

# MINERALOGICAL, GEOCHEMICAL AND ISOTOPIC STUDY OF THE ACTIVE TAILINGS IMPOUNDMENT CARÉN FROM THE PORPHYRY COPPER DEPOSIT EL TENIENTE, CHILE<sup>1</sup>

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**Abstract:** At the active tailings impoundment Carén (surface 22 km<sup>2</sup>) from the porphyry copper mine El Teniente, Chile, initial steps of primary mineral alteration and geochemical changes after deposition were studied. The tailings contained up to 3 vol% sulfides (mainly pyrite). At five points in the tailings impoundment, water samples up to a depth of 4 m were taken from piezometer. Preliminary data showed that the water, which was entering the tailings impoundment as an alkaline (pH 9.21) tailings slurry, changed to neutral (pH 7.41) conditions at the discharge of clear water from a decantation lake into a natural river system. The discharged clear water contained Cu up to 80 µg/L, Zn up to 180 µg/L, Mg up to 30 mg/L, Mo up to 0.35 mg/L and sulfate (up to 1400 mg/L) indicating the liberation of metals from the very early stage of sulfide oxidation. Initial water and mineralogical data indicated a 2-layer structure of the tailings: (1) the first layer (0 m -1 m depth) was dominated by the alkaline pH of the fresh tailings but with lower pH at the surface and higher pH at 1 m depth. Incipient pyrite alteration was observed at the surface already two weeks after deposition; pyrite grains also in the youngest layers showed small oxidation rims. This process seemed to lower the pH at the surface of the tailings impoundment. New tailings deposition renewed in a 4-weeks rhythm the alkaline conditions at the surface. (2) In the second layer (1 m to 4 m depth) the pH decreased down to near-neutral environment, possibly due to neutralisation of the bases by the tailings.

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## Introduction

The active tailings impoundments Carén (surface 22km<sup>2</sup>; Fig. 1) from the porphyry Cu mine El Teniente, Chile, offers a giant field laboratory for studies of initial steps of primary mineral alteration and geochemical changes after deposition of sulfide-containing tailings. After ceasing of deposition, these tailings often have an acidic environment due to sulfide oxidation and produce acid mine drainage (AMD) (Dold and Fontboté, 2001). The object was to study the first geochemical and mineralogical changes of low-sulfide tailings in an active tailings impoundment. The knowledge of these changes can help to understand the different parameters influencing the geochemical processes and rates, which lead to AMD production. The studied Carén tailings impoundment belongs to the El Teniente mine, actually the largest underground mine in the world. The mined ore body is one of the giant porphyry Cu systems and contains >70 Mt Cu. Its formation is genetically related to Late Miocene-Early Pliocene igneous activity. The main sulfide ore minerals are pyrite, chalcopyrite, bornite, molybdenite, sphalerite, galena and tennantite, in a gangue of quartz, alkali-feldspar, biotite, anhydrite, carbonates and locally tourmaline. The ore was treated after the crushing and milling process by an alkaline flotation process (pH 10.7).

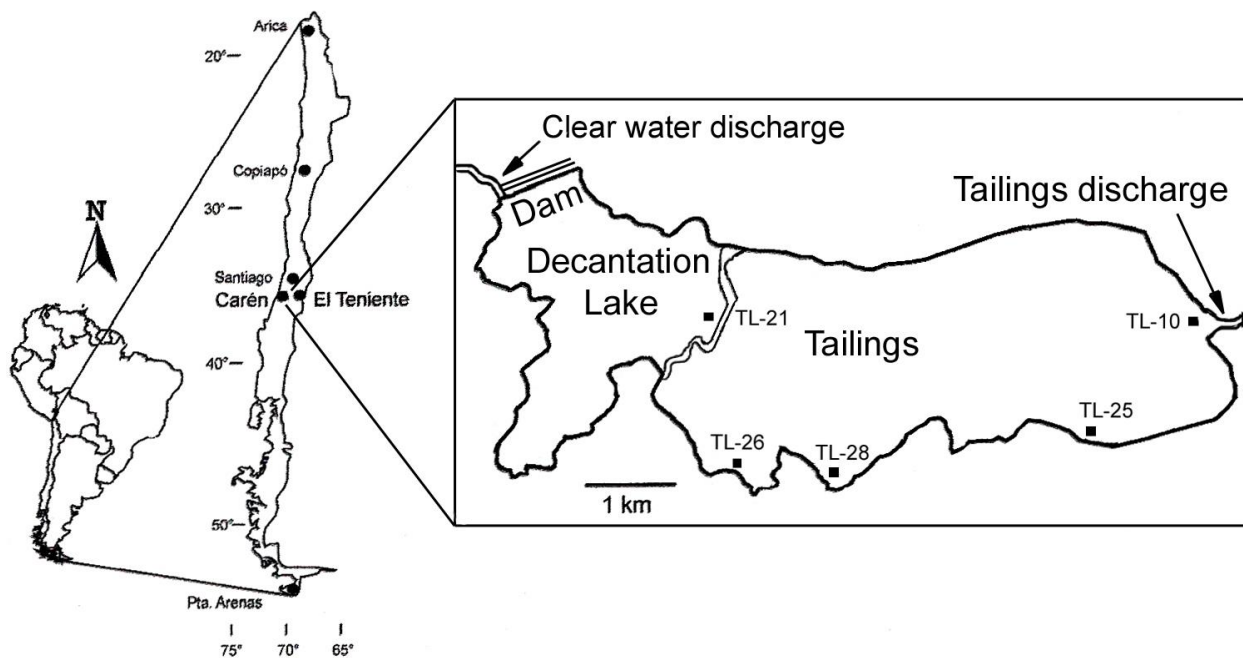


Figure 1. Location of the sampling points TL-10 to TL-28 at the Carén tailings impoundment, Central Chile.

At the time of sampling the Carén tailings impoundment occupied an 8.5 km long and up to 2.5 km wide sector of a valley, including a downstream decantation lake and an impoundment dam (Fig. 1). The impoundment received per day ca. 200,000 t of tailings via an 87 km long channel from the flotation of the El Teniente mine. For the last 3 km the tailings flow in a

natural riverbed. After entering the tailings impoundment the tailings river meandered in the nearly flat, with tailings filled valley from the northern to the southern bank in a nearly constant 4-weeks-rhythm. The sedimentation started rapidly near the discharge point in the upstream zone of the tailings impoundment. This process caused a grading of tailings material from sandy at the discharge point to clayey towards the decantation lake and the dam. In the decantation lake the finest materials settled down. At the dam clear water was collected, discharged into a natural riverbed and used downstream e.g. for irrigation. The deposition of tailings material was controlled only by the level of the decantation lake; a lower lake level increases the relief, the main settlement zone of tailings is moved downstream. This procedure was used periodically to stabilize the dam by the settlement of coarser tailings material in the decantation lake basin.

### Methods

Drive-point piezometer were installed at six sampling points (TL-10 – TL-28, Fig. 1) in the tailings impoundment to sample water to 4 m depth (Fig. 2, left). Tailings samples were taken at these sampling points up to 2.5 m depth (Fig. 2, right). Eh, pH, alkalinity, Fe(II)-concentrations of water samples, and sample colour, texture and paste-pH of tailings samples were measured immediately.



Figure 2: Sampling at point TL-26; water sampling by drive-point piezometer with measurement of pH and Eh (left picture) and sampling of tailings by a hand-corer (right picture).

Additionally, sampling was undertaken in the tailings channel from the mine to the tailings impoundment at three sampling points, at the discharge point of tailings, at the decantation lake near to the dike of the tailings impoundment, and at the discharge point of clear water from the decantation lake into the natural river downstream. Water samples were geochemically analyzed by inductively coupled plasma mass spectrometry (ICP-MS) and ion chromatography (IC). Solid samples were mineralogically analyzed by thin sections and X-ray diffraction (XRD), and geochemically by X-ray fluorescence spectroscopy (XRF).

## Preliminary results and discussion

The water pH changed from pH 9.21 at the zone, where fresh tailings entered the tailings impoundment, to 7.41 where clear water from the decantation lake leaved the tailings impoundment and was discharged in a natural riverbed (Fig. 3).

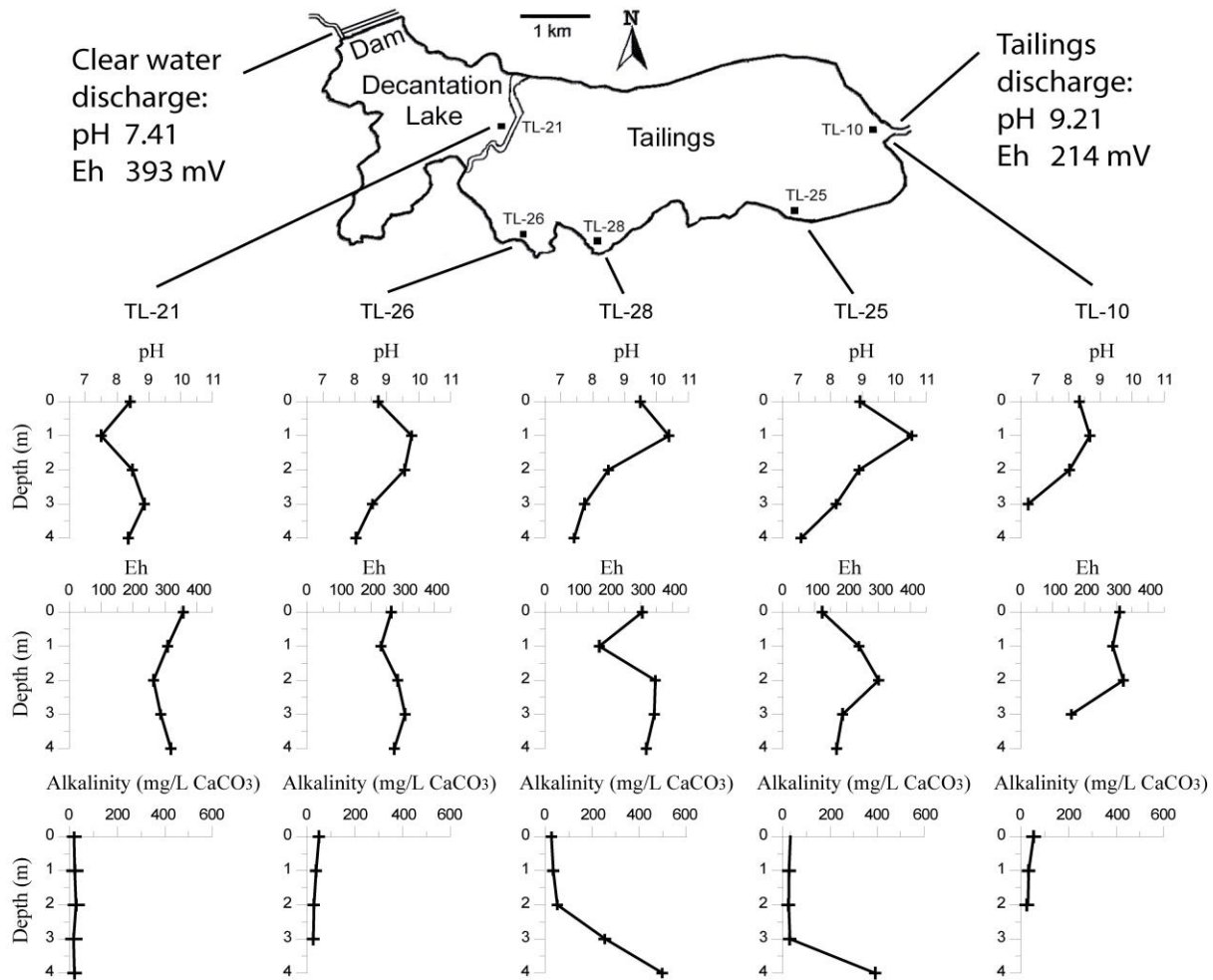


Figure 3. Map of the Carén tailings impoundment, position of sampling points and water data (pH, Eh, Alkalinity) from piezometer.

The water discharged from the tailings impoundment contained heavy metals (Mo up to 0.35 mg/L, Cu up to 80 µg/L, Zn up to 180 µg/L, and Mg up to 30 mg/L) and  $\text{SO}_4^{-2}$  (up to 1400 mg/L) indicating that element liberation took place in the active tailings impoundment. In the not water-covered tailings impoundment, data from pore water up to 4 m depth (sampling points TL-10 - TL-26) showed a 2-layer structure of the tailings. The environment of the upper layer (0 m to 1 m depth) seemed to be controlled by the meandering tailings river. After the sedimentation of a new, alkaline tailings layer and the shifting of the tailings river towards the other side of the valley minerals at the surface can react with the atmospheric  $\text{O}_2$ . Pyrite grains showed thin oxidation rims also in the youngest top layers. This suggests that, while the tailings

river was flowing on the northern side of the tailings impoundment, pyrite and other sulfides oxidized near the surface of the southern side in contact with atmospheric O<sub>2</sub> and lowered the pH at the surface. Deeper zones of this layer were protected against oxidation due to the water-saturation of the tailings. The periodically returning tailings river set the environment in the surface layer (0- 1 m depth) back to alkaline environment and deposited a new layer of tailings.

In the second layer (1m to 4 m) depth, the pH decreased to circumneutral values (minimum pH at 4 m, pH 6.7 (TL-10) - pH 8.1 (TL-28); Fig. 3). This may result from a slow neutralisation process of the basic pore water by the tailings material.

In the sediments of the decantation lake (water-covered tailings; sampling point TL-21) near to the uncovered tailings, the highest pH was found in the deeper zones (3 m depth, pH 8.8). As a possible reason a stratum with new tailings material (as result of a low decantation lake level) is assumed.

A clear trend of different pH values with distance to the discharge point was not observed, suggesting that the grading of tailings was less important for sulfide oxidation than the depth and the environment involved (availability of O<sub>2</sub>). A clear Eh trend with depth was only found in the parts of the profiles deeper than 2 m. At the both sampling points close to the discharge point (TL-10 and TL-25) the Eh at 2 m and 3 m decreased from oxidizing to intermediate environment (Fig. 3). This trend could be observed also at the other sampling points at the not water-covered part of the tailings but did not decrease at these points below oxidizing environment.

In the upper 2 m of the tailings impoundment, clear trends of Eh were not observed.

At sampling point TL-21 (tailings flooded by the decantation lake, near to the not flooded tailings) generally the highest Eh values in tailings pore water (up to 358 mV) were found and did not decrease with depth. This observation supported the assumption that at TL-21 a relatively fresh tailings layer was deposited as result of a low decantation lake level.

### **Preliminary conclusions**

The active tailings impoundment Carén (surface 22km<sup>2</sup>) from the porphyry Cu mine El Teniente, Chile, contained up to 3 vol% sulfides (mainly pyrite). The tailings showed a 2-layer structure: (1) the first layer (0 m -1 m depth) was dominated by the alkaline pH of the fresh tailings. The meandering slurry river covered periodically the sampling zone. Only during the time when the tailings river was located at the other side of the valley minerals at the surface could react with atmospheric O<sub>2</sub>. The oxidation of pyrite and other sulfides at the surface lowered the pH slightly. This oxidation process was stopped when the tailings river returned, set the environment back to highly alkaline conditions and sedimented a new tailings layer. (2) The pH decreased in the deeper tailings (1m to 4 m depth), probably due to a neutralisation process of bases by the tailings.

The clear water discharged from the tailings impoundment into a natural riverbed had neutral pH (7.4) and low elemental concentrations, except of SO<sub>4</sub><sup>-2</sup> (max. 1400 mg/L) and Mo (max. 0.35 mg/L).

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### **References**

Dold, B. and L. Fontboté, 2001. Element cycling and secondary mineralogy in porphyry copper tailings as a function of climate, primary mineralogy, and mineral processing. *Journal of Geochemical Exploration* 74 (Special Issue: geochemical studies of mining and the environment), pp. 3-55.