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pH-dependent release characteristics of antimony and arsenic from typical antimony-bearing ores

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ABSTRACT

The pH-dependent leaching of antimony (Sb) and arsenic (As) from three typical Sb-bearing ores (Banxi, Muli and Tongkeng Antimony Mine) in China was assessed using a pH-static leaching experiment. The pH changes of the leached solutions and pH-dependent leaching of Sb and As occurred in different ways. For the Banxi and Muli Sb ores, alkaline conditions were more favorable for the release of Sb compared to neutral and acidic conditions, but the reverse was true for the pH-dependent release of As. For the Tongkeng Sb ore, unlike the previous two Sb-bearing ores, acidic conditions were more favorable for Sb release than neutral and alkaline conditions. The ores with lower Sb and As contents released higher percentages of their Sb and As after 16 day leaching, suggesting that they are the largest potential sources of pollution. This work may provide key information on the geochemistry of Sb and As in the weathering zone.

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Introduction

Areas related to mining exploitation and ore smelting contain significant amounts of heavy metals and metalloids. These sites represent some of the most important hazards for waters, biodiversity, and food chains. The most important natural source of antimony (Sb) is stibnite (Sb_2S_3), which, in the supergene environment, is associated with its principal weathering products senarmonite (cubic Sb_2O_3), valentinite (orthorhombic Sb_2O_3), and stibiconite ($\text{Sb}_3\text{O}_6\text{OH}$) (Filella et al., 2009). Recent studies have shown that Sb pollution is a global issue (Amarasiriwardena and Wu, 2011; Filella et al., 2009; Krachler et al., 2005; Shotyk et al., 1996; Shotyk et al., 2005) because of its toxicity to humans and its role in causing liver, skin, and respiratory and cardiovascular diseases (Girgis et al., 1970; Kuroda et al., 1991; Schnorr et al., 2007), especially in mining areas. Antimony mining and smelting activities produce residues that frequently contain high levels of Sb in the form of sulfides, such as stibnite (Sb_2S_3). The residues are readily oxidized when

exposed to air and meteoric water and can release Sb into the aquatic ecosystem (Casiot et al., 2007). They are responsible for most of the world's environmentally significant Sb contamination. Very high levels of pollution have been detected around smelter sites (Baroni et al., 2000; Flynn et al., 2003; Ragaini et al., 2002; Wilson et al., 2004). The exploitation of the Chinese Xikuangshan Sb mine, the world's largest Sb mine during several periods from 1897 to the present, has resulted in mining dumps being highly contaminated with Sb. For example, high Sb concentrations in water (up to 29.4 mg/L), sediments (up to 1163 mg/kg) and soils (up to 5045 mg/kg) were found near the Xikuangshan mining and smelting areas in China (He, 2007; He et al., 2012; Li et al., 2014). The World Health Organization stated that the maximum permissible pollutant concentration for Sb in receiving soils is 36 mg/kg (Chang et al., 2002). In general, the Sb pollution from this mine is very severe and has resulted in significant environmental problems in China (He and Yang, 1999). Arsenic commonly occurs in the same geochemical environment as Sb; thus, both elements may be anomalous in

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rocks, soil, stream sediments and waters. Serious Sb pollution generally occurs with As pollution (Ashley et al., 2007; Fu et al., 2010; Wilson et al., 2010). Although the two elements have some similarities, numerous investigations have revealed that they have strikingly different behavior in the environment (Fu et al., 2011; Gál et al., 2007; Majzlan et al., 2011; Müller et al., 2007; Wilson et al., 2010).

The metals contained in the ores or waste rocks are released from the mining field to the environment by various mechanisms (weathering, leaching, particulate transport) and are dispersed by gravitational transport and fluvial and atmospheric pathways (Davies, 1980). Leaching is an important metal releasing process for mining and smelting wastewater or stormwater. Generally, the release of metals is controlled by the solubility of various solid phases, directly affected by changes in the pH (Astrup et al., 2006a, 2006b; Cappuyns and Swennen, 2008; van der Sloot et al., 1996; Van Herreweghe et al., 2002; Vítková et al., 2009). Thus, the pH is one of the key parameters controlling the leaching process. The pH of mining and smelting waste water can also be acid, neutral or even basic, depending on the mineralogy of the site. It is known that the oxidative dissolution of sulfide minerals leads to the net release of protons, a phenomenon known as acid rock drainage. Acid drainage can be naturally attenuated if certain rocks or minerals are present, in particular carbonates such as calcite and dolomite, which provide sufficient acid neutralizing capacity.

Previous studies have been performed on Sb and As distribution and mobility in the aquatic environment around Sb mines (Ashley et al., 2007; Casiot et al., 2007; Fu et al., 2010). Additionally, the distribution and phyto-availability of Sb at Sb mining and smelting areas and Sb pollution in China have been studied (He, 2007). Some studies showed that the dissolution of Sb-bearing ore minerals is thought to contribute significantly to the Sb pollution in water draining zones. The kinetics of the mobilization of Sb from stibnite, Sb_2O_3 and Sb_2O_3 under environmental conditions has been studied in detail by Biver and Shotyk (2012, 2013). Hu et al. (2014, 2015) studied the release kinetics and mechanisms of Sb from stibnite (>98%) and Sb_2O_3 (>98%) under irradiation by light. The release of As from orpiment and amorphous As_2S_3 and realgar and amorphous AsS (Lengke and Tempel, 2001, 2002, 2003), and Sb and As from a mined orogenic gold deposit (Druzbecka and Craw, 2013; Kerr et al., 2015) were also studied. Given the growing recognition of Sb as an emerging contaminant and globally important atmospheric pollutant, there is a real need to develop a better understanding of the geochemistry of Sb and As in the weathering zone, beginning with its release from natural Sb ores and waste rocks.

The aim of our present study is: (1) to investigate pH-dependent release characteristics of Sb and As from three typical Sb-bearing ores, (2) to compare Sb and As release behavior, and (3) to compare release characteristics of different Sb ore types.

1. Materials and methods

1.1. Antimony ores

Three typical Sb ores were collected from three large Sb mines in China: Banxi Antimony Mine in Hunan Province, Muli

Antimony Mine in Yunnan Province, and Tongkeng Antimony Mine in Guangxi Province. The Sb ores from Banxi and Muli are mainly antimony sulfide, and the Sb ore from Tongkeng is a polymetallic sulfide ore. The rock deposit types of Banxi, Muli and Tongkeng Antimony Mine are quartz vein, carbonatite sedimentary-modified and stratoid integrated Sb-plumbum sulfosalt deposits, respectively (Wu, 1993). The composition of the ore samples is reflected in the subsequent characteristics of the Sb ores. A large volume of ore fragments were broken with a steel hammer. Pieces with no superficial oxidation products were crushed in a steel percussion mortar and ground to powder in an agate mortar. The powder was sieved and the fraction between 0.15 and 0.075 mm was retained for elemental analyses and leaching experiments. Stibnite (Sb_2S_3) with more than 97% Sb_2S_3 , 0.01% Fe, 0.2% As, and 2% free S by weight percent, was purchased from Tianjin Guangfu Fine Chemical Research Institute (China) and used as a comparison.

1.2. pH-static leaching experiment

The pH-static experiments were performed at $25 \pm 1^\circ\text{C}$ for 16 days. A mass of 0.50 g of ore samples was placed in a 100-mL PE bottle, and 50 mL of Milli Q+ deionized water was added. To ensure that the solid-liquid ratio was the same for each sample, a separate bottle was used for each sampling time. The pH range of 2 to 10 (2, 4, 5.7, 7.5 and 9.8) was selected to account for acid, neutral or basic conditions encountered in the mine areas. Sulfuric acid (guaranteed reagent) or sodium hydroxide (analytically pure) was added to adjust the pH values. The reactors were put in a vapor-bath constant temperature vibrator at 120 r/min. The leachate was sampled after 1, 2, 4, 8, 12 and 16 days and filtered through 0.45 μm membrane filters (Membrana, Germany). The pH values were recorded using a Sartorius PB-10 pH meter (Sartorius, Germany). The leachate was prepared for concentration analyses of Sb and As. All of the experiments were performed three times and with procedural blanks.

1.3. Analytical methods

The heavy metal contents in three Sb ore samples were analyzed using inductively coupled plasma-atomic emission spectrometry (ICP-AES) (ULTIMA, JobinYvon S.A.S., France) after digestion in reagent-grade acids (HF-HCl-HNO_3). The total digestions were performed three times for each sample. Two standard reference Sb ores, GBW07174 (Sb = $1.1\% \pm 0.11\%$, As = $0.98\% \pm 0.12\%$) and GBW07176 (Sb = $39.7\% \pm 0.49\%$ and As = 0.36%), were used to check the accuracy of the solution measurements.

The leached solutions were analyzed for concentrations of Sb and As using atomic fluorescence spectrometry (AFS-9800, Beijing Haiguang Instrument Co., Ltd., China) with detection limits for Sb and As below 0.01 $\mu\text{g/L}$ under standard analytical conditions.

The mineralogy of the three Sb ore samples was analyzed using X-ray diffraction (XRD). The XRD patterns were recorded on a PANalytical X'Pert Pro diffractometer (X'pert pro MPD, PANalytical B. V., Holland). Conditions: Cu K_α radiation, 40 kV and 40 mA, 2 theta range 10–70° with a scan rate step of 0.05°/sec, using an X'Celerator detector. The qualitative analysis of the XRD

patterns was performed using MDI Jade software (version 6.5) and the ICDD PDF-2 database.

2. Results and discussion

2.1. Characteristics of Sb-bearing ores

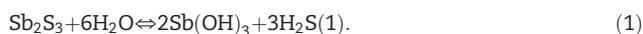
The percentages by weight (wt.%) of metallic elements for the three Sb ores are listed in Table 1. Actually, many elements were present in the three Sb ores; for the sake of brevity and clarity, only the most hazardous heavy metals and most important metals (Fe and Mn) in the environment are listed in Table 1. The compositions of the three Sb ores were very different. The Sb content in the Banxi ore was the greatest (64.5%), followed by the Muli ore (34.7%), with both much greater than the 0.156% in Tongkeng ore. In addition to different ore types, the samples represented high, medium and low grade Sb ores. The As contents were much less than Sb in the Banxi Sb ore and Muli Sb ore, but higher than Sb in the Tongkeng Sb ore. In general, metal (except Sb) contents in Tongkeng Sb ore were greater than in the other two ores.

The XRD patterns of stibnite (Sb_2S_3) and the three samples are shown in Fig. 1. It is worth noting that the peak intensities in the XRD patterns are representative of the crystallinity of different phases to a large extent, but not absolutely representative of the amounts of different components in samples. Based on the ICDD PDF-2 database and analysis of the experimental data, we obtained the main compositions of the three ores. The Banxi Sb ore is mainly Sb_2S_3 (major) and quartz (SiO_2) (minor), representing a typical sulfide ore. The Muli Sb ore is composed of quartz (major) and stibnite (minor) and a small amount of stibiconite ($\text{Sb}_3\text{O}_6\text{OH}$). Unlike the previous two types, the main composition of the Tongkeng Sb ore is SiO_2 , calcite (CaCO_3) and a small amount of silicon (Si). No significant peaks of Sb phases were detected because of its extremely low content in the Tongkeng Sb ore, and no significant peaks of As phases were detected because of its extremely low content (<0.2%) in the three ores used in this study. It is worth noting that secondary antimony oxides, such as senarmonite (cubic Sb_2O_3) and valentinite (orthorhombic Sb_2O_3), as the most important weathering products of stibnite, may be present in the three ores (Ashley et al., 2003), even though no diffraction peak for these phases was found. In addition, the total Fe in three ores is 0.337%, 0.414% and 11.3%, respectively (Table 1), but no peak of pyrite was found in XRD patterns, illustrating that its content was below the detection limit (approximately 3 wt.%) of XRD or that it existed in other forms. Even if pyrite was present in the ores, due to its extremely low content it would not affect the pH of the leaching solutions to a great extent. Thus, we did not consider the effect of pyrite on the pH of the leaching solutions.

2.2. Sb and As release characteristics of Sb-bearing ore from Banxi Antimony Mine

The pH changes of leached solutions and Sb and As release characteristics of the Sb-bearing ore from Banxi Antimony Mine are shown in Fig. 2. The pH changes fell into two categories. The first was an almost unchanged pH of approximately 2 with an initial pH of 2. The other pH values tended to have a similar value (pH 6–7) after 1 day of leaching. This illustrated that the ores provided a large enough buffering effect at pH higher than 4.

Fig. 2a shows that the Sb concentration increased over time. The alkaline condition was more favorable for the release of Sb than neutral or acidic conditions. The Sb-bearing ore is composed of stibnite, which dissolves in water to form the hydroxide $\text{Sb}(\text{OH})_3$ and is formally represented by:



However, $\text{Sb}(\text{OH})_3$ behaves more like an acid than a hydroxide; therefore, it is often written as H_3SbO_3 (antimonous acid). It can dissociate to form an anion (negatively charged species) by:



Eq. (2) is sometimes also written as:



As the pH increases, more of the H_3SbO_3 is converted to anionic form. The charged anion H_2SbO_3^- is very soluble in water (Brown, 2011).

The concentration of Sb, except in the pH 2 leached solution, has little effect. At pH higher than 4, this is consistent with the pH changes. The Sb concentration at pH 2 was much less than those at other pH values because the pH corresponds to the pH_{PZC} (pH at 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 influences surface chemical bonds and in general, minimum dissolution rates of minerals occur at the pH_{PZC} . Stibnite is the main composition of the Banxi ore and it followed this rule. The control experimental result is shown in Fig. 3. The Sb concentration in the leached solution was slightly below that of the Sb-bearing ore from Banxi, even though it has higher Sb content. The associated components in the natural Sb ores may facilitate the dissolution of Banxi ore. The overall pH dependent release trend of Sb was similar. The pH changes for initial pH other than pH 2 (non-pH 2) are similar during the leaching process, resulting in similar release plots at non-pH 2. These figures also affirmed that pH 2 was the pH_{PZC} of Sb_2S_3 . All of these results are consistent with Biver's research on stibnite dissolution kinetics (Biver and Shoty, 2012).

Table 1 – The content of metals in three ores from different antimony mines in China (wt.%).

	Sb	As	Cd	Pb	Cr	Fe	Mn
Antimony-bearing ore from Banxi	64.5	0.0620	0.0002	0.00400	0.00700	0.337	0.00600
Antimony-bearing ore from Muli	34.7	0.00850	0.0002	0.00150	0.0375	0.414	0.004400
Antimony-bearing ore from Tongkeng	0.156	0.213	0.008	0.0924	0.000833	11.3	0.0986

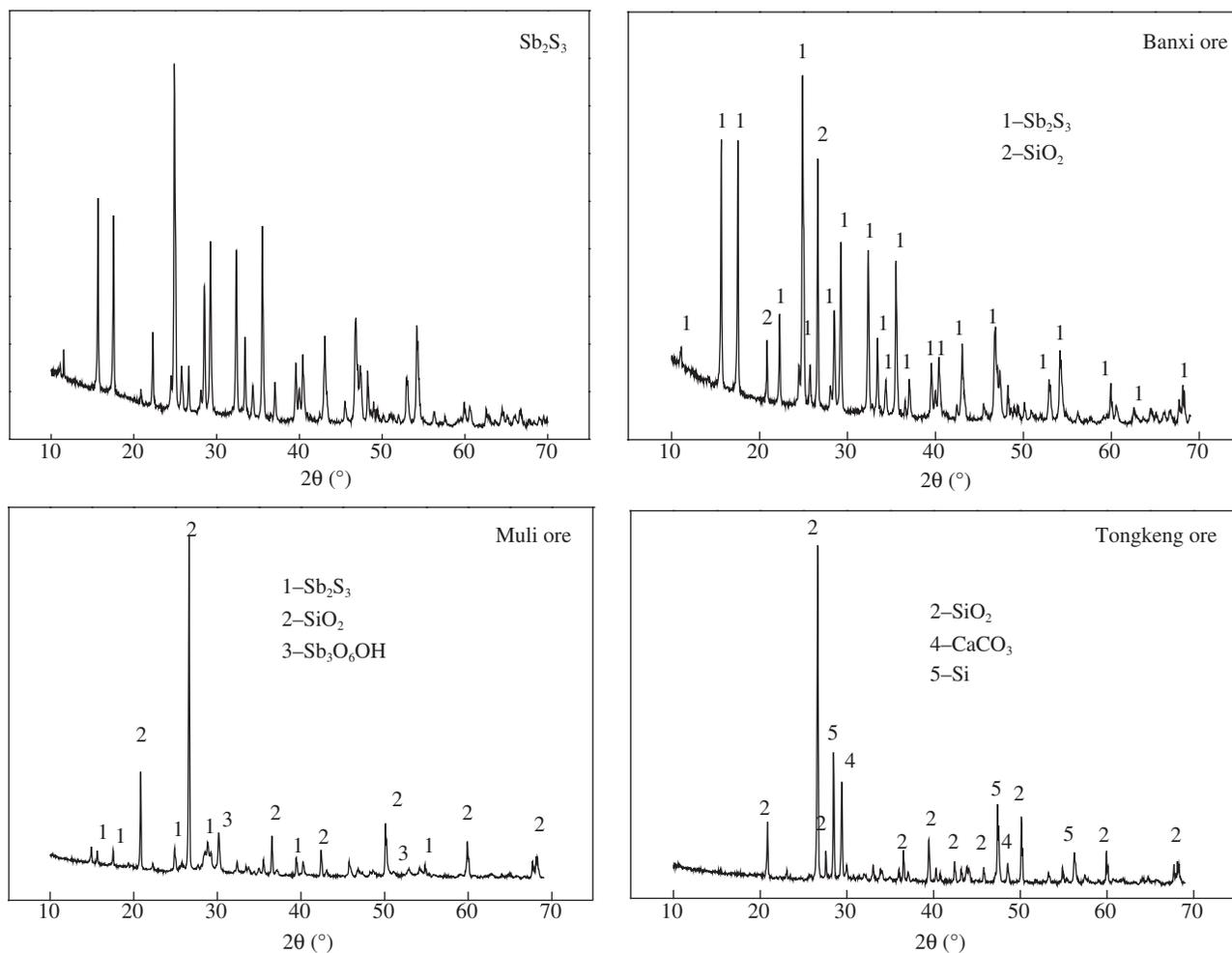


Fig. 1 – X-ray diffraction (XRD) patterns of Sb_2S_3 , Banxi, Muli and Tongkeng antimony ores. 1— Sb_2S_3 , 2— SiO_2 , 3— $\text{Sb}_3\text{O}_6(\text{OH})$, 4— CaCO_3 , 5—Si.

Fig. 2b also shows that the pH-dependent release of As varies with time. The pH dependence for As release is inverse to that of Sb, meaning that an acidic condition is favorable for release of As.

One interpretation may be that stibnite in mesothermal vein systems hosted in low-grade metamorphic rocks may be abundant, and commonly associated with elevated contents of

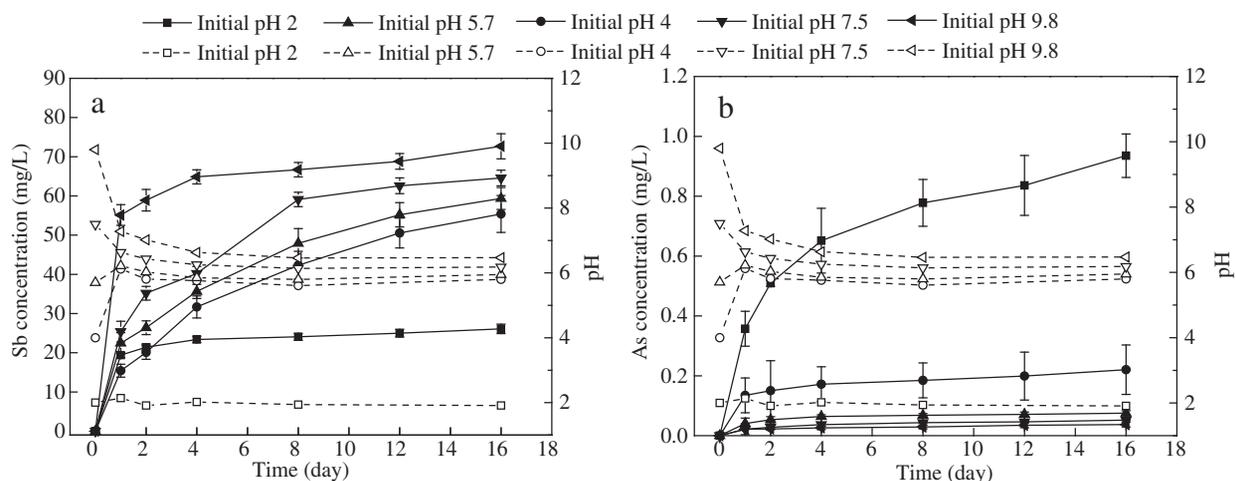


Fig. 2 – Leaching of the antimony-bearing ore from Banxi Antimony Ore. The leached concentration changes of Sb and As (solid labels) and pH changes of the leached solution (corresponding dashed labels).

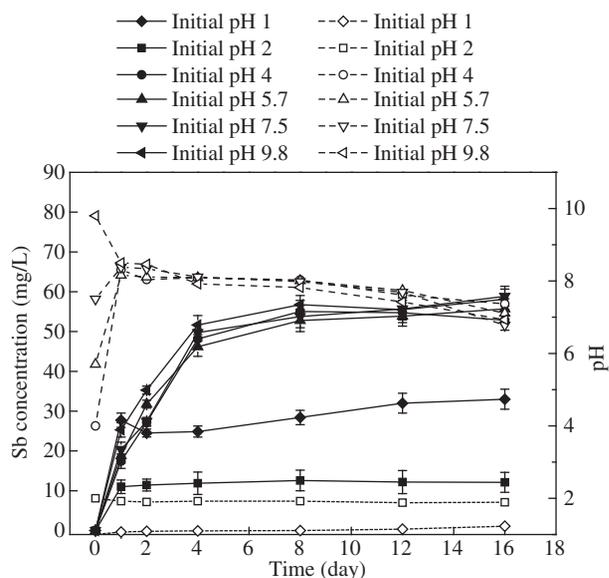


Fig. 3 – Leaching of commercial Sb_2S_3 : The leached concentration changes of Sb (solid labels) and pH changes of the leached solution (corresponding dashed labels).

As, Au and, locally, Hg and W (Groves et al., 1998; Nesbitt et al., 1989; Williams-Jones and Normand, 1997). Arsenic in solid solution in the above-mentioned ores dominantly occurs as arsenopyrite ($FeAsS$) and arsenian pyrite (FeS_2 , with up to several wt.% As), which easily dissolve under acidic conditions (Ashley et al., 2003; Kerr et al., 2015). When the pH of the solution changes from acidic to basic pH, precipitation of iron phases takes place. An Fe-coating grows on the rock surface and prevents the diffusion of aqueous species through it. Thus, the output concentration of As release decreases.

2.3. Sb and As release characteristics of Sb-bearing ore from Muli Antimony Mine

The pH changes of leached solutions and Sb and As release characteristics of Sb-bearing ore from Muli Antimony Mine are

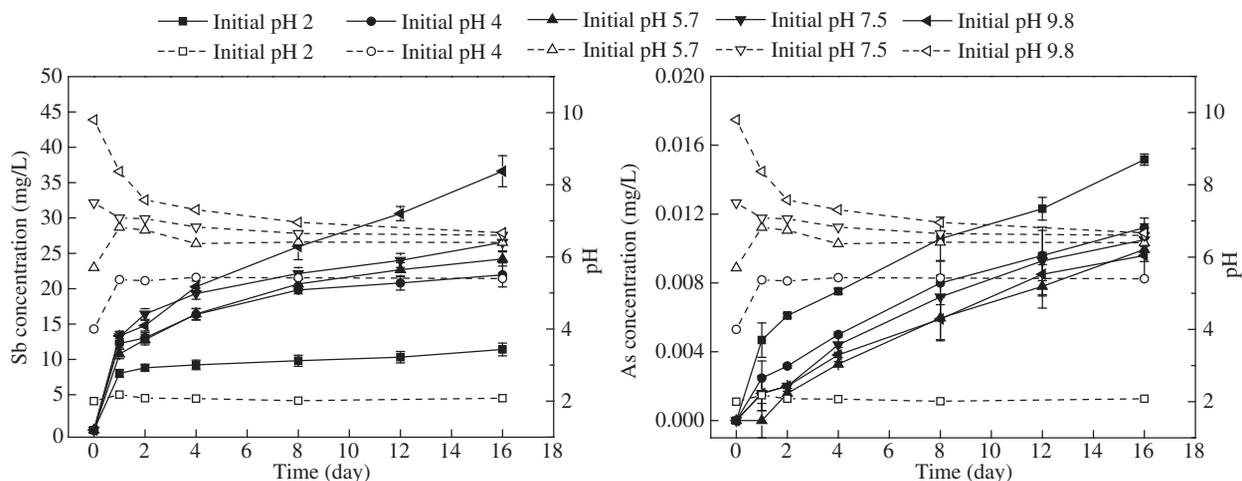
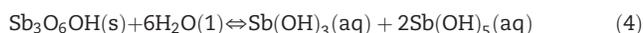


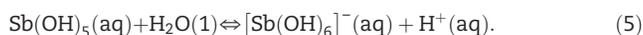
Fig. 4 – Leaching of the antimony-bearing ore from Muli Antimony Ore: The leached concentration changes of Sb and As (solid labels) and pH changes of the leached solution (corresponding dashed labels).

shown in Fig. 4. Similar to the Sb-bearing ore from Banxi Antimony Mine, the pH changes fell into two categories. This is because the two ores have similar compositions, Sb_2S_3 and SiO_2 .

The pH-dependent release of Sb and As from the Sb-bearing ore from Muli was similar to that from Banxi, except for the concentration. The released concentration of Sb in Muli Sb-bearing ore (e.g., 35 mg/L at pH 9.8 for the 16th day) was less than that for Banxi Sb-bearing ore (e.g., 75 mg/L pH 9.8 for the 16th day) (Fig. 2). That is because the Sb content in Banxi ore (64.5%) is greater than that in Muli ore (34.7%). In addition, the presence of $Sb_3O_6(OH)$ did not make a difference in the pH-dependent tendency because the dissolution reactions of stibiconite may be expressed by Eqs. (4) and (5) (Biver and Shotyck, 2013):



where $Sb(OH)_5$ is a weak acid:



The dissociation of $Sb(OH)_3$ follows Eqs. (2) and (3). Therefore, as the pH increases, more of the H_3SbO_3 and $Sb(OH)_5$ is converted to anionic forms. Once the anions $H_2SbO_3^{-}$ and $[Sb(OH)_6]^{-}$ are formed, they are very soluble in water. The standardized release percentage of Sb in Banxi and Muli Sb-bearing ore had the same order of magnitude, even though more Sb was released in Muli Sb-bearing ore. Although there is a small difference between initial non-pH 2 changes, large differences exist between the release plots of pH 9.8 and other pH values. Presumably, an initial solution pH of 9.8 promoted the release of Sb from Sb_3O_6OH .

In addition, a reverse pH-dependent trend of As release compared to Sb was found, just like in Banxi Sb-bearing ore. That is to say, the identical mineralogy of As (arsenopyrite and arsenian pyrite) in the Muli Sb-bearing ore and sulfide ore is easily dissolved under acidic conditions (Ashley et al., 2003; Kerr et al., 2015). However, the released concentration of As in Muli Sb-bearing ore (e.g., 0.015 mg/L at pH 9.8 for the 16th day) was less than for Banxi Sb-bearing ore (e.g., 0.95 mg/L at pH 9.8 for the 16th day) (Fig. 2). That is because As content in

Muli Sb-bearing ore (0.0085%) is much less than that in Banxi Sb-bearing ore (0.062%) (Table 1).

2.4. Sb and As release characteristics of Sb-bearing ore from Tongkeng Antimony Mine

Fig. 5 shows the different pH-dependent Sb and As release characteristics for Sb-bearing ore from Tongkeng Antimony Mine. All initial pH values showed large changes. Different from the previous two ores, the initial pH of 2 changed to approximately 7 and the other initial pH values approached approximately 8 after 1 day of leaching. This illustrates that CaCO_3 and other associated components in the sample provided sufficient acid neutralization and buffer capacity.

Unlike the previous two ores, a different pH-dependent release of Sb occurred in this sample, while the same pH-dependent release of As as in the previous two ores was obtained, meaning that initial acidic conditions were beneficial for release of both Sb and As. Three reasons may explain the result: (1) Sb in the form of senarmontite is present in Tongkeng Sb-bearing ore, because the cumulative mass of total Sb from dissolving Sb_2O_3 increased with the decrease of pH value (Biver and Shotyk, 2013); and As still has the same mineralogy (arsenopyrite and arsenian pyrite) (Ashley et al., 2003; Kerr et al., 2015) in this sample as in the previous two ores, which easily dissolve under acidic conditions; (2) it can be seen that 11.3% Fe was contained in this sample (Table 1), much greater than the levels (0.337% and 0.414%) in the previous two ores, thus when the pH of the solution changed from mildly acidic to basic pH, precipitation of iron phases took place. An Fe-coating grew on the ore surface and prevented the diffusion of aqueous species through it; and (3) the Tongkeng Sb-bearing ore is based on CaCO_3 and SiO_2 . Under acidic conditions, especially pH 2, the ore structure is loosened after the abundant CaCO_3 is dissolved. This facilitates the release of Sb. Additionally, due to the lower Sb (0.156%) and higher As (0.213%) contents in Tongkeng Sb-bearing ore than in Banxi (64.5% for Sb, 0.062% for As) and Muli Sb-bearing ore (34.7% for Sb, 0.0085%

for As), less Sb and more As (e.g., 2.6 mg/L of Sb and 1.2 mg/L of As at pH 9.8 for the 16th day) were released from Tongkeng Sb-bearing ore than those from Banxi (Fig. 2) and Muli Sb-bearing ore (Fig. 4). These results indicate that the release of Sb and As depends on their contents in the ore, types of ore deposits, mineralogy of Sb and As and other compositions coexisting in the ores.

2.5. Release percentage of Sb and As from different Sb-bearing ores

The release percentage of available Sb and As that were leached from three ores at different pH values is another issue. Fig. 6 summarizes the release percentage of Sb and As after 16 days from the three ores at different pHs. The Tongkeng Sb-bearing ore, which had the smallest Sb content (0.156%), released the highest percentage of Sb (43%) at pH 2. Stibnite, which had the most Sb (>97%), only released approximately 2% of the total Sb. The Banxi Sb-bearing ore, which had less As (0.0620%) than the Tongkeng Sb-bearing ore (0.213%), released more As (15%) than Tongkeng Sb-bearing ore (7%). These results suggest that ores with lower Sb and As released higher percentages of the elements, making them the largest potential pollution sources. In addition, in each ore, the release percentage of Sb and As was substantially different at different pHs. For instance, in Muli Sb-bearing ore, approximately 3 times as much Sb was released at pH 9.8 than that at pH 2, and 30 times as much As was released at pH 2 than that at pH 9.8. In Sb mining areas, a tremendous amount of crude rock, waste mining rock and tailings, containing low contents of Sb, As and other hazardous elements, have been piled in the open for years. According to incomplete statistics, more than 300,000 tons of waste rocks and tailings from Sb mining and smelting are stockpiled in the environment in China every year. Most of them are not properly managed. Because of the long-term exposure to water and air, a vast amount of heavy metals, especially Sb and As compounds, will be released into the environment, and aggravate the pollution. Research by He et al. (2012) showed that Sb with

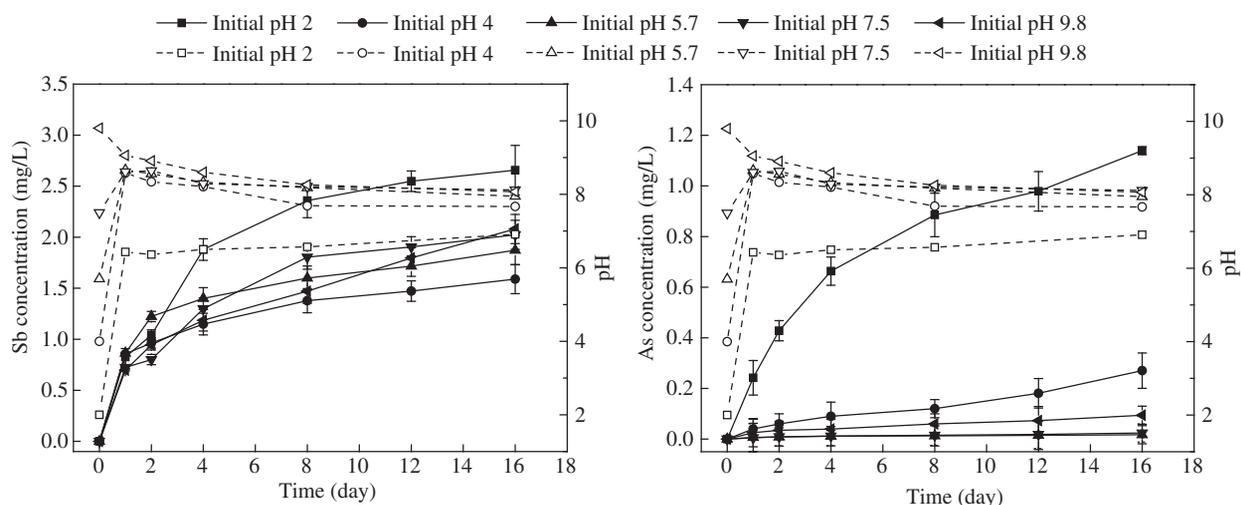


Fig. 5 – Leaching of the antimony-bearing ore from Tongkeng Antimony Ore: The leached concentration changes of Sb and As (solid labels) and pH changes of the leached solution (corresponding dashed labels).

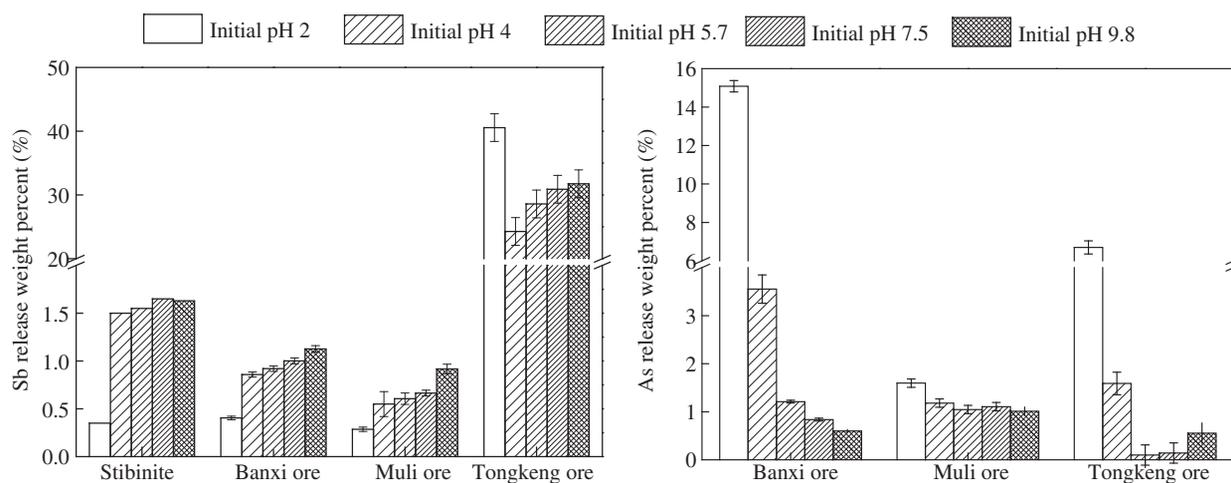


Fig. 6 – Release percentage of available Sb and As, from commercial Sb_2S_3 , Banxi, Muli and Tongkeng antimony-bearing ore, that have been leached for 16 days at different initial pHs.

higher concentrations in water (up to 29.4 mg/L) and sediments (up to 1163 mg/kg) was mainly limited to the proximity of mining and smelting areas rather than at faraway places (<5.00 mg/L for water and <3.00 mg/kg for sediments, respectively). Plants growing in these contaminated soils accumulated high levels of Sb (up to 143.7 mg/kg) and exceeded the tolerable concentration (5 mg/kg), thus threatening the health of local inhabitants. Soils in the XKS Sb mine area were mainly co-contaminated by Sb (74.2–16,389; mean: 3061 mg/kg) and As (7.40–596; mean: 216 mg/kg) (Li et al., 2014). Therefore, it is not surprising that serious water and soil pollution is occurring in mines or near mine areas. Effective regulatory measures should be taken as soon as possible to avoid the worst outcomes. The first is from the standpoint of government regulation: stricter laws should be enacted to prohibit random stockpiling and air storage of waste rocks. More importantly, such waste rocks have accumulated over a number of years into very large heaps and it is desirable to seek new economic solutions that can contribute towards their reuse in the context of the global effort to achieve sustainable development. For instance, further extraction of valuable metals from waste rocks, partial refilling of open pits, simple use as materials for building revetments, revegetation and phytostabilization of mining wastes, or conversion of mining landscapes into wetlands instead of drylands (Fellet et al., 2011; Otte and Jacob, 2008). Even so, for the regulation of waste rocks and tailings, there is still a long way to go.

3. Conclusions

The pH-dependent leaching of Sb and As in the antimony-bearing ores from different Sb mines in China was found to follow different pathways. More Sb is released at an alkaline pH from Banxi and Muli Sb-bearing ores with Sb_2S_3 and SiO_2 , with an opposite trend for the release of As. More Sb and As is released at acidic pHs from Tongkeng Sb-bearing ore. All these results depend on the mineralogy

of Sb and As and other coexisting compositions (e.g., Fe and $CaCO_3$) in the corresponding ores. The release percentages of Sb and As did not correlate with their total content, and even had an inverse proportional relationship. Thus, waste rocks and tailings with low contents of Sb and As stockpiled in mines are a huge potential source of pollution, and extra care needs to be taken. Additionally, the release of Sb and As from typical Sb ores is a source of Sb and As in the weathering zone, information that helps us better understand Sb and As pollution accidents in mines or near mines and their geochemical processes.

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