Small scale mining in the area of the Choapa river, Central Chile: an environmental risk?

Michael Wrobel, Thomas R. Rüde, Stefan Wohnlich

Institute of General and Applied Geology, Ludwig-Maximilians-Universität, Luisenstr. 37, D-80333 Munich, Germany. e-mail: thomas.ruede@iaag.geo.uni-muenchen.de

Abstract: The Choapa valley is typically for the northern part of Chile with agriculture based one hundred percent on irrigation influenced by serious variations of precepitation. It will also become one of the major copper mining districts of Chile due to the increase in production of the mine Los Pelambres. For a further development of the water resources esp. groundwater a baseline research was done, besides other studies, on the impact of former small scale mining of copper in the center part of the valley. The slightly alkalic river waters and groundwaters are uncontaminated with respect to As, Cd, Cu and Pb. The determination of the net acid producing potential, net acid generation tests and kinetic tests on waste rocks demonstrate that in most cases carbonates and esp. Cu-carbonates buffer the systems hindering the formation of acid rock drainage and heavy metal release. The tailing pond of the only modern middle scale mine in the area is seeping and a sulfate plume emerges from the tailing pond downstream. Due to the high pH metals are not transported in aqueous form. The risk of particulate transport of metals with fine silts washed out of the pond will be studied.

1 INTRODUCTION

The valley of the river Choapa is located 200 km to the north of Santiago de Chile (Figure 1). It is an east - west trending valley from the chain of the High Andes down to the shorelines of the Pacific ocean. This semiarid area has besides its agriculture on 100 % irrigated land a long tradition of small scale mining of gold and copper. Today the people are looking forward to a major change in their economy and social structures due to the mining project of Los Pelambres. This mine is situated in the highest part of the Choapa valley, in the Andes, and will be one of the biggest copper mines of Chile. The mine is in operation since the beginning of the Nineties. It is now in the process of increasing the production of copper concentrate which is pumped over a distance of 100 km down to the harbour of Los Vilos where a new pier for sea vessels was built during the last two years.

Agriculture is solely depending on irragation with surface water especially of the river Choapa. Only some wells for drinking water were drilled. The water resources are heavily fluctuating with climate. After several years of drought during the middle of the Nineties with less than 1 m^3/s of discharge from the Choapa at the gauge of Salamanca (a small town in the center of the valley), it increased during the El Niño of 1997/1998 to 90 m^3/s and decreased in the following year again to a value of only 3 m^3/s. A planned exploration of the goundwater seems to be the future resource to stabilize the local economy and to meet the increased demand of the mining project Los Pelambres and the spin-off effects of it.

It is a typical situation in central and northern Chile that surface waters are the major base of the local economies. This resource is strongly fluctuating and is heavily overused. Future demands by the local communities and also major economic activities cannot be met by surface discharge.

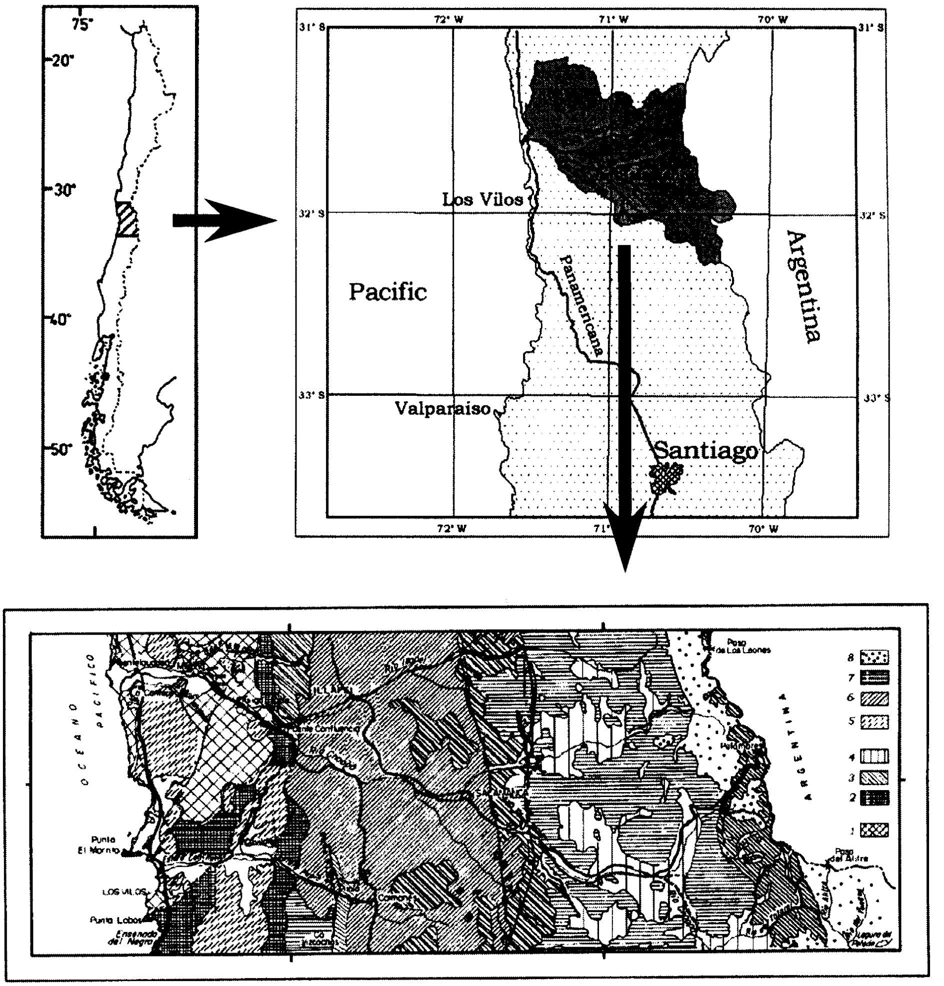

Figure 1 Drainage area of the river Choapa (grey area in part b) and its geology (part c). The geological map was compiled with data of Rivano & Sepulveda (1991).
1- Metamorphic and sedimentary rocks of Paleozoic age, 2- Triassic and Jurassic sedimentary and volcanic rocks, 3- Lower Cretaceous sedimentary and andesitic rocks, 4- Upper Cretaceous andesitic, dacitic rocks, 5- Jurassic pluton, 6- Lower Cretaceous plutons, 7- Upper Cretaceous plutons, 8- Tertiary plutons and ignimbrites

We started a hydrogeological research in the valley of the Choapa and one subproject deals with the environmental effects of the former small scale mining especially in the middle part of the Choapa valley around the town of Salamanca (Figure 1). The results of this work presented here give also a baseline with regard e.g. to heavy metals before Los Pelambres is in full production.

2 GEOLOGY

The area has a long history of subduction related magmatism and terrain accretion with an eastward propagation of the magmatic arc since the end of the Triassic from the present coastline to the High Andes where magmatism ceased during the Tertiary. The central part around Salamanca is dominated by Cretaceous acidic volcanics and sediments related to an initial back arc extension which were later intruded by magmatic arc plutons during the eastward shift of the volcanic arc (Figure 1).

Major features are two N-S trending transtensional faults east of Salamanca. Most of the copper deposits in that part of the Choapa valley are related to these faults and also the only middle scale mine south of Salamanca in the canyon of the Durazno (Soexplo mine) was mining copper along the fault system. At a production of 200 t of concentrate per day the mine was shut down during the copper crisis in 1998/1999. Primary ore minerals are chalcopyrite, bornite, chalcosite and covellite. Some deposits were enriched in copper by secondary cementation processes. This results in the copper carbonates malachite and subordinate azurite.

3 MATERIALS AND METHODS

In April 1999 we sampled waters of the river Choapa and well waters in the central part of the Choapa valley. Well waters were taken after pumping for at least one hour. Due to the dry conditions of the La Niña year of 1999 no springs or small streams, the so called Quebradas, were sampled. The samples were filtered (0.45 µm), split into two aliquotes for determination of anions and cations and the cation sample acidified with nitric acid. Besides the titration of bicarbonate in the field, some samples were analyzed for nitrate, sulfate and phosphate by a field photometer to control artifactes due to transportation of the samples. All analyses were done in the laboratory in Munich by atomic absorption spectrometry for cations and ion-chromatography for anions.

Seventeen waste rock dumps of former small scale mines were localized in the study area and their volume estimated. Two kg of samples were taken from ten of them. Only one of these mines is nowadays from time to time in production. Samples were also taken from the flotation pond of the Soexplo mine and from a small stream downstream the tailing pond. Six samples of soils on volcanic/sedimentary and plutonic rocks should give estimates of the natural background. The samples were sieved and minerals determined by microscopy, x-ray diffraction and differential thermal analysis. The concentrations of heavy metals and arsenic were determined after acidic dissolution and the concentrations of carbonate and sulfur by thermal analysis. The potential of the materials to generate acid waters was tested by the net acid producing potential, the net acid generation test and by leaching in humidity cells (Department of Mineral and Energies 1995). Also heavy metals and arsenic were determined in the leachates.

4 THE PRESENT LEVEL OF HEAVY METALS IN THE WATERS

The Choapa river has pH-values between 8 and 9 and the groundwaters are around 7. The electrical conductivity of the samples is between 400 and 500 μS/cm. The major ions are shown in the Piper diagram (Figure 2) demonstrating a vey homogeneous cation composition and an alkaline-earth - bicarbonate type of the waters. The Durazno samples will be discussed later. With regard to heavy metals the waters are uncontaminated. Lead is in all

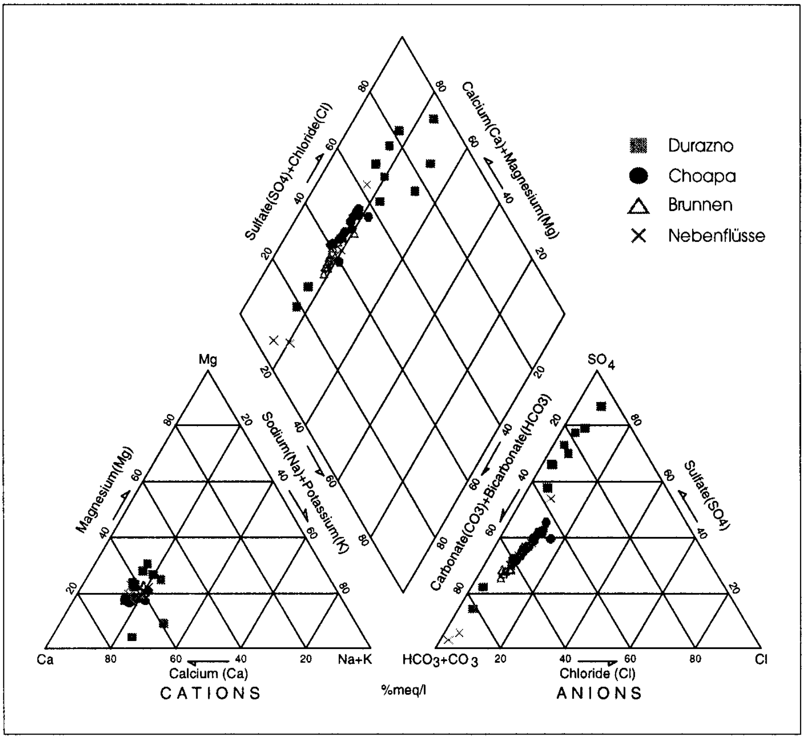

Figure 2 Piper diagram showing the major ion composition of the analyzed surface waters and groundwaters of the river Choapa, its tributaries, groundwaters and the small creek Durazno downstream the Soexplo tailing pond

samples below the detection limit of 2.5 μg/L, arsenic is in many samples below 1.5 μg/L and up to a few μg/L in some samples. Except one sample with 7 μg/L also Cd is in most samples below the detection limit of 0.25 µg/L. Copper has a maximum of 35 µg/L and in most samples only a few µg/L. All in all the surface and groundwaters are uncontaminated with respect to the analyzed metals.

The waters of the small creek below the tailing pond of the Soexplo mine are alkaline-earth type like the others but with a dominancy of sulfate (Figure 2). A sample of the tailing pond has 320 mg/L of sulfate but low metal contents as for example Cu of only 36 µg/L. Figure 3 shows the concentrations of sulfate and copper as an example of the metals downstream of the tailing pond. The leakage of sulfatic waters out of the tailing pond is demonstrated by the low sulfate concentrations (of some tens) upstream the creek - the samples D6 and D7 of Figure 3. But, the mobility of heavy metals is actually limited due to the high pH (around 8) of the tailing waters.

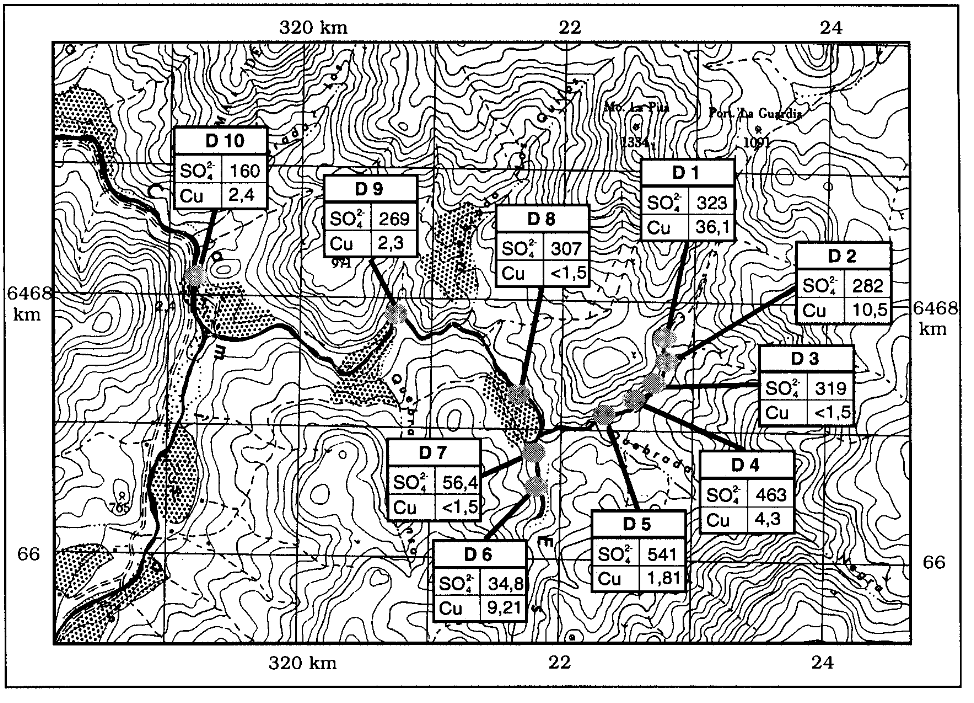

Figure 3 Sulfate [in mg L^{-1}] and copper [in µg L^{-1}] in water samples downstream of the tailing pond (D 1) of the Soexplo mine. The samples show the leakage of waters from the tailing pond and the influence on the creek Durazno. See text for discussion

The survey of the surface waters and groundwaters indicate that there is actually no contamination due to heavy metals - the same is true for nitrate and phosphate - especially from the former small scale mining activities. The dam of the Soeplo mine is not constructed with state of the art technical standards with respect to environmental aspects. Waters are seeping through the dam and influence the creeks downstream. The low total metal concentrations of the tailings (see below) and the high pH prevent the scarce and valuable water resources from heavy metal contamination.

5 THE POTENTIAL FOR ACID ROCK DRAINAGE

The waste rock dumps were examined to evaluate their potential to release heavy metals especially after heavy rains. The sizes of the dumps are very different and they have volumes between appr. 7 and 1800 m^3. The hydraulic conductivities are between $1.7*10^{-4}$ and $1.8*10^{-3}$ m/s. The tailings of the Soexplo mine are coarse silts and have a volume of approx. 20 000 m^3 and a hydraulic conductivity of $7*10^{-9}$ m/s. Sediments downstream the dam of the tailing pond consist of fine silts which are washed out of the tailing pond.

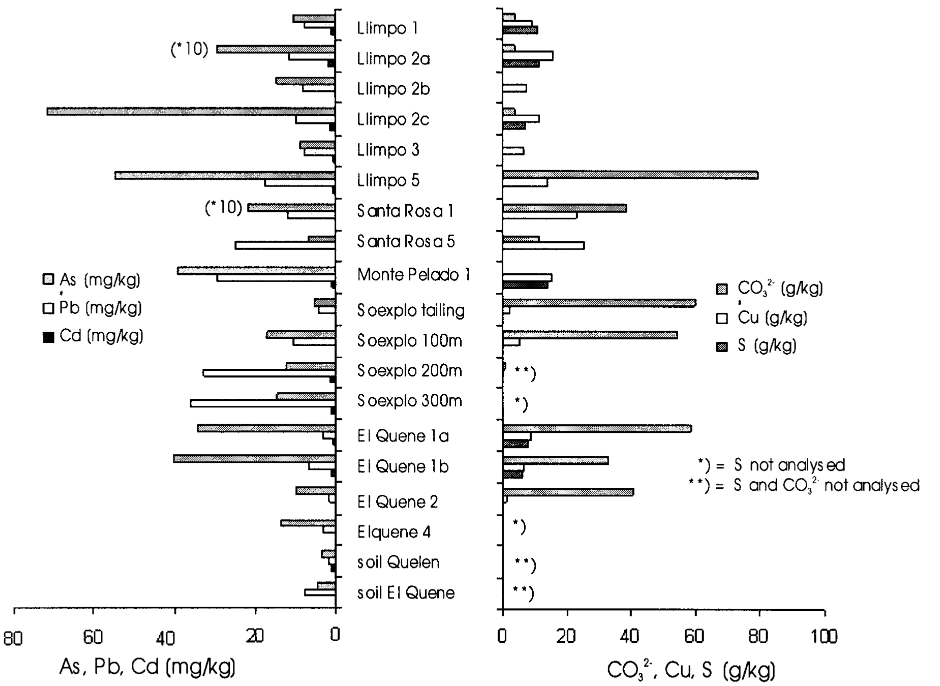

Figure 4 Concentrations of sulfur, carbonate and metals in the samples of the waste rock dumps, the Soexplo tailing pond and soils as comparison

The metal concentrations of arsenic, cadmium and lead in the waste rock dumps are significantly higher than the background of the soils but still low with values of some tens of µg/g of arsenic and lead and up to 2 µg/g of cadmium (Figure 4). There is only one exception which has an arsenic concentration of 300 µg/g. Copper has high concentrations up to 25 mg/g which equals the reported mean value of the ores (Rivano & Sepulveda, 1991). The highest sulfur concentration is 16 mg/g and carbonate has concentrations from 8 up to 80 mg/g. The carbonates calcite, malachite and others show no dissolution features and also the sulfides are fresh with no oxidation rims with the exception of one sample where carbonates are partially dissolved and Fe-hydroxides are precipitated.

The tailings of the Soexplo mine are also low in arsenic, cadmium and lead and also copper has only a value of 2 mg/g. The fine sediments sampled downstream the tailing pond show an increase of the concentrations of As, Cd and Pb by factors of 2 to 10 but not for Cu. This indicates that the former metals are enriched in the finer fractions of the tailings and are washed out with them from the pond.

The potential to produce acidic waters was tested on the grain sizes below 6.3 mm, which were ground to analytical fineness. The net acid producing potential (NAPP) is in four samples between 17 and 42 kg H_2SO_4 t^{-1} but most samples have a negative NAPP of down to -65 kg H_2SO_4 t^{-1} indicating that they are able to buffer more acid than can be released from them. The net acid generation (NAG) results also only for the samples with positive NAPPs in acidic pH-values of 3.3 to 4.6. Most samples show the same neutral to alkaline pH-values as for water extracts. This is even the case if sulfides are oxidized by the hydrogen peroxide reagent of the NAG test resulting in a strong exothermic reaction like e.g. for the El Queñe sample (Figure 5). Six samples out of the 17 react exothermic in the NAG-test and they release 80 % to 100 % of their sulfur content together with 30 to 65 % of the total copper concentration, which means 2.5 to 7.5 kg Cu t^{-1} of waste rock. The relative release of Cd is high but in absolute values negligable like As and Pb. The mechanism of copper dissolution is the oxidation of Cu-sulfides indicated by the good correlation of copper and sulfur in the NAG solutions. Tests with non grinded samples failed to react exothermic.

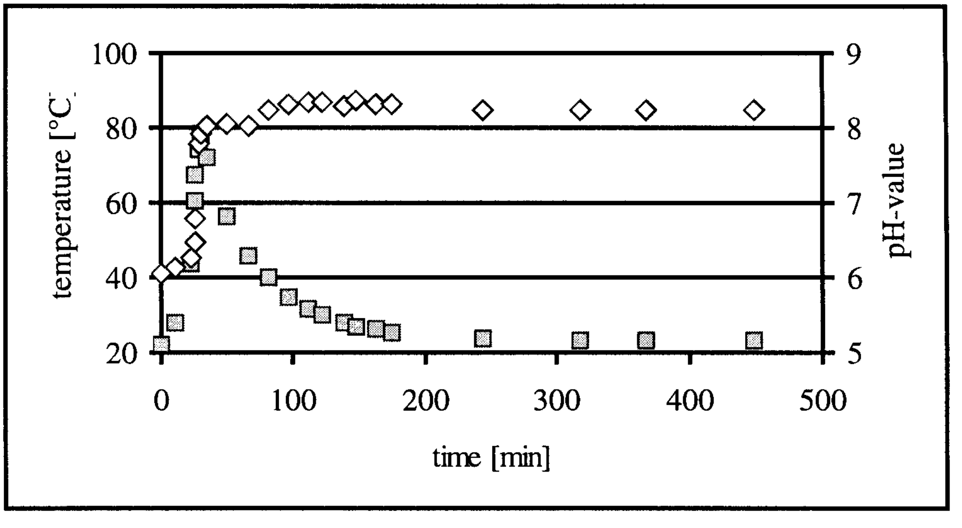

Figure 5 Temperature and pH of the NAG-Test of a sample (El Quene 1a). The content of 9 mg g^{-1} of sulfur is oxidized but the acid is buffered completely by carbonates

Eight samples 250 g each were also tested by a kinetic test, i.e. by humidity cells (Pool & Balderrama 1994) over a period of 7 weeks at 40 and 80 % humidity. The pH-values of the effluents are alkalic over the whole period except for one sample with a pH of 6.0 to 6.5. All of them show an exponential wash-out of sulfate from values of 80 to 1.300 mg/L down to a few tens of mg/L at the end. Also copper is released with high values of 100 to 400 µg/L at the beginning and ends with a few tens of µg/L. There is only one exception which runs from 19 mg/L to 3 mg/L of copper. This sample consists of oxidized sulfides and secondary minerals like iron hydroxides (see above). In contrast to sulfate and the other metals copper dissolves after three weeks in more or less constant rates.

6 CONCLUSION

The scope of this research is to establish a baseline of the present environmental impact of small scale mining in the central part of the Choapa valley and to test the source potential of old waste rock dumps. The Choapa river itself and the groundwaters are uncontaminated with respect to the analyzed metals arsenic, cadmium, copper and lead. The relicts of the former mining activities are dispersed over the area and have only a small inventory of metals except copper which is dumped sometimes in ore grade concentrations. Even a very rigid dissolution test like the NAG-test on finely ground materials gives an acidic reaction and metal release only in some samples. Cu-carbonates which were mined as cementation ores or formed in the dumps due to sulfide oxidation (Alpers et al. 1994) and calcite buffer the system in most cases.

The oxidation of sulfides even possible by humic air (Borek 1994) is a very slow process in the semiarid climate of the Choapa region. Most of the sulfides are more or less fresh. The products of sulfide oxidation and carbonate dissolution are stored in the dumps and can be washed out during the periodic heavy rains. This can cause local contaminations of small streams but the high discharge of the major streams during rainy periods will rapidly dilute the seepage from waste rock dumps.

Sulfatic waters are seeping out of the tailing pond of the former middle scale mine in the southern part of the study area. This has to be observed very critically as a major water reservoir is under construction downstream. Actually, the content of heavy metals is low in the tailings and the alkalic pH in the pond hinders the transport of heavy metals. As metals are washed out of the pond with the finest material of the tailings, the investigation will be followed up with a research on particulated transport of heavy metals at that locality.

REFERENCES

Alpers C.N., Blowes D.W., Nordstrom D.K. & Jambor J.L. 1994: Secondary minerals and acid-water chemistry. In: Jambor J.L. & Blowes D.W. (ed): *Short course*

handbook on environmental geochemistry of sulfide mine-wastes. Miner. Ass. Canada, Short course handbook 22.
Borek S.L. 1994. Effect of humidity on pyrite oxidation. In: Alpers C.N. & Blowes D.W. (ed): *Environmental geochemistry of sulfide oxidation*. Am. Chem. Soc., Symp. Ser. 550, 31-44.
Department of Mineral and Energies (ed) 1995. *Technical guidelines for the environmental management of exploration and mining in Queensland*, Brisbaine.
Pool, D.L. & Balderrama, R.M. (1994): Evaluation of humidity cell parameters - their effect on pecesion and repeatability.- In: US-DOE (ed): *International land reclamation and mine drainage conference and third international conference on the abatement of acidic dainage*, Vol 2, Bureau of Mines Spec. Publ. SP06B-94, 326-333.
Rivano G.S. & Sepulveda H.P., 1991. *Hoja Illapel - Carta Geológica de Chile 1 : 125 000 No 69* (in Spanish), Servicio Nacional de Geológica y Minera, 132 pp.

Eksploatacja górnicza na małą skalę na obszarze rzeki Choapa, środkowe Chile: zagrożenie dla środowiska?

Michael Wrobel, Thomas R.Rüde & Stefan Wohnlich

Streszczenie: Dolina Choapa jest typowa dla północnej części Chile, z rolnictwem opartym w 100% na irygacji bazującej na różnych wariantach opadów. Obszar ten stanie się także jednym z głównych obszarów wydobywających miedź w związku z nasileniem eksploatacji kopalni Los Pelambres. Dla rozpoznania wykorzystania zasobów wodnych tego obszaru, zwłaszcza wód podziemnych, wykonano podstawowe badania wpływu wcześniejszej eksploatacji miedzi w centralnej części doliny na środowisko wodne. Stwierdzono, iż lekko alkaliczne wody rzeczne i podziemne nie zostały zanieczyszczone metalami As, Cd, Cu i Pb. Badania potencjału zakwaszenia, testy zakwaszające i kinetyczne na skałach odpadowych wykazują, że w większości przypadków węglany a szczególnie węglany miedzi buforują system stanowiąc przeszkodę w tworzeniu się odcieków kwaśnych wód ze składowisk i uwalnianiu się metali ciężkich. W stawie poflotacyjnym w jedynej współczesnej kopalni średniej wielkości na tym terenie występuje proces przesączania i plama siarczanów pojawiła się w pobliskim strumieniu. Z powodu wysokiego pH metale nie są przenoszone drogą wodną. Ryzyko transportu metali z drobnym iłem wypłukiwanym ze stawu flotacyjnego będzie przedmiotem dalszych badań.