

# Distribution and behavior of arsenic in soils and waters in the vicinity of the former gold-arsenic mine of Salanfe, Western Switzerland

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## Abstract

The mine wastes and their environmental impact described in this paper are related to a skarn-type ore deposit, located in the Variscan crystalline basement of the Aiguilles Rouges Massive, Western Switzerland. The main minerals of the deposit are arsenopyrite, löllingite, hematite, scheelite, magnetite, pyroxene, amphibole and dolomite. The ore has been mined for arsenic and gold between 1900 and 1928, producing about 700 t As and 55 kg Au, and leaving mine dumps of several hundred m<sup>3</sup>, situated on a relatively steep hill above the small Lake Ottans, at an altitude of 2200 m. This work was undertaken to determine the extent of the As-contamination, its environmental impact and to identify actual geochemical processes. Dump materials contain As and sulfur in the 10% range, contaminated soils contain between 50 mg/kg and several % As. Mine and dump percolating waters are weakly mineralized of the Ca–Mg–HCO<sub>3</sub>–SO<sub>4</sub>-type and have conductivities between 20 and 170 μS/cm, pH values around 8, and As contents varying from 60 to 4000 μg/l. Waters below the dump zone are of the same type and have slightly lower As-contents: in Lake Ottans, 200 m below the mine area, As is still between 100 and 160 μg/l. Our results indicate that: (1) the contaminated area is limited to about 500 m in radius (1.2 km<sup>2</sup>) and that its environmental impact is rather limited, except for grazing cattle, (2) below the mine, the As decreases more rapidly in the soils than in the waters, (3) the distribution of the As seems to be determined by predominant alkaline pH in the surface and ground waters and by the distribution of the secondary solid phases (Fe-oxyhydroxides, clays, carbonate minerals, especially in the lower part). Transport by gravity creep or as suspended particles in water seems to be of secondary importance.

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## 1. Introduction

Arsenic has gained increased attention in recent years mainly for three reasons: (1) Elevated natural concentrations of arsenic have been discovered in many countries (Smith et al., 1998; Smedley and Kinniburgh, 2002; Frankenberger, 2002) especially in Asia, e.g. West Bengal (India)–Bangladesh (Nickson et al., 2000; McArthur et al., 2001; Chakraborti et al., 2002; Bose and Sharma, 2002; Harvey et al., 2002), Vietnam (Berg

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et al., 2001) and Taiwan (Wu et al., 2001), but also in America (Davis et al., 1994; Welch et al., 1999; Sancha, 1999; Rosas et al., 1999; Smith et al., 2000; Ongley et al., 2001) and Europe (Heinrichs and Udluft, 1996; Svetina and Pirc, 1998; Robert, 1998; Moreno et al., 1999; Weiss et al., 1999; Mardones, 2000; Pfeifer & Zobrist, 2002): (2) New toxicity assessments have shown that arsenic can be harmful also at low concentrations, when consumed with drinking water (WHO, 1999; EPA, 2000; Ng, 2001; Centeno et al., 2002), (3) arsenic exhibits a physical-chemical behavior distinctively different from other common metal contaminants such as Pb, Cu, Zn or Cd from mining activity (see below) and is therefore difficult to handle with classical immobilization methods for mine waste (Williams, 2001).

In ore deposits, As is usually contained in common sulfide-type minerals such as pyrite, pyrrhotite, chalcopyrite and arsenopyrite (Criddle and Stanley, 1993; Savage et al., 2000). Percolating rain water easily oxidizes them (Fig. 1), resulting in the formation of aqueous As(V)-anions ( $\text{H}_2\text{AsO}_4^-$ ,  $\text{HAsO}_4^{2-}$ , Brookins, 1988; Vink,

1996; Pfeifer et al., 2004) and solid As-bearing phases such as scorodite. The anions can in turn be adsorbed by positively charged solid surfaces such as clay edges, Fe- and Al-oxy-hydroxides and related chelating organic matter (Smith et al., 1998; Halter and Pfeifer, 2001; Goldberg, 2002). Increasing pH drives the charge of solid surfaces negative, releasing As to the solution (mainly As V). Reducing conditions (e.g., induced by water logging of soils and related microbial activity, loss of contact with the atmosphere in deep aquifers), lead to neutral and negatively As(III)-species ( $\text{H}_3\text{AsO}_3^0$ ,  $\text{H}_2\text{AsO}_3^-$ ), which also sorb on mineral surfaces, preferentially on Fe-oxy-hydroxides. The latter, under reducing conditions, dissolve easily, especially at pH below 7, and release the adsorbed As(V) or As(III) to the solution (Bose and Sharma, 2002; Pfeifer et al., 2004).

In this paper we have studied the environmental behavior of As in relation to an ore deposit containing arsenopyrite as main ore mineral, which has been mined for about 30 years at the beginning of the 20th century in a mountainous area of western Switzerland.

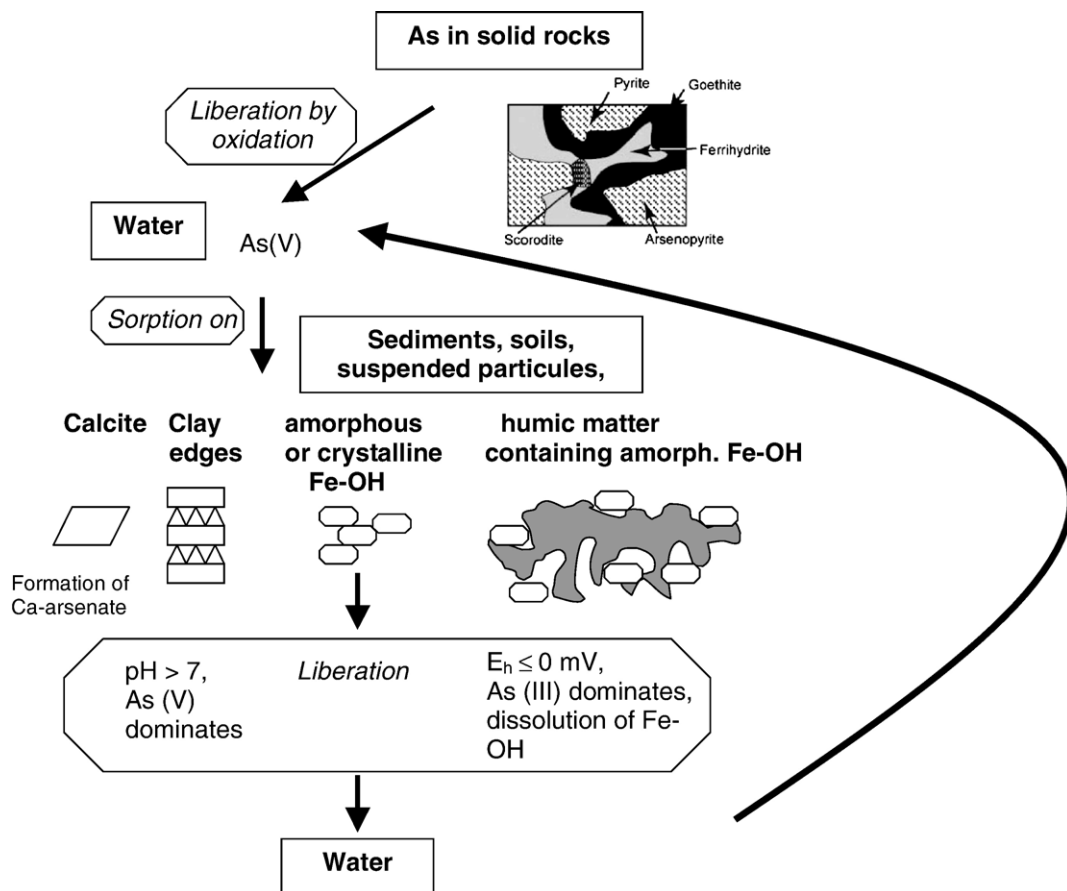


Fig. 1. Typical features of the behavior of arsenic in the environment (compiled from various sources which are discussed in Pfeifer et al. 2004).

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