Reflected-light microscope and SEM/EMP observations on the behaviour of aurostibite (AuSb$_2$) during amalgamation

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Abstract

The Mobale gold mine (Kivu, Zaire) has been worked since 1923, but the presence of aurostibite in the ore was recognized only very recently. The discovery of the mineral has also led to the recognition of its heretofore unsuspected reactivity during the amalgamation ore dressing operations. At the surface of aurostibite a layer of up to 30 μm thickness forms which has an overall brown colour and a low reflectivity, and is composed of several variegated, concentric zones. These zones contain gold, mercury, antimony and oxygen, with traces of iron and arsenic. Oxygen is present with a concentration range of 2–4 wt.% (20-30 at.%). The zones form at the expense of aurostibite, according to micrographical criteria. In complex grains formed of gold–arsenopyrite–galena–aurostibite, only aurostibite is affected by the formation of the external brown zones. Later pure gold veneers are deposited on the outermost surface of the brown layers during the processing of the ore. The newly discovered features of processed aurostibite could explain some of the difficulties met with during the dressing of antimonian gold ores.

KEYWORDS: amalgamation, aurostibite, ore dressing, Zaire mineralogy, gold-mercury-antimony-oxygen compound.

Introduction

BESIDES its diagnostic problems (Graham and Kaiman, 1952; Mehliss, 1969; Ramdohr, 1980), aurostibite has some interesting and troublesome mineralogical properties which may influence the gold recovery from genetically diverse antimonian ores of various geologic environments (Wilson, 1982):

(*i*) Its frequent occurrence as rims around gold grains (Coleman, 1953; Sobotka, 1954; Mehliss, 1969; Swash, 1986), as myrmekitic gold/aurostibite intergrowths (Nysten, 1986), and as inclusions in gold, all habits which affects the recovery of gold;

(*ii*) Its easy artificial formation when gold ores containing antimony, stibnite or sulfo-antimonides are roasted to decompose the sulphides (Graham and Kaiman, 1952; Coleman, 1953; Swash, 1986);

(*iii*) Its alleged absence of reaction towards mercury and cyanide (Coleman, 1953; Sobotka, 1954; Henley, 1975), and consequently, its influence on the recovery of antimony-bound gold.

There is no doubt that some of the difficulties encountered in the extraction of gold from antimoniferous ores are, at least partly, attributable to these peculiarities of aurostibite. A closer look at the mechanisms which are responsible for these difficulties is thus required. However in the literature, most present day assertions about the unreactivity of aurostibite towards amalgamation and cyanidation go back to the already quoted papers by Graham and Kaiman (1952), Coleman (1953) and especially to the paper by Henley

(1975). This latter review paper contains no references to first-hand observations, and has been widely quoted afterwards (Morrison, 1978), and endorsed even as late as 1990 (Harris, 1990), but apparently without any further supportive observations. The hypotheses put forward in the first two papers have been incorporated in the literature, without detailed observations of the reaction mechanisms.

Careful observation of processed aurostibite from the Mobale Mine (Kivu, Zaire) provides some fresh data and, although no theoretical support for the observed textures can be presented here, these data may open up debate and lead to a full investigation of the phenomena reported.

The Mobale mine and ore

The Mobale gold mine is sited about 5 km south of Kamituga (E 28° S 3°), and has been worked since 1923 (NOTICE EXPLICATIVE, 1974). The ore body consists of three quartz sheets which cut quartz–biotite schists of Burundian age conformably. The ore minerals comprise: arsenopyrite, pyrite, chalcopyrite, and pyrrhotite, with galena, sphalerite and bismuthinite as minor species. Aurostibite has been discovered only recently, and was not reported during an earlier thorough light microscopy investigation of polished sections (Allard, 1989). The gold content varies between 50 and 400 g/tonne. The ore is treated along a classical flow sheet of grinding, jigging, gravity tabling, flotation, amalgamation and cyanidation. Amalgamation is conducted in a rotating barrel with steel balls. The barrel is cleaned at least once a week. Since the concentrates and overflows are continuously recycled, a given sample normally contains mineral grains which have been subjected to several gravity/amalgamation cycles. The observed phenomena thus represent various residence times of the mineral grains concerned.

Studied samples and methods of study

Three concentrates of the gravity separation and amalgamation not subjected to flotation and cyanidation were collected. The concentrates contain aurostibite in concentrations approximately equal to those of the gold, which gives an idea of its original concentration, certainly well under the 1% level.

The concentrates were inspected under the binocular microscope, and gold and polymineralic grains containing gold were extracted by hand, mounted in bakelite and polished. The mounts were then investigated under the reflected light microscope, under the scanning electron microscope (SEM) and the electron microprobe (EMP) fitted with an energy dispersive spectrometer (TRACOR TN-2000). Semiquantitative chemical analyses were obtained with an automatic standardless program (TRACOR SSQ). The figures for mercury were not obtained directly from the automatic program, since the near-overlaping of the Au and Hg peaks in the energy spectrum prevents accurate determination of mercury by this method. Approximate Hg concentrations were achieved by measuring the half-surface of the Hg peaks, and calculating the mercury content by assuming that the peaks of this element are generated in a manner similar to those of gold, also taken as pure standard. The figures are thus not as reliable as those for gold and antimony. Oxygen was analysed directly with a light element energy dispersive spectrometrer (TN-5402) and with an automatic standardless program.

Results

Observations in reflected light. Aurostibite generally occurs associated with the other opaque minerals, including gold, galena, pyrrhotite and arsenopyrite, or included in gold and galena (Figs. 1 and 2). The colour is grey, and may be reminscent of that of galena, hence the diagnostic confusion. But when near to galena, the latter appears definitely darker: reflectivities are respectively 63 and 43% (Figs. 1, 2 and 4). The dispersion of its reflectance is also different to that of galena.

When aurostibite has undergone amalgamation, its outer layers can be seen to consist of bands parallel to the exterior outline (Figs. 1 and 2). The thickness of these bands on different aurostibite grains varies between 1 μm and 30 μm. The other minerals (gold, galena and arsenopyrite) do not show these brown bands (Figs. 2 and 4), which thus result exclusively from a reaction on the exposed aurostibite, and not from deposition from a solution.

A closer examination of the bands shows a fine zoning, due to differences in hue and reflectivity (Figs. 3, 4 and 5). The general colour is brown, with a greenish hue (mustard colour). The general reflectivity is rather low, like that of goethite, but very finely mottled. Some very smooth, intermediate veneers have a yellow colour and higher reflectances, and are very similar to gold (Figs. 3, 4 and 5).

Some other morphological features should be pointed out:
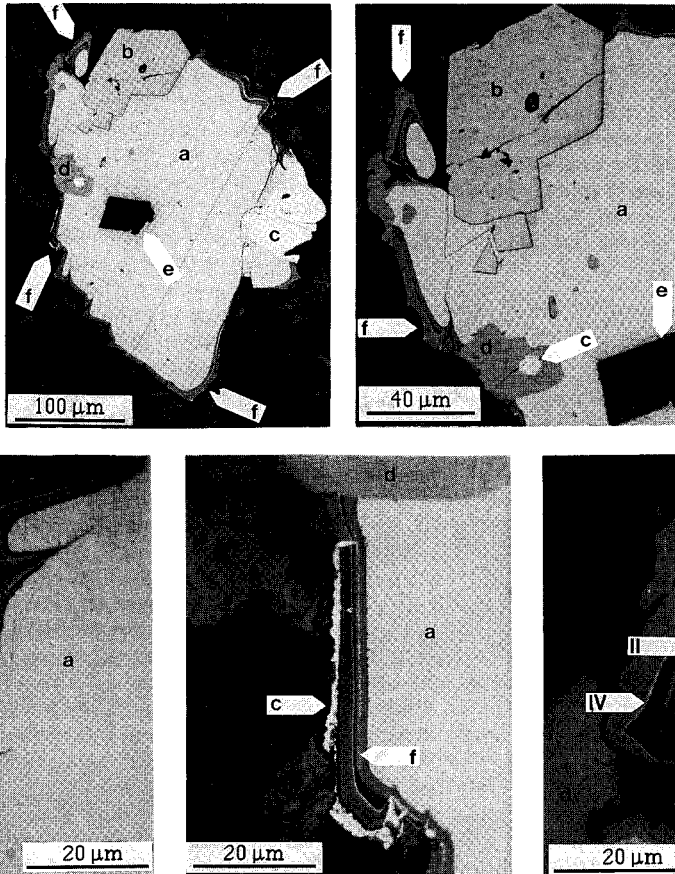
FIGS. 1–5. All photographs were obtained under the reflecting light microscope, oil immersion: (*a*) aurostibite; (*b*) arsenopyrite; (*c*) gold; (*d*) galena; (*e*) feldspar; (*f*) brown bands. FIG. 1 (top left). General view of a polymineralic grain. FIG. 2 (top right). Enlarged part of the same. FIG. 3 (bottom left). Zoned brown band thickened at apices and penetrating along cracks in aurostibite. FIG. 4 (bottom centre). Zoned brown band affecting aurostibite, but not galena. (*c*) later gold. FIG. 5 (bottom right). Residual aurostibite with thick zoned brown band. (Roman ciphers refer to analysed zones in Table 1).

(*i*) The formation of the brown bands preserves the general outline of polymineralic grains: there is no discontinuity of the grain outline where the bands form (Fig. 2). This indicates that the bands are formed at the expense of the locally exposed aurostibite with an apparent conservation of the volumes;

(*ii*) Exposed sharp angular grains of aurostibite are more deeply affected by the bands than the straight edges (Fig. 3);

(*iii*) The brown bands propagate along fissures in the aurostibite, and along gold/aurostibite interfaces (Fig. 3);

(*iv*) The outermost brown zone is frequently covered with a later, discontinuous layer of pure gold (Fig. 4). Other exposed minerals such as galena and arsenopyrite never have these later deposited gold layers (Fig. 2);

(*v*) The later gold frequently penetrates beneath the brown zones (but not in the aurostibite) along radial cracks and between zones (Fig. 4). This later gold sometimes forms filigree nets in the entire brown layer.

Chemical analyses. Electron microprobe analyses of the aurostibite with the TN-2000 show a rather good agreement with theoretical composition (Table 1, analyses 1 and 2). The brown bands are composed of gold, antimony and mercury, with iron and arsenic appearing only as trace components. Table 1 gives the compositions of

successive bands for the heavy elements Au, Sb and Hg, from the aurostibite outwards (Fig. 5 and Table 1, analyses 3–5). One does not observe clear directional variations of composition. Mercury is present in the innermost zone. The bright yellow veneers observed under the light microscope are indeed enriched in gold, but still contain antimony and mercury (Table 1, analyses 3.II and 3.IV). The mean composition for the heavy elements of the band as a whole is as follows (mean of 7 analyses):

Au = 68.67 ± 7.40 wt %   60.77 at. %
Sb = 21.47 ± 7.90   30.74
Hg = 9.76 ± 1.47   8.48

Considering that the dull brown colour displayed by some zones could not be that of an intermetallic compound, they were tested for oxygen with the TN-5402. This element is indeed present, and at a concentration of about 4.03 wt.% (30.03 at.%) in zone 3.III (Table 1, analysis 4). Another zone has also shown the presence of oxygen in lower concentrations of the order of 20 at.% (Table 1, analysis 5).

Given the uncertainties affecting these figures, which were obtained without standards and on a very limited number of analyses, it seems nevertheless established that one is not dealing with intermetallic compounds, but with oxidic compounds, with overall estimated ratios of (Au + Hg) : Sb : O = 1.33 : 1 : 1 for Zone 3.III and 3 : 1 : 1 for Zone 3.V. It should be stressed here that 'oxidic' includes here the indistinguishable oxygen and hydroxyl anions.

Discussion

The morphological, optical and chemical data indicate that aurostibite is affected by a surface reaction during its processing, contrary to assertions put forward previously. However, a natural feature quite similar in chemical composition, colour and texture has recently been discovered in unprocessed gold ores from Yakutia (Gamyanin *et al.*, 1988). Here, aurostibite in contact with valentinite is altered along its border to two gold antimony oxides of the general formula $AuSbO_3$ and of brown colour. But in the Mobale case, the observed brown compounds have very different elementary ratios, and the presence of mercury in the reaction bands is a good proof of their origin during ore treatment. Clearly, these are not the same compounds. The definitive demonstration of this origin for the brown bands would of course have come from the observation of unprocessed aurostibite, but this could not have been achieved until now, due to the low concentration of the mineral in the crude ore.

Another approach to the understanding of the observed phenomena would be the establishing of the possible physicochemical reaction(s) which could promote them. This approach is not a straightforward one, since it will also be necessary to take into account the various chemicals which are added to the amalgamation slurry, like sodium hydroxide and litharge.

The presence of later pure gold, deposited on the outermost oxidic bands, shows that some gold is present as a dissolved species, even in the absence of cyanide. Its deposition on and in, the

Table 1 : Chemical composition of the Mobale aurostibite and of its brown border

	1	2			3				4	5
(wt. %)			3.I	3.II	3.III	3.IV	3.V	(at. %)	(at. %)
n =	1	4	1	1	1	1	3		
Au	44.74	43.30±0.45	60.81	72.89	58.44	80.82	72.63±0.49	34.24	52.31
Sb	55.25	56.62±0.49	33.69	21.09	31.81	11.81	18.25±0.83	30.15	21.26
Hg			5.50	6.01	9.74	7.35	9.09±0.46	5.60	6.42
O								30.00	20.00

Column 1: aurostibite, theoretical composition (for AuSb2)
2: aurostibite from Mobale
3: successive zones, from the aurostibite (a) outwards: I, dark brown; II: golden yellow; III: dark brown; IV: golden yellow; V: pale brown.
4: wt. composition of zone 3.III recalculated as at. % and at O = 30 at. %
5: wt. composition of zone 3.V recalculated as at. % and at O = 20 at. %

brown bands, and exclusively on them, shows that the latter have a reduction capacity towards the gold solution, but it is well known that the latter are easily reduced by almost any oxidic compound (Pascal, 1957).

Conclusions

The recent discovery of a previously unrecognized gold mineral in an old gold deposit is probably not an isolated case. The fact that the presence of antimony in gold ores has been recognized for a long time as a problematic factor for gold recovery lends support to the hypothesis of a more widespread occurrence of aurostibite. The discovery of an oxidic reaction zone affecting autostibite exposed to amalgamation, and of late gold redeposited on the outer surface of the reaction zones could perhaps indicate where the recovery difficulties lie and how they might be overcome. A thorough re-examination of all the minerals passing through the amalgamation barrels is thus necessary if one suspects gold losses in the dressing of antimonian ores (Sobotka, 1954).

Acknowledgements

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