Weathering and Hydrochemistry Associated with the Old Mine Workings at Fonte Santa (NE of Portugal)

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The Fonte Santa Mine: W-Bearing Quartz Veins and Old Mine Workings

The Fonte Santa Mine is located in the Northeast of Portugal (Fig. 1). The quartz veins inside the mine consist of scheelite, pyrite, pyrrhotite, sphalerite, chalcopyrite, arsenopyrite, galena, iron oxides, Al, Fe and Pb hydrated phosphates and Fe sulphates. Scheelite has a homogeneous composition, but their fractures are filled with stolzite and ferritungstite (Gomes, et al., 2010) (Fig. 2).

The area was mined for W between 1942 and 1982 and 2784 tonnes of tungsten were produced (Parra et al. 2001). Since then there has not been any development . At the end of November 2006, a flood event damaged the dam tailings of the Fonte Santa mine, releasing contaminated material and increasing contaminant levels in water within the area of influence of the mine (Gomes, et al., 2010).

Geologic Setting

The Fonte Santa area is located in the autochtonous Central Iberian Zone (ZCI), where Ordovician rocks crop out extensively (Fig. 1). The mine country rocks consist mainly of Lower Ordovician chloritic phyllites with rare intercalations of Armorican quartzites and Cambrian metasediments (Parra et al. 2001). Magnesian marbles crop out close to the area. The mine is associated with the Bemposta-Moncorvo shear zone, and is emplaced along tensional fractures. Two generations of veins are recognised in the mine. The oldest generation is an irregular to lenticular vein set, folded by the last kinematic Variscan deformation phase, and the youngest generation forms a stockwork with mining shafts oriented along the tension and shear cracks. Scheelite occurs mainly in quartz veins hosted by pelitic rocks, but is also found in skarns that have replaced magnesian marble in the apical area of Fonte Santa muscovite granite.

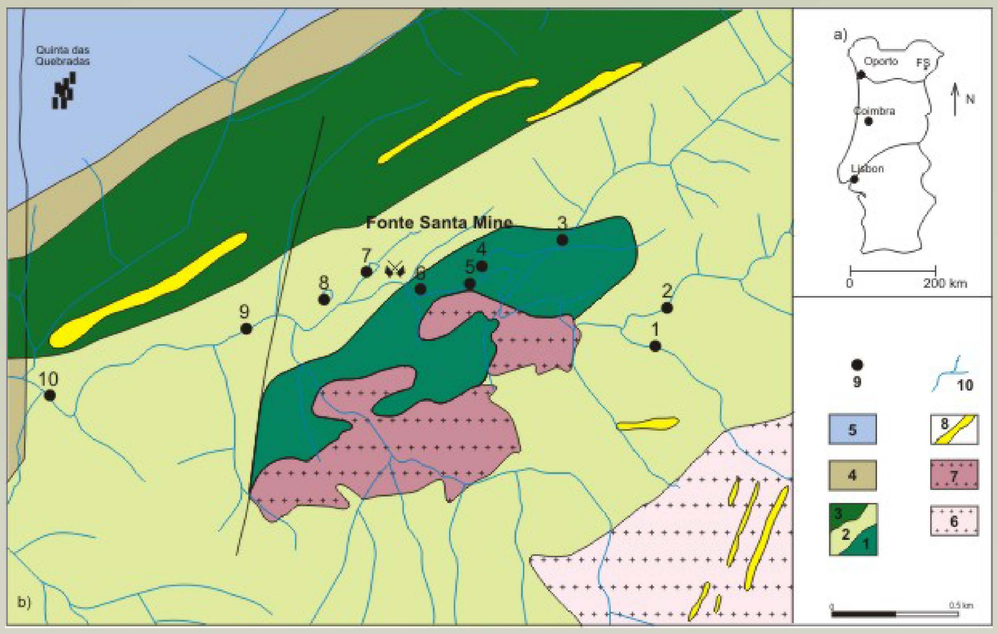

Fig. 1. Geological map of the Fonte Santa mine Ordovician Quartzitic Marão Formation: 1. Lower quartzites, 2. intermediate schists, 3. upper quartzites, Ordovician schists-Moncorvo Formation: 4. slates, 5. lower Silurian quartzites, 6. medium- to coarse-grained porphyritic muscovite-biotite granite (G1), 7. fine- to medium-grained muscovite granite (G2), 8. quartz veins, 9. faults.

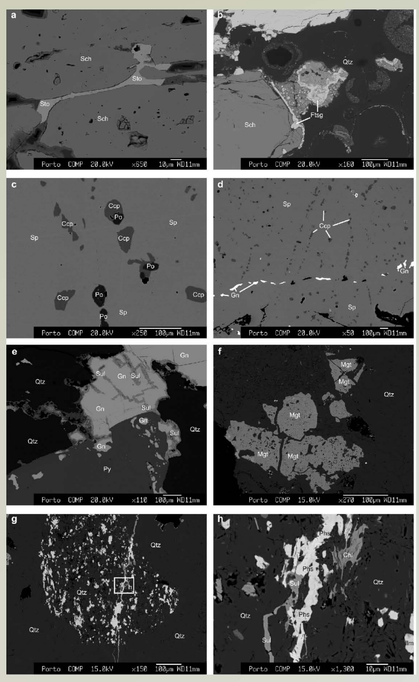

Fig 2. Backscattered images of some minerals from W-bearing quartz veins from Fonte Santa: a) scheelite (Sch) showing stolzite (Sto) along fractures, b) ferritungstite (Ftsg) replacing scheelite (Sch), quartz (Qtz), c) phyrrotite (Po) included in chalcopyrite (Ccp) and both included in sphalerite (Sp), d) "chalcopyrite disease" (Ccp) in sphalerite and a fracture filled with galena (Gn), e) galena (Gn) penetrated by Pb-sulfate (Sul) and replacing pyrite (Py), quartz (Qtz), f) subhedral grains of magnetite (Mgt), g) and h) brecciaed fragments replacing quartz (Qtz) with ilmenite (Ilm), chlorite (Chl), Fe sulfates (Sul) and Al, Fe and Pb hydrated phosphates (Phs).

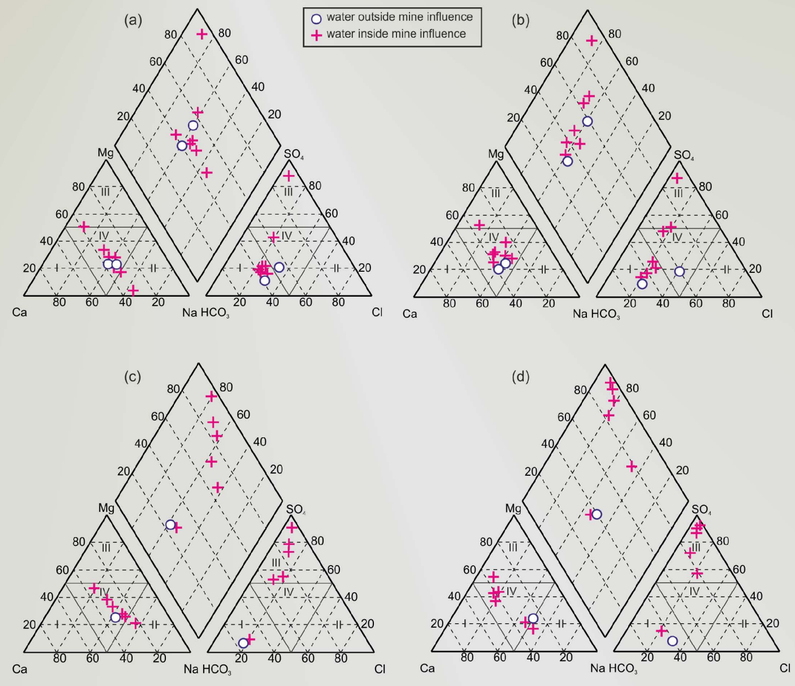

Fig. 3. Piper chemical classification of waters from Fonte Santa. Waters collected on: (a) January 2007, (b) April 2007, (c) August 2007, (d) December 2007. Cations: I. Ca-type, II. Na-type, III. Mg-type, IV. mixed type; anions: I. HCO_3-type, II. Cl-type, III. SO_4-type, IV. mixed type.

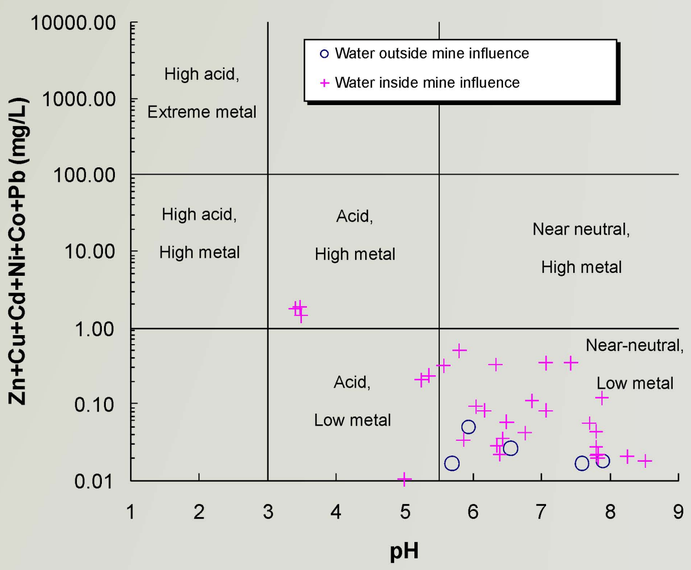

Fig. 4. Water samples from Fonte Santa plotted on the pH-metal concentrations (Zn+Cu+Cd+Ni+Co+Pb) diagram of Ficklin et al. (1992).

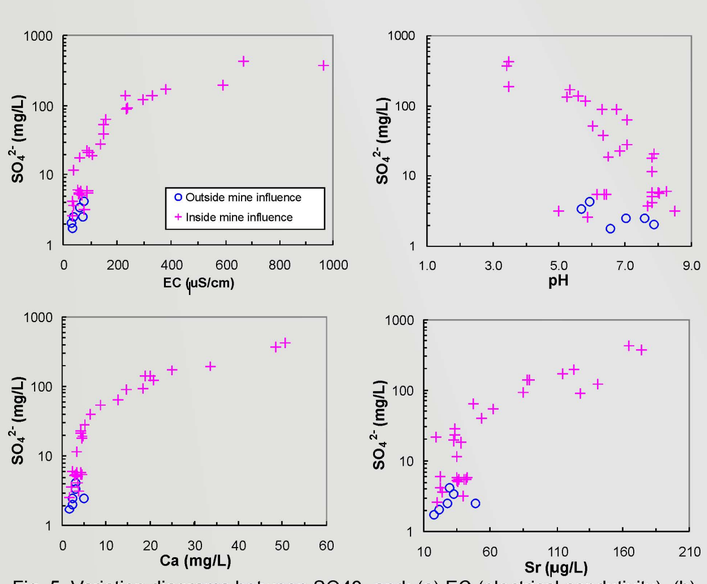

Fig. 5. Variation diagrams between SO42- and: (a) EC (electrical condutivity), (b) Ca, (c) Sr, (d) (Cu+Zn+Pb+Ni+Co+Cr) of waters from Fonte Santa.

Weathering

The alteration of albite, chlorite and muscovite from country rock is responsible for Na, Mg and K contents in the waters, whereas the weathering of carbonates and scheelite are probably the sources of Ca (Fig. 7). The weathering of rock-forming minerals and ores caused the precipitation of secondary phases (halloysite, smectite, vermiculite, ferritungstite and Fe sulphates). Weathering agents are carbonic and sulphuric acids and the latter has a strong influence in areas draining fine-grained mine tailings (Gomes, et al., 2010).

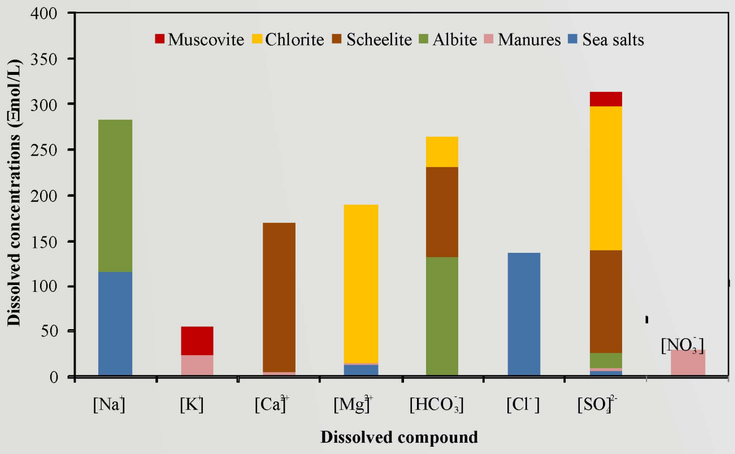

Fig 7. Contribution of weathering of minerals and inputs of manures and sea salts to the composition of Fonte Santa waters.

Hydrochemistry

Most waters from Fonte Santa are of mixed type, some are of Na-Mg and HCO_3^--SO_4^{2-} type (Fig. 3). They are poorly mineralized (Fig. 4). However, most parameters and element contents show an increase from outside to inside the mine influence due to the effect of abandoned old mining activities (Fig. 5). There is no significant acid drainage associated with the old mine workings, which can mainly be attributed to the presence of calcium carbonates in country rocks that probably neutralized the waters and decreased metal concentrations. The most acid waters with the highest SO_4^{2-} and metal contents are from the mine lagoons, which received waters from fine-grained tailings and waste rock. The environmental impact of the Fonte Santa mine area is essentially related to a flooding event that carried a suspended contaminated load, increasing the Fe and Al contents in natural stream waters inside the mine influence. Most waters associated with the mineralized veins and old mine activities have Fe and Mn concentrations that forbid their uses for human consumption and agriculture. Some waters present concentrations above parametric Portuguese values for other contaminants (SO_4^{2-}, NO_2^-, Mg, Zn, Al, Ni and Co) and must not be used for human consumption (Fig. 6).

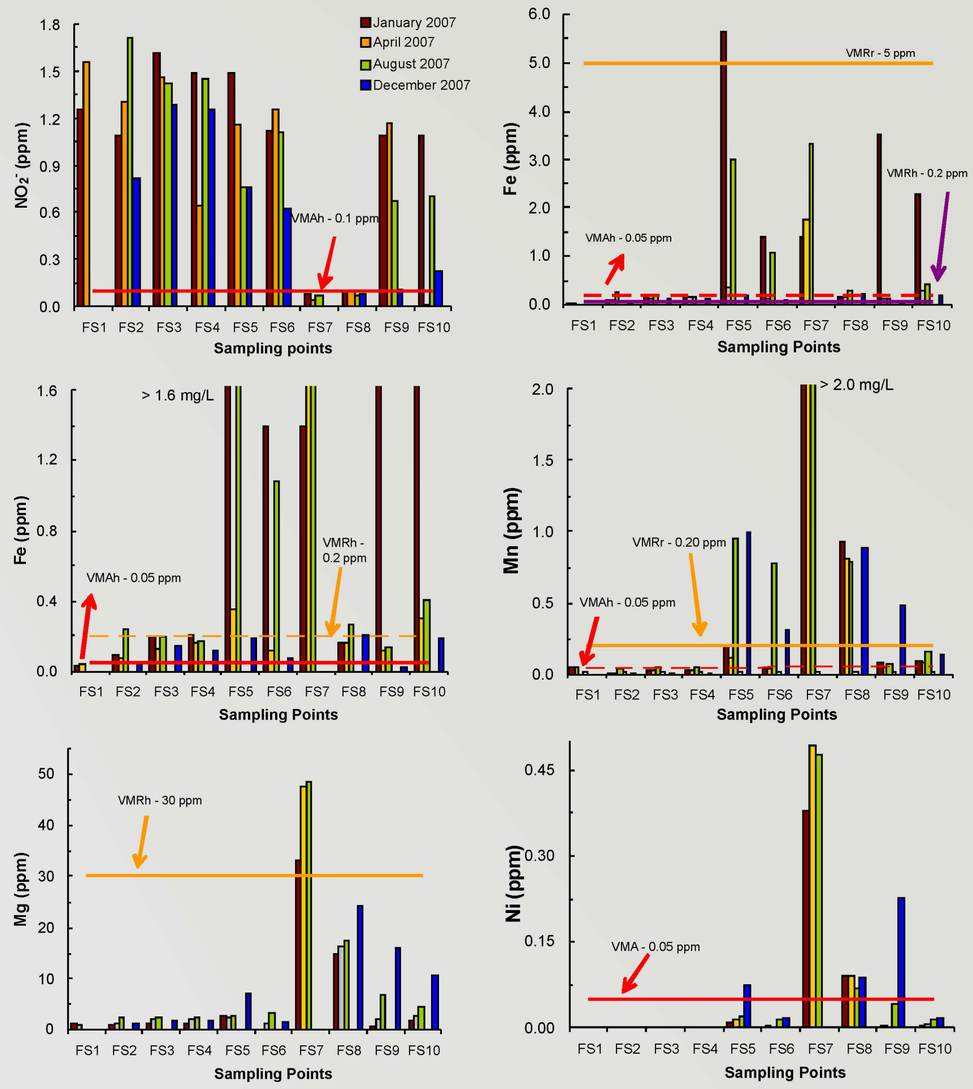

Fig.6. Diagrams of water contents on: a) NO_2^- (mg/L), b) Mg (mg/L), c) Fe (mg/L); d) Fe (mg/L), ampliation of c), e) Mn (mg/L), f) Ni (mg/L) from Fonte Santa. VMAh maximum accepted value for human consumption; VMRh recommended value for human consumption; VMRr recommended value for agriculture use (Portuguese Law 2007). FS1 and FS2 water samples collected outside mine influence; FS3 to FS10 water samples collected inside mine influence.

Acknowledgments

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