1 **The leaching characteristics and changes in the leached layer of**
2 **antimony-bearing ores from China**

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Abstract

China has the most abundant antimony (Sb) resources of any country in the world. Large quantities of Sb have been released from mining and smelting processes, causing serious Sb contamination in the mine or nearby areas. To understand the leaching characteristics of hazardous Sb, As, Pb and Cr from antimony minerals, 12 samples of antimony-bearing ores from eight large mines from China distributed in Hunan, Yunnan, Guizhou and Guangxi provinces were studied. The main compositions of these minerals are Sb_2S_3 , SiO_2 or CaCO_3 . The pH changes during the leaching indicated that some minerals themselves are alkaline, providing sufficient acid-neutralizing capacity during leaching. However, some alkaline minerals release much more Sb, As, Pb and Cr than others. Inconsistencies between totals amounts and the released content of Sb, As, Pb and Cr were also found. The surface topography of an antimony sulfide mineral and the species changes of Sb and sulfur (S) on its leached surface were also characterized by scanning electron microscopy (SEM) and X-ray photoelectron spectroscopy (XPS), respectively. It is the oxidation-dissolution of Sb_2S_3 that releases Sb. Sb(III) and S^{2-} on the surface of the fresh mineral were oxidized to Sb(V) and $\text{S}_2\text{O}_3^{2-}$ and SO_4^{2-} , respectively, and finally, an equilibrium of dissolution was reached over time. The release of Sb, As, Pb and Cr from typical antimony ores is a source of Sb, As, Pb and Cr in the weathering zone; with this in mind, it is easier to understand the geochemical processes and the pollution accidents involving Sb and As within the mining areas and their surroundings.

Keywords: antimony-bearing ores; leaching; antimony; arsenic; leached surface

38 **1 Introduction**

39 Antimony (Sb) is widely utilized for a variety of purposes, including flame retardants, brake linings,
40 polyethylene glycol terephthalate, lead-acid batteries and alloys (Amarasiriwardena and Wu, 2011; Takahashi
41 et al., 2008). Previous reports have shown that like lead (Pb), arsenic (As) and mercury (Hg), Sb is a toxic
42 element of global concern. The majority of Sb pollution appears to originate from mining and industrial
43 emission sources (Adriano, 1986; Guo et al., 2014; Telford et al., 2009; Wilson et al., 2010) because very high
44 levels of pollution have been detected around smelter sites (Ainsworth et al., 1990; Baroni et al., 2000; Filella
45 et al., 2002; Ragaini et al., 1977; Wilson et al., 2010). China has the most abundant Sb resources of any
46 country in the world. It has been responsible for approximately 90% of all antimony metal produced globally
47 over the past decade (Carlin and James, 2012). Serious Sb pollution in China had been reported (He et al.,
48 2012). For example, high Sb concentration in water (up to 29.4 mg/L), sediments (up to 1163 mg/kg) and soils
49 (up to 5,045 mg/kg) were found nearby Xikuangshan mining and smelting areas in China (He, 2007; He et al.,
50 2012; Li et al., 2014). Antimony pollution in the aquatic environment results from rock weathering, soil runoff
51 and anthropogenic activities (Filella et al., 2002). Some studies showed that the dissolution of Sb-bearing ore
52 minerals is thought to contribute significantly to the Sb pollution in waters draining zones. The kinetics of the
53 mobilization of Sb from stibnite, $\text{Sb}_3\text{O}_6\text{OH}$ and Sb_2O_3 under environmental conditions has been studied in
54 detail by Biver and Shotyk (2012, 2013). Hu et al (2014, 2015) studied the release kinetics and mechanisms of
55 Sb from stibnite and Sb_2O_3 under the irradiation of light. As we know, in the natural environment the oxidative
56 dissolution of abundant sulfide ore leads to the net release of protons, a phenomenon known as acid mine or
57 acid rock drainage (Kwong et al., 2009; Verplanck et al., 2009). Subsequent leaching of ores by acidic
58 drainage waters causes elevated concentrations of a broad range of potentially toxic elements, especially the

chalcophile elements such as cadmium (Cd) and Pb, which are enriched in metal sulfides. The elevated concentrations of these “heavy metals” and the predominance of their generally more harmful cationic forms at low pH present serious risks to all forms of life in receiving water bodies (Asta et al., 2010; Domènech et al., 2002; Edwards et al., 2000; Moncur et al., 2005; Moncur et al., 2009). In the majority of mine districts, acid drainage is a serious environmental geochemical issue. Thus, serious Sb pollution in waters and soils in China may be concerned with leaching raw ores, tailings and waste rock by acid drainage as a result of the mining activity.

Therefore, 12 samples of antimony-bearing ores from 8 different mines distributed in Hunan (Banxi, Xikuangshan, Zhazixi and Chenzhou antimony mines), Yunnan (Muli antimony mine), Guizhou (Xinghua antimony mine) and Guangxi (Chehe and Dachang antimony-bearing polymetallic mines) provinces in China were sampled. The release characteristics of Sb and other heavy metals were determined. Through comparing the release of hazardous heavy metals from different mines, we hope to obtain background information for heavy metals contamination remediation and management and implementation of reduction programs.

2 Materials and Methods

2.1 Sample collection and pretreatment

Origins of 12 samples of antimony-bearing ores, which were named by their sites and grades (e.g. Banxi high-grade and low-grade antimony ores from Banxi antimony mines, North of Xikuangshan and two South of Xikuangshan antimony ores from Xikuangshan antimony mine, Muli high-grade and low-grade antimony ores from Muli antimony mines, and Zhazixi, Xinghua, Chenzhou, Dachang and Chehe antimony-bearing ores from their corresponding mines) and their corresponding antimony deposit types (Wu, 1993) are listed in Table 1. Large bulk ores were broken crushed with a steel hammer and then crushed in a steel percussion

80 mortar and ground to powder in an agate mortar. The powder was sieved, and the fraction between 0.15 and
81 0.075 mm was retained for elemental analysis. Individual samples of 0.1000 g were digested in 9 mL of
82 concentrated nitric acid, 3 mL of hydrochloric acid and usually 3 mL hydrofluoric acid for 30 minutes using
83 microwave heating (180 ± 5 °C) (Refer to USA EPA METHOD 3052). After cooling, the vessel contents were
84 filtered, decanted and diluted to volume. The total digestions were performed in triplicate for each sample.
85 The analytical accuracy was checked by triplicate digestions/measurements of standard reference material
86 CRM/RM information center of China GBW07174 (Sb = 1.1 ± 0.11 percent by weight) and GBW07176 (Sb =
87 39.7 ± 0.49 percent by weight) (antimony ore). All reagents used were analytical pure grade or better.

88 **2.2 Experimental methods**

89 Leaching experiments were conducted in the series of 100-mL propene polymer (PP) batch reactors. One
90 reactor was used for one sampling time to ensure the same solid-liquid ratio after sampling. For every run, 50
91 mL of sulfuric acid aqueous solution with an initial pH of 2 (1 mol/L sulfuric acid was used to adjust pH) and
92 an accurately weighed mass of approximately 0.5000 ± 0.0002 g ores were introduced into the reactor. These
93 reactors were put in a vapor-bathing constant temperature (25 °C) vibrator at 120 rpm. At every interval (one
94 or two days, please see the x-coordinate of Fig.2-Fig.5), 10 mL leached solution was taken, filtered using
95 disposable PP/PE syringes (Shanghai Zhiyu medical equipment Co., LTD, China) with CME 0.45 μ m
96 hydrophilic syringe filters. The solution pH was determined using PB-10 pH probes (Sartorius (Shanghai)
97 Trading Co., LTD, China). The concentration of metals (Sb, As, Pb, Cd and Cr) in the leached solution was
98 measured over time. The remaining solid was decanted into plastic tubes and then rinsed with clean acid
99 solution to prevent contamination of the surface. The samples were frozen in liquid N₂ and stored in a freezer

100 until immediately prior to surface analysis. This procedure has been shown to inhibit significant surface
101 speciation alteration (Smart, 1991).

102 **2.3 Analytical methods**

103 Digestion and leached solution were analyzed by ULTIMA inductively coupled plasma atomic emission
104 spectrometry (ICP-AES) (HORIBA JobinYvon S.A.S., France) according to the water and sludge analysis
105 standard EN ISO 11885:1997.

106 The main composition of the ore samples was analyzed by X-ray diffraction (XRD) (PANalytical B. V.,
107 Holland). The XRD patterns were recorded on an X'Pert Pro diffractometer. Conditions: Cu K α radiation, 40
108 kV and 40 mA, 2 theta range 10-70° with a scan rate step of 0.05 °/s, using an X'Celerator detector. The
109 qualitative analysis of the XRD patterns was performed using MDI Jade software (version 6.5), plus the ICDD
110 PDF-2 database (ICDD, 2004).

111 The scanning electron microscope (SEM) micrographs collected from fresh particles and particles leached for
112 12 d and 16 d were obtained on a Hitachi S-4800 field emission scanning electron microscope (Hitachi Ltd,
113 Japan).

114 The species changes of Sb and S on the leached surface at different times was determined by ESCALAB MK
115 II X-ray photoelectron spectroscopy (XPS) (VG Scientific Ltd. UK) analysis with a monochromatic Al K α
116 source and a charge neutralizer. Carbon cloth (C 1s binding energy of 284.6 eV) was used to calibrate the
117 spectrometer. Each spectral peak position was charge-corrected with reference to the adventitious hydrocarbon
118 C 1s binding energy of 284.8 eV (Metson, 1999).

119 **3 Results and Discussions**

3.1 The characteristics of antimony-bearing ores

3.1.1 Composition analysis

The XRD patterns of ores (Figure 1) showed that their diffraction patterns differ from one another. However, by examining these patterns carefully, compositions of ores generally fall into three categories: (1) patterns of ores from Banxi, Zhazixi, Xinghua and Muli could be well-indexed to Sb_2S_3 (major) and SiO_2 (Fig. 1a); (2) patterns of ores from Banxi (low grade), Muli (low grade), South of Xikuangshan, North of Xikuangshan and Chenzhou could be well-indexed to SiO_2 (major) and Sb_2S_3 (Fig. 2b). Specifically, other than SiO_2 and Sb_2S_3 , $\text{Sb}_3\text{O}_6(\text{OH})$ was identified in the ore from Muli (low grade); (3) patterns of ores from South of Xikuangshan-2, Chehe, Dachang could be well-indexed to SiO_2 , CaO_3 and a little Si (Fig. 1c). No Sb diffraction peak was found due to extremely low Sb content ($< 5\%$) in these ores. The ores contained SiO_2 and CaCO_3 , which closely relate to their silicification and carbonatization in wall rock alteration, respectively.

3.1.2 Element analysis

The results of elemental analysis (Table 2) showed that the Sb content from different antimony-bearing ores is very different. The maximum of antimony content is as high as approximately 66%, compared with the minimum of 0.066% by weight. Overall, high-grade antimony raw ores, such as ores from the Banxi, Zhazixi, Xinghua and Muli antimony mines, exist mainly in the form of Sb_2S_3 , which has been confirmed by XRD patterns. Even from the same mine, the antimony content can also be different. For example, the Sb content in high-grade ore from the Banxi antimony mine was approximately 20 times as much as that in the low-grade ore.

In addition to Sb, all of the ore samples contained different levels of other heavy metals, especially highly toxic As, Pb, Cd and Cr. In polymetallic ores, the content of As is even higher than that of Sb. Mine area contamination is bound to occur as a result of the release of these metals through the leaching and weathering

processes of ores, especially under acidic conditions. Moreover, Fe and Mn contained in these ores could affect the release of hazardous metals (Belzile et al., 2001; Lafferty et al., 2011; Ying et al., 2012).

3.2 Leaching characteristics of different antimony-bearing ores

According to the XRD results, the leaching characteristic of each category in three categories was discussed separately in the following sections. It should be noted that only Sb, As, Pb and Cr could be detected in the leachate; thus, only the four metals were discussed in each ore category.

3.2.1 The pH changes during the leaching process

Although the initial pH is the same, pH changes during the leaching are different (Fig. 2). Strikingly, the pH changes for all ores based on Sb_2S_3 (major) and SiO_2 (black tabs in the figure) and some ores based on SiO_2 (major) and Sb_2S_3 remained basically unchanged at approximately pH 2. However, the pH for all ores in Fig. 1c and some in Fig. 1b rapidly increased to pH 5-7, and then remained unchanged. The results closely related to the composition of ores. Ores with more Sb_2S_3 retained a basically unchanged pH in the process of leaching; ores with less or no Sb_2S_3 increased the initial pH to nearly neutral or neutral. These ores with less or no Sb_2S_3 are based on CaCO_3 and SiO_2 , which could provide sufficient acid neutralizing capacity during leaching. However, Banxi (low grade) and South of Xikuangshan antimony-bearing ores with the same main composition generated different pH changes with North of Xikuangshan and Chenzhou antimony-bearing ores. According to antimony deposit types, it is inferred that low content alkaline components contained in the Banxi (low grade) and South of Xikuangshan antimony-bearing ores provided a little acid neutralizing capacity during leaching, and almost no acid neutralizing components was contained in the other ores (Table 1).

3.2.2 Leaching characteristics of high grade antimony sulfide-bearing ores

Figure 3a-d shows the release concentration and percent of Sb, As, Pb and Cr from ores based on Sb_2S_3 (major) and SiO_2 . The results are: (1) the concentration of Sb (13-15 mg/L) in the leachate was much greater than concentrations of As, Pb and Cr; (2) the release concentration of Sb from the Zhazixi and Muli ores reached a plateau with similar levels (Fig. 3 b and c), while a decreased Sb concentration was found in the leachate of the Xinghua and Banxi ores (Fig. 3 a and d); (3) the release percent of As, Pb and Cr accounting for their total content was higher than Sb at the 16th day, for example, in the Zhazixi ore, the release percent of As (16%), Pb (2%) and Cr (4%) were much more than that of Sb (close to 0%). The corresponding reasons are: (1) the release concentrations of Sb, As, Pb and Cr were closely related to their total contents in the ores: The Sb content in these ores is approximately hundreds of times greater than the content of As, Pb and Cr; (2) the released Sb reached a saturated solubility in these four ores and some Sb released from the Xinghua and Banxi ores can be adsorbed on the ore surface or can reach an adsorption-desorption dynamic; on the other hand, the pH is in the pH_{PZC} (point of zero charge) of Sb_2S_3 (Healy and Fuerstenau, 2007; Stumm and Morgan, 1996). Stumm and Morgan (1996) emphasized that the pH-dependent surface charge of minerals is an important factor for their dissolution because the polarization causes surface chemical bonds and generalized minimum dissolution rates of minerals at the pH_{PZC} . Sb_2S_3 is the main component of the Banxi ore; thus, it followed the law. (3) the species of As, Pb and Cr favored their release in acidic solution; for the ores with low contents of As, Pb and Cr, they had an extremely low concentration in the leachate, but a high release percent could be calculated.

3.2.3 Leaching characteristics of low grade antimony sulfide-bearing ores

Figure 4a-e shows the release concentration and percent of Sb, As, Pb and Cr from five ores based on SiO_2 (major) and Sb_2S_3 . The results are as follows: (1) on the whole, the release concentration of Sb from each ore was the highest except for the Banxi (low grade) ore, which released the highest concentration (18 mg/L) and

185 percent (18 %) of As at the 16th day; (2) a release concentration (21 mg/L) and percent (6.5%) of Sb from the
 186 South of Xikuangshan antimony ore at the 16th day even was higher than the release concentration (13-15
 187 mg/L) and percent (close to zero) from ores based on Sb₂S₃ with approximately 40-60% total Sb, the Banxi
 188 ore included. The reasons are as follows: (1) Sb was still the most abundant metal in these ores; (2) The
 189 arsenic content in the Banxi (low grade) (0.97%) and Chenzhou (0.46%) ores was higher than that in the other
 190 ores. The release concentration of these metals was closely related to their total content in the ores. However,
 191 the above conclusion only applies to the same type of ores. The dissolution rate of Sb₂S₃ increased with the
 192 increase of pH (Biver and Shotyk, 2012). We found the pH of leachate had changed to approximately 5 (Fig.
 193 2). However, even at the same pH 2, the ore from North of Xikuangshan with 1.7% Sb still released the same
 194 concentration of Sb (approximately 14 mg/L) as the Muli ore with 40% Sb. The causes of these problems can
 195 be traced to the species of Sb. Sb₂S₃ and Sb₂O₃ are two of the most significant antimony minerals. Previous
 196 studies (Biver and Shotyk, 2012, 2013) have shown that dissolution rate of Sb₂S₃ increased with the increase
 197 in pH, and there is a sharp increase in the dissolution rate of Sb₂O₃ with decreasing pH. Thus, it may be Sb in
 198 the form of Sb₂O₃ contained in the ore from North of Xikuangshan. In addition to the above factors, the
 199 dissolution of minerals containing Fe-Mn oxides and hydroxides coexisting with the antimony-bearing ores
 200 also played an important role in the dissolution of antimony-bearing ores (Fan et al., 2014; Lafferty et al.,
 201 2011; Manning et al., 2002; Postma and Appelo, 2000; Wang et al., 2012; Ying et al., 2012).

202 *3.2.4 Leaching characteristics of antimony-bearing polymetallic ores*

203 Figure 5a-c shows the release concentrations and percentages of Sb, As, Pb and Cr from ores based on SiO₂
 204 and CaCO₃. These showed wholly different results with the above two types of ores: (1) the release
 205 concentrations of Sb and As increased linearly; (2) the release concentration and percent of Sb and As had a
 206 similar trend, that is, high concentration corresponding to a high percent; (3) low total Sb in the ores but high

207 release concentration in the leachate just like South of Xikuangshan and Banxi. First, these results may be
 208 attributed to the increased pH due to the dissolution of CaCO_3 contained in these ores. Because the pH of a
 209 leached solution of this type of ore increased to approximately pH 7 (Fig. 2), according to the reasoning in the
 210 above section, the increased pH (>2) prompted the release of Sb. Second, much of the CaCO_3 dissolved,
 211 which loosened the structure of the ore, so that the surface area of the ore-water interface increased, favoring
 212 the dissolution of ores and release of Sb and As.

213 **3.3 Leached surface changes**

214 The surface topography of the ore from Banxi and the species changes of Sb and sulfur (S) on its leached
 215 surface were characterized by SEM and XPS, respectively.

216 *3.3.1 Surface topography before and after leaching*

217 Strikingly, with the increase of leaching time, the surface roughness of the ore increased. The original smooth
 218 surface (0 d) of ores was eroded, and more small holes (16 d) appeared (Fig. 6). This illustrated that
 219 dissolution of ores mainly began with the ore-water interface.

220 *3.3.2 Species changes of Sb and S on the leached surface*

221 The changes to Sb and S species on the leached surface of the ore from Banxi characterized by XPS are
 222 illustrated in Fig. 7a and 7b, respectively. In Fig. 7a, the solid peaks were assigned to $\text{Sb}3d_{5/2}$ (located at
 223 529.5 and 529.8 eV) and $\text{Sb}3d_{3/2}$ (located at 539.1 and 539.7 eV) of Sb^{3+} . The two dashed peaks located at
 224 532.1 and 532.9 eV at 12th and 16th d were assigned to $\text{Sb}3d_{5/2}$ of Sb^{5+} (Url 1). In Fig. 7b, the dotted peak
 225 located at 161.0 eV and the dashed peak located at 162.5 eV were assigned to $\text{S}2p$ of S^{2-} and $\text{S}_2\text{O}_3^{2-}$,
 226 respectively. The solid peaks at 12th and 16th d located at 169.4 eV were assigned to $\text{S}2p$ of SO_4^{2-} (Url 2). That
 227 is to say, the initial surface of the ore, prior to leaching is rich in Sb(III) (Fig. 7a – 0 d) and is composed of

228 S^{2-} and $S_2O_3^{2-}$ (Fig. 7b – 0 d). Within 12 d of leaching, the Sb(III) on the surface layer had begun to be
 229 oxidized to Sb(V) (Fig. 7a – 12 d), and an increase in SO_4^{2-} (Fig. 7b – 12 d) was observed, which revealed
 230 oxidation dissolution of Sb_2S_3 formally regarded as:

234 In addition to O_2 , other oxidants, such as Fe and Mn oxides / hydroxides that coexisted in the
 235 antimony-bearing ores also prompted the oxidation dissolution of ores (Fan et al., 2014; Lafferty et al., 2011;
 236 Manning et al., 2002; Postma and Appelo, 2000; Wang et al., 2012; Ying et al., 2012). Upon further leaching
 237 to 16 d, the surface species of Sb and S approached approximately the same appearances as at 12 d, which
 238 illustrated that the reaction of ore-water reached equilibrium.

239 **4 Conclusions**

240 The main compositions of antimony-bearing ores are Sb_2S_3 , SiO_2 or $CaCO_3$, which closely relate to their
 241 silicification or carbonatization in wall rock alteration. The pH changes during the leaching and the release
 242 characteristics of Sb, As, Pb and Cr are closely related to the type of antimony-bearing ore. The release of
 243 metals is dependent on their total content in the ores based on Sb_2S_3 , SiO_2 , but inconsistencies between the
 244 totals and the released content were found in ores based on $CaCO_3$ and SiO_2 . These results mainly related to
 245 ore type, species of Sb and pH of solution. The characterized leached surface of the Banxi ore showed the
 246 oxidative dissolution of Sb_2S_3 . In conclusion, to prevent contamination by highly toxic metals in mines or
 247 areas near to mines, those ore heaps with low Sb and As should be especially noted. This study only showed
 248 the leaching results of different ores from one side. Actually, the dissolution of ore was complicated, which

can be affected by pH, temperature, light irradiation, dissolved organic matter and so on. Thus, we will study other factors affecting the dissolution of natural antimony-bearing ores in our future work.

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Table 1 Abstract summary of typical antimony deposit in China

Antimony ores	Mines	Type	Primary minerals	Wall alteration	rock
Xikuangshan antimony deposit, Hunan	South of Xikuangshan, North of Xikuangshan	Carbonate stratiform and stratoid deposit	Stibnite(Sb_2S_3), Valentinite(Sb_2O_3), Germanite (Sb_2O_4), Cervantite ($\text{Sb}_3\text{O}_6\text{OH}$)	Silicification(major) carbonatation, baratization, pyritization, fluoritization, sericitization	
Banxi antimony deposit, Hunan	Banxi antimony mine	Quartz vein-type deposit	Stibinite (Sb_2S_3)	Arsenopyritization, pyritization, Silicification, sericitization, carbonatation,	
Zhazixi antimony-deposit, Hunan	Zhazixi antimony mine	Filling-metasomatic vein deposit	Stibinite (Sb_2S_3)		
Dachang antimony-polymetallic deposit, Guangxi	Dachang antimony mine	Stratoid integrated Sb, Pb sulfosalt deposit	Jamesonite($\text{Pb}_4\text{FeSb}_6\text{S}_{14}$), Cassiterite(SnO_2), Arsenopyrite(FeAsS), Pyrrhotite(FeS), Pyrite(FeS_2), Marcasite(FeS_2), etc.	Bleaching, Weak silicification, Recrystallization	
	Chehe antimony mine	Vein staggered Sb-W deposit	Stibnite (Sb_2S_3), Berthierite (SbFeS_3)	Skarnization, Silicification and Carbonatization.	
Banpo antimony deposit, Guizhou	Xinghua antimony mine	Clastic sedimentary-modified hydrothermal deposit	Stibnite (Sb_2S_3), Pyrite (FeS_2), Valentinite(Sb_2O_3), Germanite(Sb_2O_4)	Silicification, Carbonatization, Recrystallization, Pyritization and Sericitization	
Muli antimony deposit, Yunnan	Muli antimony mine	Carbonatite Sedimentary-modified deposit	Stibnite(Sb_2S_3), Pyrite(FeS_2), Germanite(Sb_2O_4), Cervanite($\text{Sb}_3\text{O}_6\text{OH}$), Valentinite(Sb_2O_3)	Silicification, Carbonatization, Recrystallization, Pyritization, Calcilization,	

Table 2 Main elemental composition of antimony-bearing ores (g/t)

Ore sampes	Sb	As	Pb	Cd	Cr	Fe	Mn	Zn	Cu
Xinghua	6.6×10^5	1.6×10^2	75	2.0	80	8.5×10^2	10	70	25
Banxi	6.5×10^5	6.2×10^2	40	2.0	70	3.4×10^3	60	1.4×10^2	30
Zhazixi	4.4×10^5	1.0×10^3	20	2.0	90	2.1×10^3	5.0	25	10
Muli	4.0×10^5	95	10	3.0	5.4×10^2	4.5×10^3	45	1.1×10^2	20
Muli (low grade)	3.5×10^5	85	15	2.0	3.8×10^2	4.1×10^3	40	85	15
Banxi (low grade)	3.2×10^4	9.7×10^3	10	1.0	1.1×10^2	2.5×10^4	1.6×10^2	70	10
North of Xikuangshan	1.7×10^4	2.8×10^2	20	1.0	1.1×10^3	1.6×10^4	1.2×10^2	1.9×10^2	15
South of Xikuangshan	3.2×10^4	3.6×10^3	55	3.0	1.6×10^2	5.7×10^3	75	1.8×10^3	10
South of Xikuangshan-2	3.9×10^3	1.1×10^2	45	3.0	2.2×10^2	8.1×10^3	75	5.9×10^2	10
Chenzhou	2.2×10^3	4.6×10^3	80	3.0	1.1×10^2	2.4×10^4	5.0×10^2	1.8×10^3	15
Chehe	1.6×10^3	2.1×10^3	9.2×10^2	80	8.0	1.1×10^5	9.9×10^2	5.2×10^4	4.9×10^2
Dachang	6.6×10^2	1.7×10^3	1.4×10^3	2.5×10^2	8.0	9.4×10^4	1.1×10^3	3.7×10^4	4.1×10^2

Figure Captions

Fig. 1 XRD patterns of three types of antimony-bearing ores: 1-Sb₂S₃, 2-SiO₂, 3-Sb₃O₆OH, 4-CaCO₃, 5-Si

Fig. 2 pH changes during leaching for 16 d

Fig. 3 Release concentration (solid lines) and percent (dash lines) of Sb, As, Pb and Cr from ores based on Sb₂S₃ (major) and SiO₂

Fig. 4 Release concentration (solid lines) and percent (dash lines) of Sb, As, Pb and Cr from ores based on SiO₂ (major) and Sb₂S₃

Fig. 5 Release concentration (solid lines) and percent (dash lines) of Sb, As, Pb and Cr from ores based on SiO₂ and CaCO₃

Fig. 6 Surface topography of the original and leached ore from Banxi

Fig. 7 Species changes of Sb (a) and S (b) on the original and leached surface of the ore from Banxi

Fig.2

Fig. 2 pH changes during leaching for 16 d

Fig. 3a-d

Fig. 3 Release concentration (solid lines) and percent (dash lines) of Sb, As, Pb and Cr from ores based on

Sb_2S_3 (major) and SiO_2

Fig. 4a-e

Fig. 4 Release concentration (solid lines) and percent (dash lines) of Sb, As, Pb and Cr from ores based on SiO_2 (major) and Sb_2S_3

Fig. 5a-c

Fig. 5 Release concentration (solid lines) and percent (dash lines) of Sb, As, Pb and Cr from ores based on SiO_2 and CaCO_3

Fig.6

Fig. 6 Surface topography of original and leached ore from Banxi

Fig. 7

Fig. 7 Species changes of Sb (a) and S (b) on the original and leached surface of ore from Banxi