Implications of expansive mineralogy on the production process in the Fortuna de Cobre mine. Lomas Bayas, II Region of Antofagasta, Chile.

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Abstract. Lomas II, also referred to as Fortuna de Cobre or simply Fortuna, is characterized for being a low ore grade porphyry whose ore is mainly composed of sulfates. It is operated through the open-pit method and the extraction process consists in four main unit operations: drilling, blasting, loading and transportation, with daily movements of materials weighting 180,000 tons. Higher ore grade materials is crushed and sent to the HEAP leach, whereas the lowest ore grade material is directly sent from the mine site to the ROM heap. Both heaps are static and copper is recovered through solvent extraction and electro-winning in high-purity cathodes.

This summary records the results obtained from the mineralogical analyses performed in Fortuna samples with the purpose of identifying and quantifying the critical mineralogy for the production process where inconvenient have occurred in the crushing line, heap leach and solvent extraction (SX).

Key words: DRX, CEC, FTNIR, sulphates, swelling clays.

1   Introduction

Fortuna is located 3 km south of Lomas Bayas (Lomas I), both owned by Compañía Minera Lomas Bayas (CMLB) and located at ~110 km northeast of the city of Antofagasta and 1.700 m.a.s.l. in Region II of Chile (Figure 1).
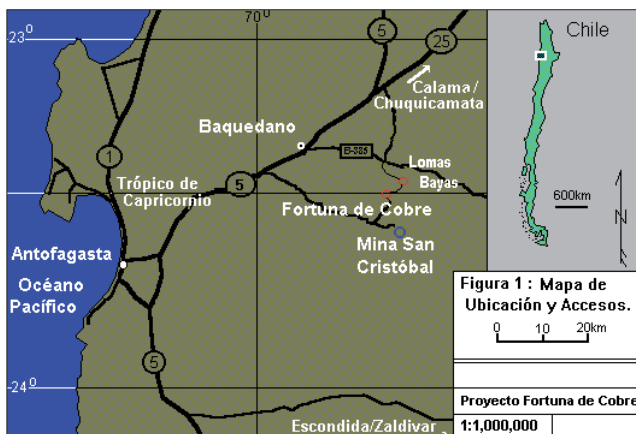

Figure 1. Location and access to Fortuna de Cobre (taken and modified from Sanguinetti, 1999).

In accordance with the analyses performed these consistently indicate a mineralogy exists that is characterized by the high contents of clays and sulfates, both with high swelling potential, which in aggregate result in material expansion when having contact with water phases and subsequently its cohesion, as it has been empirically confirmed.

2   Background information

Material extracted at Fortuna has the property that when in contact with moisture increases its volume, changes its color and coheres. In order to show changes in the material, Figure 1 shows sections of a diamantine drill core that were exposed to intense short-duration rains.
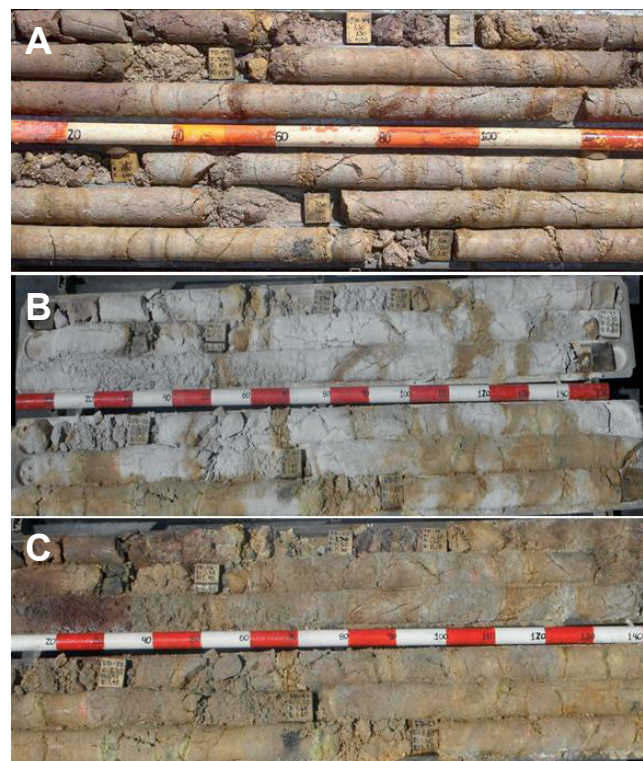

Figure 2. Photographs of tranches of a diamond drill hole: **(A)** Original core sample. **(B)** sample of the original core, exposed to rain and dried naturally. **(C)** Washed core sample.

Figure 2A shows sections of drilling prior to the rain, whereas that Figure 2B shows the same sections partially dried by the sun, after the rain, where the development of white efflorescents can be noted. Figure 2C shows the same sections but washed to eliminate efflorescents and noting changes in the rock. The rock is noted notoriously swollen with changes in color and texture. In addition, on site it was noted that the work was cemented and pasted to the metallic tray log.

Previous mineralogical analyses, reconnaissance in drilling and the pit, highlight that Fortuna contains a high concentration of fine material and a wide variety of sulfates (Rojas *et al.*, 2015a).

With the purpose of identifying and quantifying the mineralogy causing the aforementioned effects, 90 reversal circulation drilling samples were collected for QEMSCAN analysis, X-ray diffraction, cationic exchange capacity and spectrometry.

3 Mineralogy

The 90 samples were pulverized and divided into several portions with the purpose of conducting the following analyses:

- X-ray diffraction (DRX) in total rock to characterize and quantify the mineralogy.
- Cationic exchange capacity (CEC) to quantify the clay contents.
- QEMSCAN to confirm the existence of iron hydrated sulfates.
- Spectrometry to create chemometric models and follow-up on the mineralogy of the finest fractions.

The first CEC analyses performed indicated very high concentrations of swelling clay and; accordingly, a QEMSCAN analysis was conducted, based on DRX, at four samples, to confirm the existence of iron hydrated sulfate, noting the following in each of them:

- Sample 704049 = very low quality of hydrated FeSO4 (~2%). Not detected by DRX because of the detection limit.
- Sample 704770 = high quantity of hydrated FeSO4 and high CEC value.
- Sample 705674 = high CEC value, not detecting FeSO4. Evidence of expansive clay, high in the DRX pattern.
- Sample 707224 = high quantity of hydrated FeSO4 and high CEC value.

Sulfates detected correspond to simple hydrated sulfates; e.g., melanterite ($FeSO_4 \times 7H_2O$), rozenite ($FeSO_4 \times 4H_2O$) or szomolnokite ($FeSO_4 \times H_2O$).

Such simple salt have has the property of being extremely sensitive to changes in moisture and local temperature and; accordingly, their hydration status varies (Jambor *et al.*, 2000) to be stable to the new environmental conditions.

With the purpose of verifying the effect of hydrated iron sulfates in CEC analyses, the four samples were washed using water. The CEC was repeated for the washed samples resulting in a significant reduction in the value of expansive clays in samples that contained the hydrated phase $FeSO_4$ (Table 1). Through DRX in the slag, it was confirmed that sulfates were removed from the samples by washing them.

Table 1. Preliminary results of CEC analysis with original samples and these samples washed using water.

Sample ID	704049	704770	705674	707224
Original Swelling Clay (CEC)	11.88	33.70	25.10	30.27
Washed Swelling Clay (CEC)	8.83	5.30	22.34	8.37
Difference	3.05	28.40	2.76	21.90

The presence of hydrated phases of $FeSO_4$ soluble in water increase the values of swelling clays; accordingly, the remaining samples were washed and dried for the performance of the related CEC analyses.

Final CEC analyses indicate that expansive clay is the dominant clay, with swelling clay >> kaolinite, whereas DRX indicate the existence in almost all samples of $FeSO_4 \times nH_2O$ iron sulfates.

Total DRX analyses indicate that the main components that constitute the sample are Muscovite/Sericite, Chlorite, Swelling Clay, Kaolinite and QKPT (Quartz, K-feldspar, Plagioclase, Tourmaline), for each of which quantitative calibration models were generated (Chemometric) for the Fourier Transform Near-Infrared (FTNIR) with the purpose of developing predictive models.

Overall proportional amounts of mineralogy identified and quantified using DRX, CEC and FTNIR are shown in the table below.

Table 2. Results of the DRX, CEC and FTNIR analyses of the 90 samples taken in FLSmidth. Detection limits for the individual phases reported by the DRX analysis are estimated between 1 and 3 wt%. For FTNIR, negative values indicate noise associated with detection limits of reference data (DRX).

Wt. %	FTNIR Calibration	max	min	average
Muscovite/Sericite	True Value (DRX)	29.50	4.00	16.83
	FTNIR Prediction	28.37	5.77	16.82
Chlorite	True Value (DRX)	8.90	0.00	4.45
	FTNIR Prediction	8.83	-0.71	4.46
Swelling Clay	True Value (CEC)	23.30	6.50	12.98
	FTNIR Prediction	24.23	6.21	13.00
Kaolinite	True Value (DRX)	10.20	0.00	1.92
	FTNIR Prediction	7.60	-1.92	1.90
QKPT	True Value (DRX)	79.70	40.20	53.50
	FTNIR Prediction	73.92	36.61	53.47
Water Soluble %	True Value (water soluble %)	25.20	0.50	6.44
	FTNIR Prediction	24.78	-0.28	6.44

In addition to measurements performed using spectrometry through Terraspec® conducted on an ongoing basis in

reverse circulation drilling and blast holes samples focused on the finest fractions (<#5), indicate that mainly the mineralogy comprising the Fortuna material contains phyllosilicates (micas, clays and illites), being recurring the smectites, acid-soluble and water-soluble sulfates (mainly ferric sulfates) and iron oxide (Figure 3).
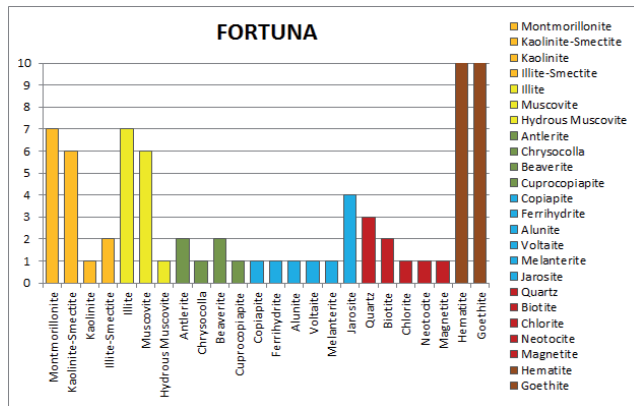

Figure 3. Average count of mineralogy interpreted via spectrometry in Fortuna samples: phyllosilicates (orange and yellow bars), copper oxides (green bars), water-soluble sulfates (light blue bars), gangue (red bars) and iron oxides (brown bars).

Additionally, interpretations of measurements performed in efflorescents formed in leaching heaps show that they are composed of 100% sulfates, with copiapite ($Fe^{3+}_2(SO_4)_3 \times 9H_2O$), bloedite ($Na_2Mg(SO_4) \times 4H_2O$), römerite ($Fe^{2+}Fe^{3+}_2(SO_4)_4 \times 18H_2O$) and jarosite ($KFe^3(SO_4)_2(OH)_6$).

4 Implications of mineralogy in the production process

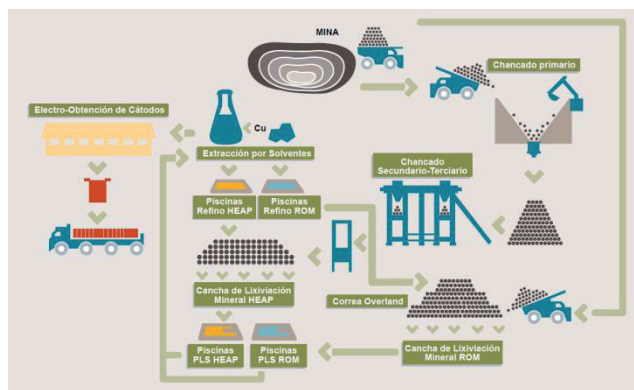The production process used at Lomas Bayas is structured as follows: (Figure 3):

Figure 4. Production process at Lomas Bayas diagram.

Throughout the process chain the following inconveniences have been generated in the treatment of material extracted from Fortuna:

• At the crushing phase, jams have occurred because of material compaction (Figure 5), resulting in a disruption of the operations. The excess of fine material in the fine line generates overflows and the activation of the belt detection alarms.

Figure 5. Material jammed in the crushing line.

• In leaching heaps cementation, water puddles, unevenness, channeling, run-off of water and slides (Figure 6).

Figure 6. Leaching heap with water puddles and efflorescents.
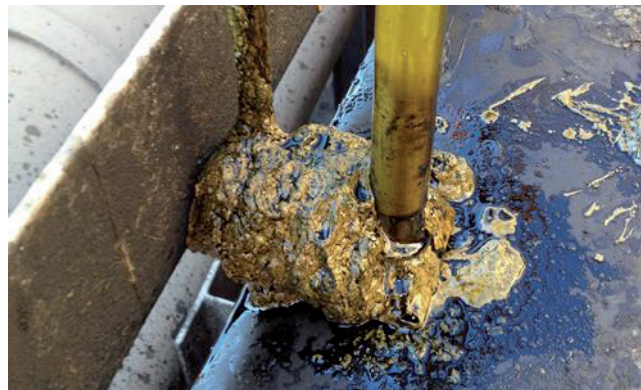
• Formation of crud in the SX process (Figure 7).

Figure 7. Crud form in the SX plant.

In accordance with the results from the analyses conducted, high concentration of clay exists where clay that is capable of incorporating water in its structure is predominant. Concentrations over 15 % may lead in heaps to permeability, channeling, water logged, poor agglomeration and geotechnical issues. In addition, these clays have the property of exchanging their own ions with those of copper dissolved previously, and; accordingly, metal will remain in the material as a complex that is very

difficult to re-dissolve (Avendaño 2005).

In addition, samples also contain high concentrations of other micaceous minerals (muscovite-sericite, chlorite and illites, the latter being interspersed with smectite per the spectrometry), which favor the impermeability and the inconsistent flow of solutions in the heaps, as they are segregated forming levels with blind (dry) areas. They also generate the compacting of material as they behave as clays by occluding spaces among particles and can also cover particles encapsulating the copper ore (Aceituno, 2000).

High concentrations of total phyllosilicates (>30%), may also result in difficulties in material management, such as material jammed in conveyor belts and transfers (Ausburn, 2015).

$FeSO_4 \times nH_20$ water-soluble sulfates such as melanterite or szomolnokite, contribute with Fe in the PLS (Pregnant Leach Solution), which results in the precipitation of jarosite in heaps, which may include copper in its structure during its formation through impregnation. Upon being formed, jarosite is refractory and; accordingly, any copper incorporated therein is lost essentially as solid. Likewise, high concentrations of sulfates and iron in the solution, promotes the formation of crud in the SX process (Avendaño, 2005), by polymerization and hydration reactions that form colloids (Aceituno, 2000). In addition, the high contents of iron, especially from sulfates, may generate acid when oxidized, increasing the oxidizing conditions, resulting in the co-precipitation (Rojas *et al*., 2015b) of impurities remaining in suspension.

Depending on the pH conditions of heaps and time, highly-radioactive feldspars can be decomposed and form smectite-kaolinite and release K, Ca, Na, Si and Al, biotite can decay to smectite, releasing K, Mg, Fe^{2+}, Mn, Al and Si and chlorite Mg, Fe^{2+}, Mn, Al and Si. In certain cases, these elements may precipitate as illite and vermiculite and jarosite (Aceituno, 2000) and also, there is a high probability that other complex compounds may be formed during an acid attack, because of the previous dissolution of silicates, forming other colloidal compounds with properties similar to those of exchange clays, capable of fixing previously dissolved copper (Avendaño 2005).

For leaching in heaps, pyrite continues to decompose with the subsequent formation of hydrated iron sulfates, generally observed as efflorescents such as rozenite/szomolnokite ($FeSO_4$), melanterite ($FeSO_4 \times 7H_2O$) and the generation of sulfuric acid, as follows, which is added to that included in the heap leach process. These products are often seen in yellow and orange mainly. The new sulfates become stable under the new acid conditions. If saturation of the material occurs because of water, these soluble phases in solution will be eliminated, which may also generate more acid. (Czerewko & Cripps, 2006). This will lead to overdissolution of mineral species associated with the rock, with the subsequent production of holes or spaces in the mass, which may collapse and result in the caving in portions of a heap ceiling.

Everything previous has meant a mining challenge and geometallurgical for the treatment of minerals of Fortune, by what they have be optimizing the productive lines with technology of the first level, specially in systems of control, managing of solutions and identification and mineralogical characterization.

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