallurgical model to be built for Rockliden and to be used in forecasting the metallurgical response and furthermore in production planning and management.

Critical process-relevant parameters at Rockliden include the Sb content of the Cu–Pb concentrate, and the purpose of this work is to gain detailed knowledge of this component of response (cf. Jackson et al., 2011). This study compiles the Sb mineralogy at Rockliden and outlines controls on the Sb distribution in laboratory flotation tests. In earlier studies on the Sb mineralogy of Rockliden, tetrahedrite, bournonite and gudmundite were identified (Karup-Møller and Makovicky, 1980). The list of Sb-bearing minerals was extended in this study, and additional information was collected, such as the grain size of the Sb-bearing minerals and their mineral association, i.e. their mode of occurrence in the uncrushed drill core material. This data was then used to qualitatively evaluate the liberation distribution of the Sb-bearing minerals as found in the flotation products from laboratory flotation tests.

2. Methods

Two types of samples were studied: uncrushed drill cores and flotation products from laboratory tests from three composite samples. Locations of drill core intersections are shown in Fig. 2.

Prior to sample collection for mineralogical studies on uncrushed drill core samples, all Rockliden drill core assays available from the Boliden archive were evaluated to capture the variation