Pilot study of improved soils as a cover alternative for mine closure of waste rock dump, Peru

Alfredo Gallardo[1], Eduardo Ruiz[2], David Arcos[3]

[1]Amphos 21 Consulting Peru S.A.C. Jirón Paseo del Bosque 500 of. 201, Urb. Chacarilla del Estanque – San Borja, 15037 Lima, Peru, alfredo.gallardo@amphos21.com

[2]Amphos 21 Consulting Peru S.A.C. Jirón Paseo del Bosque 500 of. 201, Urb. Chacarilla del Estanque – San Borja, 15037 Lima, Peru, eduard.ruiz@amphos21.com

[3]Amphos 21 Consulting S.L. c/ Veneçuela 103, 2ª plta., 08019 Barcelona, Spain, david.arcos@amphos21.com

Abstract

This study proposes the use of improved soils as an alternative to the more traditionally used cover layers for sulfide waste rocks. The theoretical advantage of these improved soils lies in their capacity for self-regeneration, so that they do not require maintenance. In addition, the design of the improved soil layers is based on the site conditions and focuses on reducing infiltration into the underlying system and also generating anoxic conditions that help to reduce the rate of sulfide oxidation.

To this end, a testing program was developed and started in 2015, in which, a cover was designed and installed on the backfilled surface of an exhausted open-pit section at a mining operation. In addition, a monitoring system was designed and installed to evaluate the effectiveness of the cover. This paper describes and discusses the monitoring results and the implications for the strategy to ensure an environmentally and economically sustainable closure of the mining operation, highlighting some of the key findings.

Keywords: Improved soils, mining closure, hydrogeochemical monitoring, full-scale test.

Introduction

In Peru, the guidelines for closure of mining operations suggest the use of a defined cover developed in layers, where the priority is to reduce infiltration with low permeability materials (GDMEA 2006). However, there are alternative concepts that are possible which are based on imitating nature. With these concepts the very structure of some soils promotes water retention and evapotranspiration, thereby limiting infiltration and reactivity with the organic fraction that promotes oxygen consumption.

In this context, a pilot project has been developed for the closure of a section of the pit in a gold mine in a high sulfidation epithermal deposit. This type of deposit is known to present lithologies with a large variety of hydrothermal alterations all of them with elevated potential acid generation (PAG) as indicated by Plumlee et al. (1999). Closing the pit area consists of backfilling a pit area of approximately 80,000 m^2 with sulfide waste rocks and which are covered with improved soils, known as technosols (Santos et al. 2019, Macías et al. 2023). The project consists of evaluating the effectiveness of this technosol with respect to its capacity to minimize infiltration (target hydraulic conductivity is in the range of 10^{-2} to 10^{-3} m/d) and also reduce the oxidizing capacity of waters that may infiltrate using different types of instrumented boreholes.

Figure 1 Site view before (above), during (lower left) and after (lower right) cover implementation.

Methods

The target pit area was backfilled with waste rock and then covered with a combination of three 15 cm-thick manufactured soil layers (Fig. 1) being, from bottom to top: 1) a lower layer of andic technosol, whose purpose is both to neutralize the generation of acids and also reduce the mobility of anions; 2) a reducing technosol, to reduce the rate of sulfide oxidation (i.e., pyrite) and, 3) an eutrophic-calcareous technosol, whose objective is to promote local plant growth (a feasibility study with local vegetation was conducted) and increase microbial activity and biodiversity, as well as to buffer the system to alkaline conditions.

To test the effectiveness of the improved soil cover, a monitoring system was designed and installed (Fig. 2). This monitoring system consisted of:

1. **Near-surface boreholes:** just below the soil cover and isolated from the waste rock by a layer of quartz gravel. The purpose of these instrumented boreholes is to evaluate the effect of the cover on oxygen consumption and the quality of the infiltration water, before encountering the waste rock.
2. **Deep boreholes in the backfill:** Their purpose is to allow for the sampling of water that might infiltrate to the base of the backfill inside the pit basin.
3. **Instrumented wells**: These wells included a series of continuous measurement sensors (temperature, conductivity, suction pressure, water, oxygen and CO_2 content), as well as suction lysimeters at different depths in the backfilling; and
4. **External piezometers:** Drilled upstream and downstream of the pilot test area and at different depths to monitor the potential impact on the groundwater quality.

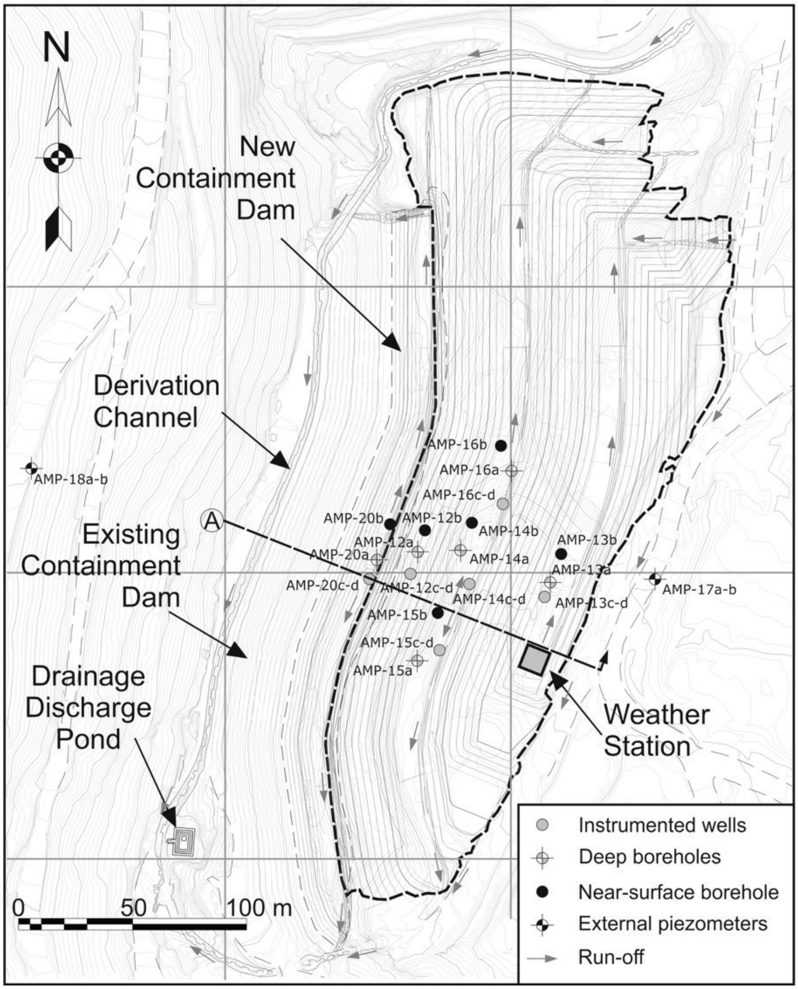

***Figure 2** Map of the full-scale cover test with location of the different types of boreholes.*

5. **Drainage and groundwater collection pond:** This is the outlet of the drainage system where water samples and field measurements are periodically taken.
6. **A weather station:** Installed on the pilot area.

This project started reporting water quality indicators in 2018. The sensors in the project were programmed to generate daily information. Additionally, during the wet season, more exhaustive monitoring was carried out with specific measurements of some of the parameters and water sampling from the suction lysimeters, deep boreholes and external piezometers.

Results and Discussion

Geology in the open pit and its surroundings correspond to volcanic tuffs, ignimbrites, andesites with small patches of Quaternary alluvial cover. The first 5 to 20 meters of rock depth present a high degree of weathering and fracturing, giving it a high contrast of permeability with respect to the deeper fresh bedrock, favouring the circulation of water through this surficial layer.

The climate of the area is characterized by two distinct seasons, a dry season from June to October and a wet season from November to May, with an average annual rainfall of approximately 1,200 mm. Fig. 3 shows the difference in precipitation between dry and

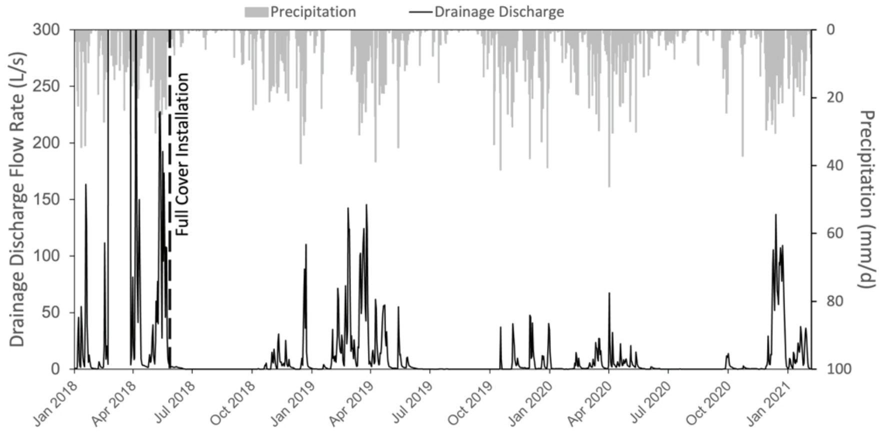

Figure 3 *Monitoring of the discharge flowrate of the pilot.*

wet season, leading to a rapid response to rainfall events in the drainage system of the pilot area. Monitoring results show that the overburden is not saturated with respect to water content, but increases briefly after each rainfall event, without reaching saturation. The time and magnitude of response to rainfall events depends on the depth of the sensor in each borehole. It is also worth noting in Fig. 3 the difference in flow rate before (beyond the scale limits) and after the cover is installed.

Also, the geochemical information of waste rocks used in the backfilling, including lithological and mineralogical descriptions, and geochemical analysis and tests was reviewed. The main source of analytical data came from ABA, NAG and SFE tests and hydrochemical analysis (Table 1) confirming their PAG (Potential Acid Generation) behaviour.

The results from the surface boreholes indicate that, as expected, a decrease in redox conditions (ORP) is recorded since the first half of February 2018. The decrease recorded is 200-300 mV. Furthermore, in most of these boreholes, the water is kept at a near-neutral to slightly alkaline pH (pH = 7 – 8), while the conductivity values remain relatively low (0.5 – 3.5 mS/cm).

Most of the instrumented boreholes show similar results, with lower oxygen contents at the bottom of the backfill. This means that oxygen consumption is also occurring in the waste rock and not only in the cover (Fig. 4). However, at the sampling points of the borehole drilled in the containment dam location, the behaviour is different, with higher oxygen contents at the lowest point of the backfill, at 20 m depth (nearly atmospheric values). This behaviour indicates that the toe of the dam constitutes an air entry zone, likely due to the larger granulometry, especially at the base, and therefore greater air permeability. Furthermore, the high temperatures recorded in this borehole (40 – 50 °C) indicate that pyrite oxidation is taking place. The temperature gradient generated may result in enhanced air circulation.

The quality of the drainage water from the system has been monitored by systematic sampling at the drainage discharge pond. The results indicate that, in addition to the decrease in drainage flow indicated above (Fig. 3), sulfate and metal concentrations show a significant decrease since the installation of the cover (Fig. 5). Specifically, sulfate presents a decrease from concentrations >10,000 mg/L to concentrations <5,000 mg/L, just four years after the installation of the cover. Similarly, copper concentrations decrease from >200 mg/L to <80 mg/L, similar decreases occur with the other metals. It is noteworthy that the first samples of each wet season show higher concentrations, which decrease throughout the season (Fig. 5). This effect is characteristic of this type of system (Nordstrom 2007), where, during the dry season, the wastewater continues to react with

Table 1 Baseline drainage water compositions prior to installing the improved soil cover (concentration values in mg/L).

	pH	Eh(mv)	SO_4	TSS	Pb	Cu	Zn	Fe	Mn
Baseline (Jan 2016)	1.8	603.4	11,542	150	2.2	187.7	3	910.5	27.1
Average values	1.7	591.4	5,307	91	0.7	197.4	7.3	2,234.9	18.6

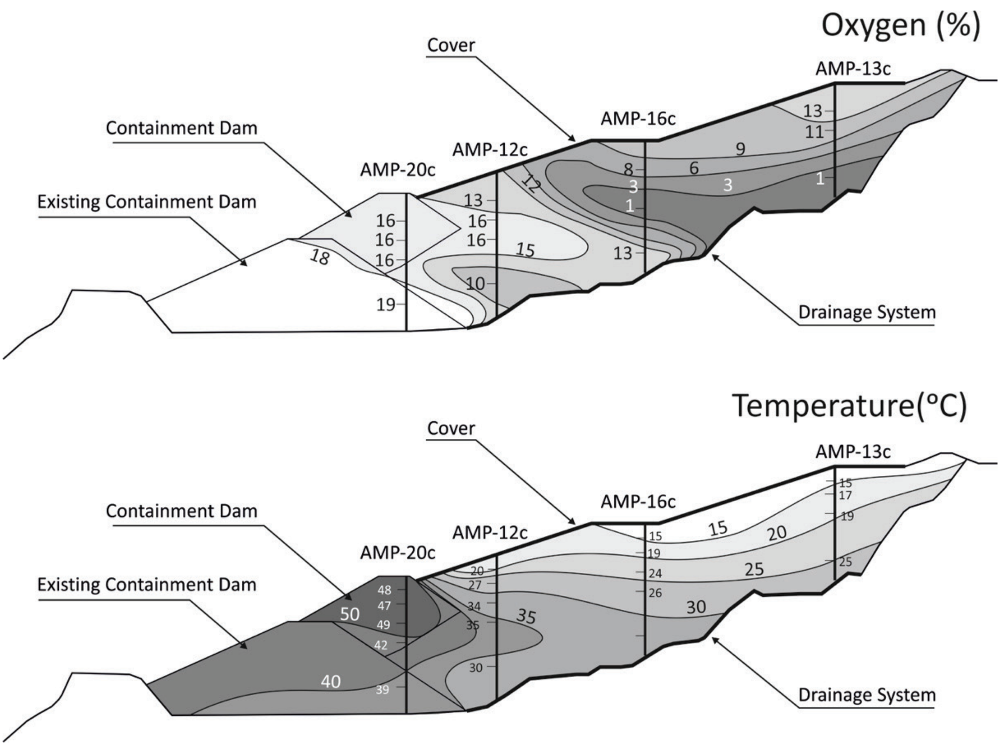

Figure 4 Cross section A of the backfill – cover system as shown in Fig. 2, with mean data of the last half year recorded for oxygen content (above) and temperature (below).

the waste rock and the solutes accumulate in the form of precipitated secondary phases and, at the beginning of the wet season, the first filtrations redissolve these phases producing this effect of increased concentrations.

From the implementation point of view, the cover can be considered successful. One of the aspects to highlight is the healthy development of a vegetation cover, its integration into the landscape and without requiring additional maintenance. This vegetative cover increased evapotranspiration, while reducing water infiltration. The drainage flow at the base of the backfill decreased by more than an order of magnitude. In addition, the decrease in oxygen entry through the cover decreased the rate of sulfide oxidation, reducing the concentration of metals in the drainage water. Although trends are positive, values remain above the maximum permissible Peruvian values, indicating that restoration remains a long-term path.

Conclusions

The use of improved soils as cover material can be considered a viable option since, in addition to promoting the phytostabilization of metals and good revegetation in general, it facilitates oxygen consumption, generating anoxic environments to minimize

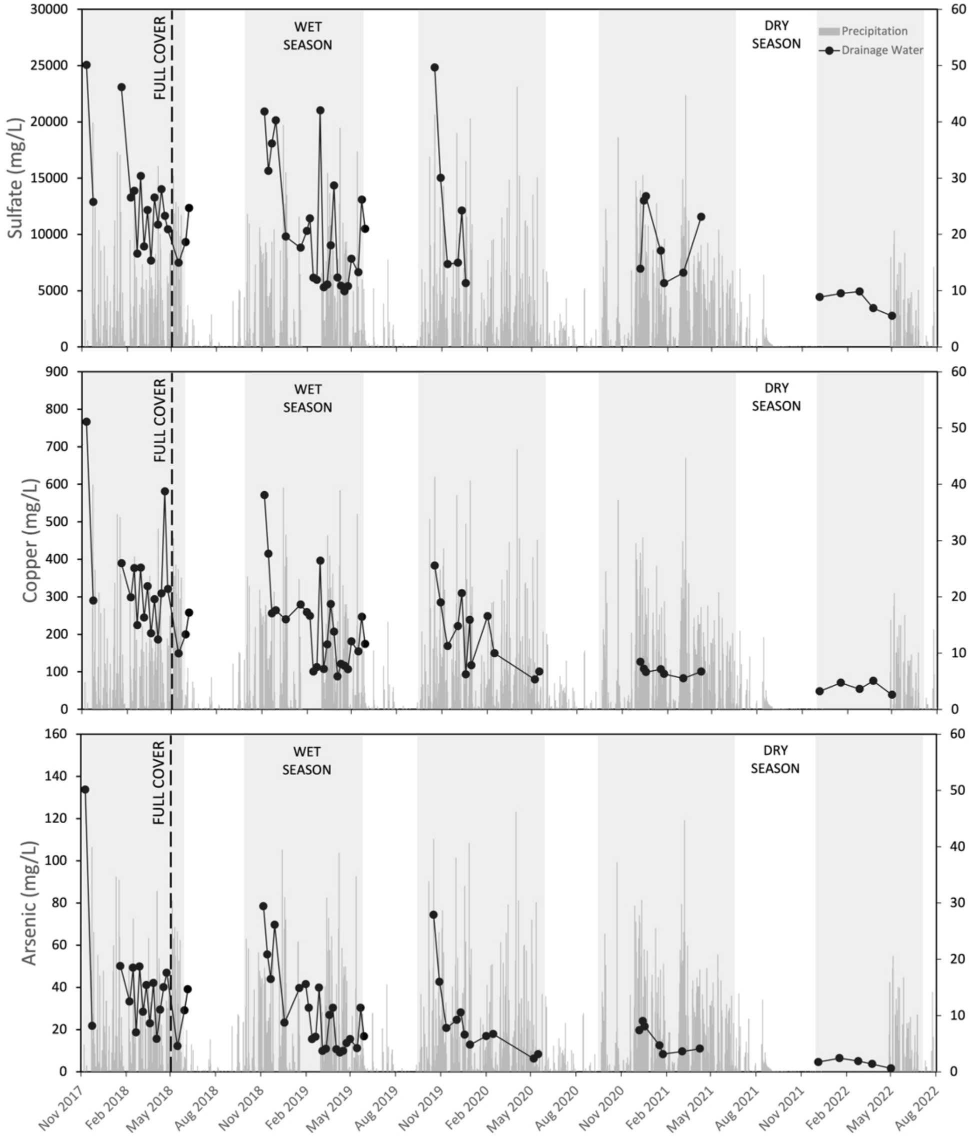

Figure 5 Graphics presenting chemical evolution for selected components in the water collected at the drainage discharge pond.

acid rock drainage. The increase in the evapotranspiration rate due to vegetation growth and, therefore, the reduction of percolation has been shown to be efficient, showing another benefit of using this cover concept.

The evolution of water quality indicators, infiltration, runoff and evapotranspiration, have been similar or better than those obtained by traditional systems of layers with low permeability materials such as clays, which are used in many cases of mine closure in Peru. In this case without the added cost of material acquisition (often outside the mining units), transport and disposal, becoming a living pilot study that continues to yield results that can be used to focus other cases of closure based on sustainable solutions.

On the other hand, although the results are satisfactory, areas for improvement have been identified. For example, alkaline irrigation could be considered prior to the installation of the cover, this approach would help to eliminate very acidic water and therefore deactivate the oxidising capacity of the ferric ion, which is much more powerful than oxygen. For the case study, in a context of advanced ARD (pH<2) and after several years of monitoring, the investigation confirms that facility closure is a long-term process and the guarantees of restoration of the conditions prior to mining operations are difficult to achieve solely with the installation of the cover.

Acknowledgements

The authors thank all the staff of the mine for their support along the project, helping in the design, construction and data acquisition phases, as well as for their useful discussions on the results.

References

García FM, García IM, Vázquez FM (2023) Environmental and Productive Applications of Tailor-Made Technosols: Biosphere Learnings. In: Chaminé HI, Fernandes JA (eds) Advances in Geoengineering, Geotechnologies, and Geoenvironment for Earth Systems and Sustainable Georesources Management. Advances in Science, Technology & Innovation, pp. 219-225.

MINEM (2016) Guide to developing mine closure plans (in Spanish). https://cdn.www.gob.pe/uploads/document/file/5217286/Guía Cierre de Minas.pdf

Nordstrom DK (2007) Effects of seasonal and climatic change on water quality from acid rock drainage in the western United States. In: Cidu R, Frau F (eds.) Water in Mining Environments. pp. 11-16, Cagliari (Mako Edizioni).

Plumlee GS, Smith KS, Montour MR, Ficklin WH, Mosier EL (1999) Geologic controls on the composition of natural waters and mine waters draining diverse mineral-deposit types. En The environmental geochemistry of mineral deposits. Part B: case studies and research topics. Littleton, Colorado: Society of Economic Geologists, Reviews in Economic Geology, v.6-B, pp. 373-432.

Santos ES, Abreu MM, Macías F (2019) Rehabilitation of mining areas through integrated biotechnological approach: Technosols derived from organic/inorganic wastes and autochthonous plant development. Chemosphere 224: 765-775.