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Arsenic Mobility from Mining Tailings of Monte San Nicolas to Presa de Mata in Guanajuato, Mexico

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Abstract**—**Mining tailings represent a generating source of rich heavy metal material with a potential danger the public health and the environment, since these metals, under certain conditions, can leach and contaminate aqueous systems that serve like supplying potable water sources.

The strategy for this work is based on the observation, experimentation and the simulation that can be obtained by binding real answers of the hydrodynamic behavior of metals leached from mining tailings, and the applied mathematics that provides the logical structure to decipher the individual effects of the general physico-chemical phenomenon. The case of study presented herein focuses on mining tailings deposits located in *Monte San Nicolas, Guanajuato, Mexico*, an abandoned mine. This was considered the contamination source that under certain physicochemical conditions can favor the metal leaching, and its transport towards aqueous systems. In addition, the cartography, meteorology, geology and the hydrodynamics and hydrological characteristics of the place, will be helpful in determining the way and the time in which these systems can interact.

Preliminary results demonstrated that arsenic presents a great mobility, since this one was identified in several superficial aqueous systems of the micro watershed, as well as in sediments in concentrations that exceed the established maximum limits in the official norms.

Also variations in pH and potential oxide-reduction were registered, conditions that favor the presence of different species from this element its solubility and therefore its mobility.

Keywords**—**Arsenic, mining tailings, transport.

I. Introduction

FROM very old times, the metallic mineral deposits have played a very important role in the economic and technological development of the society. Due to the high industrialization, the demand of metallic sources mineral has increased. This way, it is priority to increase the activities of exploration and operation of these deposits [1]. Nevertheless, with this priority, it initiates another necessity in our society: the preservation of a clean environment (air-water-soil) [2]. In most of the historical cases, the operation of deposits has been accompanied by a negative impact to the water (mainly underground water).

In Mexico, the mining has been an economically available activity and represents around 5% of the gross internal product of the country. Nevertheless, the operation of mineral deposits generates great amounts of mining tailings (of nahuatl *xalli*, fine sands). The mining generates 65% of the industrial residues produced in Mexico. Around 95% to 99% of the extracted material of the mines is deposited in mining tailings deposits.

The main associated environmental problems to mine residues are the acid drainages, result of the sulfide oxidation (mainly pyrite), the metallic oxide hydrolysis and the high heavy metal concentrations (Pb (lead), Zn (zinc), Cu (cooper), Cd (cadmium), Cr (chromium), Fe (iron), Mn (manganese), As (arsenic), Se (selenium), Sb (antimonium), etc.), that can be leached and be transported to diverse aqueous systems like rivers, lakes, dams, aquifers, etc.

The arsenic is an element very common in the atmosphere, the hydrosphere and the biosphere. It is mobilized to the environment through a combination of processes that include natural processes (biological activity, volcanic emissions), as well as anthropogenic processes (mining activity, fossil fuel use, use of pesticides, herbicides, conservatives of the wood) [3].

In the city of Guanajuato, Guanajuato, Mexico, due to the mining-metallurgical activity, there exist sites where the tailings are confined, result of the mining activity (mining tailings deposits). This type of deposits represents a potential source of metal contamination to several aqueous systems such as rivers, streams, dams, and aquifers. Possibly, in this type of deposits also accidents by spills or drainings, accentuated specially at times of pluvial precipitation can be registered, causing therefore the mobilization of the confined material. In these situations, these affluents can be contributing in a decisive way to the degradation of the quality of the water of the dam and somehow they can also be hitting, aquifer route, in the quality of the water that supplies the potable water well system. Therefore, the present policy in

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environmental matter requires to implement among other things, the creation of zones of reserve, aquifers regulation, monitoring of levels of water, projects of recharge, vulnerability letter elaboration, in addition to the prevention, treatment of the contamination, design and use mathematical model to predict its behavior, its mobility, its transport and fate.

II. Methodology

A. Identification of the Zone of Study

This study was carried out by means of the search of previous works made in the mining tailings of *Monte San Nicolas, Guanajuato, Mexico*, obtaining the geologic data of the site. Also, information on its cartography by means of small-scale charts provided by the National Institute of Statistical Geography and Informatics (INEGI), [4] and [5] was obtained.

B. Sampling

For sampling purposes, several locations were visited. Different sediments and superficial body samples were taken for analysis.

C. Characterization of Mining Tailings and Aqueous Samples

Of the collected samples of mining tailings and water "in situ" were determined the variation of pH through the micro watershed, as well as the several metals concentration.

III. Results and Discussion

A. Identification of the Zone of Study

The Mining District of Guanajuato is located to 360 km to the northwest of the city of Mexico between 21º05' and 21º00' North latitude and 101º 20' and 101º10' west longitude. Most of the mines of the district are located within the sub watershed of the Guanajuato River, that has an extension of 103.255 ha and belongs to the watershed of the Lerma river (Fig. 1).

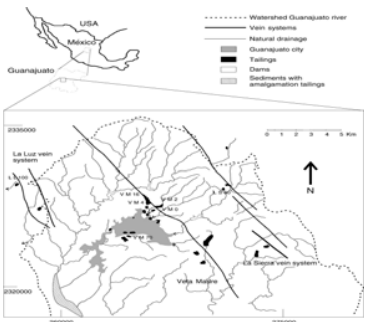

Fig. 1 Location of mine district [6]

The region has a very steep topography, varying in height of 2.800 m snm in the *Sierra de Guanajuato* to 1.900 m snm, 15 km to the SW in the valley where the Bajio begins and is the local aquifer.

The mine *Monte San Nicolas* and the mining tailings are located to the north of the city of Guanajuato and belong to the *Sierra* vein system. (Fig. 2).

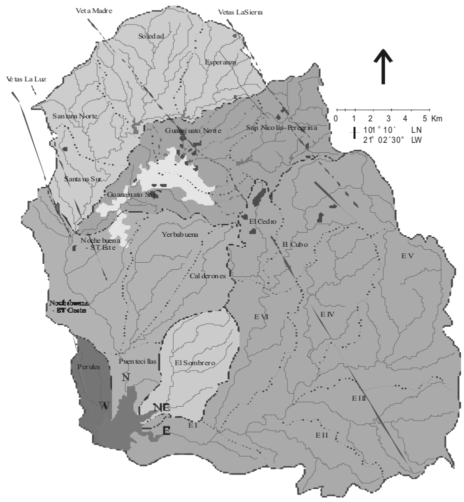

Fig. 2 Location of study zone

The mine operated from the last years the XVIII Century to 1920. The deposits consist of three deposited layers different on the south orient from an inclined hill. The volume combined of tailings is approximately of 5 million tons. The oldest and heavy layer, is located at the bottom and finalizes in two finer and recent layers. The mines tailings deposits failed and they eroded significantly (approximately a 25% of the total) during an exceptional season of very intense rains about 40 years. Most of them eroded, were deposited in the alluvial plain of the *Presa de Mata* (4 km downstream the area of San Nicolas). In the alluvial plain, a continuous layer of more or less 10 cm of thickness could be observed during the season of drought. This water body was used in industrial processes (extraction of minerals), and for some years for municipal use in Guanajuato [7].

Geology consists of a conglomerate with interleaves of arenaceous, of thin stratification to thickness; in the base there are present volcanic sands and andesitic lava named Guanajuato Conglomerate. Its formation is of continental origin of the Eocene Means that rest on Guanajuato Sedimentary Volcanic Complex (CVSG) and have a minimum thickness of 1.500 ms [8]. Near fractured zones it presents propylitic alteration and green color by the chlorite presence. In Fig. 3 the litological units are distinguished that arise in the surface as well as the faults and the main mines.

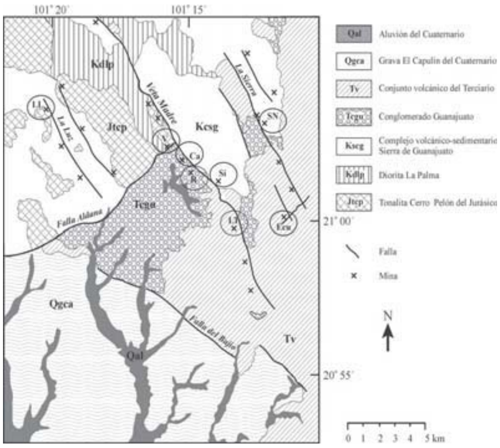

Fig. 3 Geology of mining district

B. Sampling

Sampling of water was carried out at the point source, as well as in the aqueous systems near the affected site (stream, Presa of Mata, superficial wells), These sites are shown in Fig. 4.

Fig. 4 Sampling of superficial bodies

The taking of solid samples was made in the site where spillings exist of mines tailings (micro watershed Monte San Nicolas-Presa of Mata), as it is possible to be appreciated in Fig. 5.

Fig. 5 Geology of mine district

C. Characterization of Mines Tailings and Aqueous Samples

The analysis of the liquid samples was performed for: Arsenic (As), Cadmium (Cd), Cooper (Cu), Iron (Fe), Manganese (Mn), Nickel (Ni), Silver (Ag), Lead (Pb), and Zinc (Zn). The quantification took place by means of Spectroscopy of Atomic Flame Atomic Absorption, and for As, it was done by Hydride Generation Absorption. The results are reported in Table I.

TABLE I
CONCENTRATION OF SOME ELEMENTS IN LIQUID SAMPLES OF SPILLS OF MINING TAILINGS

Distance upstream (m)	Sample	mg Mn/L	mg As/L	mg Pb/L
4000	Well 1	0.111	0.038	0.22
3700	Well 2	0.125	0.045	0.22
3200	S1	0.097	0.036	0.00
2700	S2	0.097	0.036	0.00
2500	S3	0.111	0.038	0.00
2000	S4	0.111	0.036	0.13
1700	S5	0.139	0.042	0.00
1500	S6	0.125	0.038	0.13
1200	S7	0.125	0.036	0.13
1000	S8	0.042	0.033	0.25
900	S9	0.125	0.042	0.00
750	S10	0.167	0.040	0.33
500	S11	0.208	0.042	0.33
400	S12	0.222	0.042	0.44
300	S13	0.236	0.040	0.44
200	S14	0.236	0.042	0.44
100	S15	0.111	0.047	0.44
50	S16	0.097	0.042	0.44

The results reported in this Table show that the amount of arsenic present in the liquid samples exceeds the limits established according to norm NOM-127-SSA1-1994 for potable water that is of 25 ppb [9]. The method by alkaline fusion and the acid digestion was used. The results obtained for this analysis are reported in Table II.

TABLE II
ELEMENTAL ANALYSIS OF SOLID SAMPLE

Sample	mg Mn per g of tailing	mg As per g of tailing	mg Pb per g of tailing
SS1	0.647	7.36	0.110
SS2	0.553	7.74	0.087
SS3	0.669	10.71	0.147

Table II shows that the highest concentration in the sediment corresponds to silver, this maybe because during the flotation stage, the remainder material is sent by means of pumping to the mines tailings deposits, containing these considerable amounts of material that are not recovered in the process. Also, pH of the samples collected in the zone of spilling (3500 m upstream of the Presa of Mata) and the graph was constructed (Fig. 6).

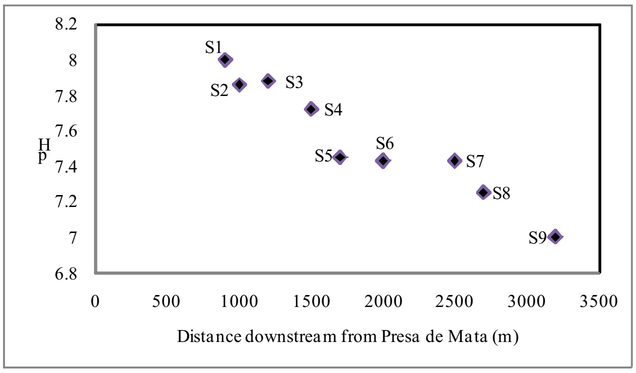

Fig. 6 Variation of pH through micro watershed *Monte San Nicolas-Presa de Mata*

As this Figure shows, the value of pH in the affected zone initiates in a value of 7 (neutral) and increases throughout the zone until reaching a final value of 7.86. This may be caused by the oxidation state of the arsenic and its mobility, since are fundamentally controlled by the redox conditions (potential redox) and pH. The arsenic is a singular element between heavy nonmetals and forms oxianiones by its sensitivity to mobilize itself in the typical values of pH of underground waters (pH 6,5-8,5) [10].

IV. Conclusion

With the results obtained in this work, the presence of arsenic through of micro watershed was shown. In addition, the mobility was preliminary demonstrated. Arsenic solubility depends on pH and the reduction-oxidation potential conditions.

Transport model that describes the behavior of arsenic through the micro watershed can be simulated by means mathematical modeling using computational software as Visual MODFLOW V. 2.7.2, introducing concentration data, properties (conductivity, storage), since it simulates the transport of porous means polluting agents and water flows in three dimensions.

Acknowledgment

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