Mobilisation of trace elements from an epithermal high sulphidation mineralization in the sediments of Sa Forada artificial lake. South-Sardinia, Italy

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Abstract. The Sa Forada man-made lake is an intermediate reservoir of the Flumendosa water supply system that carries a silty clayey material which has already formed a fairly thick deposit on the lake floor. Because water flowing into the lake drains the ore bodies, one may expect dissolution and subsequent transport of several trace elements (mostly Cu, As, Sb, Au) into the lake with potentially environmentally hazardous concentrations in the water and sediments.

Introduction

The Furtei mine is a typical example of a volcanic-hosted high-sulphidation epithermal gold deposit. Mining commenced in 1997 for confirmed reserves totalling 2,150,000 metric tons containing 2.82 g/t Au. The research area includes a small man-made lake, called Sa Forada, located at the Furtei Mine in the southern part of Sardinia. It receives water from the Flumendosa-Mulargia lakes and supplies first a power-plant, then the Campidano plain, mostly for agricultural purposes. The volume of water draining into the lake is extremely modest, but carries with it material coming from an intensely mineralized area currently under exploitation. Consequently the elements contained therein may have a non-negligible influence on the characteristics of the water discharged from the reservoir.

Sardinia has a semiarid climate, and the shallow soils in this region are less than 50 cm deep the natural vegetation consisting of Mediterranean scrub, dominated by plants of the genus "cystus".

This study concerns the bottom sediments of the lake sampled prior to commencement of mine workings. The metal content distribution in the sediments, which corresponds to their supply source in natural conditions and before mining operations began, allow to derive hypotheses as to their mobilisation and transport.

Study Area

The study area is characterised by a volcano-sedimentary sequence of Oligo-Miocene age, overlaying marine and fluvial-lacustrine sediments of late Eocene-Early Miocene age, which in turn rest on a Paleozoic basement, composed of meta-sediments, metapelite and quarzite. The outcropping volcano-sedimentary sequence consists of andesitic sub-volcanic domes and of volcaniclastic products such as fall, surge and ash-flow deposits. These outcrops are locally and partially overlain by Miocene and Quaternary fluvial-lacustrine and marine sediments.

Most of the volcano-sedimentary complex in the area have undergone hydrothermal alteration and mineralisation. Four types of alteration have been recognized: propylitisation, argillisation, strong argillisation and silicification. Hydrothermal alteration was overprinted by supergenic, secondary argillisation, mainly after oxidation of the sulphide phases. Pyritisation is widespread in all types of alterations considered with major concentrations occurring in the innermost areas of intense alteration, where it practically grades into the ore bodies.

The main mineralised bodies, already explored and mined in their upper oxidized portion, are the Santu Miali, Is Concas and Sa Perrima group. The paragenetic study revealed typical high-sulphidation assemblages, in order of abundance: pyrite, enargite-luzonite, tetrahedrite, tennantite, chalcopyrite, covellite, digenite, galena, sphalerite, arsenopirite, wurzite, tellurides, native Au, and native Te (Fiori et al. 2001).

The drainage basin and sampling

The natural drainage basin of Sa Forada covers an area of a few square kilometres, delimited by a roughly semicircular watershed culminating in the hills of Santu Miali, Coronas Arrubias and Sa Perrima (Fig.1).

Near the outcrops, deep oxidation related with the abundant pyrite transforms these bodies into an assemblage of Fe hydroxides, quartz, sulphates (gypsum, jarosite, barite) and minor arsenates and other secondary minerals. Gold easily survives as native Au, and remnants of sulphides and sulphosalts are also commonly present.

The mineralised zones drained by this basin include part of the Santu Miali hillside but not the two main ore bodies, and an outcrop forming the ridge of Sa Perrima. At Coronas Arrubias pyrite prevails, but minor gold values have been detected.

The bottom sediments of lake Sa Forada were sampled when it was emptied for dam maintenance works. The samples were collected following the pre-existing drainage pattern, both along the talweg lines and in the inter-talweg surfaces. Sediment thickness ranged from a few centimetres near the shoreline, to a few metres near the dam. Given the small size of the lake, 44 samples were collected.

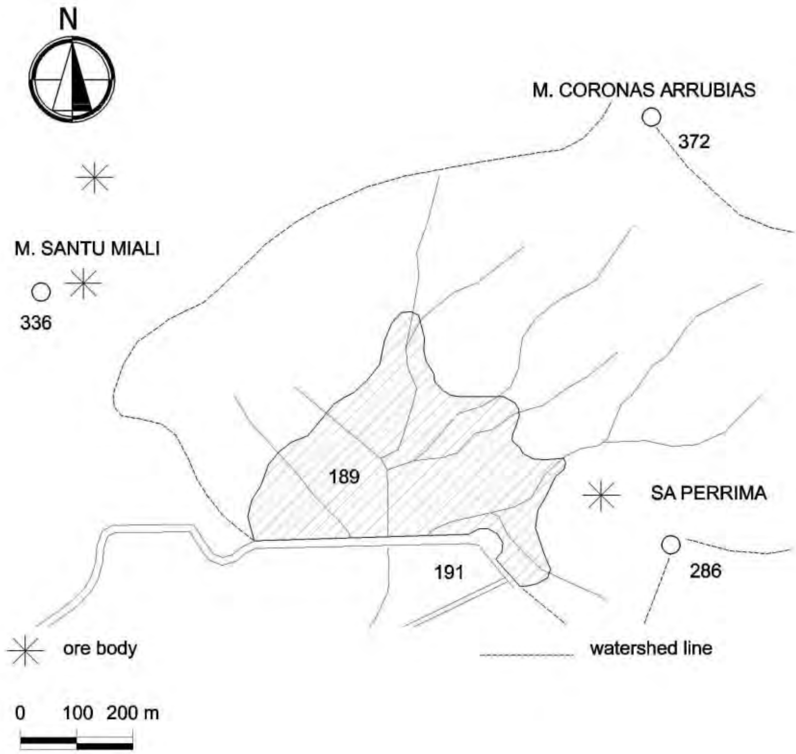

Fig. 1. Schematic map of the lake Sa Forada area, with drainage pattern.

Sample preparation and analysis

The samples, averaging some 300 g in weight, were first dried then split into two batches, one of which was stored for further controls where necessary. The remaining lot was further split into two and one half was sieved to -2mm and prepared for analysis. On the other half particle size analysis was performed on most samples. The following analyses were then conducted:

- chemical determinations using AAS and ICP-MS for the trace elements typically contained in the surrounding rocks and ore deposits;
- diffractometric analysis on all samples, to determine the distribution of both the most common and some minor minerals characterising the local sources of clasts.

The choice of the elements to be investigated stems from the present knowledge of the ore mineral assemblages in the known ore bodies.

This assemblage includes Au as well as the base metals and other elements commonly contained in high-sulphidation epithermal occurrences, plus Sn and W, often been observed in local ore samples.

Data treatment

From the chemical analyses, kriging was performed on the analytical values of minor elements and the results then mapped.

The data for trace elements in the lake sediments were treated using statistic methods and their populations were defined. For most of the elements examined, the statistical analysis of the results showed that generally at least one main population exists. Given the comparatively small number of samples, the data were arithmetic processed.

The statistical parameters given in Table 1 concern, for each element, the statistical population as derived from total sample distributions.

The mean population values have been compared with the mean world concentrations for siltitic-pelitic rocks and sediments reported by Wedepohl (1978). This comparison showed that Zn, Cd, Sb, As, Te, Pb and Au have mean concentrations significantly higher than those reported by Wedepohl, Cu content is higher and W slightly higher than the "normal" mean whereas Co, Bi and Sn appear fairly "normal".

Table 1. Main statistical parameters for the studied elements. Anomaly thesholds are given, for a normal populaton by: means plus 1,2 and 3 standard deviations.

Element	Mean value	Standard Deviation		Anomaly thresholds	
	m(ppm)	s(ppm)	possible	probable	sure
Zn	199.22	54.52	253.74	308.26	362.78
Hg	0.19	0.09	0.28	0.37	0.46
Cu	46.93	11.1	58.03	69.13	80.23
As	25.84	9.24	35.08	44.32	53.56
Sb	3.99	1.18	5.17	6.35	7.53
Te	0.25	0.09	0.34	0.43	0.52
Pb	52.54	17.12	69.66	86.78	103.9
Au	0.024	0.012	0.036	0.048	0.060

Discussion and conclusion

Our results indicate widespread and elevated concentrations of nearly all the elements examined. The distribution pattern shown in Figs.2, 3, compiled using Arcview geographic information software, shows that despite the small number of samples examined, a correlation does exist between the sources of mineral supply and the relative samples of stream sediments.

All the examined metals display regular distributions, with unimodal histograms and few clearly anomalous values. On the other hand, for most of these elements mean concentrations are significantly higher than those reported for similar sediments in other parts of the world, or are comparable with the highest known values. These observations are consistent with the small size of the drainage basin, its lithological homogeneity, and the abundance of several ore minerals in the basin. The mode of transport of these metals is governed by their chemico-physical properties. Gold, a typical "clastic" element, reaches the basin mostly after acid leaching of the sulphides. The Te in the paragenesis of metallic ore bodies occurs as tellurides, Te-rich tetrahedrite and in the native form. Even for high oxidising potential these stable mineral phases tend to release the Te, especially in arid climates, in highly oxidising and acid leaching environments (Wedepohl 1978), Hence, in the basin concerned, tellurium and its mineral phases may have travelled in the form of both clasts and ions.

Tin does not occur in the paragenesis in its most common form of cassiterite but as stannite which was detected by means of electron microprobe. The presence of tungsten is more complicated in that no mineral phases containing this element have been recognised among the mineral paragenesis.

As far as arsenic is concerned, the main As-carrier are sulphosalts and the strongest anomalies have been observed at the lake edge. This finding is consistent with the sudden precipitation of the ions due to adsorption by the clay fractions and iron oxides and hydroxides and rapid settlement of the clasts. The fact that the highest concentrations of As, Te, Sb, Hg, contained in enargite e tennantite mineralogical phases, were found in the eastern portion of the lake strongly suggest that the minerals reach the basin within clasts. The high content of mobile elements in the analyzed material can be explained, at least for Cd and Pb, by the fact that their ability to be adsorbed onto colloidal particles increases with pH. The same considerations hold for Cu and especially for Zn which are readily mobilised and have been observed to accumulate in the innermost parts of the basin.

Given the small size of the basin and the semiarid climate it can be reasonably assumed that the leaching solutions are strongly acid, though only minor amounts are involved. On the other hand, the Sa Forada reservoir continously receives waters from the much larger lakes of the Flumendosa system, characterised by a far higher pH, about 8 (Fadda et al. 1996). Thus the seasonal acid waters carrying metallic ions blend with the slightly alkaline lake water. The resulting increase in pH leads to a much greater amount of soluble elements being bound on the colloidal particles and on the clay fraction and Fe hydroxides.

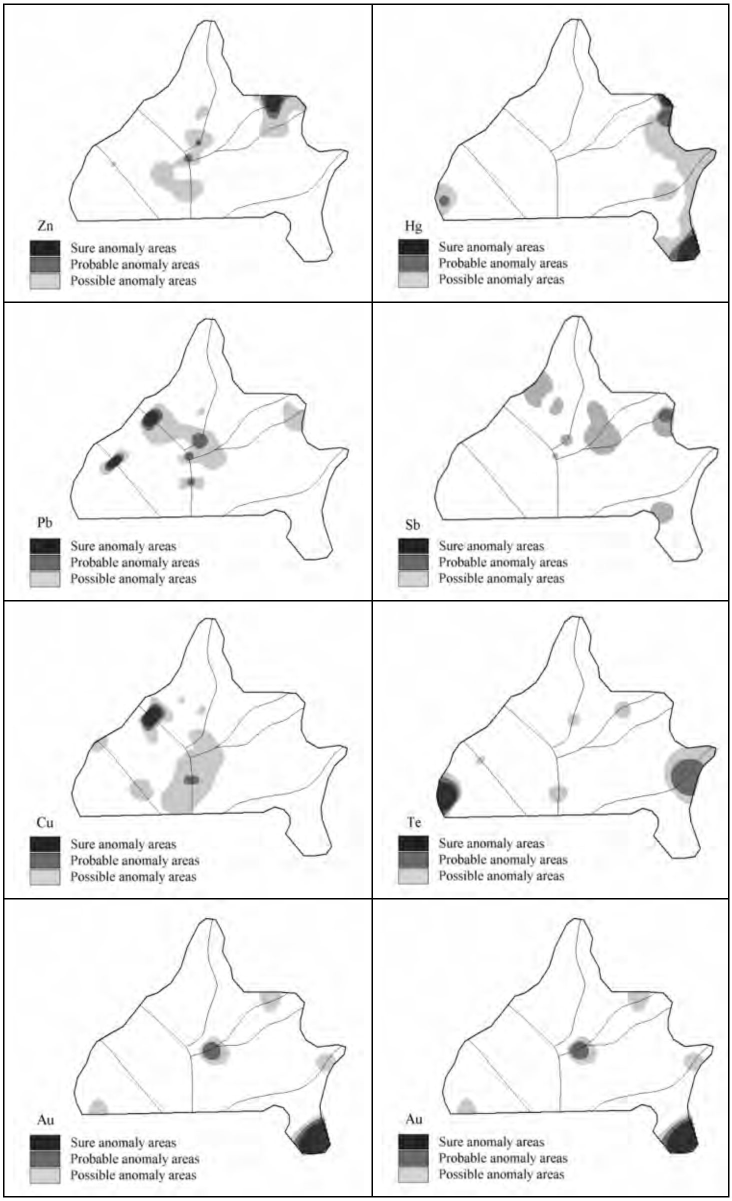

Fig. 2. Distribution of the study elements according to the anomaly thresholds given in table 1.

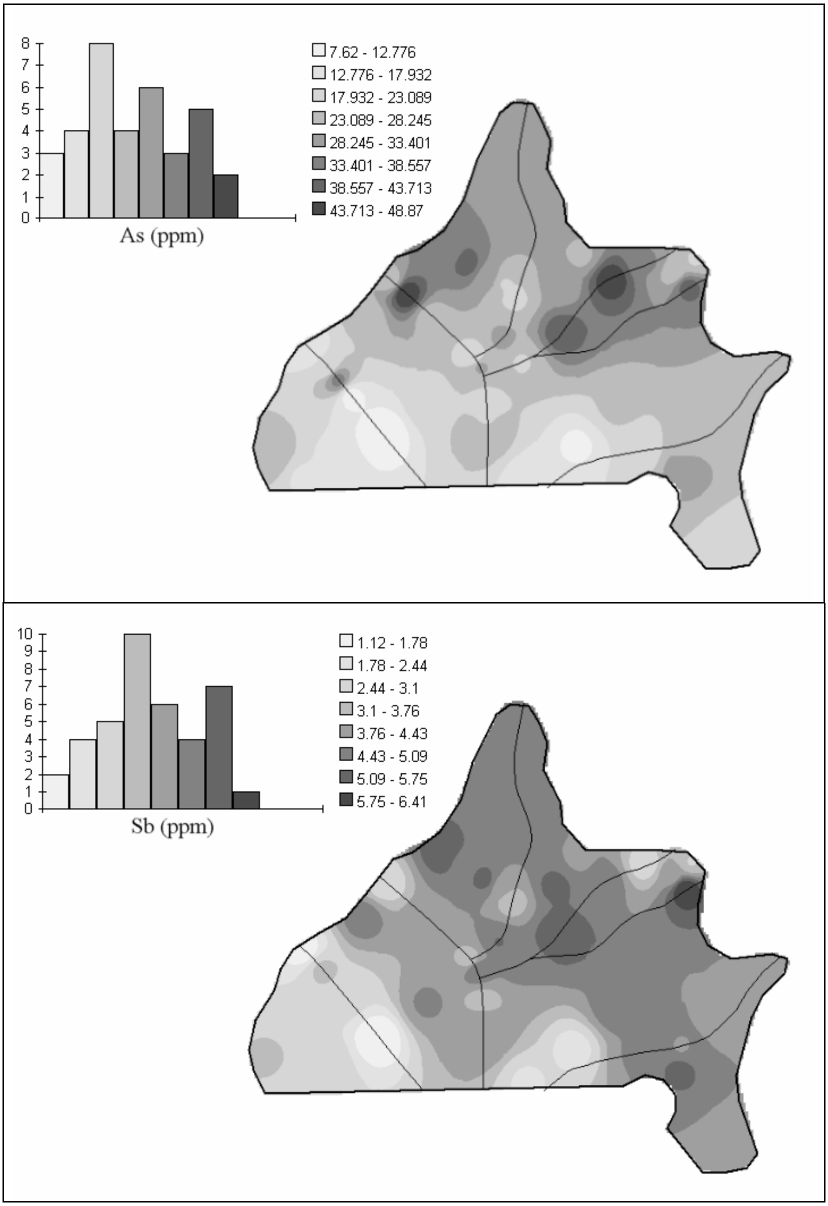

Fig. 3. Distribution of As and Sb according to the frequency classes of his histograms.

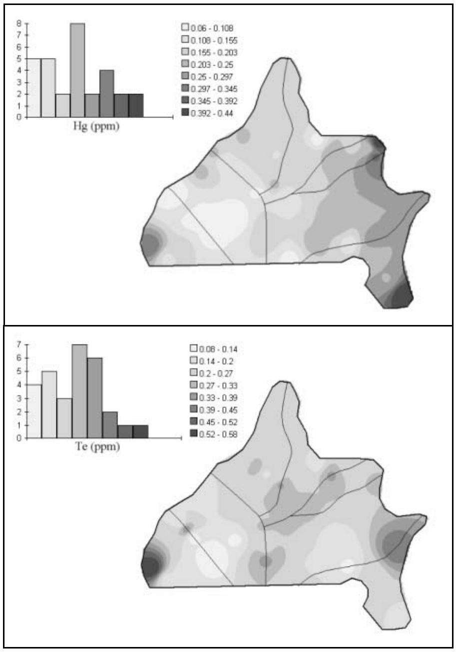

Fig. 4. Distribution of Hg and Te according to the frequency classes of his histograms.

Moreover, the anomalous values are generally spatially related to the metal sources. The above findings suggest the lake sediments act as a trap both for mineral clasts and metallic ions.

Acknowledgements

This study was supported by the Centro Studi Geominerari e Mineralurgici del CNR, Facoltà di Ingegneria, Piazza d'Armi, 09123 Cagliari, Italy

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